BERRYESSA SNOW MOUNTAIN
NATIONAL MONUMENT

Exploring the Berryessa Region

A Geology, Nature, and History Tour

CONTRIBUTORS
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In Memory of Eldridge M. Moores (1938–2018)

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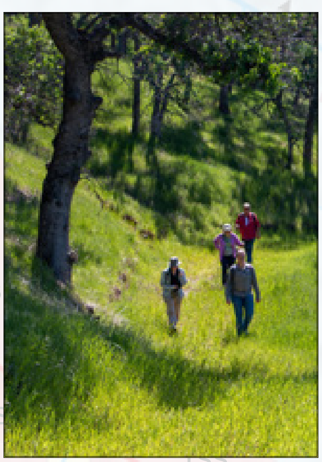
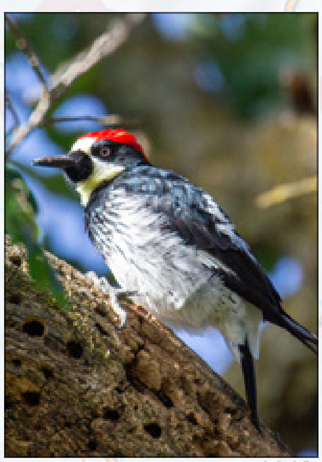
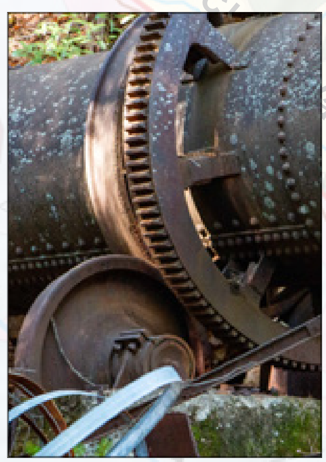
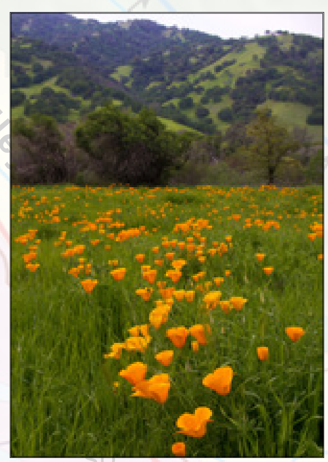

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Cover image by Obi Kauffman. Obi Kaufmann is an American naturalist, writer, and illustrator. He is the author of The California Field Atlas, a guide to the state's ecology and geography.

Dedication to Eldridge

"Here, in the Berryessa Snow Mountain National Monument region, is the best place in the world to see plate tectonics."

—Dr. Eldridge Moores, (1938–2018), Professor Emeritus, Geology, University of California, Davis

We dedicate this book to our dear friend Eldridge Moores, who recently passed away. Eldridge and Judy Moores, his wife and partner, are the inspiration for this work. It is based on many of the field trips that they led, during which they shared their love for geology and this land.

Eldridge was a leader in the plate tectonics revolution. He contributed to our emerging understanding of how oceanic crust develops by sea-floor spreading, how oceanic crust has varied through time, how it's emplaced on land, and the tectonic significance of that emplacement, knowledge that is still regarded as foundational. It is these foundational elements and more that we see in the Berryessa Snow Mountain region.

John McPhee's book *Assembling California* introduced Eldridge's work to people all across the country. After its publication, he had so many requests from the public for fieldtrips that he and Judy began to lead them regularly as fund-raisers for local non-profit organizations. Over the past 20 or so years, they led up to 50-plus folks at a time on car-pool trips all around Northern California. In total, several thousand enthusiastic people went on these daylong adventures. Judy and Eldridge came home exhausted and exhilarated by the success of every trip.

Eldridge was a professor of geology at UC Davis, the geology department chair, the editor of the earth science journal *Geology*, the president of the Geological Society of America, and the vice president of the International Union of Geological Sciences, where he provided vital leadership. He long promoted education in the earth sciences in schools.

He was also a father, a concert cello player, and—to so many—a friend.

We miss you, Eldridge.

FIGURE 1

TOP: Eldridge Moores at the Tehama Formation near Winters, California.

MIDDLE: Eldridge and Judy Moores leading a public tour of the Coast Range geology

BOTTOM: Several of the authors at Aetna Springs - Judy Moores, Peter Schiffman, Eldridge Moores, and Marc Hoshovsky.

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Figures

Acknowledgments

The authors would like to thank and acknowledge the many who came before us in exploring, understanding, and researching the Berryessa Snow Mountain region. The Introduction provides more detail on the history of efforts to know and care for the area.

It is important to acknowledge the Native Americans who have lived here for thousands of years and continue to be part of this community. More recently, ranchers, farmers, rural folks, and town folks have occupied the land. Their histories tell a rich story.

Professors and students at UC Davis, especially those in the Nature and Culture Program and the Putah-Cache Bioregion project, studied the region's biodiversity, geology, history, and cultures. These people included Michael G. Barbour, Susan P. Harrison, Peter B. Moyle, David Robertson, Gary Snyder, G. Ledyard Stebbins, Rob Thayer, Dennis Pendleton, and Joyce Gutstein. In the late 1990s, they inspired many people to take a greater interest in the region through their multiple field trips in the Putah and Cache watersheds. Information about the area was later augmented by the Blue Ridge-Berryessa Partnership.

Several non-profit organizations have encouraged people to explore and protect this region for many years, including Putah Creek Council, local Audubon chapters, UC Davis Natural Reserve System, Putah Creek Trout, Napa County Historical Society, Yolo Hiker, and Tuleyome.

Geological map information in this guide was developed by K. F. Fox, Jr. and J. D. Sims in the early 1970s, and this information still forms the basis of many of the geology maps in the region. This guide also incorporated other more recent localized mapping. Geological information was derived from valuable research and road guides developed by Stephen P. Phipps, Jeffrey R. Unruh, David Wagner, John Wakabayashi, and others.

Amy Boyer was a great help in editing this guide and improving it considerably. Amy is a writer, editor, and group facilitator who currently works at Insight Garden Program in Berkeley. Tim Messick substantially improved the quality of the geology and land management maps, as well as many other figures throughout the book. Tim is a cartographer, botanist, and photographer who recently retired at ICF International Inc. in Sacramento.

We thank Chad Roberts for his authoritative information on fire ecology in the region. This is currently a critical issue in California and in our region. It is vital that we establish science-based policies for managing our shrublands and forests.

We thank Rob Zierenberg and David Wagner who reviewed the geology; Truman Young and Susan Harrison who reviewed the ecology and biological diversity; and John Parker who reviewed the Native American history.

Thank you also to Lindsay Weston, whose support helped get this project completed.

Marc's wife, Carrie Shaw, inspired him to develop a deeper understanding of the region's natural history and tolerated his research passion as this guide developed. In this process, Marc became our primary author continually adding sections and information to the geology, nature and history of the region making this guide as thorough as it could be. Thank you, Marc.

Any mistakes, omissions or errors within this volume are solely the responsibility of the authors.

Figure 2. Carpets of lupines cover the hills of Putah Creek Canyon the year after the 2014 Monticello Fire.

Preface

This guide was inspired by Eldridge and Judy Moores' passion for teaching others about geology in the field and by the efforts of others to provide more detailed, location-specific information about geological features, biodiversity, and cultural history to the public.

The authors felt it was an opportune time to share our knowledge and love of the southern portion of the Berryessa Snow Mountain National Monument, the Berryessa Region, with visitors to this "undiscovered landscape."

We recognize that lots of technical information exists on these subjects for Putah Creek and the Berryessa Region, but this information is difficult for general readers to locate and understand. We also recognize that more popular geology guides exist, but they do not cover this region in detail.

Geologists have long valued field trips as part of their scientific conferences, and most conferences publish detailed—and quite technical—field trip guides for the region where the conference is held (see Appendix D). Eldridge was very much a part of those conferences, and he led field trips and published field guides for them throughout Central California, including trips for the Geological Society of Sacramento, the Northern California Geological Society, and the Geological Society of America.

Eldridge and Judy saw a need for the interested public to have a chance to learn about the region, hence the geology tours they began leading in the early 1990s.

Eldridge and the authors of this guide also realized that these guided tours could only reach a small audience and that many others were eager to learn more about the regional geology. Thus arose the idea of a printed guide, designed for general readers and readily downloaded from the Internet, which would inform and inspire others about the world renowned geology of this place. This coincided with our interest in expanding people's appreciation of the relatively new Berryessa Snow Mountain National Monument, so we broadened the scope to cover natural and cultural history.

This volume opens with a discussion of this undiscovered landscape and its biological diversity. Next is an introduction to the science of geology with an emphasis on plate tectonics. This is followed by a detailed road guide from Winters along Lake Berryessa to Pope Valley that includes a portion of California State Scenic Highway 128. Additional information is contained in the appendixes.

We hope that you enjoy your time here and that the knowledge in this book adds to your enjoyment.

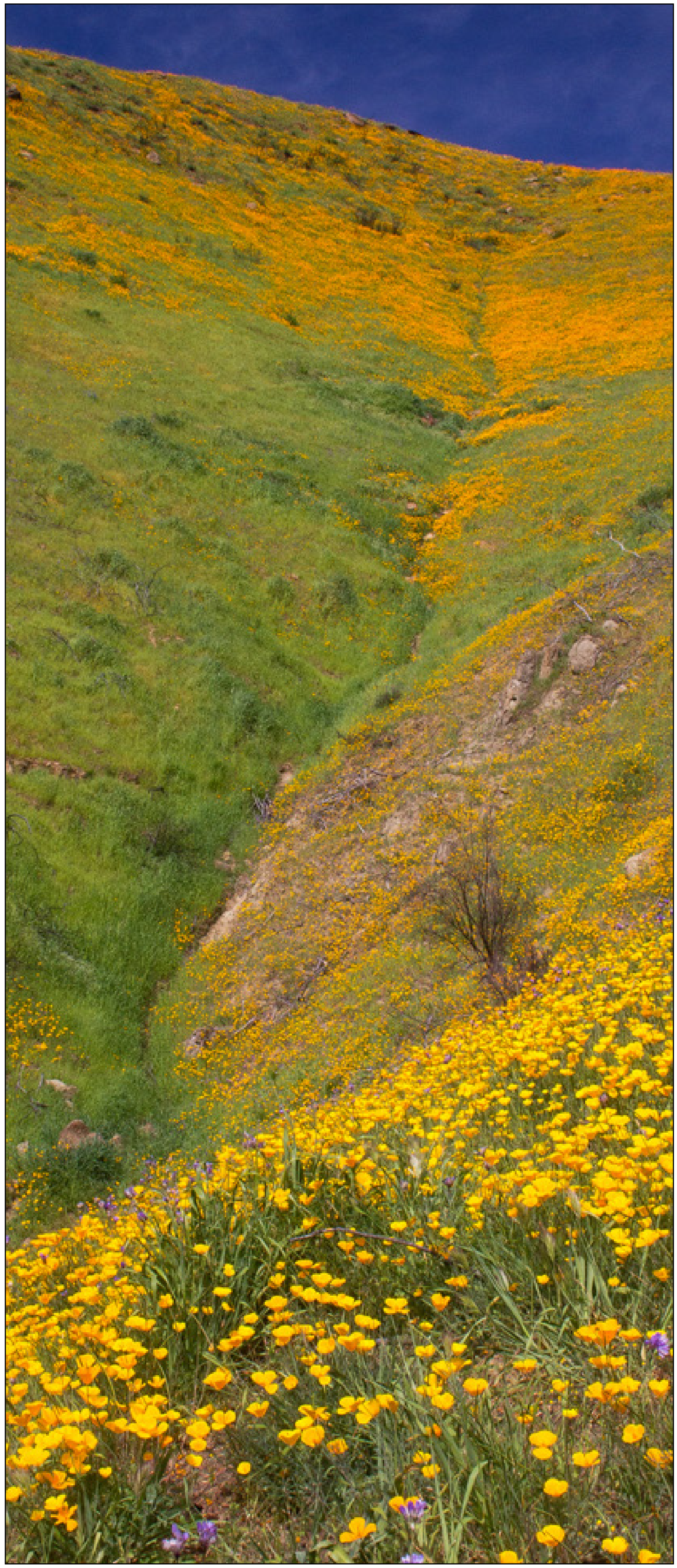

Figure 3. Foothill poppies in Bray Canyon.

INTRODUCTION

The Undiscovered Landscape

Many of us have referred to the Berryessa Snow Mountain region of California as The Undiscovered Landscape. Certainly, Native Americans, descendants of early settlers, and long-time residents know this land. But perhaps even they have only recently realized how important this place is to the planet for its geology, biological diversity, and migratory corridors for wildlife. These are relatively recent discoveries, driven in part by the modern-day plate tectonic revolution which emerged in the 1960s.

It is for these globally significant geological and ecological characteristics that parts of the federal public lands in this region were designated as the Berryessa Snow Mountain National Monument. The region also matters because of its historical and cultural assets, especially those related to Native American cultures and mining history; its many recreational opportunities, including hiking, camping, birding, botanizing, horse riding, boating, and managed off-highway vehicle use; and valuable resources such as water, forests, and ranchlands.

Much of the region is a matrix of public and private lands. As you enjoy the public lands, please be respectful and do not trespass on private lands.

It is helpful to understand that this region's biological diversity is the result of both ecological processes and, more recently, cultural evolution that began with Native Americans who have been in the region for at least 12,000 years. They managed the land in many ways to increase its natural production of wildlife and crops such as acorns, grains, and bulbs for food; sedges, willow, and redbud for weaving baskets; and tule for making clothing, houses, and boats. These management practices included seasonal burning, thinning, trimming, planting, and selective gathering of species.

Over the last 50 years many farmers and ranchers in the region have promoted conservation practices including no-till planting, protection of riparian habitats, and innovative grazing practices. The farming and ranching communities have also partnered with conservation organizations to protect prime farmland from urban development and to restore biodiversity within these highly managed landscapes.

This is not to say that there are not ongoing conflicts among different land uses. There clearly are. But it is important that much of the dialogue has been and continues to be respectful and inclusive.

The modern activist conservation that led to the designation of the Berryessa Snow Mountain National Monument has roots in the battle to ensure adequate water flows in Putah Creek. Putah Creek flowed wild until Monticello Dam was completed in 1957. The dam curtailed flooding and provided water to Solano County farms and cities. It was not until the drought of the late 1980s, when children watched the creek dry up and fish die on its banks, that local folks understood the problems with how Putah Creek water was managed. They formed Putah Creek Council, which sued to ensure adequate water flow. In 2000, the Putah Creek Water Accord, providing for increased water flows and funding for riparian restoration, was signed and embraced by all sides. An important basis of this agreement was Peter Moyle's long-term monitoring data of Putah Creek fish populations since the 1970s. It is gratifying now to witness salmon in the creek that have returned to spawn in late fall. In November and December, you might see them from the Winters Railroad Bridge.

Three key developments really opened the door to the Berryessa Snow Mountain region in the late 1990s.

In 1997, UC Davis provided substantial funding for the Putah-Cache Bioregion Project, which had been developing since the early 1990s. Many examples of bioregional thought and practice influenced the project as it evolved, including the writings of poet and UC Davis professor Gary Snyder. Snyder's circumambulation of Mount Tamalpais, with Allen Ginsberg and Philip Whalen, provided the model for "circumdrives" of the Putah and Cache Creek watersheds. The UC Davis Artists in Bioregional Residence program, developed by David Robertson, supported local artists in using the region as inspiration for their writings, paintings, photography, and music.

In 1997, Ray Krauss, who implemented a cutting-edge environmental mitigation plan for the Homestake Gold Mine, and others initiated the Blue Ridge-Berryessa Partnership. The Partnership brought together agricultural stakeholders, user groups, and conservation organizations to study the region, work through issues in a collaborative manner, and provide guidance toward consensus for a sustainable region.

In 1999, Andrew Fulks began Yolo Hiker. Andrew and Sam Bledsoe led hikes on the public lands of the region, introducing over 500 people each year to a region largely unexplored by urban users. He wanted folks here to share opportunities to be in nature that he had experienced on the public lands of the San Francisco Peninsula.

In 2002, Tuleyome was founded by a small group of knowledgeable and experienced public land advocates. In 2005, the Cache Creek State Wild and Scenic River was designated. This was followed by the 2006 Northwest California Wild Heritage Act, which included the designation of the Cedar Roughs and Cache Creek Wilderness Areas and expanded the Snow Mountain Wilderness Area. Tuleyome also began a program to get folks outdoors and a land program to protect key ecological and recreational lands.

Led by Bob Schneider, Sara Husby, and others, work began to protect the federal public lands of the region. It was a conscious decision to be open and inclusive in this effort, working with a wide variety of stakeholders and user groups, including hikers, mountain bikers, horse riders, and managed off-highway-vehicle users; businesses; ranchers and farmers; elected officials; and many others. (See Appendix D for some of the organizations.)

In July 2015, as a culmination of this effort, President Barack Obama declared 330,780 acres of federal land as the Berryessa Snow Mountain National Monument.

We have come to love this place and greatly enjoy exploring and learning more about the region and sharing that knowledge with others. But we also believe that if we are to protect these special places into the future, the users of our public lands must represent the demographics of California and the nation. We will need to be inclusive in this effort and reach out to diverse stakeholders.

We hope that this book helps to break down barriers and introduce more of California's residents and visitors to this very special place.

OVERVIEW OF THE BERRYESSA REGION

This road guide focuses on the Berryessa Region in the context of the larger Berryessa Snow Mountain National Monument. The Berryessa Region only covers the southern parts of the National Monument near Lake Berryessa, with the lands surrounding them, but it has particularly interesting geology to explore.

Berryessa Snow Mountain

In the Inner Coast Range west of Sacramento, California, and within easy driving distance from San Francisco, lies a wild place of steep-sided canyons, mountainous terrain, and fields of wildflowers. Bald and golden eagles soar overhead, sedimentary rock layers stand on end, and numerous unique plant species abound. While renowned for its world-class geological features, the area is also a biological diversity "hot spot."

In 2015, President Obama designated the area between the Berryessa Region and the Snow Mountain Wilderness Area in Northern California as a National Monument. The monument designation highlights the area's unique geology, protects the natural biological diversity and wildlife migratory corridors of Northern California's Inner Coast Range, preserves prehistoric and historic legacy sites, and facilitates improved stewardship of U. S. Forest Service and Bureau of Land Management (BLM) lands. It also takes care to honor the region's importance for ranching and outdoor recreation.

During a one-day excursion through the Berryessa Region portion of the BSMNM, it is possible to examine world-class geological, ecological, and human cultural features. Roadside rock outcroppings display the eroded remnants of an ancient subduction zone in which one tectonic plate was shoved beneath another. Uplifted portions of the Earth's ancient mantle now serve as the substrate for unique serpentine soils, on which grow plant species found nowhere else. Human history goes back thousands of years, encompassing many Native American tribes and, more recently, miners, cattle ranchers, farmers, and vintners.

Geographical Setting

The Monument encompasses 330,780 acres within the northern Inner Coast Range of California, from the southern end of Lake Berryessa to Snow Mountain Wilderness Area in the north. At the northwest side of the Monument are the headwaters for the Main and Middle Forks of the Eel River, which flow 200 miles (320 km) northwest to near Eureka, California. On the east side are Cache Creek and the headwaters of Stony Creek, and the southern part is drained by Putah Creek. The highest elevations are in the northern part of the Monument region, including Snow Mountain (7056 ft; 2150 m) and Goat Mountain (6121 ft; 1865 m). These peaks are often snow-covered during the winter and visible from much of the Sacramento Valley. The Monument is at its lowest elevations (300–600 ft; 90–180 m) in the Berryessa Region along Cache and Putah Creeks.

The Berryessa Region at the south end of the Monument is primarily the central part of the Putah Creek watershed, including the Blue Ridge, Lake Berryessa, and the mountains west of Lake Berryessa. Putah Creek, an 85-mile-long stream, has its headwaters in the Mayacamas Mountains above Napa, flows into Berryessa Valley (now Lake Berryessa) to what was known as "Devil's Gate" (the current location of Monticello Dam) as it passes through the Blue Ridge, and then into the Sacramento Valley (see Figure 4).

The Patwin name for Putah Creek was Leivai. The current name of Putah Creek may be derived from either the name of the Patwin village "Puta'to" (on Putah Creek near the present-day Monticello Dam) or from Lake Miwok words "put'a wuwwe" (grassy creek). The Patwin word "Puta'to" means "eastward flowing water," a distinction that only applies to a few streams on the west side of the Sacramento Valley. Most Sierran and Coast streams flow west, south, or north.

Elevations of valleys in the Berryessa Region generally range from 300 to 400 feet (90–120 m), and its ridges rise to 2000–3000 feet (600–900 m). The Blue Ridge, generally above 2500 feet, dominates the landscape, with Berryessa Peak (3057 ft; 931 m) its high point.

Temperatures and precipitation vary across the Berryessa Region, depending on varying elevations in the watershed, distances from the coast, and California's highly variable Mediterranean climate. Average temperatures decrease with increasing elevation and decreasing distance from the coast (or the Sacramento Delta). During the summer, average valley temperatures range from 55°F at night to 95°F (13–35° C) during the day. Winter daytime highs in the valley average 55°F and nighttime lows about 39°F, with regular frosts.

Precipitation decreases rapidly towards the Sacramento Valley, with the Coast Range catching most rainfall because of the rain-shadow effect. Most of the rainfall occurs during the winter (snow is rare), averaging 4 to 7 in. each winter month. Summers are extremely dry and sunny, with average rainfall (if any) less than 0.1 in. per summer month. With climate change we are beginning to experience fewer, but more intense, storm events.

Public and Conservation Lands

The National Monument formally consists of only federal public lands. Approximately 197,000 acres of the Monument are managed by the U. S. Department of Agriculture's Forest Service (USFS), including part of Mendocino National Forest, and about 133,000 acres are managed by the U. S. Department of Interior's Bureau of Land Management (BLM). While the USFS and BLM are governed by different laws and policies, the agencies share many common goals as they work together on the Monument Management Plan. Land uses on these federal lands, such as recreation, grazing, fire management, and timber operations, are allowed to continue, subject to a National Monument management plan. However, greater restrictions are placed on mining, and motor vehicle use is limited to designated roads and trails.

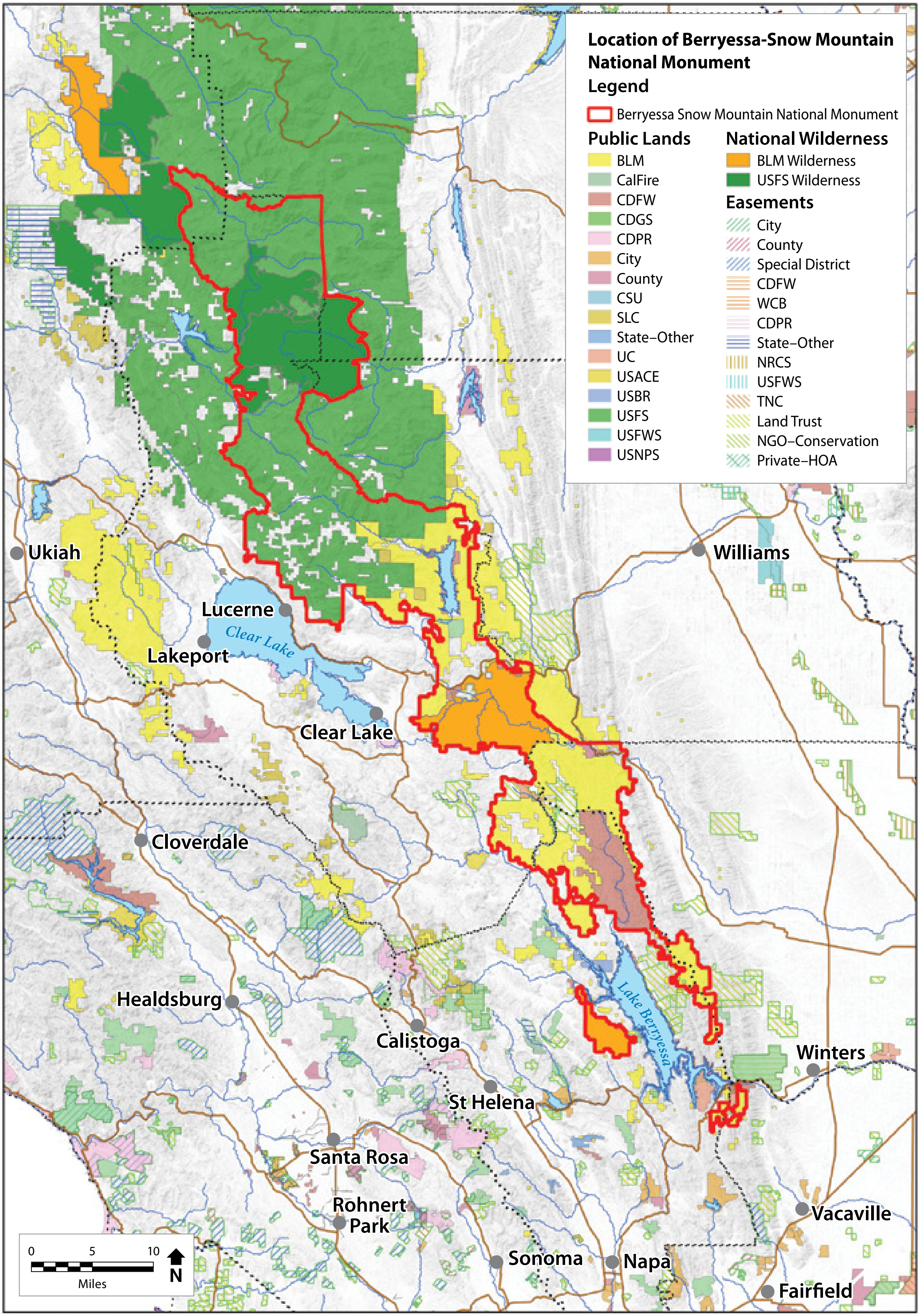

Figure 4. Location of Berryessa-Snow Mountain National Monument.

Other important public, tribal and private lands are located within or near the monument boundaries. The monument designation affects only federal public lands and does not directly affect management of these other lands. Still, the designation has led to greater cooperative stewardship among land managers.

In the Berryessa Region, these other public lands include U. S. Bureau of Reclamation lands around Lake Berryessa, three California Department of Fish and Wildlife wildlife areas (Knoxville, Cache Creek, and Putah Creek), four University of California reserves (McLaughlin, Quail Ridge, Stebbins Cold Canyon, and Cahill Riparian Reserves), and local government open space lands administered by the counties of Napa, Solano, Lake, and Yolo.

The region also encompasses important private conservation lands and easements owned and managed by Tuleyome, Land Trust of Napa County, Napa County Regional Parks and Open Space District, Solano Land Trust, California Rangeland Trust, and Audubon California's Bobcat Ranch (see Figure 5).

Cultural History

Cultural sites in the Monument include Native American hunting and mineral gathering sites (in the high country) and many of their village sites (in the interior valleys) as well as 19th century roads, buildings, hot spring resorts, and mine sites.

The area covered by the Monument has been inhabited for at least 12,000 years by seven or more different Native American groups, including the Patwin, Pomo, Lake Miwok, and Wappo peoples. Just before European arrival in the Berryessa Region, the Patwin/Yocha Dehe Wintun territory encompassed parts of Berryessa Valley, Cache Creek Valley, and the western Sacramento Valley. The Lake Miwok people occupied the upper Putah Creek watershed. Today the Yocha Dehe Wintun Nation owns land in the greater Cache Creek area (see Sidebar 1 [Patwin] and Sidebar 20 [Lake Miwok]).

Spanish, Mexican, and British explorers passed through the area in the early 19th century, followed by American miners searching for gold and mercury in the mid-late 19th century. Native populations were decimated by cholera, malaria, and smallpox introduced by the early explorers. For example, the 1833 malaria epidemic and the smallpox epidemic of 1837–1839 are estimated to have killed at least 75% of native people in the Putah Creek watershed. Explorers and settlers arriving after these events found few original inhabitants in the area.

Later, in a tragic and unjust period of our history, massacres such as the one at Bloody Island in 1850, located at Clear Lake, further devastated the local Native American peoples.

During the 1840s, many American and Mexican settlers started homesteading in the region. To help manage the influx of Americans, the Mexican government granted many large ranchos to Mexican citizens. In the Berryessa Region, the largest land grant was Rancho Las Putas, 35,516 acres in the Berryessa Valley, granted in 1843 to José de Jesús and Sexto "Sisto" Berreyesa (Berryessa was spelled various ways). Other grants in the Berryessa Region included Rancho Los Putos (Vacaville Area, 1843, Juan Vaca and Juan Peña), Rancho Cañada de Capay (Capay Valley, 1846, Francisco Berryessa), Rancho Chimiles (Green Valley, 1846, Jose Ygnacio Berreyesa), Rancho Locoallomi (Pope Valley, 1841, William Pope), Rancho Catacula (Chiles Valley, 1844, Joseph B. Chiles), Rancho La Jota (Angwin, 1843, George C. Yount), and Rancho Rio de los Putos (Winters area, 1842, William and John Wolfskill) (see Figure 7).

By chasing their free-range cattle across their land grants, these ranchers explored many parts of the region on horseback. After California's admission to the United States in 1850, these land grants became the center of substantial confusion and conflict due to squatters and land speculators.

During the 1846 Bear Flag Revolt, which resulted in the U. S. acquisition of California, John Fremont and the California Battalion used the Berryessa Region as both an espionage route and a route for moving troops (see Figure 8).

Until the mid to late 1850s, no wagon roads were built or maintained in the region. By 1858, new roads had been constructed to connect the region to Napa Valley (Berryessa–Napa Road) and Sacramento Valley (Putah Creek Turnpike and Capay Valley-Berryessa Toll Road).

The discovery of mercury (for example, at the Phoenix and Washington mines in Pope Valley, Redington Mine at Knoxville, and Oat Hill Mine west of Aetna Springs) and borax deposits (at Clear Lake) in the early 1860s, greatly spurred settlement in the region.

From the 1850s into the 1970s, mercury deposits were mined in the upper Cache Creek and Putah Creek watersheds and processed to produce the elemental form known as quicksilver. Mercury mined in this region was used during the Gold Rush throughout much of the Sierra Nevada to amalgamate with and recover gold particles from ore and placer deposits. More recently, mercury was mined during World War II for ammunition and between 1950 and 1970 for hearing aids.

Most of the creeks and lakes in the Cache Creek and Putah Creek watersheds are considered impaired (that is, they do not meet water quality standards) by mercury contamination. In waterways, elemental forms of mercury can be converted to methyl mercury, a highly toxic and bioaccumulative form that is typically 10 million times more concentrated in predatory fish than in the water. Eating too much contaminated fish can result in neurological damage, particularly to fetuses during pregnancy and to children.

There are about 50 abandoned mercury mines in the Putah Creek watershed, including the drainages of Pope Creek, upper Putah Creek, and Eticuera Creek, which all flow into Lake Berryessa.

The serpentinite masses in northeastern Napa County, west and northwest of Lake Berryessa, were an important source of chromite and magnesite. Many mines were developed in the late 1800s and early 1900s to extract these ores. Chromium is derived from chromite and typically is used for alloying and plating elements on metal and plastic substrates for corrosion resistance. A total of 2132 tons of chromite were shipped between 1916 and 1941. Production was greatest during World War II. Magnesite is an important heat-resistant material used as a lining in blast furnaces, kilns, and incinerators. In 1891, Napa County was the second county in California to start pro-

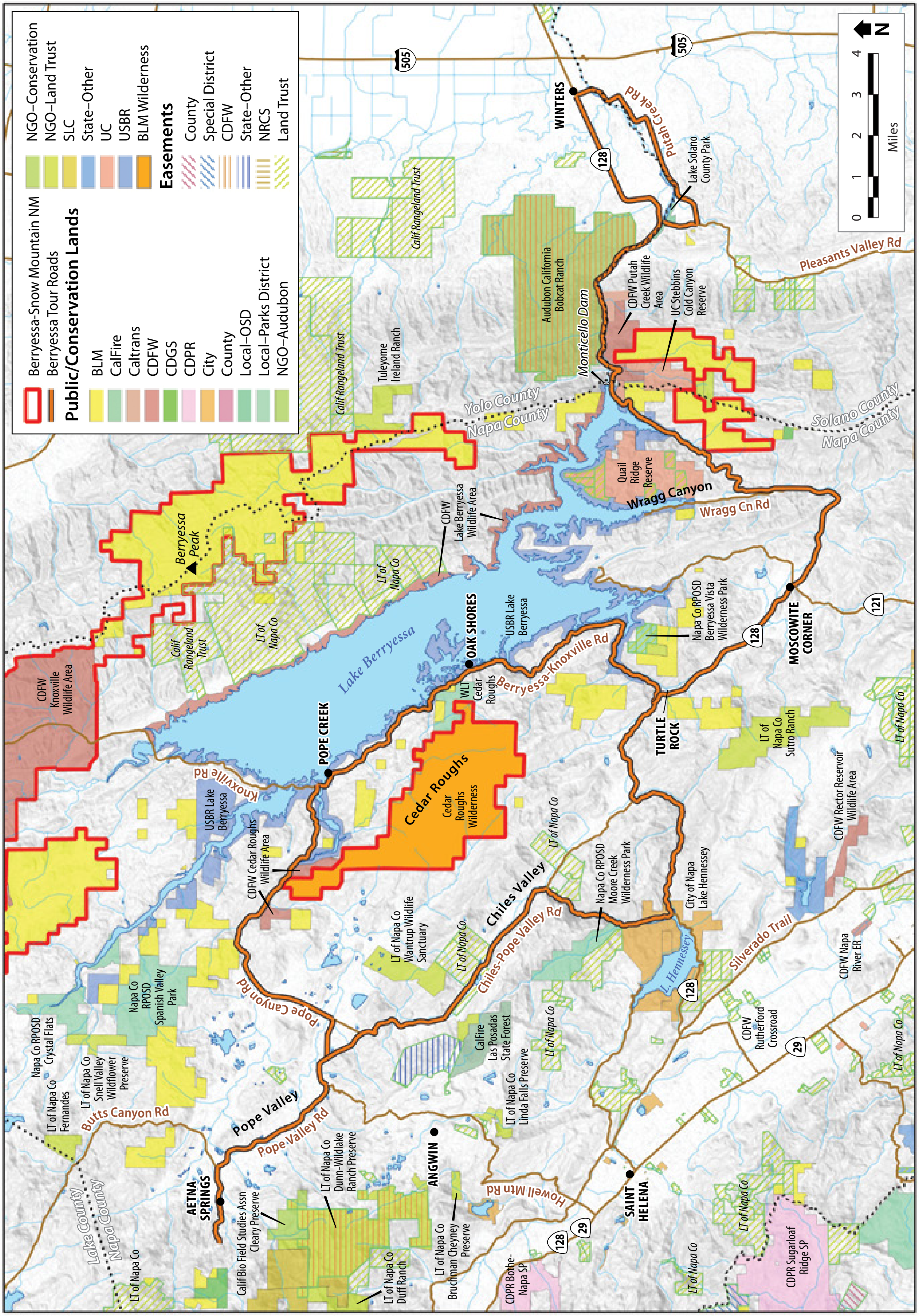

Figure 5. Public and conservation lands in Berryessa region. Lands with conservation easements are private lands with restricted public access. Acronyms are listed in Appendix B. Source: GreenInfo Network 2019.

SIDEBAR 1

Patwin and Wintun People

The earliest peoples in the area spoke a language belonging to the Yukian language family. They populated the Sacramento Valley and California's North Coast for at least 12,000 years. These early people are the ancestors of the Wappo who live in the area today. After their arrival, a Hokan-speaking people from the Sierra Nevada and Great Basin moved into part of the Yukian territory, including the area that makes up the National Monument. The Hokan speakers became the Pomo people of today. Sometime between 2000 and 3500 years ago, people of the Penutian language family moved northward from the San Joaquin Valley into the San Francisco Bay area and north into the BSMNM area. These people are the Patwin, Wintun, and Lake Miwok that currently inhabit the area.

Most of this guide travels through historic Patwin lands. "Patwin" is the Southern Wintun word denoting "person" or "people." The Patwin lived on the southwest side of the Sacramento Valley, south of Princeton and Lodoga to Suisun Bay. These people were not a specific political unit, but rather a group of contiguous bands who spoke similar languages and had similar culture. Patwin and their neighbors the Wintun spoke languages that were mutually unintelligible. They subsisted by hunting, fishing, and gathering acorns and grains as their main staples, supplemented by berries, nuts, and bulbs. The Patwin kept dogs and used them in hunting. Food harvest areas were owned communally by each tribelet, and the village chief decided when, where, and how food was distributed. They constructed family houses, ceremonial dance houses, sweathouses, and menstrual huts. All of these were semi-subterranean structures, with earth piled on top of the wooden framework. Communal houses were constructed by all villagers working together.

Figure 6. Patwin woman with basket at Choo-hel'-mem-sel village near Lodoga, Colusa Co. Source: Merriam, undated, 1890-1938.

The aboriginal population of both the Patwin and their northern Wintun neighbors in the early 1800s was about 12,000, but due to epidemics of diseases introduced by Europeans, enslavement for a labor force for the Spanish missions or large landowners, becoming indentured laborers during early California statehood, and other causes, no Patwin were alive on Putah Creek by 1877. By 1924, the entire Patwin population numbered between 20 and 150 and they had been completely extirpated south of Rumsey.

In the early 1900s, the remaining Patwin were forcibly removed to a federally created rancheria in Rumsey. The land was barren and difficult to farm. In 1935, the US Bureau of Indian Affairs reported 20 people living on the rancheria. In 1940, the tribe were successful in relocating to a better location farther south in the Capay Valley, near Brooks. New federal gaming law in 1988 finally provided the tribe a means of becoming more economically self-sufficient on their trust land. In 2009, the tribe legally changed their name from "Rumsey Band of Wintun Indians" to "Yocha Dehe Wintun Nation", reflecting the name of their ancestral village meaning 'Home by the Spring Water'. The tribe is an independent, self-governed nation that supports tribal people and the Capay Valley community by strengthening their culture, stewarding their land and creating economic independence for future generations. They have donated millions of dollars to charities in Yolo County including a recent $2.5 million donation to the Yolo Food Bank. As of 2019, the tribe owns almost 20,000 acres of land in the Capay Valley for farming and ranching. They also produce the commercial Séka Hills brand of wine, olive oil and honey.

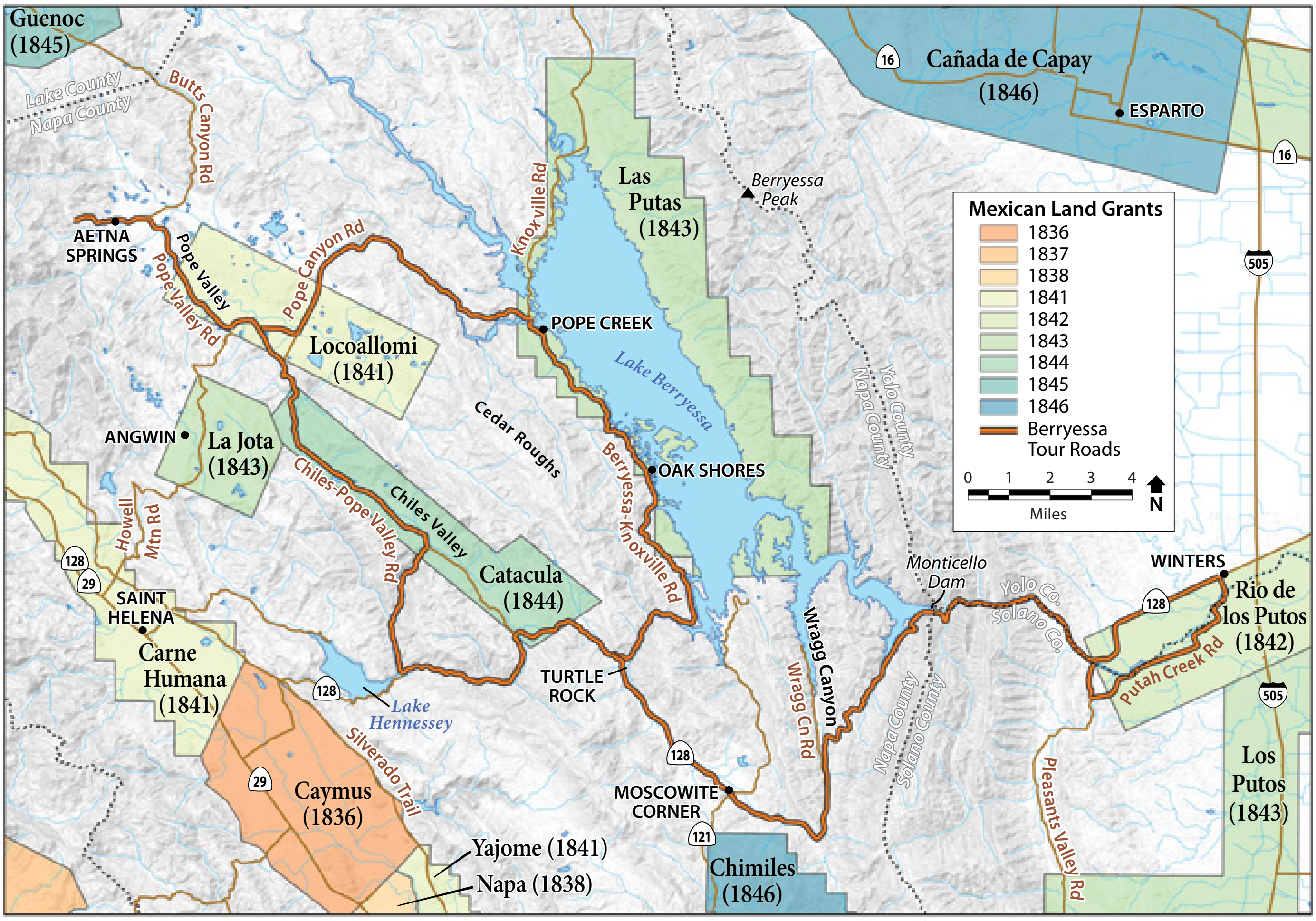

Figure 7. Mexican land grants on tour route.

ducing this ore. All of the major deposits are located east of Pope and Chiles Valley.

During the early 1900s, manganese was mined at several locations in northeastern Napa County, and several companies drilled for petroleum in Berryessa Valley. The Manhattan Mine, later renamed the McLaughlin Mine, at the northern tip of Napa County, produced gold, silver, mercury, lead, and antimony between 1863 and 2002.

Starting at the beginning of the 20th century, several new reservoirs altered water flows and land use in the Berryessa Region. The largest impoundment in the region was Lake Berryessa, formed by the 1957 completion of the Monticello Dam across Putah Creek.

In 1890, C. M. Wooster and others initially purchased land in Berryessa Valley for a reservoir and appropriated Putah Creek water for irrigation. Solano County farmers hired three

Figure 8. Putah Creek Bridge in Berryessa Valley. Source: Wallace 1901.

engineers to design a large dam at Devil's Gate in 1907. Damming Putah Creek would flood Berryessa Valley and the town of Monticello, which had been established there in 1867, so Napa County interests strongly opposed a dam.

The battle over flooding Berryessa Valley was fiercely waged until Monticello Dam was formally authorized for construction in 1948. The town of Monticello was then evacuated, all roads through the valley were rerouted, and the dam was completed in 1957. The valley was flooded, and anadromous fish such as salmon and steelhead could no longer access the upper tributaries of Putah Creek.

During the planning of the reservoir, Napa and Yolo County declined to participate in receiving water deliveries. Yolo County was invited to participate in building Monticello Dam, but declined, saying that it would never need the water. The U. S. Bureau of Reclamation then designed the dam to meet and supply only the projected needs of Solano County plus a small flow dedicated to UC Davis. Also, the Solano Diversion Dam, which diverts much of Putah Creek out of the creek into water delivery canals in Solano County, formed Lake Solano downstream of Monticello Dam. Generally, only "excess" water was allowed to travel downstream below the dams although a paltry minimum flow of 5 cubic feet per second was required.

Water diversions during dry years of the 1980s and 1990s completely dried up Putah Creek near Davis, prompting a public trust lawsuit by the Putah Creek Council. UC Davis (the only Solano Project customer in Yolo County) and the City of Davis joined this suit. In 2000, the lawsuit was resolved by the Putah Creek Water Accord, which provided more reliable flows downstream for fish and plants and additional funding for riparian restoration. By 2016, excellent cooperation by many different organizations had improved flows and restored some of the riparian habitat, once again enabling an anadromous fishery in Putah Creek, at least below the dams. Over 1800 salmon returned to Putah Creek in 2016.

Biological Diversity

The California Floristic Province (an area that overlaps with much of California and is recognized for its distinctive plant life) is one of the world's top 25 biodiversity "hotspots," having thousands of native species found only there. Among all the states, California has by far the highest biological diversity by any measure—plants, animals, vegetation types, and species found nowhere else. The Berryessa Snow Mountain National Monument captures a great deal of what makes California biologically special as the Klamath-Siskiyou and Central Valley eco-zones overlap here.

The Berryessa Snow Mountain National Monument region is emblematic of northern Inner Coast Range diversity. The Monument contains around 1700 plant species, including several dozen plant species that only live there, and around 80 distinct vegetation types—making it more diverse than all of the other states in the country.

Old, mature forests in the northern part of the Monument provide homes for uncommon animal species, such as the northern spotted owl and Pacific fisher. The northernmost of the few herds of tule elk in California roams Lake County. Nocturnal animals include northern flying squirrels, California kangaroo rats, and 13 of the state's 21 species of bats. River otters, osprey, and golden and bald eagles (both wintering and breeding) thrive on lakes and along waterways. In addition to eagles, visitors may have the luck to see reclusive black bears, mountain lions, bobcats, or gray foxes.

The lower elevations and southern areas of the Berryessa Region have extensive stands of blue oak, gray pine, and chamise and other types of chaparral, with grasslands and valley oak woodlands on valley floors and riparian habitat along streams and creeks. Middle elevations also support blue oak, gray pine, and chaparral, as well as widespread montane hardwood forests that have live-oaks, madrone, and black oak. Higher elevations have ponderosa pine, Douglas-fir, incense-cedar, and montane chaparral. There are several stands of old-growth ponderosa pine and Douglas-fir in the northern areas (see Figure 9).

The broader National Monument region also supports several of California's rarity hotspots (concentrations of very rare species) for plants and invertebrates. Especially notable are rare plants and habitats that grow only on serpentine soils. These include leather oak scrub, knobcone pine, McNab cypress, and Sargent cypress. This area includes some of the most important habitat types in California, with more than 300 wildlife species directly associated with its oak woodland habitat areas.

For decades, ecologists and evolutionary biologists have recognized the National Monument region as a living laboratory for understanding the origin and maintenance of biological diversity. The great evolutionist Ledyard Stebbins once described tropical areas of high diversity as both a "cradle" and a "museum"—a "cradle" where new species are born in response to unique environmental conditions, and a "museum" where ancient lineages have survived for tens of millions of years. He also made similar statements about the North Coast Range, that is, it was botanically diverse because of both past and new evolutionary conditions.

The Berryessa Region serves as an essential habitat connectivity link in California, providing bridges between natural areas in the southeast Coast Range and the east Bay Area with extensive protected areas farther north and west. Regional landscape connectivity fosters ecological resilience, as climate change requires plant and animal species to adapt to, and move in response to, altered conditions. The Monument provides a secure pathway northward and upslope for animals and plants that need to seek cooler, wetter climates to survive.

Role of Fire

The role of fire in California and the Berryessa Snow Mountain region is a critical issue, much in the news. It is vital that we carefully craft our policies on forests, fire, and fuels management based on the best science. This synopsis provides a basic background.

California ecosystems evolved with fire, and each plant and animal species in this biologically complex region is adapted for living and reproducing in fire-affected landscapes. Ecosystems within the Monument region exemplify evolutionary responses to fire regimes, which are recurring patterns of fire at landscape scale.

Figure 9. Riparian Habitat in Putah Creek Canyon.

Fire regimes are defined according to the following factors, because they affect mortality and potential reproduction or regeneration after fires:

- Typical fire frequencies (often expressed as the length of time between fires, called the fire return interval),
- Seasonality,
- Patchiness in size of burned areas,
- Patchiness in intensity (amount of heat released by the fire), and
- Patchiness in severity (biological impacts of the fire, especially mortality).

Fire is an essential element in California ecosystems, including those in the National Monument. Fire acts as an ecosystem stressor, that is, as a natural element that shapes the systems. The highly biodiverse landscape in California is a direct consequence of differences in fire regimes as they interact with variations in topography, underlying rocks, soil development, precipitation and drought, and temperature regimes. Fire is not a disaster in complex ecosystems; it alters, restores, and rejuvenates them, providing conditions such as open space and high nutrient availability that favor species that may be uncommon without a fire's disturbance. Fire adapted habitats often recover quickly (see Figure 10).

Different areas and ecosystems have different fire regimes, with different degrees of fire exposure for the species within them. The species that make up grasslands, chaparral, oak and/or mixed woodlands, and coniferous forests each have their own responses to the fire regimes in which they have evolved.

