19 Coastal Landscapes

The Pacific Ocean has large influences on California. Aside from the climatic effects, there are about 1,350 km of coastline, or 5,515 km including inlets, where the Ocean has direct effects upon coastal landscapes. Two types of landscapes that are strictly coastal are marine terraces and estuaries.

Marine terraces consist of wave-cut platforms with beach deposits left on them when the sea level declines, as it does when water accumulates in continental glaciers. Land along the California coast has been rising tectonically, such that a terrace from one interglacial high sea level is higher than sea level at the next interglacial high. As the land continues to rise over many glacial cycles, flights of many terrace steps have been preserved along the coast of California..

Marine estuaries are where terrestrial streams approach coastal environments. They are where fresh water merges with sea water. The soils and plant communities of coastal marshland and the aeolian features around the esturaries are unique.

19.1 Marine Terraces

Through the Pleistocene, glaciers have advanced and retreated in approximately 100,000 year (or 100 ka) cycles, with minor retreats and advances in 20 and 40 ka cycles.. The ice age glaciers held so much water that the oceans shrank about 120 to 150 m from their current levels during full glacial stages. When the glaciers melted and the water from them flowed back to the oceans, the oceans rose to near the current levels, and ocean waves cut broad platforms along the shorelines. The platforms were covered by wave transported sediments. Parent materials of soils on marine terraces are generally sandy, commonly with aeolian additions of fine sand and silt.

The California coast has been rising for hundreds of millennia. Marine terraces many meters above sea level along the California coast attest to the magnitude of uplift. Rates of uplift are variable, depending on the magnitudes of tectonic displacement at different places and time. According to Muhs et al. (1992), uplift

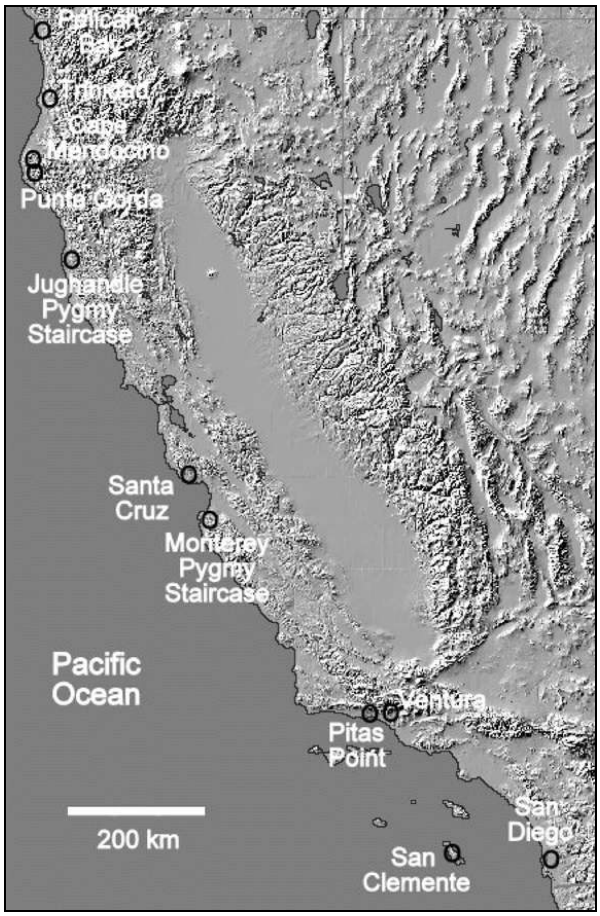

Figure 19-1. Locations of marine terraces featured in this chapter.

rates in the past 125 ka have been on the order of 0.45 to 1.08 meters per thousand years north of the Mendocino triple-junction and 0.15 to 0.35 m/ka southward, west of the San Andreas fault. Generally, only a few terraces are readily recognizable at any one location along the coast, The older marine terraces have commonly been modified or obliterated by tectonic deformation and erosion. Nevertheless, a sequence of 13 terraces was recognized on the Palos Verdes Peninsula in the Los Angeles basin (Woodring et al. 1946). Terrace soils have been investigated at locations shown in Figure 19-1, but there is little information about the vegetation on most of them.

