CALIFORNIA COASTAL NATIONAL MONUMENT

GEOLOGIC CHARACTERIZATION

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INTRODUCTION

The California Coastal National Monument (CCNM) is defined as being "all unappropriated or unreserved lands and interests in lands owned or controlled by the United States in the form of islands, rocks, exposed reefs and pinnacles above mean high tide within twelve nautical miles of the shoreline of the State of California". The CCNM provides habitat for a wide range of sea life from sea lions to mussels and microbes. The Bureau of Land Management (BLM), which administers the CCNM, is charged with protection of the Monument and its life forms. In order to carry out this and other mandates, the BLM has sought a characterization of the physical, biological and socio-cultural dimensions of the monument by which to develop policies for its protection. This document is a first effort to characterize the geologic features. It is anticipated that this report will form the basis for more detailed studies.

The geologic character of the CCNM is presented as a table. Four columns present brief summaries of four geologic characteristics, in so far as time, available literature and limited field observations allow. The four characteristics are geology, morphology, petrography and structure.

The column headed GEOLOGY describes the formations (i.e., mappable units of rock) shown on the Geologic Map of California (20) as intersecting the coast. These formations are the source for most of the islands, rocks, exposed reefs and pinnacles that constitute the adjacent CCNM. Exceptions to this generality may occur when faults or stratigraphic relationships juxtapose a different formation.

The column headed MORPHOLOGY describes the shape or form of the features derived from the adjacent on-shore formations and attempts to relate these shapes to observable controlling features, such as joint systems, bedding, faults, or the lack of these.

The column headed PETROGRAPHY describes the mineralogy and/or sedimentalogical composition of the rocks, along with their texture and such internal structures as bedding or, in the case of metamorphic rocks, foliation.

The final column is headed STRUCTURE and this describes faults, folds and igneous features that intersect the coast, are close to the coast or are such that they might be of interest to visitors to the CCNM. In a few cases there seem to be no clearly understood structural features that meet these criteria and column is left blank.

References are noted by numbers in parentheses, which refer to citations listed at the end of the table.

GENERALIZATIONS

Certain characteristic shapes of features derived from specific formations are sufficiently consistent to warrant some generalizations concerning morphological controls. The Franciscan formation of Jurassic and Cretaceous age, the upper Cretaceous strata, and the upper Miocene strata have distinct characteristics that seem to persist from area to area.

The Franciscan formation contains a stratigraphic order that can be recognized throughout its outcrop area. The lower part of the Franciscan consists of metamorphosed basaltic lava flows that were extruded onto the bottom of the oceans and were later metamorphosed to greenstones. The greenstone is followed by banded chert and shale layers and above those the shale continues without the chert, but has buried within it mile-scale blocks of sandstone, limestone and ultrabasic rocks which originated elsewhere. The rock unit in which these exotic blocks occur is called a *mélange*. The exotic blocks are weathered from the shale around it to form distinct features in the CCNM.

The greenstone weathers to make large domal hills like the 350 foot high Trinidad Headland. Similar domal structures, although a bit smaller are found along Big Sur south of Point Sur. Domal structures are common large-scale erosional products of the greenstone and banded chert sequence.

The Franciscan mélange also produces large rocks and islands. The mudstone and shale, in which the exotic blocks were buried, erodes to small chips. In this way, the exotic blocks are exhumed and often form large blocks on hillsides underlain by mélange. The same process at the shore produces large, irregular blocks of various sizes.

Smaller greenstone blocks are of a scale close to the spacing of joints and other planes of weakness, resulting in smaller, irregularly shaped blocks.

Cretaceous strata are composed of a varied suite of sedimentary rocks that includes sandstone, shale and conglomerate. The shale and sandstones are often thinly interbedded, but thick beds also occur. The conglomerates are coarse and make beds several feet thick. When wave erosion works on these varied rock types they produce blocks of all sizes. Some are large and angular; others are small and flaggy, making a boulder beach at the base of a sea cliff´s cut into Cretaceous strata.

The last of these strongly characteristic formations is the middle Miocene. The rocks consist of thin bedded, light colored mudstones of surprisingly low density, so that the rock is very light for its size. The strata weather into smooth, bulbous, softly rounded blocks, mostly under a foot in length. Yet the strata erode to form large sea stacks, steep cliffs and ragged bays with intervening headlands that become separated from the mainland. These blocks form large, low islands that are ideal nesting places for sea birds.

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California Coastal National Monument
Geologic Characterization

California Coastal National Monument

CCNM Subunit: 1
Name: Pelican Bay
Date: July 2007

CCNM Subunit 1
From the Oregon border to Point St. George -16 mi

GEOLOGY

A. Oregon border to Prince Island - 3 mi
Franciscan formation greenstones and cherts line the coast between the Oregon border at 42^{o} N and Prince Island. Offshore rocks and pinnacles are abundant (1) (18).

Bedded chert is characteristic of the lowermost part of the Franciscan formation (13) and consists of inch-thick beds of white chert separated by partings and layers of shale up to an inch or more thick. Reddish chert occurs as lenses two or three inches in thickness. The chert beds are very hard and contribute to the strength of these rocks in resisting erosion. Boulders of mica schist are found on the beaches among boulders of greenstone and chert, suggesting that aluminous meta-sedimentary layers also are present within the Franciscan (18).

B. Prince Island to Point St. George - 13 mi
South of Prince Island, Quaternary dunes and alluvium form the shore and few rocks or pinnacles are present.

MORPHOLOGY
Dome or mound shaped, smooth to irregular-sided rocks dominate the offshore area. Some are over 100 feet high above sea level, ranging down to boulders a foot or so in diameter. The minerals that form these greenstones are soft and easily broken, but the rocks they form are strong, eroding to form steep cliffs along the mainland coast and rounded forms off-shore (18).

Quaternary and Holocene sediments form beach bars and alluvial terraces along the Smith River. Marine terraces of Pleistocene age lie at altitudes up to 200 feet.

PETROLOGY
The northern outcrop belt of the Franciscan formation consists mostly of greenstone and bedded chert. In places, beds of arkosic sandstones and blocks of ultramafic rocks are found within the Franciscan sequence (13).

Greenstones are soft rocks of low metamorphic grade that consist mainly of the minerals chlorite, epidote, pumpellyite and asbestos-form amphiboles along with quartz and plagioclase feldspar (13). All of these are greenish or neutral in color and give the rocks their characteristic hue

STRUCTURE

The greenstones and associated chert beds are strongly deformed throughout the region. What appear to be flatlying beds often turn out to be the recumbent limbs of tight chevron folds (18).

The chert unit has been interpreted as lying stratigraphically below the greenstones (13). Occurrences of cherts higher in the Franciscan probably are repetitions of the basal chert unit by folding or faulting (13). The greenstones above the cherts are interpreted as metamorphosed basaltic volcanic rocks that are part of the oceanic crust. These contain pillow structures, which are bulbous shapes formed during submarine eruptions (18). Ultrabasic rocks, originally composed of olivine and pyroxene have been altered to serpentine (1). Ultabasic rocks are interpreted as part of the Earth’s upper mantle (13).

California Coastal National Monument

CCNM Subunit: 2
Name: Crescent City
Date: July 2007

Subunit 2
Point St. George to Crescent City - 9 mi.

GEOLOGY

Franciscan formation greenstones and cherts crop out along the coast near Crescent City and form most of the off-shore rocks (1).
Round Rock is one of many offshore features along the east-west shore between St. George Reef and the coast. Mapping indicates that Franciscan formation rocks underlie the large offshore islands and that the Franciscan is exposed in patches on the mainland, where it is mostly covered by Quaternary marine sediments (1).

MORPHOLOGY

The offshore rocks and islands are low-lying near Crescent City and tend to be flat-topped. Boulders of greenstone and chert from the Franciscan pave some shallow offshore areas that are exposed at low tide.

PETROLOGY

The coastal belt of the Franciscan formation consists mostly of greenstone and bedded chert. In places, beds of arkosic sandstones and blocks of ultramafic rock are found within the Franciscan sequence (13).

Greenstones are soft rocks of low metamorphic grade that consists mainly of the minerals chlorite, epidote, pumpellyite and asbestos-form amphiboles along with quartz and plagioclase feldspar (13). All of these are greenish or neutral in color and give the rocks their characteristic hue.

