Geologic Resource Evaluation Scoping Summary
Golden Gate National Recreation Area, California

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The Geologic Resource Evaluation (GRE) Program provides each of 270 identified natural area National Park System units with a geologic scoping meeting and summary (this document), a digital geologic map, and a geologic resource evaluation report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and monitoring and research needs. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity to discuss park-specific geologic management issues, and if possible include a site visit with local experts.

In a meeting room overlooking Rodeo Lagoon and the Pacific Ocean at Fort Cronkhite, Marin Headlands, the National Park Service conducted a GRE scoping meeting for Golden Gate National Recreation Area on September 26–28, 2007. On September 26, Tim Connors (Geologic Resources Division) facilitated the discussion of map coverage, and Bruce Heise (Geologic Resources Division) led the discussion regarding geologic processes and features. Participants had a separate discussion of coastal and marine features and processes on September 28. On September 27, participants toured portions of Golden Gate National Recreation Area and traveled into Point Reyes National Seashore.

Participants at the meeting included NPS staff from Golden Gate National Recreation Area, Point Reyes National Seashore, San Francisco Bay Area Network, Pacific West Regional Office, Geologic Resources Division, and Washington Office, and cooperators from the Presidio Trust, National Marine Sanctuary, National Oceanographic and Atmospheric Administration, U.S. Geological Survey, California Geological Survey, and Colorado State University (see table 1).

Park and Geologic Setting

In order to preserve coastal beaches, shorelines, adjacent hills, and mountains in the San Francisco Bay Area, Congress established Golden Gate National Recreation Area in 1972 largely from former military lands. Extending from San Mateo County, south of San Francisco, to the Point Reyes peninsula in Marin County, the legislative boundary for Golden Gate National Recreation Area far exceeds those lands currently managed by the National Park Service. New land acquisitions continue to expand Golden Gate National Recreation Area, which is presently 31,570 ha (78,000 ac). Within the area's administrative boundaries are two other National Park System units: Muir Woods National Monument and Fort Point National Historic Site. In addition to Fort Point, Golden Gate National Recreation Area hosts four other national historic landmarks: the Presidio of San Francisco, San Francisco Port of Embarkation, Alcatraz Island, and San Francisco Bay Discovery Site (Portola Site Acquisition Monument). Within the legislative boundary are the San Francisco watershed in San Mateo County and Angel Island State Park (Elder et al. 2007). Point Reyes National Seashore manages Golden Gate lands bounding the national seashore east of the San Andreas Fault.

One word sums up the geology of Golden Gate National Recreation Area—mélange. This is also a good word to describe the park setting, which is a mixture of landscapes, seascapes, wooded areas, ridges, beaches, bays, lagoons, headlands, and cultural resources. According to the park brochure, "Golden Gate is one of the most-visited national park areas in the nation." Certainly a variety of activities draws visitors to Golden Gate but possibly the *je ne sais quoi* of its mélange geology also draws attention. Radiolarian chert and chevron folds along Conzelman Road are prime geologic attractions.

As Bonnie Murchey stated during the scoping field trip, "This is the best place in the country to see scraped off subduction zone rocks." The Franciscan Complex "represents the detritus [or mélange] of California's earlier geologic history of subduction" (Hough 2004). Now a transform plate boundary has replaced the subduction zone, but 30 million years ago, various terranes (i.e., Alcatraz, Marin Headlands, and San Bruno Mountain) were accreting themselves to the North American continent. A mélange matrix of serpentinite and graywacke (i.e., Fort Point–Hunters Point and City College) surrounds these terranes.

Geologic Mapping for Golden Gate National Recreation Area

During the scoping meeting Tim Connors (Geologic Resources Division) showed some of the main features of the GRE Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRE Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRE Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRE digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, FGDC-compliant metadata, a Windows HelpFile that captures ancillary map data, and a map document that displays the map and provides a tool to directly access the HelpFile. Final data products are posted at http://science.nature.nps.gov/nrdata/. The data model is available at http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm.

