GEOLOGY OF BIG BASIN REDWOODS STATE PARK,

SANTA CRUZ COUNTY, CALIFORNIA*

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by

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INTRODUCTION

Big Basin Redwoods State Park (BBRSP) is located in the central Santa Cruz Mountains approximately 19 miles northwest of Santa Cruz, California (Figure 1). The park is situated on the northwestern margin of Santa Cruz County along the boundary with San Mateo County. Eastern parts of BBRSP are accessed by California State Highway 236 which forms a loop from State Highway 9. State Highway 1 crosses the western part of BBRSP and provides access from the north and south to this region. The only access to central parts of the park is via foot trails and fire roads.

Purpose

The purpose of this report is to provide the California Department of Parks and Recreation (CDPR) with geological information needed to effectively develop and manage natural and recreational resources of BBRSP. The data can also be used by CDPR to classify park land and develop resource management and protection plans for use in assessment and mitigation of potential environmental problems and in routine maintenance and operation of the park.

Methods

Geologic field data were compiled from field mapping, aerial photographic interpretation, existing literature, and unpublished sources. The topographic base maps used in preparing the geologic map are the Big Basin, Franklin Point, Ano Nuevo, and Davenport 7.5-minute quadrangles (Figure 1; Map G-1). Approximately 40 days were used for geologic mapping and to check existing field data from investigations by others. Field data are presented on a

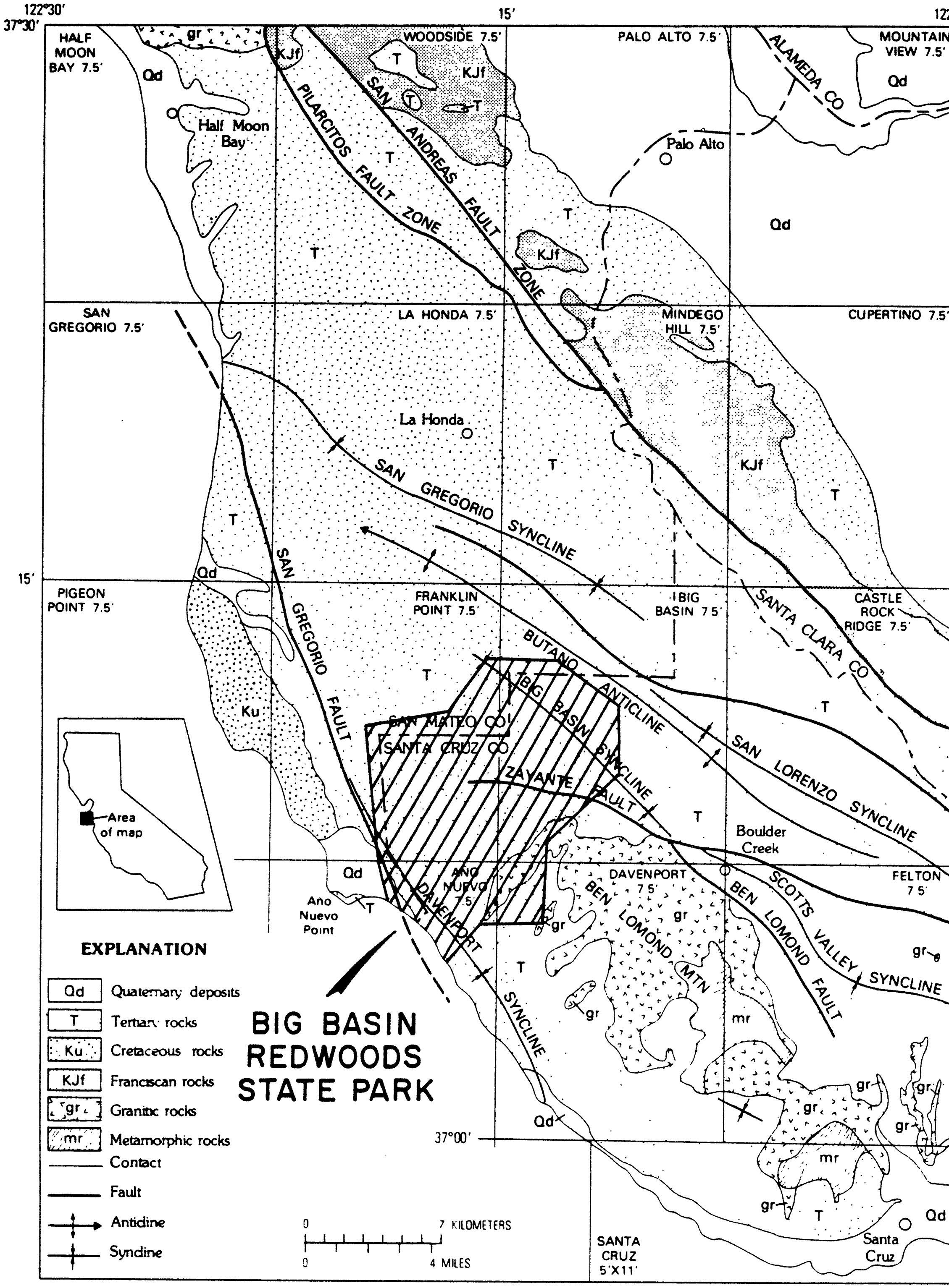


FIGURE 1. - Generalized geologic map of the northern and central Santa Cruz Mountains after Brabb and others (1977) showing 7.5-minute topographic map coverage. The Big Basin Redwoods State Park study area is diagonally lined.

EXPLANATION

SURFICIAL DEPOSITS

Quaternary	Qa	Alluvium	Unconsolidated gravel, sand, and silt
Quaternary	Qls	Landslide material	Arrows show direction of movement Note: Only largest landslides in area are shown (see Plate 3).
	Qm	Marine terrace material	Unconsolidated, yellow-brown sand and gravel with local shell debris

UNCONFORMITY

Cenozoic / Tertiary	Tp	Purisima Formation	Thick-bedded, semi-friable, yellow-gray siltstone and sandstone
	Tsc	Santa Cruz Mudstone	Medium- to thin-bedded, olive-gray to gray-brown, siliceous organic mudstone
	Tsm	Santa Margarita Sandstone	Thick-bedded, locally cross-bedded, medium-grained, gray to white, friable arkosic sandstone

UNCONFORMITY

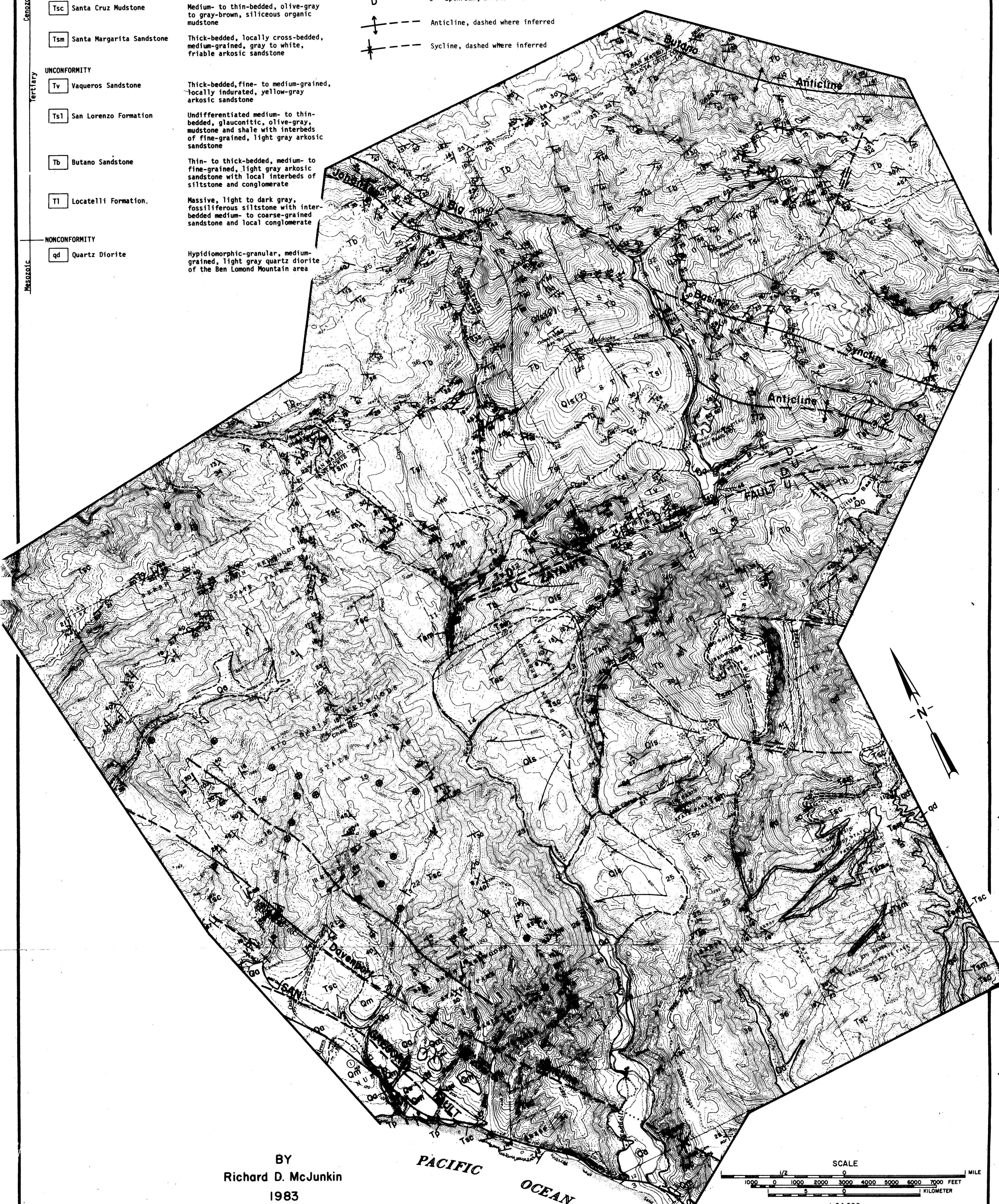
Tertiary	Tv	Vaqueros Sandstone	Thick-bedded, fine- to medium-grained, locally indurated, yellow-gray arkosic sandstone
	Tsl	San Lorenzo Formation	Undifferentiated medium- to thin-bedded, glauconitic, olive-gray, mudstone and shale with interbeds of fine-grained, light gray arkosic sandstone
	Tb	Butano Sandstone	Thin- to thick-bedded, medium- to fine-grained, light gray arkosic sandstone with local interbeds of siltstone and conglomerate
	Tl	Locatelli Formation.	Massive, light to dark gray, fossiliferous siltstone with inter-bedded medium- to coarse-grained sandstone and local conglomerate

