Mendocino Power Plant *Artist's Concept*

UNITS 1 AND 2
MENDOCINO POWER PLANT
PACIFIC GAS AND ELECTRIC COMPANY

PG and E

PRELIMINARY

SAFETY ANALYSIS REPORT

VOLUME II

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I. INTRODUCTION

This supplement is presented in response to the Atomic Energy Commission's letter dated January 5, 1972, referring to Docket Numbers 50-398 and 50-399. This letter requested additional information to demonstrate the adequacy of the proposed earthquake design basis and to establish that the OBE and DBE are appropriately conservative for nuclear power plant design purposes. As indicated in the PSAR and further elaborated in this supplement, we have selected the OBE and DBE on a basis normally considered conservative; that is, taking the greatest earthquake intensity which occurred at the site during the period of record as the OBE. The DBE was based on the intensity value one unit greater than that experienced at the site. These two intensities would be VIII-1/2 and IX-1/2, conservatively estimated to produce accelerations of 30%g for OBE, and 50%g for DBE according to the Neumann curve.

It should be noted that these intensity values are based on damage to structures that were founded generally on soils; whereas the plant design required that all soils be removed (plus the top section of surface rock), and the nuclear facility be founded on good quality rock.

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Figure I shows several of the different curves which are used to correlate earthquake intensity (MM Scale) with acceleration. The Neumann curve shown in the figure is one of the most conservative of those shown.

In responding to the AEC request to provide additional indication of the conservatism involved in the OBE and DBE values, we utilized four additional approaches which are included in this section. The first is Dr. Perry Byerly's approach to selecting the OBE and DBE. Dr. Byerly considered a conservative intensity VIII-1/2 for the area nearest the epicenter in San Francisco. Actually, the highest intensity experienced in the City of San Francisco, on even reasonably similar foundation conditions and at a distance of about four miles from the fault, was VII-VIII.*

*G.D. Louderback in his paper on "Faults and Earthquakes", 1942, states on page 315: "For example, the greater part of the (mostly soil-covered) bedrock hill lands of San Francisco were designated D or E on Wood's Map (corresponding to VIII and VII of Rossi-Forel) even where within three miles of the fault."

lighthouse should give a reliable indication of the ground acceleration that occurred at the Mendocino plant site during the great earthquake, and which could be expected to re-occur during the Design Basis Earthquake.

We have also considered the relationship of the location of the epicenter of the 1906 earthquake with respect to the site. Though the epicenter is considered to have been located in the San Francisco area, the iso-seismal lines shown on Fig. VII demonstrate that maximum intensities occurred not only close to the epicenter, but along the entire portion of the fault which broke during the 1906 earthquake. This shows that the energy was not released at a point source, but along the full length of fault breakage, and in our opinion this is the only reasonable geologic conclusion consistent with strike-slip fault movement. Further, the U.S. Geological Survey reports the maximum ground displacement along the fault occurred near Manchester, about five miles northeast of the site (Fig. VIII). Hence, the energy release per unit area along the San Andreas fault may have been somewhat higher near the site than it was at the epicenter near San Francisco.

In the opinion of the applicant and its consultant, the various methods included in this supplement in arriving at a conservative Operating Basis Earthquake (OBE) and the Design Basis Earthquake (DBE), represent all reasonable approaches available within the present state of the art. They include two methods generally accepted as being conservative. Four independent evaluations support the ground acceleration values selected for the Mendocino Site.

II. SEISMIC HISTORY

The seismic history of the area is illustrated in Fig. II which uses six maps to show the site and the area surrounding it, to a distance of 50 miles. Six maps have been used so that earthquakes may be separated on the basis of intensity.

Earthquake epicenters and their date of occurrence are plotted on the maps and are shown by either a Roman numeral or an Arabic number. (See Table 2.6.2)

A Roman numeral indicates the epicenter of an earthquake and the highest intensity reported which was given on the Modified Mercalli Scale of 1931.

An Arabic numeral indicates the epicenter and Richter magnitude of an earthquake.

All the epicenters on the maps are either field epicenters (non-instrumental) or instrumental epicenters. Non-instrumental epicenters are those intensities shown on the maps which are not circled. Instrumentally located shocks are indicated on the maps by an intensity or magnitude, which is circled. Instrumental epicenters recorded at sea are shown with Roman numerals having an "L" placed next to them, indicating that the intensity was the highest reported on land.

Map A uses "F's" to show the epicenters of earthquakes which were felt but with no intensity or magnitude given in the USC & GS references.

Map B shows all earthquakes of intensity III on land, in addition to several small shocks with magnitudes 3.0-3.5, which have been recorded off the coast within 50 miles of the site.

Earthquakes of intensity IV are shown on Map C; of intensity V (plus one shock of intensity V-VI) on Map D; and of intensity VI on Map E.

Map F shows one earthquake of intensity VII, which occurred in 1962, one of intensity VIII-IX (the earthquake of April 14, 1898), and one of XI, which is the 1906 "field epicenter"-- the point of maximum displacement on the fault.

The closest shock to the site is an epicentral intensity III earthquake, which was reported from the Point Arena Light Station on June 22, 1932, about 2 1/2 miles from the site. The next closest shock is about 11 miles from the site. It occurred 6 1/2 miles north of Gualala on December 16, 1953, and was of intensity III. The April 14, 1898 shock, 13 miles distant, is next closest. The intensity at the site was probably VIII-VIII-1/2. The next closest epicenter lies 17 miles sourthwest of the site and occurred on October 14, 1962. A Richter magnitude of 4.7 was recorded for this shock, but no maximum intensity was assigned. A number of shocks around the Ukiah area to the east, also lie within 50 miles of the site, most of these being of epicentral intensity IV, V and VI and onlv one of intensity VII, which occurred in 1962.

The relationships between the number of earthquakes felt at the site and their intensities, may be seen on Fig. III. Several earthquakes of intensity IV (MM) have been felt at the site, but only two shocks of medium intensity (VIII-MM) have been recorded.

Fig. IV shows the total number of earthquakes that have occurred at different distances from the site. No epicenters of earthquakes with maximum intensities greater than III (MM) have occurred within ten miles of the site.

As previously mentioned, the highest intensities experienced historically in the area of the site occurred during the April 18, 1906 earthquake. Intensities of VIII-IX (MM) have been assigned, but reports from the towns nearest the site show that poor design and bad foundation conditions contributed greatly to the damage. Some structures near the Point Arena Lighthouse, which were founded on rock were "not affected in the least," by the 1906 earthquake (Lawson, 1908). The site is on the same rock formation, as these structures and it is 0.4 mile farther from the fault than the lighthouse and these structures, therefore the intensity at the site could not have exceeded VIII 1/2 (MM) and was probably no greater than VIII. Structures constructed on rock near an earthquake epicenter frequently fare better than more distant buildings constructed on soft ground. Fig. V and VI use the San Francisco earthquake of 1906 to illustrate this principle. Fig. V is a Generalized Geologic Map of San Francisco showing the different rock units underlying the city. Fig. VI shows 1906 earthquake intensities in the same area. By comparing these two maps, a correlation between rock type and intensity can be seen.

Though the epicenter is considered to have been located in the San Francisco area, the isoseismal lines shown on Fig. VII indicate the energy was not released at a point source, but along the full length of breakage. This is the only reasonable geologic conclusion consistent with strike-slip fault movement. The U.S. Geological Survey reports the maximum ground displacement along the fault occurred near Manchester, about five miles northeast of the site (Fig. VIII). Therefore, the energy release per unit area along the San Andreas fault may have been somewhat higher near the site than it was near San Francisco.

Extensive surface faulting took place along the San Andreas fault during this earthquake and resulted in the longest known fault break for any historical earthquake. The length of the rupture was generally accepted to have been 270 miles.

In view of the following information, it is our opinion that the 1906 earthquake is the greatest possible earthquake for the site area.

First, it is likely that the source of any future strong shaking at the site will be from the same fault, and from the same type of fault movement.

Next, it is logical to assume that the best estimate of the effects of a future earthquake at the site can be obtained by analyzing what has happened previously in the same area, as a result of an earthquake originating from a common source.

Finally, Byerly in his attached report (dated 12-11-71), explains why many seismologists believe that a fault break longer than 270 miles during any one earthquake is not possible along the San Andreas Fault, and therefore, no earthquake greater than the 1906 earthquake is possible.

Recordings of vibratory ground motions may vary considerably in successive shocks, even though the shocks may be of similar magnitude and distance from a given point. However, the 1906 earthquake was unusual in that it produced evidence of the effect of these different motions over at least 180 miles. Therefore, evaluating the effects four miles from the fault along the area of the 1906 break would provide a range of intensities; and the maximum recorded on similar geologic foundations would be a reliable estimate of the behavior to be expected during any future earthquake.

The earthquake of April 14, 1898 also produced intensities of about VIII at the site. The field epicenter is plotted at Elk, which is thirteen miles north of the site and near the San Andreas fault. Reports of maximum damage came from Point Arena, Elk (Greenwood) and Mendocino. The maximum intensities assigned to this shock are VIII-IX (MM), but these undoubtedly reflect foundation conditions that are poorer than those at the site, since the towns of Elk and Mendocino lie on Pleistocene non-marine and marine terrace deposits.

All other earthquakes have resulted in intensities of much less than VIII at the site.

III. DERIVATION OF DESIGN BASIS EARTHQUAKE

Figure I shows several of the different curves which are used to correlate earthquake intensity (Modified Mercalli scale) with acceleration.

The Neumann curve shown on this figure is one of the most conservative of those shown. On this figure, the curve branches into two lines at intensity VIII (MM): into the "lower curve" (Jb on this figure) and the "upper curve" (Ja on this figure) so that two values of acceleration are given for intensities above VIII. The curve was drawn by Neumann to fit data from ten earthquakes varying in intensity from V to VIII at the locations where the peak accelerations were recorded. On his graph, the part above intensity VIII was extrapolated in a straight line due to lack of data for the higher intensities. It is now known the acceleration does not increase as steadily with intensity as on Neumann's extrapolated portion of the curve, so for this reason, Neumann's "lower curve" was drawn. This "lower curve" reduces the common ratio to 1.5 to 1, from the 2 to 1 ratio on the part of the curve below intensity VIII. Data from the San Fernando earthquake on February 9, 1971 showed an acceleration of about 1.0g and a N.O.A.A. estimated intensity of XI. This approximates an extension of the lower curve.

Best evidence indicates that the intensity of the 1906 earthquake at the site was probably VIII. Therefore, VIII-1/2 has been used as the intensity in computing the accelerations for the OBE and DBE. By consulting Neumann's lower curve, it can be seen that the value of 30 percent g is appropriate for the OBE. The DBE is found by increasing the intensity used for OBE, by one full unit to IX-1/2 and again consulting Neumann's lower curve. This indicates a value of 50 percent g. Therefore, 30 percent g will be used for the OBE and 50 percent g for the DBE.

An additional approach assumes that the 1906 earthquake epicenter is on the fault about four miles from San Francisco. If this epicenter is moved to a point on the fault nearest the Mendocino site, the intensity at the site would be at most VIII-1/2. When a single intensity is assigned to a city, the highest intensity which occurred in any part of that city is usually the one selected. The 1906 intensity has been said to be X+ (MM); however, this intensity occurred in only a few areas which were on made land or fill. The intensity in most of the city where foundation conditions are similar to those at the site, was about VII-1/2. Consequently, an intensity of VIII-1/2 at the site would be conservative and the accelerations of 30%g for OBE and 50%g for DBE, based on intensities of VIII-1/2 and IX-1/2, are also conservative.

In the derivation of the design earthquake, four points of view have been considered. Three of these have been formulated by Perry Byerly, Bruce Bolt, and I.M. Idriss. The fourth evaluates the structural damage to the Point Arena lighthouse. All four use ground motion accelerations as a basis, and can be seen on Figure IX.

IV. THE 1906 SAN FRANCISCO EARTHQUAKE

On April 18, 1906, one of history's most devastating earthquakes occurred. At 5:13 A.M. (Pacific Standard Time) the San Andreas fault released its pent-up energy in the form of a magnitude 8.3 earthquake. Duration of the strong shaking was from 40 to 60 seconds as determined by scientists in the Bay Area, and in this time a great cracking appeared from Upper Mattole in Humboldt County to San Juan Bautista in San Benito County. Along northern portions of the fault, displacements up to 21 feet were reported.

The shock was felt (perceptible to the senses) from Coos Bay, Oregon, on the north, to Los Angeles on the south, a distance of 730 miles. To the east, it was noticed in Winnemucca, Nevada, (about 300 miles from the coast), and if its effects also extended to the west of the coast for the same distance, then the area over which the earthquake was perceptible was about 372,700 square miles. Though not felt outside the area just described, earth waves were propagated all the way around the globe and were recorded instrumentally at many seismological stations.

The shock was felt over quite a large area, but the distribution of the higher intensities was quite linear and was definitely related to the fault line. This is clearly shown on Figure VII which is a map of the intensity (Modified Mercalli) distribution in the region affected by the earthquake of April 18, 1906. However, proximity to the fault was not the only factor which determined the degree of intensity. The soft saturated alluvial deposits of the valley bottoms, and "made land" or fill were much more severely shaken than the higher ridges underlain by rock. Consequently, structures on the valley bottoms and fill suffered extensively, while little structural damage occurred on the hills where buildings had solid foundations.

The cause of the earthquake was the sudden rupture of the earth's crust along the San Andreas fault. This fault is California's most spectacular and well known structural feature and extends some 650 miles from Shelter Cove in Humboldt County to Southern California.

As is usually the case with major faults, the San Andreas is not a single break, but is a zone, made up of several lines of activity which are roughly parallel. In some places, the zone may be less than 100 yards wide, but in most areas, it is several hundred yards wide and includes a number of sub-parallel fault lines.

Motion along the fault is generally right-lateral strike-slip, that is, horizontal movement parallel to the fault. However, toward the northern end of the fault, there was questionable evidence of a vertical displacement, though it probably did not exceed two or three feet.

The movement of the fault on the day of the earthquake was a horizontal displacement on an approximately vertical fault plane or zone in such a way that the country on the southwest side of the fault was moved to the northwest and the country on the northeast side was moved to the southeast. This displacement was displayed at the surface by the offsetting of fences, roads, dams, bridges, railways, tunnels, pipes and other structures which crossed the fault. The amount of displacement along the fault trace was commonly from eight to fifteen feet. At the southern end of the fault, the displacement was notably less and finally became inappreciable.

In Humboldt County small horizontal displacement was exhibited in some places. No vertical movement was evident. Damage included toppled chimneys, moved furniture, broken windows and houses thrown off their foundations.

From Shelter Cove to Fort Ross, rupture of the ground and differential displacements were strongly marked; one offset fence near Manchester showed a 16-foot displacement. Vertical displacement was small and only amounted to one foot in a few places presenting a low scarp facing the northeast. Some buildings were demolished, railroad tracks buckled, chimneys thrown down, dishes broken and furniture moved.

Fort Bragg was severely damaged. Several brick buildings were demolished and a number of wooden buildings also collapsed. At Point Arena, chimneys were thrown down, brick buildings collapsed and windows broken. The Point Arena light-house was thrown out of the vertical and sustained several horizontal cracks through its masonry.

At Fort Ross, displacement was well displayed. A wagon road was shifted 12 feet 3 inches and on the southwest side of the fault, a stream trench was moved northwesterly about 12 feet.

Between Bodega Head and Tomales Bay, a vertical movement of one to two feet was noted. The greatest horizontal displacement measured was an offset of 21 feet near Olema, but this was probably due to slumping and shifting of soft marshy sediment rather than actual displacement of rock. If this interpretation is correct, the maximum known offset on the fault was the 16 foot displacement near Manchester. There were also several landslides, as well as a slight change in water level in Bolinas Lagoon. Damage reported included chimneys toppled, buildings shifted, some buildings collapsed, foundations cracked and water pipes buckled.

Of particular interest is the effect of the 1906 earthquake on the city of Santa Rosa. This city was damaged relatively more severely than any other place in California, with the possible exceptions of Sebastopol and Fort Bragg. The shock and the fire which followed cost 61 persons their lives, and practically destroyed the business section of Santa Rosa. Some seven to eight blocks were destroyed by the earthquake and four to five blocks by the fire.

The shock was violent in areas of San Francisco where homes and businesses were built on made land or fill. "The earth slumped and lurched, knocking houses from their foundations, stripping buildings of steeples and walls, buckling tram-rails, and leaving gaping fissures in the streets. However, few lives were lost and little structural damage occurred on the hills where buildings had solid foundations."

"The fire, ignited by overturned stoves and broken gaslines, followed close on the heels of the earthquake. It was a holocaust of nightmarish proportions. With the city's water facilities destroyed, the fire soon raged out of control, obscuring much of the earthquake effects before they could be recorded. By midnight, most of downtown San Francisco was aflame."

"The fire continued to burn unchecked for three days." (Earthquake Information Bulletin, March-April, 1971) It was finally ended before it crossed Van Ness Avenue.

Effects of the earthquake were also spectacular in areas south of San Francisco. Horizontal displacements up to 13 feet were recorded and damage was great in areas underlain by deep alluvium. In San Jose many buildings in the business district were damaged beyond repair and most of the other towns along San Francisco Bay (including San Mateo and Palo Alto) were hit severely.

Despite reports of severe damage in the San Francisco area, it was found that the earthquake itself did relatively little damage. "Immediately following the San Francisco earthquake of 1906, two of the foremost consulting engineers of California, Mr. A. M. Hunt and Mr. George Dillman, both men of large experience in construction, were engaged to investigate the relative proportions of earthquake and fire damage throughout the burned district."

After two weeks of painstaking inspection, "they found the actual ratio of earthquake damage to total damage within the burned district did not exceed five percent." (Freeman, 1932)

REFERENCES

1. Byerly, Perry, "History of Earthquakes in the San Francisco Bay Area", Geologic Guidebook of the San Francisco Bay Counties, California Division of Mines and Geology, 1951.

2. Oakeshott, Gordon B., "The San Andreas Fault in the California Coast Ranges Province", Geology of Northern California, California Division of Mines and Geology, 1966.

3. Freeman, John R., Earthquake Damage and Earthquake Insurance, 1932.

4. Lawson, Andrew C., The California Earthquake of April 18, 1906 (Report of the State Earthquake Investigation Commission), 1969.

5. United States Department of Commerce, "Earthquake Information Bulletin", March-April 1971.

V. SEISMIC INTENSITIES IN SAN FRANCISCO - 1906 EARTHQUAKE

The intensities experienced in different parts of San Francisco during the 1906 earthquake are shown on a map prepared by H. O. Wood (Figure VI). A map of the city showing locations of districts, lakes, streets, etc., mentioned in the following text is included as figure Xa. The intensity range was VI to X+. The maximum intensity of X+ was confined to the southwest corner of the city, and intensities of VIII+ to X occurred in five large areas scattered around the city. The average intensity over most of the city was about VII. The differences in intensities were governed mainly by the foundation geology.

Zones of VIII+ to X Intensity. The map prepared by H. O. Wood shows five major areas of intensity subsequently evaluated as VIII+ to X on the Modified Mercalli Scale. (See Figure VI.)

The largest area of high intensity was on the west shoreline of the city, extending from just south of Point Lobos, along the Great Highway to Lake Merced; there it turned to the southeast, along the west shore of the lake, paralleling the San Andreas Fault. The ocean shoreline, south of Lake Merced to Mussel Rock, and between the VIII+ to X zone and the fault is evaluated at a possible X+. The second area was a wide strip extending eastward from the Civic Center to China Basin and the bay. The third area was a fat S-shaped strip in the outer Mission District, just east of Mission Dolores, in the vicinity of South Van Ness and 15th Streets. The fourth area extended along the Embarcadero from Rincon Point to Fisherman's Wharf, bulging westward up Lower Market Street. The fifth major area was the Marina Basin, on the northern end of the peninsula.

In addition to these large areas, several small, isolated areas of comparable intensity were scattered throughout the city.

Between Point Lobos and Lake Merced the zone estimated intensity VIII+ to X along the west margin of the city, is underlain by thick deposits of uniform, fine to medium grained dune sand. It forms unstable and shifting slopes and is easily eroded. Sand has migrated eastward within historical times and covers with varying thickness most of the western and north-central portions of the city, between the hills. Thicknesses of up to 100 feet have been measured. Compressional wave (P-wave) velocities in typical windblown sands in San Francisco have been measured as 1000-1100 fps.

Most of the windblown sands of the city are probably underlain by sediments of the Quaternary Colma formation. This formation is predominantly composed of unconsolidated sands and silts, and is everywhere quite soft and easily eroded, often forming a miniature "badlands" topograph. The Colma formation is exposed in a broad band in the southwest and southcentral part of the city, along the southern city limits, and it also crops out beneath the dune sands on the west-facing sea cliff along the Great Highway.

The following table summarizes typical properties of the Colma formation in the Westlake area, south of Lake Merced. (Adapted from Bonilla, 1959)

TABLE I

	Dry Weight (PCF)	Unconfined Compressive Strength (PSI)
Sand (3 samples)		
Maximum	109	8
Minimum	107	4
Average	108	6
Loam (1 sample)	110	5

Near Lake Merced, P-wave velocities in thick deposits of Colma sands have been measured as 900-1000 fps near the surface increasing to 1850 to 2200 fps with depth.

South of Lake Merced, where the intensity was X+, and where the VIII+ to X zone swings to the southeast, the dune sands terminate against higher ground which is underlain by the Merced formation. The Merced formation, which is exposed at the surface except where covered by discontinuous patches of the Colma formation, is a sequence of Plio-Pleistocene marine sediments about 5000 feet thick. There is wide variation in the physical properties of the different members of this formation. Bonilla (1959), in discussing the Merced formation immediately to the south of Lake Merced, in the Westlake area, refers to the principal member as "....uncemented, friable, ...easily excavated...".

Table II is a summary of test data from the Westlake area for the prevalent materials in the Merced formation. (Adapted from Bonilla, 1959)

TABLE II

	Dry Weight (PCF)	Unconfined Compressive Strength (PSI)
Sand - Maximum	129	30
Minimum	93	3
Average	104	14
Loam - Maximum	95	52
Minimum	88	34
Average	92	45
Silt & Clay - Maximum	102	71
Minimum	67	5
Average	88	40

Table III summarizes additional data concerning the Merced formation just south of San Francisco, near the San Andreas Fault. (Woodward, Clyde 1970)

TABLE III

Depth	Lithology	Dry Weight (PCF)	Unconfined Compressive Strength (PSI)
8"	Very dense, poorly cemented friable, silty sandstone	120	42
8'	Medium dense, damp, clayey silt	95	17
14'	Medium dense, damp siltstone	101	36
28'	Very dense, silty clay	99	15
10'	Loose silty sand with organic inclusions	103	5
26'	Very dense clayey silt	115	90
18'	Medium dense, damp, poorly cemented fine sand	112	37

34'	Dense, damp, sandy silt	120	97
10'	Loose moist, silty sand	100	6

Seismic profiling on typical massive sandstone of the Merced formation exposed in Daly City resulted in P-wave values of 2100 to 2450 fps to at least a 50-foot depth.