STRUCTURE

The greenstones and associated chert beds are strongly deformed throughout the region (1) (13) (18). What appear to be flat lying beds often turn out to be the recumbent limbs of tight chevron folds (18).

The chert unit has been interpreted as lying stratigraphically below the greenstones (13). Occurrences of cherts higher in the Franciscan probably are repetitions of the basal chert unit by folding or faulting (13). The greenstones above the cherts are interpreted as metamorphosed basaltic volcanic rocks that are part of the oceanic crust (13). These contain pillow structures, which are bulbous shapes formed during submarine eruptions (18). Ultrabasic rocks, originally composed of olivine and pyroxene, have been altered to serpentinites. Ultrabasic rocks are interpreted as part of the Earth's upper mantle (13).

California Coastal National Monument

CCNM Subunit: 3
Name: Redwoods National & State Parks
Date: July 2007

CCNM Subunit 3
South of Crescent City to Big Lagoon - 42 mi

GEOLOGY

A. Crescent City south to Del Norte-Humboldt County line - 21 mi

Franciscan formation crops out along the coast for the entire distance of 21 miles. Abundant rocks and pinnacles derived from Franciscan units lie off-shore (1).
The Franciscan in this region consists largely of greenstones. However, bedded chert is characteristic of the lowermost part of the Franciscan formation and consists of inch-thick beds of white chert separated by partings and layers of shale up to an inch or more thick. Reddish chert occurs as lenses two or three inches in thickness (18). The chert beds are very hard and contribute to the strength of these rocks in resisting erosion.

B. Humboldt County line to Big Lagoon - 21 mi.

For seven and one-half miles to the south of the Humboldt county line, the Franciscan formation is buried beneath Holocene beach and dune sands (1). These deposits protect the underlying Franciscan formation from erosion by waves and, for that reason, pinnacles and intertidal rock debris are lacking off-shore.

MORPHOLOGY

Dome or mound shaped, smooth to irregular-sided features dominate the offshore area. Some are over 100 feet high, others range downward in size to boulders a foot or so in diameter (18). The greenstone that forms these features is soft, but strong, eroding to form steep cliffs along the mainland coast and rounded forms off-shore.

Offshore rocks and pinnacles are present off headlands that bound Stone and Big Lagoons (1). The lagoons are formed by eastward indentations of the coastline that are closed off from direct access to the sea by long barrier bars.
The bars north of Big Lagoon close off Stone Lagoon and Fresh Water Lagoon from the sea, then continue as a very long beach for 15 miles to the north (1). As is most often the case, where beaches and coastal dune fields are well developed, rocks and pinnacles offshore are few.

PETROLOGY

Greenstones are soft rocks of low metamorphic grade that consist mainly of the minerals chlorite, epidote, pumpellyite and asbestos along with quartz and plagioclase feldspar. All of these are greenish or neutral in color and give the rocks their characteristic hue.

STRUCTURE

The greenstones and associated chert beds are strongly deformed throughout the region (1). What appear to be flatlying beds often turn out to be the recumbent limbs of tight chevron folds (18).

The chert unit has been interpreted as lying stratigraphically below the greenstones (13). Occurrences of cherts higher in the Franciscan probably are repetitions of the basal chert unit by folding or faulting (13). The greenstones above the cherts are interpreted as metamorphosed basaltic volcanic rocks that are part of the oceanic crust. These contain pillow structures, which are bulbous shapes formed during submarine eruptions (13) (18).

Ultrabasic rocks, originally composed of olivine and pyroxene, have been altered to serpentinite (1). These are found stratigraphically below the chert or in fault contact with chert and other rocks. Ultabasic rocks are interpreted as part of the Earth's upper mantle (13).

California Coastal National Monument

CCNM Subunit: 4
Name: Trinidad
Date: July 2007

CCNM Subunit 4
Big Lagoon to south end of Little River State Park - 13 mi

GEOLOGY

The Franciscan formation of Jurassic and Cretaceous ages crops out along the ten miles of coast between Rocky Point and Crannell (1). Pleistocene marine terraces with tops at 400 to 600 feet above sea level overlie the Franciscan starting at Trinidad Head and continue southward past Crannell (1). The Franciscan remains exposed at sea level below the Quaternary marine deposits. Wave erosion of Franciscan strata characteristically develops rocks and pinnacles of the CCNM that range in size from small, fist-sized boulders to large islands 200 to 300 feet high (1) (18).

Bedded chert is characteristic of the lowermost part of the Franciscan formation in the coastal areas north of Point Arena. The chert beds consist of white chert an inch thick or less, separated by partings and layers of shale also up to an inch or more thick. Less abundant reddish chert occurs as lenses two or three inches in thickness. The chert beds are very hard and contribute to the strength of these rocks in resisting erosion. Boulders of mica schist are found on the beaches near Trinidad among boulders of greenstone and chert, suggesting that aluminous meta-sedimentary layers also are present within the Franciscan (18).

MORPHOLOGY

Domed or mound-shaped, smooth-sided shapes dominate the large offshore rocks and islands in the area (18). Some are over 100 feet high and one (Trinidad Head) is over 350 feet high (1). On the low end of the size scale are irregular boulders a foot or less in diameter. The greenstone that forms these features is composed of soft minerals, but the rock is strong, eroding to form steep cliffs along the mainland coast and rounded forms off-shore.

PETROLOGY

The northern outcrop belt of the Franciscan formation consists mostly of greenstone and bedded chert. In places, beds of arkosic sandstones and blocks of ultramafic rocks also are found within the Franciscan sequence (1).

Greenstones are soft rocks of low metamorphic grade that consist mainly of the minerals chlorite, epidote, pumpellyite and asbestos along with quartz and plagioclase feldspar. All of these are greenish or neutral in color and give the rocks their characteristic hue.

STRUCTURE

The San Andreas Fault divides the Franciscan rocks into two distinct belts. Rocks in the belt west of the San Andreas Fault, including those exposed in Subunit 4, are composed largely of greenstones and banded cherts, while those east of the Fault, like the Franciscan exposed around San Francisco Bay in Subunits 16 and 17, expose wide belts of folded and faulted Franciscan mélange above the chert layers. *Mélange* refers to chaotic strata containing large exotic blocks buried within weak black shale.

The greenstones in Subunit 4 and associated chert beds are intensely deformed throughout the region. What appear to be flatlying beds often turn out to be the recumbent limbs of tight chevron folds (18).

The chert unit has been interpreted as lying stratigraphically below the greenstones (13). Occurrences of cherts higher in the Franciscan probably are repetitions of the basal chert unit by folding or faulting (13). The greenstones above the cherts are interpreted as metamorphosed basaltic volcanic rocks that are part of the oceanic crust. These contain pillow structures (13) (18), which are bulbous shapes formed during submarine eruptions.

Ultrabasic rocks, originally composed of olivine and pyroxene, have been altered to serpentinite. These are found stratigraphically below the chert or in fault contact with chert and other rocks. Ultrabasic rocks are interpreted as intrusions that originated in the Earth's upper mantle (13).

California Coastal National Monument
CCNM Subunit: 5
Name: Humboldt Bay
Date: July 2007

CCNM Subunit 5
Crannell to Eel River – 37 mi

GEOLOGY

Quaternary marine deposits continue southward in a three-and-a-half-mile wide band from the area of Crannell to the Mad River, just north of Arcata (2). They range in altitude between sea level and 400 feet. The shore line in this region is composed of Holocene dunes that continue southward for over 37 miles, passing the Arcata and Humboldt Bays and the Eel river estuary (2). No rocks of the CCNM are exposed along this coast.

MORPHOLOGY
The coastline is lined with Holocene dunes and bay mouth bars across the Arcata and Humboldt Bays and the Eel River estuary (2).

California Coastal National Monument

CCNM Subunit: 6
Name: Lost Coast
Date: July 2007

CCNM Subunit 6
Eel River to Anderson Cliff - 70 mi

GEOLOGY

Between the Eel River (Redding Sheet) and Anderson Cliffs (Ukiah Sheet), mountainous relief is underlain by Cretaceous strata that have been eroded into sea cliffs that in places reach more than 1000 feet above sea level. This elevated terrain lines the coast to the south of the Eel River for over 70 miles to Anderson Cliffs and beyond (1) (2).

Cape Mendocino, the westernmost point on the California coast (Redding Sheet), lies south of the Eel River. It is the place where the east-west trending, submarine Mendocino Fault intersects the coast and the termination point of the San Andreas Fault.

