ANNALS OF THE FORMER WORLD

JOHN MCPHEE

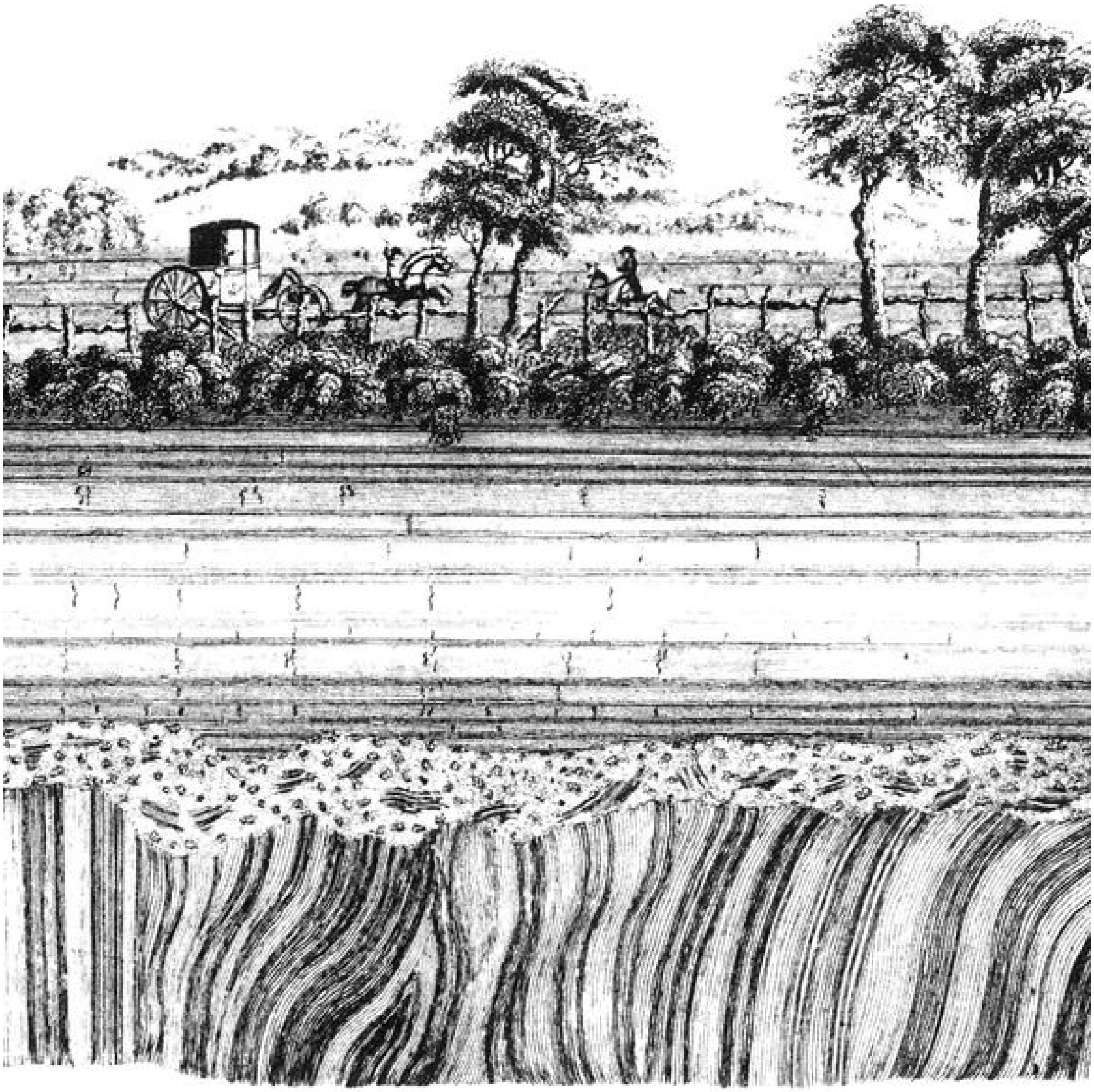
ANNALS OF THE FORMER WORLD

Yolanda Whitman

Table of Contents

Book 1

Basin and Range



The poles of the earth have wandered. The equator has apparently moved. The continents, perched c their ~~plates, are thought to have been carried so very far and to be going in so many directions~~ that seems an act of almost pure hubris to assert that some landmark of our world is fixed at 73 degrees 5 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, f what is generally described as the foreseeable future, bring you with absolute precision to the we apron of the George Washington Bridge. Nine A.M. A weekday morning. The traffic is some gros demonstration in particle physics. It bursts from its confining source, aimed at Chicago, Cheyenn Sacramento, through the high dark roadcuts of the Palisades Sill. A young woman, on foot, is bein pressed up against the rockwall by the wind booms of the big semis—Con Weimar Bu Transportation, Fruehauf Long Ranger. Her face is Nordic, her eyes dark brown and Latin—th bequests of grandparents from the extremes of Europe. She wears mountain boots, blue jeans. Sh carries a single-jack sledgehammer. What the truckers seem to notice, though, is her youth, her lon bright Norwegian hair; and they flirt by air horn, driving needles into her ears. Her name is Kare Kleinspehn. She is a geologist, a graduate student nearing her Ph.D., and there is little doubt in h mind that she and the road and the rock before her, and the big bridge and its awesome city—in fac nearly the whole of the continental United States and Canada and Mexico to boot—are in state manner moving in the direction of the trucks. She has not come here, however, to ponder glob tectonics, although goodness knows she could, the sill being, in theory, a signature of the events th created the Atlantic. In the Triassic, when New Jersey and Mauretania were of a piece, the region said to have begun literally to pull itself apart, straining to spread out, to break into great crust blocks. Valleys in effect competed. One of them would open deep enough to admit ocean water, and s for some years would resemble the present Red Sea. The mantle below the crust—exciting and excite by these events—would send up fillings of fluid rock, and with such pressure behind them that the could intrude between horizontal layers of, say, shale and sandstone and lift the country a thousan feet. The intrusion could spread laterally through hundreds of square miles, becoming a broad ne 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, ar she smacks it with the sledge. An air horn blasts. The passing tires, in their numbers, sound like heav surf. She has to shout to be heard. She pounds again. The rock is competent. The wall of the cut sheer. She hits it again and again—until a chunk of some poundage falls free. Its fresh surface asparkle with crystals—free-form, asymmetrical, improvisational plagioclase crystals, bestrew against a field of dark pyroxene. The rock as a whole is called diabase. It is salt-and-peppery charcoa tweed savings-bank rock. It came to be that way by cooling slowly, at depth, and forming thes 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." Movir along the cut, she points out xenoliths—blobs of the country rock that fell into the magma and becan encased there like raisins in bread. She points to flow patterns, to swirls in the diabase whe solidifying segments were rolled over, to layers of coarse-grained crystals that settled, like sediment in b~~eds. The Palisades Sill—in its chemistry and its texture—is a standard example of homoge~~neou magma resulting in multiple expressions of rock. It tilts westward. The sill came into a crustal bloc whose western extremity—known in New Jersey as the Border Fault—is thirty miles away. As th block's western end went down, it formed the Newark Basin. The high eastern end gradually erode shedding sediments into the basin, and the sill was ultimately revealed—a process assisted by th creation and development of the Hudson, which eventually cut out the cliffside panorama of Ne Jersey as seen across the river from Manhattan: the broad sill, which had cracked, while cooling, in 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 th cracks running through the cuts are too various to be explained by columnar jointing, let alone by th impudence of dynamite. The sill may have been stressed pretty severely by the tilting of the fau 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 moo Twice a day the solid earth bobs up and down, as much as a foot. That kind of force and that kind o 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 bee *through* here!" They have fungoed so much rock off the walls they may have set them back a foo And everywhere, in profusion along this half mile of diabase, there are small, neatly cored holes, in n way resembling the shot holes and guide holes of the roadblasters, which are larger and vertical, b small horizontal borings that would be snug to a roll of coins. They were made by geologists takin 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 directio in those years was northerly. The earth's magnetic field has reversed itself a number of hundreds o times, switching from north to south, south to north, at intervals that have varied in length. Geologis have figured out just when the reversals occurred, and have thus developed a distinct arrhythm yardstick through time. There are many other chronological frames, of course, and if from oth indicators, such as fossils, one knows the age of a rock unit within several million years, a look at th mineral compasses inside it can narrow the age toward precision. Paleomagnetic insights hav contributed greatly to the study of the travels of the continents, helping to show where they may hav been with respect to one another. In the argot of geology, paleomagnetic specialists are sometim called paleomagicians. Enough paleomagicians have been up and down the big roadcuts of th Palisades Sill to prepare what appears to be a Hilton for wrens and purple martins. Birds have show no interest.

