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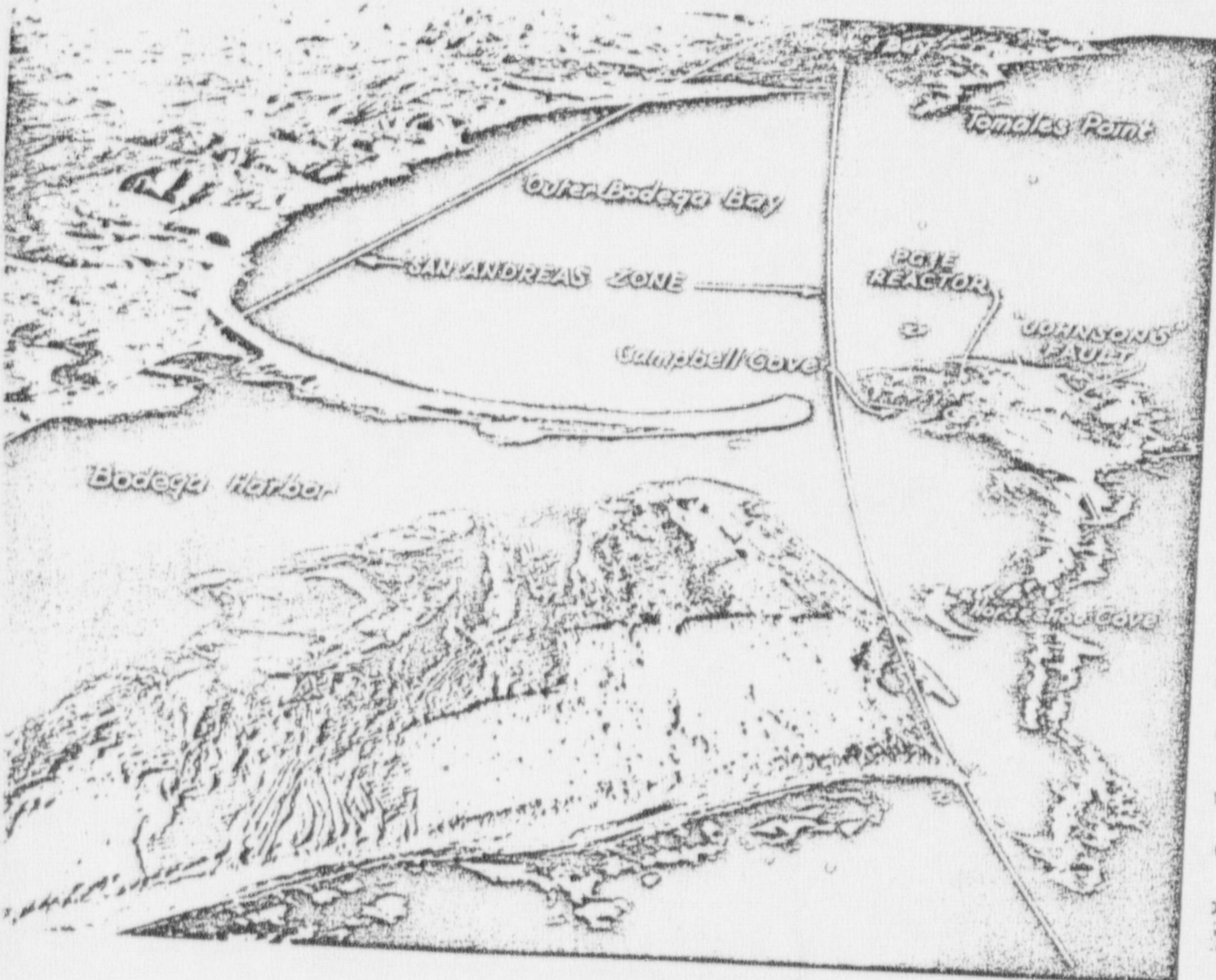
Geologic and Seismologic Study of Bodega Head

BY

Pierre Saint-Amand



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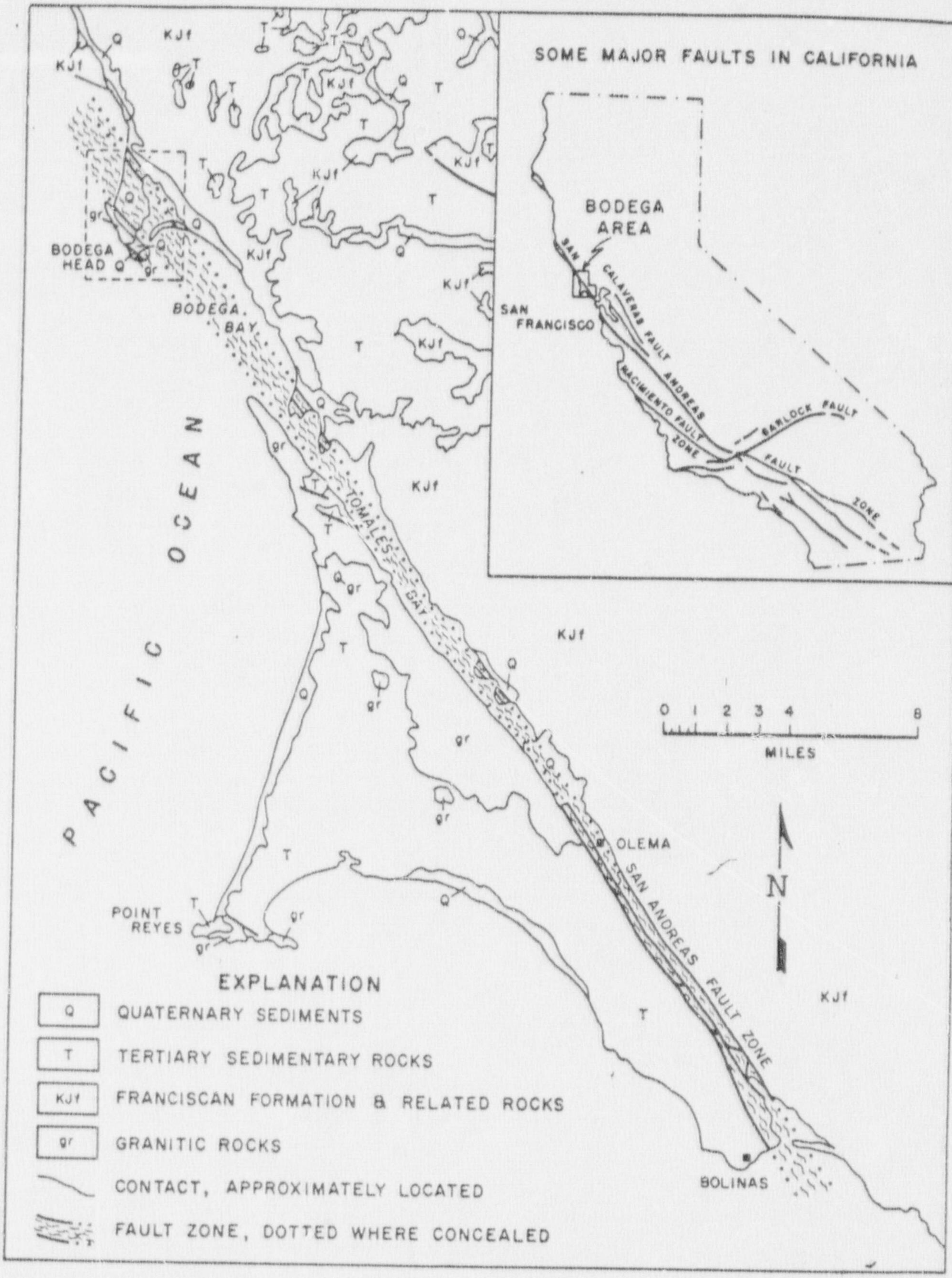
INTRODUCTION