A small fault block of Franciscan rocks underlies Point Delgada (2).

Mountains line most of the shore. The areas between mountain spurs host small coves and pocket beaches (2). Offshore, numerous rocks and pinnacles inhabit the shallows.

MORPHOLOGY
Quaternary marine deposits continue southward in a three-and-a-half-mile wide band from the area of Crannell to the Mad River, just north of Arcata. They range in altitude between sea level and 400 feet. The shore line in this region is composed of Holocene dunes that continue southward for over 37 miles, passing the Arcata and Humboldt Bays and the Eel river estuary. No rocks of the California Coastal National monument are exposed along this coast.

PETROLOGY
The Cretaceous rocks are composed of sandstones, shale, greywacke and conglomerate (2) (18). The sandstones are mostly impure, some containing significant amounts of potassium feldspar grains (arkose), others contain grains of quartz and shale mixed with grains of earlier formed rocks. These are termed *greywacke.* Conglomerates consist of rounded pebbles of mixed type.

STRUCTURE

The Cretaceous strata have been strongly deformed, and in some places, have undergone low grade metamorphism (2) (18). Thin-bedded mudstones and sandstones occur along the coast, some crossed with calcite veining.

California Coastal National Monument
CCNM Subunit: 7
Name: Cape Vizcaíno/Westport
Date: July 2007

CCNM Subunit 7
South end of Anderson Cliff to Ten Mile River - 10 mi

GEOLOGY

The steep scarps that line the coast at Anderson Cliff continue southward to Ten Mile River.
Along this trend, the mountains intersect the shore as steep spurs and cliffs, crowding Pleistocene wave-cut terraces into a narrow coastal band, mostly at or below 400 feet (2) (3).

MORPHOLOGY
High and steep cliffs line much of the shore in Subunit 7. Pinnacles and large rocks are numerous (2) (3). The sizes of all these rocks are controlled by the intersection of sedimentary bedding and joints or faults.
Many large rocks are long in horizontal dimension, but low in altitude, possibly due to bedding control.

PETROLOGY

The Cretaceous rocks are composed of sandstones, shale, greywacke and conglomerate (3). The sandstones are mostly impure, some containing significant amounts of potassium feldspar grains (arkose), others mix grains of quartz and shale, along with grains of earlier formed rocks. These are termed *greywacke.* Conglomerates consist of rounded pebbles of mixed type.

STRUCTURE

The Cretaceous strata have been strongly deformed, and in some places, have undergone low grade metamorphism (2) (3) (18). Thin-bedded mudstones and sandstones are seen along the coast, some crossed with calcite veining (18).

California Coastal National Monument

CCNM Subunit: 8
Name: Fort Bragg/Mendicino
Date: July 2007

CCNM Subunit 8
Ten Mile River to Little River - 24 mi

GEOLOGY

The coastal interval that comprises Subunit 8 between Ten Mile River and Little River includes a wide belt of Pleistocene marine terrace deposits that overlie the coastal Cretaceous rocks. The Pleistocene in this area extends up to 3 miles inland, as compared to a half mile farther south and north (3). All the terrace surfaces lie at 400 feet above sea level, or slightly higher.

MORPHOLOGY

The coast along Subunit 8 lacks the steep cliffs found farther to the north. Instead, broad marine terraces extend inland for up to four miles, each capped with Pleistocene marine sands (3). The Pleistocene units are thin and the Cretaceous continues to crop out at sea level. Consequently, the offshore is littered with rocks of the CCNM.

PETROLOGY

The Cretaceous rocks are composed of sandstones, shale, greywacke and conglomerate (3). The sandstones are mostly impure, some containing significant amounts of potassium feldspar grains (arkose), others mix grains of quartz and shale, along with grains of earlier formed rocks. These are termed *greywacke.* Conglomerates consist of rounded pebbles of mixed type.

STRUCTURE

The Cretaceous strata have been strongly deformed, and in some places, have undergone low grade metamorphism (2) (3). Thin-bedded mudstones and sandstones occur along the coast, some crossed with calcite veining.

California Coastal National Monument

CCNM Subunit: 9
Name: Jan Damme Navarro Head
Date: July 2007

CCNM Subunit 9
Little River to Navarro River - 7.5 mi

GEOLOGY

North of the Navarro River, the broad belt mapped as undifferentiated Cretaceous rocks is shown as underlying a broad, flat terrace at 400 feet. A similar terrace at 400 feet at the Fraser Ranch on the Albion River is mapped as Cretaceous, but it too might be underlain by Pleistocene marine deposits (3).

MORPHOLOGY

Marine terraces of Pleistocene age are found over much of the California coastal region. Up to seven levels range in altitude from 10 feet to over 700 feet. Zone 9 terraces can be found at 200, 400 and 600 feet, according to the California Geologic Atlas, Ukiah Sheet (3). Cretaceous rocks crop out at sea level and produce numerous rocks, reefs and pinnacles in the near offshore area.

PETROLOGY

The Cretaceous rocks are composed of sandstones, shale, greywacke and conglomerate (3). The sandstones are mostly impure, some containing significant amounts of potassium feldspar grains (arkose). Other beds mix grains of quartz and shale, along with grains of earlier formed rocks (3). These are termed *greywacke.* Conglomerates consist of rounded pebbles of mixed type.

STRUCTURE

The Cretaceous strata have been strongly deformed, and in some places, have undergone low grade metamorphism (3). Thin-bedded mudstones and sandstones are seen along the coast, some crossed with calcite veining (3) (18).

California Coastal National Monument

CCNM Subunit: 10
Name: Elk
Date: July 2007

CCNM Subunit 10
Navarro River south to Alder Creek at 39^{o}N - 24 mi

GEOLOGY

The coastal terrain of Subunit 10 is underlain by Cretaceous rocks (3). Scattered patches of Pleistocene marine deposits lie on one or more wave cut terraces at or below the 600 foot contour (3). One patch is mapped above 800 feet on a ridge crest between Greenwood and Elk Creek.

MORPHOLOGY

Cretaceous strata make high cliffs along the shore with boulders and outliers offshore (3). Immediately back from the coast the Cretaceous outcrop belt forms rounded hills covered with forest. Exposures of the bedrock are rare and are found mostly in stream channels.

Offshore rocks, pinnacles and outliers form sharp, sometimes fin-shaped features at all scales. Examples are seen along the beaches at Elk and at Mendocino.

Sizes of rocks and pinnacles formed from Cretaceous strata appear to be controlled by bedding, joints and faults, which bound these strongly indurated sedimentary rocks. Low lying, long blocks might reflect control by horizontal shear planes seen in some coastal exposures.

PETROLOGY

The Cretaceous rocks along the coast of Subunit 10 are composed of sandstone, shale, greywacke and conglomerate. The sandstones often contain significant feldspar grains (arkose) (3). When the content of shale and older rock fragments also increase, the sandstones grade into greywacke. Conglomerates contain coarse pebbles of varying composition, including quartz, sandstone, shale and chert. (3)

STRUCTURE

Cretaceous rocks have been strongly deformed by folding and faulting. Steep dips are ubiquitous.(18)

California Coastal National Monument

CCNM Subunit: 11
Name: Point Arena
Date: July 2007

CCNM Subunit 11 Arena Cove to
39 degrees north - 8 mi

GEOLOGY

At Point Arena, Miocene marine deposits dip gently seaward and are overlain by thin Quaternary terrace deposits. Dune sand overlies all other deposits on the north end of the point (4).

Point Arena is three miles west of where the San Andreas Fault passes northwestward into the Pacific Ocean (4). Rocks to the east of the fault belong to the North American Plate and those to the west, including Point Arena, belong to the Pacific Plate (13).

Lower Miocene strata are exposed in cliffs that line the coast from Point Arena southward. The rocks consist of light tan colored mudstones and shales. A notable feature that appears exclusive to the Miocene strata is their very high microscopic porosity, resulting in a rock of surprisingly low density (18).

MORPHOLOGY

Erosion by waves follows well developed joint sets and has cut deep local embayments into the coast immediately south of Point Arena. Islands of an acre or two in area illustrate a process by which narrow embayments indent the coast and then detach headlands between bays by a process of cave and arch formation near the landward end of the embayments (18). Commonly, an arch eroded through the headland collapses, leaving the former headland detached from the mainland. This process is enhanced by the very low density of the rock.