- Grasslands (now largely dominated by Eurasian species naturalized in California) characteristically burn relatively frequently, typically at low intensity. Fire in grasslands enhances nutrient availability and removes colonizing shrub and tree seedlings, maintaining dominance by grasses and forbs (non-woody, non-grass plants).
- Many oak savannas and woodlands have grassy understories that may burn often enough to affect oak regeneration, but many oak and other hardwood species occurring in California have adaptations that allow them to survive fire. They readily replace fire-damaged leaves scorched by low-intensity fires. Thick bark layers help shield larger oak trees of some species, such as blue oak and valley oak, from low- or moderate-intensity fire. The above-ground portions of smaller trees, and those with thinner bark, are often killed by fire, but many hardwood species, especially oaks, sprout from root crowns or burls afterward.
- Plants in California's shrub-dominated ecosystems, like chaparral, respond in several ways to fire. Many shrub species have adapted to dry-season moisture stress by producing waxy or resinous leaves, which typically cause them to burn at very high intensity. Most shrub species either sprout from burls or root crowns that survive fires or germinate after fire from buried seeds that survive for long periods in a soil seedbank; some species can exercise both strategies. Shrublands typically harbor native plants that persist in the seedbank for many years. Shade cast by overtopping shrubs often inhibits growth of these plants. That shade is removed by wildfire, creating better germinating and growing conditions, and often resulting in spectacular wildflower displays.
- Most coniferous species, including the large trees in conifer forests in the Monument region, can survive low- to moderate-intensity fires, but they lack the resprouting ability of other species. Regeneration relies on seeds produced by surviving trees within burned sites. Some species, including Douglas-fir and ponderosa pine, develop very thick bark as large trees, and slough off lower branches that can feed fire up to the crown of a tree. Fires often create mosaics of lightly to severely burned vegetation that allow for natural re-seeding of damaged areas. A few species in the Monument region, including knobcone pine and Sargent cypress, evolved serotinous cones, which mostly remain closed until the heat from a fire allows them to open and release seeds as a specific adaptation to recover from relatively frequent natural wildland fires.

The biotic richness in North America reflects a great, gradual flowering of evolutionary diversification during the last 65 million years. This included the initial diversification of many of the plant and animal families that make California the biodiversity hotspot that it is today. Climate in this region varied significantly over geological time, with long periods that were warmer and/or wetter than the present—including millions of years when the region received substantial summer precipitation—and other periods that were much colder and drier than today, particularly in the Pleistocene Epoch (2.5 Ma to 12,000 years ago). The vast majority of this diversification occurred without any effects from human occupancy.

Fire was an essential structuring element in this burgeoning richness. Within ecosystems, different species would be favored by a different part of the range of conditions following a fire, from herbaceous waifs and fire-adapted conifer seedlings favored by open areas and bare ground, to tall conifers adapted to survive fire while competing for light in a high canopy of old trees.

For most of the evolutionary history of California's vegetation, almost all fires were ignited by lightning, and short intervals between fires tended to limit the accumulation of fuels that would sustain fires with high severity.

Following the initial colonization of California by Native Americans about 12,000 years ago, the incidence and consequences of fire affected local ecosystem processes in some areas

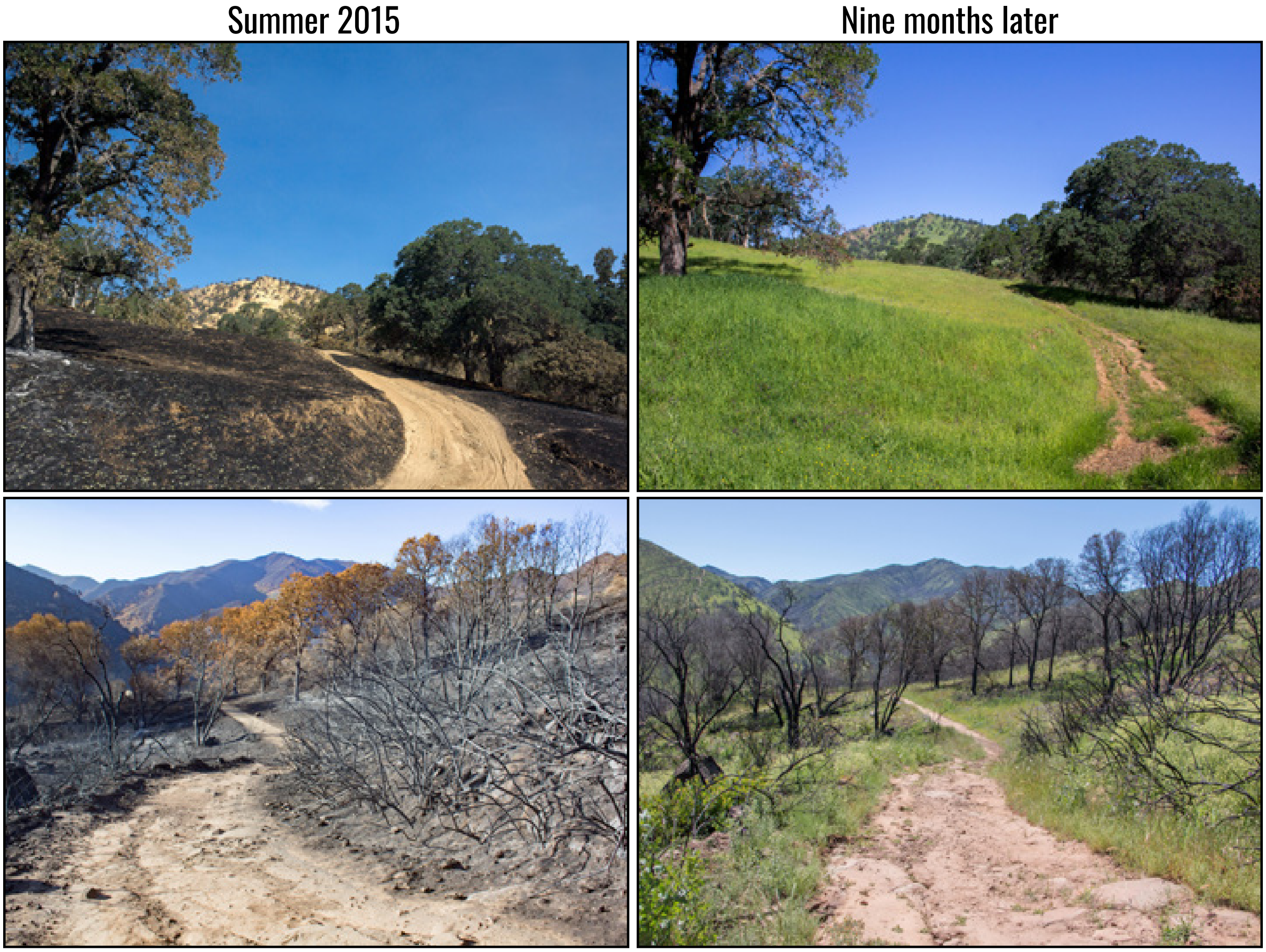

Figure 10. 2015 Wragg Fire recovery, Putah Creek Canyon. Immediately after the July 2015 Wragg Fire (left) and nine months later (right). Locations are the UC Davis Cahill Reserve (top row) and UC Davis Stebbins Cold Canyon Reserve (bottom row).

with high human occupancy. Native Americans used fire for diverse purposes to heavily manage about 20% of California, mostly near villages and in lower montane areas, valleys, and areas where there was sufficient vegetation to sustain fires. More sparsely vegetated lands, overly dry or wet areas, and remote areas, were less affected by indigenous burning. The significance of Native American fire use in shaping the natural diversity in California during this period should not be underestimated, and it progressively increased as human populations grew.

Existing evidence indicates that Holocene-epoch fires in mid-elevation conifer forests in central California naturally occurred relatively frequently, with recurrence intervals of about 5–40 years. Shrubland fire regimes were probably similar to recurrence intervals in southern California shrublands (chaparral), which range from 50 years to more than a century between fires. Fire regimes in many oak woodlands, savannas, and prairies were affected by Native American fire use, with relatively short fire return intervals and generally low-intensity fires that favored oak species and other plants used for subsistence. High-elevation landscapes are characteristically much cooler and wetter than those at lower elevations; historically these forests appear to have experienced stand-replacing fires at long recurrence intervals (up to several centuries), generally as a consequence of droughts that allowed patches in these landscapes to dry sufficiently to support high-intensity fires ignited by lightning.

Colonization of California by Euro-Americans from Mexico approximately 300 years ago appears not to have greatly changed fire regimes throughout most of the state, as common land use practices for these colonizers did not emphasize changing many native ecosystems. However, in the mid-19th century, new groups of Euro-American and other colonists began to alter vegetation and fire patterns on a large scale through practices such as widespread timber harvest, including removal of large trees throughout the state; extensive wildland grazing, particularly by sheep; and converting lower-elevation wildlands to agricultural uses. By the early 1900s, the primary cause of wildfires in much of California shifted from lightning to humans, an effect that continues to increase today because of the increased human presence in wildlands.

Fire regime patterns in the National Monument area changed considerably during the 20th and early 21st century, at least in terms of fire frequency and fire size, primarily due to changes in human activity. Most fires in California (95%) within the

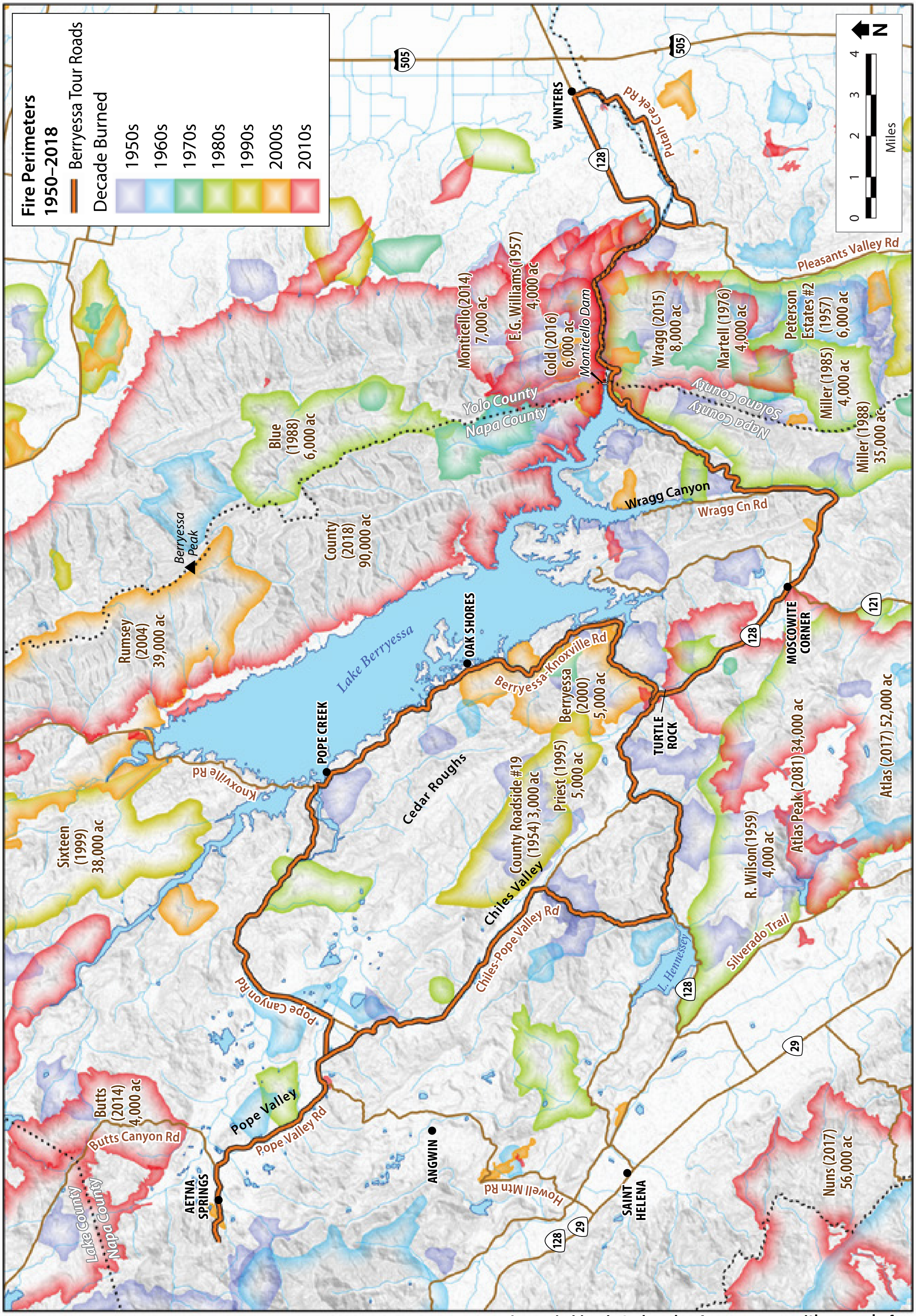

Figure 11. Berryessa region fire history, 1950-2018. Fire perimeters are color-coded by their decade of occurrence, with several of the larger fires named specifically. The high frequency of fires in Putah Creek Canyon are likely due to careless drivers along Highway 128. Source: Calfire 2019.

past 100 years were due to human activity, such as sparks from equipment or vehicles, arson, debris burning, smoking, and power lines.

Between 1920 and 1940, the monument area was sparsely populated, with few roads. Fires were generally few (3 to 5) per year, relatively small (less than 19,000 acres max), and generally burned less than 15,000 acres annually across the monument area.

Fire frequency reached a peak during the 1950s, typically more than 10 fires each year, due to an increasing rural population, increasing road density and access to flammable fuels, increased logging, limited education about fire prevention, and poor fire responses. California state government also actively promoted burning of chaparral and shrublands between the 1940s and 1970s to promote invasive grasslands for livestock grazing (see Figure 11).

In contrast, during the same time state and federal agencies began to emphasize suppressing all fires on forested lands, including eliminating many fires in what were formerly forests with short fire recurrence intervals. Fewer fires has resulted in fires with higher severity in these forests today, because a fire dearth fails to remove many small trees that normally germinate in every forest. Increased tree densities are associated with increased competition for water and decreased resistance to insect attacks and diseases, leading to increased tree death and to an accumulation of dead wood as fuel for subsequent fires.

In the mid-1960s through the 1990s, with improved fire safety education for the public, people became more aware about the risks of fire from discarded cigarettes, roadsides were more regularly maintained to reduce fire risk, state and federal agencies provided significant fire-fighting, and there were fewer arson fires. Fire frequencies were greatly reduced, back to pre-1950s levels, although these fires became increasingly variable and larger in average size.

In the past 20 years, however, fire frequency has increased to 1950s levels, with many more small fires (under 500 acres) per year and a dramatic increase in large fires (over 50,000 acres) that have a more substantial ecosystem effect.

The year 2015 was a watershed year for fires. Northwest California in general had historically experienced large fires about once every 8–10 years before 2015. However, there have been 3 or 4 such large fires in each of 2015, 2017, and 2018. In the monument area before 2015, no year had exceeded 90,000 acres of total acreage burned per year. Since then, fires in this region have annually burned about twice as much land, or more, per year: 180,000 acres in 2015; 168,000 acres in 2017; and 570,000 acres in 2018. The twelve largest fires between 2015 and 2018 account for 41% of the 2.2 million acres of land that burned in the monument area since 1939. The four largest fires in 2015 were Valley (76,085 acres), Rocky (69,834 acres), Jerusalem (25,118 acres), and Wragg (8049 acres). The largest 2017 fires were Nuns (55,798 acres), Atlas (51,624 acres, Tubbs (36,701 acres) and Pocket (17.359 acres). In 2018, the largest fires were Pawnee (15,185 acres), County (90,288 acres), and Mendocino Complex, including both the Ranch (410,203 acres) and River (48,920 acres) fires. The Ranch Fire is the single largest fire in modern California wildfire history.

Past climates clearly did affect the incidence of fire in California; for example, tree-ring records show that some increases in fire were associated with droughts lasting up to several hundred years. Future climates undoubtedly will affect fire's occurrence and significance. Climate models show increased temperatures and associated aridity that rapidly dries out the vegetation. These effects will lead to greater fuel accumulation and an increased likelihood of intense fire in California wildlands. Fire scientists have projected substantial increases in fire occurrence, size, and severity in California ecosystems during the 21st century.

Current fire dynamics in some California landscapes now show substantial departures from fire return intervals of recent millennia. Most coniferous forests are burning less frequently than they did while those ecosystems evolved, because of active fire suppression. Chaparral ecosystems in central and southern California are burning much more frequently now than they did as the individual species in them were evolving. These landscapes are also areas with substantially increased human populations, and increased human presence is associated with increased fire.

The potential effects of increased human use on fire occurrence in California landscapes, including those in the Monument, can't be predicted with certainty, but increasing population and greater use of wildlands will most likely result in more frequent wildland fires. Substantial changes in fire regimes undoubtedly will alter California ecosystems. For instance, altered climate conditions may eliminate species such as blue oak and valley oak from lower elevations and non-riparian woodlands, and fire will be one of the primary drivers of that change.

Too-frequent fire in chaparral landscapes in southern California is the primary reason shrublands there convert to annual grasslands dominated by exotic species, particularly grasses, which burn readily. Shrublands elsewhere, including those in the Monument region, could also convert to grasslands through poor fire management. Conversely, the lack of frequent fire in mixed-conifer mid-elevation forestlands and the resulting high fuel accumulations support fires of higher intensity and severity, which are likely to be human-caused. Therefore, there is a need for increasing prescribed and managed fire uses to reduce fuels in these landscapes. Fire management in these wildland landscapes affects multiple public values that must be balanced, and is likely to be difficult.

In summary, fire in the National Monument was one of the factors that affected native species, ecosystems, and landscapes. In these ecosystems, fire will continue to be a stressor that frequently has positive effects for some species even when effects on others may be negative. Fire occurrences, areas covered, and severity are all very likely to increase as consequences of climate change. Practices are available to treat fuels and help ecosystems be more resilient, although our society must decide whether and how to implement them. While wildland fire may harm people, who are both the major source of the increased fire ignitions affecting most of California and the victims of disastrous fire outcomes, wildland fires are not intrinsically 'disasters' for native species, ecosystems, and landscapes.

AN INTRODUCTION TO BASIC GEOLOGY CONCEPTS

The geology of a landscape is best understood by observing the physical features on the land and using those features to explain how that landscape evolved over time. Thus, geological interpretation requires four-dimensional thinking, in terms of three-dimensional space plus time.

However, the time scale on which geological processes operate greatly exceeds human life spans. Geologists often think in terms of millions of years and use the acronym Ma as shorthand. "Ma" is short for "mega-annum" and it refers to geological date in terms of millions of years ago. For instance, 10 Ma is 10,000,000 years ago (see Sidebar 2).

After eons of uplift, metamorphism, volcanism, erosion, and sedimentation, we are left with fragments of a former world, much like a novel with 95% of its pages missing. How do we piece together the full story?

Just as a good detective carefully gathers fragmentary clues to tell how the crime was committed, geologists use specific geological clues and logic to make broader generalizations about the landscape's history. These generalizations are also tested by gathering more physical evidence that might disprove the initial idea.

Two essential assumptions guide geological study, as well as all other scientific endeavors:

- Natural laws are constant across space and time. That is, there are factual truths describing natural phenomena that are true for every place and time in the universe. They don't change depending on the place or time. A rock, for example, would not fall at the earth's surface today, and float in midair tomorrow.
- Start with the simplest explanation and make it more complex only if, and when, absolutely necessary. This is not the same as saying "the simplest solution is the best." If processes observable today sufficiently explain the past, then don't invent extra, fancy, or unknown causes or make any unnecessary assumptions.

For example, as illustrated in the Road Guide, stream sediments may be found in vertically-oriented beds at outcrops. One could assume that these sediments were sprayed onto, and adhered, to vertical surfaces over large areas. But that is an unnecessarily complex answer, and such a process has not been observed in today's world. Geologists start with the assumption that the sediments were laid down horizontally, as they see today at beaches and along waterways, and these sediments were tilted later. Granted, such simpler explanations may not always provide the correct story. After all, much of the geological novel is gone, or hasn't been found yet, and more complex explanations might be required to be consistent with new evidence.

SIDEBAR 2

Age of Earth

The Earth's geology has been changing for about 4.5 billion years, a very long time. Here are a few thought exercises to help understand the passage of time:

- Imagine that the thickness of a credit card (0.03 inches) is equivalent to one year of time. The last Ice Age (12,000 years ago) would be about 30 feet away from you and modern humans (Homo sapiens) appeared (200,000 years ago) at about 500 feet away. Heading east from Winters, you would need to travel to downtown Sacramento to travel back in time to when the dinosaurs were wiped out (66 million years ago). The first dinosaurs (250 million years ago) would have appeared near Donner Summit. The first animals of any sort (630 million years ago) would have arrived around Winnemucca, Nevada. The origin of the Earth, 4.5 billion year ago, would be around Chicago, Illinois.
- For those who can better imagine a 100-yard football field representing the age of the earth, imagine running from the far end zone. The first animals appeared at about the 40-yard line. Dinosaurs appeared at 6 yards from the goal line and they went extinct near the one-yard line. Modern humans showed up about 1/6 inch from the goal line.
- And for those more chronologically oriented, compress the age of the earth into one year, with January 1 represent the beginning. The first animals appeared in mid-November, the dinosaurs went extinct on Dec 25th, and modern humans showed up about 11:36 pm on December 31.

Principles of Relative Dating

The clues that geologists use to explain how a landscape evolved, a process that they did not watch change over time, are based on several guiding principles or assumptions. Combining these principles with field evidence allows them to tell a story about which events most likely occurred first and which followed. Four of the most common principles are the following:

- Sediments are first deposited horizontally (Principle of Original Horizontality): Sediments initially settle under the action of gravity in horizontal layers, although later events may tilt these layers away from horizontal (see Figure 12).
- Youngest rocks overlie older rocks (Principle of Superposition): In any undisturbed sequence of rocks deposited in layers, the youngest layer is on top and the oldest on the bottom, each layer being younger than the one beneath it and older than the one above it. Disturbances like faulting or folding may flip this order upside down.
- Sediments were initially continuous across the landscape (Principle of Lateral Continuity): Layers of sediment initially extended laterally in all directions; in other words, they are horizontally continuous. This is generally true of sediment layers deposited in oceans or lakes. Conversely, sediments deposited in river channels result in less continuous layers. The Principle of Lateral Continuity implies that most sedimentary rock layers that are otherwise similar but are now separated by a valley

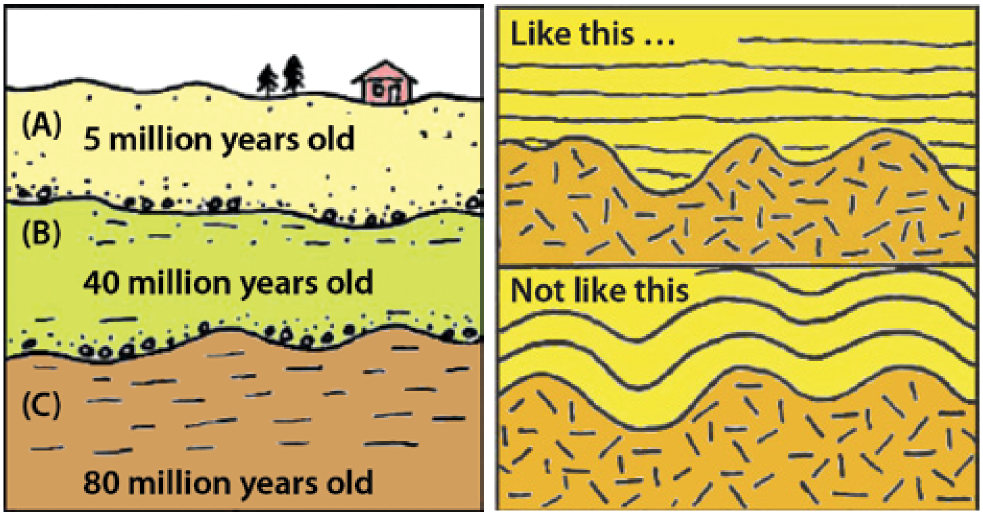

Figure 12. LEFT: Principle of Original Horizontality - Sediments are first deposited horizontally. RIGHT: Principle of Superposition - Youngest rocks overlie older rocks. Source: MiraCosta College 2018

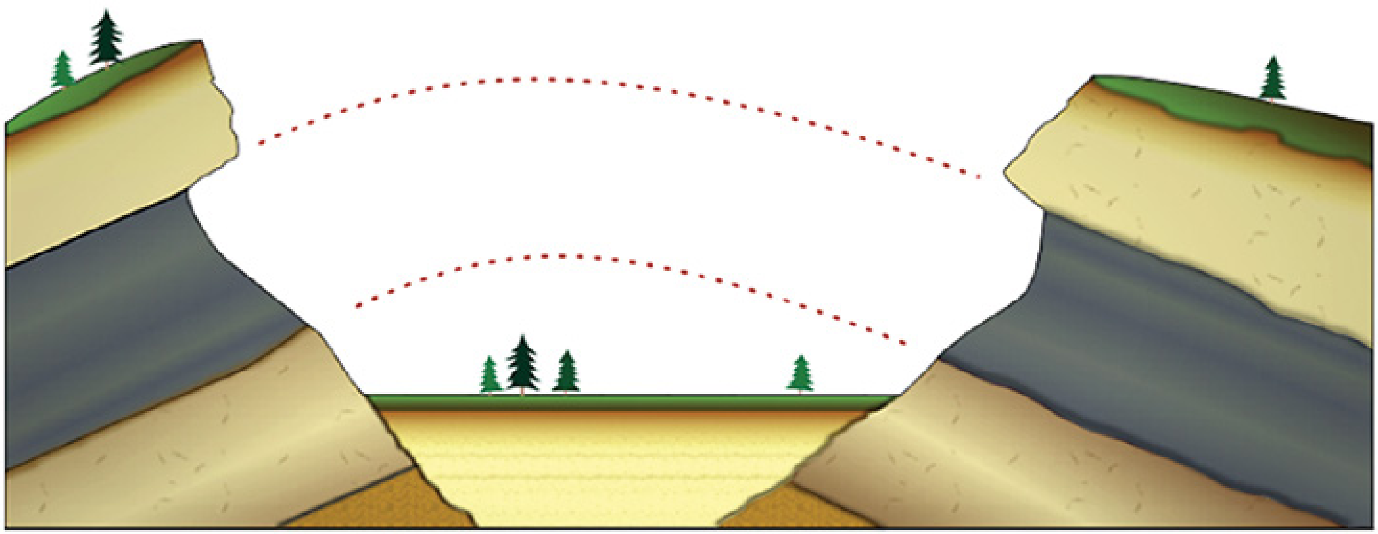

Figure 13. Principle of Lateral Continuity - Sediments were initially continuous across the landscape. Source: Geologyin.com 2014

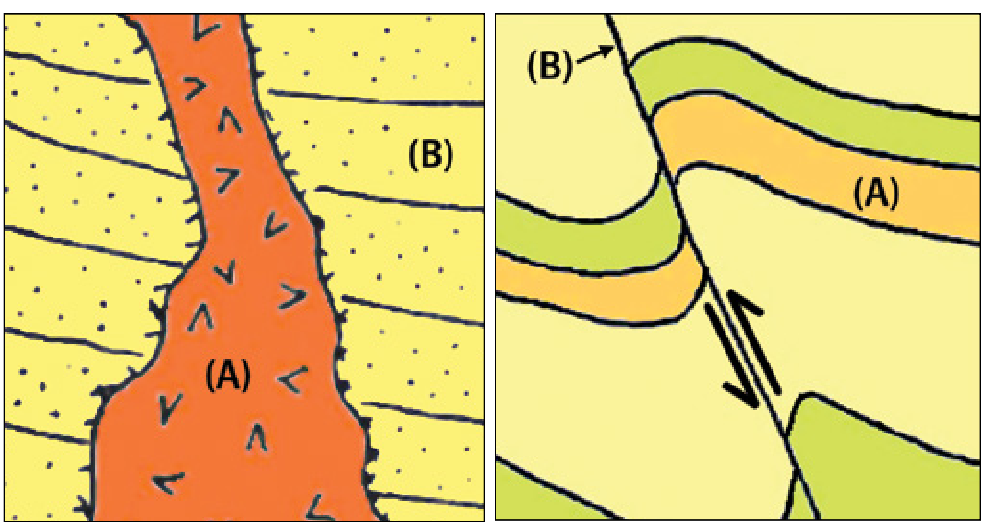

Figure 14. Principle of Cross-cutting Relationships - Cross-cutting features are younger than the features they cross. Source: MiraCosta College 2018. See text for explaination.

or other erosional feature can usually be assumed to have been originally continuous (see Figure 13).

- Crosscutting features are younger than the features they cross (Principle of Cross-cutting Relationships): Geological features, such as rock types or faults, can only cut across features that already exist. The surrounding older feature needs to exist first before another younger feature can cut across it. The diagram on the left side of Figure 14 illustrates how an intrusion (A) must be younger than the surrounding sandstone (B) that it intruded into. The diagram on the right shows how faults or folds (B) are younger than the rock (A) that is deformed by the fault or fold.

Structural Geological Concepts

Rocks that are deposited as layers can become folded and faulted, mainly through the movement of the Earth's tectonic plates.

Faults

Faults mark discontinuities in rock layers created by vertical and/or horizontal tectonic forces. There are three principle types of faults: dip-slip faults, strike-slip faults, and transform faults.

In dip-slip faults, rock layers may be displaced vertically with respect to each other along vertically tilted (or dipping) fault surfaces. If the upper fault block (above the fault surface) has moved down with respect to the lower one, the fault is a normal fault. If the upper fault block has moved up with respect to the lower one, the fault is a reverse fault. If the fault surface is tilted at a very low horizontal angle, reverse faults are called thrust faults. The normal/reverse terminology comes from observations originally made in 19th-century coal mines in central England (see Figure 15).

A strike-slip fault displaces rock layers horizontally with respect to each other. A transform fault is a major strike-slip fault that forms along a plate boundary. Most transform faults are found in the ocean basin and connect offsets in the mid-ocean ridges. The San Andreas Fault, or more correctly the 40–60 mile (60–100 km) wide fault system that at larger scale makes up the San Andreas Transform Fault Zone, is a series of parallel strike-slip faults, one of only a few examples in the world where a large transform fault is exposed on a continent.

Folding

Several different types of rock folds can be found in nature. Two important types are synclines and anticlines. A syncline is a fold with its youngest layers closer to the center of the structure. It often appears bowl-shaped or trough-shaped. An anticline has its oldest beds at its center, and often appears shaped like an arch (see Figure 16).

Synclines and anticlines can be as small as curved layers in a cliff or as large as an entire valley or mountain. Folds typically develop over long periods as tectonic forces gradually bend somewhat flexible rock layers, without breaking them as in faults.

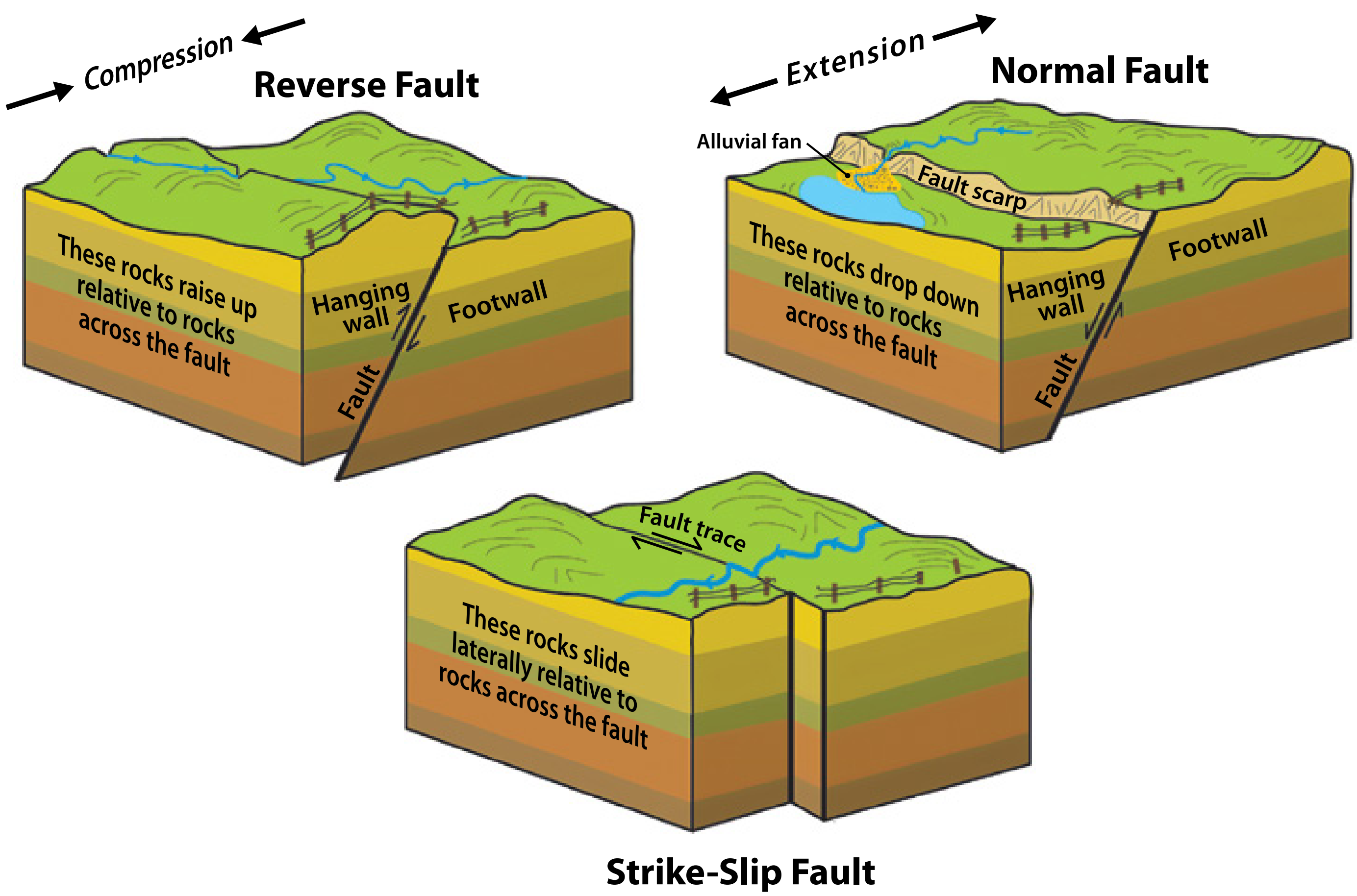

Figure 15. Types of faults. Reverse fault (top left), normal fault (top right) and strike-slip fault (bottom). Source: Earle 2014

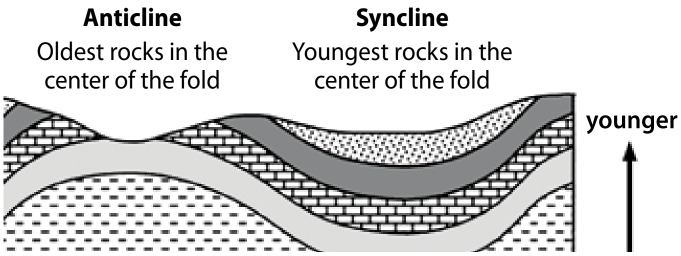

Figure 16. Anticline and syncline.

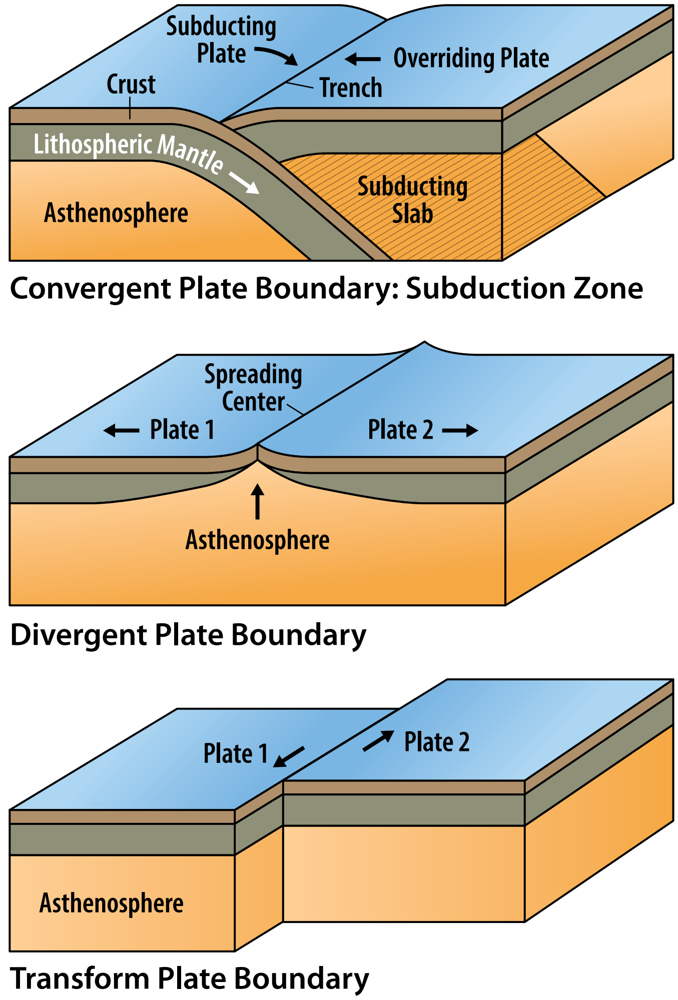

Figure 17. Types of tectonic plate boundaries: convergent (top), divergent (middle), and transform (bottom). Source: Duarte and Schellart 2016.

Tectonic Plate Boundaries

On Earth, the location of most folds and faults—as well as the earthquakes associated with their formation—coincide with the margins of tectonic plates: large, tabular sections of the Earth's outer surface that are constantly moving in a process we call plate tectonics. When a plate is pulled apart, an ocean basin is created. When two plates collide, mountains are created. As you will discover, evidence for both of these processes can be seen in the geology of the BSMNM region.

Plate tectonics entails the movement of cool, rigid "lithosphere" plates over underlying, hot, weak "asthenosphere." The upper portion of the lithosphere is called the Earth's "crust"; the lower portion is called the "mantle" (which also extends into the asthenosphere). Lithosphere plates beneath the continents are thicker (about 100–125 mi; 160–200 km) than those beneath oceans (about 40 mi; 65 km). The crust beneath continents is generally much less dense then the crust beneath oceans, and the mantle is denser than both types of crust. The rock types exposed in the BSMNM are representative of both the crust and mantle. Obviously, mantle rocks can only be brought to the Earth's surface through significant amounts of uplifting—a process which is also related to plate tectonics.

There are three types of boundaries between the Earth's tectonic plates, and the BSMNM region owes its geological complexity to processes that take place adjacent to all of them (see Figure 17).

Convergent boundary: This occurs where one plate is consumed within the Earth's interior beneath an adjacent plate. This was the scenario within the BSMNM for millions of years in the past, during which the Farallon Plate was being subducted beneath the North American Plate. Thrust faults characteristically mark the boundary between plates in subduction margins.

Divergent boundary: This occurs where tectonic plates are born and then spread apart. Normal faults are common along divergent plate margins. The divergent boundary between the Pacific Plate and the Farallon Plate (to its east) was actually subducted beneath the North American Plate, leading to the initiation of the San Andreas Fault system about 28 Ma.

Transform boundary: This occurs where two plates slide horizontally past one another. This is the present day scenario within the BSMNM, with the Pacific Plate moving northward relative to the North American Plate along the San Andreas Fault system.

Subduction Zone Metamorphism

Rocks in subduction zones are subject to varying levels of pressure and temperature, depending on their position in the subduction zone. Rocks within subduction zones generally experience some of the lowest geothermal gradients (temperature increase with depth) within the Earth. This is because a relatively cold oceanic slab, shoved beneath relatively warm continental crust, will take tens of millions of years to reach thermal equilibrium with its surroundings. Subduction zones are metamorphic refrigerators, and their coolness allows water that is locked in metamorphic minerals to be recycled deep within the Earth's interior (see Figure 18).

Low pressure-temperature combinations, near the top of the descending plate, yield zeolite and prehnite-pumpellyite metamorphic rocks. Where these rocks are found, they indicate some of the mildest metamorphic response of sediments and volcanic debris to burial. Many of the rocks on the tour—including those of the Great Valley Group, Franciscan Complex, and Coast Range Ophiolite—were metamorphosed in zeolite and prehnite-pumpellyite facies conditions. But an optical or

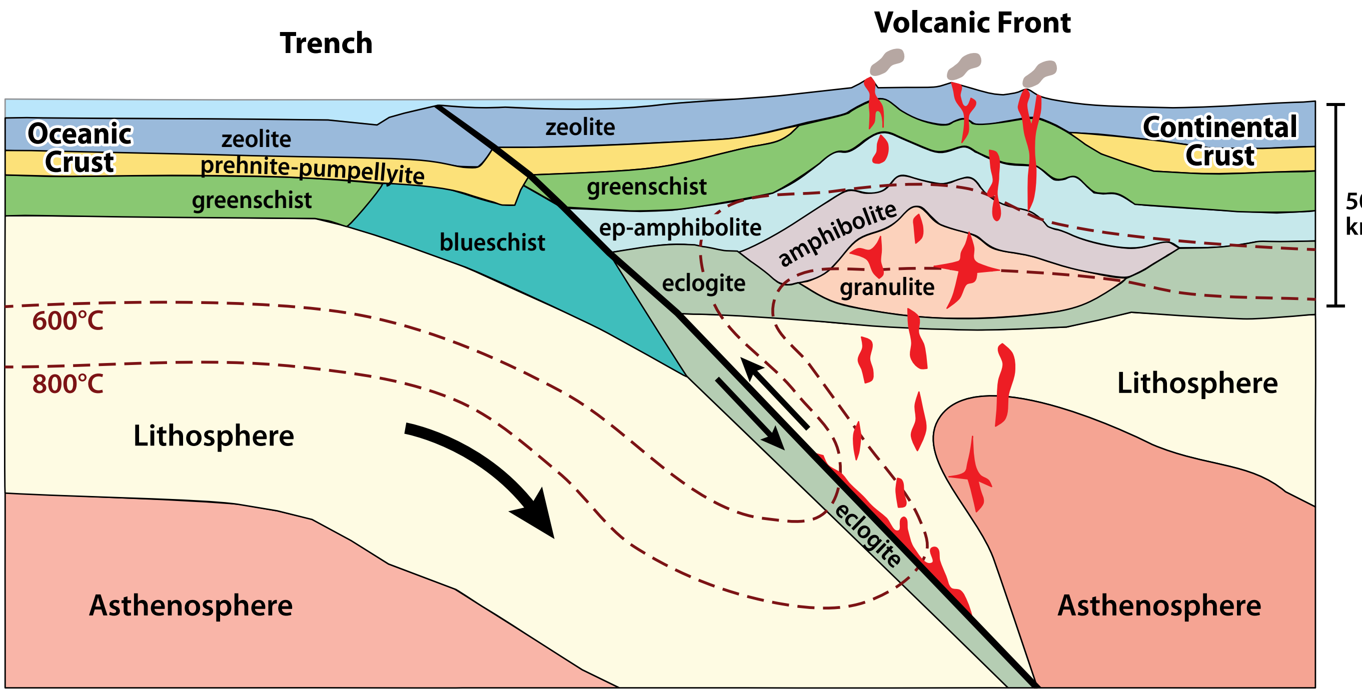

Figure 18. Grades of metamorphic rocks in subduction zone. See text for explanation. Sources: based on Palin and White 2016, Spear et al. 2016, van Keken et al. 2011, Kimura et al. 2009, and Ernst 1976.

even electron microscope is necessary to discern the metamorphism.

Greenschist, defined by the presence of the green mineral chlorite, forms with increased pressure-temperature conditions. Heated seawater at mid-ocean ridges is often enough to transform newly erupted lava into a type of greenschist.

As the slab descends, blueschist forms at intermediate depths within the subduction zone, where pressures are relatively high but temperatures are still low. Blueschists derive their name from the occurrence of the amphibole glaucophane, which is recognized by its bluish color. At depths over 6 miles (9 km), pressure begins to dehydrate rocks. The released water lowers the melting point of rock, so the rock begins to become magma. This magma rises up through the overlying crust to either solidify below the surface (producing plutonic rocks like granite) or erupt at the surface (producing volcanic rocks).

Eclogites form at greater depths (over 18 miles; 28 km) and pressures, where basalt or gabbro becomes highly compressed. Eclogites are dense rocks, comprised of garnet and the often greenish mineral omphacite (a type of pyroxene). Because of their density, these rocks tend to descend even deeper into Earth's mantle; therefore, eclogites are rarely brought to Earth's surface.

Exposure of both blueschist and eclogite on the surface is unusual. Fortunately, they are both exposed on the surface along this tour route in Sage Canyon near Lake Hennessey. Their presence here is one of the valuable clues about the tectonic forces that exerted themselves in this region.

Above the subduction zone, continental crust metamorphic rocks include amphibolites and granulites, which form at similar pressures as blueschist, but under much higher temperatures (over 900° F; 500° C). Granulites are often formed from amphibolites as temperatures increase and rocks are further dehydrated. They frequently have a granular texture similar to plutonic rocks.

GENERAL GEOLOGICAL SETTING OF THE MONUMENT

Geological Significance

The BSMNM sits in the Northern California Inner Coast Range, east of the San Andreas Fault and west of the Sacramento Valley. The Coast Range, and the Berryessa Region in particular, are one of the most geologically diverse areas on the West Coast, and they have several features of worldwide significance:

- Rock exposures exhibiting 150 million years of geological history
- One of California's thickest continual records of late Mesozoic sediments, the Great Valley Group
- Exposure of geological features normally only found on seafloors, including:
    - the remnants of a tectonic collision and subduction zone
    - accretions of oceanic islands, creating the Franciscan Complex
    - exposures of rock formed deep in the subduction zones such as blueschist and eclogite
    - ancient serpentine mud volcanoes
    - an exposed seafloor volcano, the Snow Mountain seamount, one of the few seamounts in the world exposed on a continent
    - a long transform fault system, the San Andreas Fault system, where two tectonic plates slide past each other

The geological and biological settings of the Berryessa Region form parts of an important scientific story concerning the assembling of California. With permanent protection of the landscape afforded by the designation of the Berryessa Snow Mountain National Monument, existing and future generations are the beneficiaries. Whether you're a geology student looking to see such features for the first time, a seasoned professional, or someone with a passing interest in unique rocks like blueschists and serpentinites, this monument deserves a visit.

SIDEBAR 3

Rock Types Exposed in the BSMNM

All three major rock types (sedimentary, igneous, and metamorphic) are well represented and can be seen in roadside outcrops on the field excursion.

- Sedimentary rocks form through the solidification of sediment or chemical precipitation, and include sandstone, shale, and chert.
- Igneous rocks are those that solidify from a molten or partially molten state and include basalt, gabbro, peridotite, and rhyolite.
- Metamorphic rock types are formed by temperature and pressure changes (metamorphosis) of igneous and sedimentary rocks, and these include greenschist, blueschist, eclogite, and serpentinite.

Definitions of all of these can be found in the glossary, and it might be useful to have a working knowledge of these terms before embarking on the field excursion. In addition to these rock types, you will encounter examples of alluvium (sediments deposited in modern or ancient streams that haven't solidified into rock) and colluvium (similarly unconsolidated sediments deposited at the base of hills or mountains).

Major Geological Features

The monument's stunning geology underlies its storied history and notable biological diversity. Key aspects of the monument's geology may be seen in the Berryessa Region. The distribution of important rock types and faults across the Monument is illustrated in Figure 19 (see also Sidebar 3).

The Coast Range Fault represents an ancient boundary between the upper North American Plate and the descending lower plate. This fault may have been the early subduction fault, but it has been significantly altered by subsequent faulting and folding. Its long and complex history has created a surface expression that is not a straight line across the region.

The upper plate represents part of the western edge of North America that formed as much as 140 Ma. Rocks of the upper plate include Great Valley sedimentary as well as volcanic rocks overlying remnants of ancient oceanic crust (the Great Valley Ophiolite, chiefly serpentinite).

Lower plate rocks include the Franciscan Complex—deformed and metamorphosed sedimentary and volcanic rocks—that were scraped off the down-going plate and buried 12–18 miles (20–30 km) beneath the North American edge as the plate went down. The lower plate rocks were eventually uplifted to the surface by faulting.

Another part of the lower plate are the Snow Mountain rocks. These are submarine volcanic rocks that look as if they were laid down only a few years ago. However, igneous minerals identified in the rocks indicate that they formed as a seamount far west of California, which then migrated with the down-going plate to the continental edge about 140 Ma and was buried up to 18 miles (30 km) deep, undergoing blueschist facies metamorphism. The seamount was then decapitated from the down-going plate, and finally uplifted to Earth's surface!

The active San Andreas Fault (a transform fault) system, which developed more recently, modified the earlier convergent plate situation. As a fault system, it includes the main San Andreas Fault as well as the Bartlett Springs and Green Valley Fault shown on the map.