Dr. Saint-Amand's previous publications are many. The most recent, Los Terremotos De Mayo--Chile 1960, has been published as Technical Article No. 14 by the Naval Ordnance Test Station, Michelson Laboratories, China Lake and Pasadena, California. It is the first eye-witness account of a major earthquake by a recognized expert seismologist who was there to ride it out.

Dr. Saint-Amand's interest in Bodega Head began in late 1962, when David Pesonen of the Northern California Association to Preserve Bodega Head sent him several aerial photographs of the area for study. Subsequently, Dr. Saint-Amand, accompanied by Dr. Oresti Lombardi, also from China Lake, made a two-day field trip to the headland. He enjoyed the advantage in gathering his data of seeing the proposed reactor site "opened up" by Pacific Gas and Electric Company's initial excavation. In addition, the reports of the utility's experts (both close friends of Dr. Saint-Amand), Dr. Don Tocher of the University of California and Dr. George Housner of the California Institute of Technology, were made available to him by the Association.

Apr 6-7, '63?

This report is Dr. Saint-Amand's analysis and conclusions concerning the hazards posed by the Pacific Gas and Electric Company's anticipated construction of a 325 megawatt nuclear reactor at Campbell Cove on Bodega Head.



Generalized geologic map of Bodega Head and Pt. Reyes (after San Francisco and Santa Rosa sheets of the Geologic Map of California). The area shown in dashed lines is the area shown on next page.

(Reproduced from "The Geologic Setting of Bodega Head, "Koenig, J.B., Calif. Div. of Mines and Geology, Mineral Information Svc., July 1963.)

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GEOLOGIC AND SEISMOLOGIC STUDY OF BODEGA HEAD

By Pierre Saint-Amand*

1. INTRODUCTION

1 - 1. Field Work. The author visited Bodega Head on 6 and 7 April 1963 in order to make an examination of the geology of the Head. The area was traversed on foot in company with Oreste W. Lombardi. The study consisted essentially of mapping on both aerial photographs and on a topographic map. Special attention was paid to faulting, condition of the terrain as foundation material, probability of landslides, and other aspects of engineering geology applicable to the construction of an atomic power plant on the Head.

1 - 2. Previous Work. V.C. Osmont (1905) included a discussion of Bodega Head in a paper on the regional geology. Johnson (1934, 1943) presents a general geologic study of the region. Tocher and Quaide (1960) present the engineering geology and seismology, and Housner (1961) discusses criteria for engineering design based on the work of Tocher and Quaide and on his own observations. Koenig (1963), of the State Division of Mines, has summarized the geology of Bodega Head. A study by Dames and Moore, concerned with foundational aspects, was not available to the author at the time of writing.

2. GEOLOGY

2 - 1. Geography of Bodega Head. A general view of the region is shown in Fig. 1, a close-up of the Head in Fig. 2, and the topography in Fig. 3 (from a map taken from Tocher & Quaide).

The Head is an erosional remnant of an elongated ridge lying along a SE-NW line seaward of and parallel to the main San Andreas fault zone and in the general area of deformation marginal to the fault. It is connected to the mainland by a tombolo of sand dunes lying over a mixed collection of littoral deposits and wind-blown sand. The long sand spit of Doran Beach State Park extends southwestward from the mainland to enclose the south side of Bodega Bay. A protected channel has been built to prevent sanding of the entrance to the bay, which is used as a harbor by fishing and pleasure craft.

2 - 2. Structure. Bodega Head is part of a long, thin ridge of rock, interruptedly connected to Tomales Point (4.5 miles to the southeast) by a line of submarine hills. The ridge bounds the western edge of the San Andreas fault zone, and is composed of a line of horsts, or uplifted blocks, squeezed up by movement on the fault. Similar ridges border the San Andreas and other strike-slip faults in many places. These ridges are slowly and continually being forced upward at a rate somewhat faster than that at which the forces of erosion can remove the extremely crushed and broken rock. The presence of such ridges is a diagnostic aid for estimating the activity on a fault.

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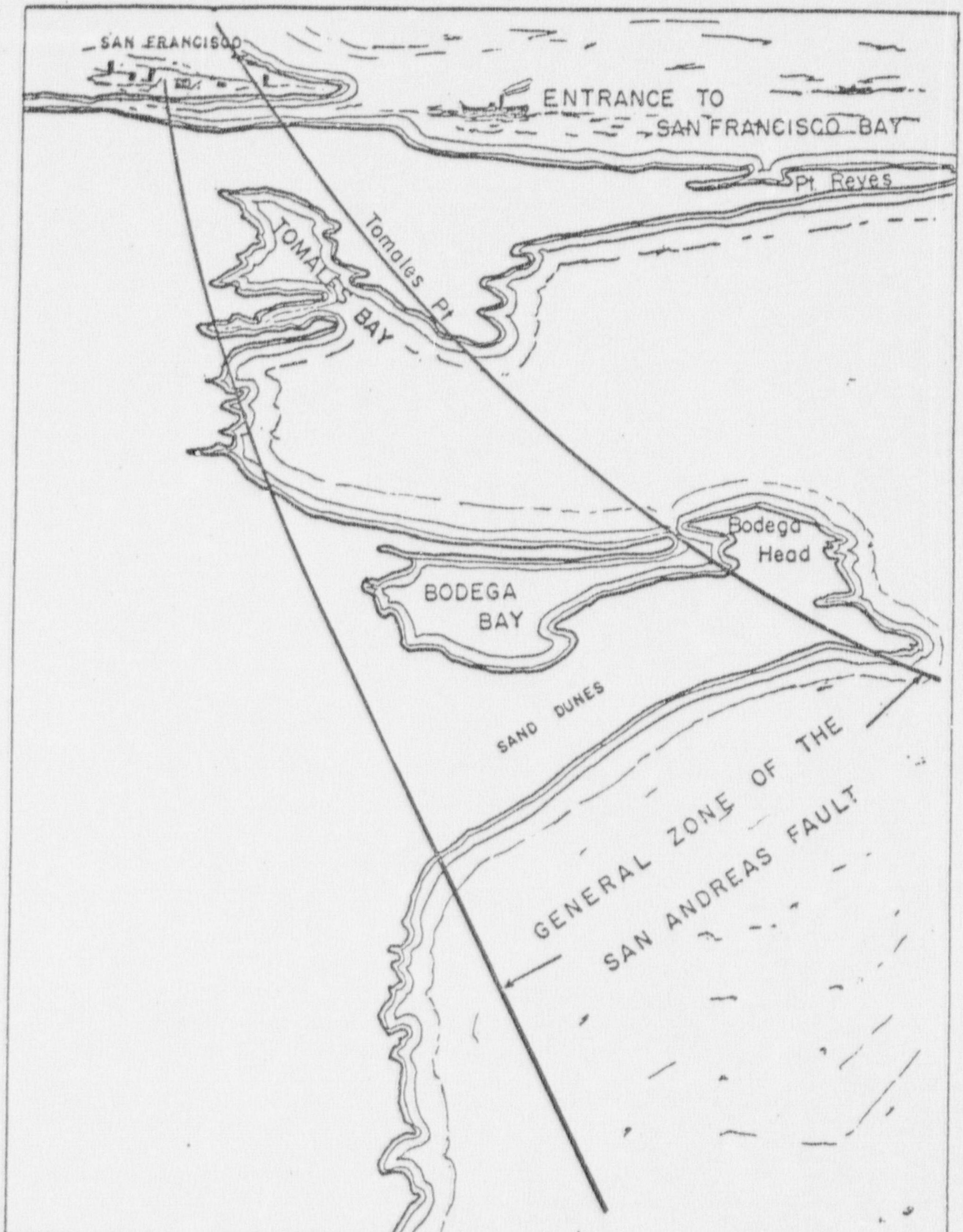

