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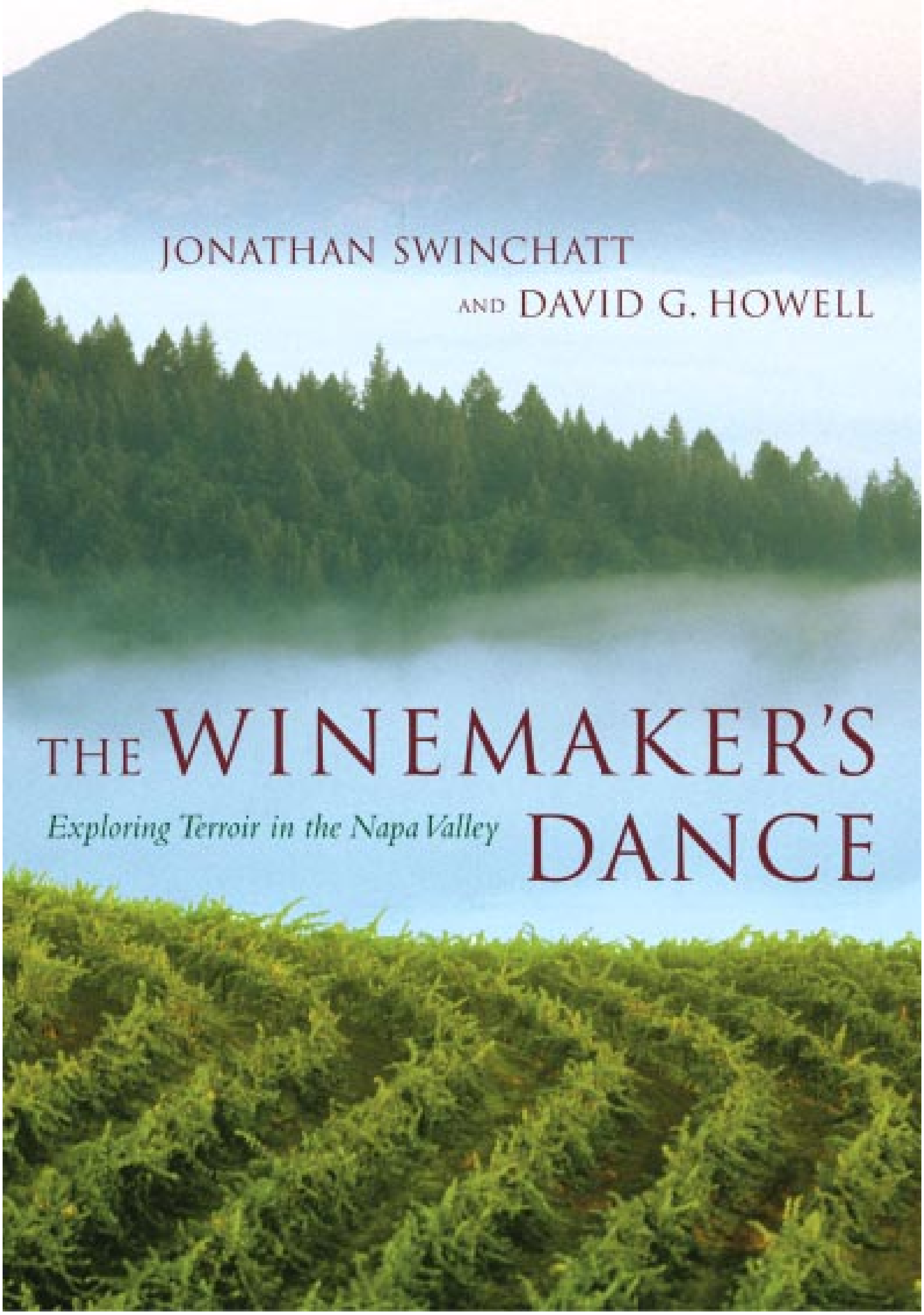

