Geology

Quail Ridge Reserve is located in California's Inner Coast Range in the sedimentary strata of the Great Valley Sequence. In this chapter we begin by describing the geologic history of the California Coast Ranges, including how they were deformed and uplifted to their present location. We then discuss the origins of the sediments found at Quail Ridge and the derivation of local soils.

Geologic History

Plate Convergence and Subduction

The geologic history of northern California begins with the series of plate convergence and subduction events that added the state to the western edge of North America. The formation and movement of the earth's lithospheric plates begins at mid-ocean spreading centers, where hot rock rises from the Earth's interior and partially melts to form new oceanic lithosphere (oceanic crust and upper mantle). As the molten rock crystallizes at these spreading centers, it forms a vertically ordered series of rocks that include peridotite at the base, followed by gabbro, diabase, and at the top, basalt flows that erupt on the seafloor. When exposed on land, this series is collectively known as an ophiolite. As this new lithosphere forms, older lithosphere migrates away from the spreading centers, subsides, and becomes buried under marine sediments. This movement inevitably leads to the convergence of separate lithospheric plates. Subduction is the disappearance of one plate beneath another during convergence; the relatively cold subducted (down-going) plate becomes heated as it sinks into the hot mantle, and partially melts to form magma sources for chains of volcanoes, such as the Andes or the Cascades. Magma that comes to rest in the crust beneath the volcanoes cools and crystallizes slowly to form granitic rocks, thus building up the continental crust.

A continent-building plate convergence occurred in the late Jurassic, Cretaceous, and Tertiary periods (about 140 to 5 million years ago), when the oceanic Kula and Farallon Plates, coming from the west, were subducted beneath the North American continental margin (Fig. 3-1). This process was instrumental in creating the rocks of both the Coast Ranges and the Sierra Nevada. As first the Kula and later the Farallon plate descended beneath the North American continent, hot fluids derived from the descending plate caused melting in the mantle below the overriding continental plate. This produced a chain of volcanoes on the continent that were very similar to the present-day Cascade volcanoes, where subduction of the Juan de Fuca Plate (a remnant of the Farallon Plate) beneath North America is still occurring today. The molten rock remaining beneath the volcanoes cooled to become the Sierra Nevada Batholith, the black and white granitic rock that characterizes that range. Similar rocks are present, but less abundant, in the Klamath Mountains.

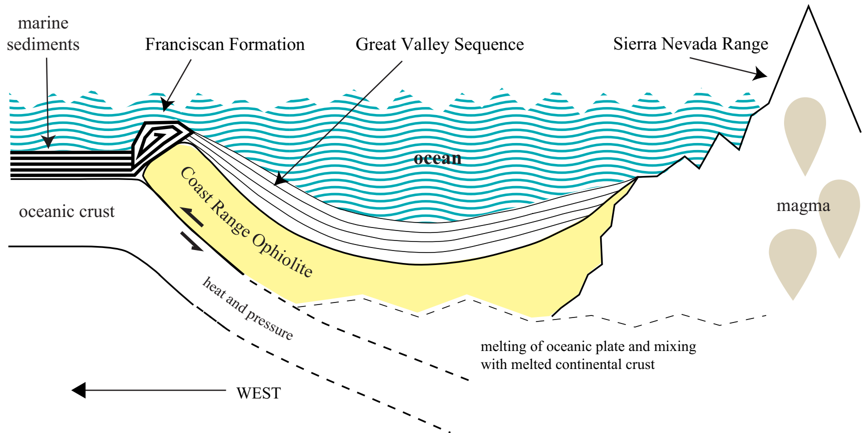

Figure 3-1. Subduction of the Farallon Plate beneath the North American continental margin, 140-100 million years ago.

Sediments derived from the ancient Sierra Nevada and Klamaths were transported by rivers to the ocean where they settled in the basin just beyond the edge of the continent. These sediments were buried and transformed into sedimentary rock that was later uplifted and exposed as the Great Valley Sequence (GVS) that forms much of California's eastern (inner) Coast Range, including all of the Quail Ridge Reserve. The material of the subducted Farallon and Kula plates, mostly marine sediments, was scraped off against the edge of the continent to create a complex of diverse rocks known as the "Franciscan mélange". The Franciscan mélange, or complex, makes up most of the western (outer) coast Range. Unlike the orderly strata of the Great Valley Sequence, the Franciscan complex became so badly deformed that it contains very complex structure and few fossils.

The Coast Range Ophiolite lies between the rocks of the Great Valley Sequence and the Franciscan mélange, and represents the oceanic crust on which the Great Valley sediments were deposited. The Coast Range Ophiolite consists largely of serpentinite, partly serpentinized peridotite, gabbro, and basalt. It was later pushed to the surface in the folding and faulting that produced the present Coast Ranges.