Figure 19 shows the geological pattern as seen on the earth's surface. Geologists learn to interpret clues from this surface pattern, well drilling, and seismic testing to project geological patterns well below the surface in the form of cross-sections. Cross-sections are two-dimensional vertical slices that illus-

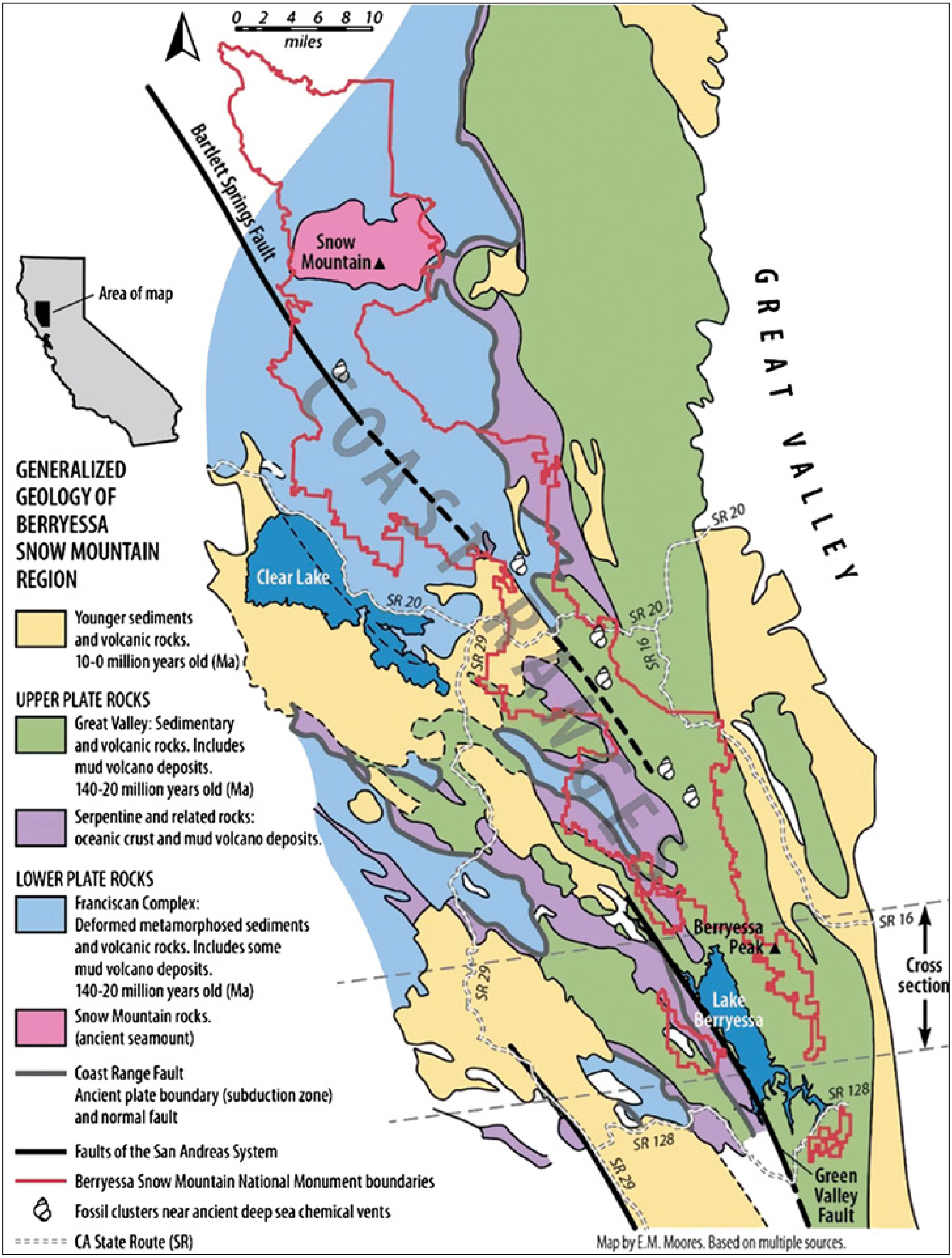

Figure 19. Geology of Berryessa Snow Mountain region. See text for explanation. Source: Moores and Moores 2015.

trate probable arrangement of strata and structures downwards from the surface.

Figure 20 shows the subsurface geology below the lines labeled "Cross-section" on Figure 19, although the width of the cross-section is much wider, extending from the Sacramento Valley westwards beyond the San Andreas Fault.

The oceanic crust (dark purple) is shown as subducting beneath the continental crust of the upper North American Plate. Below this oceanic crust is the boundary between the Earth's crust and the mantle (orange) known as the Moho (short for Mohorovičić discontinuity), which was identified using earthquake seismology.

The upper plate rocks, the Franciscan Complex (blue), the Great Valley Group (green), and the plutonic rocks of the Salinian Block and the Sierra Nevada (pink), all lie above the subducting oceanic crust. The Salinian Block is a geologic terrane which lies west of the main trace of the San Andreas Fault system in California. The Franciscan Complex consists of several tectonic belts that have been delivered to the subduction zone by the descending plate, then separated from that lower plate and thrust up onto the upper plate. This tectonic activity has created a complex set of thrust faults. The Sierra Nevada rocks are the result of the lower plate releasing water at great depths, resulting in melting, with magmas rising through the overlying upper plate and being emplaced as plutons within the crust.

The subduction process led to a large piece of oceanic crust (light purple) being thrust up onto North America during the mid-Jurassic (about 160 Ma) along the Coast Range Fault. At this time, this was a west-dipping subduction zone. This collision resulted in the westward jump of the subduction zone, which flipped to east-dipping. This action isolated this piece of crust on the continent (called an ophiolite), while subduction continued on its western edge. Subsequent movement along the Great Valley Thrust Fault System in the Paleogene split this ophiolite into two parts in this region: the western Coast Range Ophiolite in the Coast Range, and the Great Valley Ophiolite underlying most of the Great Valley. Geophysical data shows that this ophiolite is underlain by mantle material, creating a double-layered Moho in the Central Valley.

To the east of the Franciscan Complex, the Great Valley Group (GVG, green) are deep marine sediments that eroded off Cretaceous highlands and deposited on top of the ophiolite as submarine fans. During the early deposition of the GVG, the region was substantially deformed into a series of northwest trending folds which did not affect the later GVG deposits. This folding altered the surface exposures of the Coast Range Fault such that it does not appear linear from above.

During the Paleogene, all of these units (Franciscan Complex, Coast Range Ophiolite, and GVG) were offset by the Great Valley Thrust Fault System, major thrust faulting that was directed upwards and eastwards. Additional pressures created east-dipping thrust faults, the Bartlett Springs thrust faults, above these deeper faults. Later the area was disrupted again by strike-slip faults that accompanied the initiation of the San Andreas Fault system. These forces displaced rocks towards the north-northwest, nearly perpendicular to the orientation of the subduction zone, which moved rocks to the east under the edge of North America.

The vertical black lines represent strike-slip faults that moved after subduction ended and that are part of the broader San Andreas Fault system. In this region these include the main San Andreas Fault, the Hayward-Rogers Creek Fault, and the Green Valley Fault. Recent work indicates that these faults may be connected further north to the Bartlett Springs Fault and on to the Humboldt County region.

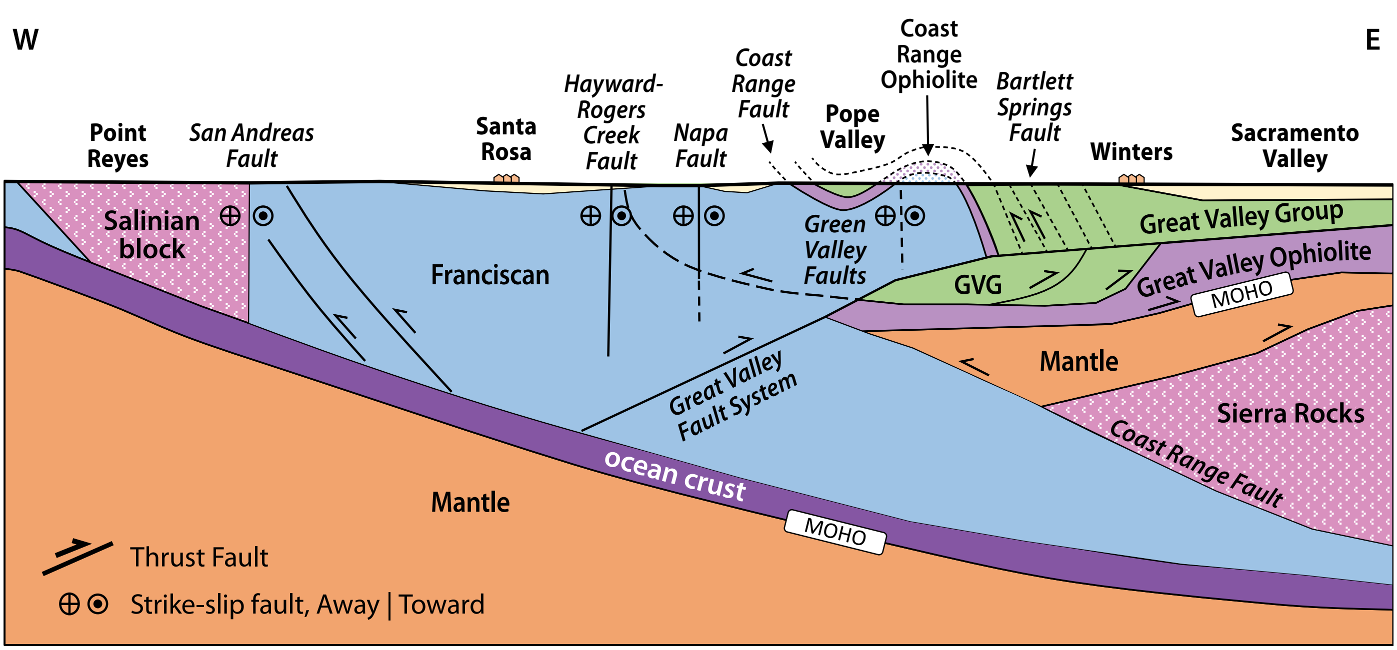

Figure 20. Generalized cross section of California through the Berryessa region. See text for explanation. Source: Moores et al. 2002

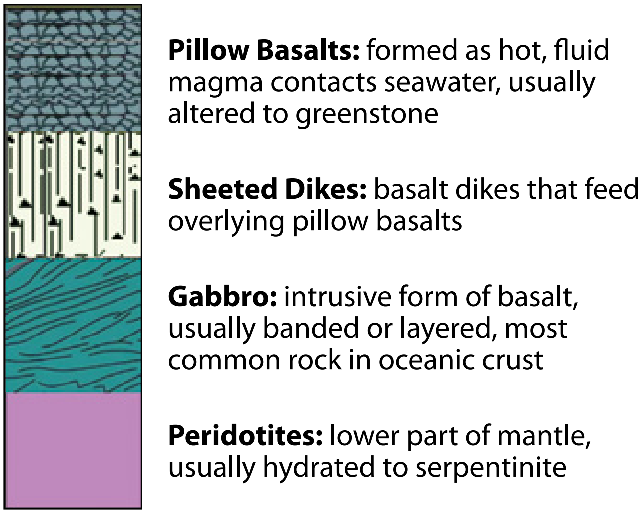

Figure 21. Complete ophiolite sequence. Ophiolites are recognized by characteristic sequences of periodite, gabbro, sheeted basalt dikes, and pillow basalts. Source: Modified from Rodriguez 2019.

Major Formations

The geological map and cross-section show four major groups of rocks that underlie the Berryessa Region.

Coast Range Ophiolite

An ophiolite is a segment of oceanic crust and mantle that is tectonically exposed on land. In tectonics, it is unusual to have dense oceanic crust placed on top of lighter and more buoyant continental crust. Where this oceanic crust was formed is still under debate. Some researchers argue for its formation at a mid-ocean ridge (a divergent plate boundary) whereas other argue for formation behind and above a subduction zone.

The Coast Range Ophiolite (CRO) is one of the most extensive ophiolite terranes in the United States and is one of the most studied ophiolites in North America. It occurs across the California Coast Range, but due to extensive folding and faulting over time, few complete sequences persist today.

Ophiolites are recognized by characteristic sequences of igneous and sedimentary rock, which they share with oceanic crust. A complete ophiolite sequence has peridotite or its altered form, serpentinite, at the bottom. These are ultramafic rocks derived from the upper part of the mantle. On top of that is gabbro, the intrusive equivalent of basalt, indicating the presence of a magma chamber. Basalt is the third element of the sequence, in the form of parallel dikes ("sheeted dikes")

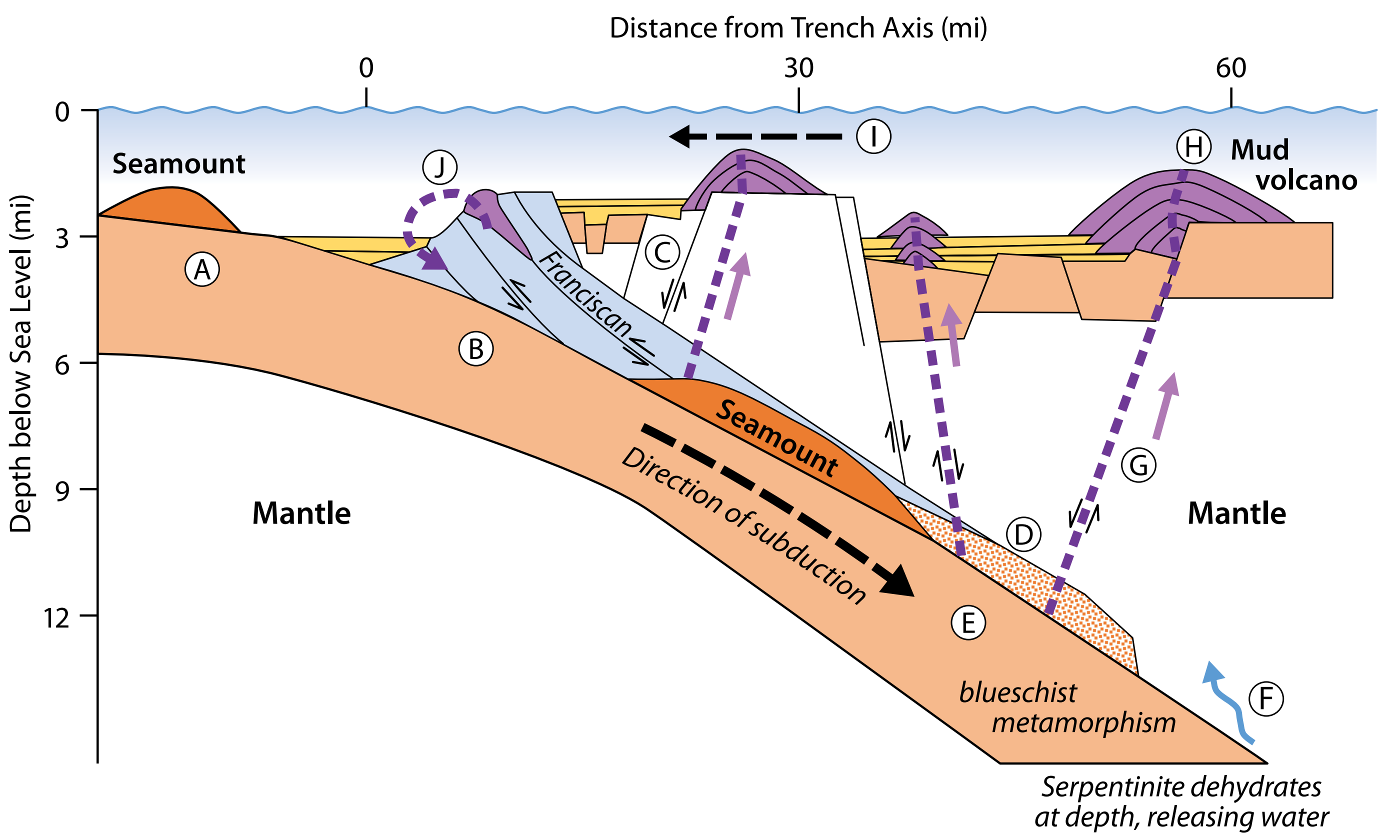

Figure 22. Conceptual model for the formation of Franciscan melange and mud volcanoes at the subduction zone. Oceanic volcanics (A) are subducted and some of it (B) detaches and adheres to the upper plate. This lifts the upper plate to create normal faults (C). The descending material breaks into a jumbled mass (D) at depth, with some forming blueschist (E). Greater subduction dehydrates the rocks, releasing water upward along faults (F), which can create a bouyant slurry of multiple rock types that rises to the surface (G) and erupts as mud volcanoes (H). The upper plate continues moving toward the trench (I), where tectonic forces leads to landslides into the trench (J). Some of the materials go through this entire process more than once. Source: Fryer et al. 2000, Phipps 1992.

that reached the surface and formed pillow basalts on the sea floor when the magma contacted sea water (see Sidebar 19: Greenstone and Pillow Basalt). A dike is a generally vertical, tabular body of igneous rock, which forms when magmas rise to the surface. On top may be found deep-sea sediments, such as muds and cherts, that were deposited after the eruptive activity ceased (see Figure 21).

The extensive serpentinite areas of northern California used to be considered part of the Coast Range Ophiolite (CRO), but these are mostly a mélange, or mixture, of blocks of disparate types of oceanic crust without the characteristic ophiolite sequence. With this new interpretation, the ophiolite sequences occur only in a handful of geographically isolated remnants. Near Lake Berryessa, two small remnants of the CRO are exposed at Pope Creek and Fir Creek. Even these remnants are incomplete sequences due to subsea faulting, and they are covered by ophiolitic breccia caused by tectonically induced landslides.

The gabbro is a dark coarse-grained rock that weathers to a bright-red soil, and it is generally not mapped separately from serpentinite. However, patches of gabbro may be identified from a distance by nearly pure stands of chamise, a shrub that is not abundant on serpentine soils.

The ophiolitic pillow basalt lava overlying the serpentinite and gabbro erupted underwater near a mid-ocean ridge. The hot sea water changed the original minerals in the basalt to the green-colored minerals chlorite, epidote, and/or actinolite, forming greenstone. It is more resistant to erosion than serpentinite and forms knobby brown boulders that protrude from the serpentine landscape. Greenstone is also more calcium-rich than serpentinite, and buckeye trees may be strikingly apparent at the bases of greenstone boulders, as they need the more calcium-rich soil.

The CRO often overlies the Franciscan Complex and underlies the Great Valley Group of submarine sediments, indicating that it was accreted to the continent during the Middle Jurassic in age (172–155 Ma), before initiation of the fore-arc basin in the Great Valley.

Franciscan Complex

The Franciscan Complex of coastal California, widely known as an example of a fossil subduction complex, is one of the premier examples of mélange, a diverse assemblage of sedimentary and metamorphic rocks created by tectonic mixing in a subduction trench. The Franciscan Complex is so named because related rocks are found in San Francisco, where every peak consists of a different rock type separated by valleys of sheared shale and serpentinite.

Most of the Franciscan Complex consists of sandstone, graywacke (a sandstone with volcanic and other materials), shales, and conglomerates. It also contains small amounts of serpentinite, basaltic volcanic rocks, chert, and rare limestone. All of these rocks may be either in large sheets or as blocks in a matrix of shale or sheared serpentinite. The sedimentary rocks come from the same sedimentary sources as the Great Valley Group (GVG), sometimes with additional contributions from an offshore island arc or other exotic terrane.

Some of the Franciscan tectonic blocks are high pressure/low temperature metamorphic rocks (blueschists and eclogites), showing signs of metamorphism (recrystallization) at about 12–18 miles (20–30 km) depth and 400–580° F (200–300° C).

The basaltic volcanic rocks in the Complex have been altered to greenstones (see Sidebar 19: Greenstone and Pillow Basalt). The basalt originally formed at a mid-ocean ridge (spreading center) or as isolated eruptions on the seafloor (hotspots or seamounts).

Geologists have debated for many years about how this Complex of so many different rock types formed. One model of the formation of the Franciscan mélange is shown in Figure 22, which links to the formation of mud volcanoes as well. The Franciscan Complex developed during a period of over 150 million years as several terranes collided with North America. During these collisions volcanic rocks, such as pillow basalts or seamounts (A), were forced underneath the overlying upper continental plate.

Some of this material detached from the lower plate and adhered to the upper plate in a set of extensive overlapping thrust sheets ("nappes") (B). These thrust sheets mixed oceanic material with buried upper-plate rocks with low-grade metamorphism (zeolite and prehnite-pumpellyite facies). This created a cumulative pileup that uplifted the upper plate, creating normal faults (C) above the subduction zone and bringing buried rocks to the surface. Descending seamounts on the lower plate sheared rocks of the upper and lower plate, breaking off blocks of both crust and mantle into a jumbled mass (D). Higher temperatures and pressures metamorphose rocks into blueschist (E). Peridotite that was initially hydrated into serpentinite close to the surface dehydrates at great depths. This process releases water into upper layers along faults and along the subduction fault (F).

The released water mixes with the blocks of metamorphosed crust, mantle, and dehydrated serpentinite, forming a low-density, buoyant mud slurry that rises through the upper plate along faults (G). The slurry contains rocks that may be derived from anywhere along the route to the seafloor, including blueschists, mafic rocks, and cherts. Therefore, although the slurry is mostly serpentinite, it contains many other rock types. Upward movement of the slurry is episodic and may be triggered by earthquakes. Deeply buried rocks may also be extruded to the surface along the thrust faults near the trench.

The mud slurry erupts onto the ocean floor, through GVG or other crust, in the form of mud volcanoes (H), massive submarine features that form near subduction zones. These "volcanoes" are a mix of ocean floor basalts, gabbro from the mantle, greenschists, blueschist, eclogites, and serpentinite. They can be 12–18 miles (20–30 km) in diameter, grow as high as one mile (1.6 km), and persist for millions of years. Some of these deposits may subsequently slump off the sides of the volcano and mix with GVG sediments. They, and the rest of the upper plate, are on a conveyor belt that is progressing towards the subduction zone, in the opposite direction of the subducting lower plate (I). Surface layers, such as GVG sediments and mud volcano deposits, are conveyed back to the trench. At the leading edge of the upper plate (J), tectonic forces create slumps and landslides of the upper plate into the trench. This mixes graywacke (originally GVG sandstones), serpentinite, volcanic greenstones, blueschists and eclogites, and other rocks, and the mixture today is called the Franciscan mélange. This explains the juxtaposition of many different rock types created by a variety of geological processes. Some of these rocks may be recycled back into the trench and undergo this process more than once. Between 100–70 Ma this mélange was rapidly uplifted toward the surface during multiple, sporadic uplift events. Subsequent erosion now reveals these deeply buried rocks.

The multiple terranes of this Complex are grouped into three main structural belts across northwestern California, each with a unique set of nested terranes that consecutively collided over time. Each belt is younger to the west and was thrust successively beneath the belt to the east as the subduction zone periodically shifted to a new location further west. The resulting pattern is called an accretionary prism.

Of the three structural belts, the Berryessa region contains only parts of the Central Franciscan belt. This belt represents an overlapping stack of largely sedimentary formations that were transformed by high pressures. These Franciscan sandstones are less permeable than GVG sandstones, allowing the streams in Franciscan-dominated canyons to flow continuously, or at least later into the summer, than streams in GVG valleys. In this region, the Franciscan rocks are overlain structurally by the Coast Range Ophiolite and the Great Valley Group, and they are separated from these overlying rocks by the Coast Range Fault.

Great Valley Group

The Great Valley Group (GVG) provides a continuous record of sedimentation from the Late Jurassic through the entire Cretaceous age (150–65 Ma). It is a 40,000 feet (12,000 m) thick sequence of submarine sediments that provides an excellent opportunity to study deep-marine sedimentation and tectonic evolution of a fore-arc basin.

The GVG sedimentary rocks were deposited originally on top of oceanic crust, which had previously been thrust onto North American continental rocks. GVG sediments were laid down in approximately 3000–5000 feet (1000–1500 m) deep seas at the edge of the North American continent.

GVG formations occur along the rim of the Central Valley and form a 13,000–20,000 feet (4000–6000 m) deep deposit underlying the Central Valley. Some of the best outcrops of these rocks are on the west side of the southern Sacramento Valley at Putah Creek and Cache Creek canyons. These same rocks extend underneath more recent alluvium into the center of the valley. The southwestern Sacramento Valley has many wells extracting gas from these underlying formations.

These sediments were eroded off of a volcanic arc immediately to the east that was active during the nearly 100-million-year period of east-dipping subduction of the Farallon Plate beneath North America. The deep roots of this volcanic arc form the extensive granite of the present-day Sierra Nevada. The volcanic carapace of this arc was eroded westward, travelling through submarine canyons, and deposited into a submarine basin that was situated west of the volcanic arc.

At first, the subduction zone was quite steep, with a deep trench just offshore, as in the current day Andes. It had no continental shelf. Sediments of all grain sizes, including large granite cobbles, were quickly transported to the basin plain, rather than accumulating on a shelf. The presence of these granite cobbles on the basin plain is strong evidence of a steep continental slope. Transport of cobbles require high-velocity currents, and these currents dissipate too quickly on broad, gentler continental slopes, without reaching the edge of the slope. Later, as the subduction shifted to lower angle flat-slab subduction, a continental shelf formed.

The oldest GVG sediments have no calcium carbonate fossils, indicating they were deposited below 10,000 to 15,000 feet (3000 to 4500 m), at depths where carbonate dissolves in sea water. The GVG sediments are rich in the uppermost metamorphic rocks of the Klamath Mountains and volcanics of the Nevadaplano (see "Geological History" for more detail). They were initially deposited on the continental shelf, and then cascaded in underwater gravity slides known as turbidity currents (see Figure 44). The slides, probably triggered by earthquakes, spilled out from the continental margin into the deeper water abyssal plain, located at depths over 10,000 feet (3000 m), where they formed submarine fans up to 40 square miles (100 km2). These were subsequently incorporated into the subduction complex.

As the Sierran-Klamath volcanic arc eroded, the underlying granitic plutons were exposed, changing the source material for the GVG sediments. The upper GVG sediments are richer in lighter-colored felsic minerals from these plutons, thus creating an upside-down record of the prior Sierra lithology.

Over time, the fore-arc basin began to fill in and the depositional environment gradually shallowed. By the late Cretaceous, the basin was no longer a deep ocean and had developed into a complex submarine fan and slope environment. By the Paleogene, the basin had evolved into a slope, shelf, and nonmarine environment.

On the west side of the Sacramento Valley, the GVG rocks are steeply folded and eroded into an interbedded series of less resistant shale, where canyons formed, and more resistant sandstones, forming ridges, which together give the landscape a striped look. The sandstones commonly show "graded bedding," from coarse sand grains at the base to finer grains at the top. This provides a means to interpret how the rocks were deposited and which beds are younger than others.

Serpentinite

Serpentinite, commonly misnamed serpentine, is peridotite (originally part of the Earth's mantle) that has been hydrated (combined with water at low temperatures) and is mainly composed of minerals of the serpentine mineral group. These minerals have a sheet-like crystalline structure, accounting for their slippery feel. Relative to most rocks of the continental crust, serpentinite is rich in magnesium and iron, sometimes rich in elemental metals such as nickel, cobalt, and chromium, and poor in calcium, silica, potassium, and sodium. As used here, "serpentinite" refers to the rock type, whereas "serpentine" is an adjective of soils or landscapes containing serpentinite.

Serpentinite and related rocks of the down-going Farallon Plate represent remnants of oceanic crust and mantle formed at an oceanic spreading center and subsequently added to the

North American continent. The hydration of peridotite that forms serpentinite can happen at mid-ocean ridges, where magmatic activity and fracturing of the crust creates strong temperature gradients and intense alteration from the heated water. It can also occur at subduction zones, where fluids from the subducting slab at depths of 18–25 miles (30–50 km) move upwards into the overlying plate. Very low temperature serpentinization continues today in the California Coast Range, where groundwater interacts with fresh peridotites. The peridotite, although low in calcium, has enough calcium to create alkaline groundwater, and some surface springs in the region are actively precipitating travertine (a calcium carbonate precipitate). Serpentinization drastically changes mantle and oceanic crustal rocks by decreasing their density, making the rock more buoyant than surrounding, unserpentinized rocks, and making them more readily deformable.

The transport of serpentinite to the surface could have happened several different ways. It may have been scraped off of the subducting plate, exposed by uplift and erosion of the overriding mantle wedge, or protruded through the overlying mantle onto the overlying seafloor as mud volcanoes.

Serpentinite is found throughout the Coast Range, from Santa Barbara County north into southwestern Oregon, and in the foothills of the Sierra Nevada from Tulare County to Plumas County. In the Putah Creek watershed, serpentinite occurs as fragmented, northwest-trending exposures over a zone about 40 miles long and up to 25 miles wide (65 km by 40 km). It takes several forms, such as faulted basal units in remnant ophiolite fragments, mélanges within the Franciscan Complex, and sedimentary layers mixed with GVG sediments. In places, it has textures identical to those of serpentinite mud volcano deposits in the Marianas Trench in the western North Pacific.

The mud volcanoes in the Marianas Trench lie one to three miles (2-5 km) beneath the ocean waters and are not directly observable. To study such rocks, geologists employ deep-sea drilling, remote sensing, small deep-diving submarines, or remotely operated vehicles. In contrast, one can walk across the preserved boundary between two former plates in the Berryessa Snow Mountain region and see rocks and geological structures formed during ancient plate interactions.

Soils formed from serpentinite rocks are very infertile because they lack enough of certain elements required by most plants (such as calcium, potassium, and phosphorous) and contain other elements that are harmful to most plants (such as chromium, cobalt, and nickel). Therefore the Berryessa Snow Mountain area came to host unique endemic plant species adapted to serpentine soils in a variety of landscapes and microclimates.

Geological History

As early as 420 Ma, in the Devonian age, the North American Plate was colliding with islands and fragments of continents (terranes) in the Pacific Ocean, with the oldest California terranes being the Eastern Klamath and Northern Sierra terranes. Meanwhile, oceanic plates in the proto-Pacific were subducting under North America in the Antler Orogeny. Continued accretion of the terranes, lasting until at least 120 Ma (in the Early Cretaceous), expanded the width of California, and new collisions shifted the subduction trench westward over time.

The oldest rocks in the Berryessa Region formed during the late Jurassic and Cretaceous, when several events were occurring at the same time (see Figure 23).

Around 170–150 Ma, a microplate of oceanic crust and lithosphere broke off and was transported laterally on top of the North American Plate during the Nevadan Orogeny. It was thrust up and over a lower layer of continental crust and mantle along the Coast Range Fault, creating a double-layered Moho) of high-density crust. This microplate of high-density oceanic crust and mantle now underlies the Central Valley and consists of the Coast Range Ophiolite (CRO).

The ophiolite's high density and integrity prevents it from being pushed upwards into mountains, thus explaining why the Central Valley is so flat and level over such a large area. Instead of forming mountains, this zone became an elongated depositional basin. This type of basin is known as a fore-arc basin because it formed in front of the magmatic arc (the ancestral Sierra Nevada), but still behind the subducting trench (see Figure 24).

On the west, starting about 165 Ma, oceanic basalts, sediments, and seamounts were scraped off the descending ancestral Pacific Plate onto North America immediately east of the trench in an accretionary sedimentary wedge. Around 163–159 Ma, some parts of the plate were buried deeply enough (20–30 miles; 20–40 km) to be transformed by high pressures and elevated (but relatively low) temperatures, into a complex mix of fractured metamorphic rock (including blueschist, eclogite and greenstone). Subsequent tectonic mixing resulted in a complex set of rocks (Franciscan Complex) that now makes up most of northwestern California.

Other parts of the descending oceanic plate were subducted to great depths (60 mi; 100 km), where water released from the subducted plate continued to induce melting in the asthenosphere underneath the North American Plate until about 80 Ma. Magmas rose vertically upwards, much farther inland, to form large masses of granite below the surface and a volcanic arc above in today's Sierra Nevada and Klamath Mountains. This area is the magmatic arc of this arc-trench system.

By 146 Ma, sediments from the eroding Sierra Nevadan and Klamath highlands started to deposit on top of the Coast Range Ophiolite in the fore-arc basin, forming the Great Valley Group (GVG) in the Central Valley area. This basin continued to deepen over time, accumulating very deep sediments (40,000 ft; 12,000 m) until about 70 Ma. The older GVG sediments contain more volcanic materials than the younger layers, allowing geologists to reconstruct a history of volcanoes on the Sierra Nevadan arc overlying granitic bodies. Between 146 Ma and 130 Ma, serpentinite was forced up from deep in the subduction zone, bringing high-grade metamorphic rocks along with it, and the mix of rocks was deposited in the fore-arc basin.

Between 130 and 120 Ma, thrust faulting contracted the width of California, which interrupted the deep metamorphism of the Franciscan rocks. Accretion of oceanic terranes continued to build, and uplift, the Franciscan Complex until 50 to 30 Ma.

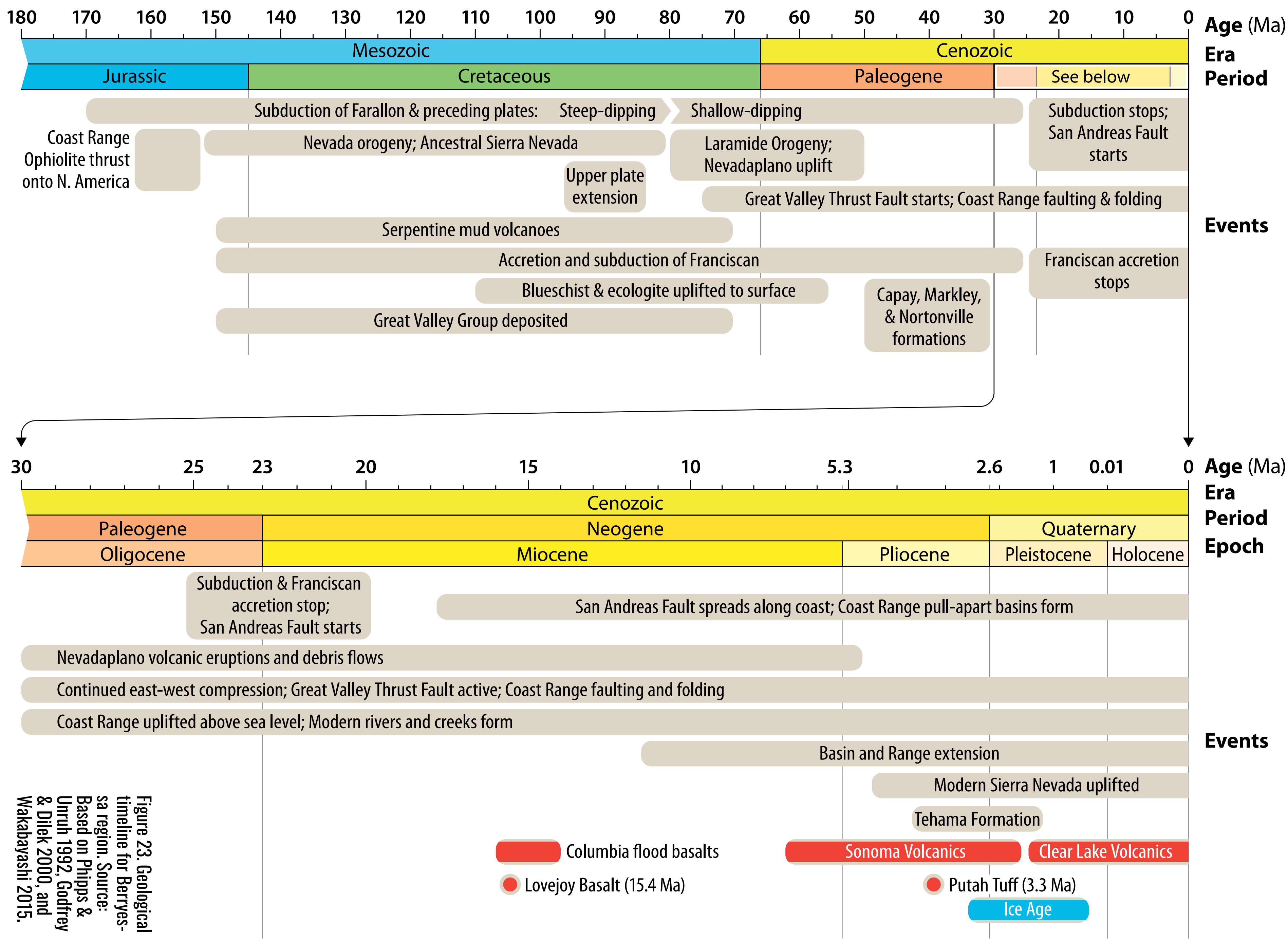

Figure 23. Geological timeline for Berryessa region. Source: Based on Phipps & Unruh 1992, Godfrey & Dilek 2000, and Wakabayashi 2015.

Between 100 and 70 Ma, regional extension of the upper plate led to widespread low-angle normal faulting. The older Coast Range Fault was reactivated as a normal fault, different from its former thrust fault nature. This normal faulting unroofed and exposed (or exhumed) the uplifted Franciscan rocks. Most of the Great Valley Group of sediments were deposited during this period.

Around 80 Ma, the angle of the Farallon Plate's subduction beneath the North American Plate shallowed significantly, with a result that arc volcanism ceased in the Sierra Nevada region. This event, the Laramide Orogeny, may have begun when a large oceanic submarine plateau, similar to today's Shatsky Rise in the western Pacific, was subducted beneath North America. This new, shallow angle of subduction also resulted in regional uplift throughout western North America. Paleogeographic evidence suggests that the region immediately east of the Sierra Nevada was a 2–2.5 miles (3–4 km) high plateau. This region has been dubbed the "Nevadaplano" to emphasize its similarities to the Altiplano of western South America. The Nevadaplano is believed to have existed until around 17–10 Ma, when the Basin and Range extension initiated.

The dramatic tilting of the GVG beds on the west side of the Sacramento Valley initially occurred about 80–50 Ma, with several periods of uplift. Substantial compressive forces thrust the Franciscan Complex eastwards over itself, the Coast Range Ophiolite, and the lower Great Valley Group along the Great Valley Thrust Fault System as a tectonic wedge. The Great Valley Thrust Fault System is a regional system of segmented blind faults that dip westwards to underlie the eastern edge of the Coast Range. The two segments of this buried fault system at the mouth of Putah Creek Canyon are the Gordon Valley Thrust and the Trout Creek Thrust, which lie over 5–6 miles (8–10 km) below the surface. This thrust faulting significantly lessened the west-east width of the GVG.

Above this thrust fault system, the upper plate was deformed by east-dipping back thrusts (the Wragg Canyon–Bartlett Springs detachment system).

By 60–50 Ma, regional compressive forces also led to multiple folds (anticlines and synclines) in the Berryessa Region and folding of the Coast Range Fault.

About 56–34 Ma (in the Eocene), fluctuating sea levels in the Central Valley led to alternating deposition and erosion. The only Eocene beds on the west side of the Sacramento Valley are exposed near the mouth of Putah Creek Canyon west of Winters. These beds include the Capay Formation, deposited in water over 3000 feet (1000 m) deep, and the younger Nortonville Shale and Markley Sandstone, which were laid down in depths over 6000 feet (2000 m) as deep-sea fans.

Subduction along the California coast ceased about 25–20 Ma. At this time, the Farallon Plate and the mid-oceanic ridge separating the Farallon and Pacific Plates were completely consumed in this region. The newly arrived Pacific Plate began to slide horizontally past North America, rather than being subducted vertically, forming a long transform fault system, the San Andreas Fault system.

This horizontal sliding is not confined to the San Andreas Fault system. About 25% of the movement between the plates is occurring on the eastern side of the Sierra in the Walker Lane Belt. The area in between is the Central Valley-Sierra Nevada microplate, a somewhat coherent region that is moving slowly NW with respect to North America, but less rapidly than the Pacific Plate. Its separation from the North American Plate seems to be a quite recent geological phenomenon, 3–1 Ma or so. Many geologists believe that millions of years in the future, the boundary between the Pacific and North American plates may shift entirely to the east side of the Sierra and that the San Andreas Fault system will no longer be active.

Over time, the length of the San Andreas transform fault extended further north and south along the West Coast (see Figure 25). It also expanded into a larger system of right-lateral, strike-slip faults, with mainly horizontal (as compared to vertical) movement. In Northern California, the Green Valley Fault Zone is the easternmost branch of the San Andreas Fault system. This fault zone extends from Concord in the eastern Bay Area north to southern Humboldt County, with the Berryessa Fault (on the west side of Lake Berryessa) representing this system

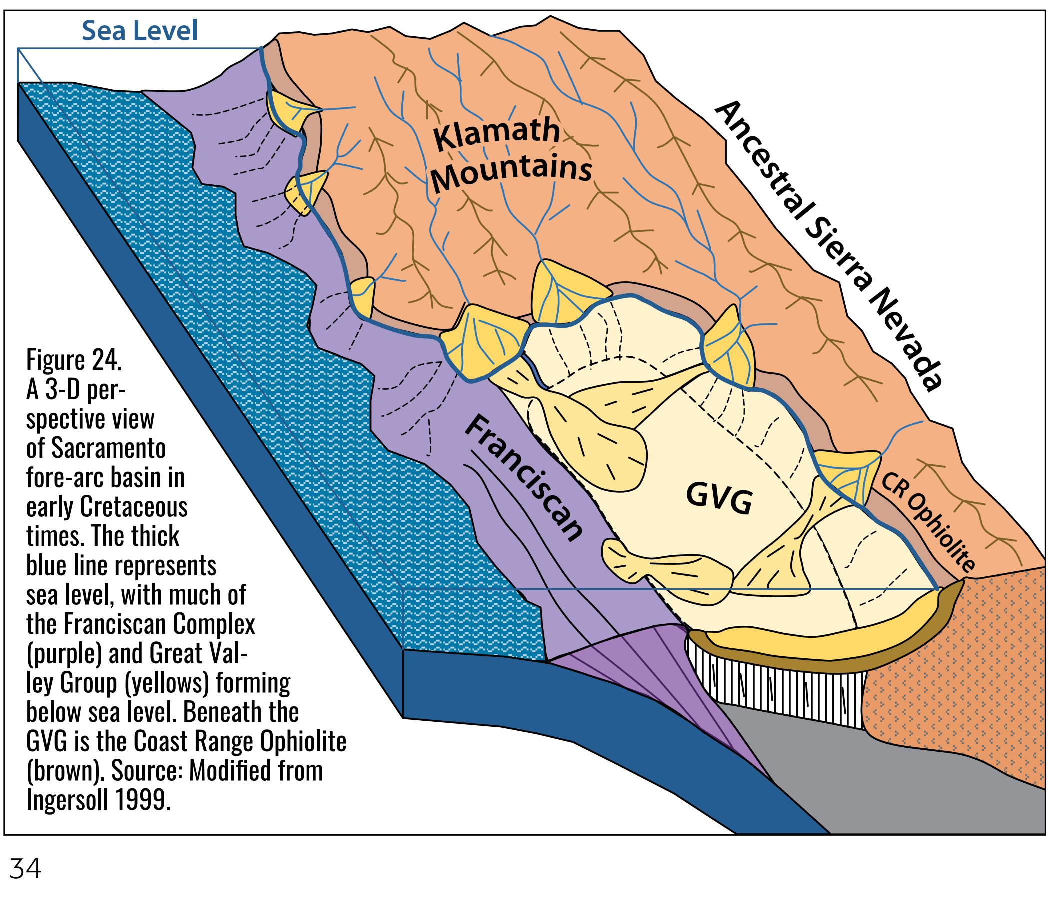

Figure 24. A 3-D perspective view of Sacramento fore-arc basin in early Cretaceous times. The thick blue line represents sea level, with much of the Franciscan Complex (purple) and Great Valley Group (yellows) forming below sea level. Beneath the GVG is the Coast Range Ophiolite (brown). Source: Modified from Ingersoll 1999.

in the Lake Berryessa area. In addition to the horizontal sliding along the plate boundary, substantial east-west compressive forces are still being exerted in this region, as evidenced by the 1892 Vacaville-Winters along deep blind faults and the continued tilting of Pleistocene beds (Tehama Formation and Putah Tuff) on the eastern side of the Coast Range.

Starting around 25 Ma, transpressional forces associated with the newly initiated San Andreas Fault system uplifted the region immediately to its east, creating the mountains of our current day Coast Range. Erosion began to carve valleys and canyons, probably including Putah Creek Canyon, removing much of the geological record of sediments back to the youngest GVG formations. Pull-apart basins began to form as land was stretched along multiple splays, or branches, of the fault system, becoming elongate northwest-southeast valleys. A pull-apart basin occurs when two overlapping faults or a fault bend create opposing tensional forces that pull the land apart, opening a sort of parallelogram that sinks lower than the surrounding land. Major pull-apart basins in the region include Sonoma Valley, Santa Rosa Plain, and Clear Lake. Berryessa Valley has a similar orientation as these pull-apart basins, but it is probably not one. Faults on either side of the valley are thrust faults, rather than strike-slip faults, and the floor of the valley consists of Mesozoic bedrock rather that more recent alluvium.

Around 15.4 Ma, the Lovejoy Basalt, a long and narrow extension of the present day Yellowstone hotspot and Columbia River flood basalts, poured across the mouth of Putah Creek Canyon, having flowed about 150 miles (240 km) from its source.

The northward migration of the San Andreas fault allowed for upwelling of hot asthenosphere in its wake, initiating melting in the overlying crust and creating extensive volcanic flows that covered the western part of this region, the Sonoma Volcanics (8–2 Ma) and Clear Lake Volcanics (2.2 Ma to 10,000 years ago).

This volcanic activity may have been accompanied by renewed uplift of the Coast Range. After a long gap in the sedimentary record, extensive sedimentary debris was deposited on the west side of the Sacramento Valley in the Tehama Formation (3.4–1.0 Ma). Ash from the Sonoma Volcanics deposited thin layers of tuff, the Putah Tuff, in the sediments of the Berryessa Region about 3.3 Ma. This tuff was eroded and redistributed by streams into a water-laid unit, and it interfingers with the concurrently-deposited Tehama Formation.

The continued compression during the Pliocene-Pleistocene tilted these beds, sometimes steeply, along the western Sacramento Valley margin. The thrust faulting was also responsible for creating the English Hills and the 1892 Vacaville-Winters earthquakes.Ongoing uplift has allowed Putah Creek to carve a deep channel in the alluvial fan of the Tehama Formation at the mouth of Putah Creek Canyon.

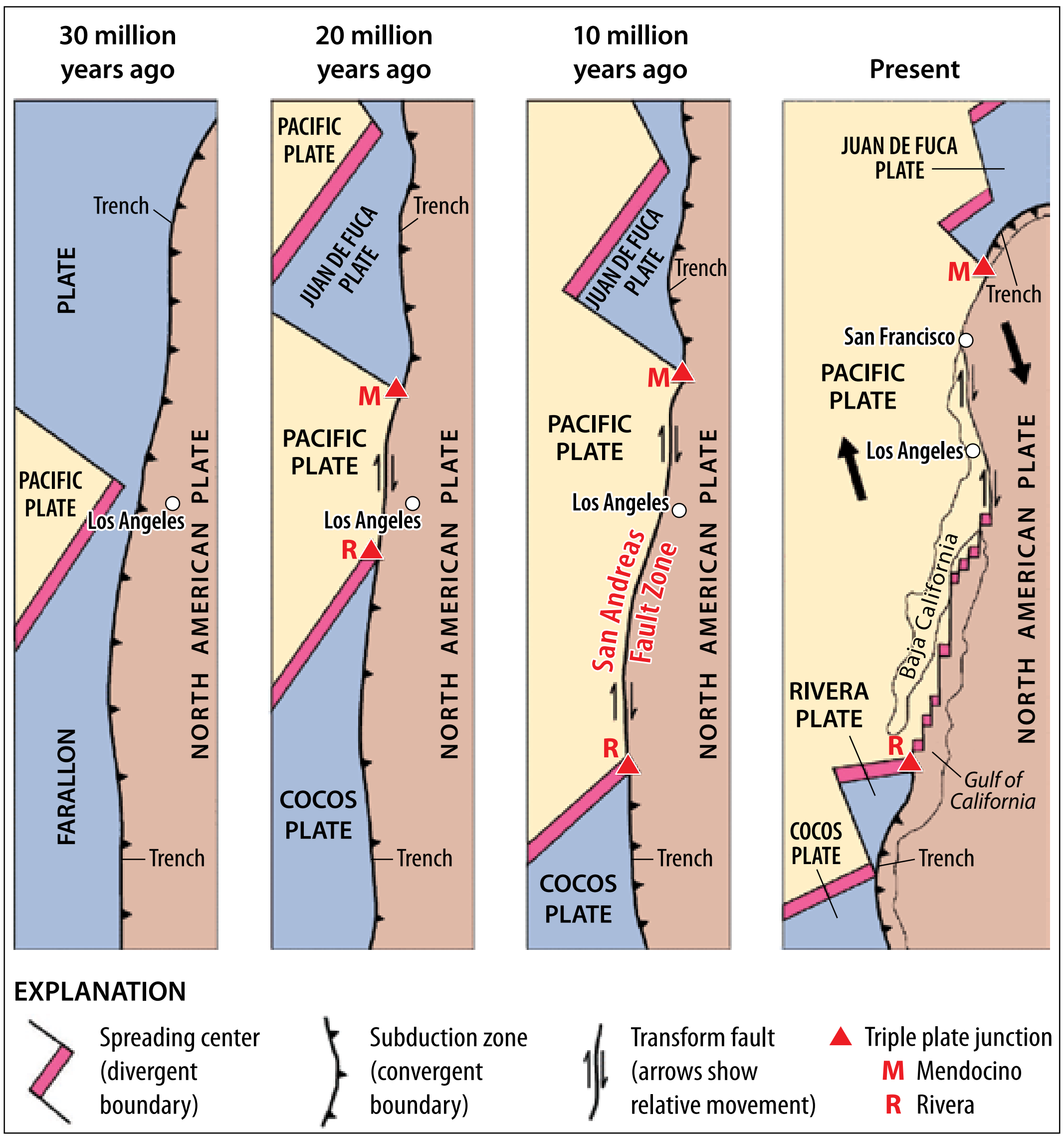

Figure 25. Transition from subduction zone to transform fault zone on the west coast of North America. The San Andreas Fault Zone continues to spread along the contact between the Pacific and North American plates as the plates slide by each other. East-west compressive forces are also still exerted in the region. Source: USGS 1999.

ROAD GUIDE

This section provides a mile-by-mile description of routes from Winters to Lake Hennessey, along the west shore of Lake Berryessa, and through Pope, Chiles, and Capell Valleys. It is written for readers who start in Winters and proceed in a generally counter-clockwise route around the region. Most of the geological topics mentioned along the drive are therefore most fully explained when first encountered in this sequence, and later only referred to in simpler terms (see Figure 26).