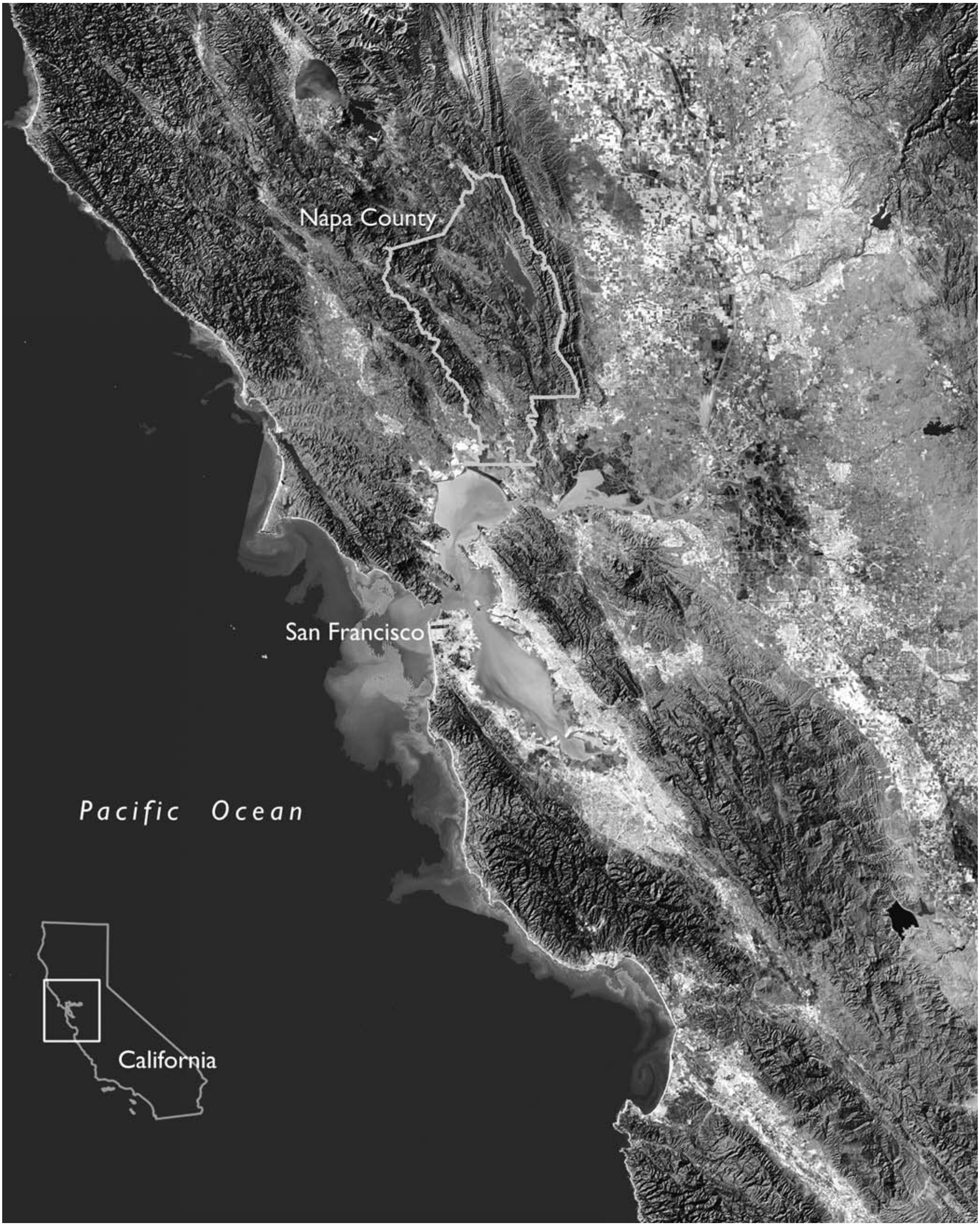

A satellite image of the San Francisco Bay Area. Napa County is outlined in yellow.

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BIRTH OF A VALLEY

FLYING FROM DENVER to San Francisco at thirty-five thousand feet, you see below, west of the Rocky Mountains, a vast desert cut through by sublinear mountain ranges. This geologic province, known as the Great Basin, extends from the Utah-Colorado border west for several hundred miles. Seared brown flats, with the remains of lakes long ago dried up, separate mountain heights and discourage most human activity. Anonymous dirt roads that seem to come from nowhere end in small clusters of buildings. It is a land that breeds paranoid fantasies of men in black uniforms, of UFOs crashing and being hidden by the government, a land some think inhabited by space aliens.

Patterns on the ground, abstractions in a brown-on-brown palette, record the water flow from snowmelt and rare rainstorms. Mesmerized by mile on mile of this scrolling canvas, you might be jolted by the sudden appearance of steep forest-clad slopes. They rise abruptly, cut by deep canyons, topped by bald gray knobs that roll away north and south into the distance. In the low sun of early morning or late afternoon, curving knife-edge ridges stand out, linking one sharp peak with another. These are the walls of glacial cirques, high-altitude bowls carved when the mountains were host to year-round ice and extensive alpine glaciers. These mountains, the Sierra Nevada, are the cause of the desert that fills the land to the east. Moisture-laden air rises up the gentle western face of the mountains, cooling as it goes, dropping most of its cargo of water on the heights and leaving little for the other side. The desert lies in the rain shadow of the Sierra, and a broad shadow it is.

Crossing the Sierra and moving on toward San Francisco, you may note the long western gradient of the mountains, carved by deep canyons that drain snowmelt and rain. These canyons have the U-shaped form that comes from scouring by valley glaciers; one is the canyon of Yosemite, its cliffs known as American icons.

Gradually the forests give way to scrub growth, and the gentle slope of the mountains merges with the floor of the Central Valley. This great trough runs the length of central California, from Bakersfield in the south to Red Bluff in the north, drained by the San Joaquin River in its southern part, the Sacramento in the north. The valley floor is a quilt of farms, one of the most productive agricultural regions in the world. If not for water from Sierra snows, stored for summer irrigation, this too would be a desert, caught in the rain shadow of the Coast Ranges.

Those hills, farther west and rising to more than four thousand feet, form the western boundary of the Central Valley and the western margin of the continent. The relatively affordable suburbs of the Bay Area swarm along the eastern flanks of these hills, while the cities and more upscale suburbs hug the shores of San Francisco Bay.

If you're flying into Oakland or taking a northern approach to the San Francisco airport, you might notice a couple of valleys that begin at the northern tip of San Francisco Bay. The smaller one to the west is Sonoma; the other is the Napa Valley. Depending on visibility, you might even be able to discern Napa's two parts, a wider southern portion and a narrow northern extension. The valley is the result of a long and complex series of events that tell the tale of how the western margin of North America was formed, a land that was not here 145 million years ago. The story of terroir in Napa begins that far back, when the foundations of the valley began to take shape.

SHAPING THE FOUNDATION

If you had flown over the Sierra 145 million years ago, the picture spread beneath you would have been vastly different, looking more like the Aleutian coast of Alaska, where flight patterns are often interrupted by volcanic activity. Your plane might have had to dodge thick plumes of ash, for the Sierra Nevada of that time consisted of a string of volcanoes that extended the length of the current range. These volcanoes formed from magma that rose as the Farallon plate descended beneath North America. Today's Cascades are the northern and most recent extension of this ancient Sierran volcanism.