Transform Movement on the San Andreas Fault System

The spreading center that created the Farallon Plate was part of the East Pacific Rise. As the Farallon Plate subducted beneath North America, the ridge (East Pacific Rise) approached and then collided with the subduction zone (Figure 3-2), bringing the Pacific plate, west of the Farallon plate, into contact with the North American plate and changing the direction of motion along the edge of North America from convergent (between the North American and Farallon Plates) to transform (between the North American and Pacific Plates). The Farallon plate was divided into two plates, which became smaller and more widely separated with time, with the progressively longer

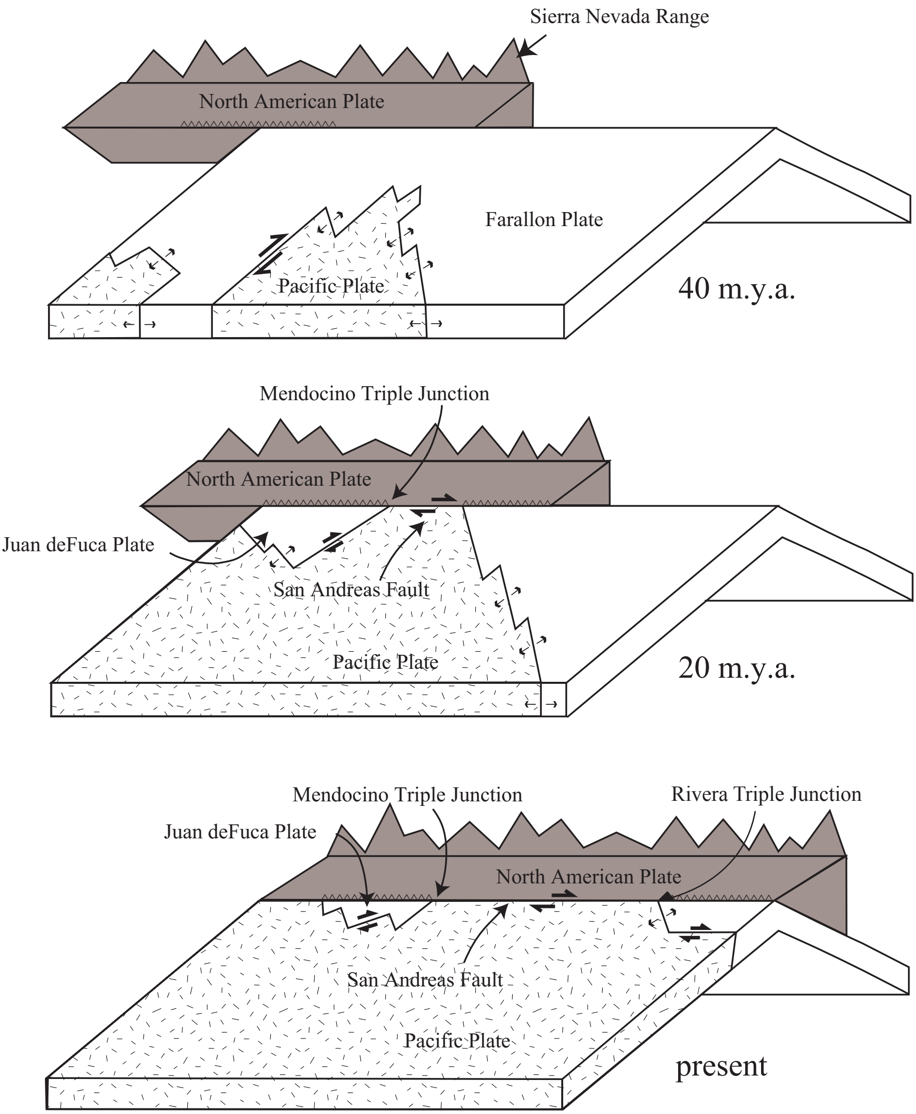

Figure 3-2. Collision of the Eastern Pacific Rise and the subduction zone and formation of the Mendocino Triple Junction, 40 - 20 million years ago.

San Andreas fault system in between. Two so-called triple junctions arose out of this process – the Mendocino triple junction to the northwest and the Rivera triple junction to the southeast. The Mendocino triple junction to the northwest is the meeting point of the Pacific, North American, and Juan de Fuca plates. North of the Mendocino triple junction, subduction continues, and as the Juan de Fuca plate disappears, the triple junction moves northwest along the continental margin like a closing zipper. As it does so, the direction of relative plate movement along the western edge of the continent has changed, with the Pacific plate moving northwest relative to the North American plate in transform or strike-slip movement. Thus the well-known San Andreas Fault system, along which the plates slide past each other, developed along the former convergent margin.