When possible, the GRE Program provides large scale (1:24,000) digital geologic map coverage for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands. Maps of this scale (and larger) are useful to resource managers because they capture most geologic features of interest and are spatially accurate within 12 m (40 ft). The process of selecting maps for management begins with the identification of existing geologic maps and mapping needs in the vicinity of the park. Scoping session participants then select appropriate source maps for the digital geologic data or develop a plan to obtain new mapping, if necessary.

In compiling the digital map for Golden Gate National Recreation Area, GRE staff will use a combination of published digital and paper maps from the U.S. Geological Survey and California Geological Survey. GMAP numbers shown in brackets in the following map citations are unique identification numbers for the GRE Program's database. GRE staff will evaluate these maps and compare data to arrive at a final simplified list.

For the northern part of Golden Gate National Recreation Area, GRE staff is considering the following maps for inclusion into the final digital map product:

Blake, M. C., R. W. Graymer, D. L. Jones, and A. Soule. 2000. *Geologic map and map database of parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma counties, California*. Scale 1:75,000. Miscellaneous Field Studies Map MF-2337. [GMAP 2526]. Reston, VA: U.S. Geological Survey.

Wagner, D. L., C. I. Gutierrez, and K. B. Clahan. 2006. *Geologic map of the south half of the Napa 30' × 60' quadrangle, California*. Scale 1:100,000. [GMAP 74823]. Sacramento, CA: California Geological Survey.

For the San Francisco north 7.5-minute quadrangle, GRE staff is considering the following maps for inclusion into the final digital map product:

Schlocker, J., M. G. Bonilla, and D. H. Radbruch. 1958. *Geology of the San Francisco North quadrangle, California*. Scale 1:24,000. Miscellaneous Geologic Investigations Map I-272. [GMAP 2522]. Reston, VA: U.S. Geological Survey.

Schlocker, J., and M. G. Bonilla. 1972. *Bedrock-surface map of the San Francisco North quadrangle, California, 1961*, and *Bedrock-surface map of the San Francisco South quadrangle, California, 1964*.

Scale 1:31,680. Miscellaneous Field Studies Map MF-334. [GMAP 9415]. Reston, VA: U.S. Geological Survey.

Schlocker, J. 1974. *Geology of the San Francisco North quadrangle, California*. Scale 1:24,000. Professional Paper 782. [GMAP 2619]. Reston, VA: U.S. Geological Survey.

For the area south of and including the San Francisco south 7.5-minute quadrangle, GRE staff is considering the following maps for inclusion into the final digital map product:

Bonilla, M. G. 1998. *Preliminary geologic map of the San Francisco South 7.5' quadrangle and part of the Hunters Point 7.5' quadrangle, San Francisco Bay area, California: A digital database*. Scale 1:24,000. Open-File Report OF-98-354. [GMAP 2617]. Reston, VA: U.S. Geological Survey.

Brabb, E. E., R. W. Graymer, and D. L. Jones. 1998. *Geology of the onshore part of San Mateo County, California: A digital database*. Scale 1:62,500. Open-File Report OF-98-137. [GMAP 21899]. Reston, VA: U.S. Geological Survey.

Brabb, E. E., R. W. Graymer, and D. L. Jones. 2000. *Geologic map and map database of the Palo Alto 30' × 60' quadrangle, California*. Scale 1:100,000. Miscellaneous Field Studies Map MF-2332. [GMAP 28446]. Reston, VA: U.S. Geological Survey.

Pampeyan, E. H. 1994. *Geologic map of the Montara Mountain and San Mateo 7.5' quadrangles, San Mateo County, California*. Scale 1:24,000. Miscellaneous Investigations Map I-2390. [GMAP 4100]. Reston, VA: U.S. Geological Survey.

For the offshore portions of Golden Gate National Recreation Area, see the discussion in the “Coastal and Marine Features and Processes” section.