It is evident from description and test results that the more or less coherent formations (Colma and Merced) in the southern and southwestern parts of the City have very low strength and stability.

The dune sands are not confined to the west shore line but also cover almost all of the western and northern portions of the city. Higher intensities along the coast are not due only to the presence of dune sands. The isopach map(Fig. X) of the overburden* shows correlation of intensity with thickness of overburden.

The isopach map shows that more than ninety percent of the western part of the City, where VIII+ intensities were felt, overlies a bedrock basin containing unconsolidated materials more than 400 feet thick, and that the shape of the basin seems to conform with the shape of the high-intensity area.

The high-intensity area extending eastward from the Civic Center and the zone east of Mission Dolores are related in that they both overlie the bedrock basin occupied by the long buried Mission Swamp. Here also, the isopach map correlates with the intensity-distribution map. Over 95% of the Intensity VII to VIII+ area, generally encompassing the outer Mission-Upper Market Street districts and extending eastward to China Basin, is underlain by at least 100 feet and up to about 250 feet of unconsolidated material. This area lies within the old Mission Creek drainage basin. Within historical times much of the lower basin was swamp land. Periodically the swampy areas were covered by windblown dune sands, and buried vegetation formed peaty beds of organic, sandy muck. Lee (1953) described these layers: "Beds of such material, subsequently buried by inorganic alluvium or windblown sand, remain saturated and may act as liquids under pressure or as highly compressible strata". Lee also points out the high susceptibility of such concentrations of organic materials to instability and settlement.

*"Overburden" here includes all material above the Franciscan formation. In the southwest part of the city it is debatable as to whether the Merced formation is bedrock

or overburden. Bonilla (1964) apparently evaluates the Merced formation as not much better than the terrace deposits, and treats it as overburden.

The drill-log data in Table IV demonstrates the typical subsurface profile in the Intensity VIII+ area, east of Mission Dolores (ASCE 1931).

TABLE IV

TEST HOLE NO. 121--Location: American Steel and Wire Co., old well on east line of Folsom Street. 235 feet south of 15th Street.

(Source of Data: #1478 O'Shaughnessy Report, Date 1913)

	Elevation		Thickness
	From	To	(Feet)
Filled ground	+8	-6	14
Grey sand	-6	-8	2
Blue mud	-8	-16	8
Marsh mud and grass	-16	-20	4
Grey sand clay	-20	-24	4
Yellow sand clay	-24	-35	11
Yellow water sand	-35	-48	13
Yellow sand clay	-48	-50	2
Grey clay	-50	-57	7
Blue clay	-57	-61	4
Blue sand clay	-61	-64	3
Grey water sand	-64	-103	39
Grey clay	-103	-107	4
Grey water sand and gravel	-107	-117	10

Soft water sand....................	-117	-128	11
Grey clay..........................	-128	-132	4
Sticky sand and clay...............	-132	-138	4
Blue clay..........................	-138	-143	5
Yellow cement......................	-143	-145	2
Rotten rock........................	-145	-148	3

Table V summarizes test data for samples recovered from beneath Market Street at the Civic Center. The samples are from depths of 40 to 136 feet below ground surface, and are from an area just outside of the Intensity VIII+ zone. The material penetrated was predominantly saturated silt with lesser amounts of sand, clay and interbedded organic layers. (Bechtel, 1966)

TABLE V

Dry Weight	
Maximum	116.3 pcf
Minimum	28.8 pcf
Average	71.5 pcf
Unconfined Compressive Strength	
Maximum	51.8 psi
Minimum	8.5 psi
Average	35.4 psi

Much of the basin is covered by compacted sand fill, particularly along the old creek routes. Damage was concentrated along such paths, probably because water that was following sub-surface drainage paths, caused liquifaction in the fill.

In discussing the collective term "alluvium", which includes the old swamp deposits as well as fluviatile deposits, Schlocker, et al (1958) evaluate the shearing strength of sandy alluvium as moderate to high, but decreasing to low as silt, clay or organic content increases.

The area around the Marine Basin of Intensity VIII+ to X is also filled swampland. Materials and conditions there are similar to those in the Mission Basin.

The area of high intensity along the Embarcadero approximates the area of filled ground east of the 1850 shore line of the bay. Bedrock of the Franciscan formation lies as much as 300 feet below ground surface in the vicinity of Lower Market Street and the Embarcadero, averaging an estimated 200 feet below ground surface.

The material above bedrock is composed of various bay sediments. Clay is the dominant constituent, but is varies in consistency, stiffness and content of sand or silt. The following boring log Table VI shows a typical profile of sediments in the Embarcadero area: (ASCE, 1931)

TABLE VI

TEST HOLE NO. 698--Location Southern Pacific Building, Spear Market and Stewart Street, Well #3.

(Source of Data: Southern Pacific Co.)

	Elevation		Thickness
	From	To	(Feet)
Sand filling	-12	-31	19
Bay mud	-31	-67	36
Soft blue clay	-67	-97	30
Stiff blue clay	-97	-110	13
Hard blue clay	-110	-117	7
*Blue sandy clay	-117	-127	10
*Yellow sand and blue clay	-127	-130	3
Hard blue clay	-130	-132	2
*Yellow sand and blue clay	-132	-134	2
Find sand (good water)	-134	-142	8
Stiff blue clay	-142	-171	29
Stiff blue clay and trace of sediment	-171	-181	10

Hard blue clay.....................	-181	-187	6
Fine sand and blue clay............	-187	-193	6
*Blue sandy clay...................	-193	-200	7
Blue clay and small pieces of stone............................	-200	-202	2
Soft blue clay, sand and loam (little water)...................	-202	-222	20
Hard blue clay.....................	-222	-224	2
Hard blue clay with small pieces of stone............................	-224	-230	6
Hard blue clay.....................	-230	-232	2
Hard blue clay with small pieces of stone............................	-232	-239	7
Concreted material.................	-239	-257	18
Stiff blue clay....................	-257	-264	7
Blue trap, shale and sharp sand, small amount of water.............	-264	-280	16
Blue trap, shale and sharp sand...	-280	-311	31
Blue shale with serpentine........	-311	-334	23
Blue shale with serpentine........	-334	-357	23

*Water bearing strata producing some water

The upper 70 or 80 feet (exclusive of fill material) is generally classed as soft bay muds or recent bay muds or clays. Below this interval the stiffer, more indurated clays represent older estuarine or deltaic deposits. Sand beds lensing through the lower clays usually represent shifts in the ancient shore line. Lee (1953) reports that the recent bay muds "...are composed of particles of silt and clay of colloidal size mingled with organic matter and often marine shell fragments". Lee also describes these deposits as "...light in weight, soft and often of a jelly-like consistency".

Table VII summarizes test data for recent bay mud from lower Market Street near the Ferry Building (Dames & Moore, 1968):

TABLE VII

Dry Weight	
Maximum	79 pcf
Minimum	68 pcf
Average	72 pcf
Unconfined Compressive Strength	
Maximum	13.1 psi
Minimum	6.8 psi
Average	10.1 psi

The recent bay muds have low shearing strength and are highly compressible. The older bay clays have moderate strength (Schlocker, et al 1958).

The bay muds are covered by fill material over a wide area. The type of fill often varies, depending on when it was placed and its source. Sand, crushed rock, rip rap, garbage and various mixtures of all these materials have all been used. Degree of stability also varies, depending on type of fill, and the strength of material underlying it.

A fill of crushed basalt with some clayey sand in the vicinity of China Basin, has a P-wave velocity ranging from 1450 to 1600 fps.

The intensity-distribution map, (Fig. VI) shows several very small "pockets" of Intensity VIII+ to X. Usually they are the result of localized foundation conditions such as the very poor fills along the shore at India Basin. Another locale of Intensity VIII+ is in Golden Gate Park at the site of the Cyclorama. It was a poorly constructed building, located on a graded hilltop of sand and was destroyed by the 1906 earthquake. In the vicinity of upper Market Street small "islands" of relatively higher intensity are situated parallel to a possible fault. These zones are located on slopes of highly sheared, soft serpentine, and appear to reflect the weakness and instability of this bedrock under seismic shaking (Wood, 1908).

The San Francisco Sheet of the State Geologic Map shows four probable faults, each over six miles long, paralleling the San Andreas under or near the city of San Francisco. These faults are concealed over most of their lengths, and apparently had no surface rupture or displacement during the 1906 earthquake. Comparison of the location of these faults and the intensity distribution maps shows that the fault traces project across intensity zones and appear to have had no bearing on the earthquake intensity.

The behavior of the ground surface at a particular point was often determined by the presence and extent of compressible layers or the degree of subsurface liquifaction.

Zones of Minimum Intensity. H. O. Wood's map of apparent intensities shows a minimum intensity of VI, based on re-evaluation using the Modified Mercalli Scale.

Comparison of the Intensity-distribution map, the overburden-isopach map, and a topographic/geologic map shows that the Intensity VI zones are generally restricted to the hilly areas of the city, where bedrock is exposed or very near the surface.

The bedrock that crops out within the city, and that elsewhere is the basement rock beneath the city, belongs to the Franciscan formation, a complex assemblage of various rock types. Within the city, the Franciscan formation has four principal members: 1) sandstones and shales, 2) basalts, 3) cherts, 4) serpentinized intrusive rock (Lee, 1953). The sandstones are by far the most prevalent. Most are hard, fine to coarse grained, thick bedded graywackes, in some places containing thin interbedded shales and siltstone lenses. Sequences of shale also occur with thin interbeds of fine grained sandstone. Where unweathered, these rocks are hard and usually quite stable. Near the surface they may be weathered and, as a result, softer and less stable on slopes. Franciscan rocks have been subjected to much deformation, and may be locally sheared or broken.

The basalts are subaqueous in origin and are usually associated with interbedded thinly-layered cherts; agglomerates and tuffs occur to a lesser degree. At depth, the basalts are usually hard and resistant; but decomposition near the surface is widespread, and usually soft and weak weathered rock can occur to about a forty foot depth.

The cherts are thin-bedded, with individual beds averaging two to three inches thick and are regularly bedded with thin shale partings. The rock is hard and brittle. Thick intervals of chert are quite stable where they are not closely broken.

The boundaries between units of the Franciscan formation are often unclear due to deformation and original overlapping and intertonguing relationships. In addition, the sedimentary and extrusive rocks have been intruded by basic igneous rocks, predominantly periodotite that has hydrothermally altered to serpentinite. The serpentinite seldom occurs as a massive, hard unit, but is usually sheared and broken. Exposed masses become unstable through deep weathering.

Comparison of the intensity-distribution map and the geologic map shows that while members of the Franciscan may be locally broken or weak, as a unit they provide much more stable foundation conditions than any other geologic unit within the city.

Table VIII summarizes test data on Franciscan rocks in the San Miguel Hills area, which experienced an Intensity VI. Rock types vary considerably. The breccia is a collective group of crushed rock that has been partially recemented. Greenstone is also a collective term and includes basalts, agglomerates and tuffs in varying degrees of alteration. The meta-sandstone (graywacke) samples represent the prevalent Franciscan bedrock. (Bechtel, 1965).

TABLE VIII

Rock Type	Dry Weight (PCF)	Unconfined Compressive Strength (PSI)	Modulus of Elasticity (PSI X 10^5)
Breccia Depth 43'-140'		6 samples	1 sample
Maximum	170	6500	
Minimum	161	220	0.43
Average	168	1810	
Meta-Sandstone Depth 27'-50'	13 samples	11 samples	6 samples
Maximum	164	3390	1.17
Minimum	161	620	0.35
Average	163	1840	0.84
Chert Depth 44'-98'		5 samples	3 samples
Maximum	181	8660	11.25
Minimum	157	3960	1.15
Average	172	6360	7.46

Greenstone Depth 16'-112'	10 samples	8 samples	3 samples
Maximum	183	6190	4.5
Minimum	162	720	0.57
Average	174	2490	2.80

Table IX summarizes results of geophysical testing, measuring P-wave velocities on Franciscan rocks exposed in San Francisco. All rocks listed are extensively weathered.

TABLE IX

Rock Type	P-Wave Velocity
Chert	0-15': 2300 fps; 15'-50': 10,000 fps
Basalt (sheared)	0-50': 2600 fps average
Serpentine	0-3': 800 fps average; 3'-25': 2100 to 2600 fps
Sandstone	0-25': 3400 fps average

Statistical Study of Intensity Compared to Overburden Thickness. Reid (1910) noted the variations in intensity on different foundation materials during the 1906 earthquake and derived a numerical "foundation coefficient" evaluating the relative stability of the materials. Gutenburg (1957) carried the work of Reid and other researchers a step further by demonstrating the influence of overburden thickness quantitatively. He concluded that generally the amplitude and duration of maximum shaking increased proportionally with increasing thickness of overburden and stated that, "....for finding the safest location for a building in a region where there are active faults, it is more important to look for sites on bedrock than for locations with a maximum distance from the faults".

Preliminary map study suggested that a graphical representation of the influence of overburden thickness on intensity could be constructed covering the city of San Francisco in the 1906 earthquake.

An isopach map of overburden (all materials above Franciscan bedrock) was superimposed on H.O. Wood's Intensity Map which had been converted to Modified Mercalli Scale. (See Figs.

VI and X). A grid of convenient scale was then established over the map, and the intersection points of the grid lines were used as checkpoints where intensity was compared to thickness of overburden. This resulted in a random distribution of 516 checkpoints, 0.3 mile apart, throughout the city.

Fig. XI shows the results of this survey expressed in one mile wide bands across the city parallel to the San Andreas Fault. While local irregularities reflect particular special conditions on the ground, the graphs show a distinct relationship between intensity and thickness. By comparing the charts for each mile it is apparent that the distance from the San Andreas Fault was of secondary importance in determining the damage.

Assuming damage to become "major" at an intensity range of VII to VIII, the graphs show that major damage becomes prevalent (over more than 50% of the area) when the overburden reaches 100 to 200 feet thick.

The graphs also demonstrate the effect of equal thicknesses of differing materials. Figure XII shows, for example, that on overburden ranging from 200 to 300 feet thick the intensity in the eight to nine mile band was generally higher than in the two to three mile band. The overburden in the band nearest the fault is dune and terrace sand, and the overburden in the eight to nine mile band is bay mud, swamp deposits and fill.

The graphs show that where conditions similar to those at the Mendocino Power plant site exist in San Francisco, a four to five mile distance from the San Andreas Fault and an overburden thickness of 1 to 100 feet, the maximum intensity was in the VII to VIII range.

<u>Design and Construction Methods</u>. Quality of design and construction is the most significant factor permitting survival of structures even where foundation material, thickness of overburden and proximity to the fault presented a high seismic risk. A prime example of this was the Crystal Springs Dam in San Mateo County, about 1300 feet from the main San Andreas fault-trace. The dam, well designed and constructed, was undamaged.

Humphrey (1907) goes so far as to attribute the failure of buildings in San Francisco to two causes:

1) economic considerations precluded safety factors and buildings built for the minimum cost to stand under normal loading, failed under extraordinary conditions such as earthquake.

2) outright dishonest design and construction.

Freeman (1932) points out the following lessons on loss ratio and structural resistance:

> "After reviewing the elaborate reports of the California Earthquake Commission and reports by Committees of the American Society of Civil Engineers, also those by Mr. W. L. Huber and others, together with notes and recollections from his own frequent visits to San Francisco, particularly that made in 1906 for the special purpose of inspecting the results of earthquake and fire, and two other tours of inspection in San Francisco, in 1926 and 1929, while working on this book, the present writer (J.R.F.) finds the chief lessons from the history of the San Francisco earthquake of 1906 are the following:
>
> 1. A distorted perspective and a large over-estimate of the average earthquake damage results from studying the various reports of wreckage that have been published, unless one gives proper attention to the many buildings which resisted the earthquake shock in localities where the shock was heaviest. For example: the Folger Building, the Young Building, the Lowry Building and many others.
>
> 2. In general, well-designed, well-built, large, office buildings, warehouses and factories of the types common 20 to 30 years ago, demonstrated excellent powers of resistance and a small loss-ratio.
>
> 3. Bricked-walled, timber-floored, factory and warehouse buildings of good design and good workmanship, up to five stories in height, showed excellent resistance and small loss-ratio, even when located on mobile ground, if provided with deep, rigid foundations.
>
> 4. In residences of brick resting on good foundation-walls, the damage was chiefly confined to the chimneys and to some cracking of plastered walls and ceilings.
>
> 5. In general, wood-frame buildings resting on good foundations withstood the earthquake shock wonderfully well, even in places where the ground was moderately soft and mobile.
>
> 6. Along the margins of "made land," over old marshes and on soft or mobile ground along the shore, buildings that were poorly designed and carelessly built, showed a serious loss-ratio.

7. That buildings of brick, with bearing walls enclosing a steel frame, can be built upon mobile ground so as to withstand a strong earthquake, was illustrated by the Folger Building (see page 352) and by many others having deep, massive foundations resting on ample piles.

8. Mr. Huber concludes from his observations at the time of the San Francisco earthquake and from his recent studies, that "buildings of substantial construction, embodying sound engineering design, will not be destroyed, nor is there likelihood of their being even seriously damaged by an earthquake of intensity equal to that experienced in San Francisco on April 18, 1906".

9. In the experiences reported from Japan in its great Tokyo and Yokohama earthquake of September 1, 1923, we have trustworthy evidence that many well-constructed buildings 100 feet tall, designed to resist an acceleration of 0.1g (or 3.2 ft. per sec. per sec.), which is the same as provided for in the new "Palo Alto code", and the new "Uniform Building Code", proposed by the Pacific Coast Building Officials Conference, described on pages 695 and 698, withstood an earthquake of greater violence than has ever yet been definitely known within the historic period in the United States or Canada".

SUMMARY

Apparent intensities in San Francisco during the 1906 earthquake were the results of several geologic factors:

1) Proximity to the main rift zone

2) Type of foundation material

3) Thickness of overburden

The thickness of overburden was the dominant factor, considering the city as a whole. Mount Sutro, approximately five miles from the San Andreas fault, experienced Intensity VI; the Civic Center eight miles distant experienced Intensity VII-VIII; and the Embarcadero, nine miles from the fault, experienced Intensity VIII+ to X, the apparent reason being that depth of overburden was greatest at the Embarcadero.

Intensities ranging from VII to VIII+ were experienced over an area underlain by sand dunes with no apparent correlation to surface geology. However, an evaluation of the overburden thickness shows that intensity increased sharply over a relatively steep-sided basin where the sand becomes much thicker. A comparison of the overburden isopach-map and the intensity map shows a general correlation that often is quite distinct. Fingers of higher intensity correspond to buried valleys south of Lake Merced. The hills formed by outcropping, resistant Franciscan bedrock all show Intensity VI, the minimum within the city. Distribution and degree of intensities in San Francisco amply illustrated Gutenburg's statement, "...for finding the safest location for a building in a region where there are active faults, it is more important to look for sites on bedrock than for locations with a maximum distance from the faults."

Where foundation conditions and situation in San Francisco most resembled the Mendocino Power Plant Site, the intensity ranged from VI to a maximum of VIII.

The influence of proper design and construction practices as demonstrated in San Francisco during the 1906 earthquake can be summarized by W. L. Huber's statement (Freeman, 1932)

> "Buildings of substantial construction, embodying sound engineering design, will not be destroyed, nor is there likelihood of their being even seriously damaged by an earthquake of intensity equal to that experienced in San Francisco on April 18, 1906".

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APPENDIX 2.5A

GEOLOGY
OF THE
MENDOCINO POWER PLANT SITE

Project 1087

Geology of the Mendocino Power Plant Site

Appendices

Illustrations

GEOLOGY OF THE MENDOCINO POWER PLANT SITE,

MENDOCINO COUNTY, CALIFORNIA

I. Introduction

The Mendocino Power Plant Site, near the southwestern corner of Mendocino County, is on the northern California coast about midway between San Francisco and Eureka (Drawing No. I-1). Its geographic coordinates are 38° 55' N. and 123° 43' W. The grossly rectangular site area is bounded on the west by the open sea, on the south by Arena Cove, and on the east by California Highway 1. It lies about 1-1/2 miles west-northwest of the city of Point Arena, and about 4-1/2 miles south-southeast, or downcoast, from Point Arena lighthouse and the mouth of the Garcia River.

The most pertinent early geological study of the area was made nearly 30 years ago by C. E. Weaver, who prepared a preliminary geologic map of the Point Arena - Fort Ross coastal region. This map, published at a scale of 4.7 miles to the inch (Weaver, 1943), includes structural and stratigraphic data for the Gualala block, a well-defined crustal unit within which the plant site area is located. Additional data for this part of the coastal region, derived mainly from geologic mapping by T. W. Dibblee, Jr., were subsequently added by J. B. Koenig in a compilation for the new Geologic Map of California (Santa Rosa sheet, 1963, scale 1:250,000).

That portion of the Gualala block extending southward from Schooner Gulch (Drawing No. II-3) was later mapped by C. M. Wentworth, Jr. at a scale of 1 mile to the inch (Wentworth, 1966). He restudied the stratigraphic section, established new units, and determined their structural relationships. The onshore portion of the Gualala block extending northward from Schooner Gulch was mapped by M. W. Boyle at a scale of 2000 feet to the inch (Boyle, 1967). His study included a stratigraphic review based in part on age determinations from collections of microfossils, along with further deciphering of structural features. Still more recently, R. D. Brown, Jr. and E. W. Wolfe prepared a map showing the latest breaks along the San Andreas fault. This map, released at a scale of 2000 feet to the inch by the U. S. Geological Survey in 1970, includes the reach of the fault zone that lies adjacent to the Point Arena area.