Near the end of the highway's groove in the sill, there opens a broad, forgettable view of the vall of the Hackensack. The road is descending toward the river. At an even greater angle, the sill—tiltin westward—dives into the earth. Accordingly, as Karen Kleinspehn continues to move downhill she going "upsection" through the diabase toward the top of the tilting sill. The texture of the ro becomes smoother, the crystals smaller, and soon she finds the contact where the magma—at 20 degrees Fahrenheit—touched the country rock. The country rock was a shale, which had earlier be the deep muck of some Triassic lake, where the labyrinthodont amphibians lived, and paleoniscid fis The diabase below the contact now is a smooth and uniform hard dark rock, no tweed—its crystals t small to be discernible, having had so little time to grow in the chill zone. The contact is a straigh clear line. She rests her hand across it. The heat of the magma penetrated about a hundred feet into th shale, enough to cook it, to metamorphose it, to turn it into spotted slate. Sampling the slate with h sledgehammer, she has to pound with even more persistence than before. "Some weird, wild minera 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 spac between the rock and the road, although the environment appears to be less welcoming than the cent of Carson Sink. There are fossil burrows in the slate—long stringers where Triassic animals travelle through the quiet mud, not far below the surface of the shallow lake. There is a huge rubber sandal b the road, a crate of broken eggs, three golf balls. Two are very cheap but one is an Acushnet Titleist. soda can comes clinking down the interstate, moving ten miles an hour before the easterly winds the traffic. The screen of trees damps the truck noise. Karen sits down to rest, to talk, with her bac against a cottonwood. “Roadcuts can be a godsend. There’s a series of roadcuts near Pikevill Kentucky—very big ones—where you can see distributary channels in a river-delta system, wi natural levees, and with splay deposits going out from the levees into overbank deposits of shales an coal. It’s a face-on view of the fingers of a delta, coming at you—the Pocahontas delta system, sh off the Appalachians in Mississippian-Pennsylvanian time. You see river channels that migrated bac and forth across a valley and were superposed vertically on one another through time. You see it a 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 lur and weave. To them, the roadcut is a portal, a fragment of a regional story, a proscenium arch th leads their imaginations into the earth and through the surrounding terrane. In the rock itself are t essential clues to the scenes in which the rock began to form—a lake in Wyoming, about as large Huron; a shallow ocean reaching westward from Washington Crossing; big rivers that rose in Neva and fell through California to the sea. Unfortunately, highway departments tend to obscure suc scenes. They scatter seed wherever they think it will grow. They “hair everything over”—as geologis 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 th mountainsides, too.”

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

“Without some roadcuts, all you could do is drill a hole, or find natural streamcuts, which are fe 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 litt 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 plac where geologists can see exposures of rock, and geologists have walked hundreds of thousands miles in and beside streams. If roadcuts in the moist world are a kind of gift, they are equally so other places. Rocks are not easy to read where natural outcrops are so deeply weathered that a hamm will virtually sink out of sight—for example, in piedmont Georgia. Make a fresh roadcut almo anywhere at all and geologists will close in swiftly, like missionaries racing anthropologists to a trib just discovered up the Xingu.