NONCONFORMITY

Mesozoic	qd	Quartz Diorite	Hypidiomorphic-granular, medium-grained, light gray quartz diorite of the Ben Lomond Mountain area

SYMBOLS

- Lithologic contacts, dashed where inferred
- Landslide contacts, dashed where inferred, dotted where buried
- 45 Strike and dip of bedding
- Strike and dip of vertical bedding
- Horizontal bedding
- U D Fault, dashed where inferred, dotted where buried, D = downthrown; U = upthrown, arrows indicate direction of apparent offset.
- Anticline, dashed where inferred
- Sycline, dashed where inferred



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TOPOGRAPHIC BASE MAP FROM U.S. GEOLOGICAL SURVEY AÑO NUEVO, BIG BASIN, DAVENPORT, AND FRANKLIN POINT 7.5-MINUTE QUADRANGLES

MAP NO.	DRAWING NO.			REVISIONS	DATE	
G-1	20522	GEOLOGY OF BIG BASIN REDWOODS STATE PARK SANTA CRUZ COUNTY, CALIFORNIA	RESOURCES AGENCY OF CALIFORNIA DEPARTMENT OF PARKS AND RECREATION APPROVED______ DATE______			DESIGNED DRAWN CHECKED

1:24,000-scale geologic map (Map G-1). Regional geology for this part of the Santa Cruz Mountains (scale 1:250,000) is provided by the San Francisco, San Jose, and Santa Cruz geologic map sheets after Jennings and Burnett (1961), Rogers (1966), and Jennings and Strand (1958) respectively. BBRSP is located in the southern part of the San Francisco geologic map sheet. The San Francisco and San Jose geologic map sheets are presently being recompiled and upgraded by the California Division of Mines and Geology (CDMG) and should be available early in 1985.

TOPOGRAPHY

Relief in BBRSP is greater than 2,000 feet (Map G-1). The elevation changes from sea level in southwestern BBRSP to slightly more than 2,000 feet on Pine Mountain approximately 4.5 miles to the northeast. The highest elevation is at bench mark 2,359 (feet) located on a ridge along China Grade Road in the northeastern part of the park.

Topography in the Big Basin area is generally expressed as a series of major north-south-trending ridges and canyons. These features have subordinate secondary ridges and valleys trending to the east and west. Terrain in this part of the Santa Cruz Mountains is steep and rugged. There are only two main regions underlain by flat ground within the park. One area is in northeastern BBRSP along Blooms and Opal Creeks just upstream from their confluence; much of this region is developed for visitor services (park headquarters, vistors center, store, campgrounds, picnicking facilities, etc.). The second area, mostly undeveloped except for an access road, is along Waddell Creek for 2.5 miles upstream from its mouth at the ocean.

Much of the mountainous topography of BBRSP is defined by bedding-plane slopes. This structure forms hogbacks that have steep drop-offs up-dip where resistant units daylight at the surface. Many slopes are hummocky and include scarps, grabens and benches formed by recent landslide and debris flow activity. Downslope movement of surface soil and rock is the main erosional process in BBRSP. Almost all slopes in the park are disturbed by downslope movement.

HYDROLOGY

Inland parts of BBRSP receive between 30 and 60 inches of annual precipitation (Kahrl, 1979). Virtually all precipitation is rain; snowfall, even at higher elevations, is rare. Much of the precipitation in the park remains on the surface and flows into the ocean.

Most of the surface water in BBRSP drains into the east and west branches of Waddell Creek (Map G-1). Both of these branches and the main creek have perennial flows. From the confluence of the east and west branches, the main drainage flows south-southwesterly for approximately 3 miles to the ocean. The Waddell Creek drainage basin underlies approximately 22 square miles of the central and eastern regions of the park.

Eastern parts of BBRSP, including mostly unattached outlying property, drain into Scott and Boulder Creeks. Several small creeks flow westerly to the ocean from "The Chalks" ridge along the western margin of the park. Many of the larger streams in BBRSP were flowing during late summer and early fall when field studies were being conducted. This suggests they have perennial flows. Most of the smaller tributary drainages throughout the park contain ephemeral streams.

A majority of the Waddell Creek drainage basin is within BBRSP. The northern limit of the drainage basin is the unnamed arcuate ridge upon which the Johansen and China Grade Roads are constructed. The park boundary in this area is along the San Mateo County line and is just below the ridge at several locations. About 1 square mile of the West Waddell Creek drainage basin is in San Mateo County beyond the northern boundary of BBRSP (Map G-1). Northeast of this area, the park boundary changes from an east-west to a north-south trend and the upper-most portion of the West Waddell Creek drainage basin is back within the boundary of BBRSP.

The region of the West Waddell Creek drainage not within BBRSP is part of the Gazos Tree Farm. This area contains essentially no occupied dwellings that could contaminate surface or ground waters. However, poor logging operations can generate severe erosion problems (see, for example, Gray, 1970; Curry, 1971; Huffman, 1977). Excessive siltation and debris in creeks caused by increased erosion from logging operations is probably the main environmental consideration for this segment of West Waddell Creek. Knowledgeable and proper logging practices can mitigate excessive erosion and creek siltation (Huffman, 1977) and should be encouraged in this region.

Blooms Creek, a tributary of East Waddell Creek, drains a large portion of eastern BBRSP. The upper reaches of Blooms Creek are east of the park boundary in section 9 (Map G-1). All of the drainage basin east of the park is privately owned. Much of this region is developed with occupied single family homes, resorts, summer homes and cottages, and other various engineered structures. Pollution from the human element in this region will probably donate long-term contamination to surface and ground waters in the East Waddell Creek drainage basin.

Private property is also occupied by permanent residents above East Waddell Creek in the Last Chance Canyon area (Map G-1). This region is not serviced by commercial electricity, water, or sanitation services. Sewage from local homes is supposed to be handled by domestic septic systems. Data for the efficiency of locally operating septic systems is lacking; however, human pollution from this area is probably entering the East Waddell drainage basin.

Springs are common and occur regionally throughout BBRSP. Many of these are seasonal and dry up in late summer during drier years. Other springs, supplied from local sources, begin discharging water quickly after storms and dry up when precipitation ceases. The majority of springs observed during this study are derived from perched water tables above landslide slip surfaces. After periods of precipitation, small intermittent springs derived from perched water tables in pockets of loose soil and rock above impermeable surfaces are also common; these surfaces are usually unfractured sandstone, sandstone with tightly closed fractures, or clay-rich strata.

The occurrence of sea water intrusion is well documented in California by the California Department of Water Resources (1975). Sea water intrusion does not presently appear to be occurring in the groundwater basin of lower Waddell Creek near the ocean; however, it does occur in Scotts Creek, the next major drainage south of BBRSP (Phillips, 1976). Unmonitored groundwater withdrawal in lower Waddell Creek should be discouraged in view of the potential for sea water intrusion; salt contamination could seriously damage the local groundwater basin for an extended period of time.

LITHOLOGIC FEATURES

The Big Basin region is underlain by Cretaceous granitic rock and Neogene marine sedimentary rocks (Map G-1). The marine rocks are sandstone, siltstone, and mudstone which have been divided by earlier workers into several formations. Formational subdivisions are at depositional hiatuses in the stratigraphic section or at horizons defined by changes in lithology. The base of the marine sequence nonconformably overlies quartz diorite of the Ben Lomond Mountain area.

Previous Investigations

Rocks underlying the Santa Cruz Mountains were the topic of several investigations prior to 1900. After 1900, many individuals studied fossils and described stratigraphy throughout the mountains. A few of these early stratigraphic studies were by Arnold (1906), Branner and others (1909), Valentine (1928), Hobson (1932), Schenck (1936), Forest (1937), Reinhart (1943), Brooks (1953), Burchfiel (1958), McCollom (1959), Travers (1959), Touring (1959), and Brabb (1960). Many of these studies were encouraged by oil interests who wanted a regional evaluation of the petroleum resource potential. A few of these investigations were theses made during the 1950's by Stanford University graduate students; their studies were mapping exercises to resolve statigraphic inconsistencies in the Santa Cruz quadrangle folio of

Branner and others (1909). More recent stratigraphic investigations are by Cummings and others (1962), Mitchell and Repenning (1963), Brabb (1964, 1983), Clark (1966a, 1968, 1970, 1981), Barnes (1971, 1972), Domning (1972), Savage and Barnes (1972), Clark and Rietman (1973), Brabb and others (1977), and Repenning and Tedford (1977). These studies, and many others less oriented toward rocks and structure in BBRSP, provide detailed information about Santa Cruz Mountain geology. Prior to this geologic investigation, the most recent detailed mapping and stratigraphic studies of parts of BBRSP were made by Brabb (1960) and Clark (1970, 1981).

Quartz Diorite

Quartz diorite underlies parts of the Pine Mountain area of BBRSP (Map G-1). This rock is part of a granitic complex, described by Leo (1961, 1967), that underlies Ben Lomond Mountain; about three quarters of the granitic complex is quartz diorite (Clark, 1981). Quartz diorite is composed of medium-sized crystals of primarily plagioclase feldspar (50-60%), quartz (15-30%), potassium feldspar (5-10%), biotite (5-15%), and hornblende amphibole (5-15%) that interlock to form an hypidiomorphic-granular texture. Accessory minerals in the quartz diorite are sphene, epidote, magnetite, zircon, apatite, and tourmaline (Leo, 1961, 1967).

Fresh exposures of quartz diorite are light gray and have blocky shapes. Weathered rock forms spheroidal outcrops with relict joint surfaces also rounded. Quartz diorite is the most resistant and inherently stable rock exposed in BBRSP. However, local areas of instability do occur in regions underlain by this rock in the Ben Lomond Mountain area.

Granitic rock of Ben Lomond Mountain near Felton yields a potassium-argon (K-Ar) date of 71.0 +/-0.9 million years (CDMG, 1965). Sphene from quartz diorite in this region yields a fission-track age of 86.9 +/-6.5 million years (Naeser and Ross, 1976). Other granitic rocks, comprising basement and the oldest rock in the Salinian block (discussed in Structural Features section), have similar K-Ar ages of between 70 million and 90 million years (Curtis and others, 1958). Clark (1981) suggests that K-Ar ages of quartz diorite in the Ben Lomond area are probably for a post-intrusive event(s) involving cooling of the pluton or possibly uplift.

Locatelli Formation

Occurrences of Locatelli Formation are restricted to the southeastern part of BBRSP. The formation, first described by Brabb (1960), crops out on the southern slope of Pine Mountain and across the valley on the northern slope of Ben Lomond Mountain where it rests nonconformably on quartz diorite (Map G-1). Fresh rocks in the formation are light olive-gray and weather to various shades of brown. Fossils recovered from these rocks establish it as being Paleocene in age (Brabb, 1960).

