

MATT BULT

Wawona Dome - Yosemite, 2002
Acrylic on Canvas, 24 x 24 in



COURTESY THE ARTIST

DALE PENDELL

Tracing the Pluton

Discovering history
in the rock layers
of the Sierra

I. The Smell of Freshly Broken Rock

The rock was so hard that my first two blows had bounced off and my ears were ringing from the impact. I put down my rock pick and walked to the toolshed and pulled out my heaviest single jack. The sample wasn't even that big—fist sized, pale and rounded, and slightly oblate. It was from the Yuba River, in the northern Sierra.

I wore gloves and safety goggles, cradled the sample into a depression in the exposed bedrock, and then swung with both hands. It cracked, and small pieces flew off ten feet in several directions. I should have wrapped it in a cloth. And then I caught the smell.

Every rock has some kind of smell, but it is usually quite faint. A dark-gray rock I had just broken a few minutes before had a cool smell. It was greenish inside and very fine grained, with a frosty look that made me imagine an ancient seafloor. A banded, baseball-sized rock that looked as if it had been made out of soft clay that had been left to settle had a chalky, slightly sour smell. It seemed to be some kind of chert. A rounded beige rock, slightly greenish, had a damp smell, with a hint of wet cardboard: it was dark inside, pyroxenes probably, with no hint of quartz. A piece of phyllite I had broken had an earthy smell. But the smell of this rock, this faintly orange and particularly tough rock, was distinctive.

This rock had a hot, burnt smell, maybe with a touch of ozone, like what one smells around electric trolley cars. Cast iron can have a similar smell, just when it begins to glow, but this was not a smoky smell. It was the smell of a fire locked in rock, a big, hot fire—not the smell of hot lava but the smell of rock at the moment of its birth, when it cooled and crystallized, when high heat was still a fresh memory. And it was a smell I knew and remembered—one of my own earliest memories.

I went to grammar school in eastern San Diego, out near Fifty-Fourth Street, and was allowed to walk home on trails through the canyons. The trails wandered through chaparral: sumac and scrub oak, California sagebrush, California buckwheat, black sage, purple sage, white sage, and a few cacti, including some cholla—I learned the plant names when I was older.

In the 1950s the canyons were still pretty wild: owls,

coyotes, roadrunners, rabbits, quail, tarantulas, trap-door spiders, and several kinds of lizards and snakes, including rattlers. I caught alligator lizards and king snakes and, once, a baby brush rabbit.

In the past fifty years, except for the very steepest slopes, those canyons have been terraced and subdivided and developed into cul-de-sacs. I don't think many kids have wild canyons to walk home through anymore. (Or, even if they did, parents who would allow them to walk a mile alone by themselves.) For me, though, they were a great gift. "The Canyon" was my favorite place to hang out, the inspiration for much of what I pursued in later life, and the source of my spiritual beliefs. It was a huge geography for a child, filled with distinctive places, most of which were named. There was The Cliff, The Slide, The Big Fort, The Six Cactuses, The Island, The Plateau, The Crossroads, The Thicket, and a dozen others that I can't remember. At the bottom of The Canyon was The Stream.

The Stream was a creek bed, dry unless it was raining, which was almost never. At a couple of places the floor of The Canyon was wide enough for the streambed to split and flow around small terraces or alluvial beds (The Island was one of those terraces that lasted long enough to be named). A few small willows clung to a battered life, enduring the pelting and smashing of rocks during the handful of rainstorms that annually caused the stream to roar and overflow its banks.

The streambed was filled with rocks, and almost all of them were rounded. There were baseball-sized rocks, basketball-sized rocks, and pebble-sized rocks. A few of them were spherical, but mostly they were ovoid or ellipsoid. They had all been in riverbeds before.

About a hundred yards up-canyon from The Six Cactuses (they were prickly pears) where I was collecting, there was The Cliff—a place the stream had cut into the side of the canyon. It was like a smaller version of the road cuts in Mission Valley, and like them was a rusty yellow-brown cemented sandstone conglomerate, with layers of river cobble sticking out of the matrix. This was the source of the rocks now being rounded yet again in the streambed.