At the latitude of Quail Ridge Reserve, this change from convergent to transform plate motion began about 5 million years ago. As the Pacific plate slides past the North American plate, localized centers of compression and extension develop at the jagged edges of former plate boundaries. Extensional centers, or pull-apart basins, became the elongated northwest-southeast valleys of the Coast Ranges, and in places these also became centers of volcanic activity. Compressional centers, characterized by reverse or thrust faulting and associated folding, are present along the Coast Ranges. Uplift of the Coast Ranges began about 2-3 million years ago, perhaps in response to a slight change in Pacific-North American relative motion, and it continues today. This uplift has brought the oceanic crustal rocks of the Coast Range Ophiolite to the surface.

Great Valley Sediments

The stratigraphy of the Great Valley Sequence (GVS) sediments on Quail Ridge is largely obscured by vegetation, but visitors who approach the Ridge from the east have the opportunity to get a great view of them at the Monticello Dam overlook, as well as in the roadcuts from there to the Reserve. Sediments at the dam and in the Reserve, originally laid down horizontally, are nearly vertical. In the gap at Devil's Gate where the dam was built, it is clear that some of the strata are more resistant to erosion than others – in general, the sandstones are more resistant than the finer grained silt and shale layers.

These sediments were laid down over a period of 75 million years, from 140-65 million years ago. They are derived by erosion from the early Sierra Nevada and/or Klamath Mountains, which were up to 3000-4000 m high (for reference, the peak of Mt. Whitney is 4417 m above sea level). The sediments appear to have been deposited off the edge of the continent in approximately 1000-2000 m of water. Pulses of sediment-rich slurries, referred to by geologists as turbidity flows, coursed off the continental shelf, apparently in response to some disturbance, possibly earthquakes, onto oceanic crust that became the Coast Range Ophiolite. Seismic data collected to guide the drilling of oil and gas exploration wells show that the GVS is currently 10,000-13,000 m thick beneath the western Sacramento Valley, but some of the original sedimentary deposits likely were not that thick. Folding and thrust faulting have resulted in stacking of the sediments upon themselves.

Although the sediments of the Great Valley Sequence have been uplifted, faulted and folded, much can still be understood about their deposition. After the large turbidity flows, particles of different sizes settled at different rates. The sandstones in particular often show "graded bedding," with coarser sand grains at the base and finer grains at the top. The finest particles, those that become shale, may have taken weeks or years to settle out after each large turbidity flow event. Between turbidity flow events, fine mud settled on the seafloor forming the thicker beds of shale. This pattern provides a means to interpret how the layers were deposited and which are the younger sediments, allowing one to infer how the strata were oriented when they were horizontal.

The size-graded sand and shale deposits formed by the large, disturbance-related turbidity flows created deposits know as "turbidites" which make up the GVS. Many turbidites have casts of grooves, scour, or gouge marks on the bottom of sandstone beds that were made when the turbidity current flowed over the underlying mud. These markings sometimes show the direction that the turbidity currents moved when the deposits were formed. This allows us to determine that the dominant currents and the downslope direction when these rocks were deposited were generally from north to south.

The mudstone, siltstone, sandstone, shale, and conglomerates in these marine sediments range from 50 to 90 million years old at the eastern (younger) edge of the deposit, to about 140 million years old in the oldest strata represented at Quail Ridge. The zone of transition to Franciscan mélange and exposed Coast Range Ophiolite is only a few miles west of the Reserve, near Muscovite Corner.

The soils on the Quail Ridge peninsula are slide prone. Slumps, like the small one above, cut deeply into unweathered materials and can rapidly displace large volumes of material.

Thus, the geologic history of Quail Ridge is one of ancient deposition by turbidites (GVS) and subduction (mélange) followed by uplift and distortion as the Coast Range was formed. Most of the rocks and sediments at Quail Ridge are relatively low in the GVS stratigraphic sequence, and thus are relatively old. They consist primarily of fine-grained depositions (mudstones to shale), although in places conglomerates are present. The latter possibly originated from isolated submarine landslides or slurry flows (turbidity currents) of beach gravel off the coast of North America.

Soils

No detailed mapping of the soils on the Quail Ridge peninsula has been pursued, and only three soil map units, Bressa-Dibble complex 30-50% and 50-75% slope and Maymen-Millsholm-Lodo association, appear in the soil survey of the area (Lambert and Kashiwagi 1978). The Bressa-Dibble complexes cover approximately 2/3 of the Reserve. All of the soils within the Reserve are derived from lower Cretaceous-Upper Jurassic marine mudstone, siltstone, sandstone, and conglomerate that were uplifted to form the Inner Coast Range about 5 million years ago. These soils are found at elevations of ca. 150 to 700 meters (492 to 2297 feet).