SAN FRANCISCO
ENTRANCE TO
SAN FRANCISCO BAY
Pt. Reyes
TOMALES BAY
Tomales Pt
Bodega Head
BODEGA BAY
SAND DUNES
GENERAL ZONE OF THE
SAN ANDREAS FAULT

FIG. 1. General View of Bodega Head and San Andreas Fault Zone

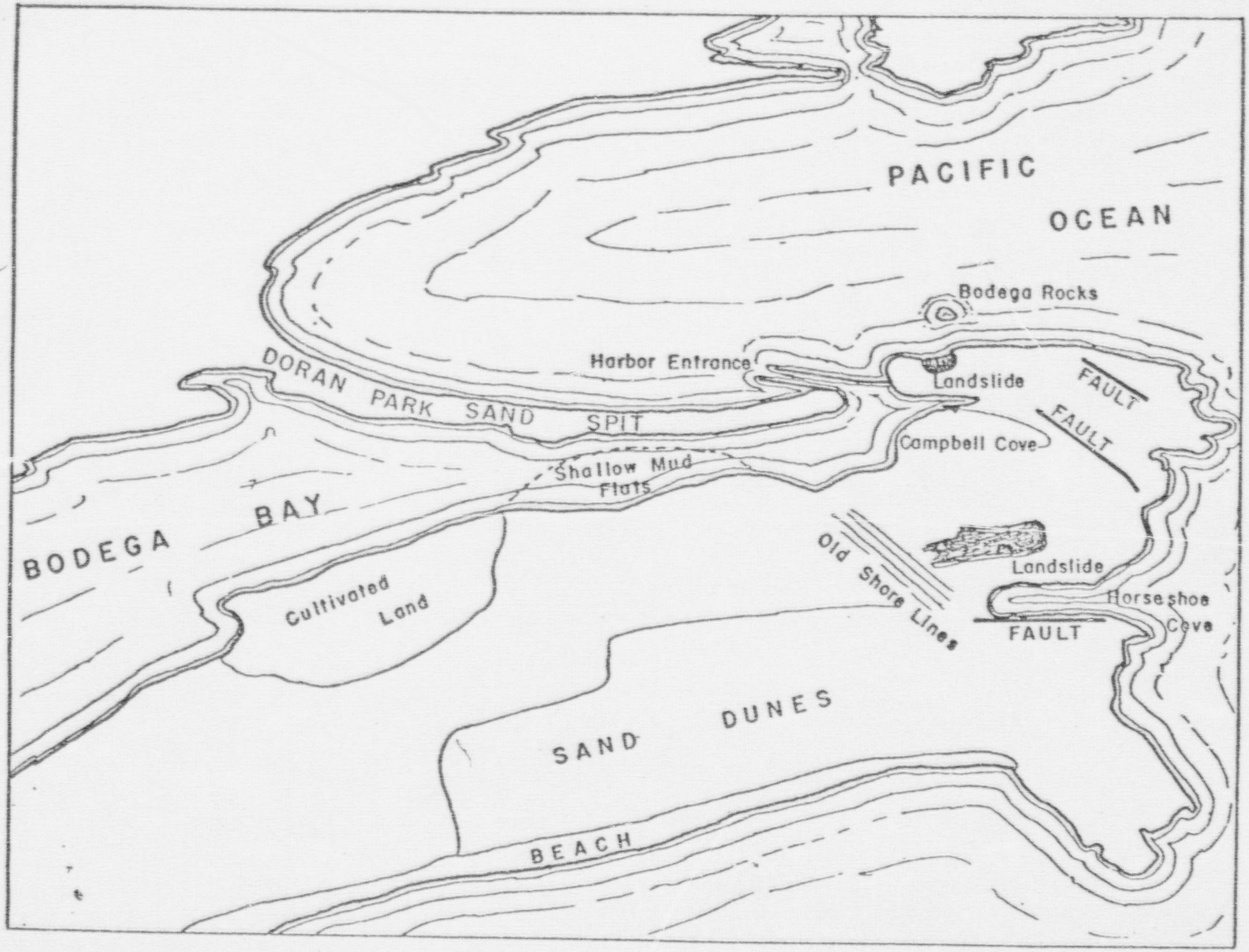
PACIFIC
OCEAN
Bodega Rocks
Harbor Entrance
Landslide
FAULT
FAULT
DORAN PARK SAND SPIT
Campbell Cove
Shallow Mud
Flats
BODEGA
BAY
Old Shore Lines
Landslide
Horseshoe
Cove
FAULT
Cultivated
Land
SAND DUNES
BEACH

FIG. 2. Bodega Head and Harbor. Note shoreline near Horseshoe Cove, also wave-cut platform.