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

In June, every year, students and professors from eastern colleges—with their hydrochloric-ac phials and their hammers and their Brunton compasses—head west. To be sure, there is plenty absorbing geology under the shag of eastern America, galvanic conundrums in Appalachian structu and intricate puzzles in history and stratigraphy. In no manner would one wish to mitigate th importance of the eastern scene. Undeniably, though, the West is where the rocks are—the vastnesse of exposed rock—and of eastern geologists who do any kind of summer field work about seventy-fiv per cent go west. They carry state geological maps and the regional geological highway maps that a published by the American Association of Petroleum Geologists—maps as prodigally colored as dr paintings and equally formless in their worm-trailand-paramecium depictions of the country uppermost rock. The maps give two dimensions but more than suggest the third. They tell the gener age and story of the banks of the asphalt stream. Kleinspehn has been doing this for some year getting into her Minibago, old and overloaded, a two-door Ford, heavy-duty springs, with odd piec of the Rockies under the front seat and a mountain tent in the gear behind, to cross the Triass lowlands and the Border Fault and to rise into the Ridge and Valley Province, the folded-and-faulte deformed Appalachians—the beginnings of a journey that above all else is physiographic, a journe 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 boundari between unalterable coasts. The United States: really a quartering of a continent, a drawer in Nor 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 the ~~world of the river frog, the extent of the Nugget formation, the range of the mountain couga~~r. Th range of the cougar is the cougar’s natural state, overlying segments of tens of thousands of oth states, a few of them proclaimed a nation. The United States of America, with its capital city on th Atlantic Coastal Plain. The change is generally dramatic as one province gives way to another; an halfway across Pennsylvania, as you leave the quartzite ridges and carbonate valleys of the folde and-faulted mountains, you drop for a moment into Cambrian rock near the base of a long climb, ten-mile gradient upsection in time from the Cambrian into the Ordovician into the Silurian into th Devonian into the Mississippian (generally through the same chapters of the earth represented in th walls of the Grand Canyon) and finally out onto the Pennsylvanian itself, the upper deck, the capston rock, of the Allegheny Plateau. Now even the Exxon map shows a new geology, roads running eve which way like shatter lines in glass, following the crazed geometries of this deeply dissected countr whereas, before, the roads had no choice but to run northeast-southwest among the long ropy trends the deformed mountains, following the endless ridges. On these transcontinental trips, Karen h driven as much as a thousand miles in a day at speeds that she has come to regard as dangerous and less emphatically immoral. She has almost never slept under a roof, nor can she imagine why anyon on such a journey would want or need to; she “scopes out” her campsites in the late-failing light wi strong affection for national forests and less for the three-dollar campgrounds where you roll out yo Ensolite between two trailers, where gregarious trains honk like Buicks, and Harleys on instrumen climb escarpments in the night. The physiographic boundary is indistinct where you shade off th Allegheny Plateau and onto the stable craton, the continent’s enduring core, its heartlan immemorially unstrained, the steady, predictable hedreocraton—the Stable Interior Craton. There a old mountains to the east, maturing mountains to the west, adolescent mountains beyond. The crato has participated on its edges in the violent creation of the mountains. But it remains intact within, an half a nation wide—the lasting, stolid craton, slowly, slowly downwasting. It has lost five centimetre since the birth of Christ. In much of Canada and parts of Minnesota and Wisconsin, the surface of th craton is Precambrian—earth-basement rock, the continental shield. Ohio, Indiana, Illinois, and s forth—the greater part of the Midwest—is shield rock covered with a sedimentary veneer that h 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 sea Iowa. Nebraska. Now with each westward township the country thickens, rises—a thousand, tw thousand, five thousand feet—on crumbs shed off the Rockies and generously served to the craton. A last the Front Range comes to view—the chevroned mural of the mountains, sparkling white on gra and on its outfanning sediments you are lifted into the Rockies and you plunge through a canyon to th Laramie Plains. “You go from one major geologic province to another and—whoa!—you really kno you’re doing it.” There are mountains now behind you, mountains before you, mountains that are s on top of mountains, a complex score of underthrust, upthrust, overthrust mountains, at the conclusio of which, through another canyon, you come into the Basin and Range. Brigham Young, when he cam through a neighboring canyon and saw rivers flowing out on alluvial fans from the wall of th Wasatch to the flats beyond, made a quick decision and said, “This is the place.” The scene suggeste settling for it. The alternative was to press on beside a saline sea and then across salt barrens so va and flat that when microwave relays would be set there they would not require towers. There a mountains, to be sure—off to one side and the other: the Oquirrhs, the Stansburys, the Promontorie the Silver Island Mountains. And with Nevada these high, discrete, austere new ranges begin to com 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 win around the noses of the mountains, the Humboldt, framed in cottonwood —a sound, substantial, yea 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~~ stairway that you climb to go out of the Basin and Range. On one step is Reno, and at the top Donner Summit of the uplifting Sierra Nevada, which has gone above fourteen thousand feet b seems by no means to have finished its invasion of the sky. The Sierra is rising on its east side and hinged on the west, so the slope is long to the Sacramento Valley—the physiographic province of th Great Valley—flat and sea-level and utterly incongruous within its flanking mountains. It was n eroded out in the normal way of valleys. Mountains came up around it. Across the fertile flatlan beyond the avocados, stand the Coast Ranges, the ultimate province of the present, the berm of th ocean—the Coast Ranges, with their dry and straw-brown Spanish demeanor, their shadows of the liv oaks on the ground.

If you were to make that trip in the Triassic—New York to San Francisco, Interstate 80, say roughl at the end of Triassic time—you would move west from the nonexistent Hudson River with th Palisades Sill ten thousand feet down. The motions that will open the Atlantic are well under way (things appear in present theory), but the brine has not yet come in. Behind you, in fact, where th ocean will be, are several thousand miles of land—a contiguous landmass, fragments of which will b Africa, Antarctica, India, Australia. You cross the Newark Basin. It is for the most part filled with re 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 h cooled quickly in the air to form the dense smooth textures of basalt. Someday, towns and landmar of this extruded hill will in one way or another take from it their names: Montclair, Mountainsid Great Notch, Glen Ridge. You top the rise, and now you can see across the rest of the basin to th 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 an more mountains beyond, and they are the folded-and-faulted Appalachians, but middle-aged and little rough still at the edges, not caterpillar furry and worn-down smooth. Numbers do not seem work well with regard to deep time. Any number above a couple of thousand years—fifty thousan fifty million—will with nearly equal effect awe the imagination to the point of paralysis. This Triass journey, anyway, is happening two hundred and ten million years ago, or five per cent back into th existence of the earth. From the subalpine peaks of New Jersey, the descent is long and gradual to th lowlands of western Pennsylvania, where flat-lying sedimentary rocks begin to reach out across th craton—coals and sandstones, shales and limestones, slowly downwasting, Ohio, Indiana, Illinoi Iowa, erosionally losing an inch every thousand years. Where the Missouri will flow, past Counc Bluffs, you come into a world of ruddy hills, Permian red, that continue to the far end of Nebrask where you descend to the Wyoming flats. Sandy in places, silty, muddy, they run on and on, near se level, all the way across Wyoming and into Utah. They are as red as brick. They will become the re cliffs and red canyons of Wyoming, the walls of Flaming Gorge. Triassic rock is not exclusively re but much of it is red all over the world—red in the shales of New Jersey, red in the sandstones Yunan, red in the banks of the Volga, red by the Solway Firth. Triassic red beds, as they are called, ar in the dry valleys of Antarctica, the red marls of Worcestershire, the hills of Alsace-Lorraine. Th Petrified Forest. The Painted Desert. The South African red beds of the Great Karroo. Triassic red roc is red through and through, and not merely weathered red on the surface, like the great Redwa limestone of the Grand Canyon, which is actually gray. There may have been a superabundance oxygen in the atmosphere from late Pennsylvanian through Permian and Triassic time. As sea lev changed and changed again all through the Pennsylvanian, tremendous quantities of vegetation gre and then were drowned and buried, grew and then were drowned and buried—to become, eventuall seam upon seam of coal, interlayered with sandstones and shales. Living plants take in carbon dioxid keep the carbon in their carbohydrates, and give up the oxygen to the atmosphere. Animals, fro ~~bacteria upward, then eat the plants and reoxidize the carbon. This cycle would go awry if~~ a gre many plants were buried. Their carbon would be buried with them—isolated in rock-and so th amount of oxygen in the atmosphere would build up. All over the world, so much carbon was buried Pennsylvanian time that the oxygen pressure in the atmosphere quite possibly doubled. There is mo speculation than hypothesis in this, but what could the oxygen do? Where could it go? After carbo the one other thing it could oxidize in great quantity was iron—abundant, pale-green ferrous iro which exists everywhere, in fully five per cent of crustal rock; and when ferrous iron takes on oxyge 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 ear 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 th present, you travel in the dark, there being not one grain of evidence to suggest its Triass appearance, no paleoenvironmental clue. Ahead, though, in eastern Nevada, is a line of mountains th are much of an age with the peaks of New Jersey—a little rounded, beginning to show age—and aft you climb them and go down off their western slopes you discern before you the white summits alpine fresh terrain, of new rough mountains rammed into thin air, with snow banners flying off th matterhorns, ridges, crests, and spurs. You are in central Nevada, about four hundred miles east of Sa Francisco, and after you have climbed these mountains you look out upon (as it appears in prese theory) open sea. You drop swiftly to the coast, and then move on across moderately profound wate full of pelagic squid, water that is quietly accumulating the sediments which—ages in the future—wi become the roof rock of the rising Sierra. Tall volcanoes are standing in the sea. Then, at roughly th 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 the somewhere, but fundamentally you are crossing above ocean crustal floor that reaches to the Chi Sea. Below you there is no hint of North America, no hint of the valley or the hills where Sacramen and San Francisco will be.