The basal contact of Locatelli Formation is siltstone containing boulder- to pebble-sized clasts of granitic rock. Siltstone, in places containing pebbles and cobbles, is the most abundant rock type in Locatelli Formation. Medium- to coarse-grained sandstone is locally interbedded in siltstone. Brabb (1960) identified common clast types in Locatelli Formation as being granitic, metamorphic, and volcanic rocks; additionally, he measured 250 feet of strata at the type section near Locatelli Ranch.

Butano Sandstone

Butano Sandstone underlies large parts of eastern BBRSP (Map G-1). The sandstone was named by Branner and others (1909) for impressive exposures on Butano Ridge north of the park. Butano Sandstone is composed primarily of medium- to coarse-grained light gray and pale yellow arkosic sandstone with a few interbeds of sandy-pebbly conglomerate. Outcrops are for the most part blocky and well exposed. Moderately to well-indurated sandstone beds are in most places 3 to 15 feet thick and form resistant strata that underlie ridges as cliff-forming units; these sandstone beds underlie some of the steepest terrain in BBRSP.

The composite thickness of Butano Sandstone in the Butano Ridge and Pine Mountain area is approximately 9,000 feet (Brabb, 1960). Siltstone is locally interbedded throughout the section and commonly occurs in thin beds. The total amount of siltstone is small in comparison to sandstone. In the BBRSP region, siltstone is common in upper parts of the sequence. Fossils collected by Brabb (1960) from Butano Sandstone indicate that it was deposited in late Eocene time.

San Lorenzo Formation

Shale, siltstone, and mudstone exposed in the region of the San Lorenzo River approximately 4 miles east of BBRSP were named San Lorenzo Formation by Arnold

(1906). These strata conformably overlie Butano Sandstone and are continuous from the San Lorenzo River area into the Big Basin region (Brabb, 1960; Cummings and others, 1962). Rock of this formation becomes coarser-grained to the west (Brabb, personal communication, 1983) and underlies a large part of northeastern BBRSP. San Lorenzo shale, siltstone, and mudstone are olive-gray when freshly exposed and contain phosphate and high percentages of clay. Clay layers decrease the stability of exposures by forming planes of weakness that generate many landslides. These rocks, interbedded in the Big Basin region with light gray to pale yellow fine-grained sandstone, are easily eroded and form benches where exposed; in contrast, the interbedded sandstone is moderatly indurated and forms slopes where exposed.

San Lorenzo Formation is subdivided into two members by Brabb (1960); the older member is Twobar Shale and is disconformably overlain by the Rices Mudstone. Both members are composed of fine-grained silty-clayey deposits. In the field, these members were mapped as undifferentiated San Lorenzo Formation for this investigation (Map G-1). Most exposures of Twobar Shale are moderately stratified and provide data for structural interpretations. Rices Mudstone is composed of such homogeneous clastic debris that a spheroidal weathering and fracture pattern has developed; this characteristic strongly resembles bedding and restricts taking arbitrary attitudes from outcrops without horizons to control stratigraphy. Brabb (1960) established from fossils that Twobar Shale is upper Eocene and Rices Mudstone is lower Oligocene. Additionaly, he interpreted that the composite thickness of these members varies between 1,830 and 2,250 feet and that glauconitic- and phosphatic-rich horizons within section probably represent stratigraphic hiatuses (disconformities).

Vaqueros Sandstone

Sandstone termed Vaqueros has been described at many locations throughout the Santa Cruz Mountains. Descriptions early in the century incorrectly identified some of these sandstone sequences as belonging to Vaqueros Sandstone (Brabb, 1960). The type locality for Vaqueros Sandstone was redefined by Thorup (1941, 1943) after much confusion about sandstones identified as being Vaquero or Vaqueros throughout the region.

Vaqueros Sandstone was deposited in middle Oligocene time (Brabb, 1960). In BBRSP this formation conformably overlies San Lorenzo Formation (Rices Mudstone) and consists of fine- to medium-grained light gray quartz-rich arkosic sandstone locally interbedded with conglomerate and olive-gray mudstone and shale. Granitic rock, quartzite, and undifferentiated volcanic rock are the most abundant clasts in conglomeratic sections. Weathered sandstone is light yellow to buff and locally has a "punky" appearance; mudstone and shale are reddish-brown where weathered. Sandstone is thickly bedded in most exposures throughout the park. Individual beds are in most places indurated and resistant to erosion. This characteristic causes hogbacks to form on the up-dip sides of folds; drop-off slopes of Vaqueros hogbacks form steep terrain in eastern BBRSP. At least 800 feet of this sandstone is exposed in the Kelly Creek region of the park (Brabb, 1960). This thickness is a minimum value because the upper part of the formation has been removed by erosion.

Measured sections of Vaqueros Sandstone indicate that the total amount of mudstone and shale increases to the north and east in the Big Basin quadrangle (McCollom, 1959); this distribution pattern suggests that the basin of deposition also increased in depth in these directions. Cummings and others (1962) indicate the provenance of Vaqueros deposits as being granitic terrane to the southwest; this interpretation is based on the arkosic character of sandstone and the thinning and decrease in average grain size of beds to the north and east.

Santa Margarita Sandstone

The Santa Margarita Sandstone was first described in the area by Branner and others (1909, p. 5) as "the distinctive formation consisting of pure white sand overlain by white shale". Brabb (1960) thoroughly described this unit as it occurs in the Big Basin area; however, he referred to this deposit as Formation B of the Monterey Group. The base of Santa Margarita Sandstone rests unconformably on all older Paleogene sedimentary rocks and is nonconformable with Cretaceous granitic rocks in the area (Map G-1). Fossils recovered by Clark (1981) indicate that Santa Margarita Sandstone was deposited in late Miocene time; in other areas, Clark (1968, 1981) describes the Miocene-Pliocene boundary as occurring within the unit.

Strata comprised in Santa Margarita Sandstone are light gray and composed of fine- to coarse-grained friable sandstone. In most places sandstone beds are poorly cemented and form rounded to subrounded outcrops. Most of this unit in BBRSP is poorly cemented. Well-cemented sandstone occurs locally and is a competent rock that forms cliffs.

Santa Margarita Sandstone has a limited occurrence in the Big Basin region. The unit is restricted to the west-central part of BBRSP where it conformably underlies Santa Cruz Mudstone. In this region, the thickness of Santa Margarita Sandstone varies along strike. The sandstone is less than 20 feet thick on the west slope of Mt. McAbee, and less than 2 miles to the north-northwest it is more than 100 feet thick. Brabb (1960) suggests more than 200 feet of section may be present in the west Big Basin region.

Santa Cruz Mudstone

Siliceous, organic-rich mudstone conformably overlying Santa Margarita Sandstone was named Santa Cruz Mudstone by Clark (1966a, 1966b). Prior to the study by Clark (1966a), Santa Cruz Mudstone had been grouped with or identified as other formations exposed throughout the region. Santa Cruz Mudstone underlies large parts of western and southern BBRSP (Map G-1). Mudstone is juxtaposed against Purisima Formation by the San Gregorio fault just west of the park.

Santa Cruz Mudstone is comprised of siliceous and slightly diatomaceous mudstone interbedded with fine-grained sandstone and sandy siltstone. Freshly exposed Santa Cruz Mudstone is olive-gray to gray-brown and weathers to white or pale yellow-brown. Bedding is well developed in this sequence; individual beds vary from a fraction of an inch to as much as 6 inches thick. Siliceous mudstone is thorougly fractured due to its brittle nature; consequently, separations along fractures and bedding yield outcrops that in most places are nothing more than piles of rock chips.

Fossils indicate that Santa Cruz Mudstone was deposited in late Miocene to early Pliocene time (Clark, 1981). Mudstone strata are several hundred feet thick in western BBRSP. Several hundred feet of section are also described on Pine and Ben Lomond Mountains by Cummings and others (1962).

Purisima Formation

Haehl and Arnold (1904) named a series of conglomerate, fine-grained sandstone, and shale the Purisima Formation for the type locally along Purisima Creek (Half Moon Bay quadrangle). Branner and others (1909) were the first to describe these rocks in the Santa Cruz Mountains. Since this time, the formation has been identified regionally throughout west-central California.

Occurrences of this formation in the vicinity of BBRSP are restricted to areas west of the San Gregorio fault (Map G-1). A section of olive-gray Purisima mudstone and sandstone is well exposed in the sea cliff east of Point Ano Nuevo. This locality has most recently been mapped by Clark (1981), who described more than 500 feet of fault-bounded strata in the area; in addition, he determined that local sandstone in the formation was deposited in late Pliocene time. Cummings and others (1962), using mega-invertibrate chronology, describe Purisima Formation as being early to late Pliocene in age.