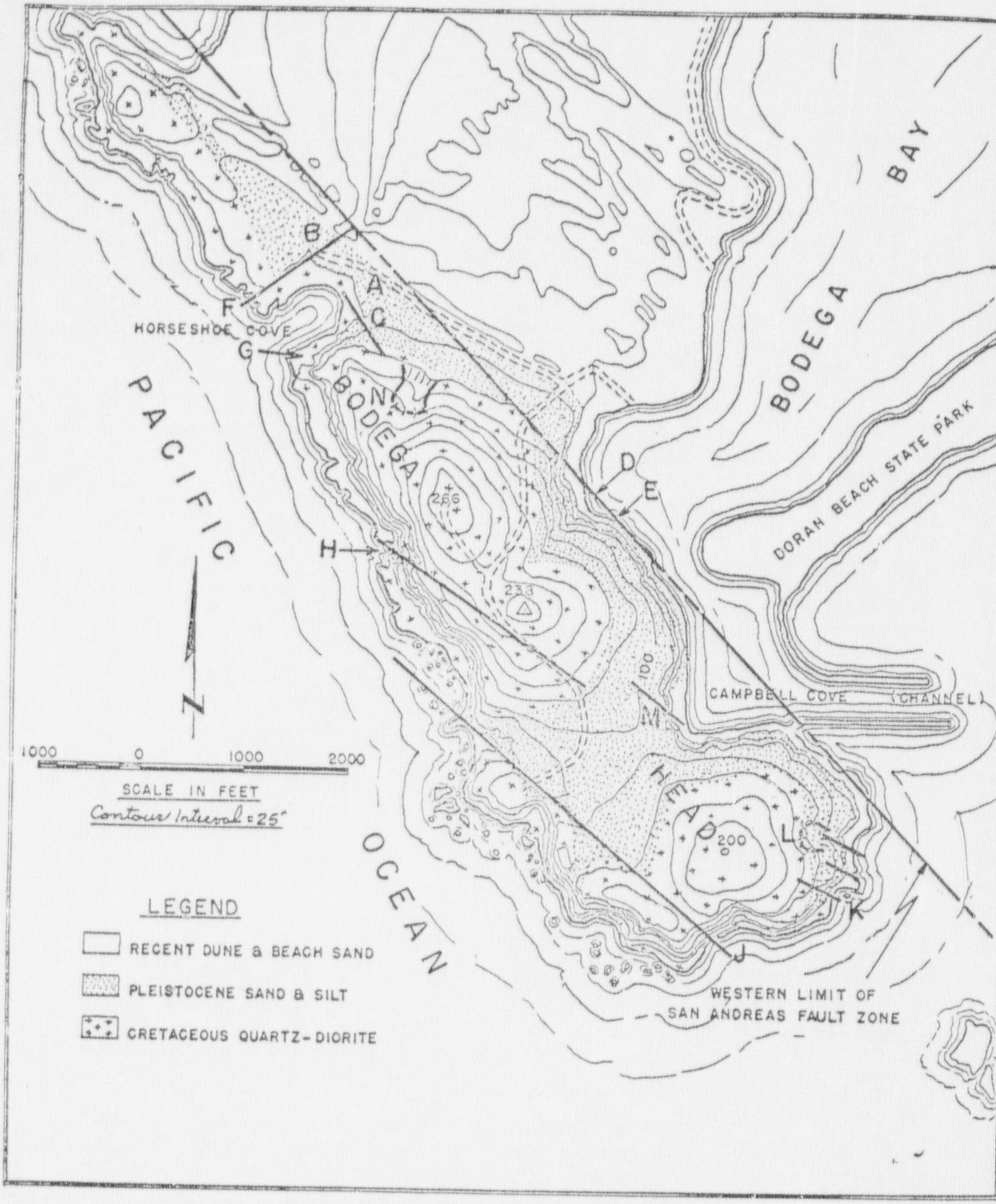

FIG. 3. Topographic and Geologic Map of Bodega Head. Modified from Tocher and Quaide.

2 - 3. Bedrock. The bedrock is a medium to coarse-grained granodiorite, called "Bodega diorite" by Osmont (1905). It is probably a part of the coast range batholith and is similar to other granitic rocks found along the coast and offshore. It is generally thought to be middle to upper Cretaceous in age; radiometric dating indicates an age of 80 to 90 million years (Curtis, et al., 1958). It is occasionally injected by acidic dike rocks. Rock crops out on the higher parts and along the seaward sides of the head; in one or two places it is exposed along the shore on the bay side of the head.

2 - 4. Weathering and Soil. In newly exposed outcrops, where the sea is actively removing material, the rock is relatively fresh but is broken into small fragments. Where erosion is less active the granodiorite is covered by a deeply weathered clay-rich residual soil derived from weathering of the granodiorite. The residual soil is usually covered by a well-weathered sand, in part of aeolian origin. A sample of the upper sand from the reactor-pit excavation shows angular to sub-rounded grains of quartz and feldspar. Horizons of the soil may be readily seen in the reactor pit and on the south side of Horseshoe Cove.

Near Horseshoe Cove, 1 meter of dark humic soil overlies 2 meters of coarse orange sand, which in turn rests upon 4 to 5 meters of light-gray arkosic sand. This material is somewhat different from that in the reactor pit. None of the sediments are in any way cemented or indurated. They are in part Recent Marine or Estuarial deposits.

Tocher and Quaide express the view that these are terrace deposits, pointing to the presence of mussel shells in the soil. Koenig (p. 6) describes these sediments in some detail, concurring in general with the other observers. They are probably correct, because although definitive evidence for these being terrace deposits seems hard to find, a series of what appears to be raised shore lines can be seen on the flat, grassy surface just west of the sand dune area (see Fig. 2, and Fig. 3, Point A).

Along the inland shore at Point D, Fig. 3, about 10 meters of coarse red sand unconformably overlies a blue-gray sand for the remainder of the exposure. Bedrock is not seen here. The sediments at this point are deeply gullied, are scarred by small slumps and ooze water from many small springs.

2 - 5. Ground Water. The sediments are loosely consolidated, porous, and permeable. At the time of this study the sediments were saturated, and numerous small springs could be seen at the water's edge. At Point E, Fig. 3, a fault cuts the cliff and a good spring has developed. Here bedrock is just visible at about sea level. As Tocher and Quaide point out, the soils are saturated during rainy seasons and probably dry out somewhat in late summer.

2 - 6. Fracturing. Tocher and Quaide describe the rock of Bodega Head as extensively sheared and broken. Johnson (1934, pp. 24-25) reports the same. The rock is indeed severely fractured, as Figs. 4 and 5 show, the fracturing being most intense near faults. In many places it is difficult to find sound rocks larger than a man's head.

Often, in shear zones and in the vicinity of faults, the fragments are augen-shaped or rudely tabular and are aligned along the general trend of the faults. In such regions the "soi-disant" solid rock has the consistency of a vertically stratified alluvial deposit. Many of the surfaces have thin mylonite zones. In some places the rock is a tectonic or cataclastic breccia. A combination of the fracturing, mylonitization, deep weathering, and an abundance of ground water render the bedrock far less stable than similar rock