I used to sit in class and listen to the terms come floating down the room like paper airplane ~~Geology was called a descriptive science, and with its pitted outwash plains and drowned rivers~~, i 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 shiftin divides, of rootless mountains and bitter lakes. Streams eroded headward, digging from two sides in mountain or hill, avidly struggling toward each other until the divide between them broke down, an the two rivers that did the breaking now became confluent (one yielding to the other, giving up i direction of flow and going the opposite way) to become a single stream. Stream capture. In the Sier Nevada, the Yuba had captured the Bear. The Macho member of a formation in New Mexico wa derived in large part from the solution and collapse of another formation. There was fatigued rock an incompetent rock and inequigranular fabric in rock. If you bent or folded rock, the inside of the curv was in a state of compression, the outside of the curve was under great tension, and somewhere in th middle was the surface of no strain. Thrust fault, reverse fault, normal fault—the two sides we active in every fault. The inclination of a slope on which boulders would stay put was the angle repose. There seemed, indeed, to be more than a little of the humanities in this subject. Geologis communicated in English; and they could name things in a manner that sent shivers through the bone They had roof pendants in their discordant batholiths, mosaic conglomerates in desert paveme There was ultrabasic, deep-ocean, mottled green-and-black rock—or serpentine. There was the sl face of the barchan dune. In 1841, a paleontologist had decided that the big creatures of the Mesozo were "fearfully great lizards," and had therefore named them dinosaurs. There were festoon crossbeds and limestone sinks, pillow lavas and petrified trees, incised meanders and defeate streams. There were dike swarms and slickensides, explosion pits, volcanic bombs. Pulsating glacie Hogbacks. Radiolarian ooze. There was almost enough resonance in some terms to stir the adolesce 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, Allegheniar 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 the conservatively. The East had once been radical—had been unstable, reformist, revolutionary, in th Paleozoic pulses of three or four orogenies. Now, for the last hundred and fifty million years, the Ea had been stable and conservative. The far-out stuff was in the Far West of the country—wil weirdsma, a leather-jacket geology in mirrored shades, with its welded tuffs and Franciscan mélan (internally deformed, complex beyond analysis), its strikeslip faults and falling buildings, its boilir 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 wou have attracted Gilbert and Sullivan. Rock that stayed put was called autochthonous, and if it ha moved it was allochthonous. "Normal" meant "at right angles." "Normal" also meant a fault with depressed hanging wall. There was a Green River Basin in Wyoming that was not to be confused wi the Green River Basin in Wyoming. One was topographical and was on Wyoming. The other wa structural and was under Wyoming. The Great Basin, which is centered in Utah and Nevada, was n to be confused with the Basin and Range, which is centered in Utah and Nevada. The Great Basin w topographical, and extraordinary in the world as a vastness of land that had no drainage to the sea. Th Basin and Range was a realm of related mountains that coincided with the Great Basin, spilling ov slightly to the north and considerably to the south. To anyone with a smoothly functioning bifoc mind, there was no lack of clarity about Iowa in the Pennsylvanian, Missouri in the Mississippia Nevada in Nebraskan, Indiana in Illinoian, Vermont in Kansan, Texas in Wisconsinan time. Meteor water, with study, turned out to be rain. It ran downhill in consequent, subsequent, obsequen resequent, and not a few insequent streams.

As years went by, such verbal deposits would thicken. Someone developed enough effrontery to ca a ~~piece of our earth an epieugeosyncline. There were those who said interfluve when they~~ mea between two streams, and a perfectly good word like mesopotamian would do. A cactolith, accordin to the American Geological Institute's *Glossary of Geology and Related Sciences*, was "a quas horizontal chonolith composed of anastomosing ductoliths, whose distal ends curl like a harpolit thin like a sphenolith, or bulge discordantly like an akmolith or ethmolith." The same class of peop who called one rock serpentine called another jacupirangite. Clinoptilolite, eclogite, migmatit tincalconite, szaibelyite, pumpellyite. Meyerhofferite. The same class of people who called one roc paracelsian called another despujolsite. Metakirchheimerite, phlogopite, katzenbuckelite, mboziit noselite, neighborite, samsonite, pigeonite, muskoxite, pabstite, aenigmatite. Joesmithite. With the X ray diffractometer and the X-ray fluorescence spectrometer, which came into general use in geolog laboratories in the late nineteen-fifties, and then with the electron probe (around 1970), geologis obtained ever closer examinations of the components of rock. What they had long seen throu magnifying lenses as specimens held in the hand—or in thin slices under microscopes—did n always register identically in the eyes of these machines. Andesite, for example, had been given i name for being the predominant rock of the high mountains of South America. According to th machines, there is surprisingly little andesite in the Andes. The Sierra Nevada is renowned througho the world for its relatively young and absolutely beautiful granite. There is precious little granite the Sierra. Yosemite Falls, Half Dome, El Capitan—for the most part the "granite" of the Sierra granodiorite. It has always been difficult enough to hold in the mind that a magma which hardens the earth as granite will—if it should flow out upon the earth—harden as rhyolite, that what harde within the earth as diorite will harden upon the earth as andesite, that what hardens within the earth gabbro will harden upon the earth as basalt, the difference from pair to pair being a matter of chemic composition and the differences within each pair being a matter of texture and of crystalline for with the darker rock at the gabbro end and the lighter rock the granite. All of that—not to mentio such wee appendixes as the fact that diabase is a special texture of gabbro—was difficult enough f the layman to remember before the diffractometers and the spectrometers and the electron prob came along to present their multiplex cavils. What had previously been described as the granite of th world turned out to be a large family of rock that included granodiorite, monzonite, syenit adamellite, trondhjemite, alaskite, and a modest amount of true granite. A great deal of rhyolite, unde scrutiny, became dacite, rhyodacite, quartz latite. Andesite was found to contain enough silic potassium, sodium, and aluminum to be the fraternal twin of granodiorite. These points are pretty fin 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 granit 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 what is now referred to as the Old Geology. The New Geology is the package phrase for the effects the revolution that occurred in earth science in the nineteen-sixties, when geologists clambered on seafloor spreading, when people began to discuss continents in terms of their velocities, and when th interactions of some twenty parts of the globe became known as plate tectonics. There were few hin of all that when I was seventeen, and now, a shake later, middle-aged and fading, I wanted to lear some geology again, to feel the difference between the Old and the New, to sense if possible how th science had settled down a decade after its great upheaval, but less in megapictures than in day-to-da contact with country rock, seeing what had not changed as well as what had changed. The thoug occurred to me that if you were to walk a series of roadcuts with a geologist something illuminatin would in all likelihood occur. This was long before I met Karen Kleinspehn, or, for that matter, Davi 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 throug various stretches of the continent. What I did first off was what anyone would do. I called my loc 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 the sciences en route to some cerebral Valhalla dangled high by the designers of curriculun Deffeyes' course is one that such students are drawn to select. He calls it Earth and Its Resource They call it Rocks for Jocks.