The housing tracts and the commercial districts near Fifty-Fourth Street are built on Quaternary alluvial deposits, but these mesas rest on much older terraces that the canyon cut through—sediments hundreds of feet thick

deposited and cemented forty million years ago in the Eocene. And the hard rounded rocks within the conglomerate are older yet, from strata metamorphosed at great depth and pressure, then raised up and eroded. The igneous mother rock was even older—formed in a mountain range, long since disappeared, hundreds of miles away in Sonora, Mexico, and transported to San Diego by a great Eocene river.

From the time I could print, I knew several things about rocks. I knew that there had been a Stone Age, when we'd made all the tools we needed out of rocks—a simplification I still find appealing. And I had heard that there was fire in rock, that you could make sparks by striking two of them together, and that it was possible to start fires with those sparks—a fact, or mis-fact, I hoped to replicate. My father had told me that the best way to make sparks was with flint and steel, but when I had asked, my mother and father had disagreed on what flint looked like and what color it was. And using steel seemed like cheating. So I just smashed two rocks together.

Like other kids in the neighborhood, I knew the names of a few rocks. Quartz was the easiest, though some of what I called quartz back then, especially the rounded cobbles from the streambed, I'm now sure were quartzite. But there was real quartz—and some big pieces. We kids recognized two kinds of quartz: milk quartz and rose quartz.

I also knew sandstone and granite, but granite was in the mountains—there was no granite in The Stream. And I knew what mica was—but that was something one found in granite. Very rarely, there would be an irregularly shaped rock that was layered and sparkly like mica, but those rocks were too soft to last long in the streambed. Because the rocks in the streambed were hard. Very hard. I knew because I would break them, or try to.

Sometimes I would start out with a "hammer" stone—something white or light colored that I could wield with two hands—and use it to try to break smaller rocks. Oblong pestle-shaped rocks I would try to break by holding on to one end and smashing them as hard as I could against a larger boulder. Sometimes, in desperation, I would just throw a rock against bigger rocks. And sometimes, the rock would break. And somehow, the fairies that guard children protected me from serious injury, even though rocks and rock fragments would ricochet in all directions.

When a rock broke, a new world opened. The inside of every rock was different and each one was a new surprise. Some were all one color, and some were speckled. And I knew that each one must have a name. There were greenish rocks, translucent orange-brown rocks, white rocks, and bluish-gray rocks. The fresh surfaces were sugary, or sparkly, or frosty—very rarely dull. Almost all of them were glassy in some way, even if only the way extra-fine sandpaper is glassy if you look at it up close.

There was a comfort in rock, and a satisfying heft. A rock was as close as one could get to what we were standing on. It was both the Earth-stuff and at the same time otherworldly—something not at all like my house or anything in it, or my father's automobile, or paper, or trees, or *anything*. I knew that each rock had a story, and that therefore they were objects of power and mystery. And I knew, or imagined that I knew, that humans had once lived much more intimately with rocks than now.

And when a rock broke, I could smell that cold fire smell that had been sealed inside the rock for thousands or hundreds of thousands of millennia—what the rock smelled like when it was first born, on some continent that no longer exists, and for which we now invent names such as Gondwana, Pangaea, Laurentia, or Rodinia.

II. Some Kind of Granite

Like many Californians, I live close to rock. There are, for sure, valleys and river bottoms in California where the "country rock" is deeply buried beneath hundreds or thousands of feet of sediments. But in most of the state—any place the topography isn't flat—the bedrock is near the surface.

My own house in the Sierra foothills rests on rock, and large boulders and outcrops poke out of the surrounding terrain in all directions. Most of the land is hilly, and some of the exposed outcrops are large enough to be suitable for climbing or bouldering.

