Park Significance-

1. The convergence of the San Andreas Fault Zone, San Francisco Bay at the Golden Gate, and the California coastline that creates a dynamic landscape and environment of exceptional scientific value.

Fundamental Resources and Values

1.1 Geologic Resources – The national recreation area's geologic resources include faults, plate margins and a subduction zone; a wide diversity of rock types and deposits representing more than one hundred million years of the Earth's history; and the complex geologic processes that continue to shape the landscape.

Analysis of Fundamental Resources and Values

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Importance of the Resources and Values

The San Francisco Bay region straddles the boundary zone between two of the Earth's major tectonic plates. The Pacific Plate is slowly moving northward relative to the North American Plate along the San Andreas Fault Zone. Sea floor spreading in the middle of the Pacific Plate has pushed the edge of that plate under the North American Plate, creating a subduction zone.

The San Andreas Fault, which extends most of the length of California, defines many of the major recognizable landforms in the park. The fault zone in GGNRA is evident along Tomales Bay, the Olema Valley and Bolinas Lagoon in Marin County, then extends offshore and makes landfall again at Fort Funston in San Francisco and is highlighted to the south by the lakes and reservoirs within San Francisco Watershed lands in San Mateo County.

Ancient marine and nearshore rocks scraped off the edge of the continent in the subduction zone form the unique geology of the Marin Headlands -- a diversity of rock types including cherts, basalts, greenstones and sandstones. Other coastal bluffs and headlands – from the Presidio to Land's End, and from Muir Beach to Stinson Beach – formed from serpentine and mélange extruded from deeper within the subduction zone.

More recent geologic history is exposed at Fort Funston and south where nearshore deposits of silts and sands were deposited in an environment of sea level rise and fall and uplift. Terrestrial mammals were fossilized in these formations.

Tectonic forces, changes in sea level related to past climate changes, combined with river and stream erosion have created an eroded landscape evidenced by large and small watersheds within and adjacent to the park. The largest example is San Francisco Bay and the Golden Gate.

Smaller watersheds at least partially within the park include Lagunitas Creek, Bolinas Lagoon, Redwood Creek, Tennessee Valley, and Rodeo Valley in Marin County; Tennessee Hollow and Lobos Creek on the Presidio; and San Francisquito Creek, Sanchez Creek and Calera Creek watersheds in San Mateo County.

The park's geologic resources are of exceptional scientific interest and value with respect to plate tectonics, dynamics of the San Andreas Fault, reconstruction of plate margin history, deep plate margin seismicity, earthquake recurrence, paleontological resources, and active estuarine and marine processes. The proximity to educational and research institutions in the San Francisco Bay Area makes the park's geologic resources easily accessible to researchers and educators.

Current Conditions and Trends

The topographical relief of the park ranges from sea level to 2,300 feet above mean sea level at the top of Mt. Tamalpais. Slopes range from almost flat marine terraces and alluvial deposits to steep canyons along some creeks, and near vertical bluffs above numerous beaches.

The San Andreas Fault extends northwest from near Fort Funston, and runs through Bolinas Lagoon and Tomales Bay. Although the park contains many faults, the San Andreas Fault is the most evident in size and influence. San Andreas is one of the most studied faults in the world and is monitored by the San Andreas Fault Observatory at Depth (SAFOD), a deep borehole observatory that began development in 2004 by National Science Foundation (NSF) and the United States Geologic Survey (USGS). This project is attempting to reveal the physical and chemical processes controlling earthquake generation within a seismically active fault. Through ongoing observations of the fault, scientists have determined that there is an average of 34mm of movement per year along the fault.

Bedrock parent materials within the park are jumbled, partly as a result of grinding movement along the San Andreas Fault. The Marin Headlands contains more resistant rocks than the more erodible mélange found to the north of Pirates Cove. Groundwater is close to the surface and frequently emerges as seeps or springs in the mélange area. The sea cliffs at Fort Funston were formed from the oldest of these tilted fossil-rich beds of sand and clay (the Merced Formation), and are easily eroded by wave action. In the last few hundred thousand years, sand and clay have accumulated as beaches, dunes, and near shore deposits and are now exposed at Sutro Heights, Baker Beach, Angel Island and Rodeo Cove.

Many abandoned quarries are found within GGNRA. Dogtown Copper Mine, located just off Bolinas Ridge, is the only known mineral development in the park. It was developed in 1863 and re-worked around the turn of the century and its two shafts are now abandoned.

Potential Threats and Issues

The greatest threat to the geologic features within Golden Gate National Recreation Area is excavation and accelerated erosion. Deep, long gullies of old roads continue to erode. Vegetation is impacted and non-designated "social trails" are found in heavily used natural areas. New road, trail and building construction often involves permanent removal of rock outcrops and other natural geologic formations.

Landslides or slumps exist in most of the small valleys throughout Golden Gate National Recreation Area. Large gully networks range in character from persistently de-vegetated slopes, to large

individual channels up to 15 feet deep and wide. These gullies have been caused by a combination of locally intense rainfall, human disturbance, and the presence of highly erodible soils. Past and current land use practices have altered vegetative composition, aggravated and encouraged soil erosion, and precipitated landslide activity and recurrent gully formation. The erosion has contributed to increasing sediment loads to streams, bays and shorelines. They have also accelerated the loss of large quantities of top soil and have resulted in prominent visual scars and contribute to recurrent maintenance costs.