Deffeyes is a big man with a tenured waistline. His hair flies behind him like Ludwig va Beethoven's. He lectures in sneakers. His voice is syllabic, elocutionary, operatic. He has bee described by a colleague as "an intellectual roving shortstop, with more ideas per square metre tha anyone else in the department—they just tumble out." His surname rhymes with "the maze." He h been a geological engineer, a chemical oceanographer, a sedimentary petrologist. As he lectures, h eyes search the hall. He is careful to be clear but also to bring forth the full promise of his topic, for l knows that while the odd jock and the pale poet are the white of his target the bull's-eye is the futu geologist. Undergraduates do not come to Princeton intending to study geology. When freshmen fi out cards stating their three principal interests, no one includes rocks. Those who will make th subject their field of major study become interested after they arrive. It is up to Deffeyes to intere them—and not a few of them—or his department goes into a subduction zone. So his eyes search th hall. People out of his course have been drafted by the Sacramento Kings and have set records 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 unimaginable events in the mantle, but his enthusiasms are catholic and he appears to be less attache to any one part of the story than to the entire narrative of geology in its four-dimension recapitulations of space and time. His goals as a teacher are ambitious to the point of irrationality: A the very least, he seems to expect a hundred mint geologists to emerge from his course—expec perhaps to turn on his television and see a certified igneous petrographer up front with the startin Kings. I came to know Deffeyes when I wondered how gold gets into mountains. I knew that most ol time hard-rock prospectors had little to go on but an association of gold with quartz. And I knew th erosional details of how gold comes out of mountains and into the rubble of streams. What I wanted learn was what put the gold in the mountains in the first place. I asked a historical geologist and geomorphologist. They both recommended Deffeyes. He explained that gold is not merely rare. It ca be said to love itself. It is, with platinum, the noblest of the noble metals—those which resi combination with other elements. Gold wants to be free. In cool crust rock, it generally is free. At ver high temperatures, however, it will go into compounds; and the gold that is among the magmat fluids in certain pockets of interior earth may be combined, for example, with chlorine. Gold chlori is "modestly" soluble, and will dissolve in water that comes down and circulates in the magma. Th 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. Silico precipitates, too, filling up the fissures and enveloping the gold with veins of silicon dioxide, which quartz.

When I asked Deffeyes what one might expect from a close inspection of roadcuts, he said the were windows into the world as it was in other times. We made plans to take samples of highway roc I suggested going north up some new interstate to see what the blasting had disclosed. He said if yo go north, in most places on this continent, the geology does not greatly vary. You should proceed i the direction of the continent itself. Go west. I had been thinking of a weekend trip to Whitefac ~~Mountain, or something like it, but now, suddenly, a vaulting alternative came to mind. What~~ abou Interstate 80, I asked him. It goes the distance. How would it be? “Absorbing,” he said. And he muse aloud: After 80 crosses the Border Fault, it pussyfoots along on morainal till that levelled up th fingers of the foldbelt hills. It does a similar dance with glacial debris in parts of Pennsylvania. needs no assistance on the craton. It climbs a ramp to the Rockies and a fault-block staircase up th front of the Sierra. It is geologically shrewd. It was the route of animal migrations, and of huma history that followed. It avoids melodrama, avoids the Grand Canyons, the Jackson Holes, th geologic operas of the country, but it would surely be a sound experience of the big picture, of th history, the construction, the components of the continent. And in all likelihood it would display in i roadcuts rock from every epoch and era.

In seasons that followed, I would go back and forth across the interstate like some sort of shutt working out on a loom, accompanying geologists on purposes of their own or being accompanied b 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 the earth often changed, changed utterly, and changed again, like the face of a crackling fire. The roc beside the road exposes one or two levels of the column of time and generally implies what went o immediately below and what occurred (or never occurred) above. To tell all the stories would be t tell pretty much the whole of geology in many volumes across a fifty-foot shelf, a task for which I a in every conceivable way unqualified. I am a layman who has travelled with a small core sampling academic and government geologists ranging in experience from a student to an *eminence grise*. wish to make no attempt to speak for all geology or to sweep in every fact that came along. I want choose some things that interested me and through them to suggest the general history of the contine 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 t return with Karen Kleinspehn, borrowed some diabase with a ten-pound sledge, and then began travel westward, traversing the Hackensack Valley. It was morning. Small airplanes engorged wit businessmen were settling into Teterboro. Deffeyes pointed out that if this were near the end Wisconsinan time, when the ice was in retreat, those airplanes would have been settling down throug several hundred feet of water, with the runway at the bottom of a lake. Glacial Lake Hackensack wa the size of Lake Geneva and was host to many islands. It had the Palisades Sill for an easte shoreline, and on the west the lava hill that is now known as the First Watchung Mountain. The glaci had stopped at Perth Amboy, leaving its moraine there to block the foot of the lake, which the glacie fed with meltwater as it retreated to the north. Some two hundred million years earlier, the runwa would have been laid out on a baking red flat beside the first, cooling Watchung—glowing fron cracks, from lava fountains, but generally black as carbon. Basalt flows don’t light up the sky. Thre hundred million years before that, the airplanes would have been settling down toward the same si through water—in this instance, salt water—on the eastern shelf of a broad low continent, where a almost pure limestone was forming, because virtually nothing from the worn-away continent w 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 u some peripheral shale—Triassic red shale. He put it in his mouth and chewed it. “If it’s gritty it’s silt bed, and if it’s creamy it’s a shale,” he said. “This is creamy. Try it.” I would not have thought t put it in coffee. In the blocky basaltic wall of the road, there were many small pockets, caves the si of peas, caves the size of lemons. As magma approaches the surface of the earth, it is so perfused wi gases that it fizzes like ginger ale. In cooling basalt, gas bubbles remain, and form these minicave 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 w ~~known about the potential uses of zeolite crystals. Nor was it known where they could be found~~ abundance. Deffeyes did important early work in the field. His doctoral dissertation, which dealt wi two basins and two ranges in Nevada, included an appendix that started the zeolite industry. Certa zeolites (there are about thirty kinds) have become the predominant catalysts in use in oil refinerie doing a job that is otherwise assigned to platinum. Now, in Paterson, Deffeyes searched the roadc vugs (as the minute caves are actually called) looking for zeolites. Some vugs were large enough suggest the holes that lobsters hide in. They did indeed contain a number of white fibrous zeoli crystals—smooth and soapy, of a type that resembled talc or asbestos—but the cut had been almo entirely cleaned out by professional and amateur collectors, undeterred by the lethal traffic not man inches away. Nearly all the vugs were now as empty as they had been in their first hundred years. the shale beyond the lava we saw the burrows of Triassic creatures. An ambulance from Totowa fle by with its siren wailing.