The offshore islands are flat-topped parallel to flat or gently dipping bedding. Smaller rocks often are more equi-dimensional and are widely distributed over shallow bays (18).

Onshore, the Miocene strata underlie a wide terrace, also capped by Pleistocene sediments (4).

PETROLOGY

Beds exposed at Point Arena consist of foraminiferal clay shales, some bituminous sandstone and cherty shales (4). All have a high percentage of microscopic porosity, causing the bulk rock to have a very low density (18).

In places, flame structures are found, indicating soft sediment deformation in which the weight of overlying beds pressurize water in the fine layers and mobilize them to move as fluids and intrude upward into stronger shales (18).

STRUCTURE

The rocks in Subunit 11 lie west of the San Andreas Fault (SAF) on the Pacific Plate. Rocks east of the SAF line the coast north of Point Arena (4).
The Miocene strata at Point Arena dip gently in some areas and are nearly vertical in others (18). Tight folding is indicated.

California Coastal National Monument

CCNM Subunit: 12
Name: Saunders Reef/Gualala
Date: July 2007

CCNM Subunit 12
Arena Cove to Gualala Point - 16 mi

GEOLOGY

Miocene and Cretaceous deposits are exposed along different segments of the coast between Arena Cove and Gualala Point. Pleistocene marine deposits overlie these units on wave cut terraces, which also are believed to be of Pleistocene age. Basalt intrusive rocks of probable Tertiary age are exposed at Iverson Point (4).

Miocene strata in Subunit 12 are similar to those exposed over much of the coast west of the San Andreas Fault. The rocks are light tan in color with very high microscopic porosity, making the rock very low in density (18). Bedding orientations vary from vertical to nearly flat within short distances, indicating tight folding. Rocks in the offshore shallows of the CCNM are relatively small north of Iverson Point. South of Iverson Point, Cretaceous rocks crop out at the shore and CCNM rocks become numerous and among the largest on the coast, as at Fish Rocks near Anchor Bay (18).

MORPHOLOGY

The marine terrace is covered with a thin cap of Pleistocene marine sands.

Large islands and rocks tend to form in the offshore where the strata are flat or dip gently. Small rocks and sharp pinnacles occur in areas of steeply dipping strata due to the intersection of steep bedding with closely spaced joints in the rock that cut across the bedding.

PETROLOGY

Miocene beds exposed at Arena Cove are similar to those seen at Point Arena, which consist of foraminiferal clay shales, some bituminous sandstone and cherty shales (4). All have a high percentage of microscopic porosity, causing the bulk rock to have a very low density (18).

STRUCTURE

The rocks in Subunit 12 lie west of the San Andreas Fault on the Pacific Plate. Rocks east of the SAF line the coast north of Point Arena (4).

The Miocene strata at Point Arena dip gently in some areas and are nearly vertical in others (18). Tight folding is indicated.

California Coastal National Monument

CCNM Subunit: 13
Name: Sea Ranch / Ft. Ross
Date: July 2007

CCNM Subunit 13
Gualala Point to Fort Ross Reef —30 mi

GEOLOGY

One mile south of the town of Gualala, at the Sea Ranch development, Paleocene strata intersect the coast and continue southward for a distance of approximately four miles.

South of Sea Ranch the coast is bordered by Cretaceous strata for a distance of about eight miles.

A three-quarter-mile segment of the coast north of Black Point exposes Tertiary basalt in a small fault slice (4). Numerous rocks and pinnacles of the CCNM line the region offshore. These presumably are composed of the various hard strata associated with the Cretaceous.

Paleocene and Eocene strata crop out along the coast for twenty miles to the south of Stewart's Point, ending one mile northwest of Fort Ross Reef (4).
The remaining mile southeast of the termination of the Eocene outcrop consists of lower Miocene strata similar to that at Point Arena (4).

MORPHOLOGY

At Sea Ranch, south of Gualala, Paleocene strata underlie a wide terrace that ends at the ocean in steep cliffs (4) (18). A number of large, flat CCNM rocks are found offshore. One of the largest is called Gualala Island and is mapped as Cretaceous (4).

Cretaceous outcrops away from the coast tend to be small, the hills being covered by forest or grassland. Sea cliffs provide the best exposures. The variation in sedimentary rock types within the Cretaceous has lead to a wide variation in the size, shape and number of CCNM rocks and pinnacles present in the offshore region.

The Paleocene and Eocene outcrop belts produce numerous CCNM rocks and pinnacles of significant size and number. At the Fort Ross Reef, the lower Miocene forms the reef to which the name refers. Similar low lying rocks are seen near and at the shore near Point Arena.

Pleistocene marine deposits cap the coastal terraces at altitudes up to 200 feet above sea level.

PETROLOGY

The Paleocene at Sea Ranch and northwest of Fort Ross Reef is composed of micaceous sandstone, grey foraminiferal shale and glauconite - bearing sandstones (4).

The Cretaceous rocks are composed of sandstones, shales, arkose, greywacke and coarse conglomerates.
The Cretaceous has been metamorphosed at low to medium grade (4)

Eocene strata consist of sandstone, sandy shale and clay shale (4).

STRUCTURE

Throughout Subunit 13, the coast lies entirely west of the San Andreas Fault. Cretaceous and Tertiary sediments form the coast of this western block (4)

The Cretaceous rocks have been strongly deformed by folding and faulting. Steep dips are common. Tertiary strata, likewise, have been strongly deformed, but without significant metamorphism (4) (18).

California Coastal National Monument

CCNM Subunit: 14
Name: Sonoma Coast
Date: July 2007

Subunit 14
Fort Ross Reef to the Bodega Point Peninsula - 70 mi

GEOLOGY

The Franciscan Formation lines the coast north and south of the Russian River (4). The rocks lie in the same belt as the Franciscan exposed near the Golden Gate Bridge in southern Marin County (13)(14). These include sandstones, greywacke sandstones, limestones, volcanic rocks and a matrix of clay mudstone (13) (14) (15).

MORPHOLOGY

The Russian River enters the Pacific Ocean near the center of a broad coastal embayment bounded by the Fort Ross Reef on the north and the Bodega Peninsula on the south (4). Unnamed on the USGS 1:250,000 sheets, we propose to call this feature Russian Bay.

PETROLOGY

The Franciscan formation east of the San Andres Fault exposes strata that are somewhat different from that exposed west of the fault (13) (14) (15). West of the fault the Franciscan consists largely of metamorphosed basaltic lava flows (13). Metamorphism has produced greenstones rich in chlorite and epidote. Above the greenstones are banded cherts that alternate with black shales, both on the order of one inch thick,
or less.

The sedimentary rock facies of the Franciscan is much more common to the east of the San Andreas, but does occur to the west of the fault as well. The sedimentary facies consists of greywacke, shale, and limestone blocks floating in a matrix of mudstone or shale. The blocks are discontinuous and are part of what is termed a *mélange* (13).

The Franciscan rocks of the coastal belt, including the coast ranges, have undergone low grade metamorphism of the glaucophane schist facies (13).

STRUCTURE

Russian Bay lies 2.5 miles eastward of the San Andreas Fault, which passes offshore at Bodega Point, passes beneath Russian Bay and reappears on land near Fort Ross Reef.(4). The Franciscan formation lines the coast east of the San Andreas Fault.

California Coastal National Monument
CCNM Subunit: 15
Name: Bodega Head
Date: July 2007

CCNM Subunit 15
Bodega Point to Estero Americano - 5 mi

GEOLOGY

Igneous tonalite and diorite underlie Bodega Ridge (4).

MORPHOLOGY

Pleistocene marine deposits locally lie on top of the Bodega ridge. The ridge itself is tied to the mainland via a sand bar that forms the north boundary of Bodega harbor.
On the mainland, Pleistocene marine deposits mantle the entire coastal area in Subunit 15 (4).

PETROLOGY

Tonalite and diorite are feldspar-rich igneous rocks. Diorite contains plagioclase feldspar with biotite or amphibole or both, and small amounts of quartz. When the quartz exceeds 20 percent, the rock is called tonalite. The biotite and amphibole are black minerals which gives the rock a salt and pepper look against the white to grey feldspar. Small amounts of potassium feldspar also may be present.

STRUCTURE

The igneous rocks of Bodega ridge lie between two faults that are part of the San Andreas Fault Zone.