FIG. 4. Crushed and Broken Rock Along Shore

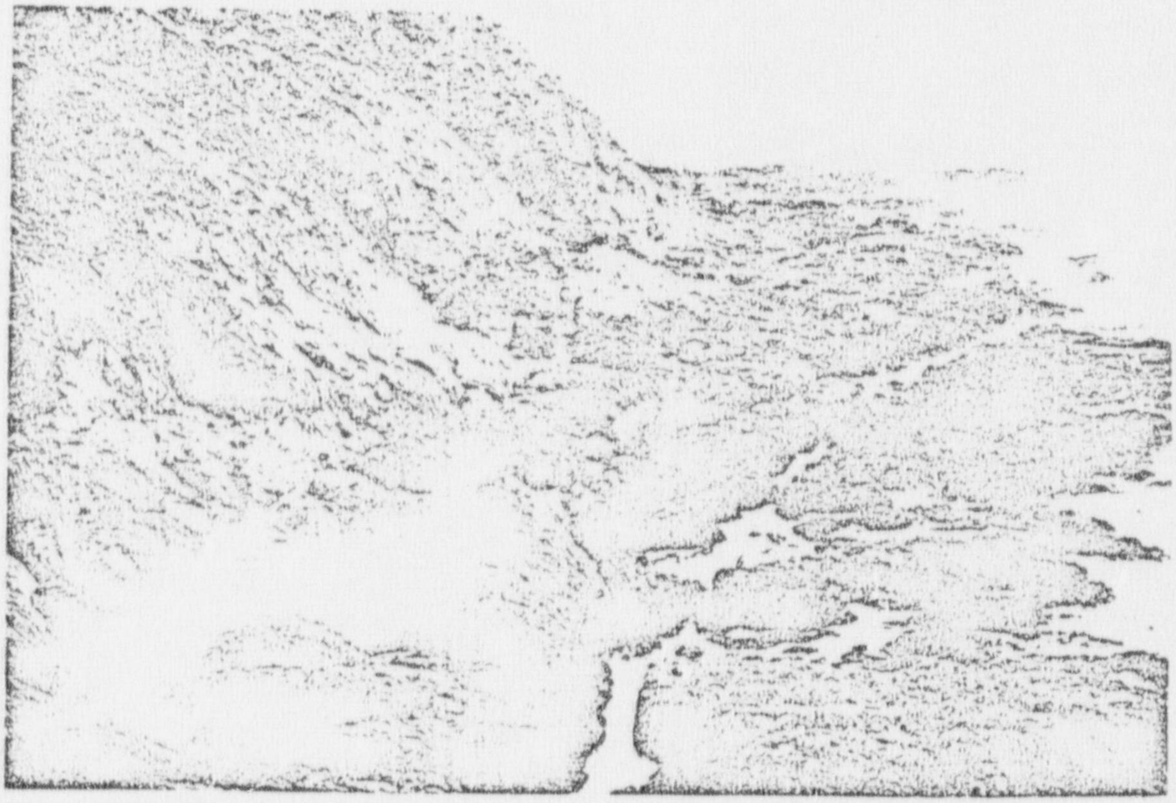

FIG. 5. Portion of Wave-cut Platform, Showing Crushing and Minor Faulting.

would be had it not been comminuted by the eons of shearing which it has undergone.

2 - 7. Faulting. Minor faults abound on Bodega Head and a few major faults can be clearly seen. The best way to appreciate the degree of faulting is to walk along the sides of Horseshoe Cove.

The Cove itself is a rentrant cut by the erosive action of the waves from the zone of a large fault that trends about N45°E. The crushed and broken rock of the fault zone has been more easily excavated than the relatively harder surrounding rock. The Cove is bordered on both sides by faults parallel to its northwesterly and southeasterly shores. The faults on the northwesterly side (Point F, Fig. 3) are very well exposed.

A good-sized fault is exposed every hundred feet or so along the south-westerly side of the Cove. Short canyons have been elaborated along these faults. In the bottoms of some of these canyons are granodiorite boulders covered by alluvium and slope wash. Six steeply dipping faults of considerable size, measuring 1 to 5 meters wide, are found between Points C and G. These faults trend between S45°E and S60°E, and are sub-parallel to the San Andreas. Occasional thrust faults, steep reverse faults and normal faults can be seen between the high-angle faults.

In fact, each rentrant along the coast is determined by a fault. One of the more notable ones (Point H) can be traced easily on air photos, and with only a little difficulty on the ground, to the southwest of the hill crest marked 238.

Between Points F and H, and as a matter of fact clear to Windmill Beach, faults sub-parallel to the coastline channel the wave-cut platform.

The wave-cut platform that surrounds the seaward side of the Head displays faulting very clearly. At several places the platform is at a different altitude on either side of a fault, indicating differential uplift across the fault.

In places the platform is destroyed or completely missing--for example, where the fault shown by Johnson enters the sea. At Point J the platform is at different elevations on either side of the fault, and the 100 meters or so of missing platform heads against a cliff so fractured (Fig. 6) that it is actively landsliding along the upper edge and face.

Near Point K a rentrant channel has developed in the wave-cut platform (Fig. 7). At the head of this channel a fault zone--50 meters wide, consisting of septa of rock caught between shear zones and curtains of gouge--is exposed in the cliff. Figure 8 shows a portion of this fault zone. Horizontal stria may be seen by exposing any of the mylonitized surfaces.

At Point L a landslide is developing in the zone of a very large fault. Material is being removed by mass movement, slope wash, and gullying.

One spectacular fault is exposed on a bedrock high on the northwest face of the excavation for the reactor, the approximate location being at Point M; the original banks on the northwest and southwest sides of Campbell Cove have been removed by the excavation and precise location was difficult, especially in the rain. The fault lies near a temporary road, a temporary drainage culvert, and a stake marked "Top Bench 55.0". The fault extends up and down the road for at least 50 meters, strikes N45°W, and dips vertically, as nearly as can be seen in the partial exposure. Numerous small fractures

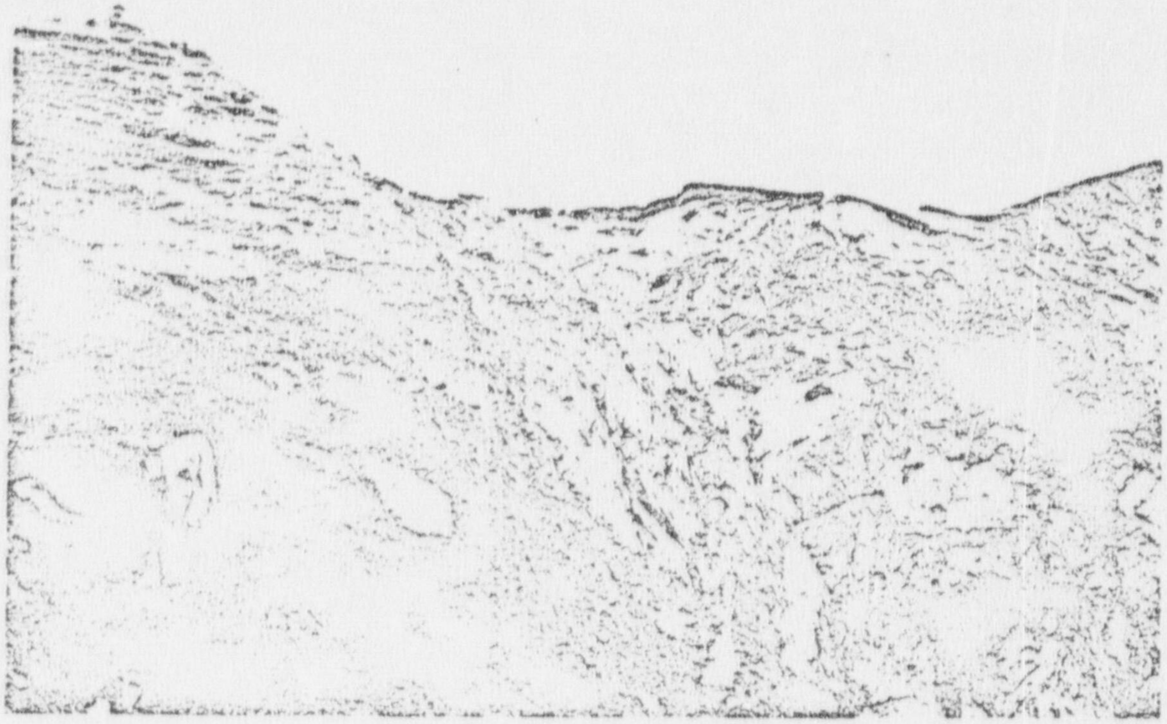

FIG. 6. Landsliding and Fracturing in Johnson Fault Zone.