Geologic Features and Processes and Related Management Issues

The scoping session for Golden Gate National Recreation Area provided an opportunity to develop a list of geologic features, processes, and related management issues, which will be further explained in the final GRE report. Participants did not prioritize these issues, but discussion made it clear that coastal, marine, and seismic features and processes have the greatest management significance. These are discussed first, followed alphabetically by other features and processes.

Coastal and Marine Features and Processes

As Chief Scientist Gary Davis (Washington Office) pointed out during the scoping meeting, “Everything in parks is protected…except fish.” Visitors cannot take a pinecone, but commercial fishing takes 8 million tons of squid every year from Channel Islands National Park. This example illustrates the lack of attention that the National Park Service and the public have given marine resources. However, the tide is turning and the National Park Service has significantly advanced marine protection efforts through a number of initiatives in recent years, for example creating the Ocean and Coastal Resources Branch. Because of the voluminous yet unknown nature of the coastal and marine resources at Golden Gate National Recreation Area, a “special session” with many invited participants was part of GRE scoping. Participants spent much of the time discussing a geologic map of the coastal and submerged portions of the national recreation area. A California Geological Survey map product of the Big Sur area may serve as a model for future mapping (Niven et al. 2008). This map provides both onshore and offshore geologic data. For more information, contact Chris Wills at 916-323-8553 or cwills@consrv.ca.gov. Participants suggested that a “gap analysis” be conducted to compile available data and consider various technologies (e.g., lidar) for completing a digital geologic map for Golden Gate National Recreation Area.

Coastal and marine features and processes will be part of the final GRE report that accompanies the digital geologic map. Related issues that require management attention will also be highlighted. The “map units” will be a driving force for what features will be discussed in the report; however, participants began to outline many of the features, processes, and issues that should be included. Some of the features that participants discussed appear elsewhere in this scoping summary (e.g., sea caves are discussed in“Cave Features and Processes,” and bluff failure and cliff erosion are discussed in “Hillslope Features and Processes”). Participants also identified a number of cultural resources that are affected by marine and coastal processes, namely the Golden Gate Bridge, Fort Point, and the Sutro Baths, but also Native American middens, paleo-fill material, lighthouses, and ship wrecks.

Features

- Beaches and spits
- Bluffs and cliffs
- Esteros
- Estuaries
- Headlands, including sea arches and stacks
- Inlets
- Islands
- Lagoons
- Rocky intertidal zone
- Submerged bathymetric features (e.g., bed forms and channels)
- Surf zone
- Tide pools

Processes

- Coastal erosion
- Currents and their effects, including longshore and cross shore sediment transport
- Freshwater stratification, freshwater discharge, and freshwater plumes (e.g., a freshwater plume extends from the San Francisco Bay and creates sand waves)
- Groundwater discharge (submarine)
- Runoff
- Sediment influx from upland sources
- Storm activity
- Tides and their effects
- Tsunami inundation, erosion, and deposition
- Upwelling
- Wave action

Issues

- Alternative energy sources such as wave, wind, and tidal—Development of these energy resources has unknown impacts but could possibly affect sediment transport, eolian processes, viewsheds, habitats and biological resources, underwater sea waves, and cultural landscapes
- Flotsam and jetsam, especially land-based debris and refuse that accumulates in “trash collection areas”
- Invasive species that stabilize submarine features and change habitats
- Nutrient loading, harmful algal blooms, and dead (anoxic) zones
- Pollution: non-point source pollution (e.g., agriculture, septic systems, mines, and roads), pollutant discharges from vessels, contaminant transport and oil spills, sewage transport boxes, and sewer outfall
- Reef burial
- Saltwater intrusion into freshwater sources

- Shipping-related issues: wakes, wrecks, grounding, and enormous submerged rocks
- Shoreline stabilization and development (hard): piers, seawalls (buried and emergent), levees, roads, coastal fortifications, constructed lagoons, dolphins (freestanding pilings), and rip-rap
- Shoreline stabilization and development (soft): sand mining, sediment bypass, dredging and dredge disposal, fill, and beach replenishment
- Urban development (e.g., concentrated storm-water discharge)
- Water development: desalinization, rerouting through delta, changing storage and release regime, removing levees, and building new dams and reservoirs

Seismic Features and Processes

Currently seismic activity is "quiet" at Golden Gate National Recreation Area. Faults appear to be locked and waiting for the next large quake. The San Andreas, San Gregorio, and Pilarcitos faults run through the recreation area; the San Gregorio is primarily offshore, and the Pilarcitos is inactive in this area. The probability of a large quake happening in the next 30 years on the San Andreas Fault is low; the probability is much higher farther east along the Hayward Fault. Management concerns for the next large quake concentrate on roads. Namely, would park managers be prepared to assist all visitors if a debilitating quake occurred during a weekend? Disaster scenarios consider damage to the Golden Gate Bridge, which would affect Point Reyes National Seashore and Golden Gate National Recreation Area. Both units have emergency response plans in place.

Geologic hazards associated with earthquakes include fault displacement, ground shaking and strong ground motion, seismically induced landsliding, and liquefaction. Both startling and hazardous is the snapping off of the tops of redwood trees in Muir Woods National Monument.

Areas of artificial fill are among the most geologically unstable, constituting a major hazard during earthquakes. Poorly or non-engineered fill settles unevenly over time and is prone to strong shaking during earthquakes. During the 1906 earthquake, areas of old fill were the most severely damaged; the same areas were damaged again in the 1989 Loma Prieta earthquake (Sloan 2006). The National Park Service has spent tens of millions of dollars retrofitting buildings to withstand seismic hazards at Golden Gate National Recreation Area. For instance, in 2007 Yerba Buena Engineering & Construction began rehabilitating the foundations of 18 historic buildings at Fort Cronkhite. The California Geological Survey is a source of information about these hazards. For more information, contact Chris Wills at 916-323-8553 or cwills@consrv.ca.gov.

Beaches and Dunes

During breaks and after scoping, many participants had the pleasure of walking along the beach near Rodeo Lagoon. The sand here is a stark (and dark) contrast to Ocean Beach and the beaches at Point Reyes. Its pebble-sized grains are a marked difference to what is typically thought of as sand (i.e., sand sized). With Franciscan rocks as the source, the headlands' sand appears reddish brown from a distance. Upon closer inspection, not only reddish chert grains compose the beach, but dark-gray graywacke and brown pillow basalt. Scattered among the darker grains are blue, green, and yellow pebbles of altered chert, eroded from the surrounding cliffs. The sand at Ocean Beach comes from the soft Merced Formation, so its lighter color and finer texture set it apart from the Marin Headlands. Landslides, which are common along Ocean Beach, contribute large amounts of sand to the shore. Although the grains consist mostly of clear quartz, other rocks contribute color: white (feldspar), green (serpentine), black (magnetite), and occasionally pink (garnet).

The beaches at Golden Gate National Recreation Area have both active (climbing) and inactive (paleo) dunes. Some paleo-dunes occur on ridge tops. The inactive dunes are not lithified. Most dunes are managed as unique habitats; some host endangered species such as San Francisco lessingia (*Lessingia germanorum* Cham.). As part of habitat restoration, the National Park Service has constructed some dunes near Lobos

Creek on the Presidio and restored dune habitat at Ocean Beach, Fort Funston, Crissy Field, and Muir Beach. Dunes may contain fossil pollen, which may be a source of paleoclimate data.

Many dunes are anchored by nonnative plant species. Park managers are making a concerted effort to eliminate one such species, European beachgrass (*Ammophila arenaria* (L.) Link). By creating an armored dune system, this species is altering natural processes (e.g., washover and sediment deposition) and changing geomorphic features (e.g., spits). Another management concern is organic enrichment of dunes, which can change the entire character of these features. Also landscaping (e.g., plantings and hard structures), roads, and walls can block wind and cause sand starvation in localized areas.

Some geology guides call San Francisco "the city on sand." Starting in 1883, the Army planted 400,000 seedlings of eucalyptus, cypress, and pine, creating the forest at the Presidio. According to the NPS guide, *Main Post Walk: 200 Years of History and Architecture*, "a forest would provide contrast between the city and post, and accentuate the government's power. It would also create windbreaks, subdue the blowing sands, and beautify the bleak expanses." Sand dunes once covered more than half of San Francisco—from Ocean Beach to the bay (Sloan 2006); some dunes were as high as 18 m (60 ft). The sand that accumulates along Ocean Beach today blows landward toward the city. Seemingly in vain, cement walks check the drifting sand, but work crews regularly close the Great Highway to return sand to the beach (Sloan 2006).

Cave Features and Processes

Sea caves—clefts or cavities at the base of sea cliffs—occur at the land-water interface. Generally wave action enlarges sea caves along the natural line of weakness in weathered rock. Because these caves are at sea level, tides may also affect them. The National Park Service estimates that more than 100 sea caves occur at Golden Gate National Recreation Area (see http://www.nps.gov/goga/naturescience/intertidal.htm), but scoping participants admitted a nearly complete lack of knowledge of this resource. Participants did, however, suspect that the sea caves provide habitat for sea lions and possibly some bird species. Not much is known about the caves as a recreational resource. They may be part of an already established informal "water trail" system as they are accessible by kayak; some are accessible by land at low tide. Through the Geoscientist-in-Parks Program, Connie Garrett is mapping sea caves at Golden Gate National Recreation Area during summer 2008. She met with Bruce Rogers, a USGS geologist who has informally inventoried some of the caves on his personal time, and has been in touch with Dale Pate and Ron Kerbo, acting and former Geologic Resources Division cave specialists. The local National Speleological Society (NSS) grotto may be interested in assisting with field work.

Climatic Change

Losing Ground: Western National Parks Endangered by Climate Disruption states, "A climate disrupted by human activities poses such sweeping threats to the scenery, natural and cultural resources, and wildlife of the West's national parks that it dwarfs all previous risks to these American treasures" (Saunders et al. 2006). The authors contend that "a disrupted climate is the single greatest threat to ever face western national parks." Because of the potential disruption that climate change could cause to park resources, including geologic features and processes, the GRE Program has begun to include a discussion of the effects of climate change to park resources as part of scoping. Participants at the scoping meeting for Golden Gate National Recreation Area identified the following as possible outcomes of climate change on park resources: (1) altered upwelling regime, (2) enhanced coastal flooding, (3) changes in the storm regime (including wave activity), (4) changes in ocean chemistry, (5) increased coastal erosion with repercussions for infrastructure and release of contaminants, (6) changes in freshwater runoff, (7) increased dead (anoxic) zones, (8) change in beach morphology, (9) more frequent algal blooms, (10) loss of wetland habitat, (11) habitat changes for seabirds and marine mammals, (12) gain of subtidal habitat and novel submerged resources, (13) increased opportunities for invasions by exotic plants and animals, and (14) local extinction of some species related to loss of geologic substrate and processes.

An action plan for responding to climate change will be part of Golden Gate National Recreation Area's general management plan, which as of September 2007 was in draft stages. Such a plan should address potential jurisdictional disputes and disputes over how to manage shoreline retreat.

Disturbed Lands

Modern human activities have disturbed more than 127,480 ha (315,000 ac) in 195 National Park System units. Some of these features may be of historical significance, but most are not in keeping with the mandates of the National Park Service. Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by mining, development (e.g., facilities, roads, dams, abandoned campgrounds, and user trails), agricultural practices (e.g., farming, grazing, timber harvest, and abandoned irrigation ditches), overuse, or inappropriate use. Usually lands disturbed by natural phenomena such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires are not considered for restoration unless influenced by human activities.

Restoration activities return the quality and quantity of an area, watershed, or landscape to some previous condition, often some desirable historic baseline. To accelerate site recovery, restoration at disturbed areas directly treats the disturbance and aims to permanently resolve the disturbance and its effects. For more information about disturbed lands restoration, contact Dave Steensen (NPS Geologic Resources Division) at dave_steensen@nps.gov or 303-969-2014.

As a result of urban expansion, more than 90% of the Bay Area's salt marshes have been developed. During the Gold Rush, San Francisco was expanding rapidly and developers considered the marshland south of Market Street as prime real estate (Konigsmark 1998). They filled the marsh with garbage, quarry rubble, and dune sand, and proceeded to build. Little did they know (or perhaps care) that they had piled this rubble on top of soft unconsolidated, water-saturated sediments. In some places, for example along Townsend Street, these sediments were more than 30 m (100 ft) thick. Moreover, much of the fill in the Marina District is from the 1906 earthquake. This rubble was dumped on soft, unconsolidated sediments along the shoreline, and buildings were constructed on the fill. The 1989 Loma Prieta earthquake showed that this was not a red-hot idea (Konigsmark 1998). Furthermore, fill in the Crissy Field area was from military projects and the Panama-Pacific International Exposition of 1915 (Tamara Williams, Golden Gate National Recreation Area, written communication, June 17, 2008).

As more regions of the bay become public lands administered by the U.S. Fish and Wildlife Service, state and county parks, or nonprofit land trusts, restoration of salt marshes is occurring. Crissy Field is an example of a successful salt marsh restoration project. Once a military waste dump, Crissy Field is now a thriving coastal habitat with many species of invertebrates and fish long gone from the area returning to the site (http://www.nps.gov/goga/naturescience/wetlands.htm).

Marincello—a large proposed development of the Marin Headlands—prompted inclusion of Golden Gate National Recreation Area into the National Park System. Marincello Road at Tennessee Valley is a remnant of that failed development. Jim Wood and Dave Steenson (Geologic Resources Division) are assisting with restoration plans for this area.

The newest acquisition to Golden Gate National Recreation Area is Mori Point, located on a promontory above the City of Pacifica. Originally part of the Spanish San Pedro Land Grant, Mori Point has been the site of many enterprises over the past 120 years, including a farm, tavern, and roadhouse. Part of the 42-ha (105-ac) Mori Point has been mined for limestone and sand; remains of the quarry and the dredging operation persist. Restoration is underway at Mori Point. During 2007–2008, restoration efforts created habitat for the threatened California red-legged frog (*Rana aurora draytonii*) and the endangered San Francisco garter snake

(*Thamnophis sirtalis tetrataenia*); the quarry itself is not proposed for restoration (Tamara Williams, Golden Gate National Recreation Area, written communication, June 17, 2008).

A large quarry at the Marin Headlands has a restoration plan in place, primarily to address erosion and safety concerns. Chert was mined for road base at this site. Additionally several WWII-vintage mining operations (e.g., a copper mine and manganese exploration) occurred on Bolinas Ridge. Under research and collecting permits, park managers have allowed small-scale removal of magnetite sand from Ocean Beach for use in interpretive science exhibits outside the recreation area.

Fluvial Features and Processes

Five moderately sized drainages dissect the northern portion of Golden Gate National Recreation Area: Lagunitas Creek, Olema Creek, Redwood Creek, Elk Creek (in Tennessee Valley), and Rodeo Creek. Many smaller creeks (e.g., Copper Mine Gulch, Wilkins Gulch, Pike County Gulch, Morses Gulch, McKinnan Gulch, Stinson Gulch, and Easkoot Creek) flow from Bolinas Ridge into Bolinas Lagoon (Weeks 2006). The National Park Service is restoring natural processes and habitat in the Redwood Creek watershed, which is home to threatened and endangered species including coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), and the California red-legged frog (*Rana aurora draytonii*). For instance, in the lower reaches of Redwood Creek, park staff has been reconnecting the creek to its floodplain, which has involved removal of some of the levees upstream of Highway 1. The Big Lagoon restoration project will include levee removal downstream of Pacific Way (Tamara Williams, Golden Gate National Recreations Area, e-mail, May 29, 2008). The National Park Service has also restored portions of Easkoot Creek, which supports steelhead.

Very few free-flowing streams still exist in the vicinity of San Francisco. Lobos Creek flows through the Presidio of San Francisco and empties into the Pacific Ocean at Baker Beach. Much of the water is diverted near the mouth, treated, and used as a potable water supply for the Presidio. The Tennessee Hollow watershed and Dragonfly Creek, which flow to Crissy Field and the San Francisco Bay respectively, are undergoing riparian restoration at the Presidio (Weeks 2006).

Sanchez Creek, a heavily altered urban stream, flows along the park boundary at Mori Point and supports both native and introduced fish, as well as amphibians. Drainages in Phleger Estates are tributaries to San Francisquito Creek, which flows to San Francisco Bay and supports steelhead habitat (Weeks 2006).

Flooding is a concern for park management. Most runoff occurs during winter storms, with maximum flows occurring during and immediately after. Steep basins and shallow soils promote rapid runoff and “flashy” storm flow. Where flooding occurs downstream of park lands, external owners often want the National Park Service to “take action.”

In places, infrastructure exacerbates flooding damage, for instance at poorly engineered culverts and where channels are armored; it also impedes natural streamflow. Enhanced incision is largely related to past land-use practices such as grazing, which have dramatically changed flooding conditions and floodplain morphology. Beginning with the Civilian Conservation Corps, construction (e.g., armored channels) has interrupted flooding, which ultimately affects the health and regeneration of the redwood forest in Muir Woods National Monument.

Geothermal Features and Processes

Deep faults (see “Seismicity” section) provide conduits for geothermal waters. For instance, the Marin County Visitors Bureau notes Steep Ravine Beach at Mount Tamalpais State Park, within the legislative boundary, as having intermittently active hot springs, one of which is in the ocean (see http://www.visitmarin.org/beaches.html). This rocky beach is only usable during very low tide, however.

Hillslope Features and Processes

According to Chris Wills (California Geological Survey), bedrock maps often show less than 20% of the actual landslides that affect an area. In general, USGS bedrock geologists intentionally do not include landslide deposits on their maps. They only include them if the deposit is massive and obscures bedrock. This is not to say, however, that landsliding is not a significant process at Golden Gate National Recreation Area, rather that they aren't often mapped with any degree of accuracy.

Throughout geologic time, large-scale submarine landslides called turbidites have slid off the coast of California. The graded bedding of Franciscan graywacke records these massive underwater slides: as turbidity currents flow onto the ocean floor, coarser particles settle out first and are deposited at the base, fining upward towards the top.

On land, the primary concern with hillslope processes is bluff failure and erosion, which may be caused by loading, added moisture, or the undercutting of a slope (e.g., at road cuts). This is particularly significant for the cultural preservation of many coastal fortifications (e.g., at Fort Funston and the Presidio).

As "Devils Slide," "Slide Ranch," and similar names attest, California Highway 1 is constantly closed as a result of landsliding and debris flows, which are common during wet winters. The California Department of Transportation regularly removes eroded material from the road, dumping it over the edge. This practice has changed the rate, timing, and amount of sediment added to the coastal budget and marine environment. Park managers have solid, historical documentation of debris flows and incision during flooding events.

Lacustrine Features and Processes

At least 14 natural year-round lakes used to exist in what is now Golden Gate National Recreation Area (Sloan 2006). Mountain Lake, on the Presidio, is one of the last remaining natural lakes in San Francisco (Weeks 2006). Highway 1 runs along the northwestern side of this lake; the National Park Service would like to reclaim a more natural setting but are constrained by existing infrastructure. The Presidio Trust is implementing the enhancement of Mountain Lake (Weeks 2006). Several small dammed impoundments also occur in Golden Gate National Recreation Area (Weeks 2006), some of which serve as habitat for threatened California red-legged frog, while others harbor nonnative invasive bull frog. Crystal Springs Reservoir, an enhanced sag pond, serves as a source of drinking water for San Francisco, including parts of Golden Gate National Recreation Area. Though the National Park Service does not manage the San Francisco watershed, it has scenic easements over the lands surrounding the reservoir.

Paleontological Resources

In late January 2007, Ted Fremd (NPS Pacific West Region) conducted a preliminary assessment of the nature and extent of the fossiliferous deposits at Golden Gate National Recreation Area (Fremd 2007). In fall 2007, Will Elder (Golden Gate National Recreation Area) completed an inventory and conditions assessment of the paleontological resources of the entire San Francisco Bay Area Network (Elder et al. 2007). Elder presented a summary of the paleontological resources at Golden Gate National Recreation Area during the GRE scoping meeting. He outlined the 11 geologic units exposed at the national recreation area and highlighted the fossils they contain.

- Alcatraz Terrane: bivalve species
- Marin Headlands Terrane: radiolarian chert, ammonites, and belemnites (probably reworked)
- San Bruno Mountain Terrane: no fossils found to date
- Permanente Terrane: limestone (foraminifera) and some radiolarian chert
- Central Terrane: radiolarian tuff and chert, potential invertebrate fossils
- Unnamed sandstone (Paleocene turbidite deposit): invertebrate fossils (e.g., oysters, mussels, crustaceans, echinoids, and gastropods)

- Whiskey Hill Formation: no fossils found in exposures in Golden Gate National Recreation Area to date; potential for microfossils (e.g., foraminifera and coccoliths), invertebrate, and vertebrates
- Merced Formation: vertebrates (e.g., ground sloth, mammoth, horse, and camel), tracks of large terrestrial mammals, invertebrate trace fossils, and mollusks
- Santa Clara Formation: potential for mammals in Quaternary gravels; abundant plant material and freshwater pelecypods and gastropods in other locales
- Colma Formation: no fossils found in exposures in Golden Gate National Recreation Area to date, but potential vertebrate material (e.g., ground sloth, bison, and mammoth), diatoms, pollen, and plant material as in other locales
- Quaternary units (e.g., marine terranes; sand dunes; fluvial, alluvial, lacustrine, and estuarine deposits): potential for many types of fossils, including vertebrates

Park managers would like to have paleontological locations as part of their GIS but do not want this layer served over the Internet. Wright (1974) may provide data for this layer.

Unique Geologic Resources

Unique geologic resources may include natural features mentioned in a unit's enabling legislation, features of widespread geologic importance, geologic resources of interest to visitors, or geologic features worthy of interpretation. The GRE Program also considers type localities and age dates as unique geologic features. Serpentinite, the California state rock, is a unique geologic resource at Golden Gate National Recreation Area. Park staff is very interested in having outcrops of serpentinite as part of the digital geologic map. Schlocker (1974) is a source for this data. Serpentinite is part of the Coast Range Ophiolite of the Great Valley Complex. Outcrops are often characterized by a rubbly surface and a thin, dark reddish soil (Sloan 2006). Because the soil is nutrient poor and contains elements that are toxic to many plants, few plants grow on serpentinite. However, those that do grow are often rare, endemic plants such as Tiburon mariposa lily (*Calochortus tiburonensis*), serpentine reedgrass (*Calamagrostis ophitidis*), Tiburon paintbrush (*Castilleja neglecta*), and Tiburon buckwheat (*Eriogonum caninum*).

Another unique (and useful) geologic resource is the paleomagnetic and age dates for many sites in the area. Geochemical data are available for basalt and chert. For more information contact Bonnie Murchey (U.S. Geological Survey) at 650-329-4926 or bmurchey@usgs.gov.

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