The coast was only a few miles to the west of the volcanic range, perhaps like the Peruvian or Chilean coast of today, where the mountains rise steeply out of the Pacific Ocean, climbing to twenty thousand feet within thirty miles of the shore. Scaling a Sierran peak of that day would have been a more difficult and dangerous task, but the view would have been impressive. You would have seen a group of volcanic is-

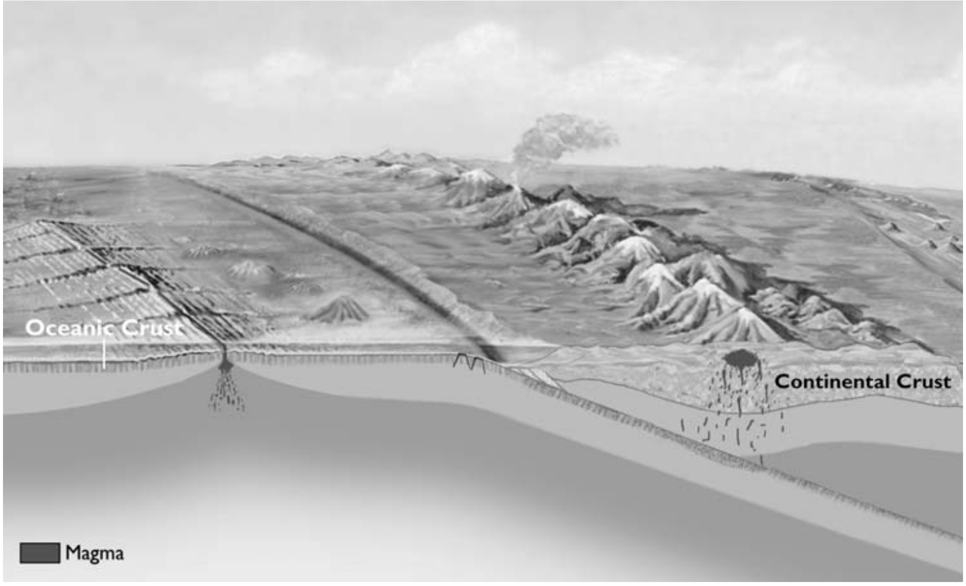

FIGURE 1. The Pacific coast of North America 145 million years ago. The Farallon plate slides beneath North America, creating a range of volcanic mountains, the precursors to the Sierra Nevada. A group of undersea mountains, some exposed as islands, approaches the coast.

lands much like the Philippines or Indonesia some distance offshore. These islands, borne on the Farallon tectonic plate, were inexorably approaching the coast. Within the next 5 million years, they would slam into North America and slide below its surface, crushed between the two plates and smeared onto the continent, beginning the creation of all of California west of the Sierra Nevada.

During subduction, in which plates or continental masses meet, one slides beneath the other, descending into the mantle, the distinct layer immediately below the Earth's relatively thin crust. On continents, the crust averages about forty miles in thickness; on the ocean basins, about ten (Figure 1). While this difference sounds large, on the scale of Earth it becomes imperceptible, like the variations in thickness in the skin of an inflated birthday balloon. The mantle that lies below the crust is rock under intense pressure and at progressively higher temperatures toward the core, the metallic center of the planet (see Figure 3). Composed of nickel and iron, the outer layer of the core is solid, while its innermost portion is a liquid nearly as hot as the surface of the sun.

As the lower plate slides down into the mantle, friction between the plates heats the rock, while entrained water lowers its melting point. At a depth of about sixty miles, the rock begins to melt. The molten magma rises through the mantle as small blobs and strings, driven by differences in temperature and density. This material rises until its density, lowered by cooling, matches that of the surrounding rock. There it accumulates, forming magma chambers some thousands of feet beneath the surface. Eventually the surface above begins to wheeze and crack under the pressure of the rising magma, which erupts either with an explosive roar, as Mount St. Helens did, or more gently, with lava flowing onto the ground in the style of Hawaiian volcanoes such as Mauna Loa. The difference lies in the composition of the fluid—with more silica, the major component of Earth's crust, the magma becomes more viscous and less likely to flow, with a greater tendency to explode suddenly.

The volcanic islands that slid beneath western North America so many millions of years ago are preserved in ocean crust rocks that lie within the foothills of the Sierra. No longer readily identifiable as islands, they exist today as isolated fragments that have been smeared out against the edge of the continent. Imagine the Philippine Islands approaching the Chinese mainland, closing the South China Sea, and then slowly sliding beneath the coast of China, crushed between the Pacific and Eurasian plates, and you'll have a picture of what was happening in California.

THE NATURE OF GEOLOGIC INFORMATION

Geologists work, at best, with limited and indirect data, trying to read a history that is recorded in a nonhuman language with a grammar and syntax made readable only through observation and progressive approximation. Perhaps reading the rocks is a bit like translating Mayan pictographs or Egyptian hieroglyphics, though at least we know those forms are of human origin. In addition, many of the processes geologists attempt to understand, such as subduction, cannot be immediately observed and move at a pace so different from our experience that we can only imagine it. The reconstruction of Earth history is like attempting to reconstruct the daily life and relationships of that early hominid Lucy, whom we know only from scattered fragments of bone. We do the best we can with what we have, but it's merely an approximation of the way things might have been.

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Given the scale of this event—an island mass colliding with a continent—the effects were far-reaching. The molding of the volcanic arc into the underpinnings of North America, a bit like squashing a piece of red clay onto the edge of a slab of green, changed the character of plate movement. The position of plates on the globe had remained unusually stable for about 80 million years, during the period that stretched from 140 million years ago to about 60 million years ago. But at the beginning of this period, some 5 million years after the islands disappeared beneath North America, the subduction zone that marked the western boundary of North America suddenly and mysteriously jumped far to the west, trapping a chunk of ocean crust and adding it to the North American plate. This chunk, now known as the Coast Range ophiolite, forms the foundation for all the other materials that later came together to form the land we call California.

We might say, in summary, that the real history of California began about 140 million years ago. At that time, the physical, geologic, and natural western boundary of North America lay some distance west of the actual coastline, beneath the waters of the Pacific Ocean. At this continental edge, the Farallon plate slid beneath North America, creating a range of volcanoes along the coast that were the precursors of today's Sierra Nevada. About this same time, a set of volcanic islands on the Farallon plate was sliding beneath North America.

As the early Sierran volcanoes built up layer after layer of lava and ash, they slowly took on the volcanic shapes we know so well—the perfection of a Mount Fuji, for example, or the magnificence of a Mount Rainier. Gradually, their weight began to depress the crust, creating a deep trough that extended the length of the range. West of the trough, on the edge of the North American plate, a bulge developed in the sea floor. This upwarp in the crust was linked to the formation of the trough—as one part of the crust is depressed, the adjacent one warps up. You can illustrate this by pressing the edge of your hand into a folded towel, forming a trough; the towel will rise on each side, forming a double bulge. (This process is far more important than it might seem from this brief description. Crustal bulges, which are associated with zones of mountain building throughout the world, contain a considerable portion of the oil and gas that have been trapped within the crust.)