FIG. 7. Rectangular Channel Cut by Waves from a Fault Zone near Point K, Fig. 3.

FIG. 8. Portion of Fault Zone from Notch in Fig. 7 was Eroded.

delineate the zone; these are interspersed with septa of crushed rock and curtains of mylonite and gouge measuring 2 meters wide. The majority of the stria indicate dexteral strike-slip displacement, but some clearly indicate vertical movement. Figure 9 shows a section of one wide gouge zone.

This fault alone might well concern the builders, and is ample reason to recommend against the use of the site because of the possibility of movement thereon during or following an earthquake.

2 - 8. Landsliding. Numerous examples of soil creep and mass wasting are to be seen along the coast. The rentrant at Point D has been the scene of several small slides. The sediments here are now extensively gullied and show small slumps, terracettes, springs, and a topography indicative of an unstable terrain. An old landslide, on a gentle slope in "solid" rock, is found at Point N; the debris that flowed out is overgrown by gorse.

The water-soaked condition of the soil, the looseness and lack of compaction, and the broken state of the rock all suggest that landsliding could be expected following a major earthquake during or just after a normal rainy season --especially following extensive construction work that will redistribute masses of earth and change the ground loading.

The former Campbell Cove is now being filled to make a dock area and to dispose of the dirt removed in excavation. Unless an excellent sea wall is placed on the bay side this deposit will be unstable even in the absence of earthquakes, and even with a sea wall the situation would be difficult in the event of an earthquake. A similar installation in Puerto Montt, Chile was destroyed in 1960 by liquefaction of the soil (Saint-Amand, 1961, p. 19, and Duke and Leeds, 1963).

2 - 9. Recent Uplift. Several lines of evidence point clearly to Recent uplift of Bodega Head:

Soil now found above sea level is in part a terrace deposit (Tocher and Quaide) that was originally emplaced below sea level, as indicated by the mussel shells. Absolute age of the deposits and hence a maximum age for the uplift could be determinable by Carbon-14 dating of wood and shells found in the deposits. Carbon 14 dates for wood from the reactor pit, taken at about sea level, yield ages in excess of 42,600 years; dates are not yet available for shells and other debris from higher in the section. A careful study of these materials will be very important and interesting from an academic point of view.

Elevated shorelines, shown in Fig. 2 and in the plain at Point A, Fig. 3, are subdued but nevertheless visible in the field. The soil is soft sand, and although it is stabilized by grass cover one would expect erosion to have proceeded so rapidly, because of the abundant rainfall, that these marks would not be very old. This bespeaks a very recent uplift.

The wave-cut platform around the head is also diagnostic of Recent uplift. It is apparently a local effect, not caused by a eustatic change of sea level as postulated for uplift of the terrace deposits by Tocher and Quaide (page 7). This platform is quite young, is at different elevations in different places, and is clearly offset vertically by some faults.

A similar platform was found around Isla Mocha and near Lebu, Chile, following the great earthquakes of 1960. At that time Isla Mocha was elevated about 3 meters and Lebu 1.5 meters (Saint-Amand, 1961).

FIG. 9. Mylonite Zone in Large Fault
in Excavation for Power Plant.

On the southeast shore of Campbell Cove there is a concavity cut by storm waves, probably before the mole was built. This is now elevated about a meter above the level at which it was formed. It was probably uplifted at the same time as the wave-cut platform.

Several of the canyons produced by erosion of fault zones now have old bottoms exposed at a height of 3 to 5 meters above present sea level (Fig. 10); they have wave-rounded boulders in the bottoms, and are filled with slope wash and soil. The same sort of boulders may be seen at the present sea level in the heads of channels produced in the same fault zone, where the sea is now fashioning them from joint-blocks and fragments. The soil in the old canyons is quite young, loose, and uncemented. This situation also indicates a Recent uplift.

The rather surprising depth of alluvium reported in Campbell Cove is suggestive of a tectonic origin for that bedrock depression. It is difficult to see how it could have been cut to that depth by erosion. Hence it is possible that it was produced by the down-dropping of a small graben; however, other explanations could probably be found as well.

2 - 10. Recency of Tectonic Movement. Although fresh fault scarps are scarce, several were noted, and abundant other evidence such as cited above indicates vigorous Recent tectonic activity on the Head.

The fault lying along Points F and B, Fig. 3, on the northwesterly side of Horseshoe Cove, clearly offsets the pattern of the old shorelines, as may be seen in Fig. 2. Another fault, at Point C, leaves a faint scarplet running subparallel to the shorelines.

The relative lack of fault scarps is deceptive. This is almost certainly because of the failure of the soft-soil overlying portions of the Head to reveal movements in the bedrock, and because rapid erosion caused by the heavy rainfall on the soft soil would quickly destroy any such scarps.

For example, in 1906 the San Andreas fault moved about 16 feet in the vicinity of Bodega Bay. Lawson (1908), p. 65, quoted by Tocher and Quaide, pp.1-3, clearly states that even this considerable movement was not visible in the sand dunes nor across the Doran Beach sand spit.

Fault movement effects produced by earthquakes have always been easier to follow over bedrock than over even the shallowest alluvium. Furthermore, the San Andreas fault and the majority of the fractures on Bodega Head undergo mostly horizontal movement, and this sort of displacement does not produce scarplets as conspicuous as an equal amount of vertical movement.

Scarplets do not long endure under the climatic regime at Bodega Head, nor in the type of soil found there. The trace of the 1906 earthquake is now quite modified. A similar example was shown in the Kern County earthquake of 1952 which broke a series of scarplets along the trace of the White Wolf fault (Buwalda and Saint-Amand, 1955); today these scarplets are scarcely visible. Far less rain falls in Kern County than at Bodega Head, and the soil is much firmer. The scarp of the 1872 earthquake in the arid Owens Valley is now so smooth and modified that it is in places difficult to recognize.

Hence, one must observe considerable caution in estimating the state of present or Recent tectonic activity on the basis of vertically displaced scarplets alone.