The present investigation dates from June 1966, when R. H. Jahns made a preliminary examination of the plant site area. Subsequent detailed studies by Jahns and D. H. Hamilton, chiefly during the period April 1970 - June 1971, included the following principal activities:

1. Detailed mapping and interpretation of nearly continuous exposures along the sea cliff and adjoining wave-cut bench that fringe Arena Cove and the open sea to the north. Enlarged vertical and oblique aerial photographs, provided mainly at a scale of 50 feet to the inch, were used as a map base. The data later were transferred to plan and vertical section maps prepared at a scale of 100 feet to the inch.

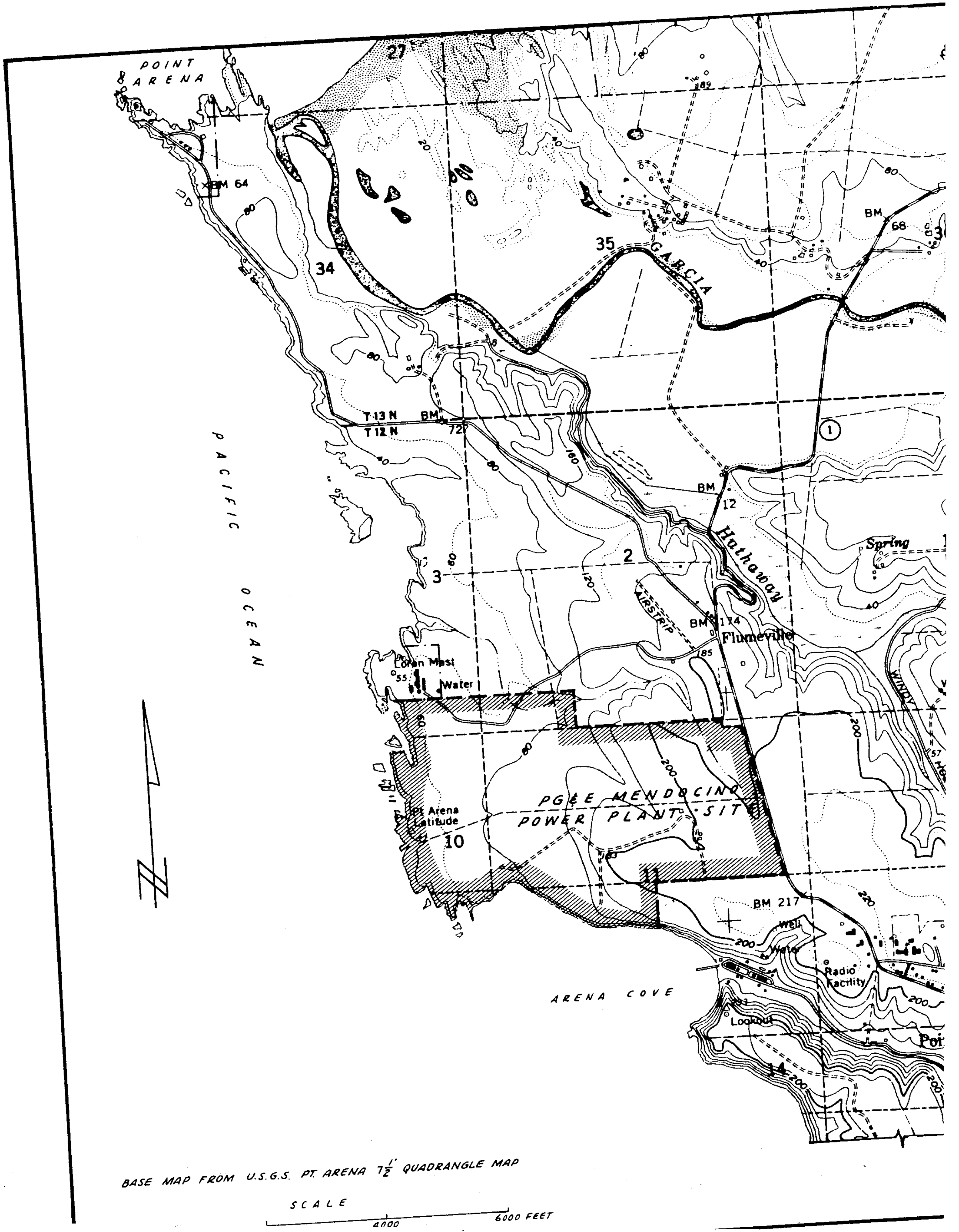
2. Extremely detailed examination and mapping of the walls of three exploratory trenches excavated beneath the terrace surface immediately north of Arena Cove. The map data were plotted on overlapping photographs and were controlled at 10-foot intervals by surveyed points. They were subsequently transferred to geologic sections prepared at a scale of 10 feet to the inch.

3. Mapping and interpretation of bedrock and surficial deposits in the entire site area. The results, presented at a scale of 200 feet to the inch, were derived from the mapping noted above, from examination of all other existing exposures, and from a study of color aerial photographs provided in stereoscopic coverage at a scale of 250 feet to the inch.

4. Preparation of a stratigraphic column, and of detailed structure sections at a scale of 100 feet to the inch.

The geologic investigations in the plant site area required approximately 42 man-days of field work. An additional 28 days was devoted to off-site investigations, mainly by Hamilton. This included the mapping of about 38 square miles in the Gualala block north of Schooner Gulch, a careful search for evidence of faults and geologically recent fault movements, and detailed trench exploration of a scarp-like feature on the H-H Ranch southeast of the site area.

The off-site geologic mapping was based on field traverses, chiefly along the coastal sea cliff, numerous stream courses, roads, ridge crests, and relatively steep slopes, and it was backed up by detailed examination of stereoscopic aerial photographs at scales of 1:80,000, 1:24,000, and, for some of the ground, greater than 1:24,000. The geologic map, compiled at a scale of 2000 feet to the inch, includes some data from Wentworth (1966) and from Boyle (1967). Other products of this work are tectonic and stratigraphic-assemblage maps of the Gualala block north of the Gualala River (scale 1 mile to the inch), and a map showing the distribution and inferred correlation of coastal terrace surfaces.


POINT ARENA
BM 64
PACIFIC OCEAN
GARCIA
T 13 N
T 12 N
Hathaway
Flumeville
AIRSTRIP
Spring
Loran Mast
Water
Pt Arena Latitude
PG&E MENDOCINO POWER PLANT SITE
BM 217
Well
Water
Radio Facility
Lookout
ARENA COVE
BASE MAP FROM U.S.G.S. PT. ARENA 7½' QUADRANGLE MAP
SCALE
4000
6000 FEET

II. The Northern Gualala Block

A. Regional Geologic and Seismic Setting.

The rocks of the Mendocino Plant Site area occupy the northerly part of a coastal structural unit that can be referred to as the Gualala block. This block is characterized by sedimentary rocks of Cretaceous to Miocene age, probably underlain by granitic basement rocks. The thick sedimentary section is folded and faulted, and on the east it is cut off by the San Andreas fault. Beyond this master break is a different structural unit, or block, that is characterized by the Franciscan Formation. This unit is part of the North American continental plate, whereas the Gualala block forms an easterly, and in part onshore, portion of the so-called Pacific plate.

The regional setting of the Gualala block can be described in terms of the major crustal features of the northern California coastal margin and adjacent parts of the eastern Pacific Basin. These features, designated in accordance with the present concept of global plate tectonics, comprise the Pacific, the North American, and the Juan de Fuca crustal plates, along with the San Andreas and Mendocino Zones of major dislocation between these plates (Drawing II-1). The form, history, and state of activity of these crustal plates have been investigated principally by geophysical means, which have included the mapping of linear magnetic anomalies in rocks of the oceanic crust, and the recording, charting, and analyzing of earthquake shocks generated by adjustments between plates and along axes of sea-floor spreading. Rationalization of the activity of the San Andreas fault with major adjustments within and between crustal plates has been possible only in the last few years, and the concept of plate tectonics opens the way to an explanation of the large cumulative displacement known to have occurred along this fault.

Tectonic activity in the northern California coastal and offshore region is dominated by frequent earthquakes along the Mendocino fracture zone and within the subsea basin and ridge area to the north, and by intermittent major or great earthquakes, in general accompanied by dextral strike-slip surface displacement, along the San Andreas fault. Many of the earthquakes originating along the Mendocino fracture zone near the triple junction of the Pacific, North American, and Juan de Fuca plates have been found, from focal depth and first motion analysis, to involve north-south thrusting at depth (Seeber et. al., 1970). This has been interpreted as indicating a condition of north-south compressive stress, possibly arising from absorption, in that part of the Mendocino zone, of dextral slip along the San Andreas fault. Fault movement and earthquake activity along the San Andreas fault itself are markedly intermittent, owing apparently to the locking effect of the curvature of the fault surface between Shelter Cove and Cape Mendocino. Fault displacements and earthquake shocks, however, are of considerable magnitude when they do occur (tens of feet fault movement; 7 to 8 plus Magnitude earthquakes). The recurrence interval for strong seismic activity along the reach of the fault in central and northern California has been estimated to be in the range of 100 to 1000 years (Wallace, 1970).

The Pioneer fracture zone, an old transform fault located south of and parallel to the Mendocino fracture zone (Drawing II-1), lies within the Pacific crustal plate. The distribution of linear magnetic anomalies across the east end of this zone suggests that its activity ceased some 29 million years ago (Atwater, 1970).

B. Stratigraphy

1. General Features.

The northern Gualala block is underlain by clastic sedimentary rocks and volcanic rocks ranging in age from late Cretaceous through Miocene. The older strata, of Cretaceous, Paleocene, and Eocene age, are exposed in the southeastern two-thirds of the northern Gualala block, whereas rocks of Miocene age crop out in the Point Arena Coastal, Hathaway Creek, and Garcia River areas in the northwesterly part of the block. Sandstone exposed north of Brush Creek has been identified as late Pliocene in age. The bedrock section is discontinuously blanketed by sub-horizontal sequences of Pleistocene deposits along several broad coastal terraces, and alluvial deposits of Pleistocene and Holocene age are present along many stream courses.

The basement rocks of the Gualala block probably are granitic, as is the case farther south in the Point Reyes Peninsula and at Bodega Head, though direct evidence of this is lacking. An earlier suggestion that the block could be underlain by a basement of Franciscan Formation (Wentworth, 1966, p. 63, 64) was based on the similarity between spilitic volcanic rocks exposed near Black Point and greenstone of the Franciscan Formation and on the supposition that the block could be a slice between two branches of the San Andreas fault system. However, recent continuous seismic profiling in the offshore area (Curray and Nason, 1967) has shown that the postulated westerly branch fault required for such a structure probably does not exist.

The stratigraphic section in the northern Gualala block is depicted graphically in Drawing No. II-2. The general distribution of bedrock stratigraphic assemblages is shown on Drawing No. II-3. The distribution of both bedrock and surficial stratigraphic units in the vicinity of Point Arena is shown on Drawing No. II-4.

2. Cretaceous and Early Tertiary Rocks

Gualala Formation and German Rancho Formation. Clastic sedimentary rocks, exposed throughout the Anchor Bay - Gualala Ridge area, have been identified from paleontological evidence as late Cretaceous and Paleocene to Eocene in age. Originally described as belonging to a single formation or "group" of late Cretaceous age, the strata were mapped and stratigraphically redefined by Wentworth (1966), who obtained age determinations, assigned formation names, and described the lithology for these rocks as follows:

Age	Formation	Member	Lithology
Paleocene-Eocene	German Rancho		Thick-bedded arkosic sandstone, in part conglomeratic, underlying interbedded mudstone and arkosic sandstone.
Late Cretaceous	Gualala	Anchor Bay	Alternating mudstone and arkosic sandstone, with intercalated sequences of coarser and thicker-bedded arkosic sandstone and conglomerate.

Age	Formation	Member	Lithology
Late Cretaceous	Gualala	Stewarts Point	Massive conglomerate, thick-bedded arkosic sandstone, and rhythmically interbedded mudstone and arkosic sandstone. In part contemporaneous with Anchor Bay strata.

Wentworth determined that the strata of the Gualala and German Rancho Formations include two facies of mineralogically contrasting arkosic sandstones that apparently were derived from unlike source terranes and were deposited by turbidity currents moving in systematically different directions. He inferred that these source terranes existed across a northwesterly trending trough-like basin. Stewarts Point and German Rancho sediments rich in potash feldspar were considered to have been derived from granitic rocks such as those now exposed southward from Bodega Head, whereas the plagioclase-rich feldspars of the Anchor Bay strata were postulated to have come from a gabbro-quartz diorite terrane. The present distribution of Anchor Bay strata, relative to possible source rocks, east of the San Andreas fault, led Wentworth to postulate the existence of a late Mesozoic basin aligned approximately parallel to the trend of the present day San Andreas fault, and to suggest that "the San Andreas fault or a northwest-trending precursor", already existed in late Cretaceous time. A contrasting interpretation, more recently suggested by Atwater (1970) on the basis of other evidence, is that the San Andreas fault could not have existed as a master break prior to Miocene time.

Wentworth measured minimum thicknesses of 8000 feet for the Gualala Formation and 20,000 feet for the German Rancho Formation. The base of the Gualala is not exposed. This formation is overlain conformably by strata of the German Rancho Formation, which in turn is overlain, apparently conformably, by the Iverson Basalt along the northwestern limits of the Anchor Bay anticline.

3. Miocene Sedimentary and Volcanic Rocks

Iverson Basalt. A sequence of flows and layers of flow breccia of basaltic composition, aggregating about 900 feet in thickness, conformably overlies mudstone of the German Rancho Formation in the area between Iverson Point and Schooner Gulch, and is in turn conformably overlain by the Skooner Gulch Formation. On the basis of their stratigraphic position, Wentworth considered the basaltic rocks to be of probable lower Miocene age. They may well be analogous to numerous other occurrences of lower Miocene volcanic rocks in the California Coast Ranges.

The Iverson Basalt is best exposed in the sea cliff at and north of Iverson Landing, 6 miles downcoast and southeast of Arena Cove. Isolated outcrops of massive, granular weathering, dark green basalt on the ridge between Galloway Creek and Schooner Gulch may represent the most northerly occurrence of this formation.

Gallaway and Schooner Gulch formations. Sandstone, siltstone, and mudstone of the Gallaway and Skooner Gulch Formations crop out along the sea cliff in a one-mile section that includes Ross Creek (Abalone Cove) and Saunders Landing. Rocks of these formations also are exposed in a zone extending northward from the north fork of Schooner Gulch, through the Hathaway Creek and Garcia River areas, to the northerly limit of the on-shore Gualala block.

The Gallaway and Schooner Gulch formations were originally named and described by Weaver (1943, 1944). The sea cliff exposure of these rocks was described in more detail by Wentworth (1966). Boyle (1967) studied the formations in considerable detail, mapped them throughout the Point Arena area, and identified them as Lower Miocene on the basis of fossil determinations. He interpreted the discordance in attitude between strata of the Gallaway-Schooner Gulch section and those of the German Rancho Formation, observed between the Hathaway Creek and Gualala Ridge areas, as an angular unconformity of as much as 70 degrees. Yet these formations and the Iverson Basalt apparently are conformable in the sea cliff exposure south of Schooner Gulch. It is here considered that the reported highly discordant contact more probably reflects structural rotation of the German Rancho strata, and that there is no demonstrably significant angular unconformity between the Eocene and Miocene sections in the Gualala block.

In the sea cliff south of Abalone Cove, diatomaceous and porcelaneous shale of the Monterey Formation is transitional downward into a distinctive section of dark gray mudstone, with sandstone interlayers that increase farther downward in thickness and closeness of spacing. This section is interrupted by the Galloway Creek fault, south of which is a section of thick-bedded massive sandstone and massive dark gray mudstone. This latter section extends stratigraphically downward to a conformable contact with the Iverson Basalt. The sequence north of the Galloway Creek fault, about 1700 feet in thickness, is lithologically distinctive because of the striking convoluted internal structure of its sandstone interbeds; it constitutes the uppermost portion of the Gallaway Formation. The section south of the Galloway Creek fault is about 1000 feet thick and forms the lowermost portion of the undivided Gallaway - Schooner Gulch section.

In the area north of the type exposures along the sea cliff, the Gallaway and Schooner Gulch Formations consist of folded and faulted sections of arkosic sandstone, siltstone, dark gray mudstone, and brown, hard, platy mudstone containing abundant fish scales.

The Garcia River section consists predominantly of indistinctly bedded, hard, dark gray and gray-brown mudstone and massive sandstone. It apparently overlies an anticlinal core of German Rancho Formation, and it probably is stratigraphically equivalent to the rocks exposed in the sea cliff south of the Galloway Creek fault.

The Hathaway Creek section is poorly exposed, but evidently consists chiefly of interbedded massive sandstone and poorly bedded olive gray siltstone, with one or more intervals of hard brown mudstone containing fish scales. Although foraminifera collected from this section by Boyle (1967) are approximately equivalent in age to those from the Schooner Gulch and the Garcia River sections, the respective lithologies do not match. The interpretation provisionally adopted here is that the sandstone-siltstone section of Hathaway Creek represents the central portion of the Gallaway - Schooner Gulch Formation, and that this section has been removed from the sea cliff area by displacement along the Galloway Creek fault.

Monterey (Point Arena) Formation. From Abalone Cove north, the Point Arena coastal area west of the Hathaway Creek fault is underlain by a sequence of rocks comprising a lower section of diatomaceous to porcelaneous shale and siltstone and an upper section of massive to thin-bedded sandstone and sandy mudstone. These rocks have been informally referred to as the Monterey Formation at various times. Weaver (1943) first described them and named them the Point Arena beds, later changing this to Point Arena Formation (Weaver, 1944). Subsequently Boyle (1967) argued that the rocks are stratigraphically and lithologically equivalent to the Monterey Formation as long defined in California coastal areas from Point Reyes south, and that this name should have precedence at Point Arena. It is here applied to the strata present in the Point Arena coastal area. The sandstone section exposed in Arena Cove, however, is a distinctive mappable unit that is quite unlike the typical diatomaceous and porcelaneous shale of the Monterey Formation. This unit is therefore informally designated here as the Point Arena Sandstone Member of the Monterey Formation.

At least 3000 feet of Monterey strata underlies the Point Arena Sandstone. Approximately 1300 feet of sandstone is exposed in the Arena Cove area, but the upper part of this section lies offshore and so the complete thickness could not be measured. Boyle and others have collected fossils of early through middle Miocene age from the lower part of the formation, and of middle Miocene age from the Sandstone Member.

The diatomaceous and porcelaneous Monterey siltstone is brown where fresh, and it weathers to a lighter tan to cream color where exposed. The bedding is prominent along the sea cliff and in other large exposures, but it commonly is indistinct or less conspicuous than jointing in outcrops of small area. In the cores of folds, the strata are locally much deformed by shearing, diapirism, crushing, and development of complex tight, disharmonic folds. Such deformation typically dies out both vertically and along strike in the section, generally within a few tens of feet.

The Point Arena Sandstone consists principally of interbedded platy to massive, very fine- to fine-grained poorly cemented sandstone, with thick intervals of sandy mudstone in the lowest 250 feet of the section. Beds and lenses of medium- to coarse-grained, locally pebbly sandstone are present at irregular intervals. They range in thickness from a few inches to about 5 feet, and one bed about 30 feet thick occurs approximately 120 feet above the base of the unit. Several of these sandstones, including the thickest one, are markedly asphaltic; some are locally cemented with calcite. Horizons of dolomitic concretions are present throughout the section.

The Point Arena Sandstone north of Arena Cove is featured by a thick, wedge-like mass containing a chaotic jumble of contorted blocks of platy sandstone, by a thick tongue of pebbly sandstone, and by masses of coarse sedimentary breccia. These bodies exhibit some cross-cutting and intrusive relations with the normal section, and apparently originated through Miocene submarine landsliding, debris flowage, channeling, and sedimentary intrusion. They are underlain and overlain by normally bedded strata.

4. Pliocene Sandstone

Boyle (1967) collected megafossils that have been tentatively identified as late Pliocene from scattered outcrops of poorly indurated sandstone on the crest of the broad ridge along the west side of the San Andreas fault rift opposite Brush Creek. He mapped the sandstone as a terrace capping and regarded it as possibly correlative with the late Pliocene Ohlson Ranch Formation, (remnants of which are preserved resting upon an erosion surface developed in the Franciscan terrane in the area east of the Gualala River.) However, the sandstone at his fossil locality appears to have been deformed, and it may dip steeply in some places. It probably forms parts of a fault-bounded sliver rather than a terrace capping.

5. Quaternary Sediments

Deposits on Coastal Terraces. The coastal terraces in the vicinity of Point Arena are characterized by discontinuous blankets of

Pleistocene deposits resting upon wave-cut bedrock platforms. The cover on each terrace comprises a patchy base of ancient beach and surf-zone deposits and overlying dune sand, floodplain deposits, and, along the bases of adjacent higher slopes, colluvial deposits.

Over most of the terrace areas south of the Garcia River, the basal marine deposits consist of clean, medium-grained sand with some beds and lenses of sandy to relatively clean pea gravel. Pockets of rubble and small boulders are present locally. Where the deposits have remained continuously submerged beneath a local water table, exceptionally well preserved driftwood is present in some of the rubble pockets. Bone fragments also have been found, and a mastodon-type tooth reportedly recovered from the beach along the north side of Arena Cove may well have come from the terrace deposits. Shells exist only as relatively rare, corroded remnants, apparently having been dissolved by acid ground water.

The terrace deposits of dune sand are homogeneous and fine grained. Various forms of cross bedding are common. Silty to clayey sand grading to sandy silty clay also is widespread in the upper parts of the terrace sequences, and is thought to be of floodplain and/or alluvial fan origin. It may well include fractions of wind-blown sand. These materials are intertongued with colluvial deposits that consist of weathered talus and slopewash debris.

The coastal terrace deposits adjacent to and north of the present floodplain of the Garcia River contain extensive beds of pebble to cobble gravel, consisting mainly of clasts of Franciscan Formation rock types. These gravels evidently were either deposited directly by the ancestral Garcia River (or Brush Creek) or were reworked from river deposits by ancient long-shore currents.

Alluvial Deposits. Alluvial sediments in the vicinity of Point Arena include river-terrace, stream-channel, and valley-fill deposits. They are of two general types -- fine-grained deposits derived from the local, poorly indurated sedimentary formations, and medium- to coarse-grained deposits derived from the more resistant rocks of the adjacent Franciscan terrane. The finer-grained alluvium consists predominantly of sand, silt, and clay with scattered pebbles, cobbles, and blocks from the coastal terrace deposits and from concretions and local cemented zones in the Tertiary rocks. The coarse-grained alluvium is present only in the area north of Gualala Ridge, where the drainage courses tap the Franciscan terrane to the east. Deposits on well-defined lower terrace surfaces along the Garcia River have not been dated, but they are probably Pleistocene in age.