You may wonder at the notion of Earth's crust bowing down under an added weight—after all, rocks are hard and unyielding, and we perceive the crust as rigid and fixed. In reality, however, the crust is quite flexible, and it floats, more or less, on the denser mantle below. Think of a steel reinforcing rod used to strengthen concrete. In short segments, the rod is rigid, impossible to bend. But in lengths of twenty feet and more, it bends under its own weight. Rocks are similar: in larger masses, they become malleable. Traveling through mountainous country—the Alps of Europe or the Appalachians and Rockies of North America, for example—you may notice layers of rock that are bent and broken, often in fantastic shapes (Figure 2). These forms reflect the immense forces that accompany the process of continents colliding, which creates pressures and temperatures that cause rocks to flow while changing their mineral composition. As the rocks cool and the pressure is eased, they become rigid and brittle. Although in Napa you won't see folded rocks quite like those shown in Figure 2, you can find rocks tilted up on edge—layers once horizontal that are now sitting vertically—along the Silverado Trail. Similar rock geometries, though not as steep, occur throughout the Vaca and Mayacamas Mountains.

FIGURE 2. Folded rocks in the Tian Shan Mountains of western China. When under pressure, rocks slowly bend and fold, sometimes in complex shapes.

THE GREAT VALLEY SEQUENCE AND THE FRANCISCAN FORMATION

Beginning 140 million years ago, then, and continuing for 80 million years, volcanic ash and lava erupted from the Sierra Nevada volcanoes. Red-hot ash and rock roared down their sides in pyroclastic flows at velocities up to two hundred miles per hour. Massive thunderstorms flooded the mountains, saturating the soft ash and rock that accumulated on their flanks and forming volcanic mudflows (lahars). We have seen these processes in relatively recent years, particularly at Mount St. Helens in 1980, when pyroclastic flows tumbled down the mountainside and lahars clogged the local rivers with mud and forest debris.

During these volcanic eons in the Sierra, rain and snow fell, rivers ran, the seasons followed one another much as they do today. Beset by weathering processes, solid rocks slowly rotted into smaller particles, which were eroded by water and carried into streams. The streams moved them from the mountains to the shore, storing the sediment temporarily in beaches, marshes, and offshore bars. As material piled up near the shore, periodic events—large storms, earthquakes, tidal waves—shook some of the accumulation loose and transported it in giant undersea mudflows into the deep axis of the trough. Here, layers of sand and silt slowly accumulated, each layer representing one of these catastrophic events.

The slurries that deposited these layers are known as turbidity currents. Scientists understand them well in part because they still occur in the deep sea. Turbidity currents were first discovered some decades ago when a series of undersea cables broke in an unusual nonrandom pattern, starting near the coast and progressing farther out to sea. Investigators determined that the cables had been cut in sequence by a strong undersea current carrying a heavy load of sediment. Geologists have now identified the remains of such currents throughout the long history of Earth and in many places, including the Napa Valley.

Volcanic edifices, composed as they are of layers of soft ash, the rubble of lava flows, and other loose debris, do not last long at Earth's surface, at least in comparison to other geologic features—one hundred thousand years is ancient for a volcano. As volcanic activity died out in the Sierra, the volcanoes were worn away by weathering and erosion that exposed their roots, the huge granite masses called batholiths that, when molten, had fed the volcanic activity. The most photogenic of these masses are the fabled faces of El Capitan and Half Dome in Yosemite National Park. Beneath these bodies, ancient ocean crust and pre-Sierran volcanic rocks lay at the foot of the mountains. These, too, contributed material to the sediments that accumulated in the adjacent basin.

For 80 million years, the boulders, gravel, sand, and clay derived from the Sierra and delivered to the trough at the foot of the mountains piled up to a thickness of about fifty thousand feet. Mind you, this is the present thickness of the pile—the depth of water in the basin itself was never more than perhaps a few thousand feet. As the weight of sediment increased, the crust slowly subsided, making space for additional geologic debris. Now solid rock, this accumulation of sandstone and shale is known as the Great Valley sequence. Slices of it, torn from the parent accumulation by the forces of tectonic faulting, form one of the primary bedrock components of the Napa Valley.

The sandstones of the Great Valley sequence are mostly arkose, a rock made up of light-colored, silica-based minerals with a high content of potassium, sodium, and calcium. The rocks are mainly shades of brown and tan, reflecting their mineral makeup. The character of the rocks in this great pile changed a bit with time, reflecting broad sea-level changes and events in the history of the Sierra, but the story of the Great Valley sequence is notably straightforward and well understood.

During this same time, the Pacific Ocean, stretching west of the crustal bulge, contained all the features that we find in modern ocean basins: extinct, undersea volcanoes with flat, eroded tops (seamounts); island arcs like the Aleutians, the Philippines, or the Indonesian archipelago; and deep-water sediments derived in part from erosion of these other features. These ocean sediments included thinly bedded cherts, rocks of pure amorphous silica derived from the shells of minute organisms that slowly rain onto the sea floor, corpses of the immensely prolific populations of tiny radiolaria that inhabit the surface of world oceans. Pure cherts only form far from land; they accumulate so slowly that delivery of dust, mud, or sand will dilute their concentration. A fraction of an inch of chert will take one hundred years to accumu-