Moss and at least five species of lichen compete for the surfaces wherever rock is exposed and undergo spectacularly colorful transformations with even a modest rain—the lichens turn pale green or blue gray or orange or black, and the moss a deep vibrant green. Where the rock is bare it has a rusty look, the color of burnt sienna

tinted with a touch of Chinese white. The soil, what there is of it, is thin, red, and rocky, with enough clay to be, in some places, nearly impervious. In the summer it's so hard a pick barely dents it.

Where the rock has cracked, and a piece has broken off, the surface shows a creamy gray matrix heavily speckled with black minerals. It was, I knew, some kind of granite. So I began to wonder about this rock that I walked over and around every day. I broke off samples from half a dozen locations around my house and inspected them first with my hand lens, and then with a dissecting microscope. Under magnification the freshly broken surface of the sample was a miniature landscape of high cliffs and jagged plateaus. There was white stuff and dark stuff. And in some of the samples, gray beads and particles of greenish-brown glass. What was this stuff?

I wasn't entirely ignorant of geology—in the sixties I'd had a mining claim in the Trinities, and I'd studied mineralogy with Robert Webb—the man who wrote the book on California minerals. But petrology is different. In most rock samples, the minerals are merely grains—and the old field techniques of testing hardness, heft, streak, and cleavage are almost impossible to apply.

And rock taxonomy is different from plant taxonomy, with which I'm familiar. In botanical systematics, plant species, at least in theory, are discrete entities—even if, in certain families, hybrids and intergrading are maddeningly common in the field. Rocks are a complete continuum. Sandstones grade into siltstones and shale, metamorphism varies from mild to extreme, and igneous rocks are defined by percentages of the half-dozen rock-forming minerals they contain.

Granitic rocks are defined on a triangle, where the three axes correspond to the percentages of alkali feldspar, plagioclase feldspar, and quartz. An incomplete list includes such names as quartzolite, tonalite, syenite, monzonite, diorite, and gabbro, as well as combinations, such as quartz monzonite, quartz monzodiorite, and quartz monzogabbro.

Another way to sort plutonic rocks is from light to dark, which, in its simplest form, goes granite à diorite à gabbro. This one-dimensional mapping is often extended to include peridotite at the dark end and varieties like quartz monzonite and granodiorite at the light end, and is much

more effective than it has any right to be. The light-to-dark axis is simultaneously the felsic (feldspar-silica) to mafic (magnesium-ferric) axis, the light-in-weight to heavy-in-weight axis, and the low-melting-point to high-melting-point axis. This wonderfully simplifying coincidence, which some might think proves the existence of God, seems to be accepted uncritically by geologists.

Coarse-grained granitic rocks that have roughly equal parts light and dark minerals are called diorite. My sample was a little darker than diorite, but maybe not dark enough to be gabbro. Trying to be like a real geologist, I called it gabbro-diorite. Except that in my notebook I followed the name with a question mark.

I needed more specimens to look at for comparison—a lot more specimens. And I wanted to find some that were already labeled by a geologist. So began my studies.

The first thing I learned was that I lived on a named unit of rock, the Pilot Peak Pluton, part of the larger Smartville Block. The Smartville Block, named for a gold-rush town just off of California State Route 20 between Marysville and Grass Valley, is a complex of igneous, ophiolitic rocks that formed in an offshore environment. The terrane, a large unit of associated rocks having a common origin or history, is bounded on the east by the Slate Creek and Fiddle Creek Complexes, stretches north-south for some two hundred kilometers, is pockmarked by a dozen plutonic intrusions, and dips to the west for an unknown distance beneath the Great Valley of California.

III. Where Are the Coconuts?

It turns out that the Pilot Peak Pluton has been carefully sampled and mapped several times. The Smartville Block is at the center of a major controversy in Northern California geology: Are the magmatic and ophiolitic rocks of the Smartville Block homegrown or far traveled? And was the Smartville Block grown in situ or did it float in from the far western Pacific. This question has tectonic implications for the other terranes further east—the Calaveras Formation, the Feather River peridotite belt, and the Shoo Fly Complex—as well as the tectonic terranes of the Coast Range and the Klamath Mountains: the whole Western Cordillera.