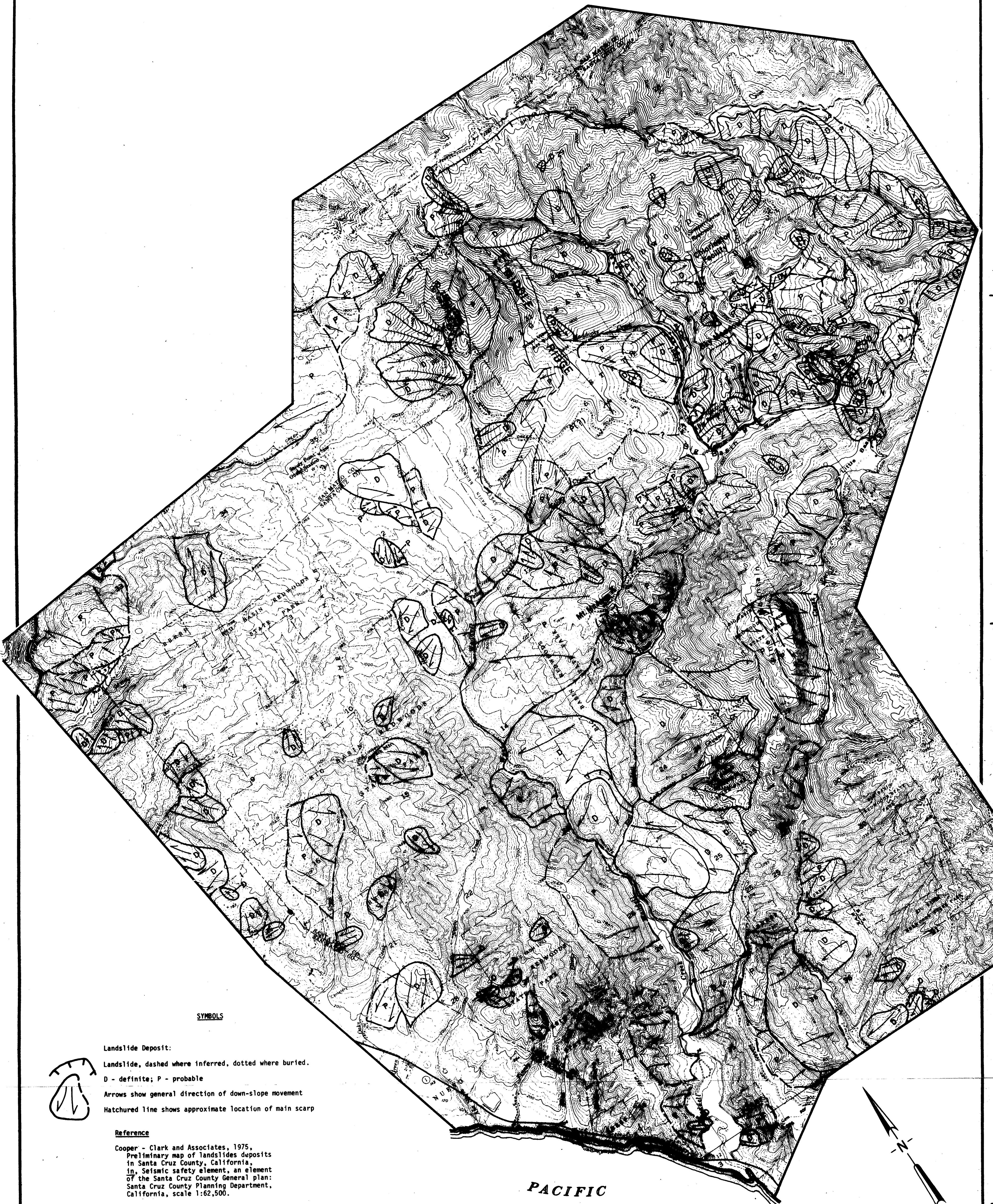
Surficial Deposits

Alluvium and colluvium, consisting of loosely consolidated sand, silt, clay, and interbedded gravel and cobbles, are deposited locally throughout BBRSP and coastal areas to the west. Along most of the park drainages, rock, sand, silt, and clay are in a state of transport; in addition, prior areas of alluvial deposition are being eroded. The upper parts of Waddell and Scott Creeks and their tributaries are capable of transporting all colluvial material supplied to them. Much of this material is derived from landslides and debris and earth flows that fail into canyons. These types of failures may temporarily block drainages (dams) and pond alluvium.

Thick deposits of alluvium are collecting in the lower reaches of Waddell and Scott Creeks. These deposits underlie major terraces along the creek channels near the ocean. Terrace alluvium deepens with proximity to the ocean. Much of the terrace alluvium probably collected during latest Pleistocene and Holocene time in response to the post-glacial rise of sea level which also raised base level of the creeks.

Alluvium in mountainous areas locally collects in landslide grabens (pull-away section at top) to form benches and small valleys or depressions. Sky Meadow in eastern BBRSP is such an example. Landsliding below Sky Meadow was active during this investigation. The employee residences in this area are situated on the margin of a back-filled graben of a higher and older landslide. Depressions which intermittently fill with water occur in the northeast part of section 24 (T9S-R4W) in the Last Chance Canyon area. These depressions are classic examples of alluvial back-filled landslide grabens (Maps G-1, G-2).

Slope wash and colluvium mantle most of the terrain in BBRSP. Soils overlying Butano Sandstone, Vaqueros Sandstone or San Lorenzo Formation (Paleogene rocks) are usually thicker and better developed than those associated with



SYMBOLS

Landslide Deposit:

Landslide, dashed where inferred, dotted where buried.

D - definite; P - probable

Arrows show general direction of down-slope movement

Hatchured line shows approximate location of main scarp

Reference

Cooper - Clark and Associates, 1975, Preliminary map of landslides deposits in Santa Cruz County, California, in, Seismic safety element, an element of the Santa Cruz County General plan: Santa Cruz County Planning Department, California, scale 1:62,500.

SCALE

1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

5 0 1 KILOMETER

1:24,000

Topographic base map from U.S. Geological Survey. Ano Nuevo, Big Basin, Davenport, and Franklin Point 7.5-Minute Quadrangles.

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MAP NO.	DRAWING NO.			REVISIONS	DATE	
G-2	20522	LANDSLIDES IN BIG BASIN REDWOODS STATE PARK SANTA CRUZ COUNTY, CALIFORNIA	RESOURCES AGENCY OF CALIFORNIA DEPARTMENT OF PARKS AND RECREATION APPROVED ______ DATE ______			DESIGNED DRAWN CHECKED

Santa Margarita Sandstone or Santa Cruz Mudstone (Neogene rocks). The Santa Margarita Sandstone is porous and Santa Cruz Mudstone is well cemented, indurated, and highly fractured. These characteristics form well-drained rocks that retain little water. Paleogene rocks, including Butano and Vaqueros Sandstones and San Lorenzo Formation, contain higher percentages of clay and are less well drained than the Neogene rocks. Ground underlain by Paleogene rock retains water and therefore sustains more vegetation than ground underlain by Neogene rock. Vegetated areas are covered with a ground layer of acid-rich humus. Acids produced in the humus chemically deteriorate underlying rock; chemically decomposed rock eventually becomes soil. Soil in areas underlain by Paleogene rock forms slowly and develops a layer of rock chips that protects against erosion. Once this protective layer is removed, the underlying soil is exposed and becomes very susceptible to erosion.

Soils on slopes throughout the park are undergoing down-slope creep. Trees with crooked trunks are common in BBRSP and locally represent evidence for creep. However, crooked tree trunks are not always indicative of creep (Phipps, 1974). Water has an exaggerated effect on downslope movement. Slopes are more susceptible to creep and mass movement when saturated. It is postulated that the majority of soil-mantled slopes steeper than 15 degrees in BBRSP are capable of failing if supplied with precipitation quickly enough to become super-saturated. Scarred slopes and deposits of loose soil containing woody-material are common throughout the Santa Cruz Mountains and indicate that downslope mass movement is regionally active.

Marine terraces are cut into ocean-facing slopes in western BBRSP. These surfaces are overlain by sandy-silty deposits locally containing pebbles, cobbles, and shell debris. Terrace material is loosely consolidated and varies from 5 to approximately 25 feet in thickness. Slope wash and colluvium locally cover higher and older marine terraces. The sea cliff cut into the lowest emergent platform provides the best exposures of terrace material.

Five emergent Pleistocene terraces are identified by Clark (1981) between Santa Cruz and Point Ano Nuevo. Radiometric dates (uranium-series) of 68,000 to 100,000 years were derived from mollusks in deposits on the lowest subaerial terrace (Bradley and Addicott, 1968). Amino acid dating of the mollusks yields an age of 130,000 +/-59,000 years for the lowest terrace (Lajoie and others, 1975). The age of the highest terrace is interpreted to be between 700,000 and 800,000 years by Lajoie and others (1972) and between 1.0 and 1.2 million years by Bradley and Griggs (1976).

STRUCTURAL FEATURES

The Santa Cruz Mountains are part of the Salinian block of west-central California. The San Andreas fault is the eastern boundary of this terrane. The western boundary trends offshore and, in this area of California, is beneath the Pacific Ocean (Page, 1982). In a plate tectonic setting, the block is comprised of terrane that has been displaced by strike-slip faulting from regions in the vicinity of Mexico or Central America and possibly even farther south (Page, 1982).

The Salinian block is subdivided into several smaller sub-blocks separated by faults (Ross, 1978). BBRSP is in the northern part of the central block of Salinian composite terrane. The San Gregorio fault is the boundary between the central and northern sub-blocks (Page, 1982). These sub-blocks can be further subdivided into smaller blocks separated by faults. Clark (1930) divided the region north of Santa Cruz into these smaller fault blocks. The Zayante fault of Hall and others (1974), identified as the Ben Lomond fault by Brabb (1960), trends approximately east-west throughout central BBRSP and is the boundary between the La Honda block on the north and the Ben Lomond block on the south.

The sequence of Paleogene sandstone, siltstone, and mudstone underlying the Big Basin region is deformed into northwest-trending anticlines and synclines. These folds are locally cut by faults that also juxtapose rock types and other geologic structures. Neogene rocks are less deformed than the Paleogene strata. In most places, Neogene rocks are warped into gentle folds superimposed on a more regional southwesterly dip. Neogene formations are juxtaposed by Holocene faulting in the vicinity of Point Ano Nuevo just west of BBRSP.

Previous Investigations

The structure of the Santa Cruz Mountains has been studied by several early researchers. A few of the more noteworthy regional and local studies are by Haehl and Arnold (1904), Branner and others, (1909), Lawson (1914), Clark (1930), Fitch (1931), Brooks (1953), Burchfiel (1958), Spotts (1958), Touring (1959), and Brabb (1960). Regional implications involving origin and development of rocks in the Salinian block were poorly understood prior to concepts of plate tectonics. Models involving plate tectonics have helped to redefine interpretations of the geological development of California. Much work in recognizing and studying allochthonous and displaced terranes of the Salinian and associated blocks has been done since 1960 (see, for example, Crowell, 1962; Cummings and others, 1962; Compton, 1966; Atwater, 1970; Wiebe, 1970; Johnson and Normark, 1974; Graham, 1978; Howell and Vedder, 1978; Silver and Normark, 1978; Streitz and Sherburne, 1980; Page, 1982).

Folds

The Santa Cruz Mountains are deformed by several northwest-southeast-trending folds. In the BBRSP region of the mountains, four major folds, including two anticlines and two synclines, are exposed (Map G-1). These folds are regional features and can be traced to the northwest and southeast of BBRSP (Brabb 1960, 1970; Cummings and others, 1962); additionally, many small-scale folds are locally developed. Folds are open and deform all ages of Cenozoic rock in the park. Investigations by Brabb (1960, 1970) and Cummings and others (1962) identify these regional folds as being truncated by major post-Miocene faults.

The Butano anticline trends northwest-southeast throughout the region and is located just outside the northeastern boundary of BBRSP. The Big Basin syncline and Johansen anticline trend northwest-southeast and are parallel structures in northeast BBRSP. The Big Basin syncline, situated approximately 0.25 mile northeast of the Johansen anticline, appears to have the greatest subaerial exposure of the two folds.

In a structural sense, the Big Basin syncline is well developed east of Opal Creek. Vaqueros Sandstone and underlying San Lorenzo Formation in this area are warped by the syncline into a trough that is concordant with the fold for several miles. The Johansen anticline is well exposed in Butano Sandstone northwest of Middle Ridge (Maps G-1 & G-2). Previous investigators have mapped the folds as unbroken structures throughout the region of Middle Ridge. For this investigation, the folds are not mapped in this area because Middle Ridge (Map G-1) is interpreted to be a large landslide (Middle Ridge landslide).