Thick accumulations of fine-grained valley filling alluvium are present in several of the ravines in the area extending inland from and south of Arena Cove. These deposits have been incised to depths of 10 to 30 feet along some reaches of these ravines. Small landslides have developed in the fine-grained alluvium at various places along these lower terrace slopes, especially in the lowest reach of Mote Creek.

<u>Other Surficial Deposits.</u> Dune sand of Holocene age covers large areas of the low terrace extending inland from the beach between the mouths of the Garcia River and Alder Creek.

Mapped landslide deposits in the area consist of slumped masses of weak rocks. Most of the larger landslides occur along the slopes of the San Andreas rift valley. Bedding-plane slides are present locally along the sea cliff in areas where the dip of bedding is seaward. The landslide materials range from virtually intact rock to thoroughly disintegrated and jumbled rocky soil.

Smaller landslides, not shown on the geologic map, have developed on many slopes in clayey alluvial terrace deposits and in thicker accumulations of colluvial and residual soils.

Colluvial deposits, consisting principally of slopewash and talus debris, are present along and near the bases of most slopes. Residual soil is most extensive on older, gently sloping surfaces, notably on older terrace surfaces and on the crestal area of Gualala Ridge. Except for patches of rock outcrop, such soil deposits form a widespread cover throughout the Point Arena - Gualala coastal area.

C. Structure

1. General Features

The name Gualala block was assigned by Weaver (1944) to the onshore area between the San Andreas fault and the coast from Fort Ross to Point Arena. This block constitutes the most northerly onshore occurrence of the coastal sequence of folded Cretaceous and younger sedimentary and volcanic rocks. The geologic structure of the southern four-fifths of the Gualala block is grossly simple, and is expressed by a series of broad folds with east-west to northeast-southwest trend. The fold belt is truncated on the east by the San Andreas fault. From Iverson Point to the northern end of the block, the structure is complicated by faulting, and the pattern of broad east-west trending folds is replaced by one of narrow northwest-southeast trending folds.

The principal tectonic features of the Gualala block are illustrated in Drawing No. II-5, which includes names that have been assigned to folds and faults during this and earlier investigations. The following discussion of geologic structure in the Gualala block is restricted to that portion of the block extending northward from the mouth of the Gualala River. This is referred to herein as the northern Gualala block.

2. Structural Units, Folds, and Faults

The northern Gualala block is readily divided into two main structural domains, referred to herein as the Anchor Bay and Garcia River subprovinces. Each of these subprovinces in turn consists of several structural units, which are outlined on Drawing No. II-3, and can be listed as follows:

Structural Province: Northern Gualala Block

Structural Subprovince	Structural unit	Dominant Structural Grain
Anchor Bay	Anchor Bay	Broad E-NE trending folds.
	China Gulch	NW-SE strike, partly overturned.
	Iverson Point	N-S to NNW-SSE strike, west dipping.
Garcia River	Point Arena Coastal	Elongate NW-SE trending folds.
	Hathaway Creek	Elongate NW-SE trending folds, and faults.
	Garcia River	Elongate NW-SE trending folds, and faults.
	Gualala Ridge	WNW-ESE strike, partly overturned.

The Anchor Bay structural subprovince is characterized by broad folds, gener- [illegible]ith east-northeast trend, and by numerous minor faults that trend northward. This subprovince is bounded by the San Andreas fault on the northeast, by the Havens Neck fault on the southwest, and by the Galloway Creek and other faults on the northwest. Its structure is continuous with that of the southern Gualala block southeast of the Gualala River. The dominant ENE-WSW structural grain within the Anchor Bay subprovince is interrupted by the upfaulted China Gulch structural unit, within which the structural grain is oriented NW-SE, and by the Iverson Point unit near the coast, where the structural grain is oriented NW-SE to nearly N-S.

The Garcia River subprovince is characterized by folds and faults that trend NW-SE, generally subparallel to the trend of the San Andreas fault. The style of deformation of the several structural units composing this subprovince is generally consistent, and the units are defined mainly on the basis of identifiable discontinuities in the structural and stratigraphic position of rocks in exposures along bounding faults. The Point Arena Coastal, Hathaway Creek, and Garcia River structural units all consist of strata in variably plunging folds with NW-SE trend, but the strata increase in age and degree of fault disturbance as traced eastward toward the San Andreas fault.

The pattern of dislocation within the northern Gualala block includes several generations of local faults that developed between middle Miocene and late Pliocene time, along with a set of strand faults related to the San Andreas system. The local faults appear to have been characterized by both dip-slip and strike-slip components of movement, with dip-slip components probably dominant for most of them. Among the best defined and probably the most important local breaks in the northern Gualala block are the Hathaway Creek and Havens Neck faults, the Iverson fault, the Section 21, Section 17, Slick Rock, and China Gulch faults, the Galloway Creek fault, and the inferred Garcia River fault. The Hathaway Creek and Havens Neck faults may have originated as a single break, which was later offset by movement along the Galloway Creek fault. Most of the faults mapped along the northeastern margin of the area, though only of local extent, probably are or were related to the San Andreas system.

The existing pattern of faulting in the northern Gualala block appears to have formed during or after development of the NW-SE trending folds in the Garcia River structural subprovince. Relatively young faults, at least some of which were formed in response to strain adjacent to the San Andreas fault, transect some of the earlier faults and folds; they appear to die out with increasing distance from the main trace of the San Andreas fault. These younger faults are most widespread in the Garcia River and Gualala Ridge structural units. Some of them extend into the Hathaway Creek structural unit, but they appear to be deflected northward to merge with the Hathaway Creek fault along the seaward side of this unit. This faulting does not extend into the Point Arena Coastal structural unit.

The Slick Rock, China Gulch, Section 21, and Section 17 faults may represent the most recent episodes of significant local rupturing not directly related to strike-slip movements along the San Andreas system. They delineate the boundaries of the China Gulch and Gualala Ridge units of partially overturned lower Tertiary strata, which may have been raised tectonically to their present highland positions in Pliocene time or even early Pleistocene time. This possible faulting would have predated development of the "400-foot" coastal terrace surface, which probably is at least as old as mid-Pleistocene. If the topographic expression of the China Gulch and Gualala Ridge units resulted from tectonic uplift along the Slick Rock - China Gulch and Section 21 - Section 17 faults, then the youngest movements would have produced changes in elevation of 500 to 600 feet across these faults.

The geologic structure in the Point Arena Coastal unit, of special interest in the present investigation, is well expressed in the thinly bedded diatomaceous to porcelaneous shales and the overlying thin-bedded to thick-bedded sandstones of the Monterey Formation. Four principal folds, two anticlines and two synclines, are present within this structural unit. These folds exist as continuous features for trend distances of $\frac{1}{2}$ mile to about 3 miles, and their axes plunge at angles ranging from nearly 0 to 50 degrees. The folding is of the concentric type, and the axial regions of the flexures range from simple, open crests or troughs to zones of complex small-scale deformation that include expressions of rupturing. The variations in style occur both longitudinally, along strike of the folds, and vertically, within their axial regions. At Arena Cove and at several localities along the sea cliff to the south, abrupt changes in scale and intensity of deformation can be observed over short distances.

Small cross-faults with displacements of a few inches to a maximum of about $2\frac{1}{2}$ feet can be observed in the strata exposed on the wave-cut benches along the westerly-facing sea cliff just north of Arena Cove. None of these breaks displaces the contact between the bedrock and overlying terrace deposits. Other small slips in nearshore sea stacks of the same area appear to be related to shifting of strata above a weak, sheared bedding plane exposed along the sea cliff. None of them extends onshore, down-section from the sheared bedding plane. However, some shifting apparently occurred along the bedding plane itself at the time of the great 1906 earthquake; this movement formed the "earthquake crack" that lies 50 feet east of the Point Arena latitude marker and was first reported by the U. S. Coast and Geodetic Survey (1963). The movement represented gravity failure rather than faulting.

3. Faulting Associated with the San Andreas System

The San Andreas fault, which forms the northeast boundary of the Gualala block, extends parallel to the coast line from Fort Ross to Manchester. The main trace of this fault, with its rift features, provides dramatic topographic expression of a zone of sheared and crushed rock, fault gouge, and larger masses of rock in fault-dragged slivers. This assemblage is diverse in lithology but includes a large representation of sandstone, shale, greenstone, and serpentine derived from the Franciscan Formation.

The main fault zone is about 1500 feet wide where it is exposed in the sea cliff north of Manchester, but it apparently narrows to widths of 500 to 1000 feet along much of its course to the south. Most of the onshore rift valley is occupied by streams, including the Gualala River, Garcia River, and Brush and Alder Creeks. Divides between drainages are low ridges, commonly with sag ponds along lines of recent ground displacement. Numerous topographic features commonly associated with large-scale transcurrent faulting, such as sag ponds, side-hill benches, scarps, and offset lines of drainage, are present within and along the margins of the rift zone. Fault displacement during the 1906 San Francisco earthquake occurred along a single general trend of ground rupturing, although in places there were as many as three strands of breakage. Right lateral slip in 1906, as determined by offsets of fences and other reference features, aggregated about 16 feet along the reach of the fault opposite Manchester.

In the southern and central parts of the Gualala block, the San Andreas fault system comprises the well-defined main fault zone and one or more parallel faults in the adjacent rocks underlying Gualala Ridge. However, in the northernmost portion of the block, north of the approximate latitude of Arena Cove, the fault system begins to splay out toward the northwest. The fault strands involved in this splaying are expressed topographically by subdued rifts, scarps, benches, and sag ponds, and they displace Quaternary terrace deposits. The zone between bounding strands of the fault system is at least $1\frac{1}{2}$ miles wide, and it may be as much as $2\frac{1}{2}$ miles wide where it reaches the coast north of Manchester. This shift in the pattern of the San Andreas fault breaks may well be related to a pronounced bend in gross alignment of the fault zone that begins a short distance north of the point where it intersects the coast north of Manchester. Results of subsea reflection profiling (Curray and Nason, 1967) have indicated that the general trend of the San Andreas fault shifts about 22 degrees toward a more northerly alignment in the 10-mile reach seaward from Manchester Beach. This must be accompanied by corresponding reorientation of the regional stress field and strain relationships in the adjacent terranes.

Recent studies of the San Andreas fault (Allen, 1968; Wallace, 1970) have suggested that the geologically recent behavior of the segment of the fault zone between Hollister and Cape Mendocino has been characterized by long intervals of relative quiescence, (100 to 1000 years), during which neither significant seismic activity nor displacement has taken place. These intervals have been punctuated by earthquakes in the magnitude range of 7 to 8-plus, accompanied by ground breakage, with dextral, strike-slip displacements of 5 feet or more.

D. Landforms

1. General Features

The principal landforms of the northern Gualala block include Gualala Ridge, a succession of broad coastal terraces on the seaward flank of this ridge, deep ravines that traverse the terrace surfaces, a wide flood plain in the lower valley of the Garcia River, and the present sea cliff. The block is separated geomorphically as well as structurally from the mainland terrain to the east by the San Andreas fault zone.

Gualala Ridge is an elongate, broad-crested upland that ranges in general altitude from 800 to 1300 feet. It probably constitutes a remnant of an ancient uplifted surface of marine erosion. The northeasterly flank of the ridge, bordering the rift valleys of the Garcia and Gualala Rivers, has a remarkably uniform slope, and it has not been significantly incised by the steep drainage courses descending from the upland surface. In contrast, the southwesterly slope of Gualala Ridge is gashed by steep-walled ravines 200 to 300 feet deep. From sources near the ridge crest, these ravines extend across the succession of coastal terraces to empty at points along the present coastline.

The Garcia River flows northwestward in the 800-foot deep San Andreas rift valley for a distance of 10 miles before veering sharply to the west and flowing between bluffs 400 feet high. Thence it traverses a wide flood plain before reaching the sea immediately north of Point Arena. Northward beyond the Garcia River, the rift valley is occupied by Brush Creek, which follows first the main rift and then a branch rift for a total distance of 4 miles. Thence this creek also turns and flows westward to the sea across another wide flood plain. Still farther north, the rift is marked by a flat-bottomed trench that contains numerous sag ponds but no established drainage courses. Subdued scarps, trenches, and side-hill benches are present along the ridge crest and the terrace surfaces on both sides of the rift zone in its most northerly 6 miles.

The present sea cliff is a prominent and nearly continuous feature 70 to 200 feet in height. Its slope ranges from about 1:1 to vertical. In most places where stratification in the exposed bedrock dips seaward, the cliff face is essentially a dip slope at angles of 35 degrees or more. In general, the steepest cliff slopes expose either very gently or very steeply dipping strata. The part of the cliff that extends from Arena Cove to Point Arena has been cut in rocks of the Point Arena Sandstone Member of the Monterey Formation. The relatively resistant nature of these thin- to thick-bedded sandstones probably is responsible for the existence of the Point Arena headland.

Sea-cliff retreat along this part of the coastline occurs through constant minor raveling and intermittent larger-scale failure. Most of the rock falls involve masses, 5 to 40 or 50 feet thick, that are bounded by fractures and bedding planes. The only areas of continuous sliding along the sea cliff mark ground that has been disturbed by faulting or that is characterized by weak sections of seaward dipping beds. Between Galloway and Schooner Creeks, both bedding-plane and earthflow types of landslides appear along extensive sections of the cliff.

The U. S. Coast Guard (1968) made cliff-margin surveys of the headland at Point Arena in 1908, and again in 1962 and 1968. Results of these surveys indicate that 10 to 30 feet of sea-cliff retreat occurred during a period of 60 years, corresponding to a rate of about 20 to 50 feet per century. The retreat was essentially confined to dip slopes, and little or none occurred in directions parallel to the strike of bedding.

2. Coastal Terraces

The coastal terraces occur along the seaward flank of Gualala Ridge as a succession of four major steps at respective general elevations of 80, 200, 300 and 400 feet above present sea level. As noted earlier, the relatively even, broad crest of the ridge itself probably also originated as a wave-cut surface; parts of the soil deposits present along this ridge may be weathered terrace deposits.

The 300-foot and 400-foot terraces are expressed as relatively isolated areas of gently sloping ground that are separated from similar remnants at like altitudes by stream-cut ravines, and from lower and/or higher terrace surfaces by intervening ground with moderate to steep slopes. The 80-foot and 200-foot terraces form broad, nearly continuous benches adjacent to the coast, and their surfaces in the Point Arena area respectively range in altitude from 40 to 100 feet and from 190 to 225 feet.

The terrace surfaces represent ancient marine wave-cut benches, generally thought to have been developed during periods of gradually rising sea level and to have received discontinuous coverings of Pleistocene marine deposits during subsequent periods of relatively lowering sea level. The marine beach and surf-zone deposits on the terraces characteristically are overlain by dune sand, flood-plain alluvium, and in onshore parts of the terrace cover along the bases of ancient sea cliffs, by various kinds of talus and colluvial deposits.

The four terraces were formed at different times during the Pleistocene epoch, and their respective ages can be correlated with their present altitudes. The lowest terrace is the youngest. Elevation of the terraces above present sea level may have been due in part to Pleistocene uplift of the Gualala block. It also is probable that the terraces were developed during former interglacial high stands of the sea, when sea level may have been as much as 350 feet higher than at present (e.g., Fairbridge, 1960). The respective roles of crustal uplift and shifting sea level in developing the succession of terraces in the Point Arena area have not yet been determined.

The extensive surface of the lowest, or 80-foot terrace slopes seaward with a gradient of 2.1 in 100, whereas the wave-cut rock surface beneath the terrace cover slopes seaward with a gradient of 1.6 in 100. The difference in slopes reflects a progressively increasing thickness of terrace cover in a landward direction. This youngest terrace shows no evidence of deformation, and the gradient of 1.6 in 100 may closely approximate the slope of the ancient wave-cut bench at the time of its formation. This gradient corresponds closely to that of the present wave-cut bench, which averages 1.5 to 2 in 100.

The gradients of the older, higher terrace surfaces also are similar to that of the 80-foot terrace. Local steeper slopes along the inner margins of these older terraces probably reflect thick accumulations of colluvial deposits, and some steeper slopes near their outer margins may have been formed by post-terrace erosion. The shoreline angles of the older terraces are rarely exposed; hence, it has not been possible to establish whether these surfaces have been deformed by warping. Some warping might be expected in ground so near the San Andreas fault zone, but none could be identified with confidence during the course of this investigation.

The broad crest of Gualala Ridge, which may represent a still older terrace, ranges considerably in altitude and has slopes of 5 to 8 in 100. This surface may have been brought to its present elevation and slope through block uplift and tilting of the Gualala Ridge structural unit along the Slick Rock - China Gulch and Section 21 - Section 17 faults.

E. Inferred Cenozoic Structural and Geomorphic Evolution of the Northern Gualala Block.

Available evidence suggests that the present structure of the northern Gualala block was developed mainly during the time between middle Miocene deposition of the Monterey Formation and Pleistocene cutting of the coastal terraces. There are no obvious unconformities within the Upper Cretaceous through Middle Miocene stratigraphic column, and no evidence of Pleistocene or younger tectonic deformation, other than that directly associated with the San Andreas fault, has been recognized. However, the Gualala block may have been affected by some general uplift during Pleistocene time, as suggested by the present positions of Gualala Ridge and the succession of coastal terraces. The deformation responsible for the folding and later block faulting of the northern Gualala block was essentially completed by the time when the presumed oldest terrace surface, remnants of which are preserved along the crest of the Gualala Ridge, was cut during the Pleistocene epoch. Indirect geomorphic evidence, discussed later in this section, suggests that this surface may have been uplifted by local block faulting, possibly during early Pleistocene time. To the east, however, fault movements associated with the San Andreas zone have continued intermittently to present times.

The Cenozoic structural and geomorphic evolution of the northern Gualala block is thought to have proceeded as follows:

1. Marine sedimentation and local volcanism occurred during a period of time from late Cretaceous through middle Miocene. Major transcurrent movement along the San Andreas fault began probably at least as early as the beginning of Miocene time.

2. Major tectonic deformation resulted in development of broad, east-west trending folds in the southerly two-thirds of the Gualala block and of narrow, northwest-southeast trending folds in its northerly third. The differing style and orientation of folding in these two adjacent areas may have resulted in part from the contrast in mechanical properties between the predominantly sandstone section to the south and the sandstone-siltstone-shale section to the north. It also seems likely that the two areas were affected by unlike stress fields on opposite sides of the Galloway Creek fault. These fields may have been active at different times, but the apparently conformable relations within the sedimentary section suggest that the Gualala and German Rancho Formations were not folded prior to deposition of the Miocene section.

Neither the east-west trending folds of the Anchor Bay - Gualala Ridge subprovince nor the northwest-southeast trending folds of the Garcia River - Point Arena subprovince bear any obvious relation to the strain pattern associated with dextral strike slip along the San Andreas fault. Boyle (1967) believed that a thrust fault might dip in a seaward direction beneath the Point Arena Coastal area, and he attributed the folding in that area to deformation of the upper plate of this postulated thrust. Despite careful search, no field evidence for such a thrust was found during the present mapping, and the thrust fault hypothesis is here considered to be conjectural. Certainly it is not necessary for an explanation of the observed structural relationships.

Most of the faults in the northern Gualala block clearly transect the folds, and therefore must be younger features. The Havens Neck and Hathaway Creek faults have similar northwesterly trends and senses of movement, down to the southwest. The northeast-trending Galloway Creek fault, which apparently separated earlier fold-generating stress fields, seems to offset this northwesterly trend; its history may include several episodes of movement, the latest postdating movements along the Havens Neck and Hathaway Creek faults. The China Gulch and Gualala Ridge structural units contain strata that have been uplifted, rotated, and partially overturned relative to the strata in the adjacent structural units.

The Slick Rock - China Gulch and Section 21 - Section 17 faults, along which the blocks represented by those units seem to have been uplifted, may well be northeast-dipping reverse faults, and their movements may have occurred in response to drag-induced compressive stresses associated with the San Andreas fault.

3. At some time subsequent to the folding and faulting just described, the Gualala block was affected by one or more episodes of uplift and planation. An erosion surface was developed across the deformed Cretaceous and Tertiary rocks, and remnants of this surface now are preserved on the crest of Gualala Ridge.

4. Relationships between the upper seaward slopes of the northern end of Gualala Ridge and the Slick Rock - China Gulch and Section 21 - Section 17 faults can be ascribed to either of two possible histories:

Following development of the surface now partly preserved on the crest of Gualala Ridge, additional block uplift of the China Gulch and Gualala Ridge structural units probably was effected by steep reverse faulting between the Slick Rock - China Gulch - Section 21 - Section 17 faults and the San Andreas fault. The uplift amounted to 500 or 600 feet, with the dislocated seaward portion of the ancient surface remaining at or near sea level to form the present 400-foot surface. The seaward-facing fault scarp was then modified by sloughing and erosion, and marine erosion extended the wave-cut bench a short distance back into the base of the scarp. According to this interpretation, the Gualala Ridge surface and the 400-foot surface originated as the same surface, and the present 400-foot surface merely reflects subsequent marine erosion; its deposits thus would be younger than those on the uplifted higher surface.

Alternatively, planation of the surface on Gualala Ridge could have been followed by 500 to 600 feet of general uplift of the northern Gualala block. Marine erosion at the level of the present 400-foot surface then could have created a wave-cut bench that extended across the seaward portion of the uplifted block, which consisted mainly of easily eroded Lower Miocene rocks. The bench-cutting stopped at the Slick Rock - China Gulch - Section 21 - Section 17 faults, bordering the sandstones and mudstones of the Gualala and German Rancho Formations.

The first explanation, involving fault uplift of the China Gulch - Gualala Ridge structural blocks, is here favored. The Gualala Ridge surface is variably tilted, whereas the 400-foot surface is not, which suggests structurally independent movements of the higher surface. Further, the rocks adjoining the Slick Rock - China Gulch - Section 21 - Section 17 faults are at least in part stratigraphically equivalent, and they probably are not significantly dissimilar in their resistance to erosion. Erosional advance of the 400-foot surface ending at these faults seems remarkably fortuitous.

5. Subsequent to the development of the 400-foot surface, other surfaces were cut during a series of retreats and advances of sea level in response to the Pleistocene cycles of waxing and waning glacial activity. Successive wave-cut benches were cut during readvances of sea level to interglacial high stands, and differences in altitude of adjacent benches may be in part attributable to intermittent or continuing uplift of the land surface. Four distinctive terrace surfaces were cut during these interglacial periods of rising sea level.