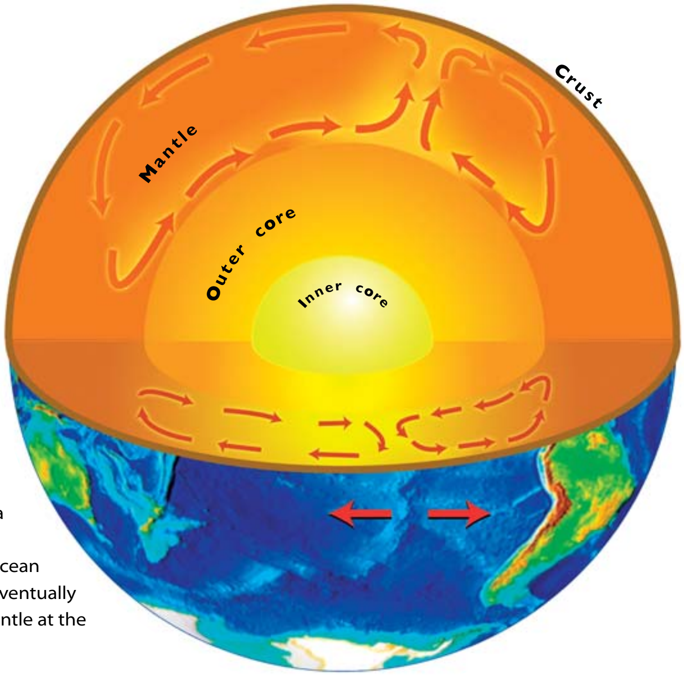

FIGURE 3. Convection currents in the mantle of Earth move with the tectonic plates that form the crust. The movement is much like a conveyor belt, with material added to the crust at a mid-ocean ridge and moving outward, eventually descending back into the mantle at the far edge of the plate.

late; a three-foot thickness represents approximately 1 million years. Cherts occur in Napa north of Lake Hennessey.

During the 80 million years of Great Valley sequence accumulation, up to seven thousand miles of Pacific Ocean crust disappeared beneath North America. Think of it: the equivalent of the entire width of today's Pacific Ocean basin sliding below North America, where it was assimilated into the mantle. As this crust disappeared, new material was added at the other side of the plate, much as new crust is appended today at the mid-ocean ridges that represent plate boundaries. Picture a conveyor belt moving at a rate of a few centimeters each year. Rock is added at the spreading ridge on one end and slides outward, away from the ridge (Figure 3). At the other edge of the belt, the plate slides beneath a continent or an oceanic island arc, returning to the mantle from which it originally arose.

Visualize that plate descending for 80 million years beneath the continent, carrying with it seamounts, volcanic island arcs, chunks of ocean crust, and a variety of sediments, some derived from erosion of adjacent land, some formed within the ocean itself. As the plate slides beneath the crustal bulge, rocks and sediments are literally scraped off and plastered onto the continent. In a crude analogy, put yourself in a kitchen cleaning up after dinner. Imagine a large spatula (North America) sliding

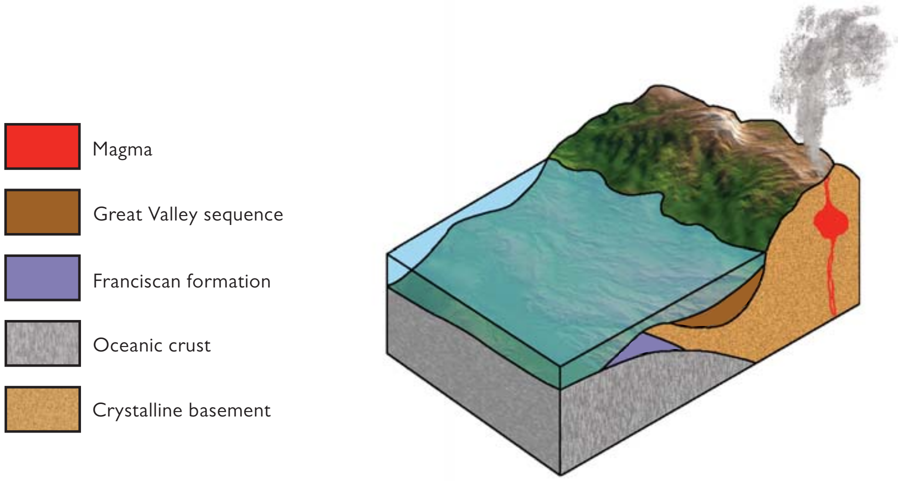

FIGURE 4. The Napa region about 90 million years ago. The weight of the growing volcanic mountains formed a deep trough along their length, with a crustal bulge west of the trough at the geologic edge of the continent. Sediments of the Great Valley sequence accumulated in the trough, while the components of the Franciscan formation were added to the continent at its edge. The crystalline basement represents the continental rocks that existed before the formation of the volcanic mountains.

over a dinner plate (the ocean crust) and beneath the leftovers (the ocean floor material) to scrape them off. The result is a conglomeration of stuff, food in this case, mashed together and smashed onto the spatula. Material from the sea floor was smashed onto the edge of North America in much the same way.

This geologic flotsam and jetsam is known as the Franciscan formation. This complex rock unit underlies much of coastal California and is one of the major bedrock components of the Napa Valley region. The Franciscan formed off the coast during the same period in which the Great Valley sequence was accumulating in the trough adjacent to the Sierra Nevada. The two rock units developed contemporaneously under quite different environmental circumstances (Figure 4).

The importance of this history was surely a mystery to Chris Howell when he arrived at Cain Vineyards high on Spring Mountain in 1990. But he has been farming these vineyards and making wine from the grapes long enough now to know well the challenges of growing fruit on the Franciscan formation—dealing with the difficult chemistry of Franciscan sediments; working with the instability of Franciscan rocks on steep, terraced slopes; and understanding these odd rocks and the soils that form on them. Howell is sure that the characteristics of the Franciscan that make it difficult to work also provide the elements for a wine of particular distinc-

FIGURE 5. Franciscan mélange at Cain Vineyards, with a large chunk of ocean crust about twenty-five feet high, called a knocker, standing out against the smooth slopes that form on finer-grained sediments. Smaller knockers are found in the undeveloped patches within the vineyard.

tion, one that truly reflects place. And that's what makes the Franciscan formation so interesting.