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Bressa-Dibble Complexes

The Bressa and Dibble soil series are the dominant soils in these map units and are so finely intermingled that they could not be separated at the scale of the survey map. The sedimentary rocks from which these soils formed generally are thinly interbedded. At Quail Ridge, the rocks are tilted to near vertical, and the soils are quite shallow, giving rise to a fine-scale variation of soils on the landscape. At the soil family level, the Bressa soils are identified as fine-loamy, mixed, active, thermic Typic Haploxeralfs; the Dibble soils are fine, smectitic, thermic Typic Haploxeralfs, and have a higher clay content than the Bressa soils.

Bressa soils are mapped only in complex with Dibble soils; the proportions vary as a function of slope. Two slope phases of the Bressa-Dibble complex are found at Quail Ridge Reserve, 30-50% slope and 50-75% slope. Bressa-Dibble complex 30-50% slope occurs on uplands at around 350-700 m elevation and consists of about 65% Bressa silt loam, 20% Dibble silty clay loam, 15% Lodo, Maymen, Millsholm, and Sobrante loams, and other small areas of clayey soils. These steep soils are characterized by rapid runoff and moderate to severe erosion.

Bressa-Dibble complex 50-75% slope consists of very steep soils comprising 70% Bressa silt loam, 15% Dibble silty clay loam, and 15% Lodo, Los Gatos, Maymen, Millsholm, and Sobrante loams, and other small areas of clayey soils. Runoff tends to be very rapid on these slopes, which also erode readily. The steepness limits the usefulness of these soils for cattle grazing, which may explain in part the unusually well preserved native grasslands on the Reserve.

Soil-type boundaries are often visible in dramatic shifts in vegetation. Above, the dense chaparral vegetation in the foreground is on the 30-50% Bressa-Dibble complex, and the open grassy area in the distance shifts to the 50-75% Bressa-Dibble complex

A representative profile of the Bressa soil described in the Napa County survey includes a pale brown, slightly acidic surface silt loam 25 cm (10 inches) thick. Subsoil is a light yellowish brown, slightly acidic, silty clay loam about 60 cm (24 inches) thick. These layers are underlain by soft weathered sandstone at about 85 cm (34 inches). A representative profile of the Dibble soil includes a surface layer of pale brown and brown, slightly acidic silty clay loam 22 cm (9 inches) thick. The subsoil is brown and yellowish brown, slightly acidic silty clay and clay 63 cm (25 inches) thick. Weathered sandstone is found at a depth of 85 cm (34 inches). All of the areas of grassland, oak woodland, and the cooler and moister north-slope forests on the Reserve occur on Bressa-Dibble soils. In general, they are thicker and have more water holding capacity than the other soil type on the Reserve.

Maymen-Millsholm-Lodo association

The remainder of the Reserve, comprising the steepest, driest, chaparral areas, is mapped as Maymen-Millsholm-Lodo association. An association is a group of soils that could be separated at the mapping scale (in contrast with a complex, which cannot be separated at this scale), but that have such similar behavior that there is no advantage in doing so. This map unit is characterized by the soil survey as "somewhat excessively drained" and shallow – no doubt important reasons that it supports only drought-tolerant chaparral vegetation at Quail Ridge.

The Maymen-Millsholm-Lodo association is found on slopes from 30-75%. Maymen gravelly loam is found in convex areas on north-facing slopes from 30-75% slope. Convex areas on steep, south-facing slopes from 50-60% on ridge tops harbor Millsholm loam. Lodo loam is in convex areas on south-facing slopes from 30-75%. In general the association is composed of about 50% Maymen soils, 20% Millsholm soils, 20% Lodo soils, and 10% rock outcrop. Maymen soils are loamy, mixed, active, mesic Lithic Dystroxerepts. Millsholm soils are loamy, mixed, superactive, thermic Lithic Haploxerepts. Lodo soils are loamy, mixed, thermic Lithic Haploxerolls.

Soils in this association have very rapid runoff and are highly prone to erosion. The majority of the large landslides on the Reserve occur on these soils.

Maymen soils typically have a pale brown, moderately acidic, gravelly loam surface layer 15 cm (6 inches) thick. The subsoil is light yellowish brown, strongly acidic gravelly loam 15 cm (6 inches) thick, underlain by fractured sandstone. Millsholm soils have a surface layer of pale brown, moderately acidic loam 10 cm (4 inches) thick. The subsoil is a yellowish brown, moderately acidic clay loam 20 cm (8 inches) thick. Sandstone occurs at a depth of 30 cm (12 inches). Lodo soils have a surface layer of brown, neutral loam 10 cm (4 inches) thick. The subsoil is a brown, neutral loam that borders on a clay loam, 8 cm (3 inches) thick. Fractured sandstone is at a depth of just 18 cm (7 inches).