California Coastal National Monument

CCNM Subunit: 16
Name: Point Reyes - GGNRA
Date: July 2007

Subunit 16
Bodega Bay to Edgemar - 57.5 mi

GEOLOGY

A) Tomale Point and Verne's Ridge - 21 mi
Verne's Ridge forms the upland spine of dioritic and tonalitic rocks along the east side of Point Reyes. There, it abuts the west side of the San Andreas Fault Zone (4) (13). Both the ridge and its extension, Tomale Point, are part of the group of igneous and meta-igneous rocks that characterize the Salinas block of the Pacific Plate. These are mapped as "granitic rocks" on the California State Geologic Map (4).

Point Reyes lies 13 miles west of the Verne's Ridge and, like that ridge, consists of tonalitic and dioritic rocks. Miocene and Pliocene strata are found between Reyes Point and Verne's Ridge.

Along the north side of these rocks a long, southwest-trending beach faces northwest to the ocean (4).

B) Drake's Bay to Bolinas Bay - 14mi

Miocene marine deposits crop out behind the shore around Drakes Bay, but at the shore Holocene beaches cover the Miocene (4).

C) Bolinas Bay to the Golden Gate Bridge - 12.5 mi

Franciscan Formation extends from Bolinas Bay to the Golden Gate. Rocks and pinnacles crop out along the entire distance (1). At the north end of Bolinas Bay the San Andreas Fault passes offshore beneath the Gulf of the Farollones.

D) Golden Gate to Edgemar - 10mi

Various volcanic lithologies of the Franciscan Formation underlie the shore area with patches of Quaternary alluvium in shoreline valleys. Franciscan rocks are cut by the San Andreas Fault where it comes onland near Mussel Rock just north of the town of Edgemar. Starting about 1.5 miles north of Edgemar, the Franciscan volcanic rocks are overlain by Pleistocene marine deposits, which in turn are overlain by Pleistocene dune sands at San Francisco with inliers of exposed Franciscan volcanic rocks at Fort Mills and Seal Rock and by ultrabasic rocks at the south end of the Golden Gate Bridge. (5) (13) (14) (15) (16).

MORPHOLOGY

Exotic blocks in the Franciscan Formation are freed from the matrix of dark mudstones by erosion and form rocks and pinnacles of the GGNCA that vary in composition, shape and size.

PETROLOGY

The Franciscan Formation includes greenstone, basalt, banded chert beds, and ultrabasic rocks in its lower part. Sandstones, greywacke sandstones, limestones, volcanic rocks as blocks in a matrix of clay mudstone predominate in the upper part (4).

The Franciscan formation east of the San Andres Fault exposes strata that are somewhat different from that exposed west of the fault (13) (14) (15). West of the fault the Franciscan consists largely of metamorphosed basaltic lava flows (13). Metamorphism has produced greenstones rich in chlorite and epidote. Above the greenstones are banded cherts that alternate with black shales, both on the order of one inch thick or less.

The sedimentary rock facies of the Franciscan is much more common to the east of the San Andreas, but does occur to the west as well. The sedimentary facies consists of greywacke, shale, and limestone blocks floating in a matrix of mudstone or shale. The blocks are discontinuous and are part of what is termed a *mélange* (13).

The Franciscan rocks of the coastal belt, including the coast ranges, have undergone low grade metamorphism of the glaucophane schist facies (13).

STRUCTURE

Blocks from the Franciscan mélange control the irregular sizes and shapes of islands and rocks in the CCNM that were derived from the sedimentary facies of the Franciscan formation. Folding of greenstones and banded cherts in the lower Franciscan produce typical mounded forms in the larger topographic features developed from these materials.

California Coastal National Monument

CCNM Subunit: 17
Name: San Mateo/Santa Cruz
Date: July 2007

CCNM Subunit 17
Edgemar to Aptos - 61 mi

GEOLOGY

A. Mussel Rocks - to Pillar Point -10 mi
Deformed and faulted Franciscan formation meta-sedimentary and volcanic rocks crop out at the shore west of the San Andreas Fault between Mussel Rocks and Rockaway Beach (5) in the town of Pacifica. Immediately south of Rockaway Beach a narrow zone of upper Cretaceous metamorphic rocks, intruded by associated granodiorite, is unconformably overlain by Paleocene sedimentary rocks. Ggranodiorite crops out at the shore between Devils Slide and Montara Point. South of Montara Point, a fault slice of Pliocene rocks extends south to Pillar Point (5).

B. Pillar Point to Año Nuevo Bay - 26 mi
Pleistocene terrace deposits line the coast along the shore south of Pillar Point as far as Martin's Beach, beyond which Paleocene strata appear.

Near Pescadero Point, Cretaceous rocks are exposed at the coast and continue past Pigeon Point as far as Franklin Point (5). The Cretaceous strata are well bedded with layers a foot to several feet in thickness. Dips are steep at Pigeon Point and elsewhere along the Cretaceous outcrop belt.

At Año Nuevo Point, Pleistocene marine terrace deposits overlie deformed Miocene strata (18). The same relationship is found three-quarters–of-a-mile offshore at Año Nuevo Island (5).

C. Año Nuevo Bay to Aptos -25 mi
The shore between Año Nuevo Bay and the town of Aptos is formed on mid-to late Miocene and Pliocene marine strata overlain by Pleistocene marine terrace deposits (5). The rocks are fine-grained mudstones and shales of very low density. Erosion produces arches, sea stacks and low offshore islands.

MORPHOLOGY

The shoreline between Mussel Rocks and Pillar Point south of the Golden Gate alternates between wide beaches and rugged, mountainous topography (5). Where mountain spurs reach the sea, the coast is bordered by steep cliffs, some as much as 800 feet high, as at Pedro Point and Devil's Slide.. Large offshore boulders are found near these features, but elsewhere large CCNM rocks are few (5). Pleistocene marine deposits lie on marine terraces cut into the Upper Cretaceous (5) between Pillar Point and Martin's Beach. Along this stretch, CCNM rocks are few and associated with scattered localities where Paleocene strata emerge at the coast from beneath the Pleistocene terrace deposits (5).

South of Martin's Beach Paleocene rocks line the coast, but make only small CCNM rocks (5).

Large, commonly flat CCNM rocks derived from Cretaceous strata lie offshore from Cretaceous outcrop areas at Pigeon Point and Pescadero Beach. Flat form reflects the strongly bedded character of the Cretaceous rocks. Pleistocene marine deposits overlie the Cretaceous along a narrow marine terrace cut ten to thirty feet above sea level. Beaches at the base of cliffs, as at Pigeon Point are composed of gravel and boulders.
Miocene strata erode to form deep inlets in the coast. Further erosion often completely separate some of the ridges between the inlets from the mainland, forming large, low profile islands close to shore.

Two to three miles inland, small to large exposures of granodiorite occur in stream bottoms 100 feet or more below the adjacent hilltops of Miocene and Pliocene strata (5) (6). This relationship suggests that a) the Miocene-Pliocene strata are on the order of a few hundred feet thick above the granodiorite, and b) granodiorite probably disconformably underlie the coastal sedimentary strata in the area.

PETROLOGY

The sedimentary facies of the Franciscan formation consists of greywacke, shale, and limestone blocks floating in a matrix of mudstone or shale. The blocks are discontinuous and are part of what is termed a *mélange* (13). The Franciscan rocks of the coastal belt, including the coast ranges, have undergone low grade metamorphism of the glaucophane schist facies (13).

Granodiorite is an igneous rock, often strongly deformed where seen along the California coast that consists of plagioclase feldspar and pyroxenes or amphiboles.
Cretaceous strata consist of interbedded sandstone, greywacke and conglomerate that have undergone low grade metamorphism.

Lower and middle Miocene mudstone and siltstone are very fine-grained, light in color and of very low density. The lightness of the rocks indicates a very high porosity. These rocks have undergone little or no metamorphism.

See description above.

STRUCTURE

Complexly folded, faulted and metamorphosed strata occur west of the San Andres Fault. Rocks of Cretaceous age and older have been metamorphosed. Tertiary strata have been strongly folded in most areas, but not metamorphosed.

Cretaceous strata were deformed and metamorphosed prior to deposition of the overlying Tertiary rocks.

Miocene and younger rocks have been strongly folded. Dips of ninety degrees are common.