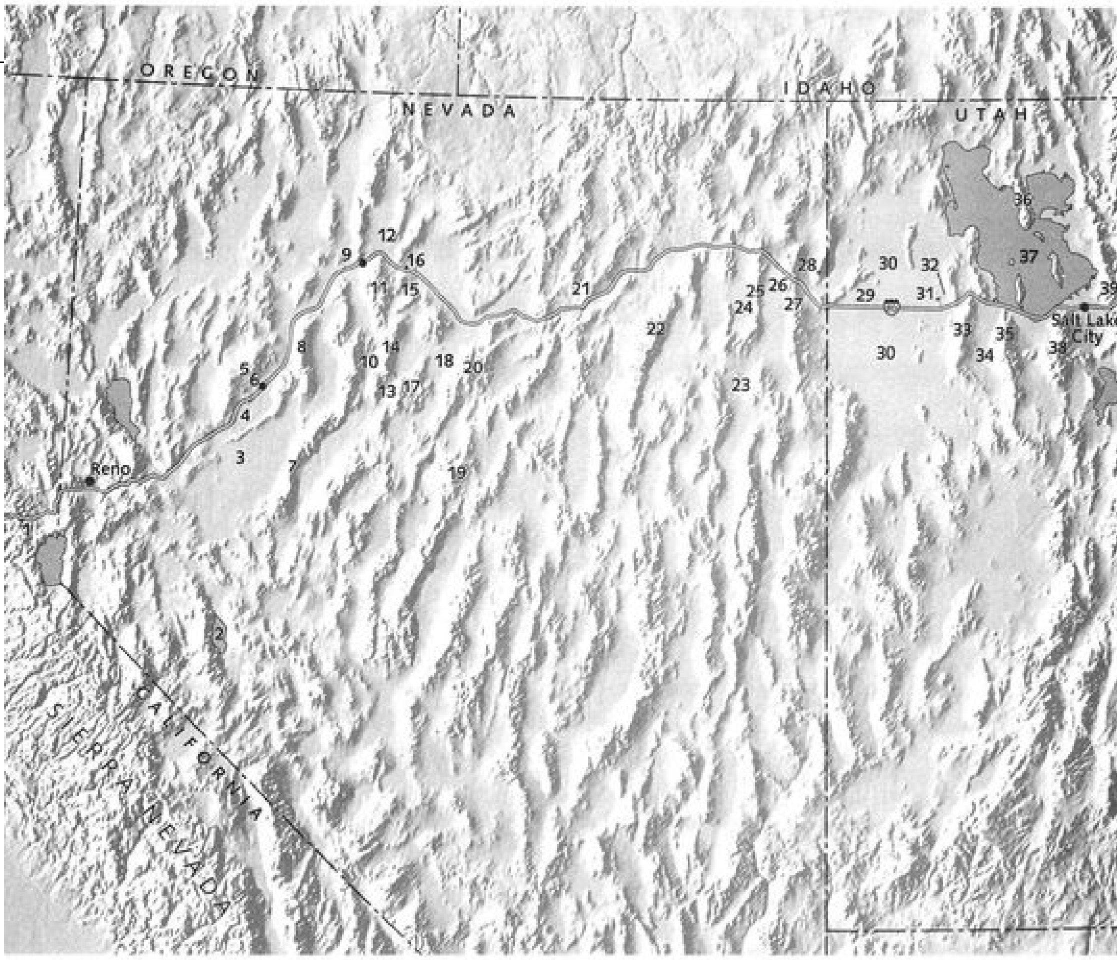
We moved on a few miles into the Great Piece Meadows of the Passaic River Valley, flat as a lak floor, poorly drained land. A meadow in New Jersey is any wet spongy acreage where you don't sin in above your chin. Great Piece Meadows, Troy Meadows, Black Meadows, the Great Swamp- Whippany, Parsippany,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

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

water that accidentally gets into the Freon. They could be used in automobile gas tanks to adso
water. ~~A zeolite called clinoptilolite is the strongest adsorber of strontium and cesium~~ fron
radioactive wastes. The clinoptilolite will adsorb a great deal of lethal material, which you can the
store in a small space. When William Wyler made *The Big Country*, there was a climactic chase scen
in which the bad guy was shot and came clattering down a canyon wall in what appeared to be
shower of clinoptilolite. Geologists were on the phone to Wyler at once. ‘Loved your movie. Whe
was that canyon?’ There are a lot of zeolites in the Alps, in Nova Scotia, and in North Table Mountai
in Colorado. When I was at the School of Mines, I used to go up to North Table Mountain just t
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 rosett of woolly mullein, growing in the rock. The Romans drenched stalks of mullein with suet and use them for funeral torches. American Indians taught the early pioneers to use the long flannel leaves this plant as innersoles. Only three miles west of us was the Border Fault, where the basin had touche the range, where the stubby remnants of the fault scarp are now under glacial debris. Deffeyes sa that the displacement along the fault—the eventual difference between two points that had bee adjacent when the faulting began—exceeded fifteen thousand feet. Of course, this happened ov several millions of years, and the mountains fronting the basin were all the while eroding, so the were never anything like fifteen thousand feet high. Generally, though, in the late Triassic, ther would have been about a mile of difference, a mile of relief, between basin and range. In flash flood boulders came raining off the mountains and piled in fans at the edge of the basin, ultimately to b filled in with sands and muds and to form conglomerate, New Jersey’s so-called Hammer Cree Conglomerate—multicircled, polka-dotted headcheese rock, sometimes known as puddingstone. He where the basin met the range, the sediments piled up so much that after all of the erosion of tw 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 plywoo over the door. I wondered why he was doing that, until boulders came tumbling down the main stre of the town. When you start pulling a continent apart, you have a lot of consequences of the sam event. Faulting produced this basin. Sediments filled it in. Pull things apart and you produce a surfa vacancy, which is faulting, and a subsurface vacancy, which causes upwelling of hot mantle th intrudes as sills or comes out as lava flows. In the Old Geology, you might have seen a sill within th country rock and said, ‘Ah, the sill came much later.’ With the New Geology, you see that all this wa happening more or less at one time. The continent was splitting apart and the ultimate event was th opening of the Atlantic. If you look at the foldbelt in northwest Africa, you see the other side of th New Jersey story. The folding there is of the same age as the Appalachians, and the subsequer faulting is Triassic. Put the two continents together on a map and you will see what I mean. Fau blocks like this one are still in evidence, but discontinuously, from the Connecticut Valley to Sout Carolina. They are all parts of the suite that opened the Atlantic seaway. The story is very similar i the Great Basin—in the West, in the Basin and Range. The earth is splitting apart there, quite possibl opening a seaway. It is not something that happened a couple of hundred million years ago. It on began in the Miocene, and it is going on today. What we are looking at here in New Jersey is not ju some little geologic feature, like a zeolite crystal. This is the opening of the Atlantic. If you want t see happening right now what happened here two hundred million years ago, you can see it all Nevada.”