I'd read about the Smartville ophiolite in John

McPhee's *Assembling California*. It's hard to write about the tectonics of California without mentioning McPhee and his seductively coherent account of several hundred million years of California geological history. McPhee visited Smartville with his geological guide, Eldridge Moores, father of the ophiolite “paradigm shift,” and McPhee begins his popular introduction to plate tectonics with the Smartville pillow lavas.

It was one of Moores's UC Davis colleagues, Howard Day (who makes a cameo appearance in *Assembling California*), who wrote, or coauthored, at least fourteen technical papers specifically, or partly, about the Pilot Peak Pluton and the Smartville Block.

Depending on which geological paper one reads, there are three, or maybe five, or maybe seven contending models for the accretionary history of Northern California and western North America. In a general way the models divide into collisional versus noncollisional, or, another way, into in situ versus far traveled, or another way, into eastward subduction versus westward subduction, and various combinations of all.

In Moores's theory, first proposed more than forty years ago, an island arc a thousand miles long rode the Pacific Plate east until it collided with the western edge of North America. In 2004, however, Day and another petrologist, Marion Bickford, found that the Pilot Peak Pluton and surrounding areas contained Precambrian zircons, much older than the parent rock of the Smartville Block, dated to 160 million years. Day and Bickford interpreted these zircons as detritus from the North American craton that was picked up by the rising Jurassic magma that formed the Pilot Peak Pluton, and that therefore the rifted arc that formed the Smartville ophiolite was offshore, but near to the continent. That is, we could say, that instead of finding coconuts from an exotic, far-traveled terrane, he found acorns.

Day admitted in his paper that his evidence was not conclusive—that the zircons might have come from some other source—but concluded that their presence was “most easily accomplished in proximity to the North American margin.” Perhaps in response, Moores prefaced a 2006 paper with a quote from New Zealand geologist Douglas Coombs: “A vital lesson of plate tectonics is that there is no validity to any assumption that the simplest and therefore

most acceptable interpretation demands a proximal rather than a distant origin.”

In the past decade, several papers favoring a west-dipping subduction of North America beneath oceanic plates have appeared, as well as grand syntheses of the older “standard” east-dipping model. There is a Mojave-Sonora Megashear hypothesis, and even larger giant shears reaching from South America to British Columbia and Alaska. There is a SWEAT hypothesis, connecting southwestern North America with eastern Antarctica.

At least four geologists have proposed grandly unifying theories centered on a lost (subsumed) ribbon continent, resting on its own plate and stretching for thousands of miles. Though superficially similar, the models are not interchangeable. Robert Hildebrand named his ribbon continent Rubia, Stephen Johnston named his SAYBIA (an acronym for Siberia-Alaska-Yukon-British Columbia), Moores proposed Cordillera, and Richard Schweikert managed to get by with Mezcalero.

In a general way, each of these models has the Sierra foothills, and, in more complicated ways, the California Coast Ranges, assembled into a unit far offshore of North America, with collisions of island arcs onto one or both sides of the ribbon continent, and subductions that at some point change polarity—that is, from eastward dipping to westward dipping, or vice versa.

Recent advances in seismic tomography (wave analysis) of the mantle, such as that of Karin Sigloch and Mitchell Mihalynuk in 2013, with the ability to image deeply subducted plates now sunk a thousand miles into the Earth, promise to add significant new constraints and tests on proposed movements and subduction of tectonic plates, perhaps heralding a second tectonic revolution.

Why is it so complicated? First, because it has been going on for such a long time. In geology, we might say, there is all the time in the world to get things done. If a continent is moving at ten centimeters per year, it can move six thousand miles in a mere 100 million years. The Mesozoic, where most of the action of adding California to North America took place in the above theories, began 250 million years ago, while the Precambrian supercontinent of Rodinia began breaking up 750 million years ago—enough time for any continent to circle the Earth twice.

Second, there are now enough geologists doing skilled

fieldwork that the number of named terranes has doubled or even tripled since the early days of plate tectonics. Each of these terranes, stacked above or below other terranes, has to fit into a coherent story in space and time.