However, readers can start exploring this area using any of the individual route segments listed in the guide. For visitors coming from the Sacramento Valley, start from the Russell Blvd/Grant Avenue exit on I-505 and head west into downtown Winters.

For visitors coming from the Napa Valley, you can start at two different locations:

- From Napa, take Highway 121 north to its intersection with Highway 128 (Moskowite Corner). From here, you can either go east, following the Winters to Moskowite Corner segment in reverse order, or you can go northwest to follow the Moskowite Corner to Turtle Rock segment.
- From the upper part of Napa Valley around Rutherford or St Helena, go east on Highway 128 to the eastern shore of Lake Hennessey. From here, you can continue east on Highway 128 to follow the Lake Hennessey to Turtle Rock segment, or you can go north on Chiles-Pope Valley Road to follow the Pope Valley to Lake Hennessey segment in reverse order.

If you choose to take the entire route, plan a full day to complete it. It is best to start out by 8 or 9 in the morning. As there are few restaurants on the route, we recommend that you take a picnic lunch, snacks, and water with you. There are no gas stations on this trip. Be sure to fill up before starting. In the summer it can be very hot; take sun protection and extra water.

Each milepost entry starts with the mileage from the beginning of the segment, reverse mileage for readers doing the segment in reverse, and the mileage gap from the previous milepost. In this example, "Mile 2.7 (20.4) [1.1]," the milepost is 2.7 miles from the beginning of the segment, 20.4 miles from the end of the segment, and 1.1 miles from the previous milepost. To help with locating yourself along the drive, the road guide lists the location of physical county highway milepost signs where they seem useful. These are abbreviated; for example, "PMP 14.05" refers to the "Physical Marker Post 14.05" sign.

Berryessa Region Geology Maps

Figure 27 provides a closer look at the geology in the Berryessa Region. Several of the formations are simplified into coarser groups to show the larger pattern of geology.

To show the underlying structure, Figure 28 provides an even more detailed map and underlying cross-section, showing greater distinction among formations in the Great Valley Group and the important faults and folds of the Berryessa Region.

Readers may want to refer to the more detailed geology maps in Appendix A. These provide a closer look at the geology along the tour route.

Winters to Moskowite Corner

(21.9 miles on CA-128 from downtown Winters to CA-121)

For visitors coming from the Sacramento Valley, start from the Russell Blvd/Grant Avenue exit on I-505 and head west into downtown Winters. Be sure to fill your gas tank in Winters because there is no gas service for the rest of the trip.

As you cross the bridge over the freeway, look at the hills to the east. This is the Blue Ridge Range, the easternmost range of the Northern Coast Range. Note the deep notch in the range, known as Berryessa Gap. This gap marks the valley through which Putah Creek flows east from Lake Berryessa toward and into the Sacramento Valley (see Figure A-1 for a detailed geology map of Winters to Wragg Canyon area).

As you approach the Coast Range, note the striking differences in vegetation on the north-facing versus south-facing slopes. The south-facing slopes get more intense sunlight during the days, which dries them out. Therefore, the north-facing slopes are more likely to support woodland or forest, and the south-facing slopes grassland and chaparral. This difference can be seen throughout similar topographies throughout California.

Mile 0.0 (21.9) (STOP 1) Intersection of Railroad Avenue and Main Street, Rotary Park, Winters.

Park in the lot for Rotary Park. Walk to the south side of the park to see a historic bridge that was once part of the railroad described below. The bridge crosses Putah Creek, which marks the boundary between Yolo County on the north and Solano County on the south. A new road bridge, completed in 2015, spans the creek just upstream.

This stop marks your introduction to the 330,780 acre Berryessa Snow Mountain National Monument, which extends from nearly sea level on Bureau of Land Management lands south of Lake Berryessa (to the west of Winters) north to the 7056 feet (2150 m) high summit of Snow Mountain and, farther north, to the 6500 feet (2000 m) high ranges of the Yuki Wilderness Area in the Mendocino National Forest (see Figure 4).

<u>Geology:</u> The area around Winters is at the top of the Putah Creek alluvial fan, where Putah Creek exits from the Coast Range. For the past few million years, Putah Creek has deposited sediments extending almost 25 miles (40 km) east to the Sacramento River, creating a very gently sloping alluvial fan. This fan descends only 120 feet (36 m) over that distance, while fanning out to a width of 25 miles at its base, stretching from Willow Slough east of Woodland to Maine Prairie south of Dixon (see Figure 29). The development of agricultural waterways has now mostly obscured this alluvial feature (see Figure 30).

<u>Nature</u>: Before the agricultural settlement of this area, much of the landscape was covered by valley oak savanna and perennial bunchgrass. Large cottonwoods, walnuts, and willows grew most abundantly along streams and rivers. This area is in

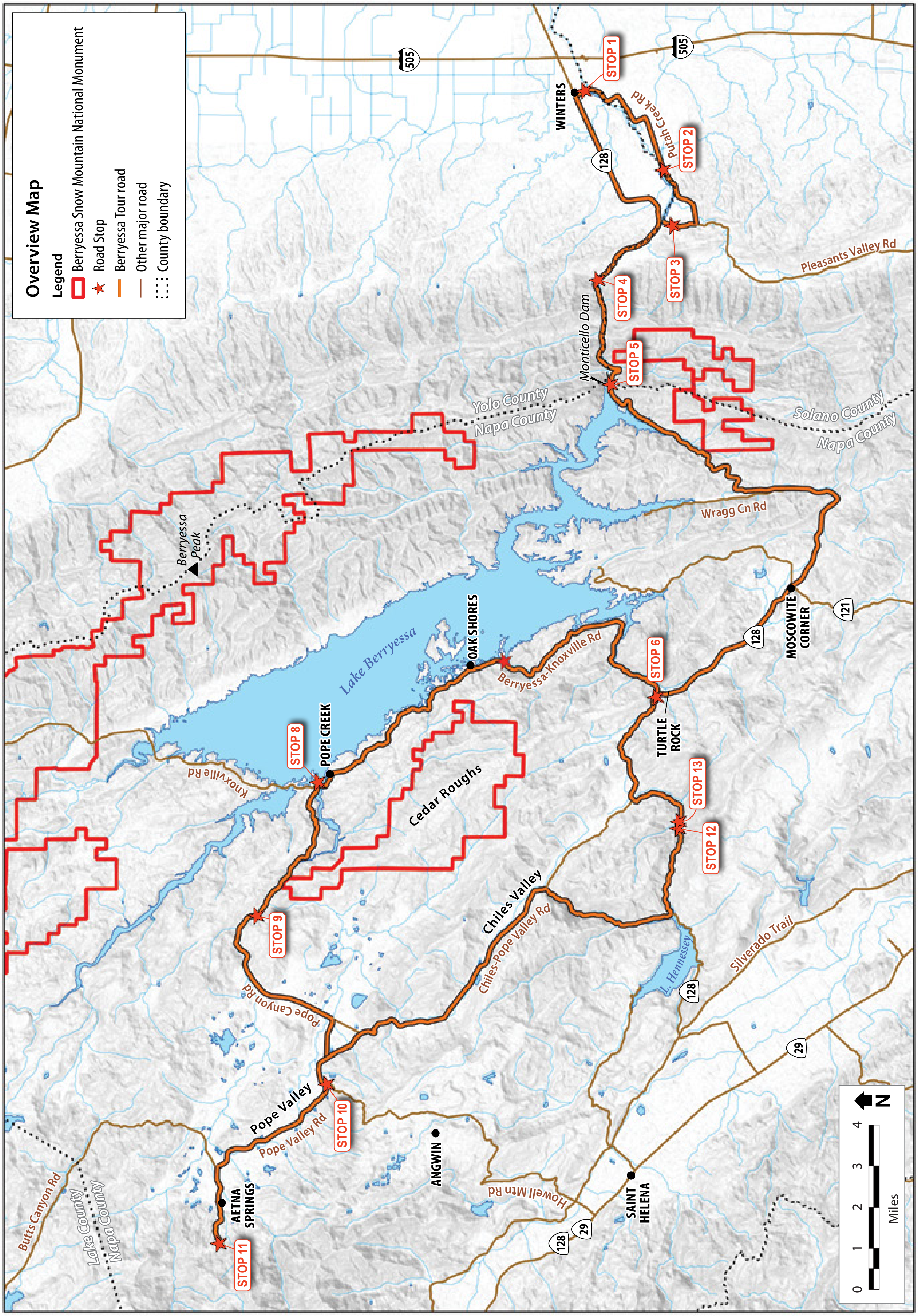

Figure 26. Overview map, showing road guide route and stops.

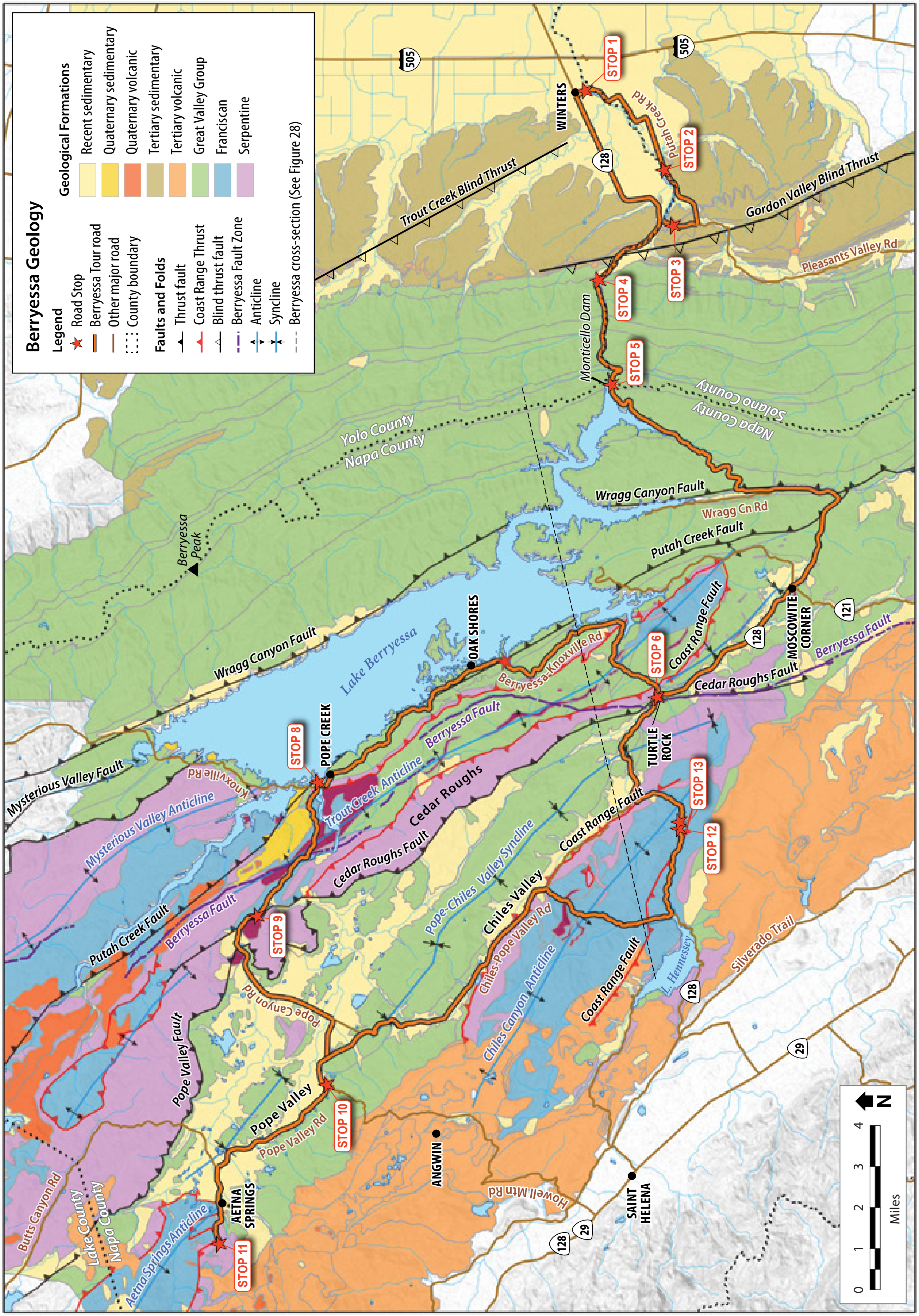

Figure 27. Berryessa Region generalized geology map. See Appendix A for detailed geology maps at a larger-scale. Source: Sims et al. 1973, Fox et al. 1973, Lienkaemper 2012, O'Connell et al. 2001, Phipps and Unruh 1992

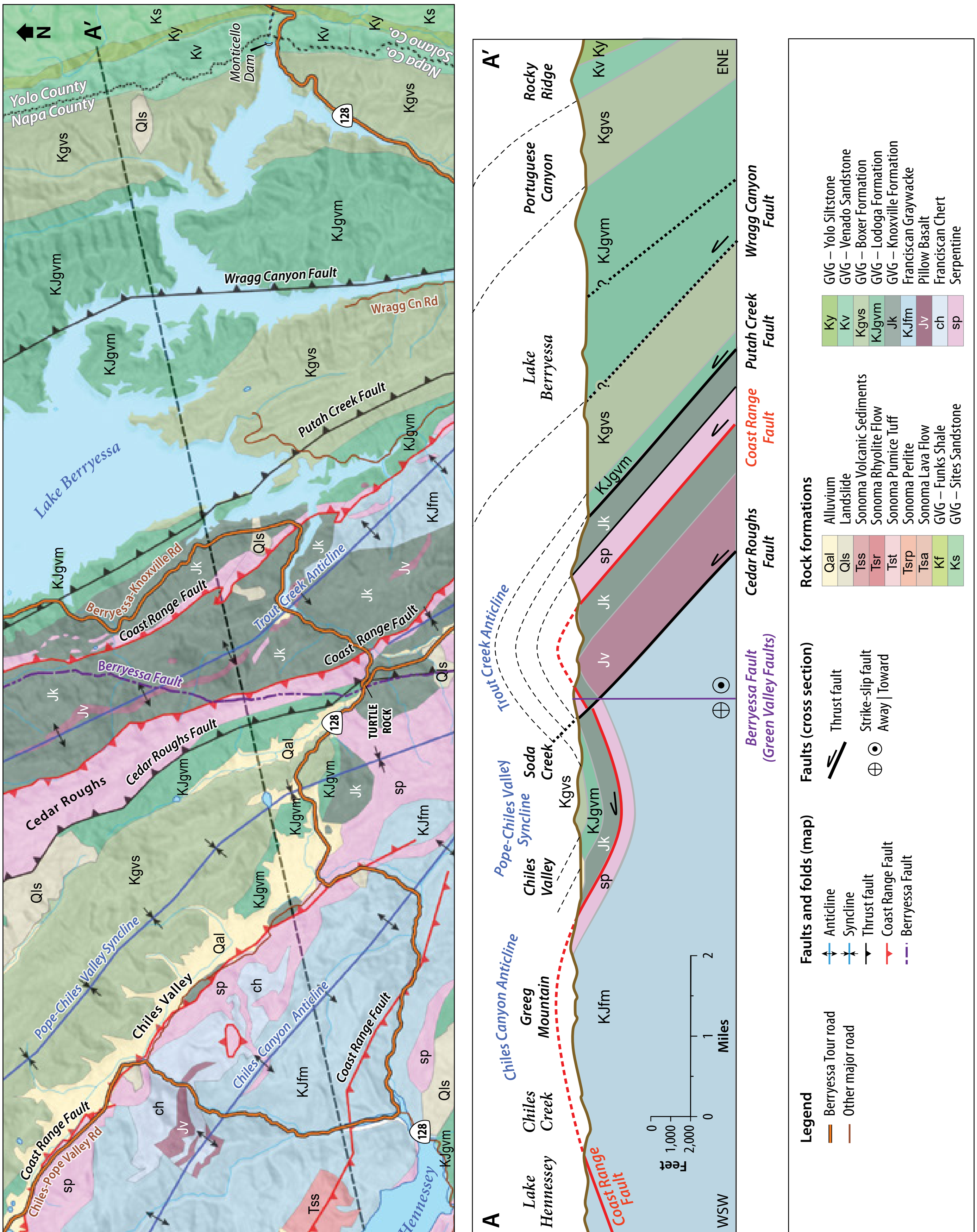

Figure 28. Hennessey (A) to Blue Ridge (A') geological cross-section. This is a closeup view of the central section of Figure 20, showing the folding of the Coast Range Fault (dotted red line), the back thrusts and folding of the Great Valley Group (on right and in center), and the more recent Berryessa right-lateral fault (center). Source: same as Figure 27.

the rain shadow of the Coast Range, with an annual rainfall of 15–18 in. per year, almost entirely in the form of wintertime rains. It is the driest segment of the tour.

History: Much of the Putah Creek watershed was occupied by Patwin people, a southern group of the broader Wintun group native to the west side of the Sacramento Valley. The name "Putah" may be derived either from the name of the Patwin village "Puta'to" (on Putah Creek near the present-day Monticello Dam) or from the Lake Miwok words put'a wuwwe or "grassy creek."

An early historian of California Indian tribes, Stephen Powers, reported that, in 1838, "Indians lived in multitudes" on Putah Creek, although they were gone from the creek by 1877. Many archaeological sites in Berryessa Valley attest to a substantial population there. For more on the Patwin people, see sidebar 1: Patwin and Wintun People.

John Wolfskill (see Sidebar 4) received ownership of this land in 1842 from the Mexican government as the Rancho Rio de los Putos. The land grant extended on both sides of Putah Creek from Lake Solano downstream to the location of Stevenson's Bridge. In 1875, with the arrival of the railroad into the area, the local people established a town, and named it after landholder Theodore Winters. Within a year, the new town had become a busy agricultural and commercial center with three trains daily. While merchants and ranchers provided the town's base, the town also included such businesses as banks, hotels, and others to serve locals, traveling businessmen, and visitors.

On April 19 and 21, 1892, two major earthquakes heavily damaged many business buildings and residences in Winters and Vacaville, most likely due to slippage along the subsurface Gordon Valley Thrust Fault segment of the Great Valley Thrust Fault system. These quakes are estimated to be magnitude 6.4 and 6.2, based on the Mercalli scale. This scale for estimating earthquake intensity is based upon direct observation, mainly of human perceptions and the extent of destruction of buildings. The greatest ground-shaking effects occurred in the English Hills south of Winters.

Newspaper reports at the time described a series of impacts. One person was killed; damage was estimated at between $225,000 and $250,000 in 1892 dollars. There are no reports on how many people were injured, nor was surface faulting observed as a result of either of the quakes. Parts of Putah Creek went dry, banks caved in and almost dammed the creek, and in some places water spurted high on the banks. For more information about the 1892 Vacaville-Winters earthquakes, see references in Appendix D. These reports provide interesting live witness accounts and a walking tour of downtown Winters highlighting some of the damage.

After these quakes, local citizens rebuilt the town, established a high school, and, in 1898, officially incorporated the City of Winters. By the turn of the century, the city had a population of about 525 people. Nowadays, the city celebrates its heritage and history with an Earthquake Festival each summer.

Winters Railroad Bridge (also known as the J. Robert Chapman Memorial Bridge) was built in 1906 to replace an earlier

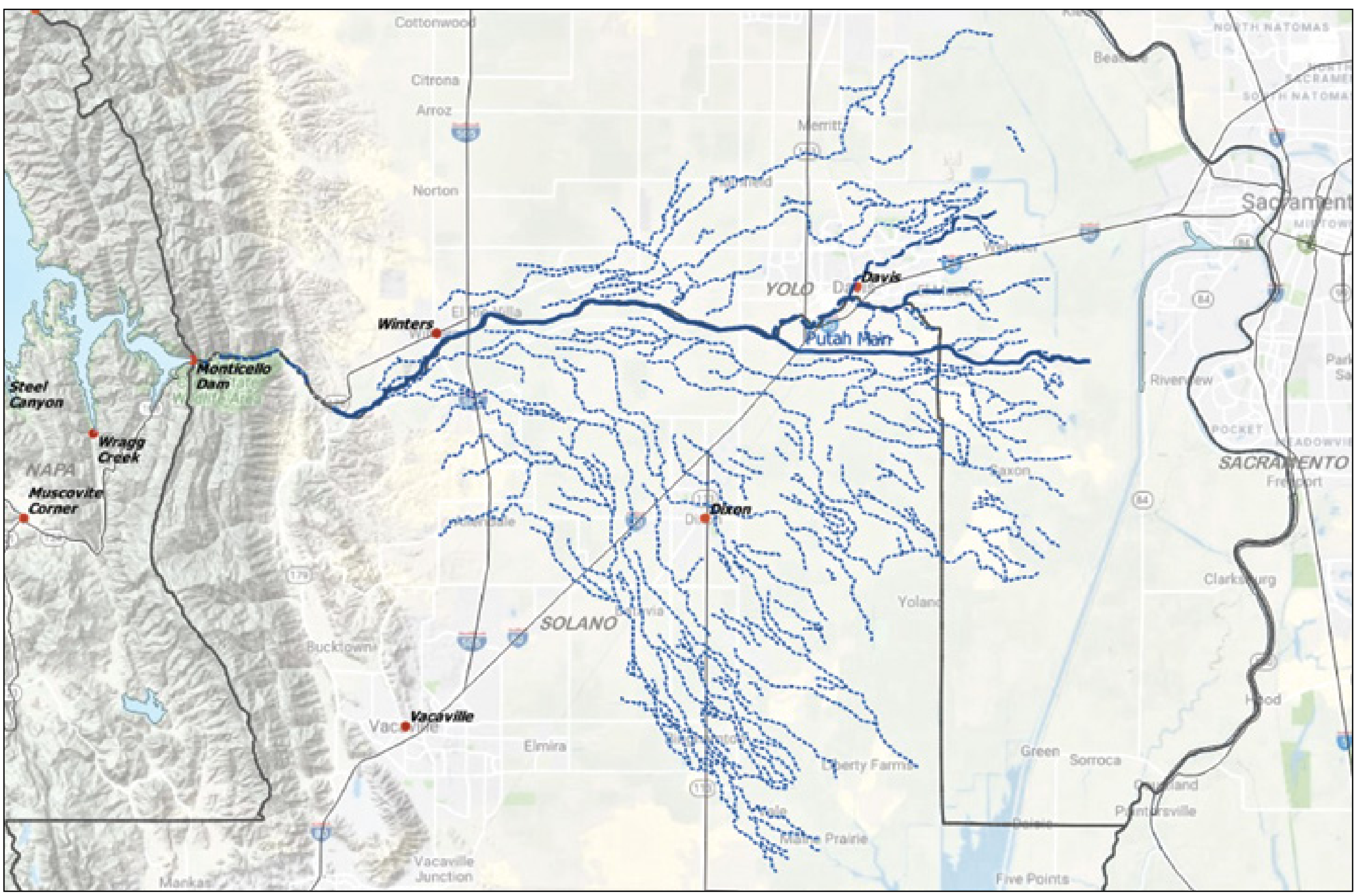

Figure 29. Presettlement channels of Putah Creek alluvial fan. These channels were mostly dry much of the time, with surface flow only along the ever-changing paths with the least resistance to flow. Source: USGS topographic maps

bridge built in 1875. The 1875 bridge was a wood trestle bridge for rail and wagons built by the Vaca Valley Railroad. For historic bridge aficionados, the newer 1906 bridge is described as a "multi-span, metal, five panel rivet-connected Pratt through truss type" in a historic bridge inventory. The bridge, 368 feet long, has three main spans.

In 1908, Southern Pacific Railroad opened a separate parallel bridge for automobiles. The railroad was abandoned in the 1960s, and Southern Pacific donated the railroad bridge to the City of Winters in 1977, along with a parcel of land for the Winters Community Center. The city renovated the railroad bridge in 2006 for pedestrian use, and a historical marker summarizes this history. By 2016, the population of Winters had grown to 7144.

As you exit the Rotary Park parking lot onto Main Street, turn left (west) to reach the intersection of Main Street and Railroad Avenue. Turn left (south) onto Railroad Avenue and set your odometer to 0.0 at this intersection. As you cross the bridge over Putah Creek, you enter Solano County. The county was named in honor of both Francisco Solano (chief of the Patwin people) and the 16th-century South American missionary saint Francisco Solano. Chief Solano's pre-baptismal name was "Sem-yeto," which signifies the "brave or fierce hand."

Mile 0.4 (21.5) [0.4] Intersection of Railroad Avenue and Putah Creek Road. TURN right (southwest) onto Putah Creek Road.

History: The road is slow and winding and passes through farmland originally given to John Wolfskill by the Mexican government in 1842.

About a quarter mile up the road, near the first major road bend, is the confluence of Dry Creek, which enters Putah Creek on the north bank. The Patwin village of Liwai was located in this general area.

Note the walnut orchards along the way. The very dark base of some of these trees is the grafted rootstock of native black walnut, a native species that has evolved with the native soil microorganisms over time. The upper white trunk and branches are grafted English walnuts, which produce better commercial walnuts, but are more susceptible to root diseases. In recently planted orchards, the root grafts come from hybrid stock that does not look as different from the English walnut stems.

Mile 1.5 (20.4) [1.1] University of California Wolfskill Experimental Orchards. 4334 Putah Creek Road.

History: The historical plaque here commemorates John Wolfskill, the father of the fruit industry in this region. The olive trees along the driveway and the main road are over 150 years old.

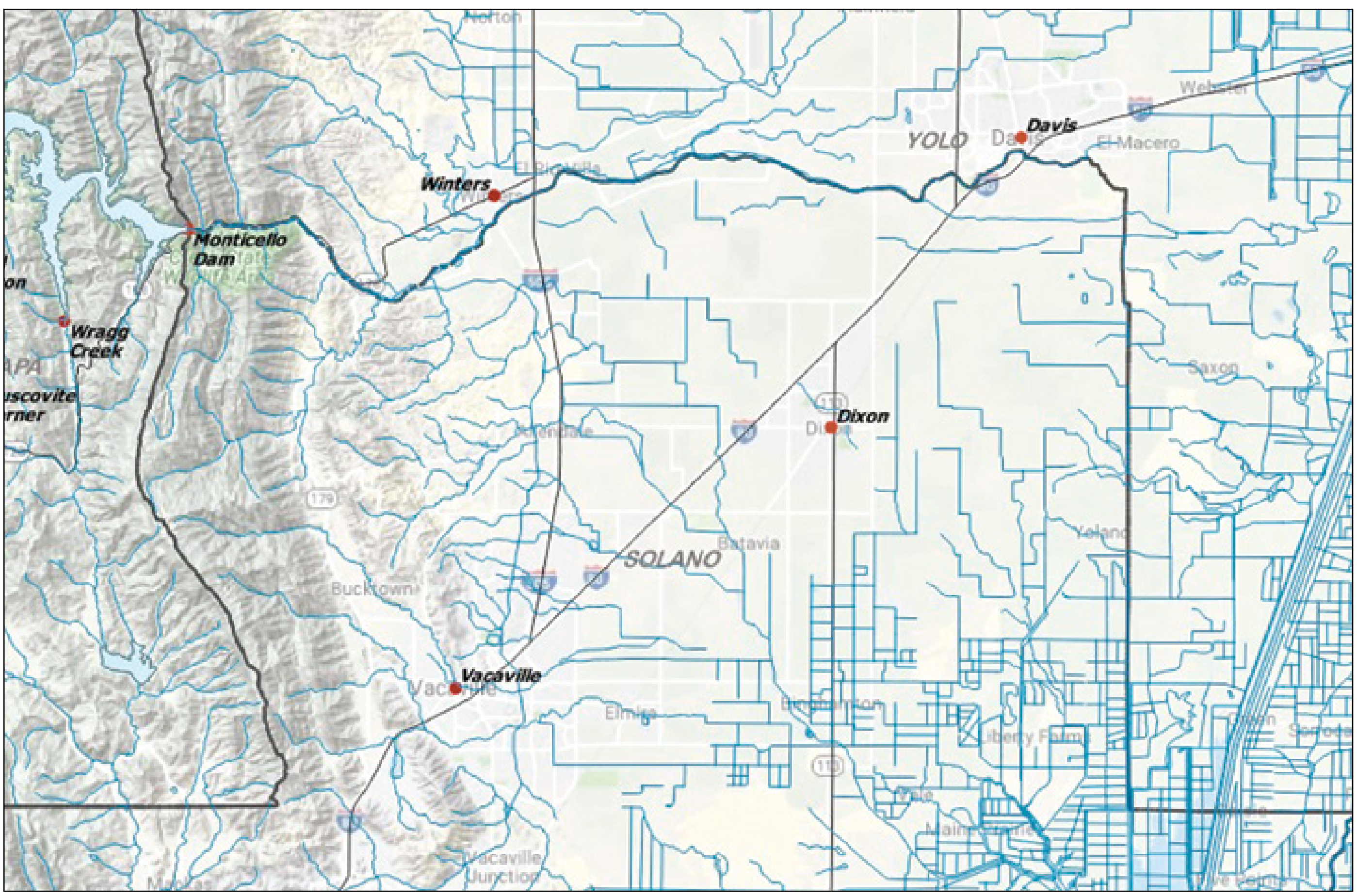

Figure 30. Present-day streams and irrigation canals. Much of the geological alluvial fan pattern has now been obscured by modern agricultural waterways. Source: National Hydrological Database

SIDEBAR 4

John Wolfskill

John Wolfskill came to California at Los Angeles in 1838, looking for his brother William. He was interested in farming, but most of the land in southern California was already taken. He ventured north to the Sacramento Valley, where he used his brother's Mexican citizenship to obtain the 17,000-acre Mexican land grant of "Rancho Rio de los Putos" in 1842.

After John was settled, his younger brothers Milton, Mathus, and Sarchal Wolfskill joined him on his land grant, which was later renamed the Wolfskill Ranch. Wolfskill's ranch was devoted to stock-raising, but he first planted olives and other crops in 1843. By 1851, he had orchards and vineyards, acquiring fig, pear, English walnut, and grape cuttings from Los Angeles. By the 1860s, he shifted to wheat, leasing land to other farmers, and then to fruit production by the 1880s. The Wolfskill family has grown fruit trees in the area since before the Gold Rush.

His 54 years of pioneering work demonstrated that dozens of crops from throughout the world would thrive in the Sacramento Valley. In 1934, John's daughter deeded 108 acres to the University of California as a fruit tree research facility. The avenue of olive trees leading to the main building was planted in 1861.

At about the same time that Wolfskill was settling, Juan Vaca and Juan Peña received a 44,000-acre grant south of Wolfskill's grant, which ambiguously overlapped Wolfskill's land. They initially named it Rancho Lihuaytos for a local creek. But they got into legal wrangling with Wolfskill in 1846, prompting them to rename their grant the very similar sounding "Rancho Los Putos." They defined their grant relative to Rio de los Putos (Putah Creek). The vague boundary problems were not resolved until the 1850s. If that's not confusing enough, there is also the similar sounding "Rancho Las Putas" in Berryessa Valley (See Figure 7).

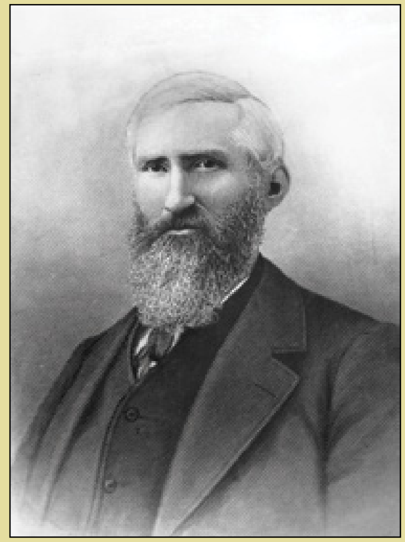

Figure 31. John Wolfskill. Source: De Pue and Co 1879.

After the road makes a left bend, followed by a right bend, notice the large old walnut trees along the roadside. The graft point is about 5–6 feet off the ground, very different from modern walnut grafts. This older style of grafting allowed the tree to grow a solid truck of black walnut, which farmers used to sell as valuable hardwood lumber.

Mile 3.4 (18.5) [1.9] (STOP 2) Solano Diversion Dam. Pullout available on left (south) side of road.

Geology: The road is leaving the flat lands of the Central Valley and entering a large alluvial fan (300–500 ft; 90–150 m high) made of Tehama Formation sediments. The top of this fan is at the mouth of Putah Creek Canyon ahead (see Sidebar 5).

Nature: On the south side of the road, the hills are covered with scattered blue oaks, gray pine, interior live-oaks, and toyon. These are typical trees of low-elevation mixed evergreen forest (see Sidebar 6).

History: Just below the dam is the historic location of Cody's Camp, a set of cabins for tourists and anglers where John Fogerty of Creedence Clearwater Revival spent his summers as a young boy. His memories of Putah Creek in the 1950s, before the dams were built, inspired him to write his song "Green River," which was on the Billboard Hot 100 Chart for 10 weeks in 1969. The song is named after his favorite soft drink in childhood and includes the line "Up at Cody's camp I spent my days, oh, with flat car riders and cross-tie walkers." W.C. Cody owned Cody's Camp. He was the father of Rory Linton, owner of Cody's Deli and Catering in Winters from 1993–2012, and the son of Buffalo Bill Cody.

Water: Note the foothills of Blue Ridge rising to the west and Lake Solano to the north of the road. The lake, which was created by the diversion dam, supplies water to Solano County and UC Davis. The dam stops passage of all fish, particularly salmon, that used to spawn in upper Putah Creek.

The development of Monticello Dam led to a chain reaction of linked geomorphic and ecological changes below the dam. Tributary streams below the dam no longer back up during high water events, as they would have pre-dam. Instead, due to the reduced storm water flow released by the dam, the flood level of Putah Creek is now 20 feet lower and side streams flow strongly all the way into Putah Creek. This stronger, faster water erodes the tributary banks, and the side streams, especially Pleasants Creek, are now heavily eroded upstream for several miles. Stream banks are three times wider and three times deeper than they were prior to the dam. The flushed-out sediments are rapidly filling Lake Solano, reducing its volume almost in half since 1973 (see Figure 34). Much of the lake is now just 2–3 feet deep, and the shallow waters have been invaded by aquatic weeds. These weeds reduce habitat for native fish and aquatic species, make recreational canoeing difficult, and clog up water diversion infrastructure at the diversion dam.

Mile 4.4 (17.5) [1.0] Tehama Formation cliff.

Geology: On its downstream path, Putah Creek here makes its first major turn since exiting the canyon. Before Monticello Dam, flood flows would have been much higher than today.

SIDEBAR 5

Tehama Formation

The Tehama Formation is an extensive layer, up to 2000 feet (600 m) thick in places, that consists of mostly poorly sorted, non-marine sediments that range in grain size from mudstones to conglomerates. In places, the conglomerates have been well cemented and form 60 feet (20 m) high cliffs. The formation occurs, both on and below the surface, from Dixon north to Anderson along the west side of the Sacramento Valley. The base of the Tehama is an aquifer of fresh groundwater in the Sacramento Valley. These sediments were eroded from the Coast Ranges and the Klamath Mountains and deposited in the Sacramento Valley by rivers capable of moving large gravel and cobbles. These deposits formed during the Pliocene and Pleistocene (3.4–1.0 Ma) when regional tectonics renewed uplift of the Coast Ranges. Continued uplift has modestly tilted the Tehama Formation and has allowed Putah Creek to carve a deep channel in this older alluvial fan.

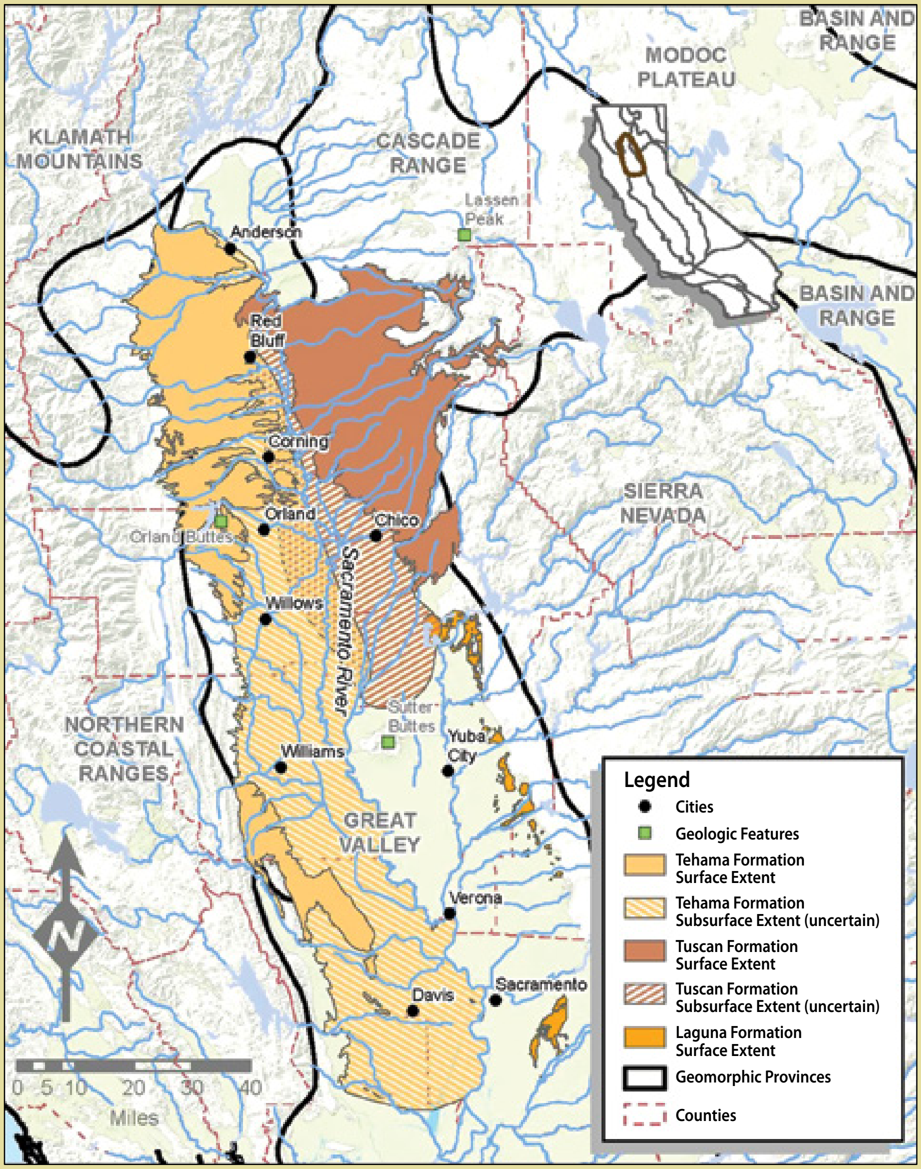

Figure 32. Approximate surface and subsurface extent of the Tehama and Tuscan Formations. Both were deposited at similar times, but from sources in opposite directions. Source: DWR 2014.

SIDEBAR 6

Blue Oak

Blue oaks are endemic to California and they are common on the lower foothills of the Central Valley at elevations below 3000 feet (900 m). They prefer well drained, gentle slopes, but they also occur on steeper slopes intermixed with annual grasslands, chaparral, and other oak woodlands.

Blue oaks are the most drought tolerant of California's deciduous oaks, due to their thicker, waxy leaves and high water-use efficiency. Trees in mature stands are typically 90 to 100 years old. Note the striking lack of sapling-sized trees in these stands. This recruitment gap is troubling and has led to planting efforts throughout the region. Most of the original native grass species under these oaks have been replaced by annual grasses, such as wild oats and cheatgrass, that have been introduced from other parts of the world.

Native grasses have a symbiotic relationship with oaks in that they draw water from 16 or 18 feet (5–6 m) down in the soil, leaving moisture in the upper soil layers for oak seedling to grow, while introduced grasses draw water from near the surface, starving the oak seedlings of water. Relict stands of native purple needlegrass (California's state grass) are more likely to be found under oak canopies than in the open areas between them. Purple needlegrass and other perennial grasses have deep roots and draw water far down in the soil, while annual grasses draw from the first one or two feet of soil depth and as a result steal moisture from acorn seedlings.

Figure 33. Blue oak.

Figure 34. Pleasants Creek debris plume flooding into Lake Solano. Source: Google Earth Imagery June 2013

The large Tehama Formation cliff to the left (south) was probably cut by those erosive flows. There are several large landslide slumps, as well as large cemented blocks of alluvial cobbles (20–30 feet across) at the base of the cliff.

Mile 5.2 (16.7) [0.8] Intersection of Putah Creek Road and Pleasants Valley Road. TURN right (north) onto Pleasants Valley Road.

Geology: Pleasants Valley Road most likely follows a north-south trending fault (strike-slip or possibly a thrust fault) within the foothills.

Nature: The surrounding landscape is covered by a mix of blue oaks, interior live-oaks, foothill pines (*Pinus sabiniana*) and annual grasslands. These trees don't occur east of here on the floor of the Central Valley because it is too dry there. Note the difference between the open woodland on south-facing slopes, which are drier due to more direct sunlight, and the more densely vegetated north-facing slopes, which are cooler and moister. Rainfall here is already 25% greater (20–25 in. per year) than the Winters area (see Sidebar 7).

History: Pleasants Valley was named after James Marshall Pleasants, who arrived here in 1850 with his son from Kentucky. He was the first settler in Pleasants Valley. Like Wolfskill, he managed fruit orchards of apricots, apples, and pears. Fruit was a major crop in Solano County in the late 19th century and early 20th century, with over a million trees in 1912. Most of the orchard workers initially were Chinese, until the

SIDEBAR 7

Foothill Pine

Foothill pines (also called grey or foothill pines) are recognized from afar by their pale needles and multiple, often curving, trunks. Their heavily spined cones are among the largest and most massive pine cones, with weights exceeding 2 pounds. Foothill pines grow on exposed, dry, rocky slopes at 100–6000 feet (30–1800 m) elevations. They are a California endemic distributed through the foothills of the Coast Ranges and Sierra Nevada. In terms of fire ecology, foothill pine and blue oak woodlands historically burned at intervals of 15 to 30 years. Although foothill pine is highly flammable (because of high resin production) and killed by fire, its thick bark, self-pruned trunks, and rapid post-fire seed regeneration allows the species to survive fires.


Figure 35. Foothill pine.

Chinese Exclusion Act passed. They were gradually replaced by workers from Japan and India by the early 1900s.

Mile 5.6 (16.3) [0.4] (STOP 3)

Top of hill, Putah Tuff. Pull to the side of the road just past a driveway to the right (east) and park safely. Then walk down the hill to see rock layers in the east side of the road cut.

Geology: The layers include river deposits (the Tehama sand and gravels) and layers of 3.3 Ma (million-year-old) Putah Tuff, which is gray-whitish and interlayered with the gravels. These deposits were eroded after they were initially laid down, and subsequently eroded and re-deposited here ("reworked"). The tuffs most likely came from a volcanic eruption from Mount Saint Helena in the northern Napa region.

Tuff (from the Italian tufo) is a type of rock made of volcanic ash ejected from a vent during a volcanic eruption. Following ejection and deposition, the ash is compacted into a solid rock.

The gravel layers represent the earliest valley sediments, with abundant debris derived from the Coast Range. The lowest layers are the oldest. As there is no evidence indicating that they have been overturned, the rocks before you demonstrate the geological Principle of Superposition, with the youngest rocks overlying older rocks.

Also, if you look to the hills to the north, you will see layered gravels and tuffs, very similar to those in this road cut and likely part of the same depositional events. This observation illustrates the Principle of Lateral Continuity.

The red soil between older (lower) and younger (upper) white tuff layers reflects the subtropical climate of Pliocene time about 3.3 Ma—the last time in Earth history when atmospheric CO_2 was as high as now (over 400 ppm). The red color reflects the oxidation of iron-bearing minerals in the soil by intense chemical weathering at that time (see Figure 36).

History: This tuff was quarried on the historic Sackett Ranch, which was located across the road from this stop, on the south side of today's Lake Solano County Park. The stone was used for buildings in Winters during the late 1800s, including in the construction of Wolfskill's house in 1865. The 1884 Stone House at 116 Main Street in Winters, the town's only stone residence, is built of Putah Tuff.

Mile 6.0 (15.9) [0.4] Lake Solano County Park.

On right (east). Public restrooms, picnic area, campground, boat launch ramp. Parking permit required.

Geology: The park offers a short walk in its upland areas, and this provides a closer look at the Tehama Formation. At the entrance to the picnic area, take the right fork to climb up onto the older stream terrace. Near the large building on the south side of the parking lot is a trail that leads to the higher sur-

Figure 36. Putah Tuff (Mile 5.6). The tuff is the thicker, more cohesive unit. The red layer between the white tuff layers in the upper view is a paleosoil that formed and was intensely weathered 3 million years ago.

SIDEBAR 8

Sea Level and Climate Change

When the Putah Tuff layers were deposited in the Pliocene, the planet was roughly 5.4–7.2° Fahrenheit warmer than today, global sea level was 80 feet (25 m) higher, and CO_2 levels were 400 parts per million (ppm). CO_2 dropped during the Pleistocene and remained below 300 ppm until the mid-1900s. Because of recent human activity, CO_2 levels have now dramatically returned to the Pliocene levels for the first time in 800,000 years. This accelerated climate change is likely to return us to a similar climate as the Pliocene. California has already been experiencing the effects of climate change, which includes less mountain snowpack, more summer droughts, more catastrophic wildfires, and increased sea level (rising more than 8 in. since 1900). With an increase of just a few feet in sea level, much of the Sacramento–San Joaquin Delta will become an extension of San Francisco Bay, shutting down the current water transfer system between northern and southern California. If human behavior does not change, these shifts will continue to worsen and greatly affect Californians' quality of life.

face of the Tehama Formation alluvial fan. This trail provides a close-up of the many different stream-deposited rocks in the Tehama Formation (cherts, volcanics, sandstones, and granite) as well as loose pieces of Putah Tuff. (see Sidebar 8).

Nature: The nature center on the west side of Pleasants Valley Road is well worth a visit, and birding groups have found that the area is great for birding. Visitors often see unusual birds, such as phainopepla and pileated woodpeckers, as well as various ducks, egrets, and geese. A group of non-native peacocks, most likely brought from India, have also made themselves at home in the park (see Figure 37).

Mile 6.1 (15.8) [0.1] Intersection of Pleasants Valley Road with CA-128. TURN left (west).

The bridge crossing Lake Solano (and Putah Creek) also crosses the Yolo-Solano county line, and the route is now back in Yolo County. As you drive west, note the layers of Putah Tuff and Tehama gravels in the roadcuts along this section of the highway.

Mile 6.6 (15.3) [0.5] Positas Road (PMP 4.25).

There is a small turnout (max 3 cars) on the right (north) side at Positas Road that again shows the Putah Tuff.

Geology: While no longer continuously exposed, the layers demonstrate general lateral continuity with the layers that we have seen at the previous stop. From here west, the tuff unit

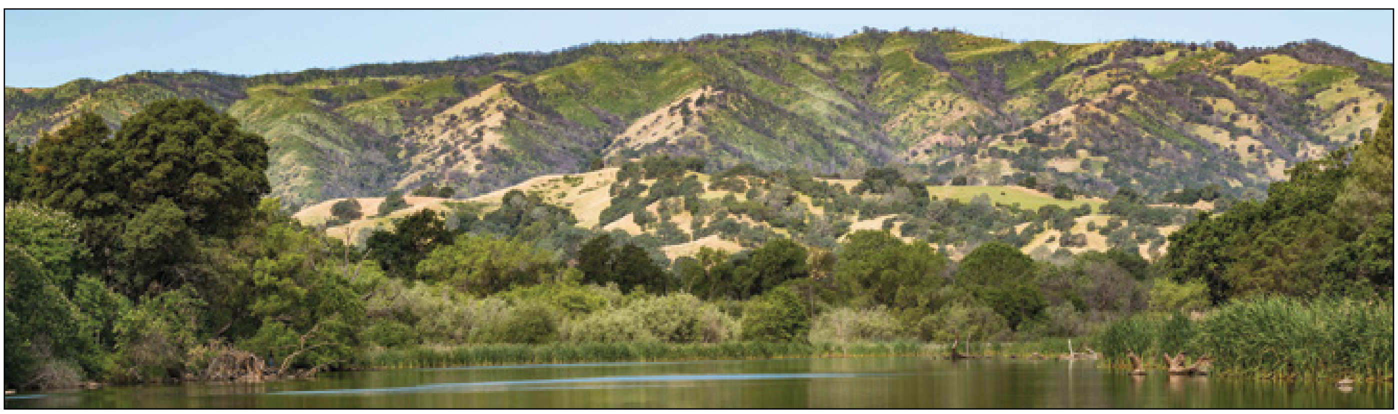

Figure 37. Lake Solano, looking upstream (west) from the Putah Creek Bridge (Mile 15.9). The low yellowish grassy hills in the mid-distance are the Eocene Markely and Nortonville formations, which do not outcrop north of Putah Creek. The higher hills are the youngest Great Valley Group sediments (Forbes and Guinda) in the region. Note the sharp vegetative difference between south-facing slopes (dry, exposed, with grasslands and blue-oak woodland) and north-facing slopes (moister, with live oak, hardwood forests and denser chaparral).

Figure 38. Putah Tuff at Mile 6.6. The tuff is the bare rock layer halfway up the slope, with Tehama sand and gravel beds above and below. The tilting indicated continued east-west compressive forces after the end of subduction. Eldridge probably wished that was his car.

slopes upwards, exposing the gravel and sand layers of the underlying Tehama Formation (see Figure 38).

Nature: The area ahead of you and in Putah Creek Canyon shows evidence of having been burned multiple times in recent decades, notably four times between 2014 and 2019. Look for burned skeletons of trees and shrubs with burn scars on their trunks. Fires are often started from careless smokers driving along the highway. Be particularly careful during dry times of the year along this drive.

Mile 7.4 (14.5) [0.8] Putah Creek Fishing Access #4 (PMP 3.19).