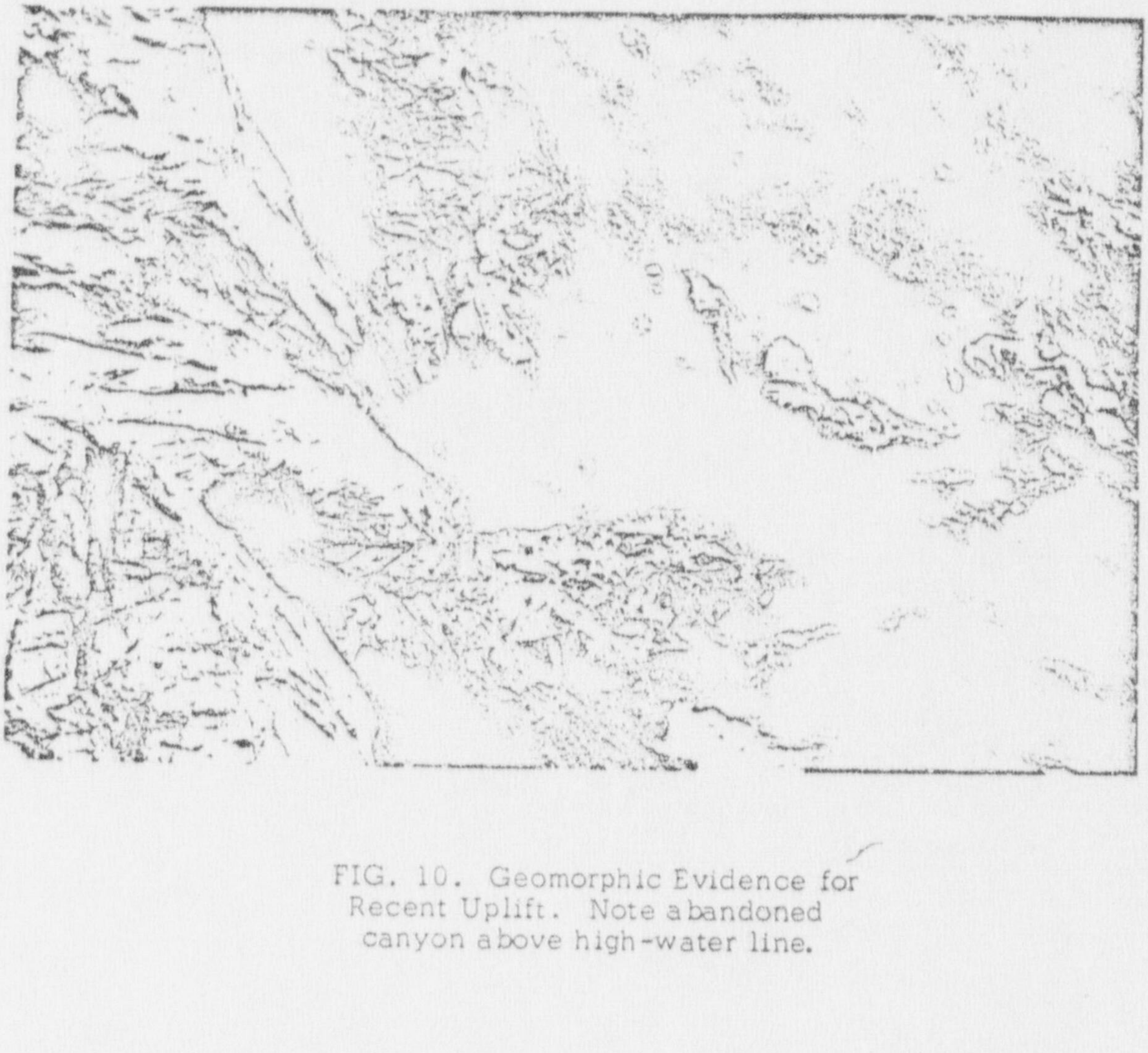

FIG. 10. Geomorphic Evidence for Recent Uplift. Note abandoned canyon above high-water line.

3. POSSIBILITY OF A SEVERE EARTHQUAKE AT BODEGA HEAD AND THE POSSIBLE CONSEQUENCES

3 - 1. Estimates of Frequency of Earthquakes. Tocher and Quaide, p. 12, in regard to Bodega Head, estimate that "at least one and perhaps two major earthquakes can be expected near the site within the next century. These may be at least as strong as or even stronger than the California Earthquake of April 18, 1906." Housner, p. 3, says "It has been estimated that a large earthquake, such as the 1906 shock, may be expected to occur along the San Andreas fault perhaps three or four times per 1,000 years. Less intense ground motion can be expected to occur with greater frequency, it being estimated that ground motions at least sufficiently strong to cause damage to poorly designed structures may be expected at the site several times during the next hundred years." The author's personal guess would be almost the same as that of Tocher and Quaide.

Small earthquakes do not often occur on the San Andreas fault. Large San Andreas earthquakes have occurred in the San Francisco region in 1838 (Louderback, 1947) and 1906 (Lawson, 1908). The 1857 earthquake (Wood, 1955) took place a little further south and is cited to indicate the general activity.

A great earthquake in 1836 was tentatively assigned by Louderback to the Hayward Fault, Fig. 11, a branch of the San Andreas fault at the western foot of the Berkeley Hills, and another great earthquake occurred on that fault in 1868.

Each time the San Andreas Fault has moved it has jumped a distance of 4 to 8 meters. Strain is estimated to be accumulating at a rate of about 6 to 7 meters per century across the fault. Hence one could expect at least one great earthquake per century.

Other similar fault systems have had a similar history. The great Yakutat Bay earthquakes of 1899 (Tarr and Martin, 1912) were probably on the same fault as those of 1958 (Tocher, 1960). In southernChile the Arauco Fault had a great earthquake in 1835 and another in 1960 (Saint-Amand, 1961).

Smaller earthquakes on nearby faults may be expected oftener. These will probably cause no serious trouble unless they occur on or near Bodega Head as aftershocks of a larger event.

3 - 2. Intensity to be Expected at Bodega Head. The intensity (severity of shaking) will be about the same as for other earthquakes of magnitude 8 to 8.4 at similar distances. Tocher and Quaide estimate a Mercalli VIII or IX for an earthquake equal to the San Francisco earthquake of 1906.

The author's own observations made in other earthquakes would incline him to guess that MM IX would be the least expectable intensity. MM X might be noted if landsliding of consequence were to occur, or if one of the faults on Bodega Head were to move. If a large fault on the Head were to move during the main earthquake the intensity could easily reach XI. It is difficult to give a good opinion for intensities above MM IX because the scale itself is not too precise and the intensity assigned depends upon the presence of certain diagnostic structures and conditions.