In the old geology, mountain-building events were defined tautologically: mountains were made by orogenies, by mountain-building events. Today any tectonic model of western North America has to account for the Antler Orogeny, the Sonoma Orogeny, the Nevadan Orogeny, the Sevier Orogeny, and several others in terms of specific collisions and subductions—and has to propose a suitable source for the momentum and kinetic energy needed to raise major mountain ranges thousands of feet into the air. Added to this are the constraints of stratigraphy: explaining why and how each formation lies atop or beneath other formations, and, while at it, how they have to be older than the dikes or plutons that cut or intrude into them.

Reading geological reconstructions often seems like reading historical linguistics: a reconstructed continent or tectonic plate or island arc is then used to reconstruct even earlier configurations. And geological stratigraphies, like languages, are inherently messy. The problem in geology is that a block of rock that doesn't fit with its neighbors is harder to explain away as a “loan word.” So accretionary models for the expansion of the western margin of Laurasia have become increasingly convoluted.

But cycles of complexity, followed by a revolutionary simplification, and then followed again by more complexity, are the way of science. There is even conflicting evidence, and interpretive debate, about the age of the Sierra Nevada. Did they arise to their present height four million years ago or forty million years ago? That's an order of magnitude of uncertainty—with supporting evidence for both theories—for one of the major mountain ranges on Earth. And while it is frustrating not to have one rock-solid explanation, the depth of the mystery is in another way comforting. Such conundrums give geologists a modicum of humility.

IV. Reading Rocks

The Pilot Peak Pluton, in western Nevada County, is two and a half miles wide and about seven miles long. It's shaped like a teardrop, the big end to the northwest and

narrowing as it trends southeast. It's a magma chamber that never erupted onto the surface—that's why it cooled slowly and the crystals are big enough to see. Its name-sake, Pilot Peak, 2,250 feet in elevation, sits astride the old California Trail used by wagon-train emigrants. It is visible from Wheatland, where the California Trail ended at Johnson's Ranch.

James Beard and Howard Day called this pluton "reversely zoned," with the most mafic rock at the core and the quartz diorite at the extreme edge, where it contacts the massive diabase into which it had been emplaced. There are several theories as to how this came about, Beard and Day favoring the idea that settling of the minerals had already occurred in the magma chamber before the magma was intruded into the diabase above it.

Beard had mapped my "some kind of granite" into six units, all of them intergrading. The rocks where I live are gabbro-diorite and another rock, gabbronorite, distinguishable by the presence of yellowish-tinted glassy grains of orthoclase. Between this rock and the olivine gabbro at the southern end of the pluton, the quartz content of the rock falls off from 10 percent to zero, and levels of clinopyroxene, orthopyroxene, and amphibole generally increase, though not always together. The presence or absence of large hornblende or biotite crystals complicates the map, as does the topography: erosion exposes lower layers, so that elevation differences show on the map as concentric rings of the layered rock units.

I scanned the Beard/Day geologic sketch of the Pilot Peak Pluton into a file, reduced the opacity, and after several scalings was able to layer it onto Google Earth. Then I printed out several 8½" x 11" composite maps.

I wanted to find some of their olivine gabbro, which would be about as close to mantle rock as I was going to get from an intrusive pluton. I lived at the other end of the pluton from the core, so I had to drive about five miles to get to the olivine zone. Some of the roads I traveled required low gear, all-wheel drive, and careful steering. The one I was on would probably wash out with the next winter storm.

I was nearing the southeast end of the pluton and stopped my car above a small reservoir where there was an outcrop exposed. It was a light-colored, fine-grained granite, with large plates of biotite mica. It wasn't rusty. Checking the geologic map I'd prepared, I decided this

must be what Beard had called biotite-two pyroxene monzodiorite. My overlay was a little off.

I followed the winding road farther up the mountain and parked again when I saw rust-colored boulders sticking up between the oaks. Breaking a piece off, I could see it was a coarse-grained gabbro or gabbronorite—I was getting close.