Public restrooms, parking lot, native plant restoration area, kiosk, numerous picnic tables, a fishing/viewing platform, interpretive nature panels, rural hiking trails, and river access.

Geology: The landscape opens up considerably here as the road passes through a large, more easily eroded shale unit, known locally as the Forbes Shale Formation. It is the youngest unit of the GVG (83–78 Ma) and was deposited as the outer part of a submarine fan. High on the slopes to the north, about 300–400 feet (90–120 m) above the road, is a thick resistant (less easily eroded) layer of overtopping Tehama Formation.

To the south, across the creek, are the only Eocene formations exposed on the tour. The 400–500 feet (120–150 m) high ridge that heads south from Putah Creek is formed by the Markley Sandstone, a 3700 feet (1130 m) thick unit that was deposited as part of a submarine fan about 40 Ma in the middle Eocene. The small valley west of this ridge exposes the older Nortonville Shale and Capay Formation from the early Eocene, about 50 Ma. These beds were deposited in a seafloor basin at more than 6000 feet (1800 m) deep that was gradually filled by the overlying Markley Sandstone. Although most other formations along the west side of the valley extend for long distances, these Eocene beds probably do not extend north of Putah Creek.

In this general area, and about 5 miles (8–9 km) below the surface, is the leading edge of the tectonic wedge that underlies much of the crust between here and the ocean (see Figure 20). The upper parts of this wedge are being thrust eastwards along a regional system of structurally segmented, west-dipping, "blind" thrust faults (the Great Valley Thrust Fault System Great Valley Ophiolite). These are called "blind" faults because no surface breaks have been found and the growing fault may not have yet reached the surface. This buried fault system is steeply dipping along the eastern edge of the Coast Range, and extends more shallowly across the Central Valley floor.

Two distinct segments of this fault system are found here. South of Putah Creek is the Gordon Valley Thrust Fault segment, which extends south to Vacaville. The Trout Creek Thrust Fault segment is to the north, extending north towards Cache Creek. The southern segment lies half a mile (0.8 km) deeper and extends 2–3 miles (3–5 km) more to the east than the northern segment. It is also thrust under the northern one, reflecting northeast-trending continent-scale compressional forces. This offset is directly underneath the full length of Putah Creek Canyon, perhaps explaining why the creek eroded here and not elsewhere. The much deeper Trout Creek Thrust segment could also explain why the Eocene beds do not occur north of Putah Creek—they may be much more deeply buried.

As you continue west, the trip passes from Putah Creek Valley into the narrowing confines of Putah Creek Canyon. Look for steeply tilted rock beds of sandstone and shale from the Great Valley Group that have been folded up in the past few million years by compression along the Pacific-North American plate boundary. The sandstone layers form ridges, whereas the shales erode more rapidly, creating valleys.

Recreation: This is the first of several fishing access points along Putah Creek below Monticello Dam. This reach of Putah Creek is a nationally known cold-water fly fishing stream that is classified as a State Wild Trout Stream, the only one in the San Francisco Bay and Delta area. The sites are managed by Yolo County under a long-term lease with the California Department of Fish and Wildlife.

Continue west on CA-128.

Mile 8.5 (13.4) [1.1] (STOP 4) Mouth of Putah Creek Canyon (PMP 2.32).

Pull off carefully to the left or right. Be very careful because of traffic.

This stop, at the boundary between the Central Valley and the Coast Range, has several interesting features.

Geology:

- Geological uplift: The Blue Ridge mountains to the west are the eastern edge of the Coast Range, a 60–70 miles-wide set of north-south trending ridges ranging from 2000–4000 feet (600–1200 m) high. The first ridge of the canyon ahead is made of the youngest beds of the GVG (80–76 Ma). These beds, and the older ones upstream to the west in Putah Creek Canyon, were uplifted and tilted starting as early as 90–80 Ma. However, they probably remained below sea level until the Miocene (20–15 Ma). The uplift has been ongoing ever since, with several periods of uplift that persists to the current day. For example, the relatively younger alluvial fan (3.4 to 1.0-Ma Tehama Formation) is modestly tilted 4–8 degrees, allowing Putah Creek to carve a 400–500 feet (120–150 m) deep channel through the fan.
- 15–20 million-year-old Putah Creek: Putah Creek has eroded an open west-to-east path for itself directly through the range. This is remarkable because most creeks flow downhill and around obstacles, such as mountains and ridges. The creek is considered an antecedent stream, that is, one that is older than the uplift of the range. In other words, the creek formed as the folded Coast Range began to rise above sea level. It was able to cut down through the layers as the range rose higher. That means that the uplift of the ranges is pretty recent, and still active.
- Millions of years of sediments gone: The more gentle slopes to the north and northeast of this stop are, from west to east, 83–78 Ma Forbes Shale Formation overlaid by Lovejoy Basalt (15 Ma) and Tehama Formation and Putah Tuff (3.4–1.0 Ma). Across the creek to the southeast are beds of Eocene sediments: Capay Formation, Nortonville Shale, and Markley Sandstone (56 to 33.9 Ma).

The direct contact of the much older Forbes Shale and the younger Lovejoy Basalt reveals a gap of 63–68 million years in the geological record. Such gaps (known as "unconformities" because the layers do not conform to each other) happen when land is uplifted and the overlying layers are eroded away. At some point, deposition restarts, whether it be from a lava flow, river deposits, or renewed submarine conditions. In this case, any younger parts of the Forbes Shale, as well as any subsequent overlying layers, were eroded, leaving a long gap where no rocks were deposited until the area was covered by the Lovejoy Basalt. The top of the Lovejoy Basalt was also eroded, resulting in a gap of 12–14 million years prior to Tehama deposition.

- Large earth flow: On the creek side of the road note the large black boulder under the tree, as well as other similar rocks in the creek below and up on the hillside to the northeast. All the black boulders have broken off from a basalt flow, the Lovejoy Basalt (see Sidebar 9) that is visible to the north higher up the hill. This is an old landslide or earth flow in the Forbes Shale, about 70 acres. The headwall of the slide is about 400 feet (120 m) above the road to the north. The surface of the slide is eroded by multiple gullies and more recent landslides, indicating its age. You can see multiple basalt boulders scattered on the lower slopes, extending all the way down, and into, the creek. Not readily visible due to grass cover

SIDEBAR 9

Lovejoy Basalt

The black basalt lava flows on the hillside are 14–15 Ma in age, based on radioactive element analysis. The volcanic basalt flows most likely came from the Thompson Peak area (near Susanville, CA), from which lavas flowed to this location and further south as well—a distance of about 150 miles (240 km)!

The flows had to be highly fluid and well insulated to keep lava molten for such a distance. The basalt erupted up to 15 times, flowing down an ancestral canyon in the Sierra over several hundred years and spreading out to cover 2000 square miles of the Sierra foothills and Sacramento Valley.The basalt occurs both north and south of Putah Creek, in Bobcat Ranch and Putnam Peak, respectively. At Putnam Peak, there are two distinct layers, totaling 300–400 feet (90–120 m) thick. Therefore the basalt flowed across Putah Creek (which existed at the time) twice. Both outcrops near Putah Creek are approximately 800–1000 feet (240–300 m) higher in elevation than the Sacramento River, which flows needed to cross from the eastside source, suggesting that this unit has been uplifted that high in the last 15 million years (see Figure 40).

This basalt is similar in composition to lavas in eastern Oregon, southern Idaho, and Yellowstone National Park, as well as those that make up Thompson Peak. It may be the southernmost extent of lava deposits typically found in eastern Washington and Oregon that were the products of the early Yellowstone hotspot.

Figure 39. Earthflow of Lovejoy Basalt (Mile 8.5). Looking south across Putah Creek towards Pleasants Valley. The ground beneath the grasses is rich in basalt cobbles and fragments. The entire earthflow has slumped from the ridge north of here.

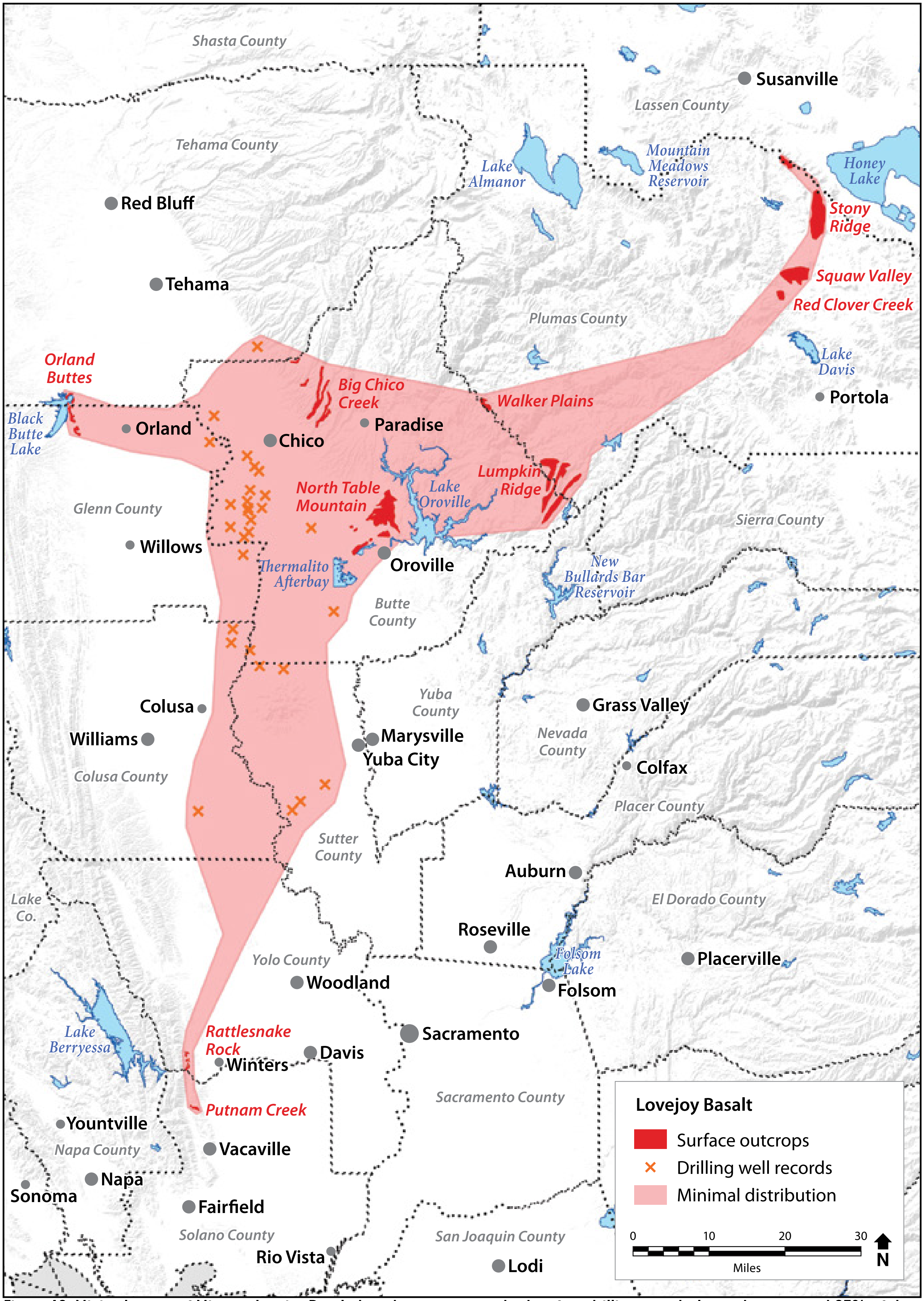

Figure 40. Minimal extent of Miocene Lovejoy Basalt, based on outcrops and subsurface drilling records. It may have covered 25% of the Sacramento Valley at one time. Sources: Durrell 1959, Garrison et al. 2008, Siegel 1988.

is the extensive, partially buried basalt talus across these lower slopes.

Underneath this landslide, and visible in the deeper wooded canyons nearby, is the Tehama Formation, with interbedded whitish outcrops of Putah Tuff, and the Forbes Shale. The shale, being less stable, frequently slumps or slides downhill, carrying the basalt and other overlying materials downhill.

Some of the boulders in the area may have detached and rolled down the hill during the Vacaville-Winters earthquakes of 1892: "Rocks of 50 tons came down the mountain a distance of 500 or 1000 feet, crashed through the pines over the road and into the creek, to join many other like bowlders, that proceeded them many centuries before from like causes." -S.B. Dunton of Winters, Woodland Mail, April 26, 1892.

Nature: The vegetation on slopes of Putah Creek Canyon strongly reflect the environmental differences between the hotter, drier south-facing slopes, with mostly grassland and blue oak woodland, and the cooler, moister north-facing slopes. These north-facing slopes support a mixed forest of interior live-oak, California buckeye, and California bay. Lower montane chaparral occurs in patches on both sides of the canyon, supporting chamise, manzanita, and wedgeleaf ceanothus.

History: Putah Creek Canyon was a difficult route to cross until 1858. Before then, people in Berryessa Valley were much more connected to Napa Valley than the Sacramento Valley. Travel through the canyon was on foot or horseback.

The canyon played an interesting role in the Bear Flag Revolt, which lead to California's admission to the United States. Palmer's 1881 History of Napa and Lake Counties described how, in 1846, advance scouts of John Fremont's California Battalion passed through here, on their way between Sutter's Fort (Sacramento) and Napa Valley, "to avoid being seen by the Mexicans . . . [and] thus arousing their suspicions" regarding the coming Bear Flag Revolt.

Adam See opened the Putah Creek Turnpike in 1858 in the canyon and charged tolls until 1875. The Daily Alta California newspaper reported in 1875 that he enforced his "demands for toll with a double-barreled shotgun, [and] few ever disputed his claims." This turnpike was replaced by a toll-free county road in 1875, originally just a bed for a never-built railroad.

Conservation Lands: The north side of the road marks the southern boundary of the Bobcat Ranch, a 6800-acre working cattle ranch, now owned by Audubon California. This ranch is an example of protecting important habitat and wildlife connectivity while continuing agricultural use of the land. Active restoration there seeks to increase recruitment of blue oaks and native perennial grasses. Across the canyon to the south is the 196-acre Cahill Riparian Reserve, donated in 2016 to the UC Davis Natural Reserve System. This new addition puts almost the entire Putah Creek Canyon into public or conservation land status.

Carefully get back on the highway and continue west.

As you drive west, watch for steeply dipping layers that are 100–80 Ma sedimentary rocks that are part of the Great Valley Group. Between here and Monticello Dam, the canyon exposes 4.5 miles (7 km) of sediments that are one of the thickest continuous cross-sections of Mesozoic sediments in California. The youngest beds, at the entrance to the canyon, are about 80 Ma, increasing in age to 100 Ma at Monticello Dam.

Mile 8.7 (13.2) [0.2] Putah Creek Fishing Access #3 (PMP 2.07).

The west side of the park contains a parking area, restrooms, picnic areas, a kiosk, native plant restoration areas, a fishing platform, and primitive hiking trails. The east side of the park offers a parking area, interpretive nature panels, rural river access, picnic areas, and a universally accessible path to a creek overlook.

Geology: Across the creek is a salt spring on the UC Davis Cahill Riparian Reserve. Several of these salt springs occur in GVG layers in this region. These springs discharge year-round, even during droughts, and exhibit high fluid pressures. Because the GVG layers are of submarine origin, most of the groundwater found in the layers is saline. Tectonic pressure in the region is squeezing the saline groundwater out of the rocks, perhaps from thousands of feet deep along faults. Many of these springs are alkaline and actively precipitating travertine (calcium carbonate). The high pH is created when the saline groundwater encounters fresh peridotite. Chemical reactions which convert the peridotite into serpentinite consume hydrogen ions, thereby enriching the fluid in hydroxide ions and making it more alkaline.

Recreation: Putah Creek, in this reach between Lake Solano and Lake Berryessa, is a California Wild Trout Stream. Cold water flows from the base of Monticello Dam throughout the year, and here we find a wild trout population with lurking large fish. The fly-fishing here is renowned throughout central California, but you need to be well accomplished to be successful. If you choose to fish, there are several fishing guides available that can help your experience.

Mile 9.2 (12.7) [0.5] Putah Creek Fishing Access #1 (PMP 1.11).

Public restrooms, parking area, paved universally accessible upland trails, picnic area, kiosk, interpretive nature panels, a fishing platform, and two universally accessible nature overlook platforms.

Geology: There are good views south across the creek of a massive sandstone ridge of the Great Valley Group that rises up 600 feet (180 m). It contains large (1–2 feet diameter) rounded calcareous concretions that are rich in calcium carbonate, prompting geologists to nickname this area "Cannonball Park" in the 1960s. About 500 feet (150 m) up this sandstone unit is a very narrow arch that is best seen looking eastwards from about 1/4 mile up the highway.

Nature: As the trip proceeds, watch for signs of fire. Fire is part of the ecology of the Coast Range, and with climate change increasing temperatures and three droughts between 2001 and 2016, large areas of the Coast Range have burned. On this route, the Bobcat Ranch, Wragg Canyon, and areas of the mountains along the length of Lake Berryessa have all burned multiple times since 2014 (see Figure 11 and Sidebar 10).

Conservation Lands: The canyon to the west of this ridge is informally known as "Arch Canyon." Both the ridge and Arch

Canyon are on the Putah Creek Wildlife Area, managed by the California Department of Fish and Wildlife. The 673-acre area, established in 1981, consists of gently sloping to steep hillsides of riparian cottonwood forest, blue oak woodland, and chamise chaparral.

Mile 9.8 (12.1) [0.6] Bray Canyon.

Geology: The east slopes of Bray Canyon expose a thick unit of mudstones to the northeast, about 500 feet (150 m) above the road, where there are white-appearing seeps of a spring that is depositing layers of travertine (calcium carbonate). These springs probably are the result of former marine salt water leaking out of Great Valley sediments along a fault under high fluid pressures, and serpentinizing peridotite along its flow path. Another rather hidden and small travertine spring is located next to the highway ¼ mile east of Bray Canyon, where the road bends northwards

The ridge on the west side of Bray Canyon, and extending between here and the Putah Creek bridge, is a massive 4000 feet (1200 m) thick sandstone unit (known locally as the Sites Formation).

Conservation Lands: Bobcat Ranch is north of the highway and the Putah Creek Wildlife Area is south of Putah Creek (see Sidebar 11).

Mile 10.7 (11.2) [0.9] CA-128 Putah Creek bridge.

Parking lot, hiking trails south of the bridge. Excellent view of Monticello Dam from here. Canyon Creek Resort is a member-only private camping resort.

Geology: The eastern slope of Cold Canyon to the south and Thompson Canyon to the north consists of a 500 feet (150 m) thick siltstone/mudstone layer, which contrasts with the massive sandstones on the west slope of these canyons.

Conservation Lands: Note the large parking lots to accommodate hikers in UC Davis's Stebbins Cold Canyon Reserve. The 638-acre reserve, located across the road to the south where the road curves around to the west, includes hiking trails to the south on UC Davis, California Fish and Wildlife, BLM, and Tuleyome lands. A 1 mile trail leads to the ruins of the John Vlahos homestead. Vlahos grazed goats and cattle in the canyon from 1938 until at least 1968. He built a stone cold-room in the shadiest part of the canyon to store cheese and milk, thereby lending the name "Cold Canyon." The University of California bought part of the land in 1979 and the remainder in 1984.

Although established for research purposes, it is one of the closest hiking areas to Winters, Vacaville, and Davis, and the only open-access public land in Putah Creek Canyon. Hikers come from other areas including Woodland, Sacramento, Fairfield, and the Bay Area. It now attracts 50–60,000 visitors per year. The reserve is surrounded on 3 sides by 2700 acres of BLM land that is the southernmost part of the BSMNM.

In addition to Stebbins Cold Canyon Reserve, the University of California manages other regional reserves including Quail Ridge Reserve, a few miles west along CA-128, and McLaughlin Reserve, about 20 miles northwest in Lake

SIDEBAR 10

Putah Creek Canyon Fire History

Since fire records began in 1930, Putah Creek Canyon has seen more wildland fires than anywhere else in the Berryessa Region. This has often been due to careless people driving along CA-128. Seventeen fires have burned in this canyon since 1955, with almost half of those since 2000. The largest was the 1988 Monticello Fire (34,564 acres), which burned most of the Blue Ridge between Putah Creek and Vacaville. The second largest was the Wragg Fire in 2015 (8049 acres), which burned much of the Blue Ridge between Putah Creek and Miller Canyon.

Despite these fires, you still see lots of trees and shrubs. Many of the fires burn in a patchy way, depending on the winds, topography, plant moisture levels, and so on. Even in burned areas, many species are well adapted to quick recovery. Some fires are blown by high winds that force the fire along at a rapid rate, burning only the grasses and toasting the lower tree leaves. But some fires burn very hot and can consume the tree or kill it by scorching all around the base of the tree.

SIDEBAR 11

Chamise

Chamise is a particularly fire-adapted species. It occurs in environments whose fire cycles range from 10 to 100 years. After fires, chamise resprouts and its seeds germinate quickly. It has several features that actually increase its flammability: it contains a lot of waxes, resins, oils, terpenes, and fats; it has many finely divided branches from the ground up to its top; and it retains dead material in its crown. Fires occurring at very short intervals can greatly reduce chamise seed banks in the soil and reduce its ability to resprout from the crown.

Figure 41. Chamise.

Figure 42. Monticello Dam, Lake Berryessa (middle distance) and Cedar Roughs (far distance, beyond lake). The view is looking west from a high ridge on the Stebbins Cold Canyon Reserve. The main ridge on both sides of the dam is Venado Formation. Note the strong vegetative difference between south-facing grassing slopes and north-facing forested slopes.

County. All of these reserves underscore the importance of the biological diversity in the Berryessa Snow Mountain National Monument region.

Mile 11.5 (10.4) [0.8] (STOP 5) Monticello Dam.

The dam is at the border between Yolo County to the northeast, Solano County to the south, and Napa County to the west. Pull off on your right (north), and take time to walk around to view the rocks, Putah Creek, the dam, and the lake. The "Glory Hole" overflow spillway is a well-known landmark. You are now in Napa County and will be in it for the rest of the trip.

This is the narrowest part of Putah Creek Canyon, where the creek cuts through steeply dipping sandstone cliffs, making it the best available location for a large dam (see Figure 42).

Geology: To the south, across the road from the dam, Cretaceous sandstone layers of the Great Valley Group stand almost vertical and are well exposed. The layers continue for miles to the west as one travels back in time to older and older layers. The rock layers at the dam are approximately 100 Ma and of the middle to upper Cretaceous. This is a very resistant, massive, 2000 feet (600 m) thick sandstone unit that forms the crest of the Blue Ridge and the highest elevations in this part of the tour.

It is exposed from near Fairfield north to Glenn County, where it is over 3000 feet (900 m) thick. Unlike older GVG units that will be seen ahead, the Venado is not exposed anywhere west of this ridge. It is an example of turbidites deposited on oceanic crust on a deep abyssal seafloor, located at depths over 10,000 feet (3000 m).

Turbidites are a type of layered sedimentary rock composed of particles that grade upward from coarser to finer sizes; they are thought to have been deposited from ancient slurries of muddy water that flowed down submarine canyons from river deposits on shallow shelf areas to submarine basins. It is thought that these "turbidity currents" were released by episodic earthquakes.

The Venado Sandstone unit here consists of sandstones and shale (mudstones) that were deposited within the inner and middle parts of a submarine fan (see Figures 43 and 44). These fans are built up over time by frequent turbidity currents, which both carry suspended sediments and disrupt existing loose sediments in their paths. The highest-velocity parts of these currents carry lots of sand particles and carve channels into the existing fan surface. These currents also carry suspended mud particles, which drift out to the sides of the main sandy channel and farther out to the distant edge of the fan. Subsequent turbidity currents often go in different directions, distributing sediments over other parts of the fan. These create sand-rich main channels elsewhere, depositing new sand on top of existing sand or mud. The new suspension of mud may be deposited on older sand channels or mud deposits.

Figure 43. Venado Sandstone at Monticello Dam (Mile 11.5). Note the alternating massive sandstone units and thinner shale beds of the submarine fan.

This back-and-forth shifting of consecutive turbidity currents gradually builds up alternating layers of sandstone and shale, as seen in this outcrop.

These cliffs are one of the best examples of such submarine formations that are exposed on land in North America and maybe in the world. Oil companies fly drilling teams in here to better understand deep ocean sediments. DON'T CROSS THE ROAD to look at them close up. There is no safe shoulder here and fast-moving cars often whip around the winding curves in the road.

The rock layers continue on the north side of Lake Berryessa, across the canyon, providing another example of lateral continuity, although these layers are all standing almost vertically.

If you walk west (very carefully while watching traffic) about a quarter mile along the sidewalk and then along the side of the road to the end of the low road barrier fence, and look south across the road, you will be able to see a very distinctive jumbled, chaotic rock layer—called a sedimentary "mélange"—with chunks of sediment and rounder boulders with river gravels on top. This unit probably was due to landslide slumping off the continental slope to the ocean floor.

If you look above the exposure of mélange, you can see a layer of gravel on top. These coarse sediments were deposited in the ancestral Putah Creek and were left behind as the active creek cut down into the GVG layers concurrent with tectonic uplift of the Blue Ridge.

Nature: Looking down-canyon, notice the contrast between the much drier south-facing slopes (blue oak woodlands) and north-facing slopes (mixed hardwood forest).

The hills on both sides of the canyon have many dead trees. The south side of the canyon burned during the summer of 2015 in the Wragg Fire, apparently started by a car parked in dry grass. (Be careful!) This area also burned in 1988 and 1957.

The north side of the canyon burned during the summer of 2018, as part of the "County Fire" that started 20 miles (30 km) to the north near Capay Valley. This fire was the most ex-

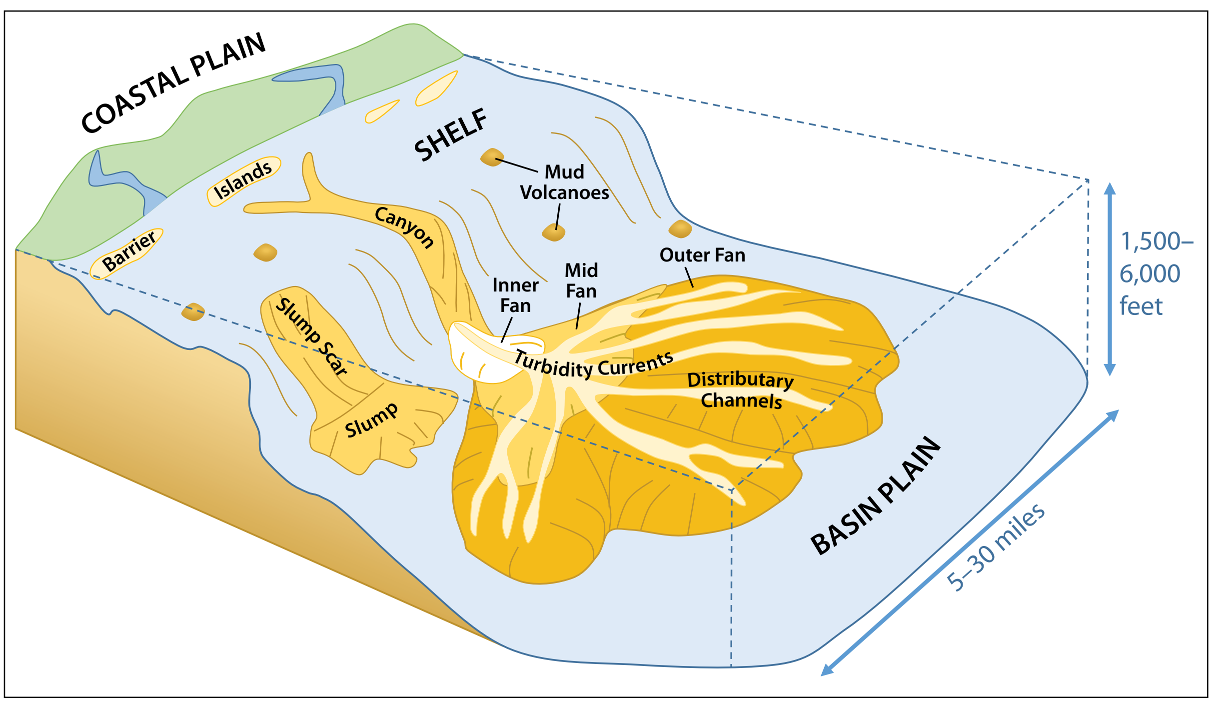

Figure 44. 3-D perspective model of a submarine fan. The dotted blue line indicates sea level. In addition to the main submarine fan, GVG sediments can also form from slumps off the continental shelf. Mud volcanoes also form in this zone, bringing deeper serpentine and Franciscan rocks to the surface. Source: Richards et al. 1998, Deville 2009.

tensive conflagration in the Berryessa Region in the past 100 years, burning 140 mi^2 (100 km^2) of the Blue Ridge. Prior to this fire, the north side of the canyon had been hit with a series of almost annual burns between 2014 and 2018. This frequency is not the normal fire regime for this area. With climate change causing increased aridity, the greater region experiences more frequent and larger fires.

History: Between 1858 and 1875, Devil's Gate was the toll-gate for the Putah Creek Turnpike toll road. Early travelers reported a sulphur spring in the vicinity, suggestive "of brimstone and things not all that pleasant to contemplate" and thereby prompting the satanic name of the area.

The sandstone in Putah Creek Canyon was used as early as 1846 as grinding stones by local gristmills (See Sidebar 21: Joseph Chiles and William Baldridge). By 1882, the Putah Creek (or Bertholet) Quarry was a commercial sandstone operation on the north side of the canyon at Devil's Gate. The 1890 State Mineralogist report described it as the only active quarry in Yolo County at the time, but operations stopped by 1908. The rock is "compact sandstone of various shades of blue and gray" and was used "for many years for local cemeteries and buildings." The stone was used for monuments in the Winters Cemetery, the 1884 Stone House at 116 Main Street in Winters, the 1892 Benoit Bertholet building at 26 Main Street in Winters, and the 1895 Michael building on Main Street in Woodland.

The origin of the name "Napa" is uncertain. No such word has been found in the Patwin, Wappo, or Miwok languages, and no village of that name has been located in the region.

Water: The history of Monticello Dam and Lake Berryessa is described above in the Introduction. Built by the Bureau of Reclamation, the reservoir holds 1.6 million acre-feet (2 billion m^3) and is famous for the "Glory Hole" that releases waters when the reservoir level is high. The funnel, called a morning glory or bell-mouth spillway, is 72 feet in diameter, and has a pipe with a straight drop of 200 feet. The Glory Hole diameter shrinks down to about 28 feet toward the bottom. The spillway has a maximum capacity of 48,000 cubic feet (1360 m^3) per second. In 2017, after heavy rains, the water started flowing for the first time since 2006, and flowed again in 2019 (see Figure 45).

The lake provides for water recreation as well as supplying agricultural and municipal water to the North Bay region of the San Francisco Bay Area, especially Solano County, and a minor amount to UC Davis.

Continue driving west. As you drive west you will travel geologically back in time and pass through older and older layers of the Great Valley Group.

Mile 12.2 (9.7) [0.7] Thin-layered shale beds.

Geology: As you drive southwest from the dam, the road winds through a series of road cuts. These road cuts show older GVG rocks that are more dominated by shale, instead of sandstone. These thin-layered shale beds (100–94 Ma, locally called the Boxer Formation) that are part of the older GVG. They are approximately 6000 feet (1800 m) thick and are exposed extensively on the upper west slope of the Blue Ridge from near Fairfield to north of Berryessa Peak.

The shale indicates an environment in which turbidity currents had lost most of their velocity, and were incapable of carrying sand, such as at the far distal ends of submarine fans. Intermixed with these shales are sandstone beds that may represent higher-velocity distribution channels within the fan. These shales have been interpreted as a mid-fan or basal slope deposit because of lack of lateral continuity in the sandstone beds. These rocks are substantially older than the middle/inner fan deposits at the dam less than a mile away. This suggests that the depositional environment of this general area changed over time, from the far edge of a fan to the higher-velocity center of the fan, where turbidity currents are still strong enough to carry sand. This could happen if the sea level shallowed, possibly due to regional uplift.

Figure 45. Morning glory spillway at Monticello Dam. Water spills over its lip when the lake reaches 1,602,000 acre feet and a reservoir elevation of 440 feet above sea level. This has occurred about 18 times since 1970, the most recent in February 2019. Although this averages every 2–3 years, it has been common to have 7–13 year gaps with no overflow.

Figure 46. Thin-layered shale beds of Boxer Formation (Mile 12.2). The sandstone beds here are fewer and thinner than at Monticello Dam, suggesting a mid-fan or basal slope deposit with lower velocity turbidity currents.

SIDEBAR 12

Measuring Tilt (Dip) of Bedding

Geologists measure dip by first marking a horizontal line across the rock surface (strike) and then measuring the acute angle perpendicular to this line. Road cuts here that are oriented north-south are parallel to the strike and therefore appear horizontal. Road cuts oriented east-west are mostly perpendicular to the strike and therefore represent the true dip of the formation.

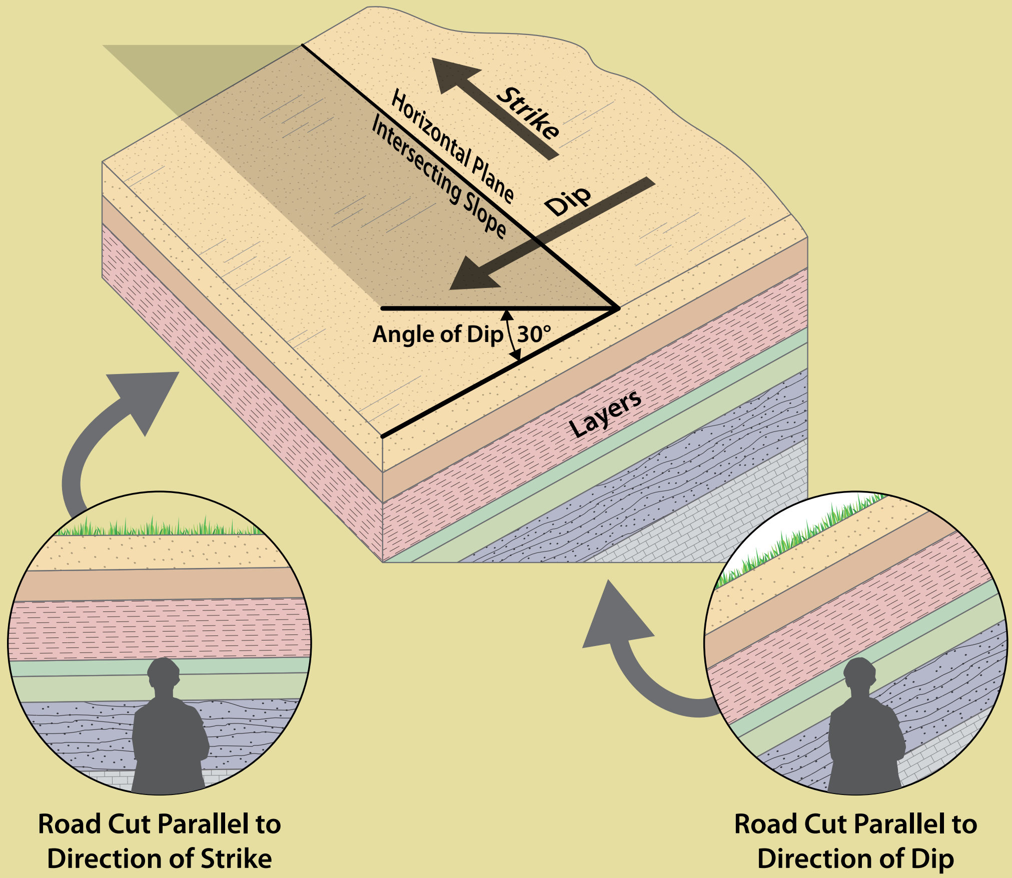

Figure 47. One's perspective about bed tilting depends on the angle of view.

These road cuts illustrate two important aspects of interpreting geology in the field. As you pass through sections with road cuts on both sides, note that the bedding and rock types are roughly the same to the left and right. These road cuts help illustrate the principle of lateral continuity, with the formations occurring on both sides of the road. Even though the cut is recent, it separates exposures of the same formation, as does erosion caused by streams and rivers (see Figure 46).

These steeply tilted beds, combined with the multiple view angles along the road, also show the value of using a standard approach for describing the tilt (or dip) of sedimentary formations that is independent of the road cut's orientation (see Sidebar 12: Measuring Tilt). Even though the beds consistently dip steeply to the east, the views from the road show horizontal bedding in some cuts, yet steeply tilted in others. In reality, the beds are mostly uniformly tilted, but it's your perspective that changes (see Sidebar 12).

Mile 13.7 (8.2) [1.5] Markley Cove Resort (approx. PMP 32.1).

One of the concessionaires located on Lake Berryessa, the resort has a store, cabins, a marina, and a boat launch ramp.

Geology: The road ahead climbs a 500 feet high (150 m) ridge consisting of moderately sheared and disrupted Cretaceous or Jurassic age sandstone and shale, with large lenses of basalt breccia. This is a winding road that is frequented by bicyclists, so watch for them and please share the road. The climb has long been known as "Cardiac Hill" because it gets the bicyclists' pulses cranking during their climb. The rocks along this climb are an older part of the lower GVG (locally known as the Lodoga Formation). It is exposed extensively north of here along the eastern shore of Lake Berryessa, as well as south of here toward Gordon Valley. The deformation indicates either multiple thrust fault events or submarine landslides, such as near the toe of the continental shelf.

History: The Patwin village of Puta'to was located in this area. It may have been the source of the name Putah given to the creek.

William Markley had a ranch in this canyon during the 1860–1870s. Little is known about him, other than that his Patwin housekeeper, Katie Ennis, while tending the house during Markley's long visits away from home, was shot and killed by Alonzo Davis, a 13-year-old white boy. Probably typical of judicial bias at the time, Davis was found not guilty by a jury of men, which included Joseph B. Chiles.

Mile 15.4 (6.5) [1.7] Entrance to UC Davis Quail Ridge Reserve on right (north) (approx. PMP 30.4).

Geology: The entrance to the reserve is at the top of the pass between Markley Canyon and Wragg Canyon. The tilted thin-layered shale units in the road cuts just before the pass are still the same 100–94 Ma beds in the Boxer Formation you have been driving through since Monticello Dam.

Conservation Lands: Quail Ridge Reserve is the third reserve managed by the University of California, Davis that is encountered as part of the tour. A 2000-acre reserve, it protects Coast Range habitat for research, teaching, and outreach. The reserve is a unique partnership between the University and the Bureau of Land Management, the California Department of Fish and Wildlife, the Bureau of Reclamation, and the Quail Ridge Wilderness Conservancy. The reserve is open for pre-arranged visits only.

The road now descends 600 feet (180 m) through a series of curves to the bottom of Wragg Canyon. The slopes on the west side of this ridge are predominantly mudstone and shale dated at 115–95 Ma.

Mile 15.9 (6.0) [0.5] View of Wragg Canyon.

Geology: At the bottom of Wragg Canyon in front of you is the Wragg Canyon Fault, part of the Wragg Canyon–Bartlett Springs detachment system consisting of Paleogene thrust faults that are oriented along bedding planes. This fault has been mapped north from here along the east side of Lake Berryessa and beyond, towards Bartlett Springs. Thrusting by the Wragg Canyon Fault has moved older GVG beds on top of younger GVG beds here. Thus, the GVG sequence we've been travelling through since Monticello Dam is roughly the same sequence, duplicated, that we will drive through again from Wragg Canyon to Moskowite Corner (see Figure A-2 for detailed geology map of this area).

History: James Ohio Patti, a Frenchman, was the first settler in Rag (Wragg) Canyon, and he was the only resident until Andrew J. Raney arrived in 1853. An earlier settler, Frank Owen, wrote in his undated memoir that the original "Rag" name referred to "the shreds of clothing left on the chaparral by the first explorers." The lower and wider part of Wragg Canyon is called Cherry Valley, where local farmers grew cherry orchards in the late 19th century (see Sidebar 13).

Mile 17.8 (4.1) [1.9] Wragg Canyon Road on right (west) (approx. PMP 28.0).

3.2 miles down this side road is Pleasure Cove Marina. Commercial campground, store, boat launch, and cabin rentals.

Geology: Ahead in the next mile, the road takes several gentle turns as the canyon floor weaves through several steeply dipping units of the GVG.

Mile 19.2 (2.7) [1.4] Leaving Wragg Canyon (approx. PMP 26.7).

CA-128 turns sharply west-northwest again and travels along the upper part of Wragg Creek towards Capell Valley.

Geology: The upper part of Wragg Creek ahead follows a branch trace of the Putah Creek Thrust Fault.

At the south end of Wragg Canyon, the Wragg Canyon Fault intersects the Putah Creek Thrust Fault. We've been travelling south along the Wragg Canyon Fault, and now we begin to travel northwest along a canyon formed by this other thrust fault. Both faults are part of the same Wragg Canyon–Bartlett Springs detachment system described above at Mile 15.9.

The Putah Creek Thrust Fault in this northwest-trending canyon also overlaps the course of the younger Berryessa Fault, a strike-slip fault that is part of the Green Valley Fault system. The active Green Valley Fault is creeping 0.04–0.15 in. per year. Geological evidence shows that, during the past 2000 years, it has experienced at least 4 earthquakes with estimated magnitudes of about 7. The Green Valley fault system represents the easternmost active strand of the more extensive San Andreas Fault System at this latitude.

SIDEBAR 13

Lace Lichen and Fog

In Wragg Canyon, watch for the long stringy green growth hanging from tree branches known as lace lichen. Californians have called this plant "Spanish moss" since Americans first arrived in California. It's likely that early pioneers assumed it was the same Spanish moss they saw while crossing the Isthmus of Panama (where true Spanish moss grows) on their way from the East Coast. True Spanish moss is not a moss; it's a flowering plant that lives on the branch of trees in subtropical forests.

Our local version of "Spanish moss" is also not a moss, but rather a lichen. Lichens consist of both algae and fungi that interact intimately and beneficially with each other. Algae photosynthesizes food for the fungus from air and water, and the fungus provides filaments that gather moisture and nutrients and keep the algae from drying out. Even when they grow on trees, they are not parasitic on the tree.

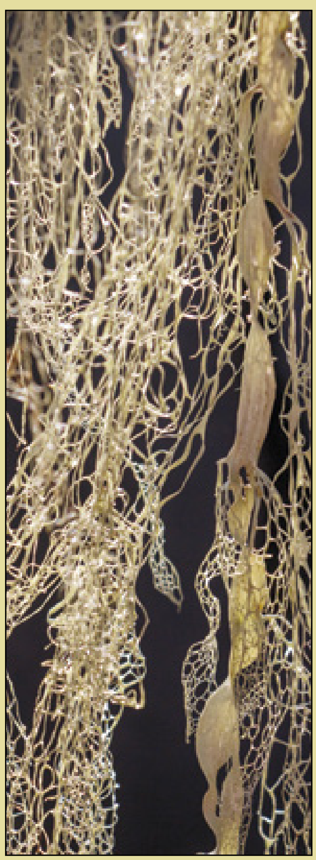

Figure 48. Lace lichen.

This lichen is California's state lichen (in 2016, California became the first state to recognize a lichen as a state symbol). It grows where moist air makes its way into valleys from San Francisco Bay or the Pacific Ocean. It requires an average of at least 2.5 hours of fog per day in summer. East of here, fog is much less frequent, preventing the growth of lace lichen.

If you look around, you'll notice other types of lichens on trees. Beard lichens have shorter pendant strands and lack the intricate lacey structure of lace lichen. These lichens produce usnic acid, which is commercially important as an antibiotic. The greenish-white bushy lichen, with branches in the shape of deer antlers, is oakmoss. It has a distinct odor (described as woody, sharp, and slightly sweet) and is used in modern perfumes.

Nature: This area marks a live-oak transition zone, with interior live-oak to the east and coast live-oak to the west. This east-west transition also occurs across the hills just west of Lake Berryessa. Both of these are trees endemic to California and Baja California and they retain their leaves year-round. Interior live-oak tolerate drier conditions than coast live-oak, which prefers moister sites like north-facing slopes and canyon bottoms.

On north-facing slopes at the southwest of this bend are black oaks. This is the only time they will be easily seen on the tour before Pope Valley. Black oaks tend to prefer cooler and moister areas than other oaks, such as low elevations closer to the coast or at higher elevations (above 1500 feet; 450 m) in the northern Coast Range and the Sierra Nevada.

History: Just south of this sharp bend is a nearby low pass that leads to the headwaters of Suisun Creek. Suisun Creek flows south to Gordon Valley, Fairfield, and Suisun Bay. Historically Suisun Creek and Wragg Canyon provided the main transportation route between Berryessa Valley and Fairfield, but it is no longer a public route.

Mile 20.3 (1.6) [1.1] Drainage divide.

The road crosses a small divide as it leaves the Wragg Creek watershed and enters the Capell Creek watershed. The tour will roughly parallel Capell Creek as it flows north and west towards Lake Berryessa.

Mile 21.3 (0.6) [1.0] Greenstone block (PMP 24.3).

Geology: The volcanic block rising above the road on the left (south) side of the road includes greenstone and chert (a deep ocean silica-rich sediment). The block is in sheared sandstone and shale, a mélange, most likely part of the Franciscan Complex or lower Great Valley deposits. This block may also have been deposited as part of a serpentinite mud volcano (see Figure 22).

This area exposes the oldest rocks of the Great Valley Group (152–126 Ma and locally referred to as Knoxville Formation). It is extensively exposed northwards from here along the west shore of Lake Berryessa. This unit, mostly black shale, is 18,000–20,000 feet (5500–6000 m) thick, and has a much higher concentration of volcanic materials than the GVG beds we've been passing through. The source rocks were mainly the andesitic-dacitic volcanic terrane that initially covered the Sierran-Klamath arc at about the Jurassic-Cretaceous boundary. Since these volcanics eroded first before the underlying Sierran-Klamath granites, they were deposited first in the GVG. This "upside-down" record helps document the Cretaceous nature of the original mountains, with erosion first removing the volcanics overlying granites as the mountains underwent simultaneous uplift and erosion.

Mile 21.9 (0.0) [0.6] "Moskowite Corner" and intersection with CA-121 (approx. PMP 24.0).

Near this intersection is the Moss Creek Winery.

Geology: West of the intersection you can see "Raney Rock," another volcanic block in the mélange. Raney Rock reaches 1261 feet (384 m) in elevation, 400 feet above Capell Valley (see Figure 49).

History: The rock was probably named after Andrew J. Raney, who initially settled in Wragg Canyon in 1853. He eventually purchased a ranch in Capell Valley and moved his family there in 1888. He surveyed roads in the Berryessa Valley and supervised their construction.

A variety of geology road guides have mistakenly called this intersection "Moskowits Corner." But the local papers and the U. S. Census Bureau spell it "Moskowite." And four generations of the Moskowite family have been farming in this area since 1917.

From here, you can continue on the "Moskowite Corner to Turtle Rock" route segment by turning northwest (right) on CA-128.

Moskowite Corner to Turtle Rock

(4.8 miles on CA-128 from CA-121 to Berryessa-Knoxville Road)

Mile 0.0 (4.8) "Moskowite Corner" and intersection of CA-128 and CA-121. (See previous description.)

Head northwest on CA-128.

Mile 0.7 (4.1) [0.7] Capell School. Entering Capell Valley.

Geology: The road parallels the south-plunging Capell Valley syncline. This fold may be a southern extension of the more pronounced Pope-Chiles Valley Syncline to the northwest. The northwest–southeast oriented ridge to the north is formed by the southern end of the south-plunging Trout Creek Anticline. This anticline, named after a 3-mile ridge on the west side of Lake Berryessa, has a core of Franciscan rocks that are exposed near the top of the ridges. The lower slopes around Capell Valley consist of Knoxville sediments with other small greenstone

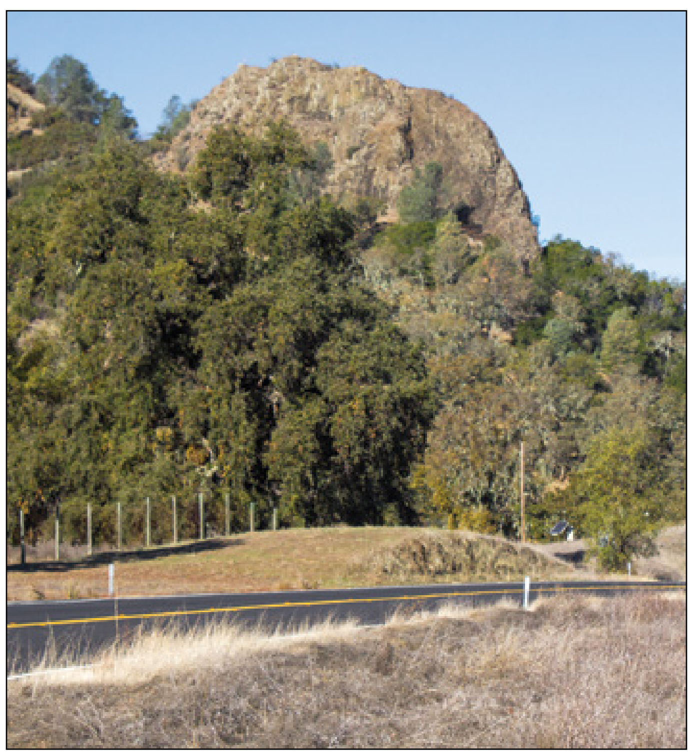

Figure 49. Raney Rock at Moskowite Corner, a large Jurassic volcanic block in the Franciscan mélange.