California Coastal National Monument

CCNM Subunit: 18
Name: Monterey Bay East
Date: July 2007

CCNM Subunit: 18
NE side Monterey Peninsula to 5 miles west of Aptos - 32 mi

GEOLOGY

Inland from the shore, deposits of Quaternary age fill a structural depression. The deposits consist of terraces and alluvium in the Salinas River Valley to the southeast and in the Santa Clara Valley to the northwest.

MORPHOLOGY

Sandy beaches and dunes line the shore. No rocks or pinnacles are found in CCNM Subunit 18.

PETROLOGY

No rocks are found in CCNM Subunit 18. The Quaternary deposits consist of silt and fine sand in the Pleistocene terraces and medium and fine sand in the dunes.

STRUCTURE

Mountain ranges that border the Salinas Valley both to the northwest and the southeast lose altitude as they approach Monterey Bay, passing below sea level within five miles of the shore (1). Similarly, mountains that border the Santa Clara Valley east of Santa Cruz descend toward the southwest and disappear beneath the Quaternary deposits associated with Monterey Bay (1) (3) (4).

These features define a large structural depression that lies west of the San Andreas Fault and which has been filed with Quaternary age marine and non-marine deposits (1), suggesting that the depression is a relatively recent feature.

California Coastal National Monument

CCNM Subunit: 19
Name: Monterey Peninsula
Date: July 2007

CCNM Subunit 19
Monterey Peninsula - 6 mi

GEOLOGY

The Monterey Peninsula is underlain by granodiorite of pre-Cretaceous age (6). The granodiorite is disconformably overlain by lower Miocene strata composed of bedded mudstone and claystone. Quaternary terrace deposits and alluvium locally overlie the Miocene (6).

MORPHOLOGY

Large sea stacks in the area have steep, joint-controlled seaward cliffs and result from a combination of chemical weathering and undercutting of cliffs by wave action. The result is collapse of the upper part of the rock face into the surf where they form loose, disarticulated blocks that are being abraded by the waves.

Miocene strata form an east-trending ridge that reaches 1000 feet in altitude. At least five wave-cut marine terraces of Pleistocene age have been identified. The City of Monterey rises in large steps from sea level to over 700 feet across these terraces (13).

PETROLOGY

The Monterey Peninsula along the shore and in accessible sea stacks is underlain by a porphyritic granodiorite (6).

Large rectangular crystals of plagioclase feldspar (19) up to three inches long developed late in the history of the rock. The term porphyry, or porphyritic, is often used to describe this texture and refers to the large size of the crystals as compared to the groundmass minerals.

Overall, the rock is equigranular and shows only a weak foliation (planar structure) due to a weak alignment of quartz and feldspar grains (18). Reddish iron-stains discolor the rock in many places.

Late dikes cut the granodiorite (18).

STRUCTURE

The minerals forming the granodiorite have been broken and fractured (18). On the Monterey Peninsula this deformation has destroyed the usual interlocking texture of igneous rocks. The plagioclase feldspar porphyries do not appear to share the deformational history of the groundmass, indicating that they were formed late in the deformational process after it had largely ceased (18).

On the scale of a few tens of feet, the granodiorite rock is cut by a well-developed joint system that dips seaward at 30-40 degrees (18). These joints intersect a second, more or less vertical, set of joints. Another set of joints is more or less flat or dips gently (18). These likely are sheeting joints formed by expansion of the rock parallel to the land surface as erosion removed the overlying load. Together, the joints sets break the rocks into large and small blocks, depending on the spacing of the joints. The joint spacing will have had a strong influence on the erosion of the rocks by waves and controls the sizes of sea stacks and the loose boulders that dot the shallow coastal waters.
Late dikes (joints intruded by late magma or aqueous solutions) up to several inches thick have a mineralogy similar to the granodiorite, but are much coarser in texture and seem to contain a larger percentage of quartz than the surrounding rock (4) (18). These dip at various angles, crossing one another.

California Coastal National Monument
CCNM Subunit: 20
Name: Big Sur
Date: July 2007

CCNM Subunit 20
Carmel Highlands to Ragged Point - 62 mi

GEOLOGY

A. Carmel Highlands to Kaslar Point - 5 mi
Coastal marine terrace deposits of Quaternary age are underlain by granodiorite (6).

B. Kaslar Point to Point Sur - 6 mi
The Palo Colorado Fault cuts the coast at Kaslar Point and brings pre-Cretaceous metamorphic rocks into contact with the granodiorite of coastal segment A (6). To the south, marine sediments of Quaternary age overlie metamorphic rocks of various ages that lie within several thin fault slices north of Point Sur (6).

C Big Sur to 11 miles south -11mi
Franciscan metamorphic and sedimentary rocks crop out at the shore in the southern half of this zone where they make rocks in the CCNM (6). They are overlain by Quaternary marine terrace deposits in the northern half and no CCNM rocks are found.

D. 11 miles south of Big Sur to Slate's Hot Spring -10 mi
Pre-Cretaceous metamorphic rocks that are intruded or in-folded with granodiorite line the coast in the north half of this section (6). Upper Cretaceous meta-sedimentary rocks line the southern half. (Go to page 2)

Neither the granodiorite, nor the upper Cretaceous strata develop large CCNM rocks.

E. Slate's Hot Springs to Ragged Point - 30 mi.

Franciscan formation in fault contact with pre-Cretaceous metamorphic rocks borders the coast.
The Franciscan consists of sandstone, shale and schist, all intruded by serpentinite dikes and plugs. One serpentinite intrusion crops out at the coast and it is accessible on the north side of Cape San Martin (6).

MORPHOLOGY

The Franciscan formation includes greenstone, basalt, banded chert beds, and ultrabasic rocks in its lower part. Sandstones, greywacke sandstones, limestones, volcanic rocks as blocks in a matrix of clay mudstone predominate in the upper part (6).

CCNM rocks and boulders line the coast in front of steep cliffs which make much of the shore inaccessible. Large blocks seen from the highway possibly are exotic blocks eroded from the Franciscan formation.
Beach sands at Ragged Point and elsewhere are characteristically black, probably due to an abundance of dark green minerals from the greenstones at the base of the Franciscan.

PETROLOGY

Granodiorite is a rock of the granite family that consists of quartz and plagioclase feldspar with smaller amounts of potassium feldspar. Small black grains of pyroxene are scattered throughout

The Franciscan formation, of Jurassic through Cretaceous age, contains sandstones, shales and metamorphic rocks in structurally complex relationships (6).

The Franciscan formation includes greenstone, basalt, banded chert beds, and ultrabasic rocks in its lower part. Sandstones, greywacke sandstones, limestones, volcanic rocks as blocks in a matrix of clay mudstone predominate in the upper part (6).

STRUCTURE

Complex folding and faulting is characteristic of the rocks west of the San Andreas Fault. Intersections of joints, faults and bedding control the sizes of boulders and other erosion products of wave erosion.

Numerous fault slices juxtapose different rock types from different formations. CCNM rocks are varied and numerous, but sources of specific rocks are obscure.

California Coastal National Monument

CCNM Subunit: 21
Name: San Luis Obispo North
Date: July 2007

CCNM Subunit 21
Ragged Point to Morro Bay – 43 mi

GEOLOGY

Ragged Point to San Simeon Point - 12 mi

A. CCNM stacks and rocks, composed mostly of Franciscan formation rocks, line the offshore (7). The Franciscan formation in this area is locally intruded by ultrabasic rocks, now altered to serpentinite, or is cut by fault blocks that carry ultrabasic rocks. The Franciscan is in places overlain unconformably by marine deposits of Cretaceous age, pyroclastic rocks of Mesozoic age or Quaternary Pleistocene marine terrace sediments (7).

B. San Simeon to north Morro Bay - 31 mi
At San Simeon, Pleistocene marine sediments overlie the Franciscan, but at San Simeon State Beach, five miles to the south, upper Cretaceous marine deposits appear between the Pleistocene terrace deposits and the Franciscan *mélange*. Franciscan rocks form the shore as far south as the north end of the beach at Morro Bay (7).

MORPHOLOGY

The Pleistocene deposits, perhaps 20 feet in thickness, occupy terraces cut into the Franciscan by waves at sea level, but which now are at altitudes that range from 200 to 600 feet, based on contours on the geologic map (7). Terrace deposits found at these various altitudes are either of different Pleistocene ages or possibly have been faulted to their present positions.