I grabbed my collecting bag and started hiking up a steep firebreak. A hundred yards up I was suddenly surrounded by yerba santa, and I could smell camphor sage even before I saw it. In my mind I was transported to a serpentine ledge a thousand feet above the North Fork of the Trinity River, where a hermitic prospector named Red Barnes had showed me how he mixed *Salvia sonomensis* into his snoose and *Eriodictyon californicum* into his smoking tobacco. Those two plants seem to love ultramafic rock.

I found a warty and rusty outcrop and sat down. There was a pile of bear shit not far from me, full of berries. A lone golden yarrow (*Eriophyllum confertiflorum*) was in bloom. I broke off two chunks of rock, recorded the latitude and longitude, and examined the specimens with my hand lens.

The plagioclase was easy to spot—long striated platelets. The biotite was easy too—I'd known mica since I was a kid—here it was formed into little stacks of thin golden sheets. The rock was chock full of hornblende, shinier than the pyroxene, and I could even make out the 120 degrees between the cleavage planes on some of the crystals. The pyroxene was mostly whatever dark stuff was left that wasn't hornblende. Some of it had a powdery surface, and something that looked like a 90-degree cleavage. And then there were other tiny crystals, yellow brown, and rusty oxidation was evident even on the fresh surfaces.

I dropped the rocks into a numbered bag, recording the same into my notebook. I wanted some of Beard and Day's "quite fresh and unserpentinized" olivine. I wasn't sure I had it yet, so I drove deeper into the zone I had marked on my map. An undeveloped piece of land near the crest of the hill was for sale, so I felt free to hike over it. A dirt driveway led off to the left to an occupied parcel. The breeze changed slightly and I was enveloped by the heavy skunky air that surrounds every large California pot farm.

Another fifty yards along the dozer path I found more yerba santa and more camphor sage and some serpentine.

But further, around the northwest side of the knoll, the rocks turned rusty again. I found a good outcrop where I could knock off a sample to get a fresh surface.

The rock was noticeably heavy—it had an extra heft. At first glance under magnification, the crystals seemed to be packed together randomly—but with a closer look, in some areas, I could see that some of the long amphibole crystals were aligned and there was a hint of a curved outline, perhaps some obscure effect of convection or cooling.

I could see shiny terraces of hornblende, rusting ledges of dark pyroxene, a few bits of biotite mica, all embedded in a sea of feldspar crystals that were jammed together like piled-up icebergs.

There were flashes from the striated cleavage planes of the plagioclase; and some tinted glassy stuff—probably the orthoclase. Some orthopyroxene had a metallic green and magenta sheen—the schiller luster. And there was this amber-colored stuff, little cubes of glass that turned completely to rust near the rim of the sample. Some of them had conchoidal fractures. Maybe that was the olivine, I thought, and if you want green olivine, don't look for it in 160-million-year-old rock. But it was hard to be sure.

I was still trying to decide if I really had the olivine gabbro as I was driving home. I needed a mounted thin section, thirty microns thick, and a petrographic compound microscope with polarized light. I needed an electron microprobe. I needed a petrology lab and a couple of geologists.

"Why am I doing this?" I thought, "I should be writing or painting or *something*." Or looking for gemstones. Or at least looking for pretty geodes, like the rock hounds. I was never going to master petrology on my own—I didn't have the resources.

The sun was already low and I was getting hungry. Then I saw all this brown slatelike rock exposed off in a field to my right. The road must have crossed the Wolf Creek Fault and put me off of the Smartville Block. It was late but I pulled over and stopped the car.

I grabbed my bag and my hammer.

Dale Pendell's books include the *Pharmako* trilogy (*Pharmako/Poeia*, *Pharmako/Dynamis*, and *Pharmako/Gnosis*), *Walking with Nobby: Conversations with Norman O. Brown*, *Inspired Madness: the Gifts of Burning Man*, and *The Great Bay: Chronicles of the Collapse*. A Santa Cruz, California resident for fifteen years, he and his wife, Laura, now live in the Sierra Nevada foothills.