The Davenport syncline trends northwest-southeast throughout western BBRSP and parallels the San Gregorio fault and coastline. The syncline is well exposed and subaerially deforms rocks of the Santa Cruz Mudstone; it is uncertain what rock types are deformed by this fold in the subsurface. South of Waddell Creek, in the vicinity of Davenport, the syncline trends offshore (Brabb, 1970; Clark, 1981).

Faults

The San Gregorio and Zayante faults are regionally exposed throughout the Santa Cruz Mountains (Figure 1). In addition, several small-scale secondary faults, some of which are mapped after Brabb (1960, 1970) and Cummings and others (1962), juxtapose rock in BBRSP (Plate 2).

The Zayante fault in BBRSP is the northwestern extension of a system of faults that includes the Vergeles fault to the southeast (Clark and Rietman, 1973). The southern end of the Vergeles fault connects with the San Andreas fault southeast of San Juan Bautista, California (Hall and others, 1974; Jennings, 1975). The Zayante-Vergeles fault is probably a secondary wrench-type fault between the San Andreas and San Gregorio faults. Structural orientation of the fault in the Big Basin region suggests the fault plane dips steeply to the south and may be locally vertical.

The cumulative amount of displacement on the Zayante fault in BBRSP is uncertain. Using stratigraphic control, Brabb (1960) postulates that the fault has up to 10,000 feet of vertical displacement in west Big Basin; however, he further indicates that local gravity surveys across the fault suggest only 3,000 feet of cumulative vertical displacement.

The western part of the Zayante fault appears to be overlain by undisturbed late Miocene Santa Margarita Sandstone and Santa Cruz Mudstone. Mapping by Brabb (1960) also indicates that these rocks are not disturbed by faulting. In contrast, east of Corralitos, recent movement along the Zayante fault is suggested by a scarp of probable Holocene age and deformation of a late Pleistocene surface (Hall and others, 1974).

The San Gregorio fault, as part of the San Andreas system of transcurrent faults, has experienced more than 70 miles of displacement in Neogene time (Graham and Dickinson, 1978). The fault zone trends north-northwest along the coast approximately 0.5 mile west of BBRSP. An active branch of the San Gregorio fault trends offshore approximately 1.6 miles northwest of the mouth of Waddell Creek. From this location, the San Gregorio fault connects with the offshore Hosgri fault zone to the south (Jennings, 1975; Silver, 1978).

Many faults comprise the San Gregorio fault zone east of Point Ano Nuevo. Lajoie and others (1979) describe the fault zone in the Point Ano Nuevo area to be more than 3 miles wide; in addition, they identify five faults in the zone that offset a 105,000 year old marine terrace. Holocene fluvial deposits are trunctated and deformed by recent movement on the San Gregorio fault just west of BBRSP (Weber and Lajoie, 1974, 1977, 1979). Average rates of late Pleistocene movement on the fault vary from 0.24 to 0.63 inch per year (Weber and Lajoie, 1979).

Many small-scale faults occur throughout the area (Map G-1). Poor exposure precludes detailed mapping of most faults beyond roadcuts or excavations. The majority of small-scale faults appear to have strike-slip displacement and probably developed by local stress readjustment during periods of folding.

GEOLOGIC HISTORY

The oldest rock in the Big Basin area is quartz diorite of the Ben Lomond Mountain area. In plate tectonic concepts, quartz diorite plutons developed above a Cretaceous subduction zone along the eastern margin of the ancestral Pacific Ocean. Granitic plutons in this region were being eroded by Late Cretaceous time (Hall and others, 1959). Plate tectonic reconstructions of western North, Central, and South America suggest that several hundred miles (possibly thousands) of right-lateral strike-slip displacement have occurred along faults in western parts of the continents. Removal of this slip suggests that terrane underlying the Santa Cruz Mountains (northern part of Salinian block) originated near the latitude of Central America (Page, 1982).

Granitic terrane was eroded to a near peneplain before the end of Cretaceous time. This surface was lowered below sea level in middle Paleocene time

(Brabb, 1960) and received a poorly sorted layer of cobble- to boulder-sized granitic clasts set in a matrix of siltstone (Locatelli Formation).

Locatelli Formation is eroded indicating a regression of the Paleocene seas. The exact timing of this early Cenozoic regression is uncertain. By late Eocene time, another marine transgression had occurred. From this sea, Butano Sandstone and the Twobar Shale member of San Lorenzo Formation were deposited. The provenance for Butano Sandstone was underlain by a potash feldspar-rich granitic rock. Another marine regression of short duration occurred in early Oligocene time. The Rices Mudstone member of San Lorenzo Formation was disconformably deposited on Twobar Shale during the subsequent marine transgression before the close of early Oligocene time; a disconformity within Rices Mudstone indicates that another short depositional hiatus occurred prior to the end of mudstone deposition.

Vaqueros Sandstone was deposited conformably on San Lorenzo Formation (Rices Mudstone) in middle Oligocene time. It is uncertain how much rock was deposited because the top of Vaqueros Sandstone is eroded in BBRSP. It is also uncertain how much rock was eroded and whether there was more than one marine transgressive-regressive episode prior to the close of late Paleogene time.

During early to middle Cenozoic time, the Salinian block (terrane west of the San Andreas fault or its ancestral trace) continued northward migration. This displacement, accomodated by continual episodes of right-lateral strike-slip faulting, was driven by interactions between the Pacific, North American, and possibly South American plates.

The region was subjected to a pre-late Miocene episode of uplift, folding, and erosion. All Paleogene rocks in the area subsequently experienced some degree of erosion. The region subsided and another marine transgression occurred in late Miocene time. From this sea, Santa Margarita Sandstone was unconformably deposited on much of the pre-late Miocene erosional surface.

Before the close of Miocene time, sedimentary conditions changed and siliceous, organic-rich Santa Cruz Mudstone was being conformably deposited on Santa Margarita Sandstone. Several thousand feet of Santa Cruz Mudstone was deposited during late Miocene and early Pliocene time.

Siltstone of the early to late Pliocene Purisima Formation is deposited conformably on Santa Cruz Mudstone in some places and unconformably in others south of BBRSP (Clark, 1981). This is suggestive of local basins within the depositional region of Purisima Formation. In the Big Basin region, Santa Cruz Mudstone and Purisima Formation are juxtaposed by the San Gregorio fault and do not occur in depositional contact. This characteristic indicates that movement on the San Gregorio fault, in places, post-dates deposition of Purisima Formation.

Geomorphic development of the present Big Basin landscape probably started in late Pliocene to early Pleistocene time. Ben Lomond Mountain began to rise from regional compression during this time and the prominant erosional surface that underlies the mountain and surrounding region started to develop. Subsequent to this period of uplift, many of the streams in the Santa Cruz Mountains established their drainage patterns.

During early to late Pleistocene time, at least four periods of world-wide continental glacial activity were associated with cooler, wetter climates. Glacial ice locked on the continent caused several fluctuations of sea level. Sea level was lowered more than 350 feet below its present elevation during periods of glacial activity and stood several hundred feet higher than at present interglacially (Shepard, 1973; Thurman, 1975).

Throughout the Big Basin region, lowering of sea level caused cycles of extensive erosive down-cutting by streams. The mouths of many local streams along the coast were eroded below present sea level in response to the lowered base level of the ocean. Rapidly eroding streams undercut mountain slopes and caused many landslides to develop. Some of these landslides are large-scale failures that disturb more than 1 square mile of mountain flank; failure of the Middle Ridge landslide (?) disturbed rock underlying more than 3 square miles of what is now central BBRSP.

The post-glacial rise of sea level caused alluvial backfilling in many of the local creek estuaries. This alluvium buttressed the toes of many of the larger landslides along the lower part of Waddell Creek. The drier climate in post-glacial times reduced, but did not eliminate, the potential for major landsliding.

In Holocene time, fault activity of the San Gregorio fault continued to displace rocks right-laterally. In addition, annual precipitation in the Santa Cruz Mountains, although much less than during glacial times, continues to be high enough to facilitate with failure of many landslides and debris and earth flows. For the future, faulting and landsliding will continue to be significant geological hazards in this region.

CONSTRAINTS AND SENSITIVITIES

Significant Features

There are several geologically significant features in BBRSP. These include exposures of Butano Sandstone along the China Grade Road and State Highway 236 in the northern part of the park, soil and weathered rock overlying Santa Cruz Mudstone in the western part of the park, collections of alluvium which form flat areas, the region encompassing the Waddell Creek drainage, and fossils within rocks throughout the area.

Rock exposures in BBRSP are rare in most places. Resistant sandstone is well exposed in the northern and eastern parts of the park where weathering has produced hogback outcrops. These hogbacks are formed by weakly cemented sandstone that flakes and spalls from outcrops. Unfortunately, portions of some outcrops have been engraved by vandals.

Soil overlying Santa Cruz Mudstone is a fragile resource. The soil forms slowly and is easily eroded once the surface is disturbed. Fire roads and trails excavated across this terrain are locally being eroded, and in some of these areas, deep gullies have formed. Many of the roads were placed to provide emergency access to fires. The majority of these roads are not used and have been closed by placing logs or piles of bulldozed earth across them.

However, unauthorized off-road vehicles were using these roads in the late summer and early fall of 1983.

Some areas underlain by Santa Cruz Mudstone weather to form a pronounced white rock. White weathered Santa Cruz Mudstone appears to be more common in stratigraphically lower parts of the section. The color and appearance of white weathered mudstone is similar to that of chalk; this is probably the reason why geographic names such as "The Chalks" and "Chalk Mountain" were used in western BBRSP (Map G-1).

Waddell Creek, including the east and west branches, is the major drainage of BBRSP. Features of special geological interest within this drainage include a large number of landslides, debris and earth flows, and some rock exposures. Erosion is responsible for the creation and eventual destruction of all features in the drainage basin. The fragile nature of this environment should be considered in resource planning.

Alluvial deposits are somewhat rare in BBRSP. The largest alluvial accumulations are along Opal and Blooms Creeks in the northeastern part of the park and along the lower part of Waddell Creek in southwestern BBRSP. Alluvium along Blooms and Opal Creeks is subject to rapid erosion. Removal of this material results in the destruction and loss of usable flat areas of the park.

Invertebrate mega- and micro-fossils are present in most of the rock types exposed in BBRSP. These fossils have been used by earlier researchers to establish structural control and relative ages of rock types exposed throughout the region. The abundance of fossils varies from exposure to exposure and formation to formation; stratigraphic horizons locally contain an abundance of fossils. Fossil-bearing strata are best exposed along creek beds. Significant fossil collecting localities throughout the Big Basin region are identified by Brabb (1960, Figure 5).