SIDEBAR 14

Valley Oak

Valley oaks are the largest North American oak and may live over 400 years. They are endemic to California and are distributed at low elevations (below 2000 ft; 600 m) in the Central Valley and other small valleys in the Coast Ranges and Sierra Nevada. They tolerate cool wet winters and hot dry summers, but they do best on deep, moist soils of valley floors. These were also often the first soils cleared by settlers for agriculture, and it is now rare to see extensive groves of this species. From a fire ecology perspective, valley oak woodlands probably burned annually in historic times, producing fast hot fires that were carried by dry grasses. Mature valley oaks are fire-resistant, and acorns buried by animals can survive fires.

Figure 50. Valley oak.

outcrops (see Figure A-2 for detailed geology map of this area).

Nature: Capell Valley, like similar small valleys in the region, has been converted from valley oak savanna to agriculture. The remaining valley oaks are in scattered locations on the valley floor and along the streams.

History: The Patwin name for Capell Creek is To-bi-pa, meaning "running water."

The 1881 History of Napa and Lake Counties reported that oil was discovered at the head of Capell ("Capelle") Valley in 1866, as well as "seams of quite good coal." The Alladin Petroleum Company was organized to do more prospecting, but no great quantities were found (see Sidebar 14).

Mile 2.2 (2.6) [1.5] North end of Capell Valley.

Nature: Note the differences in vegetation on the surrounding hills, which are a mix of serpentine and non-serpentine soils. Red Mountain (elevation 1360 ft; 415 m) to the left (west) is mostly serpentine soils, covered by chaparral and gray

SIDEBAR 15

Serpentine Plants

Serpentine plants are a key feature of California's special biological diversity. California has the largest exposure of serpentine in North America. Even though ultramafic soils cover only about 1% of the state's surface area, these soils support approximately 13% of the state's plant species (176 species, 669 different types including subspecies and varieties). Many of these plant types (295 types) are listed as "rare" or "uncommon" by the California Native Plant Society. Some of these plants are only found on serpentine soils (such as leather oak or western California coffeeberry), some are mostly found on serpentine (McNab and Sargent cypresses), and others are strong indicators of serpentine soils (knobcone pine, huckleberry oak). The North Coast Ranges support more serpentine endemic plants than any other geographic region in the state.

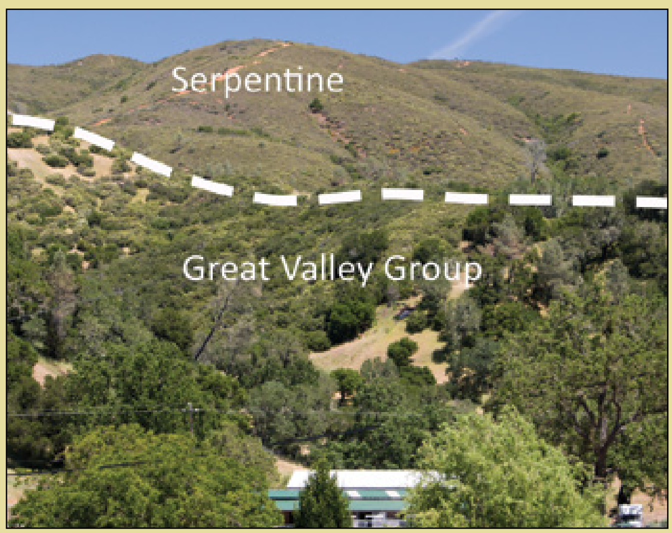

Figure 51. Serpentine soils overlying Great Valley Group sediments (Mile 2.2). Vegetation types are strongly controlled by underlying geology and soils in this area, with chaparral on the serpentine and blue-oak woodland on the GVG formations.

Serpentine vegetation contrasts strongly with adjacent plant cover on non-serpentine soils. Serpentine soils are typically dry, shallow, rocky, and poorly drained. They are high in heavy metals, such as nickel and chromium, that are toxic to most plants. Their magnesium to calcium ratio is extremely high (8:1) compared to sandstone and carbonate soils (1:6). These soils also are low in other important plant nutrients, such as nitrogen, phosphorus, and potassium. Water does not drain readily, leaving soils saturated at depth and leading to landslides and slumps on sloping ground. Plant species that can tolerate these challenging conditions have a variety of adaptations, including modifying chemical uptakes and having leaf forms that reduce water losses.

Road Guide

pine. The peak south of Red Mountain, across an intervening canyon, has the southernmost stand of McNab cypress in Napa County. The lower slopes of these mountains are non-serpentine Knoxville (GVG) soils, with woodlands dominated by blue oaks.

Oak trees (blue, valley, and live-oaks) avoid serpentine soils, whereas serpentine specialists, like leather oak (a scrub species), knobcone pines, and cypresses, can tolerate the chemical imbalances in the soil. Gray pine, like several chaparral plants such as chamise and toyon, actually can grow on both serpentine and non-serpentine soils but they tend to be sparser and stunted on serpentine soils. Many herbaceous species are endemic to serpentine soils (see Sidebar 15).

Mile 3.6 (1.2) [1.4] Capell Creek bridge (PMP 20.23).

Geology: The bridge is situated in serpentinite rocks associated with a fault and/or landslide. This is the closest roadside example of serpentinite to the Winters area. Here a landslide over the next 0.3 miles is shoving the bridge downstream.

This bridge was built in 1956. Slope stability problems were reported by 1965, due to either the landslide-prone serpentinite or local faulting, and landslide monitoring was set up in 1972. A new bridge replaced the older one in 2019 and new horizontal drains were installed to reduce slope movement.

Just up the road, note the white pipes sticking out of the serpentinite roadcut. Serpentine seems like a dry soil type because of the chaparral, but it can hold water well. These pipes flow frequently, even in dry years, to drain water out of the soil and reduce risk of slope failure (see Figure 52).

Nature: Note the low-growing, thick-leaved leather oak along the road. It is indicative of serpentine soils and rarely is found on non-serpentine. Its close relative, the scrub oak, is more common on non-serpentine soils.

Figure 52. Drainage pipes in serpentinite (Mile 3.8). Serpentine soils retain water very well and these drain pipes can flow even in dry years.

Mile 4.8 (0.0) [1.2] (STOP 6) Turtle Rock Bar and Café.

Intersection of CA-128 and Berryessa-Knoxville Road (approx. PMP 19.1). TURN right (northeast) on Berryessa-Knoxville Road towards the shores of Lake Berryessa. Café, store, public restrooms.

Geology: Across the road from the café to the west is a large exposure of "sedimentary" serpentinite—blocks of less sheared serpentinized peridotite and dunite (an olivine-rich, mantle rock) in a sheared serpentinite matrix.

The hillside across the stream to the northwest consists of similar, if more massive, ultramafic rocks. The outcrops in the region are part of a long band of serpentinite that extends about 3.5 miles (5 km) south of here and over 35 miles (55 km) north to Middletown. It has been thrust over middle-aged GVG sediments on its western edge along the Cedar Roughs Thrust Fault, and over older GVG-Knoxville sediments on its eastern edge along the Coast Range Fault. The Cedar Roughs Thrust Fault is one of a series of parallel thrust faults associated with the Wragg Canyon–Bartlett Springs detachment system.

History: Turtle Rock Bar and Café is a small tavern and local landmark that was built in the 1960s and probably named after the former owner Floyd Turtle. Pete Leung, Sr., the current owner, bought the bar in 1981, proclaiming it "Home of the World Famous Egg Rolls." His son Peter, Jr., took over management in 2001. A popular thing to do at the bar is to sign a one-dollar bill and put it on the ceiling, among the hundreds of others hanging there. Peter regularly removes the bills and donates the money to charity. Just below Turtle Rock is the site of the Lake Berryessa Bowl, an outdoor music venue during the late 1960s that hosted many famous rock groups, including Alice Cooper, Santana, and The Grateful Dead.

From here, you can continue on the "Turtle Rock to Pope Canyon" segment, or follow the "Lake Hennessey to Turtle Rock" segment in reverse order.

Turtle Rock to Pope Canyon Road

(13 miles on Berryessa-Knoxville Road from CA-128 to Pope Canyon Road)

Mile 0.0 (13.0) (STOP 6) Turtle Rock Bar and Café.

Intersection of CA-128 and Berryessa-Knoxville Road. (See previous description). TURN right on Berryessa-Knoxville Road.

Mile 0.1 (12.9) [0.1] Serpentinized peridotite.

Note the road cuts in serpentinized peridotite. There is a small pullout on the right downhill from these road cuts. The hill across the stream to the north consists of more massive ultramafic rocks (see Figure A-3 for detailed geology map of this area).

Mile 0.6 (12.4) [0.5] Re-entering Knoxville Formation.

After passing through serpentinite for about half a mile, the road crosses the Trout Creek Anticline between here and Lake Berryessa. The geology here needs more geological field work. It has been mapped both as Knoxville Formation and GVG mélange, though it might instead be Franciscan Formation. The road descends Capell Creek until the creek enters Lake Berryessa. The creek has a healthy riparian habitat consisting of willows, walnuts, and cottonwoods.

Mile 1.5 (11.5) [0.9] Olive Orchard Day Use Area on right (southeast).

Public restrooms. The road crosses the main axis of the Trout Creek Anticline here, exposing narrow zones of Jurassic age pillow basalts and volcanic breccia on both sides of Capell Creek. These volcanics have been altered to greenstone by low-grade ocean-floor metamorphism (see Sidebar 19). More blocks of this basalt-turned-greenstone will be encountered ahead on the west shore of Lake Berryessa.

Mile 2.6 (10.4) [1.1] Capell Cove boat ramp.

Public restrooms, limited picnicking amenities, boat ramp.

Once again you are encountering Lake Berryessa, after a highway detour through various canyons required by the flooding of Berryessa Valley. The road continues north along the reservoir's western shore until the Pope Creek bridge.

Geology: Just east of here was a sandstone quarry used around 1900. Stone from the quarry was used in constructing the Berryessa Road bridge over Putah Creek, now underwater (see note under the Dufer Point Visitor Center, below).

History: At this point, you are entering the former Rancho Las Putas Mexican land grant, which covered most of flooded Berryessa Valley. The rancho was granted in 1843 to José de Jesús and Sexto ("Sisto") Berreyesa. Their father, Nasario Antonio Berreyesa, was the original settler of the Berryessa Valley in the 1830s.

Recreation: Lake Berryessa provides summer water recreation and year-round fishing. The area offers many hiking, birding, and botanical opportunities throughout the year (see Sidebar 16).

Mile 2.9 (10.1) [0.3] GVG-Knoxville/serpentinite contact.

The road makes a sharp bend to the left here, and there is a small pullout on the right. As the road continues north, it alternates between GVG rock and serpentinite, although the contact zone gradually gets higher on the ridge to the left.

Mile 4.2 (8.8) [1.3] Spanish Flat Recreation Area.

Commercial campground, picnic area, and boat launch.

SIDEBAR 16

Berryessa Family and Valley

The Berryessa family was a large clan of Basque-heritage Spanish-speaking settlers in early Northern California who held extensive land in the greater San Francisco Bay Area. Maria Ana Ysabel Berrelleza and her brother Nicolas Antonio arrived in California, at Monterey, as part of the de Anza party in 1776. Although they originally spelled their name Berrelleza, they changed it to Berreyesa and later Berryessa. Nicolas had nine children, who in turn had large families themselves with 12 to 15 children. By the 1840s, the Berryessas were a dominant family in the San Francisco Bay Area, with many large land grants.

One of the first generation was Nazario Antonio Berryessa, who settled in Berryessa Valley with his wife, most (if not all) of his fifteen children, and 100 Native American vaqueros during the late 1830s. For several years, Nasario Antonio ran herds of 5000 cattle and 20,000 horses on this land and over the mountain into what is today Capay Valley. Two of his sons, José de Jesús and Sisto (also Sexto or Sixto), married twin sisters and helped their father with the ranch.

In 1843, Nasario received a land grant of eight square leagues (35,500 acres) in the names of his two sons in and around Berryessa Valley. His nephews received the 40,000-acre land grant in Capay Valley.

The Berryessas' ranch was a successful enterprise for a number of years in the 1840s and 1850s. The family build built three large adobe houses; one was 60 feet long, another 90 feet long. An ugly part of their history was their enslavement of about 150 Patwin as workers on their ranch, as reported by military inspectors in 1854.

Over time, the land was sold off piecemeal during the 1850s and 1860s to pay off gambling and other debts. By then, land developers had bought much of the valley and cut it up into small farms.

In 1858, the Putah Creek Canyon Road, or Turnpike, opened as a new road to connect Clear Lake with Sacramento. In 1867, the valley was full of new American wheat farmers. A newspaper report described it as "an unbroken, waving mass that glistens in the sunlight, and nods and bends, and toys and wrestles, and grows strong in the rustle of the waving breeze."

By 1870, the development of the mercury mines in Knoxville had stimulated traffic enough that the new town of Monticello had a hotel, blacksmith shop, general store, and stagecoach stop.

Sisto was the last Berryessa family member to own land in the valley, and that land was sold in a sheriff's auction in 1860 to settle a $1653 judgment. Sisto lived out the rest of his life in a crude cabin in Steele Canyon. Both he and his brother José de Jesús died in 1874 in their late 50s, and they were buried in Berryessa Valley.

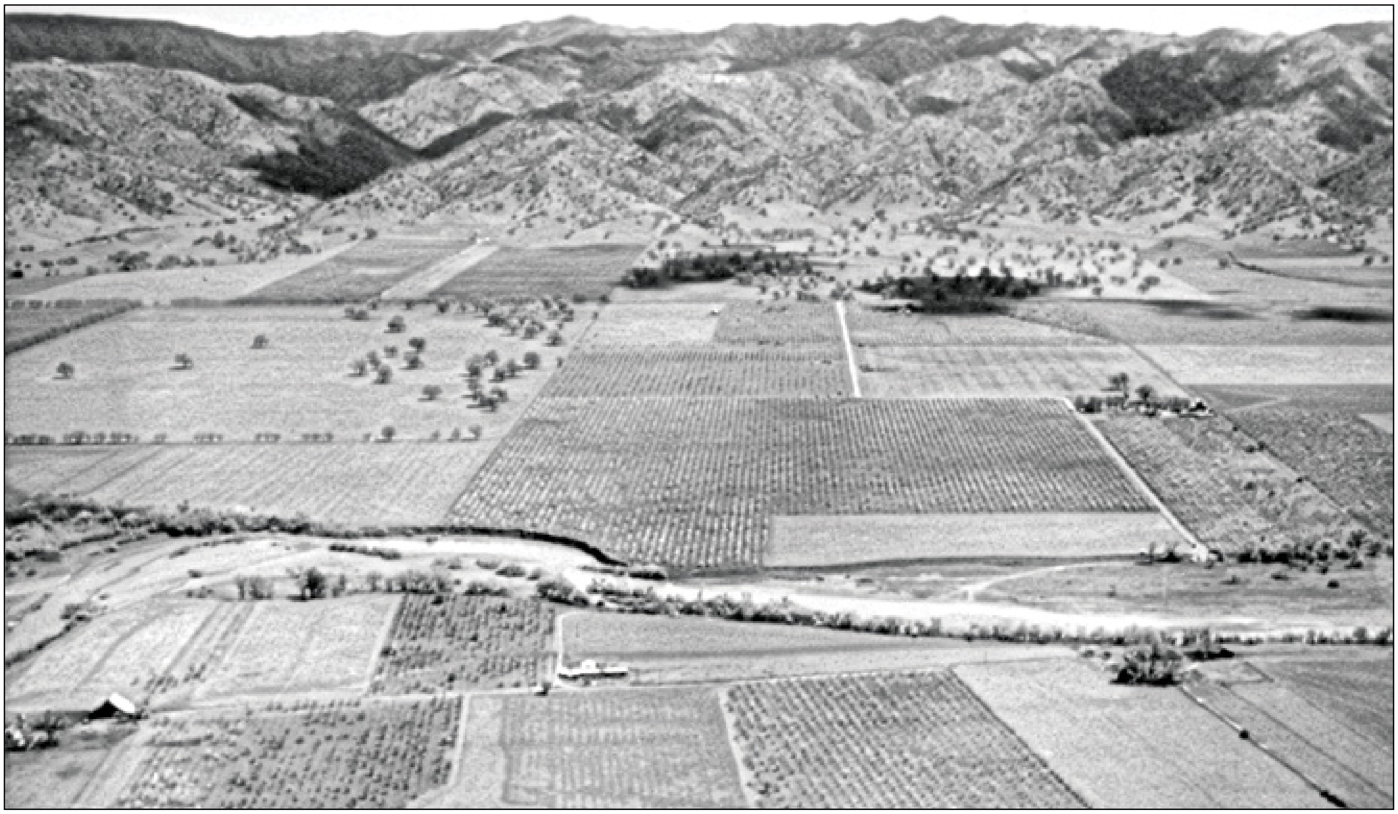

Figure 53. Berryessa Valley in 1950 before flooding. Source: Napa County Historical Society

Mile 5.0 (8.0) [0.8] Spanish Flat.

This is a good place to stop for "home-made" sandwiches at the Spanish Flat Country Store & Deli, or dinner later in the day at Cucina Italiana, an Italian restaurant.

History: East of here, in the now flooded Berryessa Valley, lie the locations of the Patwin village of Chemocu, the home of the Berryessa family, and the town of Monticello, all of which were flooded when the new reservoir filled with water. Berryessa Valley must have been well populated by the Patwin before European settlement; at least 25 archaeological sites were discovered in the early 1900s, scattered throughout the valley.

As described in the Overview, the flooding of Berryessa Valley was controversial. In 1957, Dorothea Lange and Pirkle Jones documented the "death of a valley" and the loss of the town with their photographs. The town's residents were relocated. The graves from the original Monticello Cemetery were exhumed and relocated before the lake was filled with water. The new Monticello Cemetery can be visited at the north end of Spanish Flat Loop Road.

In the deli, ask for free access to the adjacent Berryessa Valley Exhibit on local history where donations are appreciated (see Figure 53).

Mile 6.6 (6.4) [1.6] (STOP 7) Bureau of Reclamation (BOR) Dufer Point Visitor Center.

Public restrooms (open even if the center is closed). BOR manages Lake Berryessa and the public facilities along its shoreline. The visitor center offers both natural and cultural information on Lake Berryessa and the surrounding area, along with a variety of free brochures and maps. Summer hours are Monday through Friday 12 pm–3 pm and weekends 10 am–5 pm. During the winter (early September to late May) the center is only open on weekends 12 pm–3 pm.

Be sure to visit the back deck of the visitor center. It provides a beautiful view of the lake and occasional bald eagle sightings. The deck railing is decorated with tile artwork depicting local history and ecology. The center also has a short self-guided interpretive trail. Vegetation here is blue oak woodland, interior live-oak forests, and patches of chamise chaparral.

Across the lake, the west slopes of the Blue Ridge are the highest elevations encountered on this tour, with Berryessa Peak, at 3057 feet (932 m), rising 2600 feet (800 m) above Lake Berryessa. To the east-southeast, across the lake and several smaller intervening ridges, you can see the Berryessa Gap as a low spot in the Blue Ridge.

Geology: The west side of Lake Berryessa exhibits two parallel, often overlapping, faults that are segments of two much larger fault systems. Along the shoreline is the Putah Creek Thrust Fault, part of a larger set of thrust faults known as the Wragg Canyon–Bartlett Springs detachment system. This system includes the Wragg Canyon Fault (on the east side of the lake), the Cedar Roughs Thrust Fault, and the Pope Valley Thrust Fault (both to the west). These faults are oriented along bedding planes and may have formed as early as 60–50 Ma. The Putah Creek Thrust Fault separates the Trout Creek Anticline from the Mysterious Ridge Anticline, and extends almost to Clear Lake.

Higher on the ridge to the west is the Berryessa Fault, which is part of the San Andreas Fault System. These are much younger, strike-slip faults that occur over a zone 40–60 miles wide. The Berryessa Fault is considered a northerly extension of the Green Valley Fault System.

SIDEBAR 17

Regional Wilderness Areas

Cedar Roughs (6287 acres) and Cache Creek (27,294 acres) Wildernesses were established in 2006, when additions were also made to the Snow Mountain Wilderness (60,076 acres). They are now within the Berryessa Snow Mountain National Monument. The Yuki Wilderness (53,887 acres), also formed in 2006, abuts the northwest corner of the National Monument. These wilderness areas form core areas for protection of habitat and animals. The National Monument helps to protect the wildlife corridors between these core areas.

The Putah Creek Thrust Fault often overlaps the Berryessa Fault at the surface in this area, but they diverge below the surface. The strike-slip faults descend vertically, whereas the east-dipping thrust faults diverge with depth. In several places, these younger strike-slip faults have offset the older thrust faults.

The Mysterious Ridge Anticline plunges southeast into the valley from the northwest, creating a broad exposure of less-resistant GVG mudstones (probably Boxer Formation) responsible for the large flat valley. The ridge crest on the western skyline is formed by the Trout Creek Anticline, which exposes a large area of serpentinite (note its distinctive vegetation of brush, gray pines, and Sargent cypress). These anticlines were uplifted about 55 Ma.

The road continues to pass through exposures of the oldest GVG rocks (Mysterious Valley, Knoxville and Boxer Formations) along the west shore, but there are no good outcrops along the way.

History: Just east of the visitor center, Berryessa Road crossed Putah Creek. The stone bridge, built in 1896 and now underwater, was promoted in newspapers as the "largest stone bridge west of the Rocky Mountains" at the time. Built for less than $20,000, it has three 70 feet arches and a center span 42 feet above low water.

In 1900, oil was discovered on the east side of Berryessa Valley. Two of these drill sites (Harris and Fearless) are located in two separate canyons (both named "Oil Well Canyon") 4–5 miles northeast of here across the lake. Renewed oil interest in the 1920s occurred as oil companies found seepages of oil in the GVG-Knoxville Formation and large areas of the valley were secured by oil operators to develop a petroleum field. Three wells were drilled at that time within one mile of today's visitor Center, by the Griffiths Oil Company, the Associated Oil Company of California, and the Sugarloaf Oil Company. The oil was a high-gravity paraffin base oil more than crude oil. No one was able to pump enough of it to make a profit. Mounting production costs with inadequate yield forced the venture to fold.

Mile 6.9 (6.1) [0.3] Acorn Beach turnoff.

The road on the right (east) leads to Acorn Beach, part of Oak Shores Day Use Area. Parking lot, public restrooms, picnic shelters, lake access.

As you drive along the lake shore, watch for osprey nests built on large metal pans located on telephone poles and other tall structures.

Mile 7.3 (5.7) [0.4] Oak Shores Day Use Area main entrance.

The road on the right (east) leads to Oak Shores Day Use Area. Parking lot, public restrooms, picnic shelters, lake access, and boat ramp.

SIDEBAR 18

Chaotic Rocks at the Base of the Great Valley Group

Near the mouth of Pope Canyon is a chaotic rock unit: a hummocky landscape that has a jumble of different rock types, often as large blocks ranging from 3 feet to 1500 feet across.

This jumbled formation is known as the Mysterious Valley Formation. It is of late Jurassic age (152–145 Ma), it is about 1/2 mile (1 km) thick, and it extends at least 30 miles (50 km) to the northwest. Stratigraphically, it lies directly above the more uniform serpentinite to the west that some geologists consider the Coast Range Ophiolite, and below well-bedded GVG rocks to the east. It has been folded repeatedly by thrust faulting, so it occurs in several different outcrop belts in the area.

The chaotic nature of these rocks indicate that the upper plate crust at the subduction zone was rapidly uplifted due to growth of an underlying Franciscan mélange wedge. This uplift led to instability and gravitational slides that carried and mixed debris from the Coast Range Ophiolite. The depositional processes include block falls from serpentinite cliffs, debris flows from those resulting piles of serpentinite debris, and downslope creep. The debris was subsequently covered by GVG sediments.

An alternative explanation is that these rocks were detached from the subducting plate and carried up into the forearc region by serpentinite mud volcanism. This ascending mud plucked off blocks of the forearc crust, including serpentinite, mafic breccia, and others, mixed them with those of the subducting slab, and deposited the mixture as large blocks in a series of submarine debris flows. This process helps explain the exotic high grade metamorphic blocks found scattered throughout the formation.

This jumbled unit contrasts with Franciscan mélanges because it has very low grades of metamorphism, many fewer sandstone and blueschist blocks, common blocks of mafic breccia, and a matrix dominated by serpentinite. It was probably buried only 7–8 miles (11–13 km) deep, similar to the basal GVG rocks, as compared to the much deeper burial of the Franciscan.

History: As you drive north, you can see a large island, Big Island, just offshore in Lake Berryessa. The flooded town of Monticello was located along Putah Creek at the eastern end of this new island, a former ridge now surrounded by water.

Recreation: The Smittle Creek Trail is a 2.6 mile long trail (one-way) along the lakeshore that leads to the Smittle Creek Day Use Area.

Mile 7.7 (5.3) [0.4] Coyote Beach turnoff.

The road on the right (east) leads to Coyote Beach, part of Oak Shores Day Use Area. Parking lot, public restrooms, picnic shelters, lake access.

Mile 8.4 (4.6) [0.7] Future trailhead for Iron Mountain Trail to Cedar Roughs.

Nature: The Cedar Roughs Wilderness Area supports a 3000-acre stand of Sargent cypress, which only grows on serpentine soils in the north and central Coast Range of California. This stand is the largest in Napa County. The "Cedar Roughs" name for the wilderness area refers to the cypress trees, which historically were called "cedars" in California.

The ridges on both the east and west side of Lake Berryessa provide important north-south migratory wildlife habitat linkages for deer, bear, mountain lion, and other animals (see Sidebar 17).

History: Cedar Roughs Ridge supported several chromite mines during the late 1800s and early 1900s, including the Blue Jay, Dottie D, and Eagle mines.

Recreation: The Iron Mountain Trail is still under development and anticipated to open in 2021. It will provide public access to the Cedar Roughs Wilderness Area thanks to a land acquisition in July 2016 by Tuleyome, the Land Trust of Napa County, Napa County Regional Park and Open Space District, the Wilderness Land Trust, and the California Wildlife Conservation Board. When completed, this trail will offer an interesting 8 mile out-and-back trail into Cedar Roughs Wilderness Area with great views of the region.

Mile 8.5 (4.5) [0.1] Smittle Creek Day Use Area.

Public parking, public restrooms, lake access, and day use picnic area managed by BOR. This area is the northern end of the Smittle Creek Trail that connects to Oak Shores. A short half-mile trail also leads north from here along the lake shore.

Recreation: As you drive along the west shore of Lake Berryessa, look to the east across the lake towards the 9,200-acre BLM Berryessa Peak Unit, which is recognizable by the communication towers on top. This public land was not publicly accessible until ranchers John and Judy Ahmann graciously donated a trail easement allowing public access. Tuleyome then designed and built the Berryessa Peak Trail. The 15 mile round trip, which starts from mile marker 20 on Knoxville Road, ascends and descends a total of 3500 feet (1060 m) in elevation.

Mile 9.1 (3.9) [0.6] Cross Smittle Creek.

About 1000 feet upstream, this creek flows through the narrow band of serpentinite that runs along the west shore of Lake Berryessa.

Mile 9.2 (3.8) [0.1]

Lake access via road to right, through the former Lake Berryessa Marina Resort. The resort was demolished in 2009.

Mile 9.3 (3.7) [0.1]

A greenstone (altered basalt) knob is prominent on the west side of the road, similar to Raney Rock near Moskowite Corner. Regional geology maps (see Figure A-4) show this area as consisting of GVG rocks, but it may also be the southernmost extension of the chaotic rock unit at the base of the GVG in this area (see Sidebar 18: Chaotic Rocks).

Mile 10.8 (2.2) [1.5]

Another volcanic block of Jurassic greenstone to the west of the road.

Mile 11.3 (1.7) [0.5]

Serpentinite is exposed in the road cut, further suggesting that the geology is more complex than just GVG rocks, as mapped by regional geology maps.

Mile 11.9 (1.1) [0.6]

More serpentinite exposed in road cuts.

Mile 12.2 (0.8) [0.3]

Road bend to the west, entering serpentinite. Note the change in vegetation to more chaparral and gray pines.

Mile 13.0 (0.0) [0.8] (STOP 8)

Pope Creek bridge and intersection of Berryessa-Knoxville Road and Pope Canyon Road. Public restrooms.

Cross the bridge over Pope Creek and enter the parking lot on the west. The lot is on the southwest corner of the intersection of Berryessa-Knoxville Road with Pope Canyon Road.

Cross the road to the east and walk down to the lakeshore. As you get close to the lake, look to the northeast across the lake to see Berryessa Peak.

Geology: Examine the large blocks around the area of the lakeshore and in the lake. These are part of a chaotic rock unit at the base of the GVG. The blocks include oceanic volcanic rocks (altered pillow basalts), mafic breccia, chert, serpentinite, and metamorphosed gabbro. Blocks of greenstone are the most common. All of these are distinct rocks from an ophiolite sequence (see Sidebar 18).

When you return to the parking lot look for roadside outcrops of sheared serpentinite on the north side of Pope Canyon Road across from the parking lot.

History: The Lake Miwok people called Pope Creek "Nombadjara."

Northwest of here, across Lake Berryessa and north of Berryessa Peak, is a low spot in the ridge just a few hundred feet below the average elevation of the Blue Ridge. Even though it was still a relatively high pass, it was used by a group of John Fremont's California Battalion as a route to return from Sonoma (after its capture from the Mexicans in 1846) to the Sacramento Valley via Capay Valley. The men were searching for loose horses to use in their military quest, and the passage through Putah Creek Canyon was too difficult. The pass was also the route of the Capay Valley–Berryessa Toll Road between 1863 and the early 1920s. Until Highway 16 was constructed beyond Rumsey up the Cache Creek Canyon, this road was the major thoroughfare between Clear Lake and the Sacramento Valley.

From here, you can continue on the "Pope Canyon Road to Pope Valley (town)" segment by driving west on Pope Canyon Road.

Pope Canyon Road to Pope Valley (Town)

(11.1 miles on Pope Canyon Road from Berryessa-Knoxville Road to Pope Valley)

Mile 0.0 (11.1) Pope Creek bridge and intersection of Berryessa-Knoxville Road and Pope Canyon Road.

Reset your odometer at this intersection. Drive west on Pope Canyon Road.

Mile 0.2 (10.9) [0.2] Mid-ocean ridge basalt blocks.

The large gravel parking lot on the left (south) side gives access to the top of a rocky cliff at the lakeshore if you walk southwest downhill towards the Pope Creek arm of the lake (see Figure A-4 for detailed geology map of this area).

Geology: The cliff is basalt that has been altered to greenstone, as are the blocks across the Pope Creek arm and at the bridge pier to the left on the south side of Pope Creek (see Sidebar 19: Greenstone and Pillow Basalt). The rocks are rounded pillows of basalt that formed as hot magma erupted into seawater, rapidly cooling to create a rounded upper surface.

Although initially described as part of the Coast Range Ophiolite, geochemical analysis revealed these basalts to be mid-ocean ridge basalts, rather than oceanic-island-related basalts typically associated with the CRO. These rocks are part of the Mysterious Valley Formation, the chaotic rock unit discussed in the previous section (see Sidebar 18: Chaotic Rocks). These rocks were carried into the subduction zone and then detached to be carried upwards by serpentinite mud volcanism. The ascending mud also plucked blocks off forearc crust—serpentinite, mafic breccia, and felsic intrusive complex—mixed them with those from the subducting slab, and deposited the mixture as large clasts in a series of serpentinite debris flows.

SIDEBAR 19

Greenstone and Pillow Basalt

The Trout Creek Anticline along the west side of Lake Berryessa exposes altered basaltic rocks in various places, particularly where Pope Creek cuts through the anticline. These basalts erupted below sea level at mid-oceanic ridges or isolated seamounts. During eruption, heated sea water intermixed with basalt, hydrothermally altering the original minerals to green-colored chlorite, epidote, and/or actinolite.

These green minerals color much of the rock green, lending it the name greenstone. Greenstone is a convenient field term for any poorly studied igneous rock that is compact, dark green, and altered or metamorphosed. It is often applied to a variety of altered basalt types, including lava flows, flow breccias, and pillow basalts. The term "pillow" refers to the rounded and elongate shape that lava cools into when it erupts and cools quickly under seawater.

The greenstones in this region are large blocks that are surrounded by either by Franciscan mélange rocks or lower GVG rocks. These blocks are frequently found with chert (a deep ocean silica-rich sediment). As part of the underlying oceanic plate, these oceanic blocks were transported to, and entered, the subduction zone, where they were mixed with Franciscan or GVG rocks by continental shelf slumping or submarine landslides.

Franciscan-related blocks were deeply subducted and then uplifted to the surface as part of the mélange. This uplift may have occurred along normal faults or as part of serpentine mud volcanoes. Such rocks at the surface may have been recycled back into the trench more than once, as the leading edge of the upper plate broke off and was consumed in the subduction zone.

Greenstone blocks that mixed with other GVG rocks were probably less metamorphosed than Franciscan blocks. Rather than being deeply subducted, they may have been uplifted closer to the surface along with the over-thrusting of the Coast Range Ophiolite. It is difficult to determine which greenstones in this region are Franciscan versus ophiolite-related without more detailed study.

Figure 54. Jurassic pillow basalts (Mile 2.9). These basalts probably erupted at a mid-ocean divergent plate boundary. The rounded and elongate shapes formed as the lava erupts and cools quickly under seawater.

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West of here Pope Canyon Road crosses a complex thrust system, including folded strands of the Coast Range fault, and enters the Pope–Chiles Valley fault slice of Great Valley Group rocks (one of the largest fault slices in the Coast Range).

Mile 0.6 (10.5) [0.4]

Large pullout just before roadcut. This pullout provides a nice panoramic view of Lake Berryessa below and the Blue Ridge beyond.

Geology: The eastern branch of the Berryessa Fault, as well as one of the folded segments of the Coast Range Thrust Fault, both extend north and south from just west of this location. To the west is a large road cut in serpentinite. Farther west, the road passes through a mosaic of serpentinite (mostly covered by chaparral) and Franciscan Complex rocks (with blue oak woodland). Because this serpentinite separates GVG and Franciscan rocks, some geologists believe that this is part of the Coast Range Ophiolite (even though it does not show other parts of the model ophiolite sequence).

These formations are covered by the Cache Formation on the upper north-side slopes as you drive west. The Cache Formation (5.3–2.5 Ma) consists of cross-stratified sandstone with some conglomerate interbeds. These sediments were deposited during the Pliocene and Pleistocene by streams in a fault-controlled, subsiding basin. This Formation is also found around Clear Lake and near the mouth of Putah Creek Canyon, where it may correlate with the Tehama Formation.

Mile 1.1 (10.0) [0.5] Historic Samuel Soda Springs.

The road leaves the main Pope Canyon and ascends a side canyon to cross over a saddle, then rejoins the main canyon. About 1 mile south of here, across Pope Creek, and not accessible from the road, is the historic Samuel Soda Springs.

Geology: The springs are located where the Coast Range Fault thrusts serpentinite over older GVG-Knoxville sediments. As a result, the spring water, which issues from serpentine soils, has a high magnesium content.

History: About 1880, E. C. Samuels took up the land as a government claim. G. R. Morris purchased the property in 1891. By 1901, the springs had been improved as a resort, with accommodations for 150 guests, billiard and club rooms, a dance hall, lawn tennis grounds, gas lighting, and long-distance telephony, along with an on-site physician trained in medical electricity. Soaking in the springs was advertised in local newspapers at the time as a "sure cure for dyspepsia, indigestion, rheumatism and constipation." The water was bottled and sold as a carbonated table water. Water analysis showed that it was similar to the Walters Springs water, but less mineralized.

Miners found cinnabar (a mercury-bearing ore) about 1/4 mile up the canyon from the springs. During World War I, fifteen mining claims were staked for chromite deposits in this area and along the serpentinite of Cedar Roughs Ridge, which extends south from here. Very little work was done on these claims and no ore was shipped. Chromite is one of the more important ores derived from ultramafic rocks and is used in the manufacture of stainless steel.

Mile 1.6 (9.5) [0.5]

The road crosses the top of the side spur and then descends to travel alongside the bottom of Pope Creek Canyon.

Mile 1.8 (9.3) [0.2]

Franciscan bedded chert block on hill to right (northeast). There is a small pullout on the right (north) side of the road. About a mile to the west is another large hill, but this consists of altered pillow basalts on the far side of the western Berryessa Fault.

Mile 2.2 (8.9) [0.4] Trout Creek Anticline and Berryessa Fault.

The road has reached the bottom of the canyon.

Geology: For the next half mile, Pope Creek follows the western branch of the north-south Berryessa Fault and the main axis of the doubly plunging Trout Creek Anticline. A plunging anticline is one in which the main axis is not horizontal, but rather "plunging" in to the ground; a doubly plunging anticline plunges in both directions along the axis. The Trout Creek Anticline, as well as other parallel anticlines and synclines in this region, was folded around 56 Ma. It extends for about 15 miles (25 km), plunging to the northwest near Walter Springs and to the southeast in the hills north of Capell Valley. Franciscan mélange rocks are exposed in the core of the anticline along most of its length and they are the most easterly and structurally highest Franciscan rocks at this latitude. The upper slopes to the northeast consist of Cache Formation.

Pope Creek flows directly across this anticline and is an antecedent stream. That is, it existed before the anticline was formed, and continued to erode as the anticline rose around it.

History: Across the creek is the site of the abandoned World War I-era Buzzard Chromium Mine and about 3/4 mile down-canyon is the site of the similar-aged Lewis Manganese Mine.

Recreation: The Cedar Roughs Trail begins here. One hikes down to Pope Creek and crosses by hiking, wading, or boating across the creek depending on the water level of Lake Berryessa. One can also hike the Pope Canyon Trail downstream along Pope Creek to Lake Berryessa. Additional information is available at Tuleyome.org.

Mile 2.9 (8.2) [0.7] (STOP 9) Altered pillow basalts.

Pull out onto the wide gravel shoulder on the left (southwest) side of road, then walk carefully west along the road about 175 yards to the outcrop.

Geology: Note the massive outcrop of pillow basalt in the hillside. Pillow basalts form during submarine volcanic eruptions such as those that create seamounts or at mid-ocean ridges where new crust is formed. The basalt here shows chemical traces indicating that it erupted at a mid-ocean ridge (see Sidebar 19).

These pillow basalts are in the core of the Trout Creek Anticline, surrounded on adjacent hillsides by Franciscan mélange rocks. In places, the lava is on top of chert that in turn overlies graywacke. All of these contacts are sheared and the rocks show low-grade metamorphic alteration. Rather than being a depositional sequence, these are large blocks that may have been mixed by initial slumping into the subduction trench, then subducted, uplifted to the surface, and then once more slumped back into the trench. Alternatively, they could have been uplifted along with the Coast Range Ophiolite, but more research is needed to determine their history.

The steep cliffs for the next 0.3 miles west of here all consist of pillow basalts.

Mile 3.1 (8.0) [0.2] Franciscan Complex.

As you ascend Pope Creek, the higher elevation hills on both sides of the road are serpentinite on top of Franciscan Complex. Blue oaks grow on the Franciscan rocks, but the serpentinite areas are covered with chaparral.

Mile 3.6 (7.5) [0.5] Maxwell Creek joins Pope Creek on the south side of the canyon.

Geology: The road passes through Franciscan Complex rocks on both sides of the creek, with upper slopes consisting of serpentinite and Mysterious Valley Formation rocks.

Conservation Lands: On the south side of creek is one of two parcels of the California Department of Fish and Wildlife's Cedar Roughs Wildlife Area. It was acquired in 1996 by the California Department of Fish and Wildlife to both protect and restore habitat and to provide access to the federal Cedar Roughs Wilderness Area. Access is challenging because it requires fording Pope Creek and there are no regularly maintained trails.

Mile 5.1 (6.0) [1.5] Pope Creek bridge.

Geology: The road crosses the Pope Valley Thrust Fault here, which runs northwest and south. Serpentinite on the east is thrust over GVG-Knoxville sediments to the west. This thrust fault is part of a series of east-dipping thrust faults in this area associated with the Wragg Canyon–Bartlett Springs detachment system.

On the west side of the bridge are two gated roads. The first one, which may have an open gate, is the old Pope Creek road. A few hundred yards down this road is the old bridge over Pope Creek. Immediately upstream above this older bridge is a narrow, 30–50 feet (9–15 m) deep gorge. This gorge has exposures of mafic breccia (Pope Creek breccia) that rest on sheeted diabase dikes. This is a fragment of the Coast Range Ophiolite. (see Figure 55).

The second road, closed by a cable, leads into an old quarry. This quarry exposes sedimentary breccia of large angular volcanic fragments (clasts) overlying serpentinite. Clasts consist of chunks and smaller grains of rock broken off other rocks by physical weathering, probably under seawater.

Nature: On the ridge east of the springs are two of the few McNab cypress stands in the region.

History: About a mile up the old Pope Creek Road is the historic Walters Springs. Since 1998, the resort has been owned and operated by the Shadhiliyyah Sufi Order and is now used as a spiritual retreat center.

J. J. Walters discovered the springs in 1871 and he bought the land a few years later in a joint venture with J. W. Smittle of Berryessa. The springs consist of three small carbonated springs that issue from serpentinite, which adds a high proportion of magnesium to the water. Water from this spring was bottled and marketed to a small extent for table use. Manganese ore was also discovered near here by G. P. Wallace.

During the late 1800s, visitors came by wagon road over Howell Mountain from Saint Helena. By 1901, regular stages were leaving from Rutherford to this and other mountain

Figure 55. Historic Pope Creek bridge (Mile 5.1). The gorge above the bridge has breccia and sheeted dikes that are part of the Coast Range Ophiolite.

Road Guide

resorts. Visitors to Walters Springs claimed the waters cured dyspepsia, asthma, heart disease, rheumatism, indigestion, and kidney and liver complaints. In 1910 there were two lodge buildings, having accommodations for 50 people, and a pavilion at the lower spring that provided a place for dances and other social gatherings. Henry and Vina Conner and their family ran the resort for 40 years in the early 1900s.

Recreation: The Pope to Putah Trail begins here. The out-and-back hike is a 9.4 mile moderate hike. Information can be found at Tuleyome.org.

Mile 5.6 (5.5) [0.5] Pope Valley.

The landscape opens up as the road enters Pope Valley (the valley, not the town).

Nature: The climate gets moister and cooler to the west. The hills of serpentine chaparral are left behind, replaced by valley oak savanna along the valley bottom and blue oak woodland on the lower slopes. This area marks a live-oak transition zone, with interior live-oak to the east and coast live-oak to the west.

History: Pope Valley is the southern end of the Lake Miwok ancestral lands. The former Rancho Locoallomi Mexican land

SIDEBAR 20

Lake Miwok People

Pope Valley was inhabited by Yukian speaking people up until about 2000 to 3500 years ago, when Penutian-speaking people moved into the area, either displacing or marrying into the Yukian groups. The Penutian-speaking Lake Miwok people occupied the area between upper Putah Creek and Lower Lake. Near the present-day town of Pope Valley were the southernmost Lake Miwok villages, có-kyomi púkut and alókyomi pukút. Four different archaeological sites were found in this valley, some containing shell beads and obsidian points, which indicate the type of trading network that existed in the region.

The Lake Miwok were linguistically related to the Coast Miwok (in today's Marin and Sonoma counties), and somewhat more distantly related to the Eastern Miwok of the Sacramento–San Joaquin Delta and central Sierra Nevada. The Patwin/Wintun group, whose territory separates the Lake Miwok and Eastern Miwok tribes, also belong to the Penutian language family.

Lake Miwok were hunter-gatherers who had permanent villages along creeks south of Clear Lake. Trading expeditions also took them from the top of the Coast Ranges and out to Bodega Bay. The oldest Lake Miwok settlement, located a few miles south of Lower Lake, was called tú-leyomi, meaning "deep place." This name also applied to the entire Lake Miwok territory, and was adopted by the Tuleyome conservation organization. Like many California tribes, Lake Miwok used acorns for their starch staple, complemented with manzanita berries and nuts from pines and buckeyes. Deer was the most important game, hunted year-round. Only men hunted ducks, but both men and women fished.

Their earliest European contact was with Luis Argüello, a Spanish military leader in 1821. In the 1840s, Mariano and Salvadore Vallejo, who believed that they owned Native American people just as they owned the wildlife on their land, captured Lake Miwok men to work on their ranches in Sonoma. After causing a massacre at a Pomo village on Clear Lake in 1843, Vallejo was no longer welcome in the area. He sold his grazing interest and remaining cattle to Andrew Kelsey and

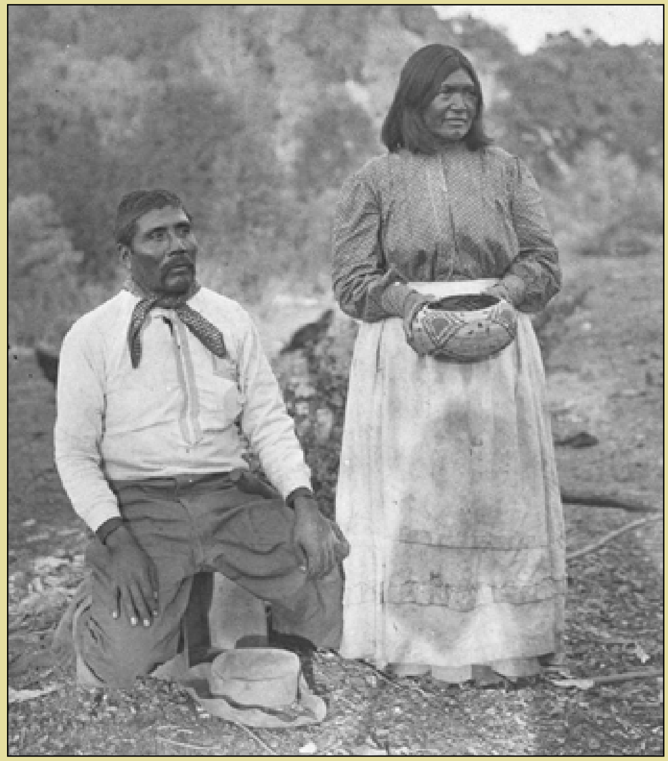

Figure 56. Lake Miwok Chief Hoo-yum-ha-yum and wife, Putah Creek, Lake County. Source: Merriam 1905.

Charles Stone. Stone and Kelsey also mistreated the local Native Americans, which led to the killing of Stone and Kelsey in 1849. Because of disease, capture for the Spanish missions, and other causes that killed the Lake Miwok over time, by 1842 only three tribal members still lived in Pope Valley.

In 1910, with federal funding, Pomo tribal members established the Middletown Rancheria at Middletown, California. Lake Miwok people, who had been landless for decades, joined the Pomo at this rancheria, along with Wappo and Wintun people. The rancheria now has approximately 200 tribal members, and the native language is Lake Miwok. In 1994, the tribe began operating Twin Pine Casino, which now has a hotel. In October 2002, the tribe purchased the Mount St. Helena Brewing Company, a micro-brewery and restaurant located in Middletown, making them the first Tribe in the United States to own and operate a micro-brewery and distribute beer.

grant covers most of Pope Valley. The 8873-acre rancho was granted to William Pope in 1841. It was the earliest land grant north of the Bay Area and beyond the Sonoma and Napa valleys. Pope was a trapper in New Mexico and arrived in Napa Valley in 1841. After receiving his land grant, he moved his family to Pope Valley in 1843. Unfortunately, he died in an accident later that same year.

The name "Locoallomi" was derived from Lakahyome, a Wappo village near Middletown in Lake County. The origins of the names are uncertain, but the "-yome" suffix on the names of many Lake Miwok villages means "place" (see Sidebar 20).

Mile 6.0 (5.1) [0.4] White Rock Mine.

The private road to the right (Barnett Road) leads north about a mile to the historic White Rock Mine (also known as Pope Valley Mine or Walters Mine).

History: Located along the serpentinite-GVG contact, this magnesite mine opened in the early 1870s, but no magnesite was shipped until 1894. In 1916, F. R. Sweasey turned it into one of the three principal magnesite mines in California. It alone was supplying much of the calcined (oxidized by high heat) magnesite used by steel mills on the Pacific coast at the time. The mine had a 450 feet long adit, or tunnel, and an aerial tramway 4200 feet long that brought the ore to a calcining plant along Pope Creek near the main road. Magnesite is one of the more important ores derived from ultramafic rocks, and it is an important heat-resistant material used as a lining in blast furnaces, kilns, and incinerators. After Sweasey's death, the mine eventually closed in 1923, and all movable equipment was transported to the Blanco-Snowflake Mine in Chiles Valley (see Figure 56).

Mile 6.1 (5.0) [0.1] View of Sugarloaf Mountain and volcanic vents.

Geology: Seven miles (11 km) to the west is Sugarloaf Mountain (2988 ft; 910 m), a massive peak with several knobs on the ridge south of it. These peaks are basalt-andesitic vents that erupted lava flows about 3.2–2.9 Ma. They are part of the Wildlake Volcanic Center, one of 11 centers in the Sonoma volcanic field that rims both sides of Napa Valley.

On the left (south) side is the entrance to the Pope Creek Quarry. It is a small operation that first opened in the 1940s to extract sand and gravel. About 15,000 tons of rock are mined per year.

Mile 6.3 (4.8) [0.2] High terrace gravels.

On the left (east), the road cuts through high terrace gravels along Pope Creek. There are also more terraces and entrenched streams to the right. Pope Creek and its tributaries are presently cutting GVG bedrock in much of Pope Valley.

Mile 6.5 (4.6) [0.2] Leaving Pope Creek.

Pope Creek comes in from due west, but the road veers southwest here to cross into another part of the valley.

Geology: The road ahead crosses the axis of the Pope–Chiles Valley Syncline that runs the length of Pope Valley. On this side of the valley, the road crosses through the oldest GVG rocks (Knoxville Formation), then progressively younger rocks until the middle of the valley. The older GVG rocks then are exposed on the far slopes of the valley rising toward the distant ridge.