Richter (1958, p. 353) gives the following table for average Mercalli intensities to be expected for metropolitan centers in California and for ordinary ground conditions:

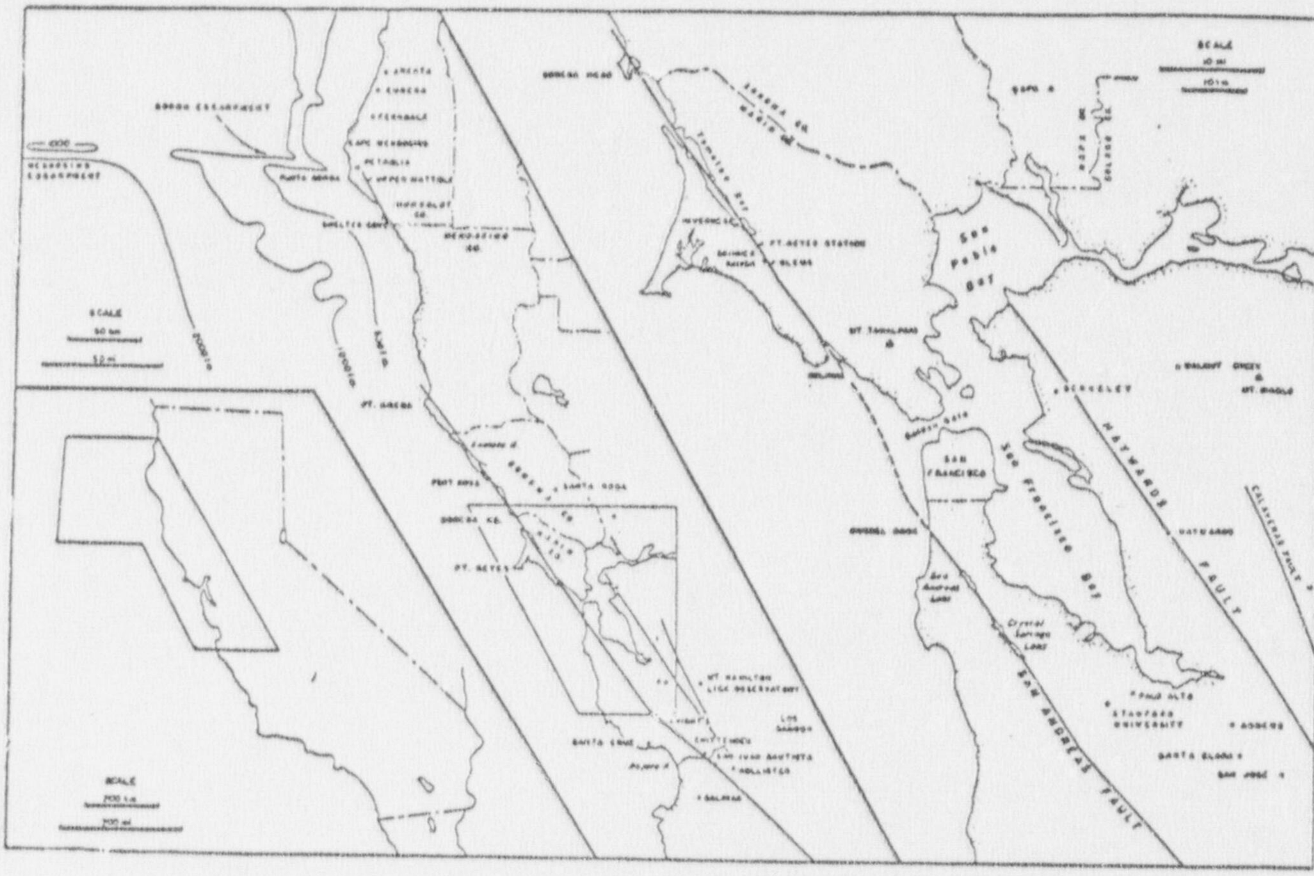

FIG. 11. Locality Map for 1906 Earthquake.
Taken from Richter 1958.

Magnitude	2	3	4	5	6	7	8
Maximum intensity M.M.	I-II	III	V	VI-VII	VII-VIII	IX-X	XI
Radius (Kms) (felt)	0	15	80	150	220	400	600

These values are in good agreement with those observed in actual earthquakes.

The author's own estimate for the severity of shaking at Bodega Head would be, for an earthquake of magnitude 8.2 - 8.4, something like an average maximum acceleration of about 0.4 g for about 1 minute, with peaks in excess of 1 g and with a vigorous shaking continuing for perhaps 3 minutes.

This is somewhat larger than the intensity predicted on the basis of the strong motion recorded in the El Centro Earthquake, as recommended by Housner. The basic idea of using actual accelerograms is quite sound and is far superior to using Mercalli intensity alone. The El Centro earthquake is the only one for which such information is available for a position near a fault. The earthquake occurred on the Imperial fault, a branch of the San Andreas system; it was originally estimated to be magnitude 6.7, but was subsequently upgraded to 7.0. The accelerograph was located about 5 miles to the west of the surface expression of the causative fault, or about 7 miles from the epicenter, the exact location of which is in some doubt. Not only did the thick alluvium alter the power spectrum by attenuating the high-frequency effects and probably augmenting the lower and middle frequencies, but also it probably does not show clearly the effects of the "fling"--an effect discussed in the next section. Further, the intensity at a point depends on the location of the point with respect to the fault and the direction of propagation of the faulting. The faulting begins at a point and progresses, usually in one direction. The shaking is much harder in the direction in which faulting progresses, with both the frequency and amplitude being changed (Benioff, 1954, p. 201). Hence, the record of the El Centro accelerogram probably indicates a lesser intensity than it would have had it been located further south.

The historical record shows very clearly that higher intensities go with larger earthquakes, and thus the use of the El Centro record will not guarantee adequate design factors for the maximum accelerations produced by a shock of magnitude 8 or more.

For example, Gutenberg and Richter (1942, p. 170 et seq.) relate Intensity I and maximum acceleration, a, for various earthquakes. They derive the semi-empirical relation:

$$\log a = \frac{I}{3} - \frac{1}{2}$$

This yields accelerations of 1 g at a Mercalli intensity of Ten and one half.

Accelerations in excess of 1 g have been noted in several large earthquakes (Oldham, 1899).

3 - 3. <u>Mechanics of Earthquake Motion</u>. The movement near a fault is quite different from that at a distance; in fact, the oscillatory motion near a fault may well be a little less. There is one movement, however, that is at maximum near a fault and diminishes rapidly with distance--this is the permanent throw or fling.

During the inter-earthquake period the blocks of land on either side of a fault move continuously and slowly with respect to each other. It is most probable that the oceanward side of a fault undergoes more absolute movement than the continental side, but this makes little or no difference regarding the intensity of the impending earthquake as it affects opposite sides of the fault zone.

The gradual drift of the land deforms the blocks (see Fig. 12) bending the rocks and storing energy in them in the form of elastic strain. The strain accumulates until the forces generated in the rock are great enough to overcome the frictional forces on the surfaces of a fault that prevent slippage. When this happens the rock on either side suddenly snaps back into its unstrained straightened condition.

In the zone near the fault, up to say 30 km, the land on both sides at this time undergoes a permanent sudden displacement. The total displacement across the fault zone may be as much as 5 to 8 meters. This takes place as a sudden high acceleration, followed by a slower deceleration; the time involved is of the order of seconds. Effects of the fling are most noticeable on or near bedrock. Most of the extremely-high-intensity effects in epicentral regions are the result of such action. The total fling may be ameliorated somewhat by drag in the fault zone, in the case of a very large fault, but this carries the penalty of movement on a variety of subsidiary faults.