Basin. Fault. Range. Basin. Fault. Range. A mile of relief between basin and range. Stillwater Rang Ple~~asant Valley. Tobin Range. Jersey Valley. Sonoma Range. Pumpernickel Valley. Shoshone R~~ange 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 Tobi Range. At the nine-thousand-foot level, there is a stratum of cloud against the shoulders of tl mountains, hanging like a ring of Saturn. The summit of Mt. Tobin stands clear, above the clou When we crossed the range, we came through a ranch on the ridgeline where sheep were fence around a running brook and bales of hay were bright green. Junipers in the mountains were thick hung with berries, and the air was unadulterated gin. This country from afar is synopsized ar dismissed as “desert”—the home of the coyote and the pocket mouse, the side-blotched lizard and tl vagrant shrew, the MX rocket and the pallid bat. There are minks and river otters in the Basin ar Range. There are deer and antelope, porcupines and cougars, pelicans, cormorants, and common loor 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 terra is not corrugated, like the folded Appalachians, like a tubal air mattress, like a rippled potato chi This is not—in that compressive manner—a ridge-and-valley situation. Each range here is like warship standing on its own, and the Great Basin is an ocean of loose sediment with these mounta ranges standing in it as if they were members of a fleet without precedent, assembled at Guam assault Japan. Some of the ranges are forty miles long, others a hundred, a hundred and fifty. The point generally north. The basins that separate them—ten and fifteen miles wide—will run on f fifty, a hundred, two hundred and fifty miles with lone, daisy-petalled windmills standing over sag and wild rye. Animals tend to be content with their home ranges and not to venture out across the b dry valleys. “Imagine a chipmunk hiking across one of these basins,” Deffeyes remarks. “The faun in the high ranges here are quite distinct from one another. Animals are isolated like Darwin finches in the Galapagos. These ranges are truly islands.”



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

Supreme over all is silence. Discounting the cry of the occasional bird, the wailing of a pack coyotes, silence—a great spatial silence—is pure in the Basin and Range. It is a soundless immensi with mountains in it. You stand, as we do now, and look up at a high mountain front, and turn you head and look fifty miles down the valley, and there is utter silence. It is the silence of the wint 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 you breath and hear absolutely nothing. No rustling of leaves in the wind, no rumbling of distant traffic, chatter of birds or insects or children. You are alone with God in that silence. There in the white fl silence I began for the first time to feel a slight sense of shame for what we were proposing to do. D we really intend to invade this silence with our trucks and bulldozers and after a few years leave it radioactive junkyard?”

What Deffeyes finds pleasant here in Pleasant Valley is the aromatic sage. Deffeyes grew up a over the West, his father a petroleum engineer, and he says without apparent irony that the smell sagebrush is one of two odors that will unfailingly bring upon him an attack of nostalgia, the oth being the scent of an oil refinery. Flash floods have caused boulders the size of human heads to com tum~~bling off the range. With alluvial materials of finer size, they have piled up in fans at the e~~dge o 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 an compressed to form conglomerate. Erosion, which provides the material to build the fans, is tearin down the mountains even as they rise. Mountains are not somehow created whole and subsequent worn away. They wear down as they come up, and these mountains have been rising and eroding fairly even ratio for millions of years—rising and shedding sediment steadily through time, always th same, never the same, like row upon row of fountains. In the southern part of the province, in th Mojave, the ranges have stopped rising and are gradually wearing away. The Shadow Mountains. Th Dead Mountains, Old Dad Mountains, Cowhole Mountains, Bullion, Mule, and Chocolate mountain They are inselberge now, buried ever deeper in their own waste. For the most part, though, the range are rising, and there can be no doubt of it here, hundreds of miles north of the Mojave, for we a looking at a new seismic scar that runs as far as we can see. It runs along the foot of the mountain along the fault where the basin meets the range. From out in the valley, it looks like a long, buf painted, essentially horizontal stripe. Up close, it is a gap in the vegetation, where plants growing sid by side were suddenly separated by several metres, where, one October evening, the basin and th range —Pleasant Valley, Tobin Range—moved, all in an instant, apart. They jumped sixteen feet. Th erosion rate at which the mountains were coming down was an inch a century. So in the mountain contest with erosion they gained in one moment about twenty thousand years. These mountains do n rise like bread. They sit still for a long time and build up tension, and then suddenly jump. Passivel they are eroded for millennia, and then they jump again. They have been doing this for about eig million years. This fault, which jumped in 1915, opened like a zipper far up the valley, and, explodin into the silence, tore along the mountain base for upward of twenty miles with a sound that suggeste a runaway locomotive.

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

Most mountain ranges around the world are the result of compression, of segments of the earth crust being brought together, bent, mashed, thrust and folded, squeezed up into the sky—th Himalaya, the Appalachians, the Alps, the Urals, the Andes. The ranges of the Basin and Range cam up another way. The crust—in this region between the Rockies and the Sierra—is spreading out, bein stretched, being thinned, being literally pulled to pieces. The sites of Reno and Salt Lake City, o opposite sides of the province, have moved apart sixty miles. The crust of the Great Basin has broke into blocks. The blocks are not, except for simplicity's sake, analogous to dominoes. They a irregular in shape. They more truly suggest stretch marks. Which they are. They trend nearly nort south because the direction of the stretching is roughly east-west. The breaks, or faults, between the are not vertical but dive into the earth at angles that average sixty degrees, and this, from the outse affected the centers of gravity of the great blocks in a way that caused them to tilt. Classically, th high edge of one touched the low edge of another and formed a kind of trough, or basin. The high edg ~~—sculpted, eroded, serrated by weather—turned into mountains. The detritus of the mountains~~ rolle into the basin. The basin filled with water—at first, it was fresh blue water—and accepted layer upo layer of sediment from the mountains, accumulating weight, and thus unbalancing the block eve further. Its tilt became more pronounced. In the manner of a seesaw, the high, mountain side of th block went higher and the low, basin side went lower until the block as a whole reached a state o precarious and temporary truce with God, physics, and mechanical and chemical erosion, not t mention, far below, the agitated mantle, which was running a temperature hotter than normal, and wa almost surely, controlling the action. Basin and range. Integral fault blocks: low side the basin, hig side the range. For five hundred miles they nudged one another across the province of the Basin an 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—easternmo expression of this immense suite of mountains—faced west. The Sierra—the westernmost, th highest, the predominant range, with Donner Pass only halfway up it—presented its escarpment to th east. As the developing Sierra made its skyward climb—as it went on up past ten and twelve an fourteen thousand feet—it became so predominant that it cut off the incoming Pacific rain, cast a ra shadow (as the phenomenon is called) over lush, warm, Floridian and verdant Nevada. Cut it off an kept it dry.