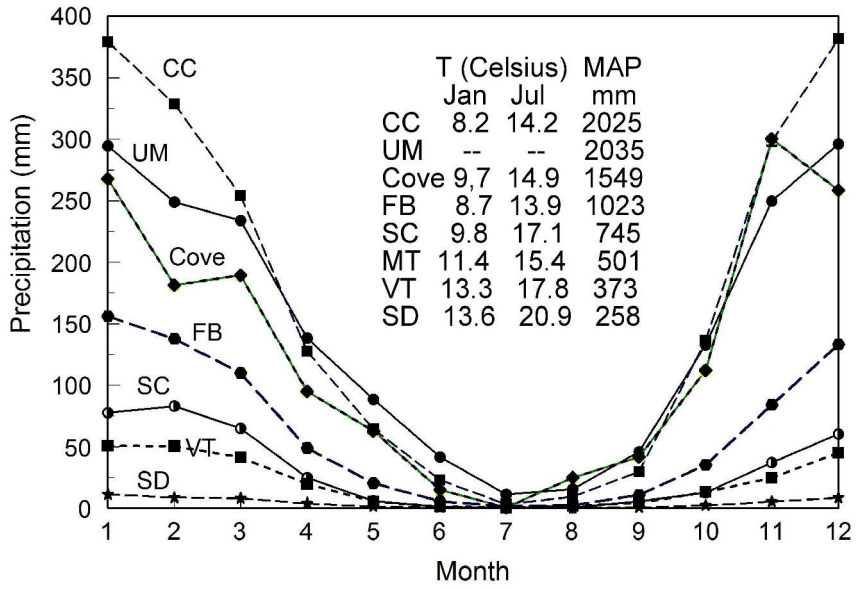

Figure 19-2. From north to south, the mean monthly and annual precipitation (MAP) and mean winter (Jan) and summer (Jul) temperatures at Crescent City (CC), Upper Mattole (UM), Shelter Cove (Cove), Fort Bragg (FB), Santa Cruz (SC), Monterey (MT), Ventura (VT), and San Diego (SD).

Soil climates on the different terraces are isomesic and mesic to thermic, and mean annual precipitation is 2000 to 300 mm (Fig.19-2). The terraces on San Clemente Island may have aridic STRs.

19.1a Pelican Bay

The terraces adjacent to Pelican Bay, where the Smith River reaches the ocean, are low (elevation <30 m asl). They are deformed and difficult to differentiate from one another. Polenz and Kelsey (1999) estimated the ages of the lower terraces to be 80 or 105 ka and the age of the highest terraces to be about 125 or 200 ka. The soils have been mapped by McLaughlin (McLaughlin and Harradine 1966) and more recently by JP Seney (USDA, Natural Resources Conservation Service). Soil temperatures are cool, with about 5° C differences from winter to summer, and the soils are generally moist (udic SMR).

The younger terrace soils are mostly oxyaquic and humic Inceptisols with Oi-A-Bw-C horizon sequences. Aquic humic Inceptisols with Oi-A-Bg horizon sequences are present, also. The older terrace soils are predominantly humic Ultisols with thick A and very thick Bt horizons. The soils are strongly leached and have low basic cation concentrations. All of them have strongly acid surface horizons and most of them have strongly to moderately acid subsoils. It is uncertain why there are no Spodosols, which are common on coastal terrace in southwestern Oregon (Bockheim et al. 1996, Bockheim and Langley-Turnbaugh 1997) and are present further south, on

the Jughandle Ecological Staircase (section 19.1d). The natural vegetation is forest with coastal redwood, Douglas-fir, spruce, grand fir, and western hemlock. Distributions of the trees are more closely related to distance from the ocean and soil drainage than to terrace age. Sitka spruce and understory red alder trees are dominant near the coast, and redwood, or redwood–Douglas– fir forests, with understory cascara trees are common a few kilometers inland from the coast. The main shrubs are salal and evergreen huckleberry. Shore pine trees are present on coastal sand dunes and may occur on some of the adjacent terrace soils, and there are willows and wax myrtle in wet depressions. Sword fern is common on the forest floor. Much forest has been cleared for homes, pasture, and cultivated crops.

19.1b Trinidad Head

At least five 80 to 200+ ka marine terraces have been identified within three km of the coast in geological investigations near Trinidad (Stephens 1982, Padgett 2013). Soil profile (solum) thickness was found to increase with age to more than two meters and the subsoil clay increased progressively from less than 18% in sandy loams on the youngest terrace to clay texturess (clay > 40%) on the oldest terrace (Padgett 2013). The main soils are oxyaquic humic Inceptisols, humic and oxyaquic humic Ultisols with thick and deeply leached argillic horizons, and aquic Alfisols. Aquic Alfisols and Ultisols on the higher terraces have very strongly acid, bleached E horizons, but none of the soils have spodic horizons (JP Seney, 2015, personal communication). There are some shore or lodgepole pine trees on the wet (aquic) Alfisols and Ultisols that have E horizons.

The soils are cool (isomesic STRs). They are not summer dry (having udic, rather than xeric STRs), even though summer rainfall is sparse, because fog provides much moisture and limits evapotranspiration.. The natural vegetation is forest with Sitka spruce near the ocean and more redwood and some Douglas-fir, inland. Salal, evergreen huckleberry, and salmon berry are common shrubs, and sword fern is common to plentiful on the forest floor.

19.1c Cape Mendocino–Punta Gorda

The terraces at Cape Mendocino and Punta Gorda were chosen for soils investigations, because they are near the Mendocino triple-junction where they have been uplifted rapidly. Terraces were sampled on five levels, up to about 300 m asl, that were estimated to be 4, 29, 40, 124, and 240 ka (Merritts et al. 1992). The terraces are high enough to minimize aeolian deposition and salty sea breezes. From youngest to oldest, the soils are haplic Mollisols, Inceptisols, and Alfisols. The soils have not been cultivated and the vegetative cover is perennial grasses.

Weathering produced clay that increased progressively with terrace elevation, or soil age, from clay <10% in the parent material of beach deposits to maximum clay >40% in soils on the oldest terrace. Other major soil forming features were found to be leaching of basic cations and silicon. Increases of soil organic matter and acidity were evident only in the younger soils. The 4

ka soil was neutral, the 29 ka soil was strongly acid, and all older soils were very strongly acid to at least two meter depths. Secondary (citrate-dithionite extractable) iron concentration and total pedon content were closely related to soil age.

19.1d Jughandle Ecological Staircase

Terraces of the Jug Handle State Natural Reserve near Fort Bragg are of special interest for the "pygmy forests" on them (Jenny et al. 1969, Westman 1975, Sholars 1982). Pygmy forests occur on marine terraces at Monterrey, also, but the dwarf tree species there are different from those on the terraces near Fort Bragg (Cylinder 1995). Numerous plant species are endemic on marine terraces along the Mendocino coast.

Five distinct terraces that have been cut into graywacke (sandstone) of the Franciscan complex along the Mendocino coast occur within six km of the Pacific coast at Jug Handle Creek, and four of the terraces still have practically flat surfaces with veneers of beach deposits. The approximate terrace elevations are 15, 50, 80, 130, and 200 meters asl. They are presumed to be related to oxygen isotope stages 5a, 5e, 7, 9, and 11, which have been dated about 80, 120, 200, 320, and more than 400 ka. Aeolian deposits, mainly sand, are widely distributed across the terraces and are thick on some edges of the terraces. The mean annual precipitation at nearby Fort Bragg (FB in Fig. 19-2) is about 980 mm and the soils are cool.

A trail from the low terrace at the mouth of Jug Handle Creek leads four km inland, across four of the marine terraces (Fig, 19-3, Table 19.1). There are two or more kinds of soils and plant communities on each terrace (Rittiman and Thorsen 2002), but only one of those seen on each terrace of the transect is shown in Figure 19-3 and characterized in Table 19.1. Sholars (1982) has described plant communities on many different kinds of the marine terrace soils.

The soil at site 1 on the edge of the first terrace (Fig. 19-3) has accumulated enough organic matter to darken a thick A horizon, which has been sufficiently leached of basic cations to make it moderately acid. The soil is assumed to have an umbric epipedon. Below a meter depth, a fluctuating water table has promoted the formation of yellowish brown Fe-rich mottles that are called *redoximorphic* features, because they are a result of the many cycles of *reduction* when the soil water is high and *oxidation* when the water recedes. Grassland with native and nonnative perennials occurs on the outer margin of the terrace. Inland a few hundred meters, or less, dense stands of krummholz trees face the ocean, with taller trees behind them. Sitka spruce is the main krummholz tree. Here near the southern limit of its distribution, Sitka spruce is found only near the ocean where its tolerance of the wind and salt spray allow it to compete with other species.

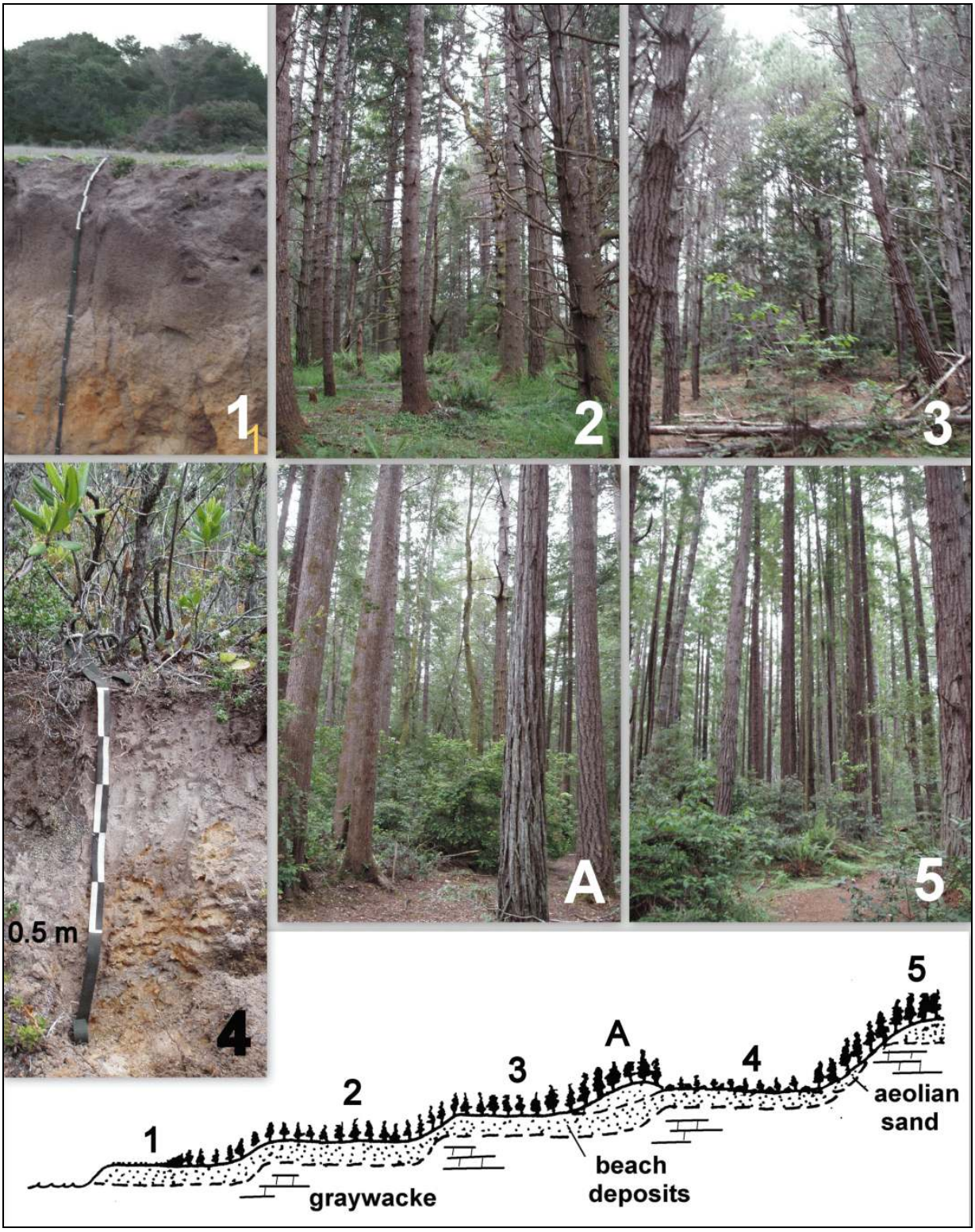

Figure 19-3. A transect on the Jughandle Ecological Staircase. There are descriptions for the transect sites in Table 19.1

Bishop pine are the main trees behind the krummholz trees. Soils on the first terrace that have argillic horizons are Alfisols with plenty of exchangeable basic cations, even though they are strongly acid, because they receive plenty of basic cations from oceanic salt spray, the salt spray also has plenty of chlorine and sulfate and much less carbonate or bicarbonate.

Soils on the second terrace are mostly haplic Ultisols and humic aquic Inceptisols. A dense stand of grand fir trees is prominent along the Jughandle trail (Fig. 19-3, site 4), but Bishop pine may be a more common tree on this terrace.

Soil and plant community distributions are similar on terraces three and four. These terraces have microrelief and sporadic distributions of aeolian sand with wide varieties of soils and plant communities (Rittiman and Thorsen 2002, Sholars 1982). The soils are mostly Ultisols with a variety of drainage conditions and diverse physical and chemical features. Weathering of the parent materials, incorporation of organic matter into O and A horizons, and leaching and illuviation of clay to produce argic (Bt) horizons are common processes that are active in the soils; for example, in haplic and humic Ultisols with O-A-Bt-C horizons.

Gardner (!967) found soils with hardpans on four of the five terraces. He counted K-feldspar and quartz grains in the soils to evaluate the amount of weathering. Morphologically the soils with hardpans were all similar, but K-feldspars that were common on the younger terraces were greatly diminished in soils and hardpans on the older terraces. The great loss of K-feldspars relative to quartz attests to aggressive weathering in the terrace soils (Gardner 1967). Plants that thrive in acid soils produce polyphenols that chelate aluminum (Al) and iron, Fe (Yu et al. 1999), promoting the leaching of Al and Fe from O, A, and E horizons to spodic Bh**,** Bhs, and Bs horizons. Many of the terrace soils have bleached E horizons and the renowned Blacklock taxadjunct of the pygmy forests has Bh and Bs, or Bsq (Table 18.1) horizons. In subsoils with fluctuating water levels, ferrous Fe migrates to locations of drying where it is oxidized and precipitated as ferric Fe. The initially soft Fe concentrations are called plinthite (*in* Glossary) while soft if they can harden irreversibly after numerous cycles of wetting and drying; for example, in aquic and plinthic Ultisols with O-E-Bt-Btv horizons that are common on the terraces. Although the Pygmy podzol has Fe concentrations in its subsoil, goethite, the only Fe-mineral found in the hardpan, is evident (questionably) only in the lower part of it (NRCS lab sample 80P045-019). Silicon (Si) from the weathering of feldspars accumulates in subsoil horizons and cements them. Laterally continuous cemented layers are called *duripans*.

Pygmy forests of the Blackwell taxadjunct soils generally consist of Bolander pine and pygmy cypress trees no more than three meters tall and shrubs, mainly evergreen huckleberry, glossyleaf manzanita, Labrador-tea, and salal, and commonly bear grass. Bolander pine, glossyleaf manzanita, and California carex are local endemic species that grow on the Blacklock taxadjunct and associated soils (Westman 1975). Extreme acidity (pH <4.5) and aluminum toxicity may be major factors limiting plant growth and survival on the soils.

Common soils on the aeolian sands of the Pygmy Staircase are Ultisols with O-E-Bt horizons. The surface soils generally have more organic matter (site A) than those lacking aeolian sand (sites 2 and 3). They support redwood–Douglas-fir forests where they are well drained or Bishop pine and other plant species where they are not well drained.

Blacklock taxadjunct

The Blacklock taxadjunct is a unique soil of the pygmy forest (Fig. 19-3). The soil horizons in the figure are Oi/Oe (1-0 cm), A (0-4), E (4-33), Bh (33-38), Bsq (38-70), and Bqm (below 70 cm). The end of the black tape rests on the Bqm hardpan). Iron and aluminum have been leached from the E-horizon and some of the iron has been retained in the strong brown to reddish yellow matrix of the Bsq (subscript **s** for sequioxides, Fe and Al oxides) and mottles of the Bqm horizon. Silica (SiO_2), mostly from silicon (Si) of weathered feldspars, has accumulated in the Bsq and Bqm horizons (subscript q for silica) and caused continuous cementation in the Bqm and discontinuous cementation in the Bsq horizon. The Blacklock series is in Oregon and has been called a groundwater Podsol. It is classified as a Duraquod (an aquic Spodosol with a hardpan) in an ortstein family. The Blacklock taxadjunct is also a Duraquod, but it is not in an an ortstein family, because the hardpan cement is silica, rather than iron oxides.

19.1e Santa Cruz

There are five readily recognized marine terraces near Santa Cruz (Bradley and Griggs 1976). The soils have developed in beach sand that was deposited on terrace platforms that have been cut into Miocene sandstone and mudstone. Sand on the terraces was derived from the Ben Lomond granite (White et al. 2008). Soils on the younger terraces are argic Mollisols and soils on the fourth and fifth terraces are Alfisols and humic Ultisols (Aniku and Singer 1990). From younger to older soils, the surface textures are sandy loam, sandy clay loam, and clay loam, and the subsoil textures are sandy clay loam and clay (Pinney et al. 2002). The natural vegetation is grassland on all of the terraces. Annual above-ground productivity was estimated to range from 280 to 600 g/m^2 (White et al. 2012).

Weathering has been studied comprehensively on the terraces (White et al. 2008, 2009, Maher 2009). Terraces sampled at elevations of 6, 67, 110, 159, and 189 meters were assigned ages of 65, 90, 137, 194, and 226 ka. Monitoring precipitation for three years indicated that the low terrace received much less rain than higher terraces, but salts were more concentrated in precipitation on the lower terrace such that the cation and anion inputs were about the same on all terraces. Molar inputs were Cl >Na >Mg >SO_4 >Ca >K. Considerable smectite was produced on the younger terraces, and some dioctahedral Fe-smectite was assumed to be from the Purisima formation. As Na is leached from the soils and the soil pH declines from neutral on the lowest terrace toward very strongly acid on the highest terrace, the amount of smectite declines and

kaolinite increases on the terraces, Mg and some Si are leached from the soils, and Al accumulates in kaolinite. Potassium and Ca are recycled through the grasses and other plants.

Soil goethite contents that increase greatly with terrace age, up to the fourth terrace are about the same on the fifth terrace, but its crystallinity increases steadily up to the fifth terrace (Aniku and Singer 1990). With the decline in subsoil pH from the second to the fifth terrace, Al substitution for Fe in the goethite increased from 8 to 21 mole percent.

19.1f Monterey Ecological Staircase

Six terraces have been identified on the Monterey Peninsula. A lower terrace is only 3 to 12 meters above the sea (asl). Terraces 2 through 6 are comparable to the five terraces of the Jughandle Ecological Staircase. The precipitation is about one-half of that at Fort Bragg on the Mendocino coast (Fig. 19-2) and there is insufficient fog to support redwood-Douglas-fir forests. Vegetation on the Monterey Ecological Staircase has been monitored in detail, but there have been no comprehensive investigations of the soils since the completion of a soil survey more than four decades ago (Cook 1978). Paul Cylinder has summarized the vegetation of the Monterey terraces and Wayne Verrill provided soils information (Cylinder 1995).

Because the lower terraces are extensively urbanized on the Monterey Peninsula, they were characterized at Point Lobos, a few kilometers to the south. A microrelief with low mounds was found on the first terrace, with an albic saline sodic Mollisol on mounds and unidentified hydric soils in intermound depressions. Bunchgrasses occupy the mounds, with prostrate coyotebrush and bush monkeyflower on the high spots, and with saltgrass, seaside plantain, and cutleaf geranium in the depressions. There are other shrub species on some low terrace soils, but no trees (Cylinder 1995).

There are Monterey pine and Monterey pine–coast liveoak forests on albic argic Mollisols of the Terrace 2 and Monterey cypress forests on inclusions of pachic (thick) haplic Mollisols with granitic grus parent materials (Cylinder 1995).

Terraces 3 and 4 have been urbanized almost entirely. The main soils on them are albic aquic Ultisols. Native vegetation was Monterey pine–coast liveoak forests, with pine trees of lower stature on terrace four than on terraces 2 and 3 (Cylinder 1995).

Pygmy forests are present only on Terrace 5 (Cylinder 1995, Griffin 1972). They are on the Narlon or similar soils, albic aquic Ultisols (Albaquults). These soils have thin O and dark colored A horizons that decrease in thickness from nearly ten centimeters in depauperate Monterey pine forests to negligible in pygmy forests, and albic horizons that diminish successively in thickness from more than 50 cm in Monterey pine forests through Monterey pine–Bishop pine forests, Bishop pine pygmy forests, and Bishop pine–Gowan cypress forests to less than 15 cm in Gowan cypress pygmy forests (Cylinder 1995). Open canopy Monterey pine and Monterey pine–Bishop pine forests have understory woolleyleaf and Monterey manzanita, coyote brush, and bush

monkeyflower. The main understory shrubs in the pygmy forests are woollyleaf and Monterey manzanita, chamise, and evergreen huckleberry. Bear grass occurs here near its southern limit.

The main soils on Terrace 6 are humic plinthic (*see* plinthite in thr Glossary) Ultisols. They support short (~12 m), open canopy Monterey pine trees with understory evergreen huckleberry, woollyleaf manzanita and other shrubs (Cylinder 1995).

19.1g Ventura

Increases in the clay content and dithionite extractable Fe from 2 ka haplic Mollisols to 40 and 80 ka argic Mollisols were tracked in warm, summer dry, marine and fluvial terrace soils near Ventura and at Pitas Point (Harden et al. 1986). The clay minerals were smectite>mica or illite>kaolinite in all of the soils, with the proportion of smectite increasing with soil age.

19.1h San Diego area

Sixteen terraces have been reported in the San Diego area, but there has been so much deformation in the area that no more than three are readily recognizable. The oldest terraces are more than 150 m asl and approximately 1000 ka (Kern and Rockwell 1992).

Entisols have been mapped on the lowest terraces and Alfisols on higher terraces (Bowman 1973). At lower elevations, where appreciable airborne salt is added to the soils, the Alfisols are sodic, and at higher elevations the Alfisols are leached and are moderately acid, and many of them have duripans (Fig. 19-4) The marine terraces were cut across weakly consolidated Cenozoic sedimentary deposits (Kern and Rockwell 1992) and some of the terrace soils with duripans are in cobbly or gravelly Eocene deposits (for example, Redding soils) and others are in sandy Pleistocene marine terrace deposits (for example, Chesterton soils). Urbanization is pervasive on the terraces. Orchards and ornamental flower production are common on the lower terraces and chamise and California buckwheat chaparral are common on the higher terraces.

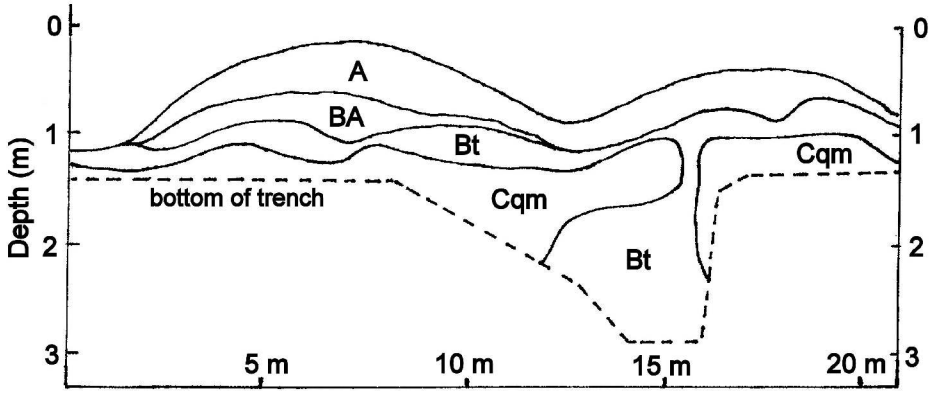

Figure 19-4. A cut through mounds of the Miramar Mounds National Natural Landmark (USDA Soil Conservation Service, 1980). The soil is a duric Alfisol on a flat wave-cut surface of the Poway conglomerate that is contiguous with and practically indistinguishable from the marine terrace surface of the Chesterton duric Alfisols.

Chapter 15, Peninsular Ranges, has more detail on the soils and vegetation. Wild oat and soft chess are common in grasslands on the terraces.

19.1i San Clemente Island

Muhs (1982) described and sampled soils on nine of the many terraces on San Clemente Island that range from 3 ka to about 1000 ka.. The Island has warm (isothermic STR) soils that are summer dry and have marginal soil moisture regimes, between aridic and xeric SMRs. They have received much aeolian silt. The younger soils are Mollisols and Alfisols and the older soils are deep Alfisols and Vertisols. Muhs (1982) named coastal cholla, coastal prickly-pear, snake-cactus, and California boxthorn as the main plant species, plus crystalline and slenderleaf iceplants, and he mentioned sporadic annual grass cover.

Most of the soil surface horizons are neutral to slightly acid and subsoils are strongly acid to moderately alkaline, with no clear relation to soil age. Electrical conductivities (1 soil: 5 water) were mostly EC <0.1 S/m in surface soil horizons and up to the 0.2 to 0.8 S/m range in subsoils. Gypsum was observed in soil horizons with high ECs (Muhs 1982). Molar ratios of cations extracted from ~3, 80 and 120 ka soils with water and with NH_4-acetate were Na >Mg >Ca >K. The lack of strongly alkaline soils is attributable to the dominance of chloride or sulfate anions rather than bicarbonate ions. The main clay minerals are smectite and mica, with the proportions of smectite increasing with soil age (Muhs 1982). Mica was found to be dominant in silty surface soils, and they lacked smectite.

19.2 Estuaries and tidal marshland

Coastal marshland in California is mostly at the mouths of streams, where they empty into the ocean. Tide water advances into the streams and retreats twice every day (Fig 19-5). The mean of the lower low tide levels (MLLW, *in* glossary) is the datum base (zero elevation, or altitude) for terrestrial surveys. Average tidal ranges, high to low, are about 2 m on the north and 1 m in southern California, with spring tide ranges about a meter greater than average tide ranges (Grewell et al. 2007). Neap tide ranges are considerably smaller than spring tide ranges (Fig. 19-5), even though the averages are the same. Tidal water does not enter California streams more than a few kilometers inland, except from San

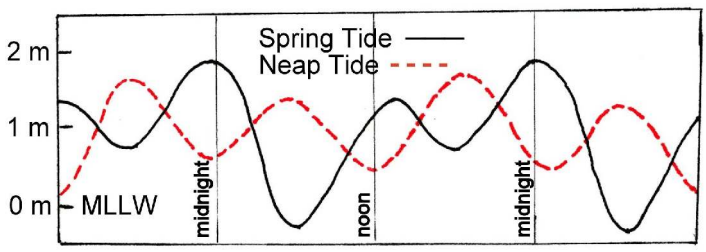

Figure 19-5. Tide water levels at the Golden Gate of San Francisco Bay over two days in June, 2015. The spring tide corresponds to the full moon on June 2 (solid black line), and the neap tide corresponds to the quarter-moon on June 9, 2015 (dashed red line).

Francisco Bay in to the Sacramento-San Joaquin Delta (Chapter 18). Outlets of the major rivers remain open throughout each year, but the outlets of many small streams are completely or partly blocked by sand berms and bars that are reinforced during winter storms. Lagoons that occupy low areas behind longshore bars and dunes may have fresh, brackish, saline, or hypersaline water, depending on the local conditions of closure and water flow. Closed outlets of California lagoons are commonly breached in the spring if streams feed enough water to the lagoons.

Much of the tidal marshland is around the large San Francisco, San Pablo, Humboldt, and San Diego Bays. The ecology of tidal marshland in California, from north to south, has been expounded by Barnhart et al. (1992), Josselyn (1983), Zedler (1982), and Zedler et al. (1992), and for the entire coast by Macdonald (1977) and Grewell et al. (2007). Most of the marshland has been greatly impacted or lost to agricultural, industrial, and urban development.

Annual or extreme floods can carry coarse stream sediments to tide lands. The coarser sediments are carried along subsurface channel bottoms, but tidal currents redirect silt and clay from streams to tidal marshland (Patrick and DeLaune 1990), making fine textured soils (McDonald 1977). Sand has been blown onto some of the soils. Patrick and DeLaune (1990 measured soil compaction and sediment accretion at three pickleweed marsh sites near the south end of San Francisco Bay, where there may have been 20 to 40 m of local land subsidence in the last 100 ka (Atwater et al. 1977). The soil bulk densities were about 0.4 Mg/m^3 near the surface and 0.6 Mg/m^3 at one meter depths, except at an abandoned commercial salt pond. There a layer of salt was buried by 0.6 m of sediment that had accumulated since the pond was abandoned in 1929. Bulk densities above the salt layer were about 0.8 Mg/m^3. Additions of sediment from tidal currents have maintained a pickleweed marsh soil surface near 0.1 m above mean high water (MHW) at the three sites as sea level has risen (Patrick and DeLaune 1990).

Marshland soils mapped by the NRCS (USDA, Natural Resources Conservation Service), from Tijuana River at the Mexican border to the Smith River near Oregon, are Entisols, some Inceptisols, and few Mollisols, all with aquic soil moisture regimes. Organic soils are common on the Suisun marsh and Delta (Chapter 18). Most of the tidal marshland soils, other than on the Delta and in some lagoons, are saline, with electrical conductivities > 4 mmoh/cm (or > 0.4 S/m). Seawater contains 34 to 35 g/L salts, with molar $Cl^- > Na^+ > Mg^{2+} > SO_4^{2-} > Ca^{2+} = K^+$. The inorganic soils are slightly acid (pH>6) or neutral to moderately alkaline (pH 8), with the exception of the Reyes soils. In San Francisco, San Pablo, and Suisun Bays, sulfate that is reduced to sulfides (for example, FeS) by anaerobic microorganisms in the Novato soils (Typic Sulfaquents) becomes oxidized to sulfates when the soils are drained for agriculture or other uses (Grass et al. 1962, Lynn and Whittig 1966). The somewhat drained and oxidized soils, Reyes series (Sulfuric Fluvaquents), are extremely acid.

There is a wide range of conditions in tidal environments from submergence with relatively constant temperature, salinity, and aeration to habitats with wide diurnal fluctuations. Eelgrass

grows in the near shore environment where it is submerged continuously. Cordgrass is partially submerged and grows up to the mean high tide (MHT) level where it yields rather abruptly to pure stands of pickleweed. At slightly higher elevations, jaumea and shoregrass appear in the stands of pickleweed. Dodder, a parasitic plant, that grows on most green plants is particularly abundant on the pickleweed. Marsh rosemary is common along with pickleweed near the upper limit of tidal water. Saltgrass, gumplant, and alkali heath are common above mean higher high tide (MHHT) where evaporation of surface water concentrates salts in the soils. Bulrushes and cattails are dominants in brackish marshes that are common in Suisun Marsh and where the Napa and Petaluma Rivers enter San Pablo Bay.

The California current that carries cold water from the north Pacific Ocean down along the coast continues southward from Point Conception where the coast of California curves eastward. Consequently, the sea shore from there southward is much warmer than it is north of Point Conception. Although the plant distributions across the sequence of tidal habitats is similar to those in San Francisco Bay and other northern tidal marshlands, some species that are common to the south are absent north of Point Conception. Notable exclusively southern species are annual pickleweed and saltwort that are common in pickleweed stands, shoregrass near the high water (MHHT) level, and glasswort above the MHHT level (Zedler 1982)..

19.3 Coastal wind-blown sand landscapes

During glacial advances of the Pleistocene, large amounts of water accumulated in continental ice sheets, lowering sea level more than 100 meters and exposing vast areas of sandy beach deposits. Much of the sand was blown inland to form longitudinal dunes that are elongated from northwest to southeast, which is the dominant wind direction along the California coast (Cooper 1967).. Some of the sand has been reworked and transverse dunes have developed along the inner edge of beach where it faces the northwest.

The dunes are eventually stabilized when grass, shrubs, and trees inhabit them. Initially the soils are sandy Entisols. With the establishment of plant cover and accumulation of enough soil organic matter to darken the soils to depths of 18 cm, the soils become humic Inceptisols from Point Reyes northward and hapilc Mollisol southward. Nearly all of the soils are slightly acid, with few that are moderately acid or neutral. In some soils, illuviated clay accumulates in thin layers that are called lamellae. The cumulative thicknesses of lamellae are great enough in some dune soils adjacent to the beach along the shore of Monterey Bay and in the Santa Maria Lowland (Chapter 17) for them to be mapped as lamellic Alfisols (Lamellic Haploxeralfs, USDA, Natural Resources Conservation Service). A variety of soils can develop on dunes that are no longer active. A soil stabilized by establishment of forest vegetation is featured at site A in Table 19.1 and Figure 19-3. Amundson and Tremback (1989) sampled dune soils in Golden Gate Park, San

Francisco, that had been stabilized by planting grass on them about 1880 and later trees. The soils under trees had O-horizons and thick A-horizons that may now be umbric or mollic epipedons, but the soils were classified as Entisols (Psamments) in 1989. The dune soils that were neutral with natural vegetation were strongly acid in the surface over slightly acid in subsoils under coast liveoak and Monterey pine trees and slightly alkaline over neutral under eucalyptus trees.

Relatively few species of plants colonize the windward sides of active coastal dunes facing the ocean. They are a few salt tolerant species such as red sand verbena, beach saltbush, and searocket (Holland and Keil 1995). A larger number of plant species grow on the leeward sides of the dunes. The pioneer plants are commonly prostrate and have long taproots or creeping rhizomes (Holland and Keil 1995). Three stretches of the California coast with different suites of plants have been recognized (Pickart and Barbour 2007), with a major division near Point Conception (Breckon and Barbour 1974). From Point Reyes northward, the main species were Euopean and American beach grasses, beach-bur, and searocket. Much of the American beachgrass has been replaced by European beachgrass. From Point Reyes and Moro Bay to Point Conception, the beachgrasses are present, but less dominant, and the main beach plants were in plant communities characterized by searocket, beach-bur, and sea fig. There are fewer plant species on recent dunes south from Point Conception and they are xeric in character. There is no American beachgrass. Beach-bur and forbs grow on active dunes of the Channel Islands (Chapter 15).

As coastal dunes become stabilize they are generally occupied by shrubs in central California and trees in northern California. Other than the yellow and chamisso bush lupines that are mainly on coastal dunes, most of the shrubs on stabilized dunes are common in other landscapes, also; for example, coyotebrush, California goldenbush, California and coastal buckwheat, California sagebrush, and black sage. No tree species grow only on coastal dunes, but shore pine trees grow only along the coast and Monterey pine grows only along the central California coast. Torrey pine trees grow on coastal dunes near San Diego (Chapter 15).

Wet dune soils are present in some swales north of Point Conception. The areas of them are generally too small for the soils to have been mapped in National Cooperative Soil Surveys. The swales are occupied by sedges, rushes, bulrushes, tules, and shrubs, with the abundance of shrubs increasing northward. The main shrubs are willows and wax-myrtle, and there are shrubby red alder trees in some swales of northern California.

Table 19.1 A transect on the Jughandle pygmy staircase..

Site	Alt. m	Soil PM	Landform	Soil Class/ Soil Horizons	Plant Community
1a	15	marine sediments	low terrace	cool umbric Inceptisol A-Cg	tufted hairgrass– California brome– rhizominous bluegrass– English plantain
1b				haplic Alfisol A-Bt-Btg-Cg	Bishop pine–Sitka spruce/wax myrtle
2	50	marine sediments	second terrace	cool, moist haplic Alfisol or Ultisol O-A-E-Bt-C	grand fir/sword fern–redwood sorrel
3	80	marine sediments	third terrace	cool, moist haplic Ultisol O-A-Bt-Btv-C	Bishop pine/tanoak–cascara
A	95	aeolian dunes	riser between terraces	cool humic Ultisol O-A-E-Bt-C	Douglas-fir–redwood–grand fir/tanoak/sword fern
4	130	marine sediments	fourth terrace	cool wet duric Spodosol O-A-E-Bh-Bsq-Bqm	Bolander pine–pygmy cypress/ evergreen huckleberry–Pacific rhododendrom–glossyleaf manzanita
5	200	marine sediments	high terrace	cool humic Ultisol O-A-E-Bt-C	redwood–Douglas-fir–coastal hemlock/tanoak/evergreen huckleberry–Pacific rhododendron–salal

An approximately 4 km transect from a sea bluff eastward just south of Jughandle Creek. The soils and plant communities on terraces 2, 3, and 4 are not necessarily the dominant ones on the those terraces, but they are prominent along the transect.