Nature: Pope Valley, like other valleys in the region, is being converted from valley oak savanna to agriculture. Many of the valley oaks remain, scattered on the valley floor and along streams.

Mile 7.0 (4.1) [0.5] Serpentinite "island."

Geology: The 200 feet (60 m) high hill on the right (west) side of the road, in the middle of the valley and covered with chaparral and scattered gray pines, is underlain by serpentinite. The lower slopes all around are lower GVG sandstone and shale (Lodoga Formation), distinctly covered by blue oak woodland. There appears to be a nearly flat contact between the two units (see Figure 57).

There are two possible explanations for this feature. It may be a lens of sedimentary serpentinite within the GVG. However,

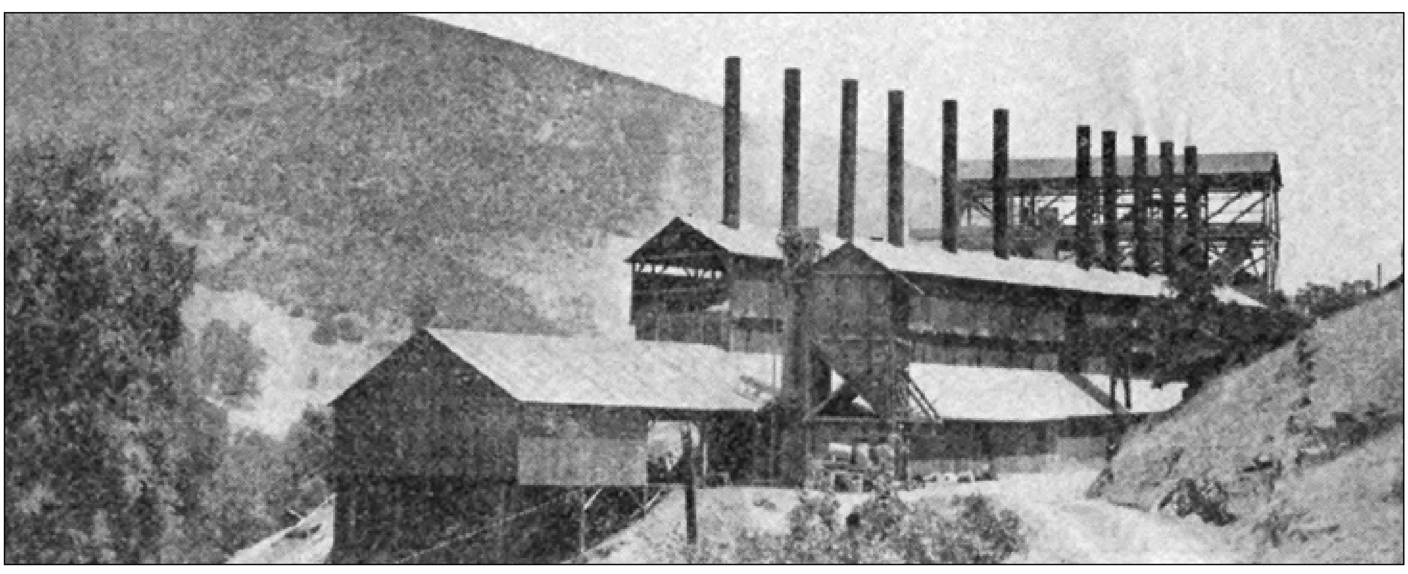

Figure 57. Historical White Rock Mine in 1917 (North of Mile 6.0). No equipment or building remains at the site now. In 1917, it was one of the three principal magnesite mines in California. Source: Bradley 1925. Photo by F.R. Sweasey.

Figure 58. Serpentine klippe in Pope Valley (Mile 7.0). The chaparral-covered serpentine at the top of the hill overlies the grassy GVG on the valley floor.

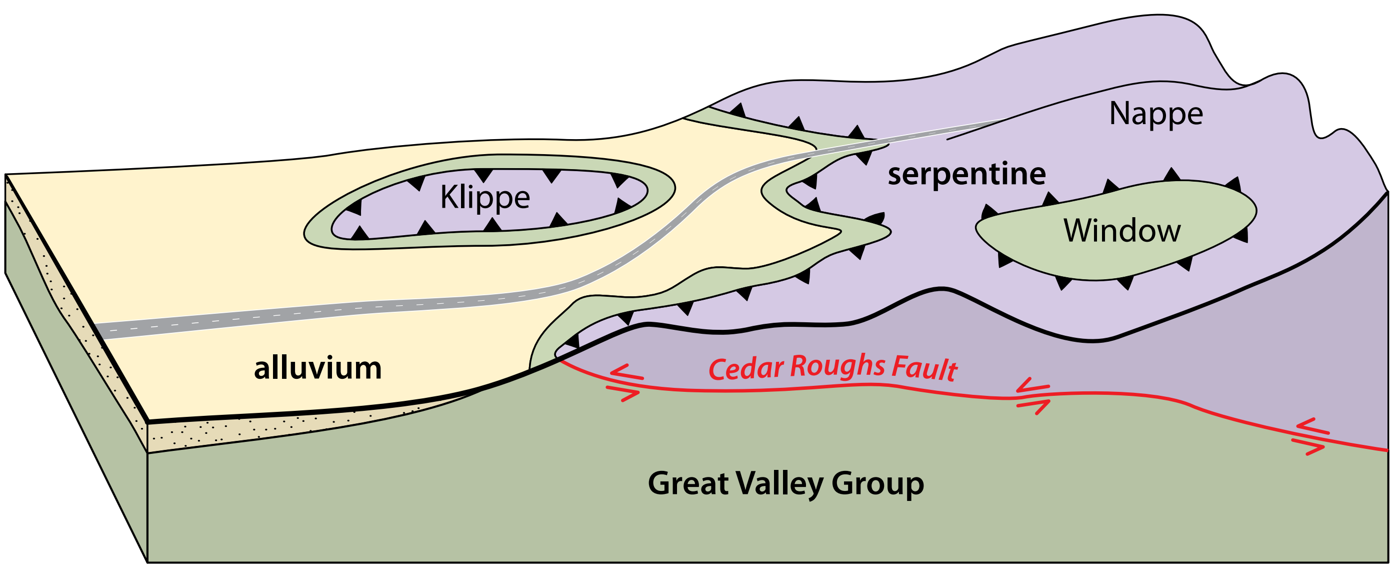

Figure 59. Conceptual diagram of leading edge of Cedar Roughs thrust. A "nappe" is a large sheet-like body of rock thrust over lower formations. Subsequent erosion may isolate parts of this thrust sheet from the main body ("klippe") or erode holes ("windows") in the nappe to expose underlying rocks

the serpentinite has no sedimentary features and there is evidence of shear foliation at the contact.

A second explanation is that the contact is the surface of the gently to moderately northeast-dipping Pope Valley Thrust Fault that places serpentinite over GVG layers. The serpentinite is isolated from other nearby serpentinite due to intervening erosion. Such isolated features on top of thrust faults are called klippen (singular, klippe). Structurally, the thrust fault carries the Trout Creek Anticline out over a complex syncline in the Chiles-Pope Valley fault slice.

You can see the main serpentinite sheet in the hills to the east and north that line Pope Valley (see Figure 58).

Mile 7.1 (4.0) [0.1] Great Valley Group.

Geology: Over the next half-mile, the road passes through several small sandstone ridges (100–200 ft; 30–60 m high) that are perpendicular to the road. These are GVG ridges topped with blue oak that stick out above the valley's more recent alluvial fill. These hills form a small drainage divide, with Pope Creek behind draining the northern part of Pope Valley, and Burton/Maxwell Creek ahead draining the southern part.

To the southwest across the valley, Howell Mountain rises 1800–1900 feet (550–580 m) above Pope Valley. The crest of this ridge is topped by ash flows and andesite lava flows of the Sonoma Volcanics. The dark forests on the crest consist of conifers and oaks, including coast redwood.

Mile 8.1 (3.0) [1.0] Intersection of Pope Canyon Road and Pope Valley Cross Road.

TURN right (west) on Pope Valley Cross Road.

Mile 9.2 (1.9) [1.1] Intersection of Pope Valley Cross Road and Chiles-Pope Valley Road.

TURN right (northwest) on Chiles-Pope Valley Road. The slope across the intersection (to the southwest) supports black oak, the first time that we've seen this tree species since Wragg Canyon.

Mile 9.3 (1.8) [0.1] Barnett Road.

This local road provides the closest view of the Pope Valley klippe with a short side trip of 0.8 miles (1.3 km).

Mile 11.1 (0.0) [1.8] (STOP 10) Pope Valley (town).

Intersection with Howell Mountain Road. STAY right (northwest) to continue on Pope Valley Road. Store, public restrooms.

The little town of Pope Valley is not much more than a wide spot in the road. However, the Pope Valley Store, located at 5850 Pope Valley Road, offers both groceries and a towing service. The Market, open 10 am–7 pm every day, provides an oasis for resting and refueling. For more services, Angwin, four miles up the Howell Mountain Road, provides gas, a larger market, and a deli.

Although the town is located in Pope Valley, the main creek flowing through this section of the valley is Burton Creek. Pope Creek itself flows on the north side of the hills that run down the length of Pope Valley (see Figure 59).

Nature: Howell Mountain Road provides access to a coastal redwood grove growing on Sonoma volcanic tuffs and andesite (less than 2 miles from junction). During the first mile, this road passes through a large stand of black oaks. Higher up, the forest transitions to coast redwood, Douglas-fir, tanbark oak, and ponderosa pines, which are not seen elsewhere on this tour. The coastal redwood forest is one of the most interior stands in the state.

History: This small village has three historical markers, all near the main road intersection. The Pope Valley Garage was built in 1915, and it has contracted with the California State Automobile Association to provide emergency roadside service since 1927. The Pope Valley Store was built in 1875 as a stopover for miners, providing a post office, saloon, hotel, groceries, and hardware.

The Henry Haus Blacksmith and Wagonmaker Shop operated from 1897 to 1950. Henry Haus and his older brother Ed emigrated from Switzerland and settled in Pope Valley in the late 1880s. The blacksmith shop was built by a Mr. McDonald in 1890 and Henry started working there. McDonald left to go gold prospecting and offered the shop to Henry (who was seventeen at the time). Henry's brother Ed married Bertha Leimbacher in 1886 and he went on to start the Pope Valley Winery in 1897.

From here, you can take the "Pope Valley (town) to Aetna Springs Road Loop" by driving north on Pope Valley Road. Or you can drive east and then south on Chiles-Pope Valley Road.

Figure 60. Pope Valley (town).

Pope Valley (Town) to Aetna Springs Loop

(6.6 miles on Pope Canyon Road from Pope Valley to Aetna Springs Mining District)

Mile 0.0 (6.6) Pope Valley (town) (STOP 10) (see previous description).

Reset your odometer at the intersection of Howell Mountain Road and Pope Valley. Drive north on Pope Valley Road toward Middletown.

Mile 1.7 (4.9) [1.7] Ink Grade Road.

This 4 mile long road provides an alternate route to the top of Howell Mountain and Angwin. It passes through vineyards on the lower slopes and redwoods, madrone, and live-oak on the upper slopes. It provides nice views of Pope Valley below. On the return trip to Pope Valley, this is an interesting alternative return route; combine it with Howell Mountain Road if you take this option.

Mile 2.1 (4.5) [0.4]

Pope Valley Winery, 6613 Pope Valley Road, is open 10–5 every day.

Geology: Northeast of the road is a 500 feet (150 m) high hill (informally called "Turkey Hill") consisting of thick sandstones. This hill is along the axis of the Pope-Chiles Valley Syncline (see Figure A-5 for detailed geology map of this area).

Nature: The surrounding hills are covered by blue oak woodlands with scattered gray pines.

History: Ed and Bertha Haus founded the winery in 1897. Ed was the older brother of Henry Haus, the Pope Valley blacksmith. Check out the 100-year-old, hand-dug "cave" and 19th century winemaking equipment on display. The cave was dug from Great Valley sediments that are part of the Pope-Chiles Valley Syncline. Picnic tables, available for the use of visitors, make this a great lunch stop (see Figure 60).

Water: The route crosses a low rise here to once again enter the Pope Creek drainage.

Mile 2.5 (4.1) [0.4] Litto's Hubcap Ranch, 6654 Pope Valley Road.

No good pullouts. Litto Damonte began collecting hubcaps in 1935. By the time of his death in 1985 at age 93, he had over 3000 hubcaps fixed to the fence along his property. Since then the collection has grown to over 5000. California State Parks erected a historical marker for this landmark in 1987, located just west of the driveway. Davis-based singer-songwriter Dave Nachmanoff has recorded a ballad about Litto, which can be found online (see Figure 61).

Mile 4.2 (2.4) [1.7] South fork of Pope Creek crossing.

Mile 4.3 (2.3) [0.1] Aetna Springs Cellars on left.

Mile 4.4 (2.2) [0.1]

Intersection of Pope Valley Road and Aetna Springs Road. TURN right onto Aetna Springs Road.

Geology: The higher hills to the northwest reveal the plunging axis of the Franciscan-cored Aetna Springs Anticline. Toward the north is the large Butts Canyon serpentinite sheet, covered in serpentine chaparral that burned in 2014 and extensively in 2018. The view to the southeast shows the Pope-Chiles Valley Syncline.

Nature: The valley floor here is covered with valley oak savanna, with an understory of invasive annual grasses. Valley oaks prefer growing on deep alluvial soils. This area is one of the moistest parts of the tour. Winter storms deliver almost twice as much rain as they do in the Winters area, with annual precipitation of about 40–50 inches.

Mile 4.9 (1.7) [0.5] Swartz Creek bridge.

Built in 1912, this is one of many masonry arch bridges built in Napa County in the late 19th and early 20th centuries. These bridges were made possible by high quality building stone from local quarries, and skilled stonemasons, most of them European immigrants.

Figure 61. Authors looking at GVG sediments in Pope Valley Winery cellar (Mile 2.1). Naturally followed by some wine tasting.

Figure 62. Litto's Hubcap Ranch (Mile 2.5). A historical landmark of sorts, commemorating a collection of 3000 displayed hubcaps.

Mile 5.4 (1.2) [0.5] Aetna Springs Resort.

The resort and spa was originally developed by Len D. Owen in the 1870s and quickly became a popular summertime destination for vacationers from San Francisco and Hollywood. Several of its structures are believed to have been designed by famed Arts and Crafts architect Bernard Maybeck. One of the first golf courses west of the Mississippi River was built on the resort's property in 1891. The rustic 19th century resort hosted tourists until it was sold in the 1970s to an affiliate of the Rev. Sun Myung Moon's Unification Church, which sold it in 2003 to a Southern California developer. The resort closed in 2009, although recent attempts have been made to reopen it. The historic buildings at the end of the maintained road were moved here in 2011 to make room for golf course improvements. However, the course itself closed in 2018 (see Figure 62).

Mile 5.7 (0.9) [0.3] Minor road junction.

CONTINUE straight. The side road goes to a small reservoir. The main road climbs steeply out of the valley, through gray pine, ponderosa pine, California bay, black oak, and manzanita.

Mile 5.8 (0.8) [0.1]

Serpentinite in small road cut, with distinctive leather oak growing on top.

Mile 6.6 (0.0) [0.8] (STOP 11) Aetna Area Mining District.

History: This area was an important mercury mining area during the late 19th and early 20th centuries. Mercury was used in the gold industry to separate the gold from its ore. In 1854, local toll-road builder John Lawley found cinnabar (a mercury-bearing ore) on the valley floor. This discovery led to development of a mercury-mining industry that lasted through WWI and included the Phoenix, Oat Hill, Corona, Twin Peaks, Silver Bow, Aetna, White Hill Magnetite and other mines. In total, there are about 50 abandoned mercury mines in the upper Putah Creek watershed. Half a mile west of here is the 1917 Cavagnaro manganese prospect (see Figure 63).

Nature: About half a mile to the west, upslope of this site, is one of the few McNab cypress stands in the region.

The paved road ends here, although the gravel road continues to Twin Peaks and Oat Hill via a primitive route. TURN around here and return to Pope Valley (town).

Pope Valley (Town) to Lake Hennessey

(11.2 miles on Chiles-Pope Valley Road from Pope Valley to CA-128)

Mile 0.0 (11.2) (STOP 10) Pope Valley (town)

(see previous description in "Pope Creek to Pope Valley (town)" segment).

Reset your odometer at the intersection of Howell Mountain Road and Chiles-Pope Valley Road. Drive east and then south on Chiles-Pope Valley Road.

Mile 0.6 (10.6) [0.6] Intersection with Pope Valley Cross Road (PMP 11.4).

STAY to the right (southeast) on Chiles-Pope Valley Road.

Geology: Chiles-Pope Valley Road is approximately along the main axis of the Pope-Chiles Valley Syncline. Both sides of the road are underlain by thin-layered shale beds that are the youngest beds of the GVG exposed in Pope Valley (Boxer Formation). To the southwest, the ridge exposes the southwest limb of the syncline, with gradually older GVG beds being exposed with increasing elevation (see Figure A-4 for detailed geology map of this area).

Mile 1.9 (9.3) [1.3] Intersection of Chiles-Pope Valley Road with Pope Canyon Road.

STAY to the right (southeast) to continue south on Chiles-Pope Valley Road. Look for evidence of landslides on the hill slopes for the next 4 or so miles. For the next 2–3 miles, both sides of the road are GVG rocks.

Figure 63. Aetna Springs Resort (Mile 5.4). A historical soda springs health resort from the 1870s.

Figure 64. Historic buildings in the now-abandoned Aetna mining district (Mile 6.6).

Mile 2.6 (8.6) [0.7] Low pass between Burton Creek (to north) and Maxwell Creek (to south).

Maxwell Creek flows northeast through the narrow canyon ahead, crossing the GVG beds and Pope-Chiles Valley Syncline at a right angle. This could be another example of an antecedent stream, one that existed before the hills rose up around it.

Mile 4.4 (6.8) [1.8] Douglas-fir.

Look across the small reservoir to see a stand of Douglas-fir, a tree that prefers moist climates. This is one of the easternmost stands of that species in this region.

Mile 5.2 (6.0) [0.8] Putah Creek and Napa River watershed divide.

Geology: On the right (southwest) is a 700–900 feet (200–270 m) high ridge that lies along the axis of the Chiles Canyon Anticline. The upper parts of this ridge consist of Franciscan rocks, with a long band of serpentinite at its base. The serpentine soils are covered with leather oak chaparral. The road travels along the contact between the serpentinite and the recent alluvium of the valley floor, as well as along the folded trace of the Coast Range Thrust Fault.

On the left (northeast) side of the valley is a 1000 feet (300 m) high ridge of thick sandstone that lies along the axis of the Pope–Chiles Valley syncline. Note the differences in vegetation: chaparral on serpentine soils, oaks on GVG soils (see Figure 64).

History: Several archaeological sites have been discovered in Chiles Valley, containing artifacts such as obsidian blades and points, mortars and pestles, and beads made from magnesite. An ancient Patwin/Lake Miwok trail from Berryessa Valley to Napa Valley passed through Chiles Valley here. It led from Pope Creek over Cedar Roughs Ridge to Hardin Creek, then over the high ridge to the southwest into Chiles Valley. The route continued down Chiles Canyon and Conn Creek to Napa Valley.

You are entering the historic Rancho Catacula Mexican land grant, which covered much of Chiles Valley between this low pass and the upper part of Sage Canyon. The 8546-acre rancho was granted to Joseph B. Chiles in 1844. Chiles named it Catacula after the local Wappo name for the valley, which translated to "Valley of Oaks" (see Sidebar 21).

Water: A road sign highlights that you are leaving the Putah Creek watershed and entering the Napa River watershed. You've been travelling up Maxwell Creek tributary for the last 4.6 miles and you will be descending Chiles Creek tributary for the next 6 miles to Lake Hennessey. Between this pass and the junction with Lower Chiles Valley Road, the route descends Chiles Valley.

Mile 7.6 (3.6) [2.4] Junction of Chiles-Pope Valley Road and Lower Chiles Valley Road.

STAY right (south) to descend Chiles Canyon.

Geology: The ridge to the northeast of Chiles Valley is the northwest-plunging Chiles–Pope Valley Syncline. Even though it forms a ridge, and synclines are typically thought of as trough-like folds, the syncline's form is due to resistant sandstone layers at the ridge top (see Figure A-2 for detailed geology map of this area).

History: The Chiles Grist Mill was built by Joseph Ballinger Chiles and William Baldridge in 1846 and was the first American flour mill in Northern California. It was still in use in the 1880s. Almost hidden from view at the top of an embankment on the southeast side of the intersection is a historic marker (No. 547) erected in 1956 to identify the mill's location.

In the next 3.5 mi, the road cuts across the main axis of the Chiles Canyon Anticline, exposing serpentinite, chert, and Franciscan rocks at its core. The road is steep and winding here, with just a few very small pullouts. Go slow so you can find them early enough to use them.

Mile 8.0 (3.2) [0.4] Northeast limb of Chiles Canyon Anticline.

Small pullout on the left (heading downhill, east) at PMP 3.3. About 100 feet downhill along the road is an outcrop of nicely bedded chert.

Geology: The Chiles Canyon Anticline is a large, relatively flat-topped, Franciscan-cored fold riding on a major thrust fault that is buried beneath the alluvium in Napa Valley. It was probably uplifted between 51 and 43 Ma. The uplift and subsequent erosion exposes Franciscan nearly adjacent to GVG rocks, separated by serpentinite less than 100 feet (30 m) thick. The Franciscan rocks, mostly coherent metagraywacke interlayered with chert, have been much more deeply buried than the adjoining GVG rocks, suggesting a metamorphic gap of 3

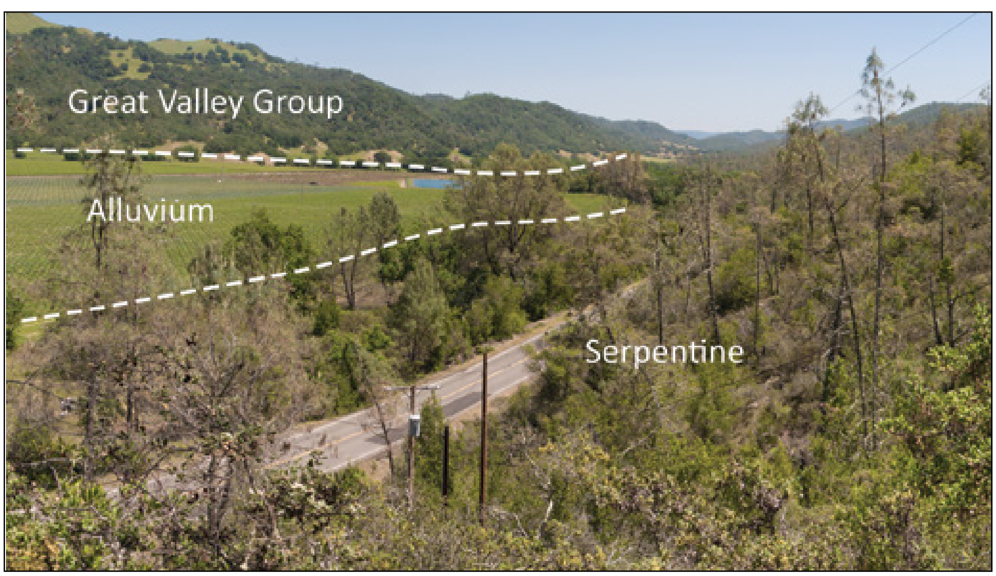

Figure 65 Serpentine and GVG sediments in Chiles Valley (looking south along Chiles Valley Road at Mile 5.2). The pine and chaparral covered slopes on the right (west) are serpentine, and are at the base of the Chiles Canyon anticline. The high ridge with blue-oak woodland on the left (east) consists of GVG sediments along the axis of the Pope-Chiles Valley syncline.

SIDEBAR 21

Joseph Chiles and William Baldridge

Joseph Ballinger Chiles and William Baldridge met in Missouri in 1840, where Chiles was a returning veteran of the Florida Indian Wars and Baldridge was a millwright. Both desired to visit California, and Chiles travelled with the Bidwell-Bartleson party in 1841, the first wagon train to cross Nevada and the Sierra Nevada. He returned home and brought his family and Baldridge back to California in 1843. In 1844, he became a Mexican citizen and received an 8546-acre land grant from the Mexican government called Catacula Rancho, which is the present day Chiles Valley. Catacula is a Patwin name of unknown meaning.

Chiles built his home at what is now the junction of Chiles-Pope Valley Road and Lower Chiles Road. He decided to build a flour mill here with Baldridge. In June 1846, Baldridge and Thomas Bradley travelled to Putah Creek Canyon (known at the time as "the Sandstone Mountains") to collect grindstones for the mill. At camp that night, they encountered John Fremont's men sneaking between Sacramento and Napa, shortly before the American capture of Sonoma.

Chiles and Baldridge eventually improved their technology by importing a French Buhr millstone, which they brought over the Sierra Nevada. That millstone was donated to the Napa Valley's Bale Mill State Historic Park near St Helena.

Here the two men operated this grist mill, raised livestock, and made wheat whiskey. Eventually Baldridge moved to Napa and Chiles moved to the Sacramento area. Between 1848 and 1850, Chiles operated a profitable rope-ferry across the Sacramento River with his son Kit (James Rumsey Chiles) and Jerome C. Davis (for whom the City of Davis is named).

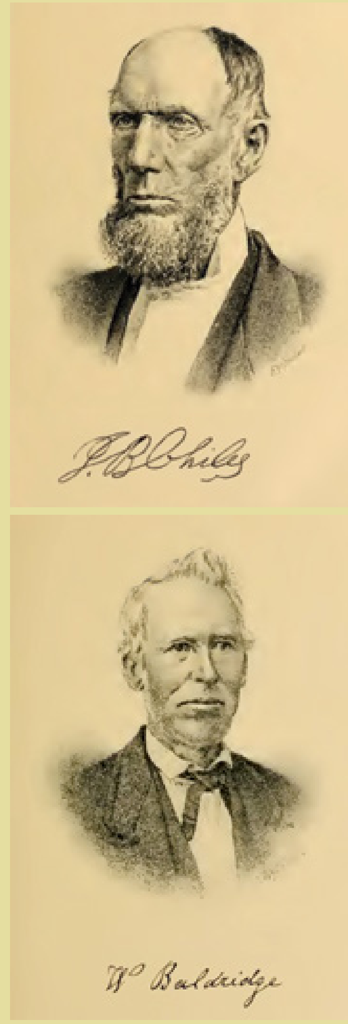

Figure 66. Joseph B. Chiles (top) and William Baldridge (bottom). Chiles was the first settler in Chiles Valley, which became his Rancho Catacula Mexican land grant in 1844. Chiles and Baldridge built the first flour mill in Northern California. Source: Palmer et al. 1881.

miles (5 km) of missing section along the fault in this area. This may represent an early stage in the thrust-wedging process of this area.

Note the outcrops on the left (east) side of the road. The rocks comprise radiolarian chert, a silica-rich, comparatively hard, fine-grained, sedimentary rock that is composed predominantly of the microscopic remains of radiolarians, tiny marine organisms. Radiolaria have an inner quartz skeleton and range in size from 0.1 to 0.5 mm. When they die, their tiny skeletons fall to the ocean floor to form an "ooze" that eventually hardens into rock. It takes about 1000 years for a 1 mm thickness of chert to be deposited. (One millimeter equals 1/25 of an inch. Thus it would take 25,000 years to make an inch of chert.) Chert generally forms in horizontal beds about 2–6 in thick. Commonly the layers in Franciscan cherts are highly folded.

History: Manganese ore was discovered within the Franciscan Complex in the ridge north of Chiles Canyon by G. E. Powers of Rutherford in the late 1890s. Farther west, on the ridge between Moore Creek and Conn Creek, the Manganese Ridge Mine produced 300 tons of manganese ore by 1917.

Mile 8.2 (3.0) [0.2] Bedded cherts.

Small pullout on the left (east, heading downhill). The exposed, thinly bedded cherts here are overlaid by sandstone(see Figure 67).

Nature: The vegetation here includes coastal live-oak, manzanita, and the aromatic California bay. The yucca-like succulent plant growing on the cliff face is called canyon live-forever. In spring and summer, the plant sends up bright red-orange stems from its gray-green leafy base.

Mile 8.3 (2.9) [0.1] Greeg Mountain Road (private road) (PMP 2.9).

Above here to the east, several hundred feet above the road and not visible to drivers, is the commercial Green & Red Vineyard, named for its red iron soils veined with green serpentinite.

Mile 9.1 (2.1) [0.8] Bridge over Chiles Creek (PMP 2.1).

Small pullout on left (east, heading downhill).

Geology: The outcrops in this area are mostly Franciscan metagraywackes. Bedding dips in these sandstones conform to the shape of the anticline. These rocks are dense and stretched thin by deformation, and the interbedded shales are highly fragmented into very thin layers. The rocks are so impermeable

Figure 67. Bedded chert in Chiles Canyon (Mile 8.2). Bedded cherts are composed of the silica-rich skeletons of tiny marine protozoans (radiolarians) that pile up into layers on the deep ocean floor at a rate of about 1 inch per 25,000 years.

that Chiles Creek flows fresh and strong within Chiles Canyon, even during summer in drought years, when the creek-bed in Chiles Valley is dry.

Nature: Chiles Canyon has extensive coast live-oaks and gray pine forests on the east-facing slopes, and blue oak woodlands on the west-facing slopes.

Mile 9.9 (1.3) [0.8] Moore Creek Park.

Public restrooms.

Water: Moore Creek flows into Chiles Creek, which feeds into Lake Hennessey, along with Conn Creek from farther north.

Recreation: The 1600-acre park was acquired in 2008 by Napa County Regional Park District and contains part of the Bay Area Ridge Trail.

Mile 11.2 (0.0) [1.3] Lake Hennessey and intersection of Chiles Canyon Road with CA-128 (PMP 11.32).

TURN left (east) onto CA-128 to ascend Sage Canyon.

Water: Lake Hennessey is the largest water reservoir in the Napa Valley drainage system. It is formed by Conn Creek Dam, built across Conn Creek in 1948 by the City of Napa. It is the primary source of water for the City of Napa, and it helps manage flooding downstream in Napa Valley. The lake was named after Edwin R. Hennessey, a local civic leader who played a role in the development of the Conn Valley Reservoir.

From here, you can take the "Lake Hennessey to Turtle Rock" segment by driving east on CA-128, heading for Winters.

Lake Hennessey to Turtle Rock

(7.4 miles on CA-128 from Chiles-Pope Valley Road to Berryessa-Knoxville Road)

Mile 0.0 (7.4) Lake Hennessey and intersection of Chiles Canyon Road with CA-128. (See previous description).

Reset your odometer at this intersection. Drive east on CA-128, heading for Winters.

Mile 0.3 (7.1) [0.3] Two wineries, Villa Del Lago Winery and David Arthur Vineyards.

Mile 0.8 (6.6) [0.5] Estancia Winery on right (south) (PMP 12.13).

Several hundred feet up on the slope to the south is another large patch of serpentinite that extends for about 1.5 miles east to west. The road ahead is on the south side of Greeg Mountain, a large exposure of Franciscan Complex rocks, with serpentinite lining its northern and southern bases. This Complex is exposed in the core of the northwest-southeast Chiles Canyon Anticline. The hot south-facing slopes here have larger patches of chamise chaparral mixed among the coast live-oak woodland.

Mile 1.2 (6.2) [0.4] Neyers Winery on right (south).

On the left (north) is a small landslide that can block the road during a wet winter, as it did in 2019.

Mile 1.8 (5.6) [0.6] Kuleto Estates Winery on left (north).

This is one of the more extensive vineyards on Greeg Mountain. The road narrows and start climbing more steeply. Note the Franciscan meta-sandstone in the outcrops along the roadsides.

Mile 2.6 (4.8) [0.8] (STOP 12) Blueschist outcrop (PMP 13.9).

Use the small pullout on the right (south), about 100 feet uphill, to park and walk carefully back downhill. There is no shoulder and plenty of traffic on this winding road. This outcrop is located just downhill from a set of concrete road barriers that line the road at PMP 14.05 (see Figure A-2 for detailed geology map of this area).

Geology: This and the next unassuming outcrops are important and rare indicators of the deep subduction, metamorphic, and uplifting processes (See Figure 18). At the outcrop note the planar color differences (foliation) in rock. Note also the linear orientation of white veins (possibly of quartz), some of which are deformed. Blueschists form in high pressure–low temperature regions in subduction zones. The blue color of the rock comes from the mineral glaucophane, a sodic amphibole that only forms at relatively low temperatures (approximately 200 to 500° C), but at high pressures that correspond to burial to a depth up to 18 miles (30 km) (see Figure 67).

Mile 2.8 (4.6) [0.2] (STOP 13) Eclogite outcrop (PMP 14.1).

An eclogite is a highly metamorphosed basalt that contains red garnet and a greenish pyroxene called omphacite. These minerals indicate that it formed at depths even greater than blueschists (30–60 mi; 50–100 km), at intermediate temperatures (300–400° C).

Mile 3.8 (3.6) [1.0]

Crossing the highly folded Coast Range Fault, the road enters a wide patch of sheared serpentinite, which extends from here to just beyond the intersection with Lower Chiles Valley Road.

Mile 3.9 (3.5) [0.1] Nichelini Winery.

History: The Nichelini family has owned the winery since its establishment in 1895, the oldest family-owned winery in Napa County. The winery, original Roman wine press, and house still stand today. The house was damaged in the 1906 San Francisco earthquake. The winery is open 11 am–5 pm, Friday–Sunday and at other times by appointment. The winery grounds feature several picnic tables and other amenities.

Upslope from the winery is the site of the former Antone Nichelini Mine. Nichelini discovered copper, manganese, and chromite on his land by 1901. In 1918, he shipped 100 tons of chromium ore from this deposit.

Mile 4.3 (3.1) [0.4] Lower Chiles Valley Road (approx. PMP 15.8).

STAY to the right (east) to continue on CA-128.

Geology: Between here and Turtle Rock Bar and Cafe, the road travels through the Pope–Chiles Valley Syncline in Great Valley sediments that overlie serpentinite. This syncline is a continuation of the one first encountered in Pope Valley.

History: About 1.5 miles west along this side road is the historic site of the Blanco-Snowflake Mine (also known as Maltby No. 2 Mine). This was among the first magnesite mines to be worked in California, with shipments of over 1000 tons per year from 1891 to 1901. It was idle from 1901 to 1917, after which the Tulare Mining Company operated it for a few more years.

Figure 68. Eldridge Moores, Peter Schiffman and Marc Hoshovsky at blueschist outcrop (Mile 2.6). Blueschist only forms at high pressures in depths of up to 18 miles below the surface.

Mile 4.8 (2.6) [0.5] Sharp bend in road.

Looking directly ahead to the southeast, you can follow the contact between serpentinite and the GVG–Knoxville Formation up the hill. The left side of the hill has oak woodland, whereas the right side has serpentine chaparral.

Mile 5.9 (1.5) [1.1] Napa River and Putah Creek divide.

Cross low pass. Somerston Estates Winery is on the left.

Geology: The ridge here is the axis of the Pope–Chiles Valley Syncline that runs north-south. Most of the exposed rocks here are GVG.

As the road descends into Soda Valley, the ridge to the east is the southern end of the Cedar Roughs Ridge. This ridge is topped by serpentine chaparral, whereas the lower oak woodland slopes are middle-aged GVG sediments. The Cedar Roughs Thrust Fault has thrust the serpentinite over these GVG sediments, forming a distinct break in vegetation. This thrust fault is part of a series of thrust faults in the region associated with the Wragg Canyon–Bartlett Springs detachment system. Along this fault line, located about 300–400 feet (90–120 m) above the valley floor, are multiple travertine springs. These may be visible between the trees as large white areas. It is these "soda springs" that gave the valley its name.

History: At the upper end of Soda Valley is the historic Priest Mineabout 600 feet (180 m) above the valley at the serpentinite-GVG contact. In the 1870s, Joshua J. Priest owned this valley and allowed some miners to start a tunnel into the ridge looking for quicksilver (mercury). The ground was so loose that it could not be timbered up and secured, so it was abandoned. After Joshua's death in 1897, his son Daniel C. Priest took over the farm and worked with his brothers to operate the Priest Soda Springs bottling works, which also had a plant in St Helena. By 1923, Daniel was also working with W. F. Detert and G. W. Elderto operate the Elder (or Detert) Magnesite Mine here, receiving equipment from the recently closed White Rock Mine in Pope Valley. North of the Elder Mine was the Berthenia Magnesite Mine. It was located on a three-feet-wide, northwest-trending band of magnesite that was traceable for several miles.

Water: The route leaves the Napa River watershed (and Sage Creek tributary) and enters the Putah Creek watershed (along Soda Creek tributary).

The road continues to descend along Soda Creek to its confluence with Capell Creek at Turtle Rock Bar and Cafe.

Mile 6.8 (0.6) [0.9] Serpentinite.

The road crosses into serpentinite for a short stretch, connected to a much larger serpentinite exposure on the ridge to the south.

Mile 7.4 (0.0) [0.6] Turtle Rock Bar and Café.

Intersection of CA-128 with Berryessa-Knoxville Road (see previous description in Lake Hennessey to Turtle Rock section).

Appendix A. Detailed Geology Maps

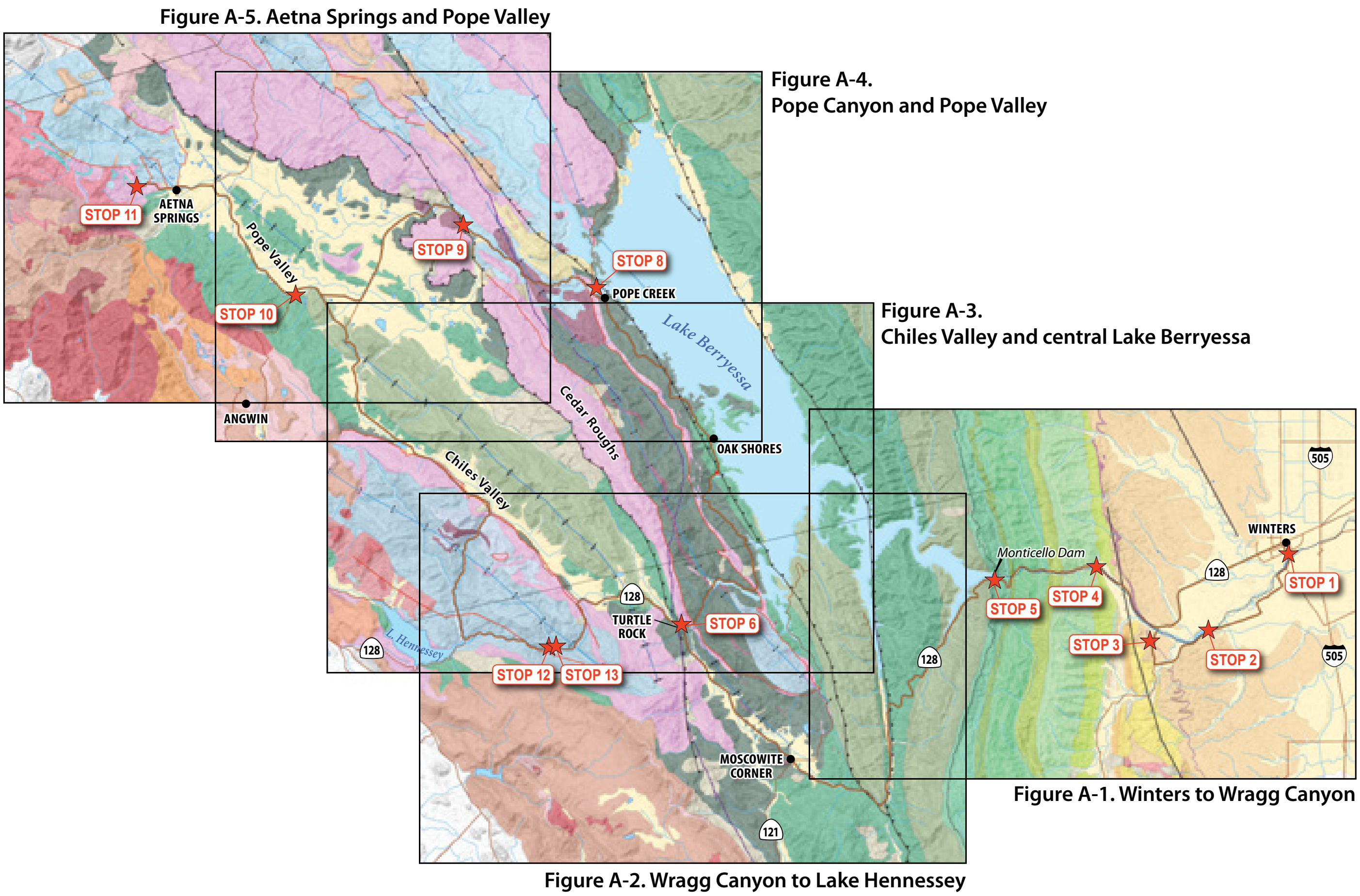

Figure A-0 Index map for detailed geology maps.
Source: Sims et al. 1973, Fox et al. 1973, Lienkaemper 2012, O'Connell et al. 2001, Phipps and Unruh 1992