Slope Stability

The Santa Cruz Mountains are scarred by active and inactive landslides and debris and earth flow activity. Mass wasting, occurring as relatively rapid downslope movement of soil and loose rock, is the primary erosional mechanism. This process is probably responsible for removing most of the material from the mountains and placing it in valleys where streams and rivers move the load to the ocean. Prolonged wet periods in the Santa Cruz Mountains are capable of producing much larger and greater numbers of landslides and debris and earth flows than are now active. Much of the presently active downslope movement began during the wet winters of 1981-82 and 1982-83.

Landslides and debris and earth flows are wide-spread in BBRSP. Scars and jumbled topography indicating many ages of landsliding are common in the park. Most hill and mountain slopes throughout the Big Basin region are subject to instability during and after periods of increased precipitation. High-intensity short-duration rains are also capable of inducing many debris and earth flows. All slopes in BBRSP should be considered capable of failing unless evaluated as being stable by a site-specific engineering geologic investigation; regions below steep slopes are also subject to local inundation by mass movements of debris from adjacent slopes.

Slope erosion is more concentrated and severe where little or no vegetation is present. Uncontrolled burn areas are subject to greater erosion than vegetated slopes. Erosional effects on land burned by wildfire are well documented by Cleveland (1973, 1977).

Landslides

Landslides are common in BBRSP (Map G-2). Prior investigations have not identified all landslides in the region of the park. Many of the local landslides are small features that involve only localized slope failure. In contrast, several of the larger landslides underlie more than 1 square mile of terrain. A comprehensive study by Cooper-Clark and Associates (1975), using aerial photographs, identified and mapped many landslides in the region. Their study identified most of the more obvious landslides in BBRSP; however, many of the smaller, less-obvious landslides were not identified.

Movement of many of the larger landslides in the Big Basin region probably occurred during late Pleistocene glacial periods. During this time, the climate was cooler and wetter, and sea level stood more than 350 feet lower than at present (Shepard, 1973; Thurman, 1975). Drainages discharged high amounts of water and rapidly eroded their channels; high erosion was partly in response to the lowered base level of the ocean. Erosive undercutting of mountain slopes and the wetter climate are interpreted to be causative factors for generating many large landslides throughout the region.

Several large landslides occur as bedding-plane failures on the northwest side of Pine Mountain and the north and west sides of Mount McAbee. Three landslides in these areas each disturb more than 1 square mile of ground. Movement of these landslides was probably caused by down-cutting and lateral erosion in the canyons. Removal of material by erosion left regional slopes unsupported. Interbedded clay in sedimentary rocks of the area renders all unsupported dip-slopes candidates for failure.

Many landslides underlie canyon side-slopes in the lower part of Waddell Creek. Most of these landslides probably failed during glacial times into the deeper ancestral canyon. Alluvium, derived during the post-glacial rise of sea level, backfills this section of the canyon and buttresses the toes of many of these late Pleistocene landslides. However, most of the older landslides are disturbed by younger superimposed failures.

Middle Ridge landslide

The largest landslide identified in this study underlies much of Middle Ridge in the northern part of the park (Maps G-1&2). The landslide is informally named the Middle Ridge landslide for this investigation. Major landslide movement, involving rocks of Butano Sandstone and San Lorenzo Formation, was north to south in a direction concordant to the regional dip of underlying bedding. It should be noted that field criteria for identifying the Middle Ridge landslide are somewhat interpretive and time was too limited for resolving boundary problems that would more positively substantiate its existence. However, much evidence for existence of the landslide is provided by geologic structure along margins of Middle Ridge and topographic expression of the local region.

Mapping by Brabb (1960), whose work has been compiled in several scientific articles, does not identify offset in the northwest-southeast trend of the Big Basin syncline where it crosses the region described in this report as the Middle Ridge landslide. The Johansen anticline, located to the south and concordant in trend with the Big Basin syncline, is mapped by Brabb (1960) as terminating at the Opal Creek fault. The trace of the Opal Creek fault of Brabb (1960) approximately corresponds to the eastern boundary of the Middle Ridge landslide. Absolute evidence for existence of the Middle Ridge landslide could be provided by mapping in detail the local Opal Creek region to determine if surface expression of the Big Basin syncline and Johansen anticline are actually offset where they cross the region of Middle Ridge and Opal Creek.

Juxtaposed rock units along the flanks of Middle Ridge provide the most evidence for Middle Ridge landsliding. In these lateral margin areas, the contact between Butano Sandstone and San Lorenzo Formation dips south and trends east-west. The contact is perpendicular to the direction of landslide movement and provides a good marker horizon. East of Middle Ridge the contact is offset in a left-lateral sense approximately 0.6 mile; on the west side of Middle Ridge, the contact is offset right-laterally approximately 0.3 mile. These displacements are interpreted as faults in mapping by Brabb (1960) and Cummings and others (1962).

The toe region of the Middle Ridge landslide, as shown on Maps G-1 & G-2, is the most interpretive margin of this large failure. In fact, the toe region may include more area to the south than is identified on the geologic and landslide maps. The head of the Middle Ridge landslide is poorly preserved.

Post-failure erosion and younger secondary landslides have destroyed most of the upper part of the landslide.

Failure of the Middle Ridge landslide was from the unnamed ridge traversed by the Johansen - China Grade Roads. The pull-away region forms an arcuate bowl-shaped indentation in the ridge. Some jointing in this area dips steeply and is locally concave toward the pull-away; these joints could have formed from resisting tensional forces in the ridge just prior to failure.

The Middle Ridge landslide probably failed during middle to late Pleistocene time. Geomorphically, the landslide appears older than many of the other Pleistocene landslides in the region. The landslide moved south into an ancestral drainage that may have connected Opal Creek with West Waddell Creek; in the present drainage pattern, Opal Creek is part of the East Waddell drainage basin.

Failure of the Middle Ridge landslide was probably facilitated by increased precipitation during a pre-Wisconsin glacial period. Much of the sandstone in the Middle Ridge area is permeable and must have accepted a high volume of water. Water percolating into the porous south-dipping rocks probably developed a tremendous head of pressure. Hydraulic effects of fluid pressure in the geological environment is thoroughly described in classic papers by Hubbert and Ruby (1959) and Hsu (1969). Hydrostatic pressure and saturated clay in the landslide were the major lubricating mechanisms during movement. Fluid pressure, possibly associated with a seismic event, is responsible for causing initial failure. South-dipping strata in the landslide moved in much the same fashion as a stack of playing cards tilted upward until they slide.

Debris Flows and Earth Flows

Downslope movement of material by debris and earth flow activity is common throughout the Santa Cruz Mountains. Definitions for these two features are similar (see, for example, Coates, 1977; Varnes, 1978). By informal definition, debris flows involve failure of soil and vegetation and some underlying bedrock, while earth flows disturb only surficial soil and overlying vegetative cover. Using these definitions, debris flows appear to be more common in BBRSP than earth flows.

Debris and earth flows are caused by periods of prolonged or intense precipitation. When the ground becomes saturated or supersaturated with water, cohesion is reduced and surficial slope material cannot support itself and the weight of added water. The result is slope failure.

Stability Problems

Most occurrences of downslope movement in BBRSP involve remote areas and do not pose a threat to park facilities or engineered structures. However, engineering problems do arise from poor stability in several areas. Some of the problems require periodic maintenance to correct damage from downslope movement. Field work for this study identified several areas of poor stability in the park that are important enough to describe.

Chlorinator facility:

A chlorinating facility (chlorinator) that produced potable water for BBRSP was destroyed by a debris flow during the winter of 1981-82. The debris flow originated upslope from the chlorinator during a storm in a prolonged wet period. Between 75 and 100 cubic yards of material, consisting of water, soil, forest humus, and indurated blocks of sandstone up to 2.5 feet in diameter, were included in the failure. Downslope velocity of the debris flow was probably several feet a second when the chlorinator was engulfed and destroyed. After this event, water for domestic use was filtered and purified by a temporary facility situated below the source of the debris flow. A new more sophisticated chlorinating facility was installed in the summer of 1983. The new chlorinator, scheduled to begin producing potable water in late summer or early fall of 1983, was constructed at the site of the earlier destroyed unit.

A small canyon is incised into the hillside directly behind the new chlorinator. An excavation was made into the hillside for the foundation of the chlorinator building. This excavation is cut into the channel bottom of the small canyon so that all run-off from local slopes is funneled onto the east excavated cut-slope. A drain constructed on a bench at the top of the cut-slope is engineered to handle water flowing down the channel and into the excavation. However, the present design of the chlorinator excavation is such that any future debris or earth flows from local slopes will be channeled into the new facility.

Mitigative measures to stabilize local slopes were not done after the chlorinator was destroyed. Additional debris flow activity, which probably would have destroyed or immobilized the temporary purification facility, did not occur during the 1982-83 winter. However, there is no reason to assume that local slopes are stable. A site-specific engineering geology investigation is necessary to determine local slope stability and to assist with preventing future damage to the newly installed chlorinator from debris flows.

Sky Meadow landslide:

Sky Meadow is a grass-covered alluvium-filled depression in northeastern BBRSP. The Sky Meadow depression formed in the pull-away graben of a prehistoric landslide. Movement was probably caused by erosion and undercutting in Union Creek. Scarp areas are now underlain by younger landslides that failed into the depression.

Landsliding along Union Creek below Sky Meadow was active during field investigation for this study. Landslide movement appears to have been more active in the 1982-83 wet winter than during the time of field studies in late summer of 1983. Landslide movement has destroyed local trails and required that a 6 inch in diameter PVC sewer line be relocated above ground to facilitate with its maintenance. The sewer line provides service to employee residences near Sky Meadow, local camp grounds, and other employee residences (?) in the eastern part of BBRSP. Down stream from this area, the line connects with sewer facilities in Sempervirens Campground. To assist with mitigating future stability problems in this region, the landslide below Sky Meadow warrants a detailed engineering geologic investigation.

Eastern Road landslide:

The road to employee residences in easternmost BBRSP crosses an older landslide approximately 0.25 mile northeast of Sky Meadow. Secondary landsliding below the road has removed part of the outside east lane of the roadway. The landslide appears to be failing across bedding and probably is controlled by joints oriented parallel to the slope. This renewed landsliding threatens the entire road at this location.

The road is cut into a steep slope and will be difficult to repair. Excavating further back into the hill-slope is not recommended because the slope is steep and rises several tens of feet above the roadway. Additional road cuts could trigger landsliding above the road. An engineering study is needed to evaluate methods of repair.

Gazos Creek Road landslide:

Gazos Creek Road crosses an unnamed active landslide on the west side of Middle Ridge approximately 0.4 mile south of the boundary of BBRSP (west-central section 1, R4W-T9S). Landslide movement has destroyed many large redwood trees on the slide mass. The road has locally been bulldozed and replaced in areas destroyed by movement. The landslide appears to be a bedding-plane failure of San Lorenzo Formation (Twobar Shale). Regular bulldozer maintenance, especially during and after prolonged wet weather, will probably be required to keep the road open to traffic.