The ancestral Garcia River occupied the rift valley of the San Andreas fault until sea level was lowered following development of the 400-foot terrace. The river then established a course across the north end of Gualala Ridge, and it has maintained that course through the remaining geomorphic evolution of the area. Similar parts of other drainage courses probably were initiated at about the same time. Three additional cycles of terrace cutting followed. The most recent episode of marine erosion in the area has followed the rise in sea level from its late Wisconsin low stand to its present elevation, and has involved formation of the present wave-cut bench and sea cliff, together with partial drowning of the lower reaches of major ravines and valleys.

Faulting has continued along the San Andreas fault system through late Cenozoic time, generally within the main rift but also at times along outer subparallel strands along the crest of Gualala Ridge, along the lower terrace surfaces north of the Garcia River, and possibly also under the river valley. Despite careful search, however, no evidence indicating Pleistocene tectonic deformation outside of the San Andreas fault system has been found in the northern Gualala block.

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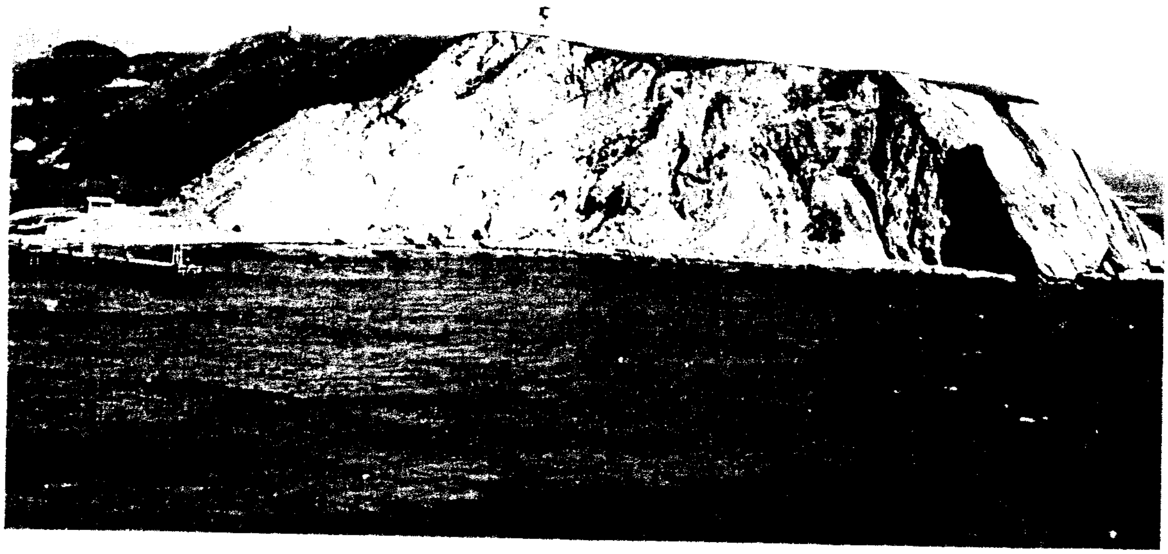


Figure (II)-1. East-southeastward view across Arena Cove to headland southeast of Cove. Axis of Arena Cove anticline, exposed in headland, plunges at moderate angles toward viewer.

Figure (II)-2. View northwestward toward south side of headland southeast of Arena Cove. Note unbroken asymmetric Arena Cove anticline exposed in sea cliff and on wave-cut bench.

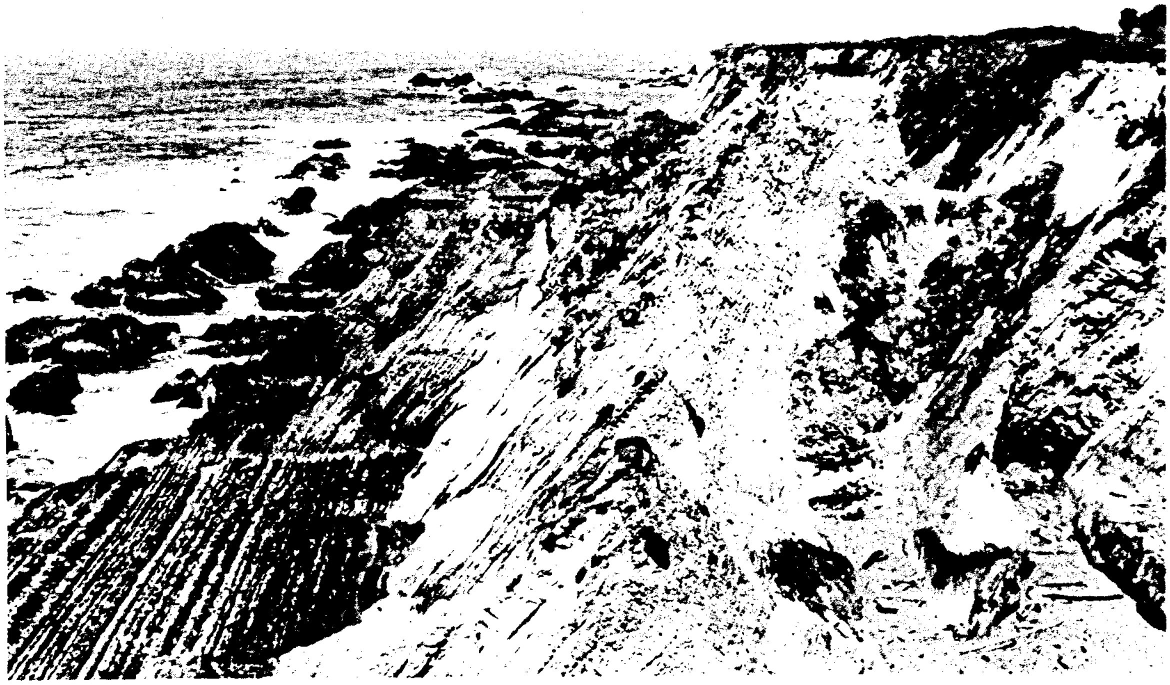


Figure (II)-3. View north-northwestward along sea cliff on seaward side of Point Arena. The cliff is a dip slope in thin-bedded Point Arena Sandstone.

Figure (II)-4. Northeastward view across ravine of Point Arena Creek near Arena Cove, showing outcrop of Monterey Formation in trough of northwest-plunging Big Terrace syncline. The 200-foot terrace appears as a level surface in middle distance.

Figure (II)-5. West-southwestward view down canyon where Garcia River cuts across the north end of Gualala Ridge toward the sea. Buildings in middle distance are on an old, bedrock-floored river terrace.

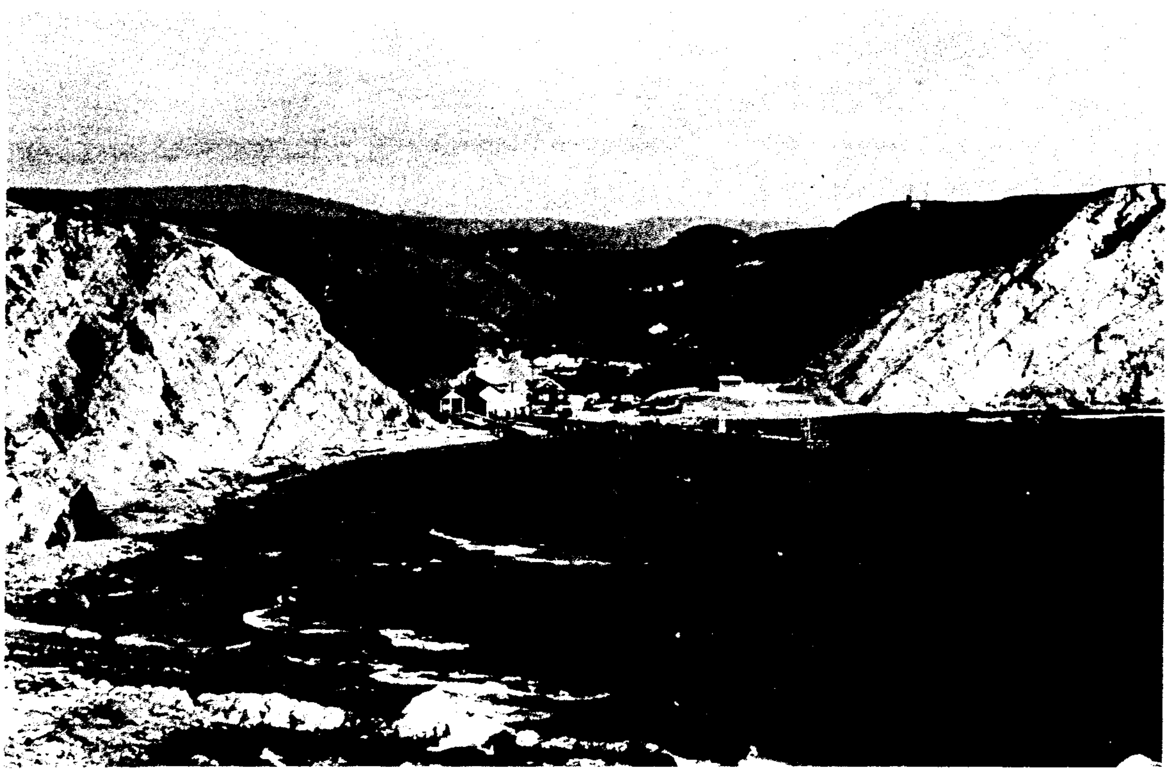


Figure (II)-6. East-southeastward view toward head of Arena Cove. Thick bed of asphaltic sandstone appears as a dark band in cliff at left side of photograph.

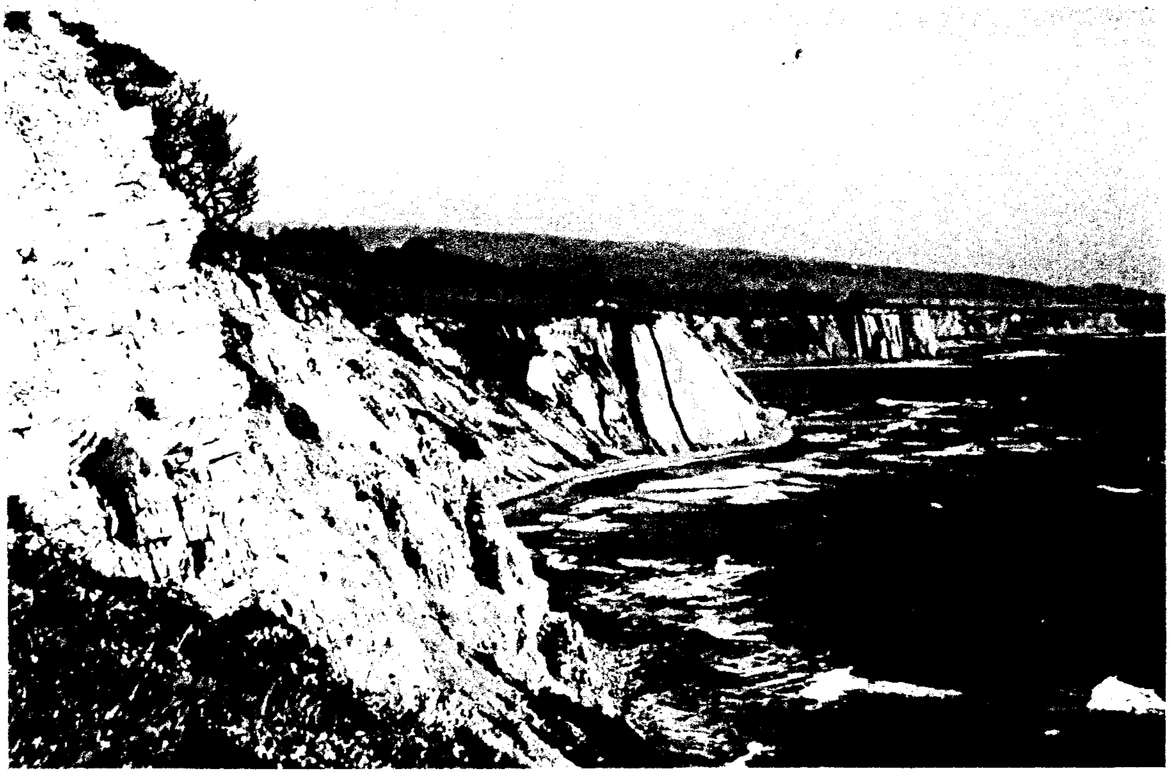


Figure (II)-7. Southeastward view showing sea cliff and lower coastal terrace surface southeast of Arena Cove. Thin-bedded diatomaceous and siliceous strata of the Monterey Formation dip gently into the cliff face in right foreground, and form prominent dip slope in middle distance.

Figure (II)-8. Northwestward view of sea cliff southeast of Ross Creek. Gradational contact between Monterey Formation (light strata) and Gallaway Formation (dark strata) is visible in right center of photo.

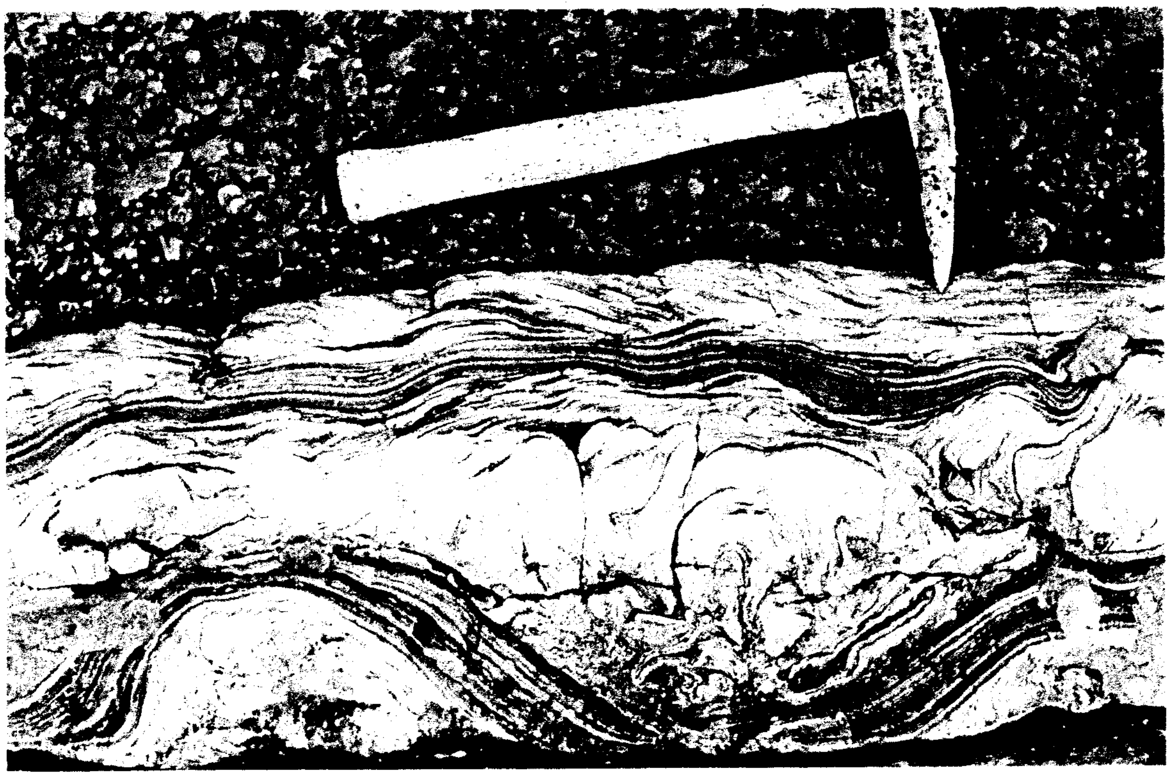


Figure (II)-9. Gallaway Formation, Abalone Cove section. Typical dark gray siltstone with layer of convoluted sandstone.

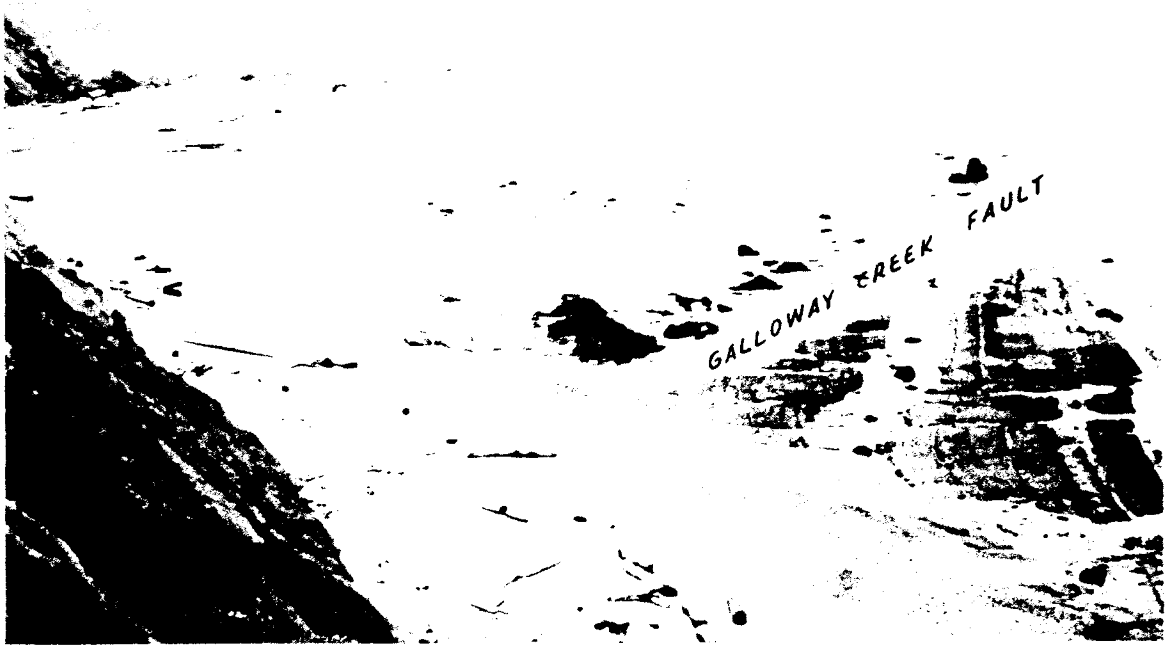


Figure (II)-10. View southward from sea cliff north of Galloway Creek, showing Galloway Creek fault. Dark gray siltstone and sandstone interbeds of the Abalone Cove section of the Gallaway Formation (bench at right) are warped and faulted against massive sandstone (dark isolated outcrops near center).

Figure (II)-11. Northwestward view showing fault cutting alluvial terrace deposits in the NW$\frac{1}{4}$ of Section 32 (T13N R16W), along the north side of the Garcia River.

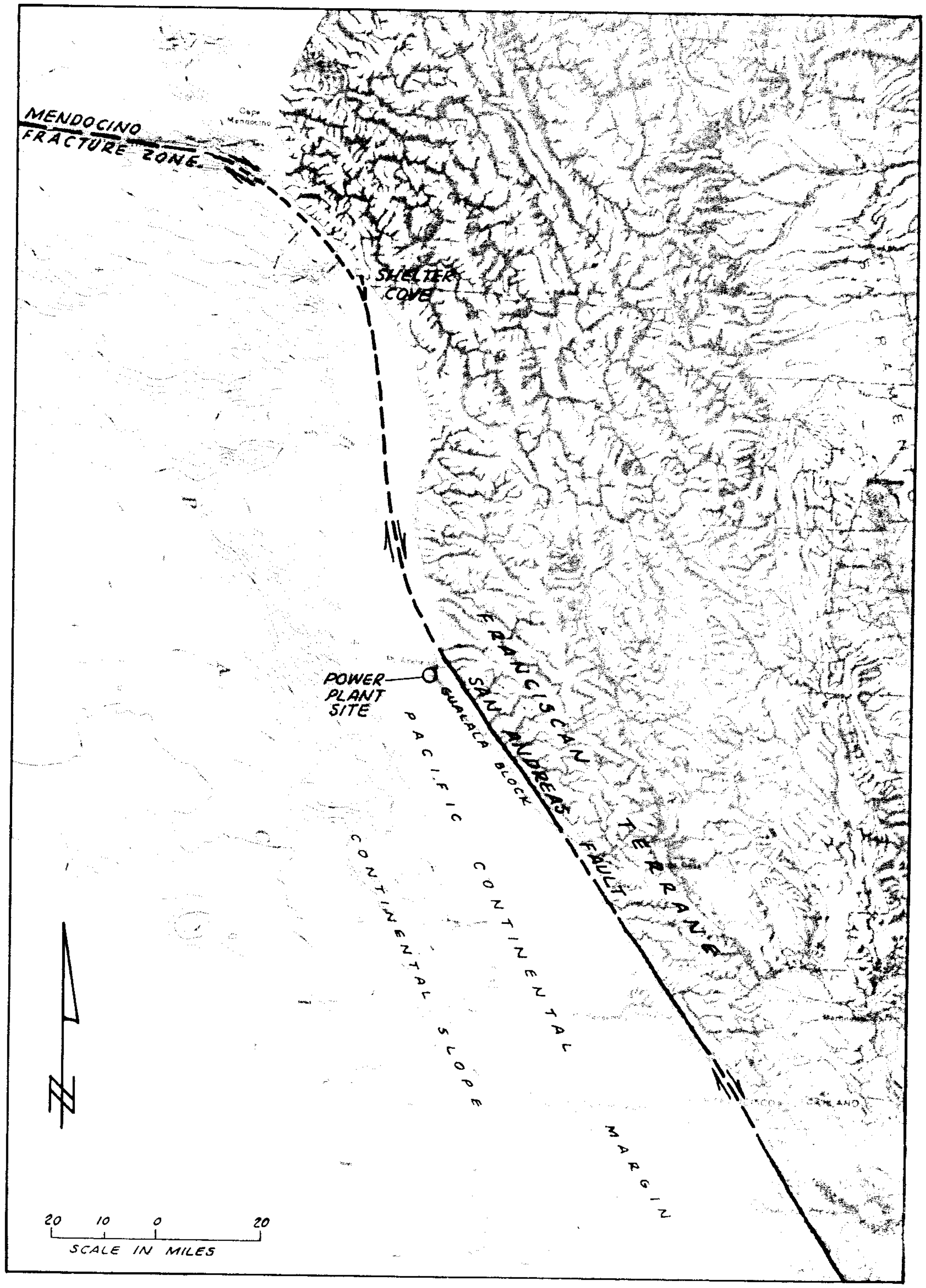
Figure (II)-12. View at same locality as shown in photograph above, showing fault offset of contact between bedrock and overlying alluvial terrace deposits. Fault is about 3500 feet southwest of main trace of San Andreas fault and approximately parallel to it.