The Franciscan formation, overall, is a heterogeneous and puzzling set of materials. It includes serpentinites—rocks containing chemical elements, particularly nickel, that are toxic to grapes. And it tends to be high in magnesium, which requires special awareness and care on the part of the winegrower, as it affects the uptake of potassium, an element vital to good fruit. Individual rock components of the Franciscan are readily identifiable in terms of their origin—an individual outcrop might be recognizable as an ancient seamount or deep sea fan, for example—but their relationship to one another is often unclear. The mechanics that brought together the components of the Franciscan formation remain something of a mystery.

When geologists can't explain the parts, they invent a term to embrace the whole. Most of the Franciscan in the Napa Valley area consists of just such a material, known as mélange, a chaotic mixture of ocean floor sediment and chunks of ocean crust. As you drive through the Coast Ranges, you can see deposits of Franciscan mélange scattered through the hills. The less resistant sea floor sediments form smooth, soft-looking, rolling hills, punctuated by sharp, irregular masses of rock often tens of feet in diameter that dot the hills like so many raisins in a rice pudding (Figure 5). These are chunks of ocean crust, harder and more resistant than the surrounding sediments, which wash away with greater ease.

Let's recap the geologic events we've been describing. For about 80 million years, the geography of California featured a volcanic mountain range that shed sediments into a trough at the western edge of North America, forming the Great Valley sequence, a diverse accumulation of sand and mud, now transformed into sandstone and shale. West of this trough, at the far edge of the continent, lay a crustal bulge. There, the Farallon plate continued to slide beneath North America, adding to the continent the complex materials of the Franciscan formation, scraped from the ocean plate. Subduction of the Farallon plate occurred in fits and starts; during certain periods, compressive forces affected the continent all the way to Colorado. By dating the timing of events such as uplift, mountain building, and volcanic activity, geologists have assembled a reasonably clear history of this process, in which periods of dormancy gave way to episodes of mountain building, all reflecting the stuttering impact of subduction at the western margin of North America.

Then, about 60 million years ago, things changed drastically. Ranges of volcanic mountains began to appear progressively eastward from the Sierra Nevada, eventually reaching Colorado. The region of mountain building, the result of compression associated with active subduction, also moved east, as far as South Dakota, where the Black Hills stand in stark witness to the process. The cause of this change is not immediately apparent, but it probably involved a sudden alteration in the angle of subduction. "Sudden," of course, is a relative term—the change occurred over some tens or hundreds of thousands of years, the equivalent of a quarter or so of the total history of the human race, but a blink for the planet. The effects were far ranging: instead of descending steeply below North America, the Farallon plate flattened considerably, probably because the younger, more buoyant, incoming crust sank more slowly into the mantle. Thus the point at which the subducting plate reached a depth of sixty miles—the depth at which melting begins—moved steadily eastward. The volcanic arc marched along with it, the rocks at the surface reflecting this history.

THE SAN ANDREAS SYSTEM AND THE NAPA VOLCANICS

Some 25 million years ago, a critical event in the history of California occurred, which haunts us still: the San Andreas fault system was born. The mechanics of its development are complex, but the pattern is easy to discern. The movement of three plates—the Farallon plate, the Pacific plate, and the North American plate—brought them together at a point on the coast that geologists describe as a triple junction, a place where three different entities converge. The particular geometry of this meeting created a transition on the coast from subduction (one plate sliding beneath an-

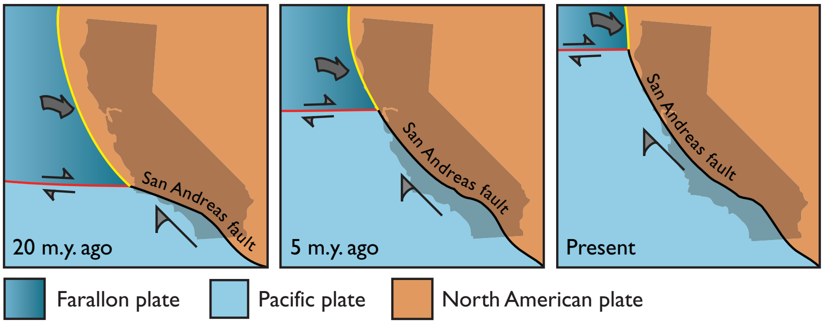

FIGURE 6. The meeting of the Farallon, Pacific, and North American plates created a triple junction that moved up the coast, forming the San Andreas fault. Complex movement of the plates continues to extend the fault system to the north.

other) to translation, in which one plate slides past the other horizontally, or laterally. This is the motion of the San Andreas fault and its related faults—the Hayward, the Rogers Creek, and the various others that splay from the San Andreas and affect much of the length of coastal California (Figure 6). As the three plates continued to move, the triple junction traveled up the coast, with the fault following along. The moving triple junction, in effect, cut into the Earth's crust just as a scalpel slices the skin, separating California into two parts, east and west of the complex system of faults.

The transition from subduction to lateral movement was accompanied by an advancing conflagration of fiery lava eruptions and outpourings of ash and gas that skipped up the coast along with the triple junction, beginning about 24 million years ago in southern California. The volcanic centers are separated from one another—after the fireworks died off at one location, and after the triple junction had traveled some distance, another would appear farther north but with no pattern other than the association with the triple junction. At each volcanic location, a thick covering of ash and lava would blanket the region for many square miles over a period of a few million years. Older volcanic accumulations were sliced up and offset by the faults of the growing San Andreas system, making the bedrock geology increasingly complex, a jigsaw puzzle of displaced fragments.