We move on (we're in a pickup) into dusk—north up Pleasant Valley, with its single telephone lin on sticks too skinny to qualify as poles. The big flanking ranges are in alpenglow. Into the cold cle 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 coupl 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 wi accumulated travertine, like the travertine walls of Lincoln Center, the travertine pools of Havas Canyon, but these pools are too hot to touch. Fall in there and you are Brunswick stew. "This is direct result of the crustal spreading," Deffeyes says. "It brings hot mantle up near the surface. The is probably a fracture here, through which the water is coming up to this row of springs. The water rich in dissolved minerals. Hot springs like these are the source of vein-type ore deposits. It's th same story that I told you about the hydrothermal transport of gold. When rainwater gets down in hot rock, it brings up what it happens to find there—silver, tungsten, copper, gold. An ore-deposit ma and a hot-springs map will look much the same. Seismic waves move slowly through hot rock. Th hotter the rock, the slower the waves. Nowhere in the continental United States do seismic wav move more slowly than they do beneath the Basin and Range. So we're not woofing when we sa 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 cru everywhere in a sense is floating on the mantle. Add weight to the crust and it rides deeper, remov cargo and it rides higher, exactly like a vessel at a pier. Slowly disassemble the Rocky Mountains an carry the material in small fragments to the Mississippi Delta. The delta builds down. It presses ev deeper on the mantle. Its depth at the moment exceeds twenty-five thousand feet. The heat and th pressure are so great down there that the silt is turning into siltstone, the sand into sandstone, the mu into shale. For another example, the last Pleistocene ice sheet loaded two miles of ice onto Scotlan and that dunked Scotland in the mantle. After the ice melted, Scotland came up again, lifting i beaches high into the air. Isostatic adjustment. Let go a block of wood that you hold underwater and adjusts itself to the surface isostatically. A frog sits on the wood. It goes down. He vomits. It goes up little. He jumps. It adjusts. Wherever landscape is eroded away, what remains will rise in adjustmen Older rock is lifted to view. When, for whatever reason, crust becomes thicker, it adjusts downwar

All of this—with the central image of the basin-range fault blocks floating in the mantle—ma
sug~~gest that the mantle is molten, which it is not. The mantle is solid. Only in certain pockets n~~ear th
surface does it turn into magma and squirt upward. The temperature of the mantle varies widely, a
would the temperature of anything that is two thousand miles thick. Under the craton, it is describe
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
his bathtub one Saturday afternoon thinking about the viscosity of the mantle. Suddenly he stood u
and reached for a towel. “Piano wire!” he said to himself, and he dressed quickly and went to th
library to look up a book on piano tuning and to calculate the viscosity of the wire. Just what h
guessed—10^{22} poises. Piano wire. Look under the hood of a well-tuned Steinway and you are lookin
at strings that could float a small continent. They are rigid, but ever so slowly they will sag, wi
slacken, will deform and give way, with the exact viscosity of the earth’s mantle. “And that,” say
Deffeyes, “is what keeps the piano tuner in business.” More miles, and there appears ahead of u
something like a Christmas tree alone in the night. It is Winnemucca, there being no other possibilit
Neon looks good in Nevada. The tawdriness is refined out of it in so much wide black space. We driv
on and on toward the glow of colors. It is still far away and it has not increased in size. We pas
nothing. Deffeyes says, “On these roads, it’s ten to the minus five that anyone will come along.” Th
better part of an hour later, we come to the beginnings of the casino-flashing town. The news this ye
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 b ~~about equally divided between the pursuit of pure science and the pursuit of noble metal. In order~~ enloft humanity’s understanding of the basins, he has been taking paleomagnetic samples of bas sediments. He seeks insight into the way in which the rifting earth comes apart. He wants to perceiv the subtle differences in the histories of one fault block and another. His ideas about silver, on th other hand, may send his children to college. This is, after all, Nevada, whose geology bought th tickets for the Spanish-American War. George Hearst found his fortune in the ground here. There wer silver ores of such concentration that certain miners did nothing more to the heavy gray rocks tha pack them up and ship them to Europe. To be sure, those days and those rocks—those supergen enrichments—are gone, but it has crossed the mind of Deffeyes that there may be something left f 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 b Nevada authentic,” Deffeyes remarked, and he swept snow off the truck with a broom. Novembe Three inches on the ground and more falling, slanting in to us from the west. We squinted, and rubbe the insides of the windows, and passed low commercial buildings that drifted in and out of sigh WILD DUCKS & PHEASANTS PROCESSED. DEER CUT & WRAPPED. DRIVE-IN WINDOV 7:00 TILL MIDNIGHT. Behind us we could not see, of course, the wall of the Wasatch, its triangle and pinnacles white, but westward of the city visibility improved, and soon other mountains—th Oquirrh Mountains—came looming out of the blankness, their strata steeply dipping and as distinct the stripes of an awning. “Those are Pennsylvanian and Permian sandstones and limestones,” Deffey said. “There was glaciation in the Southern Hemisphere at the time. The ice came and went. Sea lev 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 ha lifted the Oquirrhs—the stretching of the crust until it broke into blocks—was only among the late of many episodes that have adjusted dramatically the appearance of central Utah. As we could plain see from the interstate, the rock now residing in that striped mountainside had once been brutal shoved around—shoved, not pulled, and with such force that a large part of it had been tipped up mo than ninety degrees, to and well beyond the vertical. Overturned. Such violence can happen on an ep scale. There is an entire nation in Europe that is upside down. It is not a superpower, but it is a who country nonetheless—San Marino, overturned. Basin and Range faulting, on its own, has nev overturned anything. The great fault blocks have a maximum tilt of thirty degrees. The event that s deformed the rock in the Oquirrhs took place roughly sixty million years ago—fifty-two million yea before the Oquirrhs 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 an washed away; and now those crazily upended stripes within the Oquirrhs are the evidence an fragmental remains of those ancestral mountains, brought up out of the earth and put on view as component of new mountains. The new mountains—the mountains of the Basin and Range—a packages variously containing rock that formed at one time or another during some five hundred an fifty million years, or an eighth of the earth’s total time. It was thought until recently that older roc was in certain of the ranges, but improved techniques of dating have shown that not to be true. Seve eighths of the earth’s time is lost here, gone without evidence—rock that disintegrated and went off be recycled. One-eighth, for all that, is no small amount of earth history, and as the great crust blocks of the Basin and Range have tipped their mountains into the air, with individual faults offset much as twenty thousand feet, they have brought to the surface and have randomly exposed form 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 cle and sparkling shallow Devonian seas. There are dark, hard, cherty siltstones from some deep ocea