Figure (II)-13. Northwestward view along sea cliff southeast of Galloway Creek, showing shallow bedding-plane failure of thick-bedded sandstone in Gallaway Formation.

Figure (II)-14. Southeastward view along sea cliff between Galloway Creek and Schooner Gulch. Note dip slope on headland in middle distance, and bedding-plane slump to left of headland.

Figure (II)-15. Southward view along sea cliff north of PG&E Mendocino Power Plant site. Rocks in wave-cut bench and vertical portion of cliff in middle distance overlie a bed of soft, sheared claystone that lies stratigraphically above the dip-slope cliff face in the left near distance. "Earthquake crack" was reported by USC and GS in 1906 as being about 50 feet inland from monument, along strike of the claystone bed. Crack was probably caused by seismically triggered failure and shifting along this claystone bed.

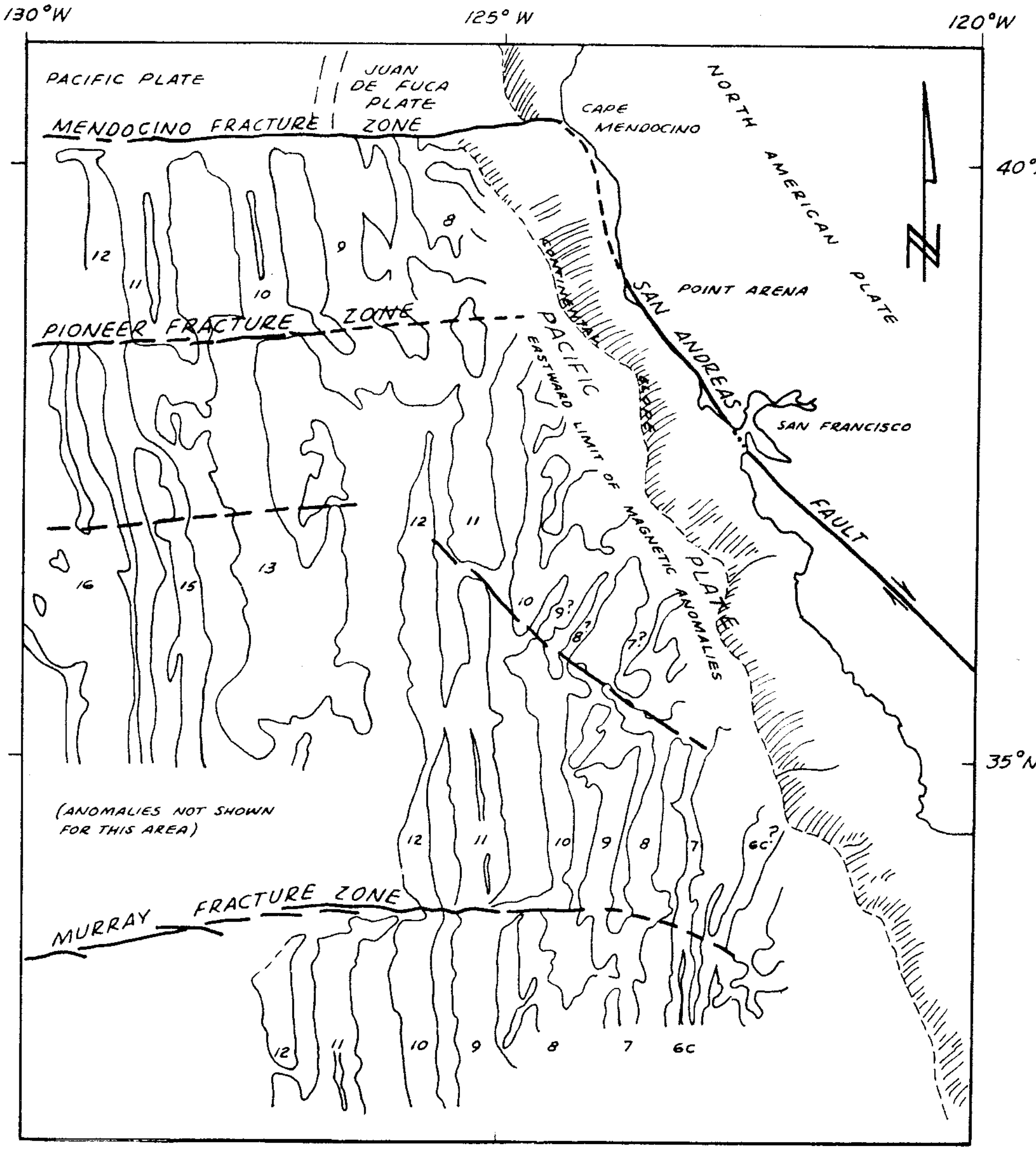
Figure (II)-16. Offset along joint in sea stack. Channel in foreground is along plane of sheared claystone bed.



A. NORTH CENTRAL CALIFORNIA COAST AND CONTINENTAL MARGIN

LOCATION OF SAN ANDREAS FAULT NORTH OF PT. ARENA FROM CURRAY AND NASON (1967)

MAP BASE REDUCED FROM A PORTION OF THE USGS 1:100,000 SCALE SHADED RELIEF MAP OF CALIFORNIA



B. OCEANIC AND CRUSTAL PLATES, MAGNETIC ANOMALIES, OCEANIC FRACTURE ZONES, THE SAN ANDREAS FAULT AND THE CENTRAL CALIFORNIA COASTLINE (AFTER ATWATER, 1970)

YOUNGEST MAGNETIC ANOMALY DISTURBED BY PIONEER FRACTURE ZONE (ANOMALY 8) IS APPROXIMATELY 29 MILLION YEARS OLD

EXPLANATION

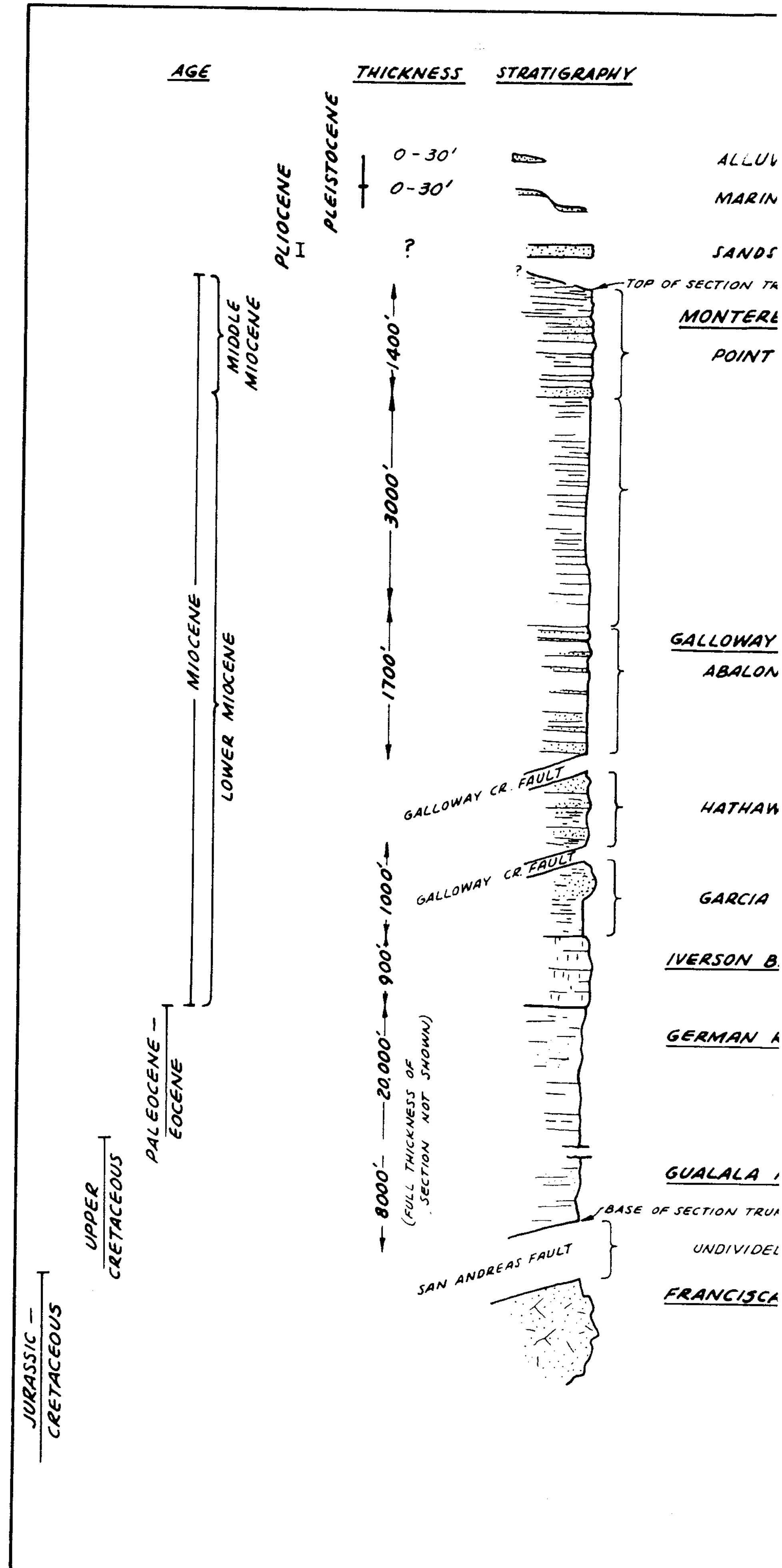
MAGNETIC ANOMALY. (STRIP OF OCEANIC CRUST HAVING MAGNETIZATION OF REVERSED POLARITY, CAUSED BY REVERSALS IN THE EARTHS MAGNETIC FIELD DURING CONTINUING OCEAN FLOOR SPREADING AND VOLCANISM. NUMBERING OF ANOMALIES AND AGE OF ANOMALY 8 FROM HEIRTZLER ET. AL. (1968) AND BERGGREN (1969) CITED IN ATWATER (1970).

OCEANIC FRACTURE ZONE (TRANSFORM FAULT WITHIN AND BETWEEN PLATES)

PG & E MENDOCINO POWER PLANT SITE GEOLOGY INVESTIGATION

REGIONAL TECTONIC SETTING, CENTRAL PACIFIC COASTAL AREA

DRAWING NO. II-1 AMENDMENT 3


AGE
THICKNESS
STRATIGRAPHY
PLEISTOCENE
PLIOCENE
0-30'
0-30'
?
MIDDLE MIOCENE
MIOCENE
LOWER MIOCENE
1400'
3000'
1700'
1000'
900'
20,000'
8000'
(FULL THICKNESS OF SECTION NOT SHOWN)
PALEOCENE – EOCENE
UPPER CRETACEOUS
JURASSIC – CRETACEOUS
TOP OF SECTION
MONTERE
POINT
GALLOWAY
ABALON
GALLOWAY CR. FAULT
HATHAW
GALLOWAY CR. FAULT
GARCIA
IVERSON B
GERMAN
GUALALA
BASE OF SECTION
UNDIVIDED
SAN ANDREAS FAULT
FRANCISCA

CRIPTION

RACE DEPOSITS (Qt)

OVERLYING NON-MARINE TERRACE DEPOSITS (Qter)

Tp)

AT SEA CLIFF

MATION (Tmm)

SANDSTONE (Tmp) MASSIVE TO THIN-BEDDED, PLATY FINE-GRAINED SANDSTONE AND SANDY SILTSTONE, WITH ZONES OF DOLOMITIC CONCRETIONS, AND INTERBEDS OF ASPHALTIC SANDSTONE. A SECTION OF SANDSTONE EXHIBITING MAJOR CROSS BEDDING AND ANCIENT SUBMARINE LANDSLIDING FEATURES IS PRESENT IN THE MIDDLE OF THIS UNIT.

WELL BEDDED TO INDISTINCTLY BEDDED DIATOMACEOUS AND PORCELANEOUS SHALE AND MUDSTONE, BECOMING MORE SILICEOUS TOWARD THE BASE OF THE UNIT

KOONER GULCH FORMATIONS (UNDIVIDED) (Tmg)

SECTION (Tmg(a)) WELL BEDDED DARK GRAY SANDY SILTSTONE WITH THIN INTERBEDS OF FINE-GRAINED SANDSTONE EXHIBITING CONVOLUTE INTERNAL STRUCTURE.

EEK SECTION (Tmg(h)) INTERLAYERED MASSIVE TO MEDIUM-BEDDED FINE-GRAINED ARKOSIC SANDSTONE AND INDISTINCTLY BEDDED OLIVE GRAY CLAYEY SILTSTONE

AND SCHOONER GULCH SECTIONS (Tmg(g); Tmg(s)) MASSIVE DARK GRAY MUDSTONE, WITH INTERBEDS OF MASSIVE FINE- TO COARSE-GRAINED ARKOSIC SANDSTONE

(Ti)

FORMATION (Tg) INTERBEDDED MASSIVE TO MEDIUM-BEDDED FINE- TO MEDIUM-GRAINED ARKOSIC SANDSTONE AND SILTSTONE.

TION (NOT SHOWN ON MAP)

BY SAN ANDREAS FAULT.

MBLAGE IN SAN ANDREAS FAULT ZONE

RMATION (KJf)

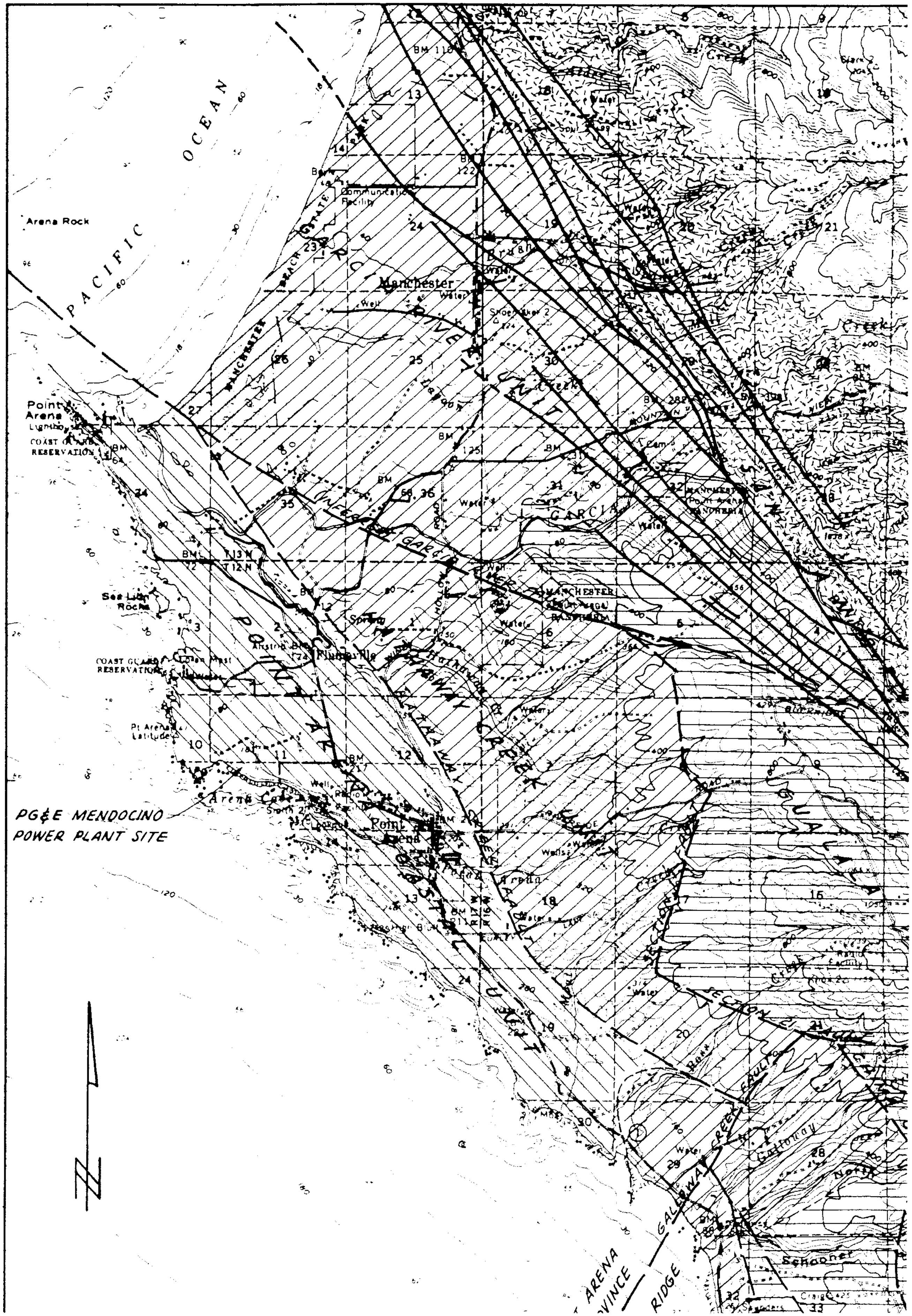
NOTE: SEE DRAWING NO. II-6 FOR A DETAILED STRATIGRAPHIC SECTION OF THE POINT ARENA SANDSTONE

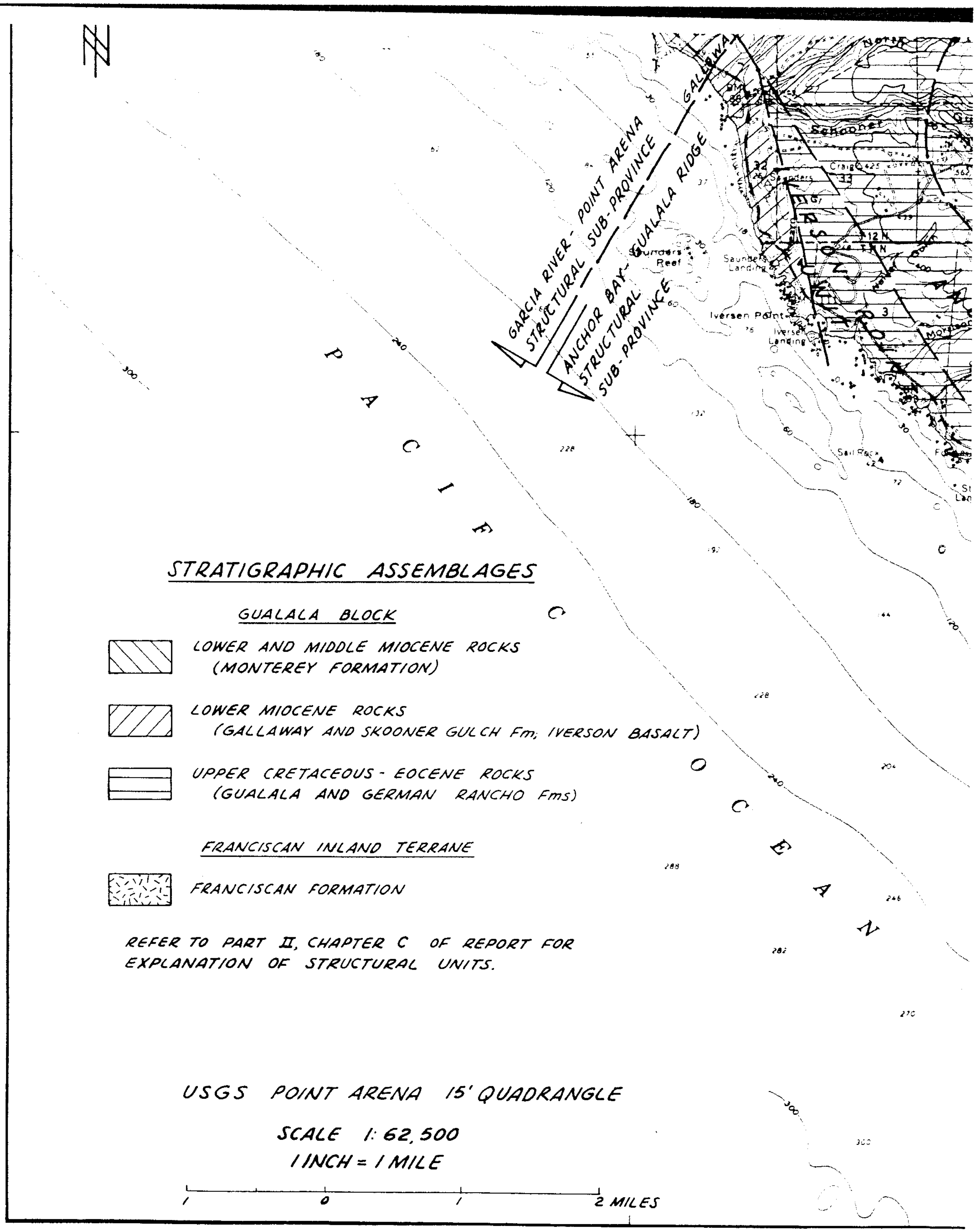
PG & E MENDOCINO POWER PLANT SITE GEOLOGY INVESTIGATION

STRATIGRAPHIC SECTION - POINT ARENA-GUALALA COASTAL AREA

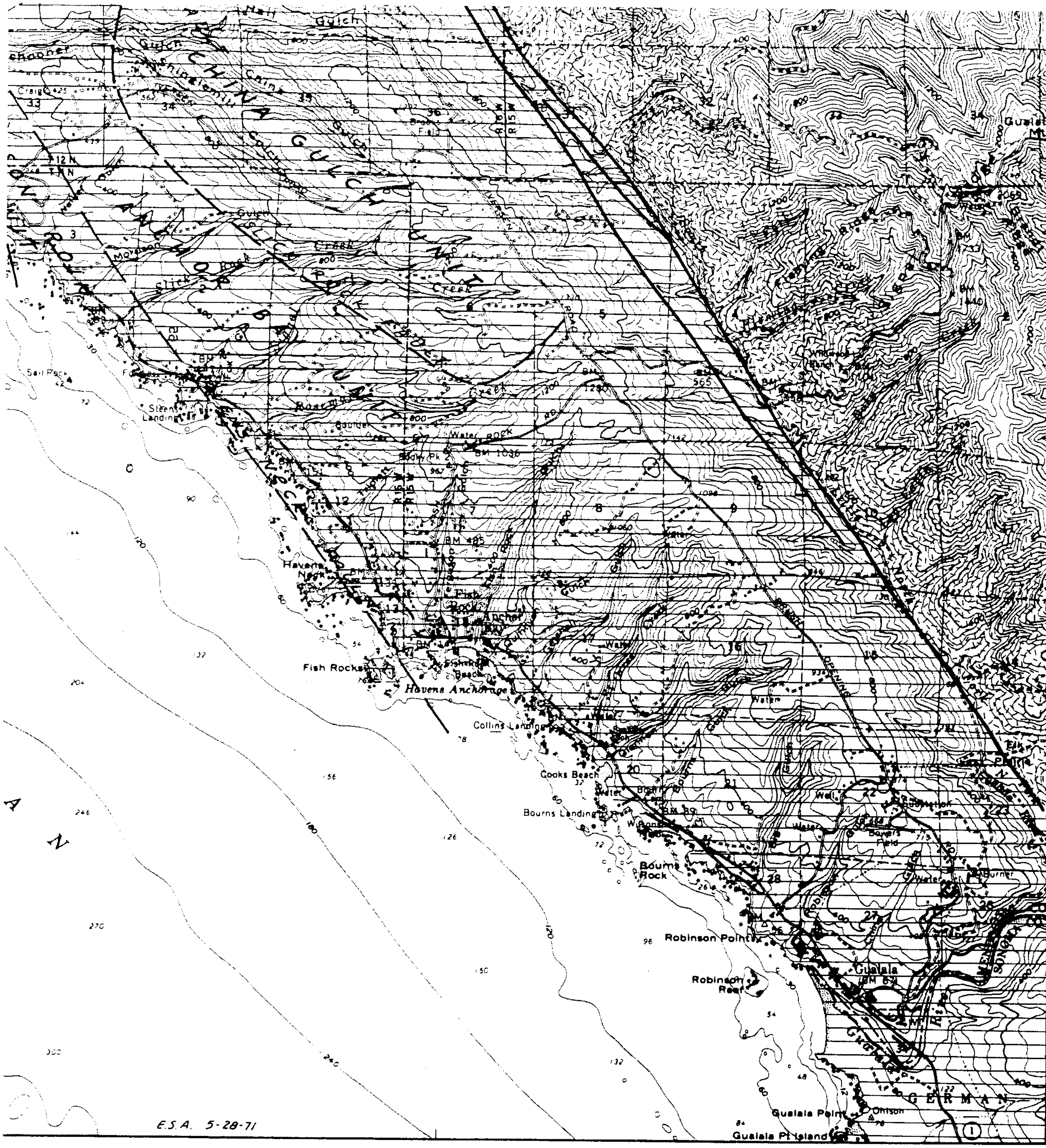
DRAWING NO. II-2

E.S.A. 6-4-71


PACIFIC OCEAN
Arena Rock
Point Arena Lighthouse
COAST GUARD RESERVATION
Communication Facility
Manchester
Garcia
MANCHESTER Point Arena RANCHERIA
Sea Lion Rocks
COAST GUARD RESERVATION
Pt Arena Latitude
Arena Cove
Point Arena
PG&E MENDOCINO POWER PLANT SITE
Galloway
Schooner
North
T 13 N
T 12 N