State Highway 236:

State Highway 236 crosses two small landslides just west of the intersection with China Grade Road (Maps G-1 & G-2). Open joints in these landslides indicate recent slumping. Neither failure appears to be a major hazard at this time; however, their actual stability is uncertain.

Subsidence

Ground subsidence is not expected to be a problem in BBRSP. The only considerations for this hazard could arise from localized liquefaction during seismic events or extensive pumping of groundwater from beneath the alluvial valley of lower Waddell Creek.

Volcanic Hazards

The youngest volcanic rock unit in the BBRSP region is volcanic breccia exposed near Point Ano Nuevo. Clark (1981) groups this unit into Vaqueros Sandstone and suggests the age to be upper Oligocene to lower Miocene. The structural setting and age of these extrusive rocks precludes any association with present-day volcanic activity. For this reason, volcanism is not interpreted to be a hazard in BBRSP.

Mineral Resources

The mineral resource potential of the BBRSP is interpreted to be low. During field studies for this project, no extensive mineralized or hydrothermal zones were observed. Finely disseminated minerals may occur in area rocks. To detect such resources would require detailed geochemical sampling and surveying. No assays or chemical analyses were made in this study.

Sand and gravel beneath the alluvial terrace in the lower part of Waddell Creek could provide a local source for aggregate; however, this area has limited reserves which would not warrant extraction, especially in the natural setting of BBRSP. Local private sources of sand and gravel have greater reserves, less sensitive environments of extraction, and are adequate to supply local construction needs.

Phosphates are finely disseminated in many marine rocks exposed in the Big Basin region. Concentrations and commercial value of phosphatic rocks were not evaluated for this study.

Numerous investigators have studied stratigraphy and geologic structure of the Santa Cruz Mountains for sources of petroleum. Several exploratory wells have been drilled in search of hydrocarbons on properties adjacent to BBRSP. These exploratory wells were unsuccessful in locating commercial quantities of petroleum. For this study, the petroleum resource potential of property within BBRSP was not evaluated.

Seismicity

Historic seismic activity within BBRSP and throughout the surrounding region has been moderate (Griggs, 1973; Real and others, 1978; Toppozada and others, 1981; Toppozada and Parke, 1982). These earthquakes have caused various degrees of seismic shaking in the park. The 1906 San Francisco earthquake which occurred on the San Andreas fault is the largest event in historic times to affect BBRSP. In the late 1970's and early 1980's several small to moderate earthquakes generated shaking in the park. Recent events of magnitude (M_L) greater than 5.0 were the 6 August 1979 Coyote Lake earthquake and the Livermore earthquakes of 24 and 26 January 1980. Many strong-motion records of the main shocks for these earthquakes were collected (see Porcella and others, 1979; McJunkin and Ragsdale, 1980). Numerous aftershocks were also associated with these events.

Several active faults are exposed both east and west of BBRSP (Jennings, 1975) and could produce significant earthquakes in the future. The San Andreas fault, located approximately 9 miles northeast of park headquaters, is the most well known of these faults. Any of the major faults in the regional area, including the San Andreas, Hayward, Calaveras, or San Gregorio faults, are candidates for producing a major earthquake. Future large-magnitude earthquakes are certain to occur on the San Andreas fault.

Structural damage and the effects of ground shaking from large-magnitude earthquakes in northern California are difficult to interpret with absolute certainty. Peak bedrock accelerations from minor and moderate events have been recorded in excess of 0.5g (g equals the acceleration of gravity) by the Strong Motion Instrumentation Program of CDMG and the U.S. Geological Survey. These accelerations are capable of causing structural damage and slope failures throughout the epicentral region. In most instances, small to moderate earthquakes have short durations of shaking and do not produce extensive structural damage.

In summary, a large earthquake on one of the major faults in the region is certain to occur at some time in the future. The seismic effects of such an event on engineered structures, geology, and society are not absolutely known. Attempts to describe damage and hazards from such an earthquake in northern California and the San Francisco Bay area are provided by many researchers (see, for example, Davis and others, 1982; Hart and others, 1982). Peak ground accelerations from such an event will probably be at least 0.5g in some areas of BBRSP; the duration of shaking for these accelerations could be a single jolt or last several seconds.

Ground Rupture and Faulting

The Zayante fault trends approximately east-west throughout central BBRSP (Plate 2). A study by Hall and others (1974) identified the Zayante fault in the Big Basin region as being moderately capable of producing surface rupture; this same study provides evidence that the Zayante fault several miles to the southeast has experienced some movement in late Pleistocene and possibly Holocene time. The western part of the fault appears to be truncated by the Santa Margarita Sandstone and thus has not moved in post-late Miocene time. To better determine past geologic activity of the Zayante fault in BBRSP, site-specific field investigations are required. Until such investigations are performed, the possibility for surface rupture to occur along the Zayante fault in BBRSP is uncertain.

The most active fault in proximity to BBRSP is the San Gregorio fault. Active traces of the San Gregorio fault zone are exposed approximately 1.6 miles northwest of the mouth of Waddell Creek. Another trace of the San Gregorio fault zone, shown as the Greyhound Rock fault in Weber and Lajoie (1979), trends northwest-southeast across the mouth of Waddell Creek a few hundred yards inland from the beach. This fault trace is postulated to be continuous to Greyhound Rock (rock exposure along coast located approximately 0.6 mile southeast of the mouth of Waddell Creek) where late Pleistocene and possibly Holocene movement is described (Weber, 1979). The potential for this fault to produce surface rupture in BBRSP is uncertain. Site-specific field investigations are required to better establish the potential for rupture along this branch of the San Gregorio fault zone.

Earthquakes occurring throughout west-central California are capable of generating slumping, lurching, landsliding, and possibly liquefaction in BBRSP. These types of failure during a seismic event would probably be enhanced if the ground were saturated. Alluvial sands deposited in the lower part of Waddell Creek are probably capable of liquefying during earthquakes if shaking is intense or prolonged enough. Drilling and sample testing are necessary to determine if sandy alluvial deposits in the region could liquefy. Unfortunately, knowing the potential for liquefaction does not indicate where ground failure will occur in areas underlain by liquefiable sands.

Floods

Wide-spread floods are not a problem in BBRSP. Localized flooding along creeks could occur during severe rainy periods or from landslides that fail into drainages and block the channel. Landslide dams that pond water are usually short-lived features. Ponded water eventually tops the dam and begins to rapidly erode landslide material obstructing the channel. If the landslide dam is composed of loosely consolidated material (sand, silt, loose rock, and mud), it is often rapidly breached by flowing water. In some instances, breached landslide dams collapse and release ponded water in a torrential downstream flood.

Sempervirens Reservoir is located in northeastern BBRSP and has a capacity of 78 acre-feet of water (California Department of Water Resources, 1976). The reservoir is located on Sempervirens Creek in the East Waddell drainage basin. The dam is an earth-fill structure built in 1951 that comprises slightly more than 46,500 cubic yards of material (California Department of Water Resources, 1976).

The reservoir and dam are situated upstream from many park facilities including the chlorination facility that supplies BBRSP with potable water. Failure of the dam would flood low-lying areas along the downstream creek system. Inundation levels would be helpful to understand which park facilities are subject to flooding from failure of the dam.

Seismic response of the dam during an earthquake is an important factor that could cause dam failure. A characteristic of earth-fill dams is that leaks in the structure are very susceptible to scour and piping of fine particles. A small opening can quickly erode to become significantly larger and may develop into a gaping notch through the dam.

Log jams are common in creeks throughout the Santa Cruz Mountains. The jams form where trees and other vegetation carried by streams get caught on projecting rocks or confinements in the channel. Log jams are generally small-scale porous dams that do not have the ability to pond much water and therefore do not pose a flood threat. Alluvium and other vegetative debris transported by streams collect behind log jams. The extent of alluvial inundation in the upstream channel depends on the size of the jam. Siltation behind log jams provides level ground for vegetation growth and slowly moving water. Alluvium deposited behind log jams will remain in place until the woody material forming the jam decomposes or is washed out by high-energy erosion. This period could last for several decades.

Coastal Erosion

A study by the U.S. Army Corps of Engineers and Dames and Moore (1971) indicates that significant coastal erosion is occurring along 86 percent of the California coastline. Steeper relief adjacent to the ocean is generally subject to greater amounts of erosion and landsliding. In coastal areas, erosion can be greatly accelerated by human foot traffic (Cottonaro, 1975).

Sea cliff retreat along coastal Santa Cruz County in the past few years is well documented. In this region, average long-term sea cliff retreat rates of approximately 1 foot (30 cm) per year are reported (Griggs, 1979). Much of this erosion is episodic and occurs during major storms. Erosion rates are partly controlled by the induration of rock types exposed. In addition, fractures, joints, and faults also influence susceptibility and rates of erosion.

Part of the coastal area of BBRSP is comprised of sea cliff. California State Highway 1 traverses the bottom of a cliff just north of Waddell Creek. This stretch of highway requires regular maintenance, especially during prolonged wet weather, to keep the roadway clear of material that has failed from the cliff. Some of this instability could have been caused by excavations for the highway. Local rates of sea cliff retreat are not known. Recent slumping of the sea cliff suggests retreat rates are several inches per year. Proper understanding and consideration of site-specific coastal settings in land-use planning can minimize erosion.

Ancestral Pleistocene sea cliffs occur along the mountain slopes facing the ocean. These ancestral cliffs are greatly flattened by erosion and preserved as breaks-in-slope that separate colluvium-covered marine terraces. Mountain slopes adjacent to the ocean directly face approaching storms and are subject to high amounts of erosion. High erosion rates are to be expected in this region.

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RECOMMENDATIONS

The following recommendations and conclusions are based on field mapping, aerial photo interpretation, and compiled or modified mapping from previous investigations by others. Recommendations are presented under the type of geological process involved. Specific corrective measures for stability problems are not provided. A detailed site-specific investigation is required to adequately evaluate unstable ground.

Slope Stability

1. Prior to installing any engineered structures in BBRSP, a geological investigation should be made to identify and resolve local slope stability problems.

2. All slopes in BBRSP should be considered unstable for engineering purposes unless evaluated as being stable by an engineering geologist. Regions adjacent to steep terrain are also subject to local inundation by mass movements of debris from local slopes.

3. The chlorinator facility to purify water for BBRSP was destroyed by a debris flow in the winter of 1981-82. A new facility was constructed in the same location in the summer of 1983. Remedial engineering is needed to design protection for the newly installed chlorinator facility. Additional debris flows from slopes above the new facility are certain to occur if sufficient precipitation is added to this ground. Risks for a failure are highest during wet

winters. Seismic events, especially during wet periods, may also trigger renewed debris flow activity in this area.