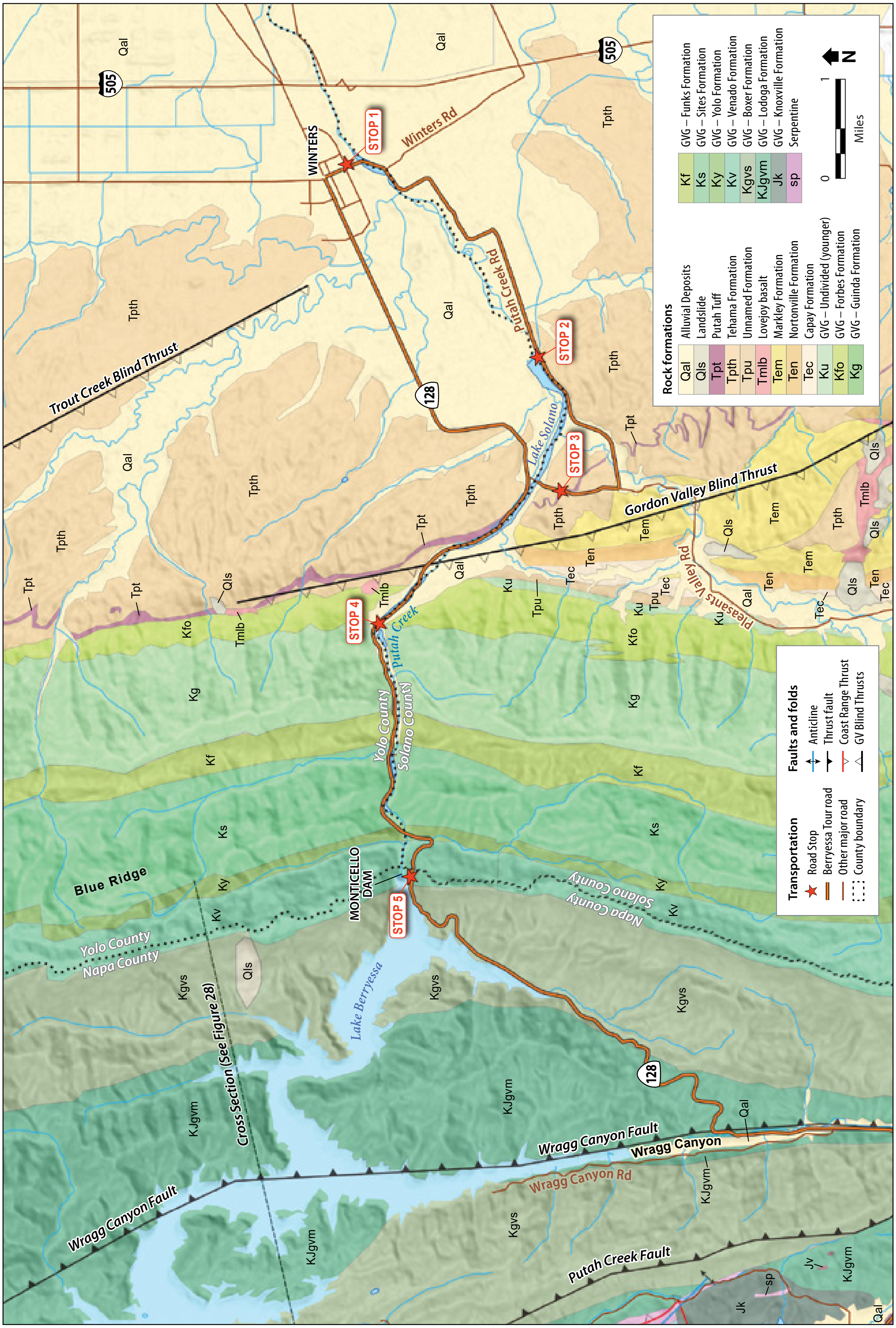

Figure A-1 Winters to Wragg Canyon detailed geology map

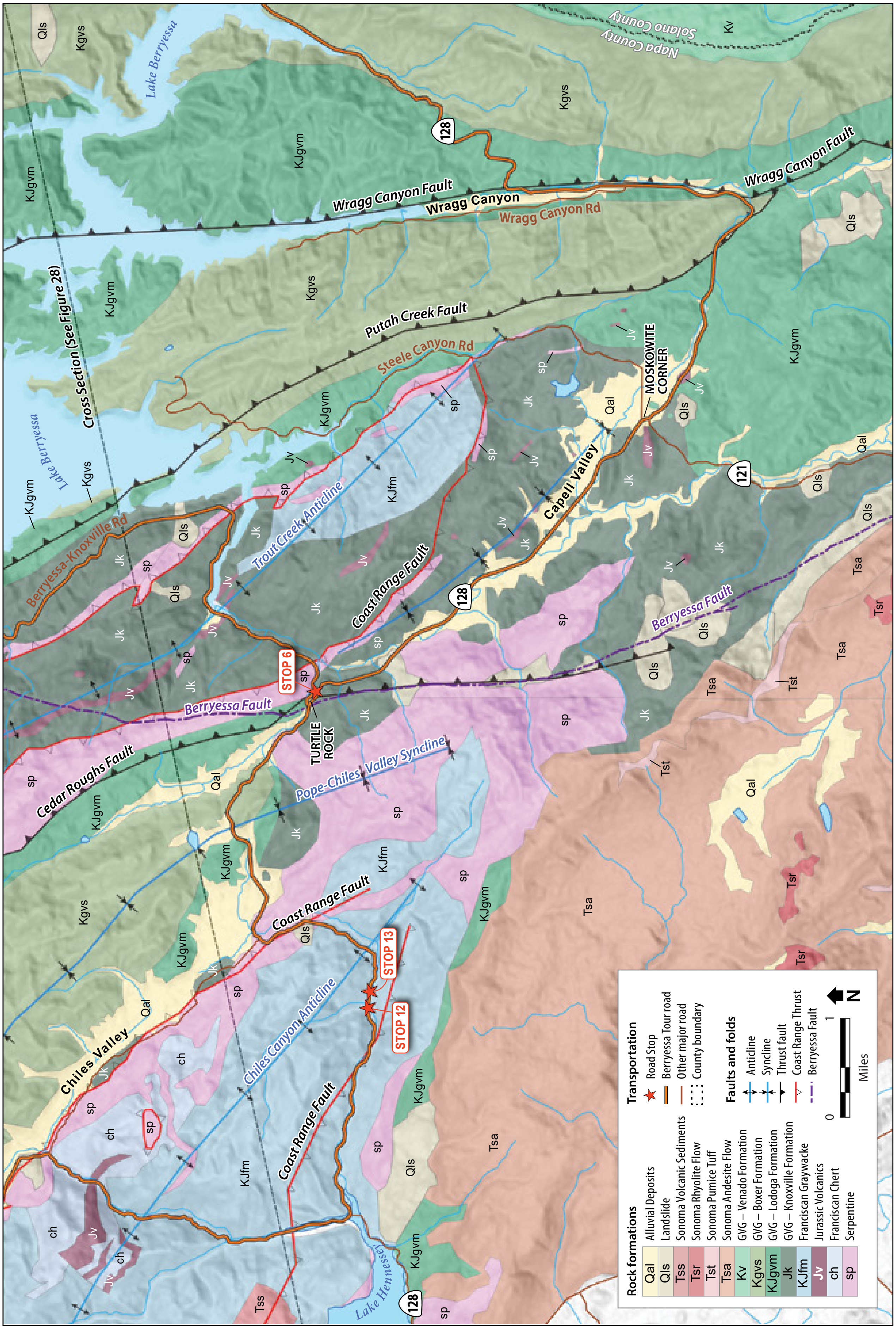

Figure A-2 Wragg Canyon to Lake Hennessey detailed geology map

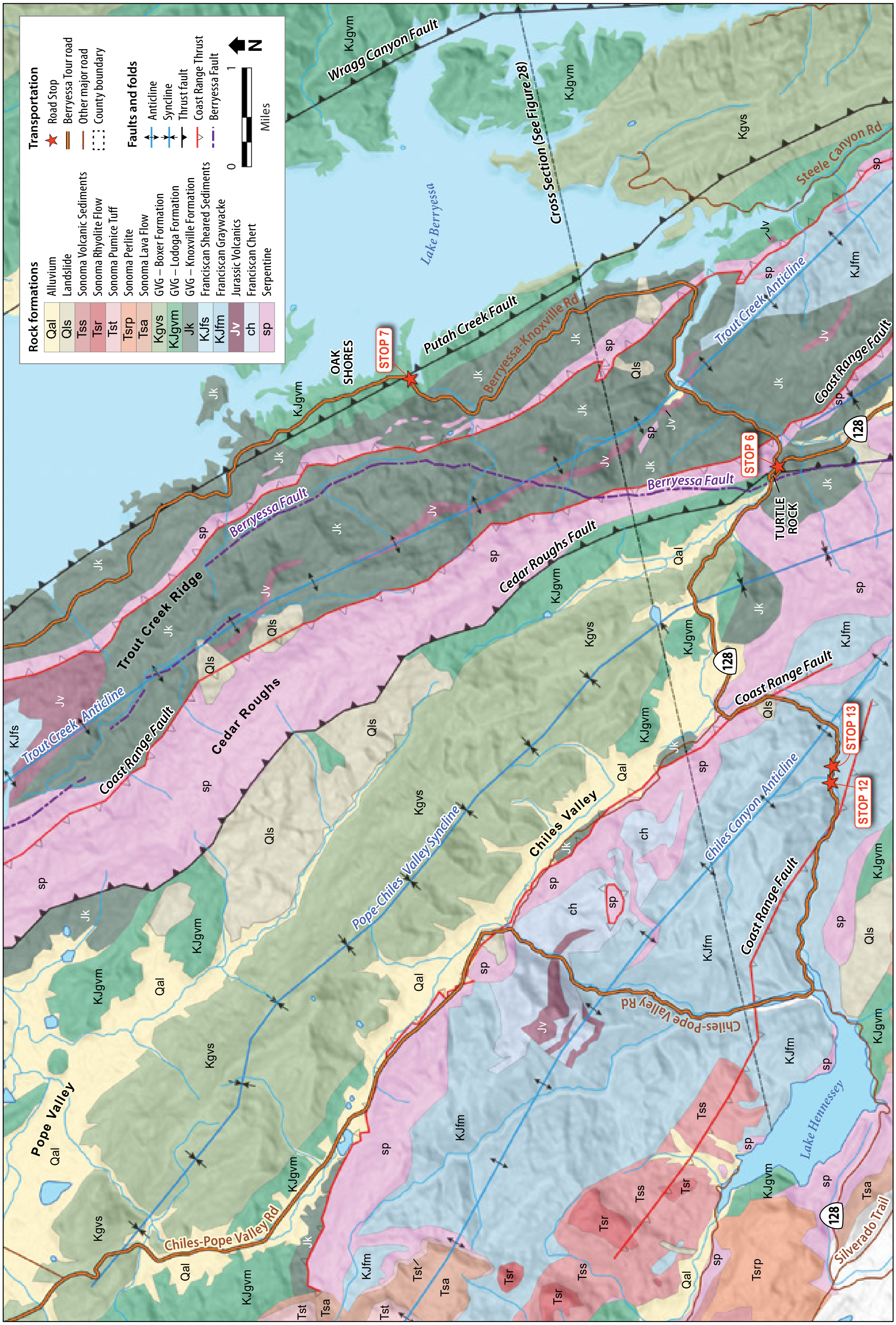

Figure A-3 Chiles Valley and central Lake Berryessa detailed geology map

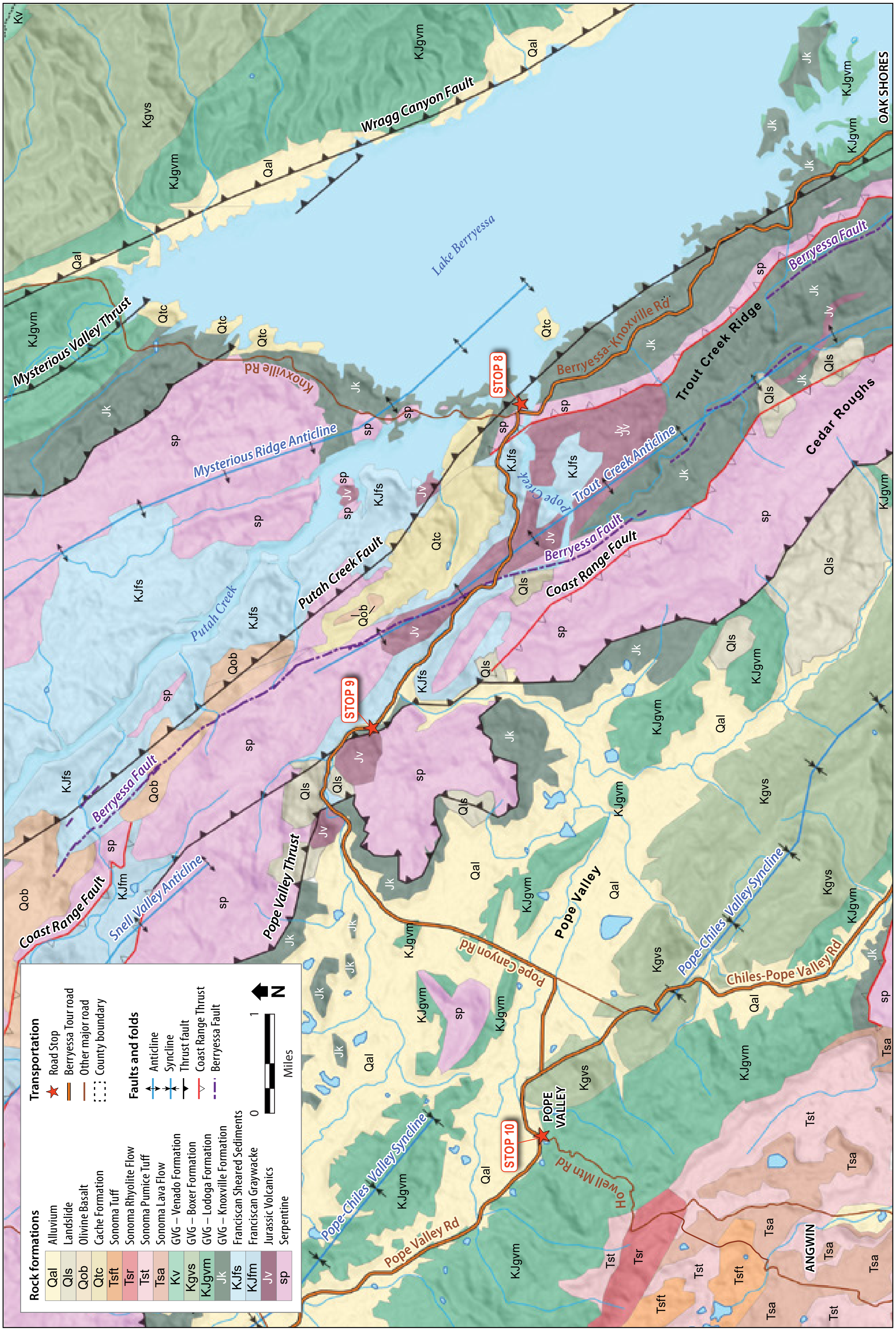

Figure A-4 Pope Canyon and Pope Valley detailed geology map

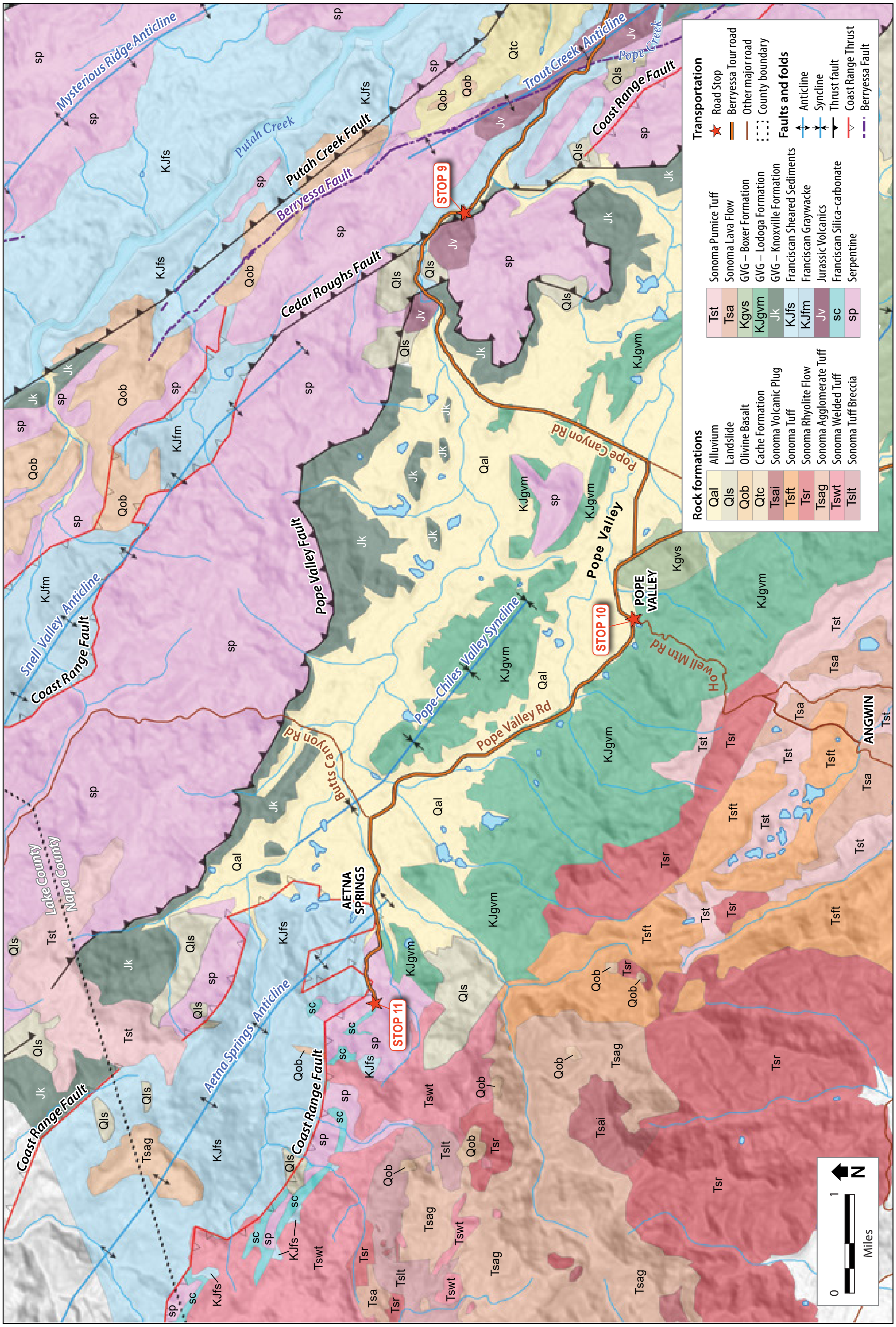

Figure A-5 Aetna Springs and Pope Valley detailed geology map

Appendix B. Abbreviations and Chemical Symbols

Abbreviations

AAPG: American Association of Petroleum Geologists

BLM: Bureau of Land Management (U. S.)

BSMNM: Berryessa Snow Mountain National Monument

Cal Fire: California Department of Forestry and Fire Protection

Caltrans: California Department of Transportation

CDFW: California Department of Fish and Wildlife

CDPR: California Department of Parks and Recreation

CRO: Coast Range Ophiolite

DWR: California Department of Water Resources

GSA: Geological Society of America

GVG : Great Valley Group

km: kilometer

km^2 : square kilometer

m^3/s: cubic meters per second

Ma: millions of years before the present. For example, 10 Ma refers to a time in the Miocene, 10 million years before present

mm: millimeter

NGO: Non-governmental organization

NRCS: Natural Resources Conservation Service, part of USDA

OSD: Open Space District

PMP: physical mile post sign installed by highway department

ppm: parts per million

RCD: Resource Conservation District

SLC: California State Lands Commission

UCANR: University of California Division of Agriculture and Natural Resources

UCNRS: University of California Natural Reserves System

USBR: U.S. Bureau of Reclamation

USDA: U. S. Department of Agriculture

USFS: U. S. Forest Service

USGS: U. S. Geological Survey

Chemical Symbols

Al = Aluminum

Ca = Calcium

$CaCO_3$ = Calcium carbonate

Cl = Chlorine

CO_2 = Carbon dioxide

CO_3 = Carbonate

F = Fluorine

Fe = Iron

K = Potassium

H = Hydrogen

H_2O = Water

He = Helium

Hg = Mercury

HgS = Mercury sulfide

Mg = Magnesium

O = Oxygen

OH = Hydroxide

P = Phosphorous

pH = ‘potential of Hydrogen,’ a measure of acidity or alkalinity of water soluble substances

S = Sulphur

Si = Silicon

SiO_2 = Silicon dioxide (silica)

Appendix C. Glossary

Accretion: In reference to plate tectonics, the process of adding new material, such as sediments or small continental masses, to the continental margin of a tectonic plate, for example, in a subduction zone.

Actinolite: A green colored mineral, $Ca_2 (Mg, Fe)_5Si_8O_{22}(OH)_2$, that is commonly found in low temperature metamorphic rocks.

Alluvial fan: Mass of sediment deposited at some point along a stream course at which there is a sharp decrease in gradient, such as between a mountain range and a plain. Essentially, a fan is the terrestrial equivalent of a river-delta formation.

Alluvium: Sediment that is deposited, generally on a floodplain, by a river or stream.

Altiplano: An elevated plateau in the central Andes, mostly in southern Peru and Bolivia, which averages 12,300 feet (3750 m) in elevation. Volcanic activity (arc magmatism) rapidly stopped in this section of the Andes between 45 to 35 Ma as the steeply-dipping subduction zone shallowed to an almost horizontal angle. This led to shortening and buckling of the crust, uplifting the entire region and creating the high plateau.

Amphibole: A group of minerals with prism or needlelike crystals that are common in igneous rocks (such as granite and andesite) and metamorphic rocks (schists and gneisses). This group includes actinolite, hornblende, and glaucophane.

Anadromous: Fish born in freshwater who spend most of their lives in saltwater and return to freshwater to spawn, such as salmon and some species of sturgeon.

Andesite: A volcanic rock that has silica content between that of rhyolite and basalt. It is commonly found in volcanic arc settings, such as in the Cascades or Aleutians.

Anticline: A fold in strata with the oldest layers in the core, usually arch-shaped and closing upwards.

Arc (magmatic or volcanic)**:** A line of active or extinct volcanoes formed on the overriding tectonic plate of a subduction zone, often in an arc shape when seen from above and parallel to the ocean trench.

Asthenosphere: The weak zone within the upper mantle, underlying the lithosphere, where the mantle rocks deform by plastic flow, as when one squeezes toothpaste out of its tube.

Basalt: The most common volcanic rock on Earth, basalt is generally dark in color and low in silica content. It underlies much of the ocean floor.

Bedding: Layering of sheet-like units, called beds or strata. A bed or stratum is the smallest distinguishable division within stratified sedimentary rocks.

Blind fault: A thrust fault that terminates before reaching the surface. There is no evidence of the fault at the surface, so it may remain undetected until it ruptures.

Blueschist: A type of metamorphic rock formed at relatively low temperatures but high pressures within a subduction zone. Its blue color comes from the mineral glaucophane.

Boxer Formation: Thin-layered shale beds (94–100 Ma) that are part of the older Great Valley Group of sediments, probably deposited in the mid-fan or basal slope of a submarine fan.

Breccia: A sedimentary or igneous rock composed of angular fragments (clasts).

Carbonate: Minerals—such as calcite—or rocks dominated by the carbonate ion CO_3. The most common carbonate rocks are limestone and dolomite.

Cenozoic: The most recent of three major geologic eras that supported living species, covering the last 66 million years. The name refers to "new life" and the era is preceded by the Mesozoic era. It is subdivided into the Paleogene and Neogene.

Chamise: An evergreen shrub that forms extensive, single-species stands of chaparral. It is highly adapted to wildland fires. The word comes from the Spanish camisa, for shirt, because it covers the hillsides like a piece of clothing.

Chaparral: A shrub-dominated vegetation type, found primarily in California and Baja California, consisting of plant species that are very tolerant of summer droughts and high temperatures.

Chert: A chemically precipitated sedimentary rock composed of the skeletal remains of radiolaria, which were deposited in deep submarine sediments and have since been replaced by silica (SiO_2). Its crystals are so minute that they are only visible with a microscope. Thus it is a form of micro-crystalline quartz.

Chlorite: A green colored mineral, $(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$, that is commonly found in low temperature metamorphic rocks.

Chromium: An elemental metal found in chromite ore that is used in the manufacture of stainless steel.

Chromite: An ore from which chromium is extracted. It is generally concentrated in ultramafic rocks like peridotite and gabbro.

Clast: A rock fragment.

Cleavage: Sets of closely spaced, generally parallel fractures within a rock which form in response to tectonic deformation.

Coast Range Ophiolite: Ophiolite of Middle to Late Jurassic age located in the California Coast Range. Remnants, disrupted by younger faults, are found underlying sedimentary rocks of the Great Valley Group.

Compression: Stress on materials that leads to a smaller volume or a shorter length.

Conglomerate: A coarse-grained, sedimentary rock comprised of rounded fragments (larger than 2 mm diameter) of other rocks that were transported and deposited by streams.

Contact (geological)**:** The surface where two rock units are juxtaposed either through deposition, tectonic actions (such as faulting), or igneous activity.

Continental crust: The type of crust that makes up continents, dominated by rocks enriched with lighter elements, such as silicon and oxygen, aluminum, and potassium. It varies between 6 and 50 miles (10-80 km) thick. It is less dense than oceanic crust, and thus floats higher on the mantle, just as a piece of Styrofoam floats higher on water than a piece of wood does.

Continental shelf: Gently seaward-sloping portion of the seafloor that extends between the shoreline and the top of the continental slope at about 500 feet (150 m) depth.

Continental slope: The relatively steeply sloping surface that extends from the outer edge of a continental shelf down to the deep ocean floor, often beyond 6000 feet (2000 m) deep.

Continuity: (geological): Unbroken and consistent layering of sedimentary rocks or volcanic layers that were deposited over a broad region or a lengthy period of time.

Convergent boundary: The boundary where two tectonic plates are moving toward each other.

Cretaceous: The third of three Mesozoic periods. It lasted from 145.5 to 66 Ma, following the Jurassic and preceding the Paleogene. Flowering plants first appeared during this period. This period had the highest diversity of dinosaurs and ended with a mass extinction event.

Crust::The thin outermost layer of the Earth.

Dacite: A light-colored, volcanic rock type containing 63–70% silica by weight.

Deformation: Folding or faulting of rock layers by tectonic forces such as subduction.

Deposit (geological)**:** An accumulation or layer of solid material, either consolidated or unconsolidated, left or laid down by a natural process. Deposits include sediments derived by water, wind, ice, gravity, and/or volcanic activity.

Descending plate: The downward-moving plate at a subduction zone.

Diabase: A dark-colored intrusive igneous rock, which often occurs in vertical, sheet-like bodies. It is compositionally equivalent to basalt (which erupts and cools quickly on the surface) and gabbro (which cools more slowly at depth to form larger crystal grains).

Dip: The angle of inclination (i.e., deviation from horizontality) of layered strata.

Disconformity: A break in sedimentation that leaves rock layers—separated in time—horizontal and parallel to each other. The gap in sediment accumulation is often difficult to detect.

Discontinuity: A break in the physical or chemical continuity of a rock mass. A discontinuity can be, for example, in bedding, foliations, joints, fractures, fissures, or fault planes.

Displacement: The relative movement on either side of a fault plane; it may be in any direction parallel to the plane.

Divergent boundary: The boundary between two plates, usually a mid-ocean ridge, where plates form and then spread away from one another.

Dunite: A coarse-grained, intrusive igneous rock—often found in the mantle—composed almost entirely of the mineral olivine.

Eclogite: A coarse-grained metamorphic rock, containing garnet, which forms at high pressures and intermediate temperatures, deep within subduction zones.

Endemic: A species that is native and found only in a particular area.

Eocene: The second of the three epochs of the Paleogene Period, extending from the end of the Paleocene, 56.5 Ma ago, to the beginning of the Oligocene, 35.4 Ma ago. Modern mammal families and the first grasses appeared, and the period was the warmest of the entire Cenozoic Era.

Epidote: A green colored mineral, $Ca_2(FeAl)_3Si_3O_{12}(OH)$, that is commonly found in low temperature metamorphic rocks.

Epoch: A subdivision of geologic time within a geologic period, generally ranging in length from 10 to 35 million years.

Era: One of the largest divisions of geologic time, such as the Cenozoic or Mesozoic era, ranging in length from 66 million years to over 1000 million years.

Exposure (geological)**:** A rock surface visible above the ground.

Extrusive rock: The subgroup of generally fine-grained igneous rocks that erupt and crystallize from hot magma above the Earth's surface. The rapid cooling prevents large visible crystals from forming within the rock. Compare with intrusive.

Facies: In metamorphism, an association of rock-forming minerals which crystallize at specific temperatures and pressures.

Fan (geological)**:** An unconsolidated sedimentary deposit that accumulates at the base of a slope, generally fan-shaped from above. It may be an alluvial fan or a submarine fan.

Fault: A generally planar surface of fractured contact between two rock bodies, caused by brittle failure due to tectonic forces, and along which observable displacement has occurred. Faults mark discontinuities in rock layers created by vertical and/or horizontal tectonic forces.

Fault gouge: Rock that has been crushed and ground by friction along a fault plane into a clay-like filling.

Feldspar: Common rock-forming silicate minerals composed of sodium, calcium, potassium, and aluminum.

Fold: A bend in rock layers caused by tectonic stresses, mainly compression.

Foliation: A continuous, flattened rock fabric within metamorphic rocks, generally caused by the orientation of dark minerals with a generally platy or tabular habit. The layers are planar and parallel to each other, but these layers are not necessarily parallel to bedding or cleavage.

Footwall: The rocks that lie directly beneath any inclined fault surface.

Forbes Shale Formation: The youngest unit (83–78 Ma) of the Great Valley Group, deposited as the outer part of a submarine fan.

Fore-arc: Also called the arc-trench gap, the region between a volcanic arc and the subduction zone that has created the arc.

Formation: A group of strata, distinguishable from others, and thick enough and extensive enough to plot on a geological map. Formations often contain a variety of related or interlayered rock types, such as thin alternating beds of shale, siltstone, and sandstone.

Franciscan Complex: An extensive complex of formations along the coast of California that developed over 150 million years during the late Mesozoic as several oceanic terranes collided with North America. Most of the Complex consists of sandstone, graywacke (a sandstone with volcanic and other materials), shales, and conglomerates. It also contains tectonic blocks of high pressure, low temperature metamorphic rocks (blueschists and eclogites).

Gabbro: A dark, coarse-grained, intrusive igneous rock, compositionally equivalent to volcanic (extrusive) basalt. The deeper rocks of the oceanic crust are generally coarser-grained gabbro.

Garnet: A group of chemically variable minerals found in both igneous and metamorphic rocks. It occurs in many colors, but it appears most commonly as reddish glassy rock. Most garnet forms at convergent margins, where garnets are found in high-grade metamorphic rocks. Garnet's many varieties are used to gauge the history of their host rocks' temperature and pressure conditions.

Geothermal: Describes areas, rocks, or conditions of high heat flow, often due to underlying magmatic or orogenic activity.

Glaucophane: A blue, sodium-bearing amphibole, found almost exclusively in blueschist facies rocks that have experienced low temperature, high pressure metamorphism, such as in a subduction zone.

Grain (geological)**:** The smallest physical unit in a rock. In sediments, grain size ranges from clay particles to boulders. In igneous rocks, coarse-grained rocks have mineral pieces that are large enough to see without a hand lens.

Granite: An intrusive igneous rock, very high in silica, nearly always massive (i.e., lacking any internal structures), hard, and tough. It has the highest percentage of orthoclase and quartz of any igneous rock.

Graywacke: A type of sandstone generally characterized by its hardness, dark color, and poorly sorted angular grains of quartz, feldspar, and small rock fragments set in a compact, clay-rich matrix. It is commonly formed from sediment deposited in submarine avalanches or from strong turbidity currents creating mixed-sediment slurries on the edges of continental shelves.

Great Valley Group (GVG)**:** A 40,000 feet thick sequence of submarine sediments exposed along the rim of California's Central (Great) Valley that provides a continuous record of sedimentation from the Late Jurassic through the entire Cretaceous age (150–65 Ma).

Greenschist: A low temperature and pressure metamorphic rock. The green color comes from the minerals actinolite, chlorite, and epidote.

Greenstone: A field term applied to any compact, dark green, altered or metamorphosed basic igneous rock (such as basalt, gabbro, or diabase) that owes its color to the presence of green-colored minerals. The term is used for outcrops that haven't been studied in enough detail to determine the exact metamorphic facies (such as zeolite, prehnite-pumpellyite, or greenschist). In the context of this region, greenstone refers to altered basalt that erupted underwater near a mid-ocean ridge. The hot sea water changed the original minerals to the green-colored minerals chlorite, epidote, and/or actinolite. These rocks may have initially formed as pillow basalts, lava flows, or flow breccias.

Hanging wall: The rocks that lie directly above any inclined fault surface.

Holocene: The second of two epochs of the Quaternary**,** comprising the past 10,000 years of geologic history.

Horizontality: The state of being horizontal, parallel to level ground.

Hotspot (biological)**:** A region that contain a disproportionately large amount of biological diversity, usually in terms of numbers of species.

Hotspot (geological)**:** A volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the surrounding mantle. Their position on the Earth's surface is independent of tectonic plate boundaries.

Igneous: The class of rocks that are form by cooling and crystallization of magma (for intrusive igneous rocks) or lava (for extrusive igneous rocks).

Interbedded (geology)**:** The interlayering or alternating of different types of sedimentary layers, such as sandstone and shale, which occur in close proximity. These patterns indicate changes in depositional environment at the same location.

Intrusive rock: The subgroup of generally coarse-grained igneous rocks that crystallized from hot magma slowly below the Earth's surface. The slow cooling allows large visible crystals to form within the rock. Compare with extrusive.

Jurassic: The second of three Mesozoic periods. It lasted from 199.6 to 145.5 Ma, following the Triassic and preceding the Cretaceous. This is the time of the oldest formations found in the Berryessa region.

Klamath: A region in northwestern California and southwestern Oregon, covering about 9900 mi^2, dominated by the Klamath Mountains and drained by the Klamath River and its tributaries.

Klippe (plural, klippen)**:** A feature of a landscape underlain by low-angle thrust faults. It is a rock unit located at the leading and upper edge of a large thrust sheet that has been isolated from the main sheet by erosion.

Knoxville Formation: One of the oldest rock formations (152–126 Ma) of the Great Valley Group. It is extensively exposed along the west shore of Lake Berryessa. It has a much higher concentration of volcanic materials than other GVG formations, and was eroded from the andesitic-dacitic volcanic terrane that initially covered the Sierran-Klamath arc at about the Jurassic-Cretaceous boundary.

Lateral Continuity (principle)**:** The geological principle that sedimentary deposits were originally dispersed over considerable horizontal distance. Therefore, isolated sedimentary rock layers observed in the field are erosional remnants of what was once laterally continuous.

Lichen: A composite organism that consists of algae or cyanobacteria living among filaments of multiple fungi species in a mutualistic relationship.

Limb (of anticline or syncline)**:** The flank of a large structural fold. Usually there is one on either side of the main axis hinge line.

Lithosphere: The upper layer of the solid Earth, on continents and underlying oceans. It comprises the Earth's crust and upper mantle. The lithosphere is made of numerous tectonic plates, which have differential motions, thus giving rise to plate tectonics.

Lodoga Formation: A mid-Cretaceous age (125–100 Ma) part of the Great Valley Group that consists of dark gray siltstone, with many lenticular beds of sandstone, deposited in a deep submarine environment. The source material was a mixture of plutonic and volcanic detritus.

Lovejoy Basalt: A 15–14 Ma basalt flow that flowed 150 miles (240 km) from its source at Thompson Peak in the northern Sierra to near the mouth of Putah Creek Canyon. It erupted multiple times, flowing down an ancestral canyon in the Sierra and spreading out to cover much of the Sacramento Valley.

Mafic: Dark-colored igneous rocks containing abundant pyroxene and olivine. The term combines parts of the words magnesium and ferric (iron), elements that color the rock dark.

Magma: Molten silicate rock, below the earth's surface, containing dissolved gases. If magma erupts on the Earth's surface and its gases are released, it is called "lava."

Mantle: That portion of the Earth's interior—between the crust and core—composed mainly of peridotite.

Markley Sandstone: A 3700 feet (1130 m) thick unit that was deposited as part of a submarine fan about 40 Ma, in the middle Eocene.

Mélange: A "mixture" of large blocks of disparate rock types, created by sedimentary deposition and/or thrust faulting in subduction zones. These deposits may also be the products of mud volcanoes.

Metamorphic: A class of rock formed from originally sedimentary and/or igneous rocks that have been transformed by the action of elevated temperatures and/or pressures.

Mesozoic: The middle of three major geologic eras that supported living species. The era is preceded by the Paleozoic ("ancient life") and succeeded by the Cenozoic ("new life"). It spans an interval of geological time from about 252 to 66 million years ago and is subdivided into three major periods: the Triassic, Jurassic, and Cretaceous.

Microplate: A small tectonic plate or tectonic "terrane."

Mid-fan (alluvial)**:** The middle—as opposed to proximal and distal—portion of an alluvial fan.

Miocene: The first of the two epochs of the Neogene Period, extending from the end of the Oligocene, 23.03 Ma, to the beginning of the Pliocene, 5.332 Ma. Many mammals with a more modern appearance evolved during this epoch, including deer, pigs, and several elephant stocks.

Miwok, Lake: Native Californians who lived in the area between upper Putah Creek and Lower Lake.

Moho: A shortened form of Mohorovičić discontinuity, the seismic discontinuity that reflects the changes in rock type at the boundary between the Earth's crust and mantle.

Montane hardwood: A tree-dominated vegetation type that supports canyon live-oak, ponderosa pine, and California black oak. It occurs between 500 and 4000 feet (150 to 1200 m) of elevation in central California, depending on topography and soils. Below this zone are warmer, drier environments that support oak woodlands and open grasslands; above it are colder, moister areas with firs and lodgepole pines.

Montane chaparral: A shrub-dominated vegetation type that supports multiple species of manzanita, shrubby oaks, and ceanothus. The growth is so dense that it is often impenetrable to large mammals.

Mudstone: A sedimentary rock formed by the burial and cementation of mud or clay. Also called shale.

Nappe: a large sheet-like body of rock that has been moved a substantial distance (usually more than a mile) along a thrust fault from its original position. The movement may fold the rock into recumbent folds, similar to what happens when you try to push a tablecloth ("nappe" in French) across a table. Subsequent erosion may isolate parts of this thrust sheet from the main body (a "klippe") or erode holes ("windows") in the nappe to expose underlying rocks.

Neogene: Geologic time period between 23.3 and 2.58 Ma. It is the new formal name for the later part of the Tertiary (now an obsolete term), containing the Miocene and Pliocene epochs.

Nevadaplano: A high elevation (10,000 ft; 3000 m), Tibet-like plateau, which extended north to south across the Great Basin, from at least central Idaho to northern Sonora, from Late Cretaceous through Eocene times. The Sierra Nevada was the western flank of this erosional highland.

Nortonville Shale: A middle Eocene shale and sandstone that was deposited as part of a deep-sea fan.

Oceanic crust: the type of crust that makes up the ocean floors, dominated by rocks enriched with darker elements, such as magnesium, iron, calcium, and sodium. It is about four miles thick in most places and is much denser than continental crust.

Oligocene: The third of the three epochs of the Paleogene Period, extending from the end of the Eocene, 35.4 Ma, to the beginning of the Miocene, 23.3 Ma.

Olivine: A green mineral, $[Mg,Fe]_2SiO_4$, that is often a major component of many mafic and ultramafic igneous rocks, such as gabbro, basalt, and peridotite. Although it is a common mineral in the upper mantle, it weathers quickly on the surface.

Ophiolite: A rock sequence that includes deep-sea sedimentary rocks overlying pillow basalt, diabase, gabbro, and peridotite. It represents a "fossil" fragment of oceanic crust now exposed on land.

Orthoclase: A potassium-rich feldspar common in granitic rocks.

Orogeny: Mountain building event caused by plate collisions.

Paleogene: Geologic time period between 65 and 23.3 Ma. It is the new formal name for the early part of the Tertiary (now an obsolete term), containing the Paleocene, Eocene, and Oligocene.

Patwin: A group of contiguous bands of native Californians who lived on the southwest side of the Sacramento Valley, spoke similar languages, and had similar culture.

Period: A major subdivision of geologic time that divides up geologic eras, generally ranging in length from 40 to 80 million years.

Peridotite: A coarse-grained, ultramafic igneous rock, the dominant rock type of the Earth's mantle, that mainly contains the minerals pyroxene and olivine.

Pillow basalt: A morphological term for basalt that erupted into water beneath the ocean surface, typically at mid-ocean spreading ridges or at a submarine volcano, and cooled quickly in rounded and elongate shapes. All pillow basalts in this region have been metamorphosed at low temperatures to varying degrees to become greenstone. This metamorphosis may be either associated with burial in a convergent margin (Franciscan metamorphism) or burial beneath the GVG. When accompanied by related sheeted-dike complexes, they form part of a classic ophiolite sequence.

Plate Tectonics: A unifying concept in geology, describing the movement of rigid lithospheric "plates" in the Earth's upper layer above a hotter, more ductile asthenosphere.

Pleistocene: The first of two epochs of the Quaternary, spanning from approximately 1.806 Ma until the beginning of the Holocene about 11,500 years ago. The epoch is marked by several glacial and interglacial episodes in the northern hemisphere.

Pliocene: The most recent of the two Neogene epochs, spanning 5.332–1.806 Ma.

Plunging (geological structure)**:** A plunging anticline or a plunging syncline is one that has its axis tilted from the horizontal so that the fold is angled into the earth along its length. Plunge direction is the direction in which the axis of the fold tilts down into the earth.

Pluton: A relatively small intrusive igneous body (a few to tens of miles across) that forms within the Earth's crust from slowly cooled magma. Multiple plutons in the same area may be large enough (up to hundreds of miles long and 60 miles across) to be called a batholith.

Pull-apart basin: A structural basin where two overlapping faults or a fault bend create opposing tensional forces (pulling the land apart), opening a sort of parallelogram that sinks lower than the surrounding land.

Pyroclastic: Refers to an explosive form of volcanism.

Pyroxene: A black or green mineral that is common to many igneous as well as high-temperature metamorphic rocks. There are two types of pyroxenes: clinopyroxenes $[Ca(Mg,Fe)_2Si_2O_6]$ and orthopyroxenes $[(Mg,Fe)_2Si_2O_6]$, which differ by their crystal structure. Pyroxenes are among the major minerals in basalt and gabbro.

Quartz: A common mineral composed of silica.

Quaternary: The most recent geological period, covering the past 1.64 Ma of geologic time, the time of modern humans. It is subdivided into the Pleistocene and Holocene epochs.

Radiolaria: Microscopic marine organisms (protozoa) whose shells are silica-rich. They are found as zooplankton throughout the ocean, and their skeletal remains, as a siliceous ooze, cover much of the ocean floor. Over time, the ooze becomes rock that is known as chert. Due to their rapid changes in species, they represent important diagnostic fossils.

Rancho: Spanish for ranch. A large land grant issued in California by the Spanish, and later Mexican, governments. Under American rule, the boundaries of ranchos were retained as part of the land survey system.

Rhyolite: A volcanic rock, high in silica content, that typically erupts explosively, and is commonly found in volcanic arc settings, like the Cascades or Aleutians.

Riparian habitat: A vegetation type that occurs along streams or rivers. It is usually distinct from more upland, and drier, vegetation types.

Right-lateral (fault)**:** A type of strike-slip fault, one with little vertical displacement. If you stand on either side of the fault, the block across the fault from you has moved, or is still actively moving, to your right.

Sandstone: A type of sedimentary rock composed of sand-sized mineral and rock grains.

Seamount: An isolated, submarine mountain of volcanic origin.

Sediment: Material derived from pre-existing rock, from biogenic sources, or precipitated by chemical processes, and deposited at, or near, the Earth's surface.

Sedimentary: Class of rocks that form either by (1) deposition of sediment and subsequent cementation (e.g., sandstone, conglomerate) or (2) chemical precipitation (e.g., chert).

Seismic: Related to vibration of the earth, often due to an earthquake.

Sequence (depositional)**:** A discrete succession of geological layers, deposited more or less continuously.

Serpentine: Describes an outcrop, soil, plants, or region dominated by serpentinite. Serpentine also refers to a group of minerals—lizardite, antigorite, and chrysotile—that are produced by the hydrous (watery) alteration of ultramafic rocks. These minerals all have the composition $Mg_6[Si_4O_{10}][OH]_8$. **Lizardite** is the most common form and has a very fine-grained, platy texture. **Chrysotile** has long, thin, highly fibrous ("asbestosform") crystals. **Antigorite** generally forms at higher temperatures than the other two minerals and often has a flaky or plate-like texture.

Serpentinite: A metamorphic rock, originally a peridotite or dunite, which is composed of serpentine minerals.

Serpentinization: The metamorphic processes through which peridotite or dunite transform into a serpentinite.

Shale: A sedimentary rock formed by the burial and cementation of mud or clay. Also called mudstone.

Sheeted dikes: A series of approximately vertically emplaced intrusive igneous rocks, typically basalt or diabase, that have been intruded against one another.

Siltstone: A type of sedimentary rock composed of grains mainly between 4 and 62.5 microns in diameter.

Slate: The metamorphic equivalent of a shale or mudstone.

Sonoma Volcanics: A volcanic complex that includes tuff, obsidian, flow rock, pyroclastic breccia, and intrusives which range in composition from rhyolite to basalt. Approximately 4.2 to about 8.5 Ma in age, they are a part of a series of volcanic complexes related to initiation of the San Andreas Fault system.

Spillway: A structure used to provide the controlled release of flows from a dam or levee into a downstream area, typically the riverbed of the dammed river itself. Spillways ensure that the water does not overflow and damage or destroy the dam.

Splay: A branch of a larger fault that is often roughly parallel to the main fault.

Strata: Layers, or series of layers, of sedimentary or volcanic rocks.

Strike: The orientation (or compass direction) that a horizontal line makes on an inclined plane.

Structure: The three-dimensional architecture (folds, faults, and so on) of rock layers in the Earth.

Subduction zone: One of the three types of tectonic plate boundaries: a convergent boundary in which one plate is subsumed within the Earth's interior under the other plate.

Submarine fan: A body of sediment on the sea floor deposited by water-rich slurries flowing off the continental shelf through submarine canyons. They vary in size from a few miles in radius to depositional systems covering over 40,000 square miles (one million km^2).

Superposition (principle)**:** A scientific assumption that strata are deposited sequentially, so that in a tectonically undisturbed sedimentary succession, each layer is younger than the one below it.

Syncline: A fold in strata, with the youngest layers in the core of the fold, usually basin or trough-shaped so the layers dip downward toward the center of the structure.

Tectonics: The processes or movements associated with large-area deformation of the Earth's crust and lithosphere as manifested by folding and faulting. See plate tectonics.

Tehama Formation: An extensive sedimentary layer of non-marine clays, silts, and volcanic sands and conglomerates along the west-side floor of the Sacramento Valley. These sediments were eroded during the Pliocene and Pleistocene (3.4 to 1.0 Ma) from the Coast Range and the Klamath Mountains.

Terrane: A fragment of crustal material formed on, or broken off from, one tectonic plate and accreted or "sutured" to crust lying on another plate. The crustal block or fragment preserves its own distinctive geological history, which is different from that of the surrounding areas.

Tertiary: A widely used term for the geologic period from 66 to 2.6 Ma. It is no longer recognized as a formal unit by the International Commission on Stratigraphy and has been replaced by the Neogene Period **(**23.03–2.58 Ma, comprising the Miocene and Pliocene epochs) and the Paleogene Period **(**66–23.03 Ma, comprising the Paleocene, Eocene, and Oligocene epochs).

Thrust fault: A type of low-angle fault, caused by compressive tectonic stresses, along which the hanging wall has moved up and over the footwall.

Transform fault: A type of strike-slip fault that occurs at plate boundaries.

Transpression: A type of strike-slip deformation that has an additional simultaneous shortening across the zone. It usually produces vertical thickening in the crust.

Travertine: Layered, whitish sedimentary rock composed of calcium carbonate that is chemically precipitated from hot or cold springs.

Trench: An elongated depression on the ocean floor, lying parallel to the trend of an island arc, directly above an active subduction zone.

Tuff: Compacted volcanic ash with grain sizes less than 2 mm.

Tuleyome: A not-for-profit, science-based conservation organization working in the Northern Inner Coast Range of California and the Berryessa Snow Mountain National Monument.

Turbidite: A sedimentary deposit created by an underwater current of rapidly moving, sediment-laden water (a turbidity current) flowing down a submarine canyon.

Ultramafic rock: Very dark-colored igneous rocks (such as dunites and peridotites) that have high ("ultra") amounts of mafic (dark-colored) minerals, mainly pyroxene and olivine. When metamorphosed in the presence of water, these rocks become serpentinite.

Venado Sandstone: A very resistant, massive, 2000 feet (600 m) thick sandstone unit that forms the crest of the Blue Ridge. It is 100 Ma in age and was deposited in the inner and middle part of a submarine fan.

Volcanic: A subset of igneous rocks, which are formed when magma erupts on the surface of the Earth.

Wappo: An indigenous people of northern California. Their traditional homelands are in Napa Valley, Alexander Valley, and the Russian River valley.

Appendix D. Sources for More Information

Appendix Contents

Local Organizations

Conservation Groups

Audubon California: ca.audubon.org

Land Trust of Napa County: napalandtrust.org

Napa Solano Audubon Society: napasolanoaudubon.com

Putah Creek Council: putahcreekcouncil.org

Putah Creek Trout: putahcreektrout.org

Quail Ridge Wilderness Conservancy: http://members.dcn.org/quail-rid/

Solano Land Trust: solanolandtrust.org

Tuleyome: tuleyome.org

Yolo Audubon Society: yoloaudubon.org

Yolo Land Trust: theyololandtrust.org

Historical Societies

Historical Society of Winters: https://www.historicalsocietyofwinters.org

Napa County Historical Society: wordpress.napahistory.org

Solano County Historical Society: solcohs.org

Yolo Historical Society: ychs.org

Land Management or Resource Agencies

City

City of Napa Park and Recreation Services: cityofnapa.org/354/Parks-Recreation-Services

City of Winters Parks and Recreation: cityofwinters.org/parks-and-recreation

County

Napa County Regional Park and Open Space District: napaoutdoors.org

Solano County Parks: solanocounty.com/parks

Solano County Water Agency: scwa2.com

Solano Habitat Conservation Plan: scwa2.com/water-supply/habitat/solano-multispecies-habitat-conservation-plan

Yolo County Parks: www.yolocounty.org/visitors/parks

Yolo County Parks: Putah Creek Fishing Access. http://www.yolocounty.org/general-government/general-government-departments/parks/parks-information/putah-creek-fishing-access

Yolo Habitat Conservancy: yolohabitatconservancy.org

Resource Conservation Districts

Napa County RCD: naparcd.org

Solano RCD: solanorcd.org

Yolo County RCD: yolorcd.org

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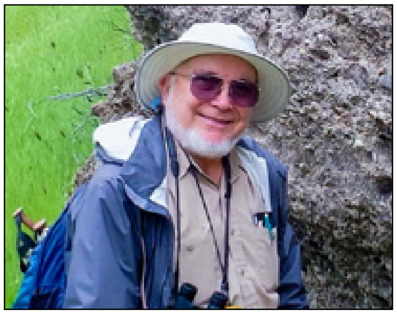
Figure 69. The Berryessa Snow Mountain National Monument was designated by President Obama on July 10, 2015. This is the community celebration on March 18th, 2016. Secretary Sally Jewell and Congressman Mike Thompson are center front.

Figure 70. Putah Creek Canyon and Sacramento Valley from a high ridgetop.

Figure 70: Volunteer trail crew at Annie's Rock above Cold Canyon at southern end of Berryessa Snow Mountain National Monument looking 100 miles north towards Snow Mountain.

Authors



Eldridge Moores (1938-2018) joined the UC Davis Geology Department (now Earth and Planetary Sciences) in 1966 and taught geology there for 47 years. His geological career spanned all continents. His studies, including plate tectonics, helped revolutionize our understanding of the geological history of Earth.

Judy Moores married Eldridge in 1965, and together they raised three children. She volunteered in local schools for several years, served on the Yolo County School Board, and co-founded the Davis Science Center, now called Explorit. In 1999, she was awarded the C.A. Covell Davis Citizen of the Year Award for her volunteer efforts. Together the Edridge and Judy Moores have introduced a few thousand people to the geology of northern California.

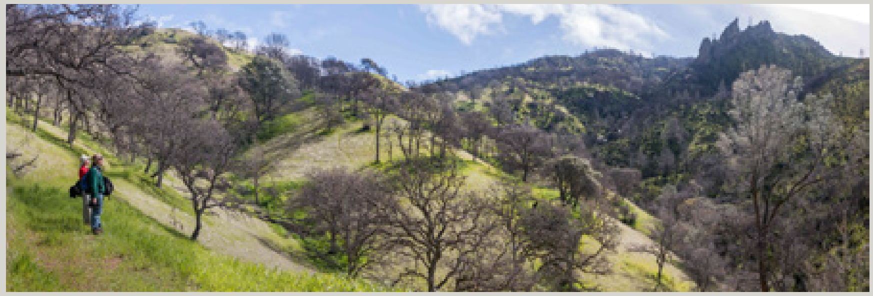
Marc Hoshovsky is a retired naturalist living in Davis, California. He spent 30 years working for state government on endangered species habitat conservation planning throughout California. He has a B.S. degree in biology from Utah State University and two degrees from Humboldt State University: a B.S. degree in geology and a M.A. degree in ecology. He has been photographing nature and landscape scenes for over 40 years, and he enjoys researching and promoting local history, geology, and ecology. He is married, with two grown sons who both have degrees in environmental science.

Peter Schiffman is Professor Emeritus and Research Geologist Emeritus in the Department of Earth and Planetary Sciences at UC Davis. His research specialty is the mineralogy, petrology, and geochemistry of metamorphic rocks, especially the metavolcanic rocks found in active geothermal systems on land (in Iceland, Mexico, Hawaii, and California), at oceanic spreading centers (in the northeast Pacific), as well as in the fossil hydrothermal systems found in ophiolite complexes (in California, Cyprus, and Oman). After receiving his Ph.D. from Stanford University in 1978, he spent two years at NASA's Johnson Space Center on a National Research Council post-doctoral fellowship, then spent three years at UC Riverside before joining the Davis faculty in 1983.

Bob Schneider has worked with passion to protect public lands since his student volunteer days in the late 1960s to establish the Redwood National Park. He later cofounded both the California Wilderness Coalition in 1976 and Tuleyome in 2002. Bob most recently spearheaded a team of hard-working people and organizations to designate the Berryessa Snow Mountain National Monument in 2015. He has a B.S. degree in geology from UC Davis, is married with two grown children, and lives in Davis.

"Where a transform fault develops any kind of bend — which is not uncommon — the bend will pull apart as the two sides move, opening a sort of parallelogram, which, among soft mountains, will soon be vastly deeper than an ordinary water-sculpted valley. Lake Berryessa lies in a pull-apart basin, and so does Clear Lake." ... Those two sentences are mine, legally, but they belong, in a much deeper sense, to Eldridge Moores, who taught me their meaning beside Lake Berryessa.

– **John McPhee**, author of **Assembling California**



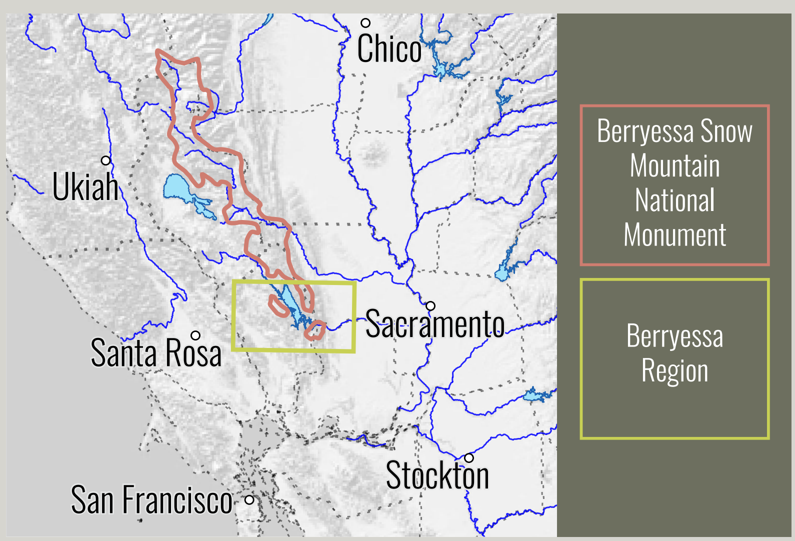
The Undiscovered Landscape

Exploring the Berryessa Region tells the story of a landscape, just west of Sacramento and north of San Francisco, born through plate tectonic forces. The Berryessa Region anchors the southern end of the Berryessa Snow Mountain National Monument and holds geologic wonders including subduction zones, thrust faults, ophiolites, turbidites, mud volcanoes, and pull apart basins. These features nurture world-renowned biological diversity which, over time, has fostered a rich history of human cultures—including Native Americans. Today recreational opportunities draw new visitors with hiking, camping, birding, botanizing, horse riding, boating, and managed off-highway vehicle use. Regional ecosystem services include water, forests, and ranchlands.

Full of rich details, this book helps visitors explore this fascinating region by car and discover how regional diversity developed. Readers can use the mile by mile descriptions as a field guide to explore these geological, ecological, and historical features.

Included in these pages:

- Mile by mile driving descriptions showcasing geologic highlights
- 70+ full-color figures and maps
- Lively sidebars exploring region natural and cultural history
- Introduction to regional geological concepts



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