GARCIA RIVER - POINT ARENA STRUCTURAL SUB-PROVINCE
ANCHOR BAY - GUALALA RIDGE STRUCTURAL SUB-PROVINCE
Saunders Reef
Saunders Landing
Iversen Point
Iversen Landing
Schooner
Sail Rock
PACIFIC OCEAN
STRATIGRAPHIC ASSEMBLAGES
GUALALA BLOCK
LOWER AND MIDDLE MIOCENE ROCKS (MONTEREY FORMATION)
LOWER MIOCENE ROCKS (GALLAWAY AND SKOONER GULCH Fm; IVERSON BASALT)
UPPER CRETACEOUS - EOCENE ROCKS (GUALALA AND GERMAN RANCHO Fms)
FRANCISCAN INLAND TERRANE
FRANCISCAN FORMATION
REFER TO PART II, CHAPTER C OF REPORT FOR EXPLANATION OF STRUCTURAL UNITS.
USGS POINT ARENA 15' QUADRANGLE
SCALE 1: 62,500
1 INCH = 1 MILE
1
0
1
2 MILES



PG&E MENDOCINO POWER PLANT SITE GEOLOGY INVESTIGATION

STRUCTURAL UNITS AND STRATIGRAPHIC ASSEMBLAGES OF THE POINT ARENA-GUALALA COASTAL AREA

DRAWING NO. II-3

III. Nuclear Power Plant Site at Arena Cove

A. Site Description.

The Mendocino Power Plant Site is situated on the northerly margin of Arena Cove about 1-1/2 miles west-northwest of the city of Point Arena and 2-1/2 miles south-southeast of Point Arena lighthouse. It includes most of the $N\frac{1}{2}$ of Section 11 and the on-shore portions of the $SW\frac{1}{4}$ of Section 11 and the $E\frac{1}{2}$ of Section 10, T12W, R17W, MDB&M. The 409-acre property has maximum dimensions of about 6000 feet east-west and about 4000 feet north-south; it includes coastal frontages of 3500 feet on the west, facing the open sea, and about 3800 feet on the south, facing Arena Cove. The east side of the site fronts on California State Highway 1, and part of its north side adjoins a U. S. Coast Guard loran station.

The principal topographic elements of the site include a 40- to 160-foot sea cliff, a terrace surface that gradually rises in altitude from 40 feet to about 100 feet and occupies about half the site area, a moderate to steep slope and northwesterly draining ravines between the 100- and 200-foot contours, and a partially dissected upper terrace at altitudes of 200 feet or more.

Most of the ground surface is covered with a thick growth of grass and other plant types adapted to the rigorous climatic environment of the coastal terraces. Small pine trees are scattered along the inner margin of the lower terrace, and a planted long row and several clumps of mature cypress trees are present on the upper terrace surface. High brush and stands of willows line the more easterly of the two ravines draining the upper terrace surface. Numerous small coniferous trees, planted in 1967 by Pacific Gas and Electric Company, are present on the upper terrace adjacent to Highway 1 and on the lower terrace near the Arena Cove sea cliff. Marshy ground can be recognized along the east-central margin of the lower terrace and in the southeastern corner of the upper terrace area.

Recent modifications in the site topography consist of three large exploratory trenches in the lower terrace adjacent to Arena Cove. These trenches are oriented east-northeast, and are 40 to 60 feet wide at the surface, 10 feet to about 30 feet deep, and 250 to 3100 feet long. They were excavated to points below the water table and were not daylighted to the sea cliff; hence they are partially water filled. The two longer trenches overflow and spill across the westernmost edge of the terrace unless frequently pumped.

B. Geology

1. Setting in the Point Arena Coastal Structural Unit.

The Mendocino site area extends as a broad strip across the westerly two-thirds of the Point Arena Coastal structural unit, which is underlain by the Monterey Formation. The onshore portion of this unit extends for a distance of at least 3 miles to the northwest, and it terminates against the Galloway Creek fault about $4\frac{1}{2}$ miles to the southeast. The Hathaway Creek fault, which separates the Point Arena Coastal structural unit from the Hathaway Creek structural unit farther east, lies about half a mile beyond the east limit of the property and about $1\frac{1}{2}$ miles east of the plant site (Drawing II-4). The strata underlying the property express two major northwest-plunging folds, the Arena Cove anticline and the Big Terrace syncline, each of which is traceable for distances of more than a mile southeast of the site area and dies out within a mile beyond this area in the opposite direction. No evidence of post-folding fault displacement of strata in the Point Arena Coastal structural unit has been found north of the vicinity of Abalone Cove, $4\frac{1}{2}$ miles southeast of the site. Faults that transect fold structures in the adjacent Hathaway Creek structural unit apparently die out within this unit or merge with the Hathaway Creek fault; they do not cross this bounding fault into the coastal structural unit.

2. Structure.

The geologic structure of the site area is dominated by the two major folds noted above. Some lesser elements of structure are variously related to local shearing, bedding dislocations, and intrusion of sandstone dikes, all of which apparently were associated with the major folding. Others, in contrast, are earlier features resulting from Miocene sea-floor disturbances that were essentially contemporaneous with the Monterey sedimentation; these are now preserved as lithified features in the bedrock section. A poorly defined zone of minor shear surfaces, small bedding dislocations, and sandstone dikes also extends from the sea cliff northward through the ground explored by trenches A-B, C-D, and E-F (Drawings III-1 and III-2).

The crestal deformation in the Arena Cove anticline is complex in detail and evidently reflects local adjustments among contrasting lithologic units. Several of the shear zones and small folds exposed in trench C-D are well defined, strongly developed features, but they die out along strike in the 300 feet between trenches C-D and E-F (Drawing III-2). Similarly, the zones of crumpled and detached bedding exposed in the sea cliff opposite Stations 7+20 and 8+00 in trench C-D can be seen to die out downward toward the base of the cliff over a vertical distance of about 50 feet. This tendency of axial-zone deformation to be present only locally, and to die out both vertically and along strike, is characteristic of concentric fold structures, and typical examples are well displayed at several other sea-cliff localities along the coast to the south.

Shearing, minor dislocations of bedding, and numerous sandstone dikes can be observed in the west flank of the Arena Cove anticline in the site area. These features occur mainly in a poorly defined north-trending zone 90 to 120 feet wide. Some of the ground in this zone is marked by fluted and slickensided surfaces and by individual beds and small pod-like masses of rock that are pervasively sheared. The shearing evidently occurred during folding of the section, as the sandstone dikes that intrude and transect the sheared rocks are not themselves sheared; nonetheless, many of these dikes occupy cross-fractures that probably developed in response to folding. The fluted shear surfaces are distinctive features, but they appear and die out within distances of a few inches to a few tens of feet, and correlation of cross-fractures on opposite sides of them shows that they involve only a fraction of an inch to a few feet of displacement.

Joints and less regular fractures are widespread in the rocks that underlie the site. Most of those exposed in the wave-cut bench fringing the site area are shown in Drawings III-3, 4, and 5. Detailed representation of the fractures exposed in the walls of the three exploratory trenches is included in the drawings with Appendix A to this report.

The relatively uniform section of platy sandstone in the west flank of the Arena Cove anticline, as exposed on the wave-cut bench along the westerly edge of the property, is characterized by a distinct set of steeply dipping to vertical joints that trend northwest and are spaced at intervals of 5 to 30 feet, and by a second set of less regularly spaced cross-joints that trend northeast and dip southeast at angles of 60 to 80 degrees. Individual fractures of both sets are traceable along strike for distances of 20 feet to more than 300 feet. Offsets of a few inches to $2\frac{1}{2}$ feet can be recognized along several of the more prominent fractures on the seaward side of a sheared failure horizon that corresponds to a bed of claystone (Drawings III-1, III-5), but none of the offsets extends stratigraphically below this surface toward the plant area farther east.

Fractures are less regularly developed in the rock exposed on the wave-cut bench facing Arena Cove. They are most abundant in three areas, each of which is related to a specific region of folding or warping. The area of most intense fracturing, in the axial region of the main anticlinal fold, corresponds to a broad wave-cut channel and so is not exposed. Away from zones of folding, the fracturing is expressed mainly as two joint sets, similar to those on the open-coast bench described above. Relatively evenly spaced cross-joints, developed at right angles to the stratification, are confined to several relatively massive, resistant beds in the lower part of the section. Other joints, in contrast, can be traced across groups of beds for distances of 50 feet to more than 300 feet.

The structural pattern within the area is shown in Drawing III-1, and in more detail in Drawing III-2. The Arena Cove anticline is well exposed in three dimensions in the south- and west-facing sea cliffs and adjoining wave-cut benches, as well as in the exploratory trenches. Scattered exposures within and adjacent to the northeast and southeast parts of the site area permit delineation of the general form of the Big Terrace syncline.

The axis of the Arena Cove anticline trends northwestward through the headland on the south side of Arena Cove, thence swings west-northwestward under the Cove sea floor before turning northwestward beneath the lower terrace in the site area. It decreases progressively in plunge from about 40 degrees in the headland through about 30 degrees in the sea cliff to less than 5 degrees north of the site. In the site area, strata in the west flank of the anticline strike about N20W and dip southwest, or seaward, at angles of 25 to 35 degrees. Beyond a zone of small-scale deformation that marks the fold crest between the sea cliff and trench C-D, strata in the east flank of the fold strike about N35W and dip northeastward at angles of 30 to 35 degrees. The dip becomes shallower in the easterly 500 feet of trench E-F (Drawing III-1). The internal deformation that marks the axial region of the anticline, as exposed in the sea cliff and in trench C-D, dies out both up section and along strike. Thus the part of the fold exposed in trench E-F is a relatively simple arch.

The axis of the Big Terrace syncline decreases in plunge from about 30 degrees to less than 5 degrees as it extends northwestward beneath the upper terrace in the site area from the canyon of Point Arena Creek. The strata in the flanks of this fold strike about N30W and dip toward its trough at angles of 30 to 60 degrees.

Markedly disturbed features of sedimentary structure are well exposed in the wave-cut bench and the sea cliff along the north side of Arena Cove, and are shown in Drawings III-3 and III-4. A thick, wedge-like complex includes a melange featured by large blocks of warped to severely contorted sandstone, a thick tongue of massive to cross bedded coarse-grained pebbly sandstone, and overlying masses of coarse chaotic breccia. A sharp fold with an amplitude of at least 60 feet is confined within the sandstone tongue. The domain of this fold is marked by slumped blocks, irregular dragged masses, and curving "peels" of shaly sandstone.

The entire complex of deformed rocks is underlain and overlain by normally layered parts of the Monterey section, and it plainly is a product of large-scale submarine sliding in middle Miocene time. Formation of the disturbed rocks evidently resulted from sea-floor disturbances that gave rise to slumping, debris flowage, channeling, and soft-sediment intrusion within a thick section of fine- to coarse-grained sandy layers. The materials within the complex subsequently were lithified along with the rest of the Miocene bedrock section.

A younger and wholly different type of local deformation is expressed by small-scale folds and dislocations that are present in the axial region of the Arena Cove anticline. These features include joints and shears, detachments in bedding, and disharmonic folds with wide ranges in form and dimensions. They are well exposed in the main sea-cliff re-entrant and in adjacent parts of trench C-D (Drawing III-2).

C. Special Considerations for Power Plant Siting

1. Tectonic Deformation.

The types of tectonic activity that have affected the Miocene rocks in the area of the Mendocino Power Plant Site at Arena Cove comprise folding, fold-related fracturing and shearing, and general uplift. The site lies $4\frac{1}{2}$ miles from the main trace of the San Andreas fault, which has been active throughout late Cenozoic time. Thus it is pertinent to consider the possibility of future warping, folding, tilting, uplift, subsidence, and faulting in the site area.

Warping and Folding. The rocks underlying the site were folded during late Miocene or early Pliocene time, between about 15 and 5 million years ago, but they have not been folded since then. Pronounced warping of Pleistocene terrace surfaces has occurred at several places along the California coast, but in the Point Arena area even the higher, older Pleistocene terraces have not been thus deformed. The lowest terrace is clearly undeformed. Marine deposits on this terrace have been dated by radiocarbon determinations as greater than 39,000 years in age, and the age of these deposits and the underlying wave-cut bench probably is at least 80,000 years. Future tectonic deformation expressed as warping or folding therefore can be eliminated as a design consideration at the site.

Tilting, Uplift, and Subsidence. Large-scale, long-term uplift of the land surface, attributable to regional tectonic warping or to the vertical component of block movements, has affected most parts of the California coast. Such uplift, however, is too broad in extent and slow in occurrence to be significant for facilities constructed along the coast.

In certain other coastal areas of the world, relatively rapid uplift, downdropping, or tilting of large tracts of land has accompanied fault movements. Notable recent examples have been described from southern Chile in 1960, Alaska in 1964, and southern California in 1971. Such known occurrences, however, have been in regions characterized by fault movements with large components of dip slip, rather than predominantly strike-slip movements like those associated with the San Andreas fault. Both geomorphic evidence and the historic record of displacements along this fault clearly demonstrate that earthquake-related tectonic changes in altitude of the land surface are very small outside of the contemporary rift zone.

Faulting. Two factors are especially pertinent to the question of whether permanent ground displacement along a fault might occur within the site area during the useful lifetime of a power plant: (1) The Middle Miocene strata underlying the area are not cut by through-going faults, as demonstrated by results of detailed mapping along the continuous sea-cliff and exploratory-trench exposures of these strata. (2) The wave-cut bedrock surface beneath the coastal terrace in the plant site area has not been displaced by faulting, as also demonstrated by detailed mapping of the contact between bedrock and overlying marine terrace deposits. This bench was formed 80,000 to 120,000 years ago. If significant fault breakage has not occurred in the past, it can be asked whether a new break might propagate through previously unfaulted rock of the Point Arena structural unit to reach the site, and whether "secondary" tectonic faulting could develop in the strata underlying the site, either along existing shear or fracture surfaces or in rocks that are now unbroken.

The existing pattern of tectonic features in the northern Gualala block reflects a regional history of ancient block faulting, and of continuing faulting along the main trace of the adjacent San Andreas fault. Recent movements probably have occurred repeatedly along various of the fault strands that splay out northward from the San Andreas zone north of the latitude of Arena Cove. Through the earlier part of the regional history, faulting either was absorbed within the ground between the Point Arena Coastal unit and the San Andreas fault or was deflected along the Hathaway Creek fault; it assuredly was not propagated into the coastal unit. Later, throughout Pleistocene and Holocene time, faulting evidently has been confined to the San Andreas zone. These features indicate that any postulated fault propagation into the plant site would require a pattern of tectonic stress for which there is neither present evidence nor precedent in 15 million years of geologic history. Such postulated faulting would have to diverge from a well-developed system of pre-existing faults and cut through relatively stronger, unfaulted rock. This is neither geologically nor physically likely, and it can be concluded that propagation of primary faulting into the site is not a significant possibility at the Mendocino site.

In regard to the question of secondary tectonic faulting in the site area, it is significant that: 1) Neither the ground surface nor the underlying Miocene bedrock at the site has been affected by any through-going faulting at any time. 2) There is no documented instance of secondary tectonic faulting occurring elsewhere except by renewed movement along a pre-existing fault. 3) There is no known example of secondary tectonic faulting occurring more than 1.5 miles and probably no more than about 1.0 mile away from the main trace of the San Andreas fault. Thus it also can be concluded that local development of secondary tectonic faulting is not a significant possibility at the Mendocino site.

2. Seismic Shaking.

Moderately severe to severe ground shaking can be expected at the Mendocino site during the useful lifetime of a power plant. The most probable source of severest motion would be a great earthquake originating on the nearby San Andreas fault, a factor that should be considered in the design of a power plant or other important structures.

3. Non-tectonic Subsidence and Uplift.

Non-tectonic subsidence or uplift resulting from regional compression or rebound in response to massive loading or unloading by glacial ice, volcanic materials, or sedimentary deposits would not be a significant factor in the design of major structures at the Mendocino site. However, non-tectonic changes in ground level also can be related either to changes in fluid pressure in the subsurface or, in some instances of local subsidence, to solution or mining extraction of subsurface materials. The rocks underlying the Mendocino site do not contain aquifers from which ground water could be extracted in large volumes, nor do they include soluble strata or mineral deposits likely to be extracted by mining. Hence ground subsidence due to removal of subsurface water, to solution of limestone, gypsum, or salt beds, or to the collapse of mine openings will not be a problem.

Oil field operations involving extraction of petroleum, gas, water, and sand can give rise to ground subsidence, and water flooding for secondary recovery of petroleum can cause surface uplift and even, under some circumstances, earthquakes or surface faulting. The rocks underlying the site area are known to contain residual liquid and gaseous hydrocarbons, and several test wells have been drilled on and near the property. No commercially valuable petroleum thus far has been discovered. In the unlikely event that a nearby oil field is developed in the future, special attention should be directed to the forestalling of any damaging subsidence, uplift, or ground rupture in the vicinity of an existing power plant.

4. Sea Cliff Retreat.

Under existing natural conditions, the sea cliff along the westerly and southerly sides of the Mendocino site area is under nearly constant attack by the surf. Wave action erodes the cliff base directly, in general by hydraulic plucking and by abrasion with beach gravel, and it also prevents the accumulation of a protective talus apron. The upper faces of the sea cliff are degraded chiefly through the slaking, spalling, and raveling of fragments that range from small chips to blocks several feet on a side. Detachment of larger rock slabs occurs from time to time; most of these are bounded by joint and bedding surfaces.

The form of the seaward-facing cliff along the westerly margin of the site area is strongly influenced by the distribution of weak claystone beds and friable sandstone layers in the rock section, and by a well-defined pattern of bedding and jointing. Most of the dip-slope part of the cliff face, which faces west-southwest, exposes sandstone immediately underlying a sheared bed of claystone. Some movement may have occurred along this bed at the time of the 1906 earthquake, as noted earlier, and hence the entire mass of rock overlying the claystone may have been displaced slightly by gravity failure in a down-dip direction. The maximum amount of displacement that could have occurred since deposition of the overlying terrace covering, however, is no more than about 1 foot. Additional movement of this slide block would displace a 400-foot reach of the cliff, as well as ground extending back about 75 feet from the rim of the cliff. Structures on other parts of the terrace surface would not be affected.

Cliff re-entrants are localized along other claystone beds lower in the section, along sandstone sills, and along the zone of small-scale disturbance in the crestal region of the Arena Cove anticline. Those faces that are transverse to the strike of bedding are roughly planar features that evidently were developed along one of the major joint sets.

The rate at which the sea cliff retreats depends chiefly on local conditions of surf action and of bedrock lithology and structure. At the Mendocino site, the westerly and relatively more exposed sea cliff has been developed in medium- to thin-bedded, moderately well cemented sandstone, and the base of the cliff is protected from all but high-tide wave action by a 100 to 200 foot wide bench and/or by adjacent sea stacks. The sea cliff $2\frac{1}{2}$ miles north, near the Point Arena lighthouse, has been developed in rock of similar lithology and structural attitude, but it lacks the protective sea-level bench. Cliff-line surveys made there by the U. S. Coast Guard in 1908, 1962, and 1968 indicate a rate of sea cliff retreat of about 20 to 50 feet per century. A somewhat lesser rate of retreat should obtain at the power plant site.