4. The sewer line below Sky Meadow, which services local residences and campgrounds, needs constant maintenance because of local landsliding. Part of the line is above ground to remedy continual subsurface destruction by the moving landslide. Geotechnical and engineering aspects of this problem should be investigated.

Erosion

1. Bridge abutments should be routinely inspected during and after periods of high precipitation in order to locate and prevent erosion that can severely damage or destroy the structure.

2. Road drains and culverts should be routinely inspected during and after wet periods to prevent clogging that can divert flowing water and cause severe erosion.

Seismicity

1. The seismic response of structures in BBRSP designed for use by the general public should be evaluated.

Hydrology

1. Portions of East and West Waddell Creeks flow into BBRSP or receive water from privately owned land. Parts of the Waddell drainage basin that receive water from outside park boundaries should be monitored for excessive siltation and pollutants from human habitation and land use.

2. Sea water intrusion into the groundwater basin of lower Waddell Creek near its mouth with the ocean does not appear to be a hazard at present. However, groundwater withdrawal in this area should be monitored in view of the serious damage that could occur from contamination by sea water.

GLOSSARY OF TECHNICAL TERMS

Definitions presented in this glossary are excerpted and in some cases condensed from the Glossary of Geology after Bates and Jackson (1980). Sources that are not from the Glossary of Geology are cited in text at the end of the definition.

Allochthonous -- Formed or produced elsewhere than in its present place; of foreign origin, or introduced.

Amino-acid dating -- A method of geochronology based on the chemical epimerization of amino acids. Amino acids of living organisms consist virtually entirely of the L-enantiomer (or diastereomer). After death the L-enantiomer (or diastereomer) for each amino acid is slowly epimerized and eventually forms an equilibrium mixture consisting of equal amounts of the D- and L-enantiomers (or diastereomers). The increase in D/L ratio can be used to obtain a measure of the time that has elapsed since the organism died. The method is sensitive to temperature, pH, and other environmental factors.

Anhedral -- Said of a mineral crystal that has failed to develop its own rational faces or that has a rounded or indeterminate form produced by the crowding of adjacent mineral grains during crystallization or recrystallization.

Arkose -- A feldspar-rich sandstone, typically coarse-grained and pink or reddish, that is composed of angular to subangular grains that may be either poorly or moderately well sorted, is usually derived from rapid disintegration of granite or granitic rocks, and often closely resembles granite. Quartz is usually the dominant mineral, with feldspars (chiefly microcline) constituting at least 25 percent. Cement (silica or calcite) is commonly rare, and matrix material (usually less than 15 percent) includes clay minerals, mica, and iron oxide; fine-grained rock fragments are often present.

Base level -- The theoretical limit or lowest level toward which erosion of the Earth's surface constantly progresses but seldom, if ever, reaches. The general or ultimate base level for the land surface is sea level, but temporary base levels may exist locally.

Bedding plane -- A planar or nearly planar bedding surface that visibly separates each successive layer of stratified rock (of the same or different lithology) from the preceding or following layer; a plane of deposition. It often marks a change in the circumstances of deposition, and may show a parting, color difference, or both.

Clast -- An individual constituent, grain, or fragment of a sediment or rock, produced by the mechanical weathering (disintegration) of a larger rock mass.

Complex -- A large-scale association or assemblage of different rocks of any age or origin, having structural relations so intricately involved or otherwise complicated that the rocks cannot be readily differentiated by mapping.

Conformity -- The mutal and undisturbed relationship between adjacent sedimentary strata that have been deposited in orderly sequence with little or no evidence of time lapses; true stratigraphic continuity in the sequence of beds without evidence that the lower beds were folded, tilted, or eroded before the higher beds were deposited.

Crop out -- The verb sense of the noun outcrop which is that part of a geologic formation or structure that appears at the surface of the Earth.

Daylighting -- In engineering geology, the exposure of a planar feature, such as bedding or a fault, by an open cut whose angle is steeper than that of the exposed feature. Such exposure may increase the likelihood of landsliding by removal of buttressing strata, but it may also reduce sliding tendancies by promoting drainage.

Debris flow -- Mass movement involving rapid downslope nonrotational flowage of weathered bedrock, surficial soil, colluvium, slope wash, and overlying vegetation. This definition is very similar to that described by Varnes (1978). The inclusion of weathered bedrock in the definition of debris flow, as informally used in this report, is to distinguish the mode of failure from earth flow.

Dip slope -- A slope of the land surface, roughly determined by and approximately conforming with the direction and the angle of dip of the underlying rocks.

Disconformity -- An unconformity in which the bedding planes above and below the break are essentially parallel, indicating a significant interruption in the orderly sequence of sedimentary rocks, generally by a considerable interval of erosion (or sometimes of nondeposition), and usually marked by a visible and irregular or uneven erosion surface of appreciable relief; e.g., an unconformity in which the older rocks remained essentially horizontal during erosion or during simple vertical rising and sinking of the crust (without tilting or faulting).

Earth flow -- Mass movement involving rapid nonrotational downslope flowage of surficial soil, colluvium, slope wash, and vegetation that is devoid of underlying bedrock. This definition is very similar to that described by Varnes (1978). The exclusion of weathered bedrock in the definition of earth flow, as informally used in this report, is to distinguish the mode of failure from debris flow.

Epimerization -- A process in which there is an alteration of the configuration at only one asymmetric center in an organic compound containing more than one asymmetric center.

Estuary -- (a) The seaward end or widened funnel-shaped tidal mouth of a river valley where freshwater comes in contact with seawater and where tidal effects are evident. (b) A drowned river mouth formed by the subsidence of land near the coast or by the drowning of the lower portion of a nonglaciated valley due to the rise of sea level.

Euhedral -- Said of a mineral grain that is completely bounded by its own rational faces, and whose growth during crystallization or recrystallization was not restrained or interfered with by adjacent grains.

Fission-track dating -- A method of calculating an age in years by determining the ratio of the spontaneous fission-track density to induced fission tracks. The method, which has been used for ages from 20 years to 1.4 billion years, works best for micas, tektites, and meteorites, and is also useful for determining the amount and distribution of the uranium in the sample.

Hypidiomorphic-granular -- Individual subhedral mineral crystals that are bounded only in part by their own rational faces.

Liquefaction -- In cohesionless soil, the transformation from a solid to a liquid state as a result of increased pore pressure and reduced effective stress.

Mass wasting -- A general term for the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses. In contrast to other erosional processes, the debris removed by mass wasting is not carried within, on, or under another medium.

Neogene -- An interval of geologic time incorporating the Miocene and Pliocene of the Tertiary. When the Tertiary is designated as an era, then the Neogene, together with the Paleogene, may be considered to be its two periods.

Nonconformity -- An unconformity developed between sedimentary rocks and older rocks (plutonic igneous or massive metamorphic rocks) that had been exposed to erosion before the overlying sediments covered them.

Paleogene -- An interval of geologic time incorporating the Paleocene, Eocene, and Oligocene of the Tertiary; the lower Tertiary. When the Tertiary is designated as an era, then the Paleogene, together with the Neogene, may be considered to be its two periods.

Peak bedrock acceleration -- The maximum (peak) acceleration of bedrock generated by seismic input. Acceleration, defined as an increase in velocity with respect to time, is generally expressed in units of gravity (g) where acceleration due to terrestrial gravity is approximately 980 cm/sec/sec or 32 ft/sec/sec at sea level; this value translates to 1.0g. Peak bedrock acceleration is expressed as a quantity of 1.0g (e.g., 0.25g, 0.5g, 0.75g, etc.). This commonly used definition is adopted from earthquake reports and publications.

Piping -- Erosion by percolating water in a layer of subsoil, resulting in caving and in the formation of narrow conduits, tunnels, or "pipes" through which soluble or granular soil material is removed.

Pluton -- An igneous intrusion. The term originally signified only deep-seated or plutonic bodies of granitoid texture.

Potassium-argon dating -- Determination of the age of a mineral or rock in years, based on measurement of the ratio of radiogenic argon-40 to potassium-40 and the known radioactive decay rate of potassium-40 to argon-40.

Quartz diorite -- A group of plutonic rocks having the composition of diorite but with an appreciable amount of quartz, i.e., betwen 5 and 20 percent of the light-colored constituents.

Radiometric dating -- Calculating an age in years for geologic materials by using the presence of a short-life radioactive element or by measuring the presence of a long-life radioactive element plus its decay product. The term applies to all methods of age determination based on nuclear decay of naturally occuring radioactive isotopes.

Salinian block -- A composite block in the California Coast Ranges that is formed by an out-of-place terrane (or group of terranes) 40 to 70 km wide and at least 500 km long. The block is bounded by the San Andreas fault on the east and the Transverse Ranges on the south. The northern limit of the terrane is uncertain but may extend to the vicinity of Point Arena; the western boundary is offshore and below sea level. Both onshore and offshore, exposed parts of the Salinian basement consist mainly of Cretaceous granitic plutons and associated high temperature metamorphic rocks of unknown age. This definition of the Salinian block is after Page (1982).

Seismic response -- A commonly used term to describe the reaction (response), harmonic or otherwise, of a mass, building, structure, or rock to earthquake-induced motion. This definition is adopted from its use in numerous earthquake reports and publications.

Slope wash -- Soil and rock material that is or has been transported down a slope by mass wasting assisted by running water not confined to channels.

Subduction -- The process of one crustal block descending beneath another.

Subduction zone -- A long, narrow belt in which subduction takes place, e.g., along the Peru-Chile trench, where the Pacific plate descends beneath the South American plate.

Subhedral -- Said of a mineral grain that is bounded partly by its own rational faces and partly by surfaces formed against preexisting grains as a result of either crystallization or recrystallization, i.e., intermediate between euhedral and anhedral.

Subsidence -- The sudden sinking or gradual downward settling of the Earth's surface with little or no horizontal motion. The movement is not restricted in rate, magnitude, or area involved. Subsidence may be caused by natural geologic processes, such as solution, thawing, compaction, slow crustal warping, or withdrawal of fluid lava from beneath a solid crust; or by man's activity, such as subsurface mining or the pumping of oil or groundwater.

Transcurrent fault -- A large-scale strike-slip fault in which the fault surface is steeply inclined.

Type section — The originally described sequence of strata that constitute a stratigraphic unit. It serves as an objective standard with which spatially separated parts of the unit may be compared, and it is preferably in an area where the unit shows maximum thickness and is completely exposed (or at least shows top and bottom).

Unconformity -- A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as an interruption in the continuity of a depositional sequence of sedimentary rocks or a break between eroded igneous rocks and younger sedimentary strata (nonconformity). It results from a change that caused deposition to cease for a considerable span of time, and it normally implies uplift and erosion with loss of the previously formed record.

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