Rare species, like the state-listed bank swallow, are affected by erosion from current land uses. At Fort Funston, visitors climb the cliffs and aggravate erosion in the sensitive cliff nesting area. Some of the worst and most obvious problem areas are in grasslands. Almost without exception, major erosional features have been caused by the diversion of streams or the concentration of seasonal storm runoff by roads and trails. Many roads developed prior to park establishment were improperly aligned and constructed. These factors have resulted in inadequate drainage, which has led to concentrations of water. These concentrations have created gullies and carried increased sediment yields into creeks, which in turn impairs water quality. In addition, water diversions and the concentration of runoff may initiate or accelerate landslides in sensitive areas.

Past grazing has increased erosion by decreasing the amount of vegetation available to capture water. It also has caused soil to become compacted and thereby deterring infiltration. This then increases runoff, which carries topsoil and sediments into the creeks. Off-road vehicles, hang gliders, bicyclists, horses, dogs, hikers, and other visitors have created denuded areas with compacted soil. Compaction also inhibits infiltration, increasing runoff and erosion. The trend of increasing trail use portends a long term and potentially increasing threat.

Dredging and dredge disposal, sand mining, and shoreline construction can alter natural coastal erosion and deposition. Global warming and associated sea level rise will exacerbate coastal erosion.

Damage from earthquakes mostly depends on the type of underlying subsurface material. Upland areas on bedrock generally have a low seismic hazard, whereas bay lands, unconsolidated sand, and artificial fill areas (such as Crissy Field, Aquatic Park, Fort Mason docks, the mouth of Lobos Creek and along Ocean Beach) may experience intense shaking, subsidence, differential settling and liquefaction.

Serpentine outcrops provide a substrate that supports many rare plants. The serpentine sites within the Golden Gate National Recreation Area are small and are threatened by a lack of protection. These outcrops are generally unstable and very erodible. While natural serpentine erosion is important for this unique habitat, human activities such as trampling and grading in or near the outcrops accelerate the erosion and disrupt the fragile habitat.

Interest of Various Stakeholders

Local and Regional Organizations
Cordilleran Section, Geological Society of America – regional professional society

National Organizations:
Geological Society of America – national professional society
American Geophysical Union – national scientific organization

Government Agencies and Tribes:

California Coastal Commission – state coastal management agency responsible for implementing the Coastal Zone Protection Act
California Department of Water Resources – state water resources management agency
California Division of Geology – state geologic resources management agency
National Oceanic and Atmospheric Administration -- federal agency focused on the condition of the oceans and atmosphere
Natural Resource Conservation Service – division of the US Department of Agriculture focused on conservation of soil, water and other natural resources
San Francisco Bay Conservation and Development Commission (BCDC) – regional agency responsible for implementing the Coastal Zone Protection Act within the San Francisco Bay
U.S. Geological Survey – federal scientific organization
State Water Resources Control Board – state water resources management agency
Regional Water Quality Control Board – regional branch of the State Water Resources Control Board
Federal Emergency Management Agency
U. S. Army Corps of Engineers

Educational and Cultural Institutions:
University of California, Berkeley, Davis and other campuses
Stanford University
San Francisco State University

Law and Policies

Geologic Resources

Source:
NPS *Management Policies 2001;* NPS-77, "Natural Resources Management Guidelines"

Policy Direction:
The park's geologic resources and processes are preserved and protected as integral components of the park's natural systems.

Management Direction:
The National Park Service will take the following kinds of actions to meet legal and policy requirements related to geologic resources:

- Assess the impacts of natural processes and human-related events on geologic resources.
- Maintain and restore the integrity of existing geologic resources.
- Integrate geologic resource management into NPS operations and planning.
- Interpret geologic resources for visitors.
- Partner with the U.S. Geological Survey and others to identify, address, and monitor geologic hazards.
- Develop programs to educate visitors about geologic resources.
- Collect baseline information on surficial geology.
- Develop a plan to address geologic research, inventory, and monitoring.
- Update geologic map of the park in digital format that can be used in the park's geographic information system (GIS).
- Update geologic history of the park, using modern theory and techniques.
- Update geologic interpretations of localities that are the subject of interpretive stops or displays.

- Prepare a geologic inventory, including the identification of the significant geologic processes that shape park ecosystems and the identification of the human influences on those geologic processes (i.e., "geoindicators"); identification of geologic hazards; inventory of type sections or type localities within the park; inventory of "textbook" localities that provide particularly good or well-exposed examples of geologic features or events, and that may warrant special protection or interpretive efforts; and, identification of interpretive themes or other opportunities for interpreting the significant geologic events or processes that are preserved, exposed, or occur in the park.

Coastal Zone Management Act of 1972
The Coastal Zone Management Act (CZMA) of 1972, 16 U.S.C. secs. 1451-1464, is the primary federal statute for protecting the nation's coastal areas from development pressures.

Issues
(Add issues once they have been explored with park staff and the public)