5. Geotechnical Considerations.

Construction of a nuclear power plant at the Mendocino site would involve extensive grading, principally in rock, along with tunnel construction, the founding of heavy structures in rock cuts, extensive earthwork, and extensive offshore work in Arena Cove. Major geotechnical considerations pertaining to this construction include ground response to seismic shaking, foundation conditions for structures, slope stability, excavation and tunneling conditions, nature and availability of earthwork construction materials, ground water conditions, and occurrences of hydrocarbon fluids in the bedrock section. Specific determination and evaluation of these conditions is beyond the scope of this investigation, and must be accomplished during the preliminary and design stage studies for the plant. Some potentially useful comments can be offered, however, from results of geologic investigations thus far completed.

Ground Response to Seismic Shaking. As pointed out earlier, ground shaking can be expected at the Mendocino site, with the most severe motion attending a great earthquake originating on the nearby San Andreas fault. The nature of dynamic ground response in the site area cannot be considered here, but the possibility of earthquake-induced permanent ground deformation can be assessed from the results of completed geologic studies.

The extremely low potential for future surface faulting at the site already has been discussed, and it can be concluded that ground rupture of this kind need not be considered in the plant design. There remains, however, a possibility of small, surficial dislocations of small rock masses along weak shear, joint, or bedding surfaces. Evidence suggesting a past occurrence of such earthquake-induced displacement was found in trench E-F (See Appendix A, Drawing No. 16). Potential sites of such minor dislocations can best be identified by detailed mapping of exposures in final construction cuts, and corrective measures, if indicated, can be taken then.

Foundation Conditions. Except where they are locally sheared and crushed in the axial region and west flank of the Arena Cove anticline, the rocks of the site area are relatively strong and incompressible. They should provide adequate foundation support for heavy structures of the plant facility. Special factors that should be considered during exploration for specific structures include the possible occurrence of soft clay-mudstone interbeds that might be compressed or otherwise deformed under some loading conditions, and the distribution and lithology of asphaltic sandstone beds that might be subject to creep deformation under heavy loads.

The 2- to 20-foot section of Pleistocene deposits on the lower terrace consist principally of dense but uncemented sand and pea gravel, with pockets of coarse rubble at its base. The uppermost parts of the section consist of sandy to silty clay subsoil, along with wind-blown sand that has been stabilized by vegetation. The terrace deposits beneath these surficial layers should provide satisfactory foundation support for ordinary structures.

Slope Stability. Within the general constraints of plant layout, the initial design of cut slopes should be compatible with bedrock lithology and structure. Final evaluation of stability should be made as early as possible during the course of the project. Any local problems thereby identified then could be resolved by means of rock bolts, tie-backs wire mesh, or other appropriate remedial treatment.

Steep slopes in the thin - to thick - bedded rocks underlying the site area should be stable in excavations except at those few localities where the strata have been intensely sheared or where they will dip out of cut slopes. Local instability of joint-bounded blocks also might be encountered in some places.

Exposed surfaces of slopes cut in the thick-bedded sandstone of the Point Arena section might well deteriorate surficially because of slaking. This should not affect the overall slope stability, but it would permit minor surface erosion of the cuts.

Cut slopes in the sandy terrace deposits are subject to piping erosion and caving in areas of seepage emergence. These materials also tend to gully rapidly when exposed on sloping cut surfaces. These problems can be controlled through interception and drainage of seepage, and by appropriate grading and planting of slopes.

Excavation Conditions. The terrace deposits at the Mendocino site are readily excavable. Poor working conditions can be anticipated, however, where basal parts of the thickest deposits lie beneath a local perched ground water table. Much of the terrace section drains slowly and cannot be easily dewatered, as the permeability of its materials is moderate to low.

Excavation of the three exploratory trenches at the site demonstrated that the uppermost 5 to 10 feet of bedrock underlying the surface of the lower terrace can be excavated by D-8 dozers (with rippers) and scrapers. Within the narrow confines of the trenches, ripping progress in the more firmly cemented intervals of thick-bedded sandstone was very slow. Better progress probably could be made in cuts of larger area; however, the seismic velocity of 7000 f.p.s. determined for much of the rock under the site indicates generally difficult or marginal ripping conditions.

Tunneling Conditions. The plant layout may include tunnels extending from the terrace area to points of discharge along or beyond the west-facing sea cliff. Such tunnels would extend across the west flank of the Arena Cove anticline, traversing the strike of the bedding at an angle of about 90 degrees. Conditions for tunneling through the Monterey strata along such an alignment should be satisfactory for the use of conventional methods, and probably for the use of a boring machine. The rock is not extremely hard, yet most of it is firm and should stand well without exceptionally heavy support. More difficult conditions might be encountered if a tunnel were driven in the highly fractured and locally sheared rocks along the axial region and the immediately adjacent westerly flank of the Arena Cove anticline. Such conditions could persist for distances of 150 to 300 feet across each of these zones of deformation. Minor inflows of mobile asphalt and inflammable gas also could give rise to special problems during construction.

Further study will be required to evaluate the stability of the rock section overlying the seaward dipping failure surface in the sheared claystone bed along the west side of the site, if a tunnel to convey cooling water to an offshore point of discharge is to be constructed across this claystone and into the overlying section. Some shifting of the rock overlying this claystone may have occurred at the time of the 1906 earthquake, hence special design provisions might be required for such a tunnel.

Earthwork Construction Materials. Material derived from excavation of the rock underlying the site will break down during handling and placement to rocky silty sand which should be a satisfactory component of compacted fill. The sand, pea gravel, and clayey silty sand of the terrace deposits also should yield good fill material, although it might be necessary to schedule grading operations so that some blending of the surficial clayey materials and the underlying clean sand can be accomplished during fill placement. Ancient wood and other organic materials are present in the rubble at the base of the terrace section, but in such small amounts that they probably can be safely incorporated in fill masses. The uppermost 6 inches to 1 foot of organic-rich sand of the terrace section probably could be stripped and stockpiled for use in landscaping.

None of the rock at or near the site is suitable for use as riprap. Gravel from the Garcia River might be found suitable, through appropriate testing, for aggregate and for drain zones.

Ground Water. A perched body of ground water exists within the Quaternary deposits along the easterly half of the lower terrace in the site area. Water lies at or near the surface in a wide belt marshy ground extending more than 2000 feet northward from the east end of trench E-F. Control of this water will be necessary to prevent it from flowing into excavations in the plant area. Some water also is present in the bedrock section, especially where fractures are abundant and closely spaced.

Hydrocarbon Fluids. Natural gas and viscous residual petroleum fluid occupy fractures in the bedrock at many places, and at least two horizons of asphaltic sandstone lenses also are present beneath the site area. Three layers of massive asphaltic sandstone that crop out near the Arena Cove landing probably underlie the site at considerable depth.

The asphalt observed in fractures is relatively mobile and flows slowly into any available open space. The gas moves more rapidly into excavations as they are developed. Special sealing measures may be required to control the flow and accumulation of these fluids during construction activities.

Figure (III)-1. Vertical aerial view of Mendocino Power Plant Site and vicinity.

Documentation of Geologic Investigation

in the

Vicinity of Point Arena Creek

Introduction

This report and the accompanying geologic map have been prepared in order to provide more detailed documentation of geologic conditions along the lower reach of Point Arena Creek. In particular, this documentation applies to the question of whether a fault might be concealed beneath the alluvium of the valley bottom. The more detailed geologic data presented here support the conclusion that no fault is present in this area, a conclusion implicit from information earlier shown on Geologic Map Drawings II-4 and III-1.

The information provided here is based on the field work carried out by R. H. Jahns and D. H. Hamilton in 1970 and 1971, along with supplemental field checking and plotting of data at a larger scale by D. H. Hamilton in 1972. The geologic data are presented on an aerial photograph base, which shows directly many of the areas of continuous outcrop along the valley walls. No large-scale topographic map exists for this area.

Geology of the Lower Point Arena Creek Area.

The lower reach of Point Arena Creek follows a west-northwesterly course for a distance of about one mile from the town of Point Arena to the mouth of the creek at the head of Arena Cove. The stream here occupies a sharply defined valley that is about 200 feet deep, 30 to 400 feet wide along its bottom, and 1000 to more than 1200 feet wide between its rims. In effect, it has cut a gash beneath the surface of the "200-foot" coastal terrace in this area.

The rocks exposed on the valley walls represent the Monterey Formation of early to middle Miocene age. They consist of marine mudstone, shale, and siliceous shale. They are variously overlain by scattered surficial deposits on several terrace surfaces preserved along the valley walls, by colluvium on slopes, by alluvium on the valley floor, and locally by minor amounts of artificial fill.

The major structural feature in the bedrock of the lower Point Arena Creek area is the northwesterly trending and plunging asymmetric fold known as the Big Terrace syncline. The axis of the adjacent Arena Cove anticline passes through the headland south of the creek and traverses Arena Cove beyond the mouth of the creek. Minor structural features consist of bedding-related joint sets and scattered more prominent cross fractures.

Discussion of Considerations Relating to the Possibility of Faulting Beneath Point Arena Creek.

Considerations pertinent to the question of whether a fault might exist along the lower reach of Point Arena Creek include the following:

1. The distribution and extent of continuous exposures of bedrock in the area.
2. The continuity of fold structures in the bedrock on opposite sides of the creek-bottom alluvial fill, and
3. The continuity of distinctive strata on opposite sides of the creek-bottom alluvial fill.

Owing to the continuous exposure of unfaulted strata in the 200 foot high sea cliff extending from the mouth of Point Arena Creek, any fault in the vicinity of the creek necessarily would be confined to the alluvium-covered valley floor at the margin of Arena Cove. The position of an easterly (landward) extension of any possible fault in this area is restricted by the numerous and extensive exposures of unbroken strata that are present within the valley. These exposures are so positioned that any fault extending through this area would have to follow a markedly sinuous course. This possibility, however, is denied by the continuity of the axis of the Big Terrace syncline over a distance of about 3000 feet from one side of the valley to the other, including a 400 foot wide section concealed by alluvium in the valley bottom.

The lack of offset of features on opposite sides of the alluvial fill is further confirmed by the continuity of two distinctive beds, one of friable tuffaceous siltstone and the other of fissile shale, in the Monterey section across a 250 foot wide valley-bottom area situated 800 feet east of the synclinal axis.

Conclusion.

Based on the evidence cited above, it can be firmly concluded that no fault involving significant displacement of the bedrock structure and stratigraphy is present within the valley along the lower reach of Point Arena Creek. It is probable that no discontinuity other than small, fold-related breaks exists in this valley.

APPENDIX D

TO

GEOLOGY OF THE MENDOCINO POWER PLANT

SITE

AMENDMENT 3

The "Control Width" and the "Zone Requiring Detailed Faulting Investigation" in the vicinity of the Mendocino Power Plant Site near Point Arena.

This memorandum presents the results of a study to determine the "Control Width" of active faulting and the "Zone Requiring Detailed Faulting Investigation" in the vicinity of the Mendocino Power Plant Site near Point Arena. The study involved analysis of the geologic conditions relating to faulting in the area between the site and the San Andreas fault in terms of applicable sections of the seismic and geologic siting criteria proposed by the Atomic Energy Commission. The results of this work can be summarized as follows:

1. The Magnitude of Earthquake to be anticipated occurring in this area is Greater than 7.5. The width of the Zone Requiring Detailed Faulting Investigation is therefore 4 x the control width.

2. The Control Width along the reach of the San Andreas fault extending for 10 miles in either direction from the point nearest the plant site is 8400 feet. The center of the zone corresponding to the control width lies about 2000 feet southwest of the 1906 trace of rupture. The Zone Requiring Detailed Faulting Investigation is therefore 33,600 feet wide, and its boundaries are 16,800 feet from the center line of the control-width zone.

3. The proposed power plant site, including the switchyard area, lies outside of the Zone Requiring Detailed Faulting Investigation. Only a few hundred feet of ground in the northeasternmost part of the site property lies within the zone.

4. The investigations carried out at the power plant site are consonant with those indicated, in the proposed AEC criteria, for sites situated in the Zone Requiring Detailed Faulting Investigation, even though the plant site is not situated in such a zone.

The accompanying drawing is annotated to show the Control Width and the Zone Requiring Detailed Faulting Investigation. Copies of Table 1 and Figure 1 from the proposed AEC criteria also are attached for reference.

Discussion

Geologic data pertaining to the Mendocino Power Plant Site, including offshore data obtained by Weston Geophysical Engineers, Inc. and by the Scripps Institute of Oceanography, were reviewed in light of the elements of the AEC proposed seismic and geologic siting criteria relating to definitions of "active faulting," fault "Control Width," and the "Zone Requiring Detailed Faulting Investigation." Because no evidence of "active" faulting in the offshore area has been found, the pattern of faults mapped onshore defines the fault "control width." The "control width" of a fault, according to the proposed criteria, is "the maximum width of mapped fault traces, including all Quaternary fault traces which join or can reasonably be inferred to join the main fault trace, measured within 10 miles along the fault's trend in both directions from the point of nearest approach to the site."

In the vicinity of the Mendocino Power Plant Site, the "main fault trace" clearly is the trace of the 1906 break within the San Andreas fault zone. The southwesternmost strand of this fault that is known (from outcrop data) to displace Quaternary deposits lies 3500 fee southwest of the main trace; however, possible geomorphic evidence of surface displacement is associated with another strand located 6000 feet southwest of the main trace, and so this more distant strand is here taken as the southwesterly boundary of the "control width" zone. For the northeasterly boundry of the "control-width" zone, a strand 2400 feet northeast of the main trace is taken on the basis of probable geomorphic evidence of surface displacement. The resulting zone therefore is 8400 feet wide. Several of the faults that are present in the ground between the "control-width" zone and the site are indicated as "possible strands of San Andreas fault zone" on Drawing II-4 of the PSAR Geologic Report; however, these faults do not exhibit any of the characteristics noted in the proposed criteria as indicating an "active" status, and they do not join the main fault trace. Accordingly, they are not considered in establishing the "control width" of the San Andreas fault for this area.

The "Zone Requiring Detailed Faulting Investigation" is established by directly applying the specifications indicated in the text of the proposed criteria (Figure 1; Total width = 4 x control width, centered along the center line of the control-width zone). In the vicinity of the site, this results in a zone 33,600 feet wide that is parallel to the San Andreas fault. The southwesterly, or seaward side of this zone lies 5000 feet northeast of the plant foundation area.

Extract from criteria proposed in 10CFR Part 100, Appendix A

Table 1

Distance from the site (miles)	Minimum length of fault (miles) to be considered in establishing Safe Shutdown Earthquake
0 to 20	1
greater than 20 to 50	5
greater than 50 to 100	10
greater than 100 to 150	20
greater than 150 to 200	40

* If the Safe Shutdown Earthquake can be associated with a fault closer than 200 miles to the site, the procedures of subparagraphs IV (a) (7) and IV (a) (8) need not be carried out for successively more remote faults.

Extract from criteria proposed in 10CFR Part 100, Appendix A

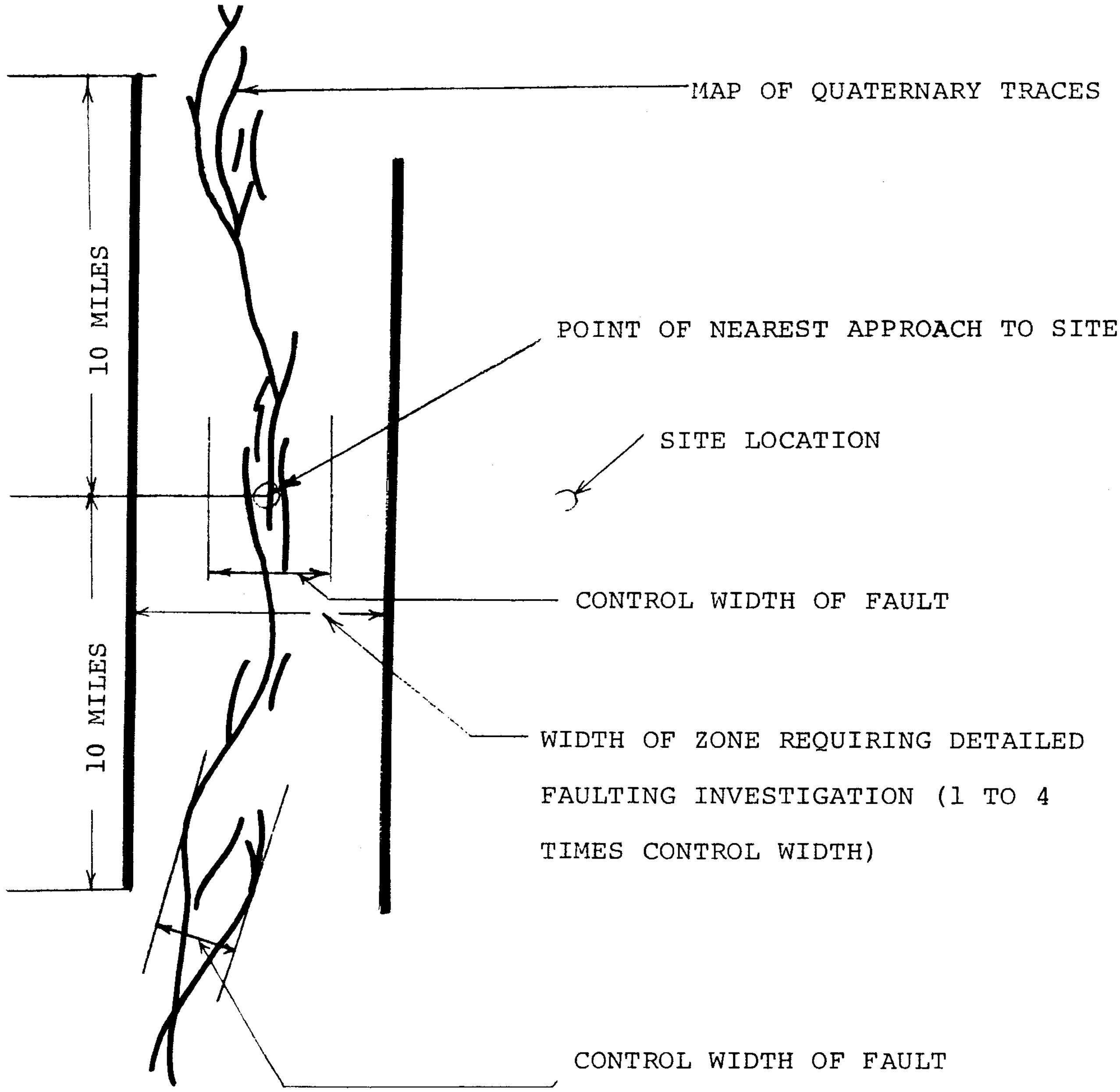
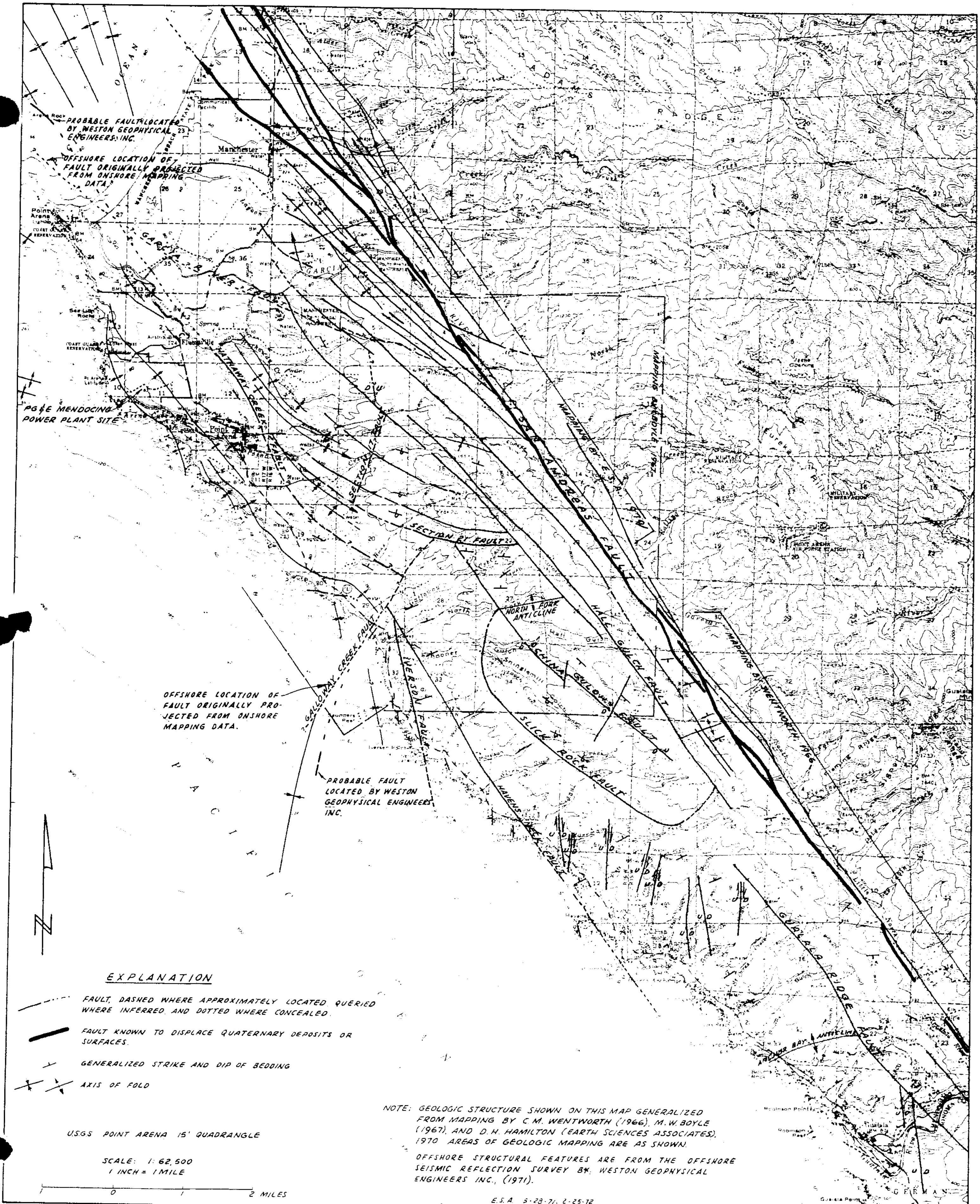


Figure 1 -- Diagrammatic illustration of delineation of width of zone requiring detailed faulting investigation for a specific site area.



PG&E MENDOCINO POWER PLANT SITE GEOLOGY INVESTIGATION

TECTONIC MAP OF THE POINT ARENA-GUALALA COASTAL AREA