And then, approximately 7 million years ago, the volcanism reached Napa, at that time an area of considerably less relief than today. As in regions to the south, volcanic rocks would cover hundreds of square miles with a thick veneer of Napa volcanics (the name we use here for what are officially known as Sonoma Volcanics) over the next 5 million years or so (Figure 7). They formed the top layer of a sand-

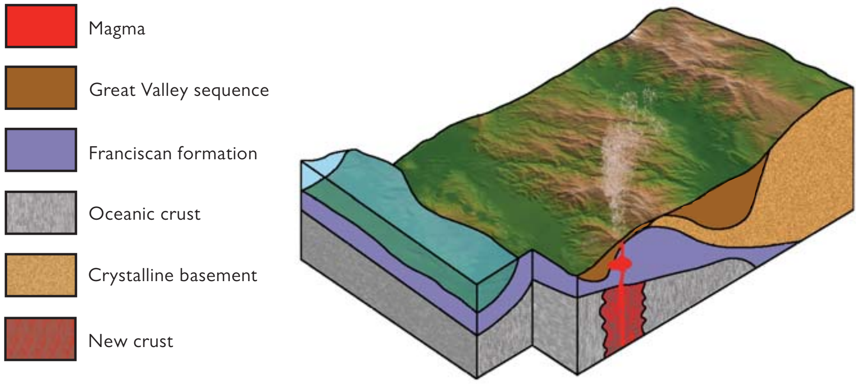

FIGURE 7. The Napa region 5 million years ago during the eruption of the Napa volcanics, which eventually covered several hundred square miles with layers of diverse volcanic rocks.

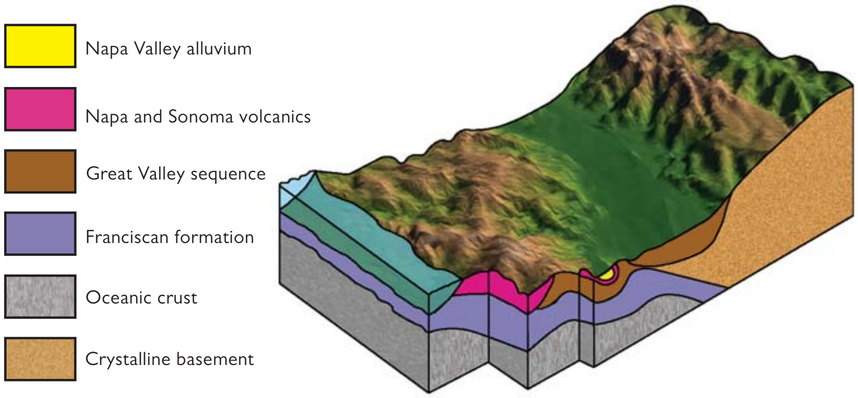

FIGURE 8. Formation of the Coast Ranges defined the topography that we see today. Napa is one of a host of valleys defined by the uplifted hills.

wich, with oceanic crust the bottom layer, and the Franciscan formation and the Great Valley sequence serving as the fill (Figure 8).

As you drive up Highway 29 from Napa north into the valley on a beautiful fall or winter day when the air is clear and crisp, the sharp outline of Mount St. Helena looms ahead. It seems to stand alone, framed by the Mayacamas Mountains on the west and the Vaca Mountains on the east. Mount St. Helena is nearly symmetrical, with the steep sides and truncated top of a classic volcano. Similarly, as you drive along the Silverado Trail in the late afternoon, after the sun has sunk behind the Mayacamas Mountains, the blue-black profile of Mount St. John, with the same symmetrical form, dominates the western sky. Everyone in the region "knows" that these two mountains were the source of the volcanic rocks that underlie so many of Napa's vineyards. But the truth is that not a single volcanic eruption burst forth from either peak. Mount St. John and Mount Veeder are made up of the sedimentary rocks of the Franciscan formation and the Great Valley sequence, respectively; and Mount St. Helena, while formed of volcanic rock, is not a volcano.

Rather than creating edifices like Mount Fuji, the Napa volcanics erupted from great elongate cracks in Earth's crust, and they must have been terrifying. These were not gentle outpourings of lava that flowed along relatively contained, and avoidable, pathways like those you can approach in Hawaii or on Mount Etna. Instead, these were violent explosions of volcanic rock, ash, and gas that burst high into the atmosphere, darkening the sun and creating their own thunderous weather. Any life in the area would have been engulfed by deathly hot rock and dust, much as the victims of the Mount St. Helens explosion were. The aligned trees at the Petrified Forest west of Calistoga, laid side by side like the downed trees at Mount St. Helens, are a mute remnant of a powerful lateral blast. Also near Calistoga, the Palisades—the prominent cliff-forming rock that caps the Vaca Mountains in this area—are made of ignimbrite, coarse-grained volcanic rocks created by large eruptive blasts in which ash and coarser fragments are thrown high into the air and fall quickly back to Earth. The coarser fragments land first, forming a flow that thickens as the material moves down gullies. The thickness acts as insulation, and the high internal temperatures of the flows cause shards of glass, cooled somewhat and solidified in the atmosphere, to remelt. As this material cools once again, it welds the coarser volcanic fragments together into hard, resistant beds like those that hold up these cliffs.

Explosive eruptions, the roar of pyroclastic flows, the rumble and grinding of lahars—all were part of the landscape during the few million years in which the Napa volcanics were forming. Violent thunder and lightning accompanied the eruptions, with torrential rains forming thick mudflows from the loose ash and other accumulated debris. But the volcanic activity was not continuous. Ric Forman's vineyard and caves on Howell Mountain, and the area near the crest of Old Howell Mountain Road, for example, contain river gravel composed mainly of Franciscan and Great Valley rocks layered within the Napa volcanics. While the name "Napa volcanics" may suggest a monolithic deposit, in truth these rocks are strikingly diverse, including tuff (volcanic ash) of various chemical and mineralogical compositions, lava flows, pyroclastic deposits, volcanic mudflows, intrusive (noneruptive) rocks, and sedimentary rocks of volcanic origin.

In addition to lateral motion, movement along the San Andreas fault also contained an element of push and pull, compression and tension. At the fault's inception, the northward-drifting Pacific plate was also moving slightly west. This pull on the crust created depressions, or basins, which filled with sediment eroded from adjacent highlands. These basins include the Southern San Joaquin Basin, the Santa Maria Basin, the Los Angeles Basin, and even the ancestral San Francisco Bay. Cold waters of the Pacific filled these quiet, oxygen-deprived depressions with rich populations of marine algae preserved in thick, organic-rich bottom deposits. This organic gunk was later transformed into some of the richest oil deposits in the world (measured not in total amount but in the volume of oil per cubic yard of rock). Similar basins formed in the area of San Diego, Bakersfield, Santa Barbara, and on up the coastal region of California. But no such basin appeared in the Napa Valley region—had it done so, the valley today might well be filled with oil derricks and pumps rather than vineyards.