PETROLOGY

Ultrabasic rocks are altered slices of the Earth's upper mantle. Before intrusion, the ultrabasic rocks consist mainly of olivine, an iron-and magnesium-rich silicate rock. When these rocks are intruded into the crust, they encounter water and progressively are altered to form more and more hydrous minerals, such as serpentine, talc and chlorite.

Despite the soft character of the minerals in ultrabasic rocks, the rock itself is surprisingly strong and often makes large, dome-shaped blocks and islands in the CCNM.

STRUCTURE

The Franciscan is a *mélange*, meaning that it is a mixture of exotic blocks of sandstone, limestone, glaucophane schist facies metamorphic rocks and serpentinite, some as much as a mile in diameter (13). These blocks slid into the basin during deposition of fine sediments and cherts in which the blocks were buried. Present erosion of the Franciscan has locally exhumed exotic blocks by removing the softer sediments that surround them. Where the Franciscan underlies near-shore areas, the exhumed blocks can form off-shore pinnacles and islands.

California Coastal National Monument

CCNM Subunit: 22
Name: San Luis Obispo South
Date: July 2007

CCNM Subunit 22
Morro Bay to Pismo Beach – 34 mi

GEOLOGY

Morro Bay - 10 mi
Morro Rock is a 581 foot-high sea stack located just seaward of the beach barrier bar at the mouth of Morro Bay and attached to the mainland by artificial fill. It is part of the Morro Rock State Reserve. Morro Rock is a more or less circular intrusive plug of Tertiary age; that is part of a 20 mile long, almost straight line of 14 intrusive plugs (on the geologic map) of varying sizes (7).

B. South Morrow Bay to Pismo Beach - 24 mi

Middle Miocene marine deposits appear at the coast south of Morro Bay at Point Buchon. At Point San Luis to the southeast, Franciscan formation is exposed. It is overlain by lower Miocene followed by Miocene pyroclastic deposits, which in turn are overlain by the middle Miocene seen at Point Buchon (7). These relations could indicate that Franciscan rocks lie offshore, where rocks are abundant as far as the shell beach parking of the City of Pismo Beach.

MORPHOLOGY

Morro Bay faces the much larger Estero Bay. A 10-mile long Holocene sand bar and dune field closes the estuary of the narrow, northwest trending San Luis Valley from the open ocean to form Morro Bay. Pleistocene marine deposits are found at altitudes of 100 feet along the valley walls (7).

Where Pleistocene deposits line the shore the consolidated bedrock is buried and rocks and pinnacles are absent in the offshore area.

Franciscan formation rocks exposed onshore will usually support a wide variety of sizes and types of offshore rocks, mostly exhumed exotic blocks from the Franciscan mélange or greenstones and cherts from the basal beds.

PETROLOGY

A quartz porphyry is an igneous rock that either extruded onto the land as a lava flow or got stuck part way up and hardened at a shallow depth. Slow cooling let the crystals of quartz and feldspar grow large, but the last bit of melt hardened somewhat faster as the rock cooled, making a matrix of the same minerals but much, much smaller.

STRUCTURE

A line of intrusive plugs over twenty miles long, along an almost straight line, strongly suggests that intrusion has taken place along a pre-existing fault. This idea is strengthened by the San Luis Obispo Sheet of the California State Geologic Map which shows a steep fault directly on line with the plugs (7).

California Coastal National Monument
CCNM Subunit: 23
Name: Pismo-Guadalupe Dunes
Date: July 2007

CCNM Subunit 23
Pismo Beach to Mussel Rock - 17.5 mi

GEOLOGY

Pleistocene dunes and alluvium line the coasr.
No CCNM rock features.

California Coastal National Monument

CCNM Subunit: 24
Name: Vandenberg Point - Point Conception
Date: July 2007

CCNM Subunit 24
Mussel Rock to Point Conception - 44 mi

GEOLOGY

A. Mussel Rock to 4 miles east of Point Sal - 6 mi
At Mussel Rock the sea is bordered by middle Miocene strata overlain to the east by Pleistocene dune sands. CCNM rocks appear offshore at Mussel Point and continue southward and eastward along the coast for 4 miles beyond Point Sal. Several geologic formations and ages intersect the coast, including Oligocene, Jurassic to Cretaceous Franciscan formation volcanic rocks and ultrabasic rocks, all of which produce boulders and pinnacles in the offshore. Four miles east of Point Sal the coast turns abruptly to the south, Pleistocene sands appear and the CCNM rocks end (8).

B. Four miles east of Point Sal to Point Conception - 38 mi
Pleistocene dunes and alluvium in the Santa Ynez River valley overlie middle and upper Miocene marine deposits. Exposures of middle Miocene strata line the coast for 6 miles north of the mouth of the Santa Ynez River where they are associated with pinnacles and supratidal outcrops of the CCNM offshore (8). Three-and-one-half miles south of the Ynez River mouth, Miocene rocks reappear from beneath Pleistocene dunes and crop out continuously along the shore to well beyond Point Conception. Low-lying CCNM rocks and exposed reefs are present in abundance in areas where middle Miocene forms the shore, but become less abundant in the area of Point Conception, where upper Miocene strata are exposed (8).

MORPHOLOGY

Dune sands east of the coast rise to at least 500 feet above sea level (8).

The Miocene and other Tertiary outcrop belts along the coast host wave-cut terraces of Pleistocene age that often are covered by marine deposits of the same age (1).

Soft upper Miocene rocks erode to sand and small rocks and do not form large pinnacles or other rocks of the CCNM.

PETROLOGY

Lower and middle Miocene mudstone and siltstone are very fine-grained, light in color and of very low density. The lightness of the rocks indicates a very high porosity (18).

Upper Miocene strata contain friable, thick bedded sandstone, soft, fissile diatomite, and shale. All may erode to make large low boulders or stacks and pinnacles.

Franciscan rocks contain exotic blocks of sandstone, greywacke, greenstone and ultrabasic rocks (13) that contribute to the offshore rocks to the CCNM.

STRUCTURE

Folds and faulted folds with an eastward trend lie inland from the east-west coast at Point Conception (8). A more or less complete stratigraphic section of Tertiary rocks lie between the Santa Ynez Fault and the coast to its south. Strata appear continuous from the upper Cretaceous through the Eocene, Oligocene and Miocene (8). Unconformities probably are present, but no faults are mapped on the Santa Maria Sheet of the California State Geologic Map (8).

The east-west trend reflects the Transverse Ranges of southern California.

California Coastal National Monument

CCNM Subunit: 25
Name: Santa Barbara – Ventura
Date: July 2007

CCNM Subunit 25
Point Conception to Point Mugu - 87 mi

GEOLOGY

A. Point Conception to Santa Barbara - 43 mi
Miocene strata with narrow terraces carrying Pleistocene marine deposits line the coast. Scattered intervals of small CCNM rocks correspond to sea level exposure of lower and middle Miocene (8).

B. Santa Barbara to Loon Point - 6 mi
Quaternary deposits at sea level. No exposed CCNM rocks (9).

C. Loon Point to Rincon Point - 6 mi
At Loon Point, the coast trends southwesterly. Quaternary deposits continue to line the coast to Rincon Point. No CCNM rocks are exposed (9), with the exception of shallow reef at Carpentaria (9)

D. Rincon Point to Pierpont Bay - 13 mi
At Rincon Point, middle Miocene, upper Miocene and upper Pliocene strata form the coast as far south as Dulah Quaternary marine terrace deposits cover the Tertiary to Pierpont Bay and CCNM rocks are no longer visible (9).

E. Pierpont Bay to Point Mugu - 19 mi
Quaternary alluvium of the Santa Clara River Valley is exposed at the shore line for 19 miles to Point Mugu. No CCNM rocks are exposed (9).

MORPHOLOGY

Miocene and other Tertiary outcrop belts along the coast host wave-cut terraces of Pleistocene age that often are covered by marine deposits of the same age (8).

PETROLOGY

Lower and middle Miocene mudstone and siltstone are very fine-grained, light in color and of very low density (8). The lightness of the rocks indicates a very high porosity.

Upper Miocene strata contain friable, thick bedded sandstone, soft, fissile diatomite, and shale (9). All are soft rocks that do not erode to make large boulders or pinnacles.

STRUCTURE

Folds and faulted folds with an eastward trend lie inland from the east-west coast at Point Conception. A more or less complete stratigraphic section of Tertiary rocks lie between the Santa Ynez Fault and the coast to the south. Strata appear continuous from the upper Cretaceous through the Eocene, Oligocene and Miocene. Unconformities probably are present, but no faults are mapped on the Santa Maria Sheet of the California State Geologic Map (8). East-west trending of structures dips southward and is part of the Transverse Ranges (8).

