Map Unit Properties Table: Golden Gate National Recreation Area, including Fort Point National Historic Site and Muir Woods National Monument

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY	Undifferentiated surficial deposits (**Qu**)	**Qu** includes artificial fill, beach sand, marine deposits, alluvium, landslides, and some Colma Formation (**Qc**). **Qu** is mapped within the managed area of the park at Fort Point, Dias Ridge, and in the Marin Headlands.	**Cenozoic Rocks and Deposits**—**Qu** includes manufactured debris in artificial fill; see artificial fill units for more information. **Landslide Deposits and Slope Movements—Qu** includes landslide deposits; see landslide deposits for more information. **Alluvium and Fluvial Processes—Qu** includes alluvium; see alluvium units for more information. **Coastal Features and Processes—Qu** includes beach sand and marine deposits; see beach and dune deposits for more information. See also Colma Formation (**Qc**) for more information.	**Earthquake, Probability, Hazards, and Risks—**artificial fill and unconsolidated material, especially if wet and/or placed over former bay floors, is likely to shake intensely during earthquakes and is highly susceptible to liquefaction. See also Colma Formation (**Qc**) for more information.	**Evolution of the Modern Landscape—**as a group, these include the youngest deposits in the park. Surficial deposits were created by a variety of processes over the past two million years, and in the case of artificial fill, within the past century or so of human modification. See also Colma Formation (**Qc**) for more information.
QUATERNARY	**ARTIFICIAL FILL UNITS** Artificial fill (**Qar**) Artificial fill over marine and marsh deposits (**Qmf**) Artificial fill, development related (**Qf1**)	Gravel, sand, silt, clay, rock fragments, organic material, and manufactured debris. Unconsolidated to very well consolidated. **Qmf** is fill placed on top of tidal flats and marshes which are composed of silty-clay similar to **Qbmo**. **Qf1** is fill made before 1965 and was almost always not compacted. Fill consists simply of dumped materials. Artificial fill is mapped within the managed area of the park in the Marin Headlands, on Alcatraz, and many locations on the San Francisco Peninsula (Mori Point, Corral de Tierra, Sweeney Ridge, Sneath Lane, Mussel Rock, Fort Miley East, Ocean Beach/Fort Funston, Fort Mason, Fort Point, and Crissy Field).	**Cenozoic Rocks and Deposits**—development over much of the San Francisco Peninsula required the use of artificial fill. Marsh restoration activities at Crissy Field removed artificial fill. **Qf1** includes spoil from tunneling operations. **Qf1** is used in riprap and the construction of highways, railroads, and airport runways, as well as earthfill dams, reservoir embankments, building-site grades, and sanitary landfills. **Coastal Features and Processes—Qar** includes some dune sand.	**Earthquake, Probability, Hazards, and Risks—**artificial fill, especially if unconsolidated and/or placed into the bay, is likely to shake intensely during earthquakes and is highly susceptible to liquefaction. **Disturbed Land Restoration—**many disturbed lands throughout the park, including Crissy Field and others underlain by artificial fill, have been targeted for restoration.	**Evolution of the Modern Landscape—**humans have long modified, and continue to modify, the landscape of the Bay Area, including efforts to restore disturbed landscapes.
QUATERNARY	**ESTUARINE DEPOSITS AND MUD** Basin deposits (**Qhb**) Bay mud, younger (**Qbmy**) Bay mud, older (**Qbmo**)	Silt, clay, organic matter, and some fine sand. Generally unconsolidated, but older deposits may be moderately consolidated. Commonly interfingers with fine-grained alluvium. Thickness may be as much as 30 m (100 ft). These deposits are not mapped within the managed area of the park. Within the authorized boundary, **Qhb** is mapped along the south end of Upper Crystal Springs Reservoir, and **Qbmy** and **Qbmo** are mapped around Tomales Bay.	**Coastal Features and Processes**—these units were all deposited at or near sea level. **Qhb** was deposited on a flat-floored basin at the distal edge of an alluvial fan. **Qbmy** and **Qbmo** were deposited in estuaries around Tomales Bay.	**Earthquake, Probability, Hazards, and Risks—**unconsolidated units, especially those saturated with water, are likely to shake intensely due to earthquakes and are susceptible to liquefaction. When wet, **Qbmo** deposits have a moderate to high potential for liquefaction. **Qbmo** deposits are soft and plastic when wet (common near the top) and firm when dry (usually occurring at depth). **Sea Level Rise—**sea level is predicted to rise by roughly 1 m (3 ft) by the end of this century; the area covered by these units would undoubtedly be affected.	**Evolution of the Modern Landscape—**cores taken from San Francisco Bay recorded as many as seven interglacial periods (indicated by estuarine rocks which correspond to times of high sea level) over the last 500,000 years

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY	**BEACH AND DUNE DEPOSITS** Beach sand (**Qbs**) Dune sand – younger (**Qdsy**) Older beach deposits (**Qob**)	Predominantly loose, well sorted beach and dune sand. Includes some pebble and cobble beaches. Thickness generally less than 6 m (20 ft) but may exceed 30 m (98 ft). Beach and dune deposits are mapped in many managed areas within the park, notably at Stinson Beach, Muir Beach, Tennessee Beach, Rodeo Beach, Crissy Field, Baker Beach, and Ocean Beach.	**Coastal Features and Processes—**these units comprise the sandy beaches and dunes in the park. Primary sediment sources are offshore submerged ancient sand dunes and weathering of local rocks. Beaches tend to be wider in summer and narrower in winter. Many of the beaches in the park have been either eroding or accreting for long periods. Dunes are mapped over the majority of the north end of the San Francisco Peninsula, however much of this area is now covered by development.	**Earthquake, Probability, Hazards, and Risks—** unconsolidated units, especially those saturated with water, are likely to shake intensely due to earthquakes and are susceptible to liquefaction. **Sea Level Rise—**sea level is predicted to rise by roughly 1 m (3 ft) by the end of this century; the area covered by these units would undoubtedly be affected. **Coastal Erosion and Sediment Dynamics—**these units and associated infrastructure have been impacted by coastal erosion. A notable example is the southern section of Ocean Beach, where erosion has been occurring for decades. Where human activities are responsible for increased erosion and altered sediment dynamics, intervention is permitted according to NPS policy. **Monitoring Aeolian Resources—**dunes protect the shoreline and provide important habitat. Monitoring dune fields could assist in determining trends and identifying which areas require protection	**Evolution of the Modern Landscape—**beaches and dunes on the modern landscape continue to evolve. Some beaches and dunes date back to the Pleistocene Epoch.
QUATERNARY	**ALLUVIUM** Younger alluvium (**Qya**) Holocene alluvial fan deposits (**Qafy**) Alluvium, undivided, younger (**Qaly**) Alluvium, undivided, older (**Qalo**) Older alluvium (**Qoal**) Pleistocene alluvial terrace deposits (**Qpaf1**)	Unconsolidated, poorly sorted gravel, sand, silt, and clay in various proportions and combinations. Organic matter such as wood fragments is common. Stream terrace alluvium (**Qpaf1**) is coarsest grained with clasts up to 35 cm (14 in) in diameter. Graded bedding is common; gravel and sand tend to fine upward to sandy or silty clay. Deposits are coarser in the headward reaches of stream valleys. Some cross-bedding occurs. In many places **Qya** is included with other alluvial deposits because of map scale limitations. Older alluvium (**Qoal**) may be moderately consolidated. Within the managed area of the park, alluvium is mapped south of the Golden Gate in the valleys of Corral de Tierra (e.g., along San Vicente Creek and Denniston Creek), in Calera Valley southeast of Sweeney Ridge, and in the Phleger Estate. North of the Golden Gate it is mapped where gulches enter into Bolinas Lagoon at Stinson Beach and in all the major valleys of the Marin Headlands (e.g., Tennessee Valley, Green Gulch, Frank Valley, Gerbode Valley, along Bunker Road). Older alluvium (**Qoal**) is mapped in Olema Valley.	**Paleontological Resources—Qaly** and **Qalo** deposits contain fossils of extant vertebrate and invertebrates. **Alluvium and Fluvial Processes**—flowing water deposited alluvium in drainage channels such as streams and valleys, on alluvial fans, as stream terraces and levees, on floodplains, and in basins.	**Earthquake, Probability, Hazards, and Risks—** unconsolidated units, especially those saturated with water, are likely to shake intensely due to earthquakes and are susceptible to liquefaction, though they are less susceptible than **Qmf** and **Qu**. **Groundwater Contamination—**pollutants tend to follow high-porosity stream channel and levee deposits. **Flooding—**flood potential on alluvial fans is a concern because models do not account for the shifting nature of alluvial fans. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Evolution of the Modern Landscape—**deposited in a variety of flowing water environments during the Pleistocene and Holocene (the past 2.6 million years).

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY	**LANDSLIDE DEPOSITS** Younger landslide deposits (**Qyl**) Landslide deposits (**Qls**) Slope and ravine debris (**Qsr**) Colluvium (**Qcl**) Older landslide deposits (**Qol**)	Generally, unconsolidated to moderately consolidated, unsorted to poorly sorted rock fragments of all sizes, sand, silt, clay, and some organic material. Composition and structure of each deposit depends on the geologic formation involved and type of landslide. May include small alluvial deposits. Due to map scale limitations, more landslide deposits may be present than are shown on the map. Throughout Corral de Tierra, "small mass movements" are abundant on slopes (see "Hazard Point Features" in GRI GIS data), and slope and ravine debris consisting of weathered granitic rock (**Kgr**) fills valleys. The valleys around Mori Point, Sweeney Ridge, and Milagra Ridge contain landslide deposits of weathered Franciscan rocks ("**Kf**" and "**KJf**" map units). The coast along Mussel Rock contains landslide deposits emanating from the Merced Formation (**QTm**). Landslide deposits of weathered mélange occur along the coast at Land's End and of weathered serpentinite north of Baker Beach. In the Marin Headlands, landslide deposits are conspicuous along US 101; they are less so in the interior. Landslide deposits of weathered mélange are present along Muir Beach.	**Landslide Deposits and Slope Movements**—landslide deposits resulted from slow to rapid downslope transport of soil and rock under the influence of gravity. Landslide deposits in the park include creep deposits, debris flows, and block slumps. Maximum accumulations of landslide deposits occur near bases of slopes underlain by sheared rock of the Franciscan Complex ("**Kf**" and "**KJf**" map units) and granitic rocks of Montara Mountain (**Kgd**). Along Mussel Rock, landslides appeared to have emanated from the Merced Formation (**QTm**). **Alluvium and Fluvial Processes**—unconcentrated surface runoff (e.g., rainwash, sheetwash) in combination with slope movements deposited slope and ravine debris (**Qsr**) and colluvium (**Qcl**).	**Earthquake, Probability, Hazards, and Risks—** unconsolidated units, especially those saturated with water, are likely to shake intensely due to earthquakes and are susceptible to liquefaction. **Slope Movement Hazards and Risks—**current landslide distribution is a good first order indicator of future landslide activity. Small, shallow landslides are abundant within slope and ravine debris (**Qsr**). Younger landslide deposits (**Qyl)** are considered active and unstable. Older deposits (**Qol**) are assumed to be inactive and/or stabilized, as no evidence of recent movement has been observed. However, they are susceptible to reactivation by unusually high or prolonged rainfall, earthquakes, and/or improper grading or drainage procedures.	**Evolution of the Modern Landscape—**deposited by slope movements that occurred during the Holocene and potentially the Pleistocene.
QUATERNARY	Marine terrace deposits (**Qtmr**)	Unconsolidated to moderately consolidated sand, silt, gravel, and clay on marine terraces (uplifted wave-cut platforms). Variable thickness, but probably everywhere less than 30 m (98 ft). Within the managed area of the park, marine terrace deposits occur near the coast in Corral de Tierra and Mori Point, and on the coastal bluffs south of Mussel Rock.	**Alluvium and Fluvial Processes—**the upper portion of a marine terrace deposit is commonly formed by sub-aerial deposition and includes alluvial gravel, colluvial clay, and stream terrace deposits which form rounded and subdued topography. **Coastal Features and Processes—**the lower portion of a marine terrace deposit is commonly of marine origin and includes beach deposits and younger aeolian (dune) sands which form near-vertical cliffs along the coast.	**Earthquake, Probability, Hazards, and Risks—** unconsolidated units, especially those saturated with water, are likely to shake intensely due to earthquakes and are susceptible to liquefaction.	**Evolution of the Modern Landscape—**marine terraces (upon which **Qtmr** sits) originated as wave-cut platforms which formed at sea level when relative sea level was higher than it is today. As sea level dropped and/or uplift occurred, these platforms became exposed. Today, they are evidence of the location of ancient coastlines.
QUATERNARY	Colma Formation (**Qc**)	Weakly consolidated, fine to medium grained sand with minor sandy silt, clay, and gravel interbeds. Thin to thick bedded, rarely massive. Beds are evenly spaced and either nearly horizontal or cross-bedded. Zones of scattered well-rounded and polished chert pebbles. Thickness unknown, but probably exceeds 30 m (100 ft). The Colma Formation is only mapped east of the San Andreas Fault. Within the managed area of the park, it is mapped in a few locations along Baker Beach, Land's End, and Ocean Beach where the formation is developed up to 150 m (500 ft) above sea level as coastal bluffs. **Qu** includes some Colma Formation.	**Cenozoic Rocks and Deposits—Qc** was deposited in a shallow marine environment during the Cenozoic Era. The sands of the Colma Formation form a good aquifer and springs are common at the contact with the underlying serpentinite at the Presidio. **Paleontological Resources—Qc** has produced mammoth fossils from within Golden Gate National Recreation Area. **Coastal Features and Processes—Qc** represents both shallow bay deposition and valley-slope debris and may include sediments that were originally deposited as dune sand. Today, the Colma Formation forms coastal bluffs.	**Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Evolution of the Modern Landscape—**the Colma Formation is a shallow marine deposit. The sand accumulated from 125,000 to 80,000 years ago (Pleistocene Epoch) during an interglacial period when sea level was slightly higher than today (Elder 2001).

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
QUATERNARY (late Pleistocene)	Olema Creek Formation (**Qoc**)	Granitic sand and gravel interbedded with mud and peat. South of Tomales Bay, thickness is as much as 170 m (558 ft). The Olema Creek Formation is mapped south of the town of Olema amidst the San Andreas Fault system. It is not mapped in the managed areas of the park.	**Cenozoic Rocks and Deposits—**the Olema Creek Formation is of alluvial and estuarine origin; sediments accumulated on a coastal plain at the head of Tomales Bay at about the same time as the deposition of the Millerton Formation (**Qml**) (Pleistocene Epoch).	None documented.	**Evolution of the Modern Landscape—**deposited in streams and estuaries at head of Tomales Bay. It is approximately contemporaneous with the Millerton Formation (**Qml**).
QUATERNARY (late Pleistocene)	Millerton Formation (**Qml**)	Clay, silt, sand, and gravel. Along the eastern margin of Tomales Bay, thickness is as much as 30 m (98 ft). The Millerton Formation is mapped along the eastern margin of Tomales Bay, amidst the San Andreas Fault system. It is not mapped in the managed areas of the park.	**Cenozoic Rocks and Deposits—**the Millerton Formation is of alluvial and estuarine origin; sediments accumulated on terraces along the eastern margin of Tomales Bay at about the same time as the deposition of the Olema Creek Formation (**Qoc**) (Pleistocene Epoch). **Paleontological Resources—Qml** contains abundant fossil fauna and flora.	**Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Evolution of the Modern Landscape—**deposited in streams and estuaries along eastern margin of Tomales Bay. It is approximately contemporaneous with the Olema Creek Formation (**Qoc**).
QUATERNARY AND NEOGENE (lower Pleistocene and upper Pliocene)	Santa Clara Formation (**QTsc**)	Moderately consolidated, poorly sorted and indurated conglomerate and pebbly to cobbly sand, silt, and clay in irregular and lenticular beds. Pebbles and cobbles are angular to sub-rounded. Contains a tuff bed near Woodside. Reaches a maximum thickness of about 500 m (1640 ft) along Coal Mine Ridge (southeast of the Phleger Estate and at the south end of Portola Valley). **QTsc** is mapped south of San Francisco, amidst the San Andreas Fault system. In the managed area of the park, the Santa Clara Formation is mapped in the Phleger Estate and in one small location at Sweeney Ridge.	**Cenozoic Rocks and Deposits—**late Pliocene uplift and erosion of Franciscan graywacke and greenstone resulted in deposition of the terrestrial sediments of the Santa Clara Formation probably as an alluvial fan. **QTsc** is the contemporaneous terrestrial equivalent of the marine Merced Formation (QTm). **Paleontological Resources—**gray to buff claystone and siltstone beds of **QTsc** on Coal Mine Ridge contain carbonized wood fragments as large as 60 cm (24 in) in diameter.	**Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Evolution of the Modern Landscape—**represent northwest–flowing braided stream deposits and probably indicate the development of the modern San Francisco watershed during late Pliocene to early Pleistocene time. Offset of this unit along the San Andreas Fault is clearly visible on the map around the south end of Upper Crystal Springs Reservoir.
QUATERNARY AND NEOGENE (Quaternary and late Pliocene)	Merced Formation (**QTm**)	Poorly to moderately consolidated, thick-bedded to massive, marine sandstone and siltstone. Beds are cross-bedded and contain scattered layers of rounded pebbles or shell fragments. Thickness ranges from 30 m (100 ft) to possibly more than 91 m (300 ft). In the managed area of the park, the Merced Formation forms cliffs at Fort Funston and Mussel Rock.	**Cenozoic Rocks and Deposits—QTm** is the contemporaneous marine equivalent of the terrestrial Santa Clara Formation (**QTsc**). The Merced Formation likely accumulated in a gap that opened up behind a northwardly migrating right bend in the San Andreas Fault. **QTm** represents shallow-marine nearshore and backshore deposits alternating with terrestrial beach dune and shore deposits. **Faults—QTm** has been uplifted and thrust over the younger Colma Formation (**Qc**) by movement along the Serra Fault. Uplift is evident at Fort Funston. **Paleontological Resources—QTm** is the most fossiliferous Cenozoic unit in the park. It contains carbonized wood, shell fragments, echinoderms, foraminifera, bison, camels, mammoths, mastodons, horses, ground sloths, marine mammals, birds, plants, and trace fossils. Holotype specimens of *Nucella megastoma* (snail) and *Pinus lawsoniani* (pinecone) were collected from **QTm**. **Coastal Features and Processes—**today, the Merced Formation forms coastal bluffs.	**Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion. **Slope Movement Hazards and Risks—**coastal areas underlain by **QTm**, for example at Fort Funston, are prone to failure where waves erode steep cliffs and undercut slopes.	**Evolution of the Modern Landscape—**640,000-year-old sediments of the Merced Formation mark the initiation of the modern Sacrament/San Joaquin River system flowing all the way to the ocean. Prior to this, it emptied into a large, land-locked lake in the Central Valley. Offset of this unit along the San Andreas Fault is clearly visible on the map. North of the Golden Gate it is on the west side of the fault; south of the Golden Gate it is to the east.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
NEOGENE (Pliocene and Miocene)	Purisima Formation (**Tps**)	Highly fractured, well indurated mudstone, siltstone, and sandstone. Also includes some chert and volcanic ash. Thickness is at least a few hundred feet but may be as much as 490 m (1,600 ft). **Tps** is only mapped west of the San Andreas Fault. It is not within the managed area of the park. **Tps** forms coastal bluffs near Half Moon Bay.	**Cenozoic Rocks and Deposits—Tps** accumulated in a local basin, which formed as basement blocks shifted due to the tectonic transition from subduction to transform movement. **Tps** is part of a continuous Paleogene marine mudstone and sandstone sequence which also includes **Tm**, **Tsm**, and **Tsc** (mapped on Point Reyes). **Paleontological Resources—Tps** deposits on the Marin Peninsula contain diatoms and cetacean bones. Lithic arkose interbeds are commonly bioturbated. South of Golden Gate, **Tps** deposits contain fossiliferous mudstone beds. Holotype specimen of *Spisula mossbeachensis* (clam) was collected from **Tps**. **Coastal Features and Processes—**today, **Tps** forms coastal bluffs and may be exposed on wave-cut platforms at low tide.	**Slope Movement Hazards and Risks—**coastal areas underlain by **Tps**, such as Seal Cove, are prone to failure where waves erode steep cliffs and undercut slopes. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Evolution of the Modern Landscape—Tps** originated to the south and was transported north by movement along the San Andreas Fault. The Purisima Formation records deposition in a shrinking shallow sea. Rocks record shift from deeper off-shore conditions (quiet water) to shallower nearshore conditions (high-energy rivers dumping into estuaries and bays).
PALEOGENE (middle and lower Eocene)	Butano Sandstone (**Tb**)	Thin to thick bedded, arkosic sandstone interbedded with mudstone and shale. Conglomerate, containing well-rounded cobbles and pebbles, is present in lower part of section. Thickness is about 3,000 m (9,800 ft). **Tb** is only mapped west of the San Andreas Fault. In the managed area of the park, it underlies the Phleger Estate. *Note*: GRI GIS data do not show this unit in the park, but recent studies indicate that it, rather than the Whiskey Hill Formation, likely underlies the Phleger Estate (Russel Graymer, US Geological Survey, research geologist, email communication, 3 December 2015).	**Cenozoic Rocks and Deposits—Tb** accumulated in a local basin, which formed as basement blocks shifted due to the tectonic transition from subduction to transform movement. The Butano Sandstone represents submarine fan deposits.	None documented.	**Franciscan Foundation—**most of the Paleocene rocks in the region (**Tw**, **Tb**, **Tsu**, and **Tsl**) are turbidites composed of weathered Franciscan material deposited on top of Salinian or Franciscan basement rocks in deep water. **Development of the San Andreas Fault System—Tb** originated to the south and was transported north by movement along the San Andreas Fault.
PALEOGENE (middle and lower Eocene)	Whiskey Hill Formation (**Tw**)	Arkosic sandstone with silty claystone, glauconitic sandstone, and tuffaceous siltstone. The sandstone beds are well cemented with calcite. Thickness is as much as 900 m (2,900 ft). The GRI GIS data show a large area of **Tw** on the west side of the San Andreas Fault over the Phleger Estate. New information indicates this area is likely the Butano Sandstone. The Whiskey Hill Formation likely only occurs east of the fault.	**Cenozoic Rocks and Deposits—Tw** accumulated in a local basin, which formed as basement blocks shifted due to the tectonic transition from subduction to transform movement. The Whiskey Hill Formation represents bathyal turbidity currents and submarine slumps.	None documented.	**Franciscan Foundation—**most of the Paleocene rocks in the region (**Tw**, **Tb**, **Tsu**, and **Tsl**) are turbidites composed of weathered Franciscan material deposited on top of Salinian or Franciscan basement rocks in deep water.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
PALEOGENE (Paleocene)	Sandstone, shale, and conglomerate – upper part (**Tsu**)	**Tsu** is a very well indurated, soft to hard, sandstone and pebble to cobble conglomerate, with lesser amounts of siltstone, claystone, and carbonate beds, all containing granitic debris. Bedding in **Tsu** is distinct and ranges from thin to massive. Thickness is between 400 m (1,300 ft) and 450 m (1,475 ft). Excellent exposures of **Tsu** occur at Point San Pedro.	**Cenozoic Rocks and Deposits—**the oldest Cenozoic rocks are two Paleocene turbidite deposits (**Tsu**, **Tsl**). **Folds—**near Point San Pedro, **Tsu** is folded into anticlines, synclines, and overturned synclines which parallel the ridges and valleys in the area. **Paleontological Resources—**contains *Turritella pachecoensis* fossils (high-spired snail shells) that suggest an age between about 62 million and 56 million years ago (in California, this period is sometimes called the "Ynezian stage"; Morgan 1981). Holotype specimen of a *Campanile greenellum* (snail) was collected from **Tsu** or **Tsl**. **Coastal Features and Processes—**today, **Tsu** forms coastal bluffs.	**Slope Movement Hazards and Risks—**coastal areas underlain by **Tsu**, for example at Point San Pedro, are prone to failure where waves erode steep cliffs and undercut slopes. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Franciscan Foundation—**most of the Paleocene rocks in the region (**Tw**, **Tb**, **Tsu**, and **Tsl**) are turbidites composed of weathered Franciscan material deposited on top of Salinian or Franciscan basement rocks in deep water. **Development of the San Andreas Fault System—Tsu** is mapped only on the west side of the San Andreas Fault and reflects late phases of subduction tectonics to the south. It formed before the development of the San Andreas Fault and was subsequently transported to its current location.
PALEOGENE (Paleocene)	Sandstone, shale, and conglomerate – lower part (**Tsl**)	**Tsl** is a laminated to rhythmically bedded, soft to medium hard, brown, fine to coarse grained, thin bedded, arkosic turbidite sandstone and black shale. The base of **Tsl** is not exposed, but thickness is estimated between 450 m (1,475 ft) and 760 m (2,500 ft). Excellent exposures of **Tsl** occur at Point San Pedro.	**Cenozoic Rocks and Deposits—**the oldest Cenozoic rocks are two Paleocene turbidite deposits (**Tsu**, **Tsl**). **Tsu** unconformably overlies Salinian granite. **Paleontological Resources—**contains *Turritella pachecoensis* fossils (high-spired snail shells) that suggest an age between about 62 million and 56 million years ago (in California, this period is sometimes called the "Ynezian stage";Morgan 1981). Holotype specimen of a *Campanile greenellum* (snail) was collected from **Tsu** or **Tsl**. **Coastal Features and Processes—**today, **Tsl** forms coastal bluffs.	**Slope Movement Hazards and Risks—**coastal areas underlain by **Tsl**, for example at Point San Pedro, are prone to failure where waves erode steep cliffs and undercut slopes. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the parks include unauthorized collecting, vandalism, and erosion.	**Franciscan Foundation—**most of the Paleocene rocks in the region (**Tw**, **Tb**, **Tsu**, and **Tsl**) are turbidites composed of weathered Franciscan material deposited on top of Salinian or Franciscan basement rocks in deep water. **Development of the San Andreas Fault System—Tsl** is mapped only on the west side of the San Andreas Fault and reflects late phases of subduction tectonics to the south. . It formed before the development of the San Andreas Fault and was subsequently transported to its current location.
CRETACEOUS	Granitic rocks of Montara Mountain (**Kgr**)	Very light gray to light brown, medium to coarse grained quartz diorite with some granite; contains abundant hornblende and biotite. Aplite, pegmatite, and rhyolite dikes are also present. **Kgr** rocks are highly fractured and deeply weathered. Jointing is common and best seen in sea cliffs. Exposures of hard, unfractured rock are rare. **Kgr** only occurs west of the San Andreas Fault and south of the Golden Gate. **Kgr** forms the bedrock under Corral de Tierra and is mapped at the surface along ridges. These are the only Salinian basement rocks mapped within the park. The other Salinian units (**Kg**, **Kgri**, and **Kgdt**) are mapped in Point Reyes, north of the Golden Gate.	**Rocks of the Salinian Complex—**intrusive igneous rocks, such as **Kgr**, originated to the south in association with the batholith that formed a volcanic arc during Franciscan subduction. Kgr was later sliced off and transported north to its present location along the San Andreas Fault. Salinian igneous rocks are strikingly different from Franciscan Complex rocks. **Slope Movements—**the southwest flank of Montara Mountain is pockmarked by numerous small, shallow landslides in **Kgr** and in grus (weathered granite). **Coastal Features and Processes—Kgr** weathers to produce beach sands.	**Slope Movements Hazards and Risks—**shallow landslides may occur in areas of grus associated with map unit **Kgr** on Montara Mountain. **Abandoned Mineral Lands**—a borrow pit of weathered **Kgr** occurs in Corral de Tierra.	**Franciscan Foundation—**granitic rocks of Montara Mountain are derived from a batholith in southern California that fueled the Sierran arc during Franciscan subduction. **Evolution of the Modern Landscape—**movement along the San Andreas Fault sliced off and carried a section of **Kgr** roughly 310 km (193 mi) north to its present location.
CRETACEOUS	Gabbro and diabase (**Kgd**)	Coarse to fine grained, equigranular to porphyritic igneous rock. Intrusive into the Franciscan Complex; occurs as segregations in serpentinite (**KJfsu**). Weathered **Kgd** rock is speckled brown and orange and ranges from crumbly to moderately hard. **Kgd** is not mapped within the managed area of the park. Within the authorized boundary, **Kgd** is only mapped on Angel Island where it occurs as small bodies within serpentinite (**KJfsu**).	None documented.	None documented.	**Franciscan Foundation—**non-Franciscan gabbro and diabase (**Kgd**) intruded the Franciscan Complex on Angel Island.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** Basalt and Greenstone (**Kfg**, **KJfg**, **KJfgs**)	This group of units consists mainly of basalt and greenstone with lesser amounts of diabase and rare gabbro. Nearly all of the basalt in the park has been altered to some extent and can also be referred to as greenstone; the names are typically used interchangeably. Gabbro and diabase have a similar chemical composition to basalt but differ in texture (crystal size). Fresh rock is structureless to strongly pillowed. Flows, breccia, and tuff are less common. Chert and/or limestone interlayers occur locally (too small to show on map). Good exposures of pillow basalt (**Kfg**) occur at Point Bonita in the Marin Headlands. **KJfg** is mapped extensively on the Pilarcitos fault block south of San Francisco and west of the San Andreas Fault. Within the managed area of the park, **KJfg** is mapped in the southeastern Marin Headlands, at Mori Point, and on Sweeney Ridge. **KJfgs** is mapped primarily in the western Marin Headlands.	**Rocks of the Franciscan Complex—**basalt and greenstone form the base of the Franciscan sequence. **Franciscan Terranes—**the Nicasio Reservoir terrane is primarily basalt and gabbro. Franciscan basalt and greenstone units are also mapped in the Marin Headlands and Permanente terranes. **San Andreas Fault System—**Franciscan rocks are primarily east of the San Andreas fault, except on the Pilarcitos fault block where **KJfm**, **KJfl**, **KJfss**, **KJfmss**, and **KJfg** are mapped west of the San Andreas Fault. **Coastal Features and Processes—**today, Franciscan basalt and greenstone form cliffs along coast. **Sea Caves—**most common in these harder rocks of the Franciscan Complex rather than in the softer Cenozoic sedimentary rocks.	**Slope Movements Hazards and Risks—**where sheared serpentinite occurs or hydrothermal alteration has produced soft clays, erosion has produced a subdued, hilly topography, which is prone to landslides. **Sea Cave Documentation and Management—**sea caves may be present in basalt and greenstone of the Franciscan Complex. **Abandoned Mineral Lands**—the managed area of the park contains two former quarries mapped in basalt and greenstone; one is at Mori Point and the other is in the Marin Headlands.	**Franciscan Foundation—**basalt and greenstone of the Franciscan Complex began forming at a mid-ocean ridge roughly 200 million years ago. They traveled with the Farallon plate and accreted to North America episodically from 160 million to 50 million years ago.
CRETACEOUS	**FRANCISCAN COMPLEX** Diabase (**Kfdb**)	Porphyritic, mafic dike rock. Thought to be a fragment of a sheeted dike complex. **Kfdb** is only mapped on Point Bonita in the Marin Headlands.	**Rocks of the Franciscan Complex—**subvolcanic (formed at shallow depths) diabase dikes are associated with the basalt and greenstone base of the Franciscan sequence. **Franciscan Terranes—Kfdb** at Point Bonita is part of the Permanente terrane. This youngest Franciscan terrane was originally deposited in association with seamounts near the equator. **Coastal Features and Processes—**today, **Kfdb** forms cliffs at Point Bonita.	**Sea Cave Documentation and Management—**sea caves may be present in diabase of the Franciscan Complex.	**Franciscan Foundation—**diabase likely formed at shallow depths below basalt and greenstone.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** Chert and Limestone (**Kfl**, **KJfc**, **KJfl**, **KJfbch**)	This group of units is primarily chert and limestone with lesser amounts of shale, some quartz veins, and clay minerals. The limestone is light-gray, hard, dense, and finely crystalline. It is massive in some places and in other places it is distinctly bedded between layers of black chert. The chert is of radiolarian origin and may be black, white, red, green, orange, brown, or gray. The chert is hard and brittle and most commonly in the form of "ribbon chert" where it is interbedded with thin shale layers. Alternatively, chert occasionally forms in very thick layers. The chert in some of these thick exposures has been recrystallized and cut by crystalline quartz veins. Along faults the chert has been hydrothermally altered into tan to buff clay minerals. Chert is also commonly interlayered with or surrounded by greenstone of the Franciscan Complex. Chert is abundant within the managed area of the park, especially on the Marin Headlands where chert forms ridges. Exceptional exposures of ribbon chert are along Conzelman Road. Limestone is less common; **Kfl** is restricted to two small masses in the San Andreas Fault system between Olema and Bolinas. Map unit **KJfl** is mapped near Mori Point; most of it is not within NPS-managed lands.	**Rocks of the Franciscan Complex—**chert and limestone form the middle of the Franciscan sequence. **Franciscan Terranes—**Franciscan chert makes up about 1/3–1/2 of the Marine Headlands terrane. Chert and limestone units are also mapped in the Permanente terrane. The Permanente chert was originally deposited in association with seamounts near the equator. **Faults—**a large fault-bounded block of **KJfbch** surrounded by mélange (**KJfm**) occurs at the eastern edge of Muir Woods National Monument. **Paleontological Resources—**chert is composed of the shells of microscopic radiolarians, and limestone contains the fossil shells of foraminifera. **Coastal Features and Processes**—today, Franciscan chert and limestone form cliffs along the coast. **Sea Caves—**sea caves form most commonly in harder rocks (e.g., chert) of the Franciscan Complex rather than in the softer Cenozoic sedimentary rocks; limestone dissolution may contribute to sea cave formation.	**Sea Cave Documentation and Management—** undocumented sea caves may be present in chert and limestone of the Franciscan Complex. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include vandalism and erosion. Unauthorized collection is not a major threat in these rocks because of the abundance of fossils and difficulty in extraction. **Abandoned Mineral Lands**—the managed area of the park contains two former quarries mapped in chert, both are located in the Marin Headlands.	**Franciscan Foundation—**chert and limestone accumulated on top of basalt and greenstone in a tropical open ocean environment near the equator beginning about 200 million years ago. They traveled with the Farallon plate and accreted to North America episodically from 160 million to 50 million years ago.
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** Graywacke and shale (**Kfgwy**, **KJfss**, **KJfmss**, **KJfsh**, **KJfbss**)	This group of units is primarily graywacke sandstone and shale with lesser amounts of conglomerate and metagraywacke. Graywacke is interbedded with thin layers (5–13 cm [2–5 in]) of fissile, generally dark-gray shale and some thick conglomerate lenses. Graywacke may be as much as 300 m (984 ft) thick. Graywacke and shale are extensively mapped in the managed area of the park. These rocks are mapped over most of Sweeney Ridge, the north end of Ocean Beach, and at Fort Mason; as well as at the Presidio, on Alcatraz, at Stinson Beach, on Bolinas Ridge, and throughout the Marin Headlands.	**Rocks of the Franciscan Complex—**graywacke and shale are the most abundant rocks in the Franciscan Complex; they form the top of the Franciscan sequence. **Franciscan Terranes—**graywacke and shale are present in most of the terranes in the park. The Alcatraz, Novato Quarry, and San Bruno Mountain terranes are all characterized by graywacke sandstone and shale turbidite deposits. Graywacke and shale are also mapped in the Marin Headlands and Permanente terranes. **Slope Movements—**graywacke and shale of the Franciscan Complex formed as a result of ancient slope movements; turbidity currents carried sediments down the steep continental slope. **Paleontological Resources**—macrofossils are rare in Franciscan rocks. Four bivalves (two of which are newly described species) and one gastropod were documented on Alcatraz; two ammonites, one gastropod, and one belemnite fossil were discovered in the Marin Headlands; one ammonite was documented from the Marin Headlands terrane in San Francisco. **Coastal Features and Processes**—today, Franciscan graywacke and shale form cliffs along the coast. **Sea Caves—**sea caves form most commonly in hard rocks of the Franciscan Complex rather than in the softer Cenozoic sedimentary rocks.	**Slope Movement Hazards and Risks—**graywacke in Marin County weathers to produce vermiculite (swelling clays), which make them more susceptible to landslides than their counterparts north of Marin County (not on the GRI map). **Sea Cave Documentation and Management—** undocumented sea caves may be present in graywacke and shale of the Franciscan Complex. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Franciscan Foundation—**graywacke and shale were deposited on top of chert and limestone by turbidity currents in the deep oceanic trench of the Franciscan subduction zone around 100 million years ago.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** Serpentinite (**KJfsu**)	Greenish gray serpentinite and small amounts of ultramafic rocks (e.g., gabbro and diabase). Occurs as lenses and irregularly shaped masses. Soft and sheared serpentinite encloses blocks (commonly less than 3 m [10 ft] in diameter) of hard and unsheared serpentinite and silica carbonate rocks (**KJfbsc**). Within the managed area of the park, serpentinite is mapped at Land's End, Baker Beach, Fort Point, the Presidio, Stinson Beach, and the Marin Headlands.	**Franciscan Mélange—KJfsu** is found within and along the boundaries of the Franciscan Mélange. **Coastal Features and Processes—KJfsu** tends to form sea cliffs where mapped along the coast. **Sea Caves—**sea caves form most commonly in the hard rocks of the Franciscan Complex rather than in the softer Cenozoic sedimentary rocks.	**Slope Movement Hazards and Risks—**weak and highly fractured rocks, like serpentinite, are the most susceptible to landslides. **Disturbed Land Restoration—**in 2002, the Geologic Resources Division recommended stabilization and waste removal at the serpentinite cliffs of Baker Beach. **Coastal Serpentine Scrub Preservation—**serpentinite produces serpentine soils that are associated with rare and endemic plant communities. Mapped serpentinite can be used to locate potential serpentine scrub communities. **Naturally Occurring Hazardous Materials—**asbestos—a known carcinogen—may naturally occur in serpentinite. Health hazards arise when activities that disturb asbestos-containing rocks and soil generate asbestos-laden dust that may be inhaled.	**Franciscan Foundation—**serpentinite likely originated as peridotite in the Coast Range ophiolite (Jurassic ocean crust that was emplaced within the continent before accretion of the Franciscan Complex). The peridotite was likely metamorphosed to serpentinite in the subduction zone and later faulted into the Franciscan Complex.
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** High grade metamorphic rocks (**KJfsch**, **KJfbm**, **KJfbmg**, **KJfmgs**)	Most Franciscan rocks are weakly metamorphosed. This category separates out the units that contain high grade metamorphic rocks, which are indicated by the presence of blueschist minerals (e.g., glaucophane and lawsonite), amphibolite, or eclogite. Chunks of these rocks are often found "floating" in the mélange of the Franciscan Complex or surrounded by serpentinite. Areas of high grade metamorphic rock are uncommon, therefore many occurrences are represented by point features (see "Mélange blocks" in the GRI GIS data). **KJfbmg** blocks are mapped within the managed area of the park near Tennessee Valley and Muir Beach. A block of **KJfmgs** is mapped in Muir Woods National Monument.	**Franciscan Terranes—**metamorphic rocks are common in the Yolla Bolly terrane, the oldest and easternmost Franciscan terrane in the park. **Franciscan Mélange—KJfbm** and **KJfmgs** are found as blocks in Franciscan mélange (point features in GRI GIS data). **Slope Movements—KJfsch (**graywacke) formed as a result of ancient underwater slope movements that generated turbidity currents.	None documented.	**Franciscan Foundation—**high grade metamorphic rocks formed during the earliest stages of Franciscan subduction. They were later brought to the surface along faults associated with accretion.
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** Silica carbonate rocks (**KJfbsc**)	Reddish brown, hydrothermally altered serpentinite (e.g., chalcedony, opal, quartz) along the margins of serpentinite (**KJfsu**) and in severely sheared mélange (**KJfm**). May contain minor cinnabar. Within the managed area of the park, silica carbonate rocks are mapped at Stinson Beach.	**Rocks of the Franciscan Complex—KJfbsc** occurs in hydrothermal areas, mainly near the north end of Bolinas Ridge, and in fissures along the margins of **KJfsu** (serpentinite).	**Naturally Occurring Hazardous Materials—**mercury occurs in the mineral cinnabar, which occurs in **KJfbsc** in very small amounts; it is not likely a health issue at the park.	**Franciscan Foundation—**silica carbonate rocks formed in shear zones during and after accretion of the Franciscan Complex to North America. **Development of the San Andreas Fault System**—some parts of the unit may be Tertiary in age where it is related to volcanism associated with the growth of the San Andreas Fault.

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Age	Map Unit (Symbol)	Geologic Description	Geologic Features and Processes	Geologic Resource Management Issues	Geologic History
JURASSIC AND CRETACEOUS	**FRANCISCAN COMPLEX** Mélange (**KJfm**)	A chaotic mixture of fragmented Franciscan rocks in an extensively sheared shale and sandstone matrix. Tectonic inclusions are largely of greenstone, chert, graywacke, and their metamorphosed equivalents, plus exotic high grade metamorphic rocks and serpentinite. Includes minor discrete masses of limestone too small to be mapped. Dark gray where fresh, yellowish brown where weathered and in places is eroded to form badlands topography. Within the managed areas of the park, mélange is abundant; it is mapped in the South Coastal Bluffs, Ocean Beach/Fort Funston, Stinson Beach, Homestead Valley, Dias Ridge, Muir Beach, Muir Woods, and Marin Headlands areas.	**Franciscan Terranes—KJfm** makes up the wide areas of mélange, sometimes called the "Central terrane," which separates the different Franciscan terranes. Mélange is also abundant within the Marin Headlands terrane. **Faults—**faults typically surround large blocks (as much as several kilometers long) of other Franciscan rocks set among mélange. **Geothermal Systems and Hydrothermal Features—** the hot spring near Steep Ravine beach is mapped in **KJfm**. **Paleontological Resources—**two bivalve specimens are reported from **KJfm** in the park.	**Slope Movement Hazards and Risks—**weak and highly fractured rocks, like mélange, are the most susceptible to landslides. **Sea Cave Documentation and Management—**sea caves may be present in mélange of the Franciscan Complex. **Paleontological Resource Inventory, Monitoring, and Protection—**threats to paleontological resources in the park include unauthorized collecting, vandalism, and erosion.	**Franciscan Foundation—**mélange formed between the Franciscan terranes during accretion to the North American continent 160 million to 50 million years ago.
JURASSIC (?)	Siliceous volcanic rocks and keratophyre (**Jsv**)	Highly altered silicic volcanic (formed at the surface) and subvolcanic (formed at shallow depths) rocks. Feldspars are almost all replaced by albite. **Jsv** is mapped west of Upper Crystal Springs Reservoir on the Pilarcitos fault block; not within the managed area of the park.	**Ancient Convergent Boundary—Jsv** probably originated as oceanic crust at a mid-ocean ridge and was subsequently emplaced on the continent in association with the Franciscan subduction zone; it may be part of the Coast Range ophiolite. **San Andreas Fault System—Jsv** is part of the "Franciscan" basement which occurs west of the San Andreas Fault within the Pilarcitos fault block; all other rocks west of the fault are Salinian Complex rocks or younger.	None documented.	**Franciscan Foundation—Jsv** probably represents Jurassic ocean crust which became trapped in the forearc basin as the subduction zone was coming together. Timing was before the accretion of the Franciscan Complex. It may be part of the Coast Range ophiolite. The Jurassic age assignment for these rocks is based on analyses of similar rocks in Alameda and Contra Costa counties.
JURASSIC (?)	Gabbro (**Jgb**)	Light greenish gray, dark-gray weathered, mafic intrusive rock. Mostly gabbro but also includes some diabase locally. **Jgb** is mapped west of Upper Crystal Springs Reservoir on the Pilarcitos fault block; not within the managed area of the park.	**Ancient Convergent Boundary—Jgb** probably originated as oceanic crust at a mid-ocean ridge and was subsequently emplaced on the continent in association with the Franciscan subduction zone; it may be part of the Coast Range ophiolite. **San Andreas Fault System—Jgb** is part of the "Franciscan" basement, which occurs west of the San Andreas Fault within the Pilarcitos fault block; all other rocks west of the fault are Salinian Complex rocks or younger.	None documented.	**Franciscan Foundation—Jgb** probably represents Jurassic ocean crust which became trapped in the forearc basin as the subduction zone was coming together. Timing was before the accretion of the Franciscan Complex. The age of this unit is unknown, but it is probably part of the Jurassic Coast Range Ophiolite.