Evidence does suggest that a small, ancestral Napa Valley formed at about this time, providing space for the sediments of the Glen Ellen formation. Modest mountains to the east shed gravels that accumulated above sea level, the debris spreading over a broad plain. Gravels and chert-rich sediments accumulated in lakes, in rivers, and on flood plains, along with thick deposits of nonmarine clays, the sediments delivered by streams and rivers draining the hills nearby. These materials make up the Glen Ellen, which underlies much of the Carneros region, providing a substrate unlike anything else in the Napa Valley AVA.

About 3 million years ago, the Pacific plate once again changed direction, now pushing the two sides of the San Andreas fault toward each other, creating a bit of compression. It was only a small force, perhaps 5 or 10 percent of the total movement along the fault, one kilometer of compression for every ten kilometers of lateral movement. But it was enough to create the California Coast Ranges and the ridges that define Napa. Slices of rock were stacked atop one another to form the Vaca Mountains, a crustal wrinkle formed the Mayacamas Mountains, and the downwarp that separated the two ranges defined the Napa Valley (Figure 9). During a respite in this process, a flat erosion surface called a pediment formed at the base of the Vaca Mountains, later to be uplifted as the Vacas rose.

The folding and faulting began in the east and progressed westward. The ranges east of the Napa Valley are more complex than those to the west, indicating a longer period of deformation. The geometry can be mind-boggling: elongate slices of crust concurrently folded and stacked, rocks of different kinds mixed higgledy-piggledy. Think of one of those highway pileups that happen in dense fog, dozens of cars and trailer trucks strewn over the road, crushed against and on top of one another,

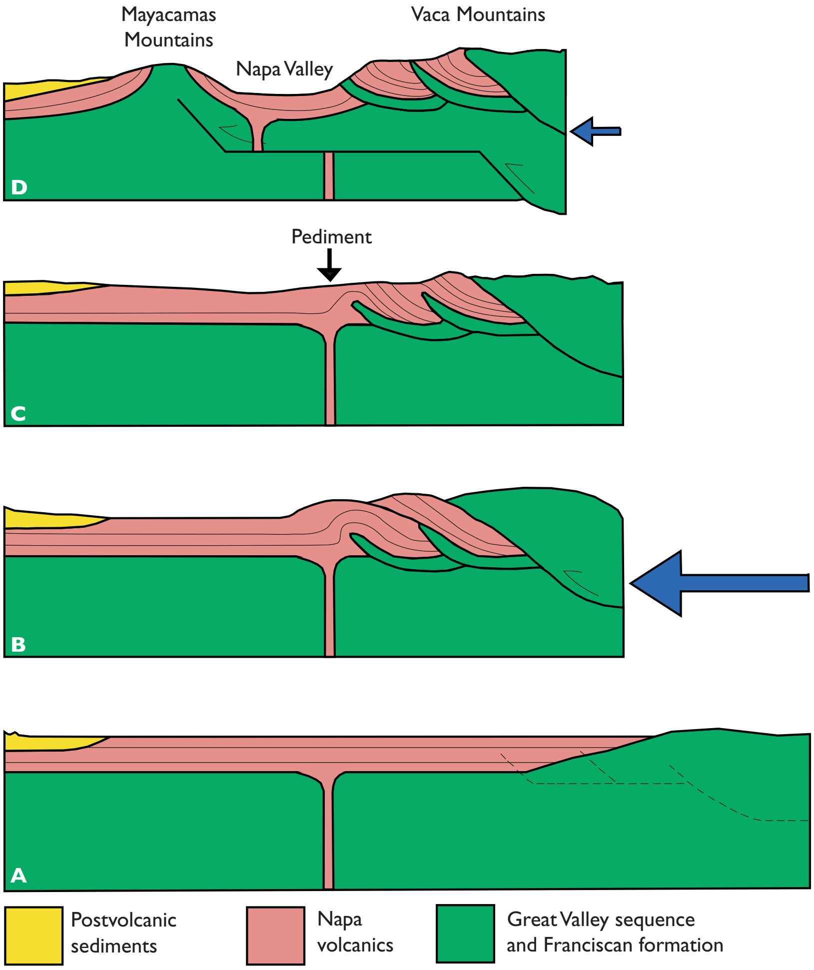

FIGURE 9. The architectural evolution of the Napa Valley. The Napa volcanics covered a relatively flat expanse of land under which lay the rocks of the Great Valley sequence and the Franciscan formation *(A)*. Within the past 3 million years or so, compression associated with the San Andreas fault began deforming the rocks, first in the east *(B)*. A period of erosion followed, which lowered the mountain front and formed a pediment at its foot (indicated by the vertical arrow) *(C)*. Renewed deformation lifted the Vaca Mountains to their present height and created the Mayacamas Mountains *(D)*.

squeezed, bent, piled in a haphazard mass. In the geologic case, the only way to understand the architecture is through detailed geologic mapping—the equivalent of working out the sequence of events in one of those fog disasters. Such work is being refined for the Napa region as we write these words. (We will discuss geologic maps further in chapter 2.)

The stage for the winemaker's dance in Napa Valley continues to change and evolve even today. Anyone who assumed stability and security for this tidy little paradise had their illusions dashed by the earthquake that shook the Mayacamas Mountains in 2001, rattling crockery and tumbling chimneys. And the slow and incremental processes that turn solid rock into the soft sediments that form the substrate for vines continue moment to moment.

The attitude of winemakers to these materials—the bedrock, sediments, and soils that are the foundations of wine—has also evolved, from a kind of superior disinterest during the 1980s to a deeply involved concern today. In the following chapters, we will examine this change and its implications. But first we need to look more closely at the foundations themselves, both to provide greater understanding and to correct some misperceptions.