California Coastal National Monument

CCNM Subunit: 26
Name: Malibu
Date: July 2007

CCNM Subunit 26
Point Mugu to Santa Monica - 54 mi

GEOLOGY

The coast between Point Mugu and Santa Monica is lined with complexly normal faulted and thrust faulted middle Miocene strata cut by Tertiary intrusive rocks and interbedded with Miocene volcanic rocks, including andesite, basalt and dacite (9). Scattered small and low CCNM rocks lie close to shore, especially where middle Miocene strata line the coast, with the exception of at Dune Point, about in the middle of the subunit. This point juts westward about ¾ of a mile from the mainland and is underlain by Mesozoic volcanic rock and connected to the mainland by middle Miocene strata (9). Scattered, small CCNM rocks and a few larger ones, such as Big Rock, lie east of the point along the shore of the mainland as far a Santa Monica.

MORPHOLOGY

The Santa Monica lowland is underlain by Pleistocene sedimentary deposits and no CCNM rocks are found offshore (9).

PETROLOGY

Lower and middle Miocene mudstone and siltstone are very fine-grained, light in color and of very low density. The lightness of the rocks indicates a very high porosity.

Miocene volcanic rocks consist of flows and pyroclastic rocks of varying composition, ranging from andesite to basalt (9).

STRUCTURE

Miocene strata have been folded and faulted, but have not been metamorphosed.

California Coastal National Monument

CCNM Subunit: 27
Name: Los Angeles South Bay
Date: July 2007

CCNM Subunit 27
Santa Monica to Redondo Beach - 22 mi

GEOLOGY

Quaternary dunes and alluvium line the coast.
No CCNM rocks (9) (10).

California Coastal National Monument

CCNM Subunit: 28
Name: Palos Verdes Peninsula
Date: July 2007

CCNM Subunit 28
Redondo Beach to Point Fermin - 16 mi

GEOLOGY

The Palos Verdes Peninsula is an outlier (once an island) of Miocene marine sedimentary rocks that lie some 24 miles west of the nearest pre-Pleistocene rocks. A wide area of recent alluvium and Quaternary terrace deposits separate the peninsula and its Miocene marine deposits from the nearest inland outcrops. CCNM rocks surround San Pedro on three sides (10).

MORPHOLOGY

The Palos Verdes Peninsula rises to nearly 1000 feet above the surrounding Pleistocene alluvial and terrace deposits.

Low, flat topped rocks and exposed reefs, probably controlled by bedding, occur as CCNM rocks in the offshore area around the peninsula.

PETROLOGY

Lower and middle Miocene mudstone and siltstone are very fine-grained, light in color and of very low density. The lightness of the rocks indicates a very high porosity.

Tertiary hypabyssal intrusive rocks of porphyry are indicated on the California State Geologic Map (10).

STRUCTURE

The Miocene strata have been folded and intruded (10).

California Coastal National Monument
CCNM Subunit: 29
Name: Long Beach - Newport
Date: July 2007

CCNM Subunit 29
Point Fermin to Balboa - 28 mi

GEOLOGY

Quaternary terrace deposits and alluvium line the coast.
No CCNM rocks (11)

California Coastal National Monument

CCNM Subunits: 30 - 31
Name: Laguna Beach - San Diego
Date: July 2007

CCNM Subunits 30 - 31
Balboa to Rocky Point - 22 mi

GEOLOGY

Miocene strata capped by Pleistocene marine deposits line the coast. Scattered CCNM rocks lie offshore as far south as San Clemente. They are largely absent farther south to Rocky Point (11) (12).

MORPHOLOGY

A smooth, curving coastline is lined with narrow exposure of pre-Quaternary strata (11) (12).
Pleistocene terrace deposits intermittently cover at least five marine terraces over a wide area south of the Los Angeles basin from San Clemente to the Mexican border (11) (12).

PETROLOGY

Lower and middle Miocene mudstone and siltstone are very fine-grained, light in color and of very low density. The lightness of the rocks indicates a very high porosity (18).

Upper Miocene strata contain friable, thick bedded sandstone, soft, fissile diatomite, and shale. All may erode to make large low boulders or stacks and pinnacles.

STRUCTURE

Miocene and underlying Eocene dip gently seaward. At least five marine terraces have been eroded into these strata (11) (12).

California Coastal National Monument

CCNM Subunit: 32
Name: La Jolla – Pt. Loma
Date: July 2007

CCNM Subunit 32
Rocky Point to Coronado - 22 mi

GEOLOGY

Upper Cretaceous and Eocene strata on the La Jolla Peninsula are capped by Pleistocene marine terrace deposits. Various small CCNM rocks are supported by the Cretaceous outcrop area (12). Eocene strata onshore dip gently seaward and line the coast (12).

MORPHOLOGY

Marine terraces have been cut into the
La Jolla Peninsula and are capped by Pleistocene marine deposits (12).

The Cretaceous strata erode to form joint and bedding bounded blocks of moderate to large size.

PETROLOGY

Cretaceous strata consist of interbedded sandstone, greywacke and conglomerate that, in many areas have undergone low grade metamorphism (12).

STRUCTURE

The La Jolla Peninsula has been up-faulted, bringing Cretaceous and lowest Eocene strata to the surface.

California Coastal National Monument
CCNM Subunit: 33
Name: San Diego South
Date: July 2007

CCNM Subunit 33
Coronado to San Ysidro and Mexican border - 18 mi

GEOLOGY

San Diego Peninsula is composed of Quaternary beach and dune sands (12).
No CCNM blocks are present.

REFERENCES CITED

(1) Geol. Atlas of California, Weed Sheet, 1:250,000.

2) Geologic Atlas of California, Redding Sheet, 1:250,000

(3) Geologic Atlas of California, Ukiah Sheet, 1:250,000

(4) Geologic Atlas of California, Santa Rosa Sheet, 1:250,000

(5) Geologic Atlas of California, San Francisco Sheet, 1:250,000

(6) Geologic Atlas of California, Santa Cruz Sheet, 1:250,000

(7) Geologic Atlas of California, San Luis Obispo Sheet, 1:250,000

(8) Geologic Atlas of California, Santa Maria Sheet, 1:250,000

(9) Geologic Atlas of California, Los Angeles Sheet, 1:250,000

(10) Geologic Atlas of California, Long Beach Sheet, 1:250,000

(11) Geologic Atlas of California, Santa Ana Sheet, 1:250,000

(12) Geologic Atlas of California, San Diego – El Centro Sheet, 1:250,000

(13) Kleist, John R., 1981, The Franciscan Complex of Northern California, in, Kleist, J. R., ed., The Franciscan Complex and the San Andreas Fault from the Golden Gate to Point Reyes California: Guidebook, Pacific Section AAPG, V. 51, pp. 1-8.

(14) Rice, Salem J., 1981, Stops 1, 2 and 3, in, Kleist, J. R., ed., The Franciscan Complex and the San Andreas Fault from the Golden Gate to Point Reyes California: Guidebook, Pacific Section AAPG, V. 51, pp. 9 -16.

(15) Hall, N. Timothy, 1981, The San Andreas Fault in Marin, County, California, in, Kleist, J. R., ed., The Franciscan Complex and the San Andreas Fault from the Golden Gate to Point Reyes California: Guidebook, Pacific Section AAPG, V. 51, pp. 17 – 20.

(16) Hall, N. Timothy, 1981, Stops 4, 5, 6 and 7, in, Kleist, J. R., ed., The Franciscan Complex and the San Andreas Fault from the Golden Gate to Point Reyes California: Guidebook, Pacific Section AAPG, V. 51, pp. 23 – 28.

(17) Dupré, William R., 1990, Quaternary Geology of the Monterey Bay Region, California, in, Greene, H. G., Weber, G. E. and Wright, T. L., 1990, Geology and tectonics of the central California coastal region, San Francisco to Monterey: Volume and Guidebook: AAPG Pacific Section,.

(18) Shaw, C. E., 2007, field observations

(19) Ernst, W. G, et. Al., 2000, Peninsula Geological society Field Trip, May 2000.

(20) Jennings, Charles W., Geologic Atlas of California: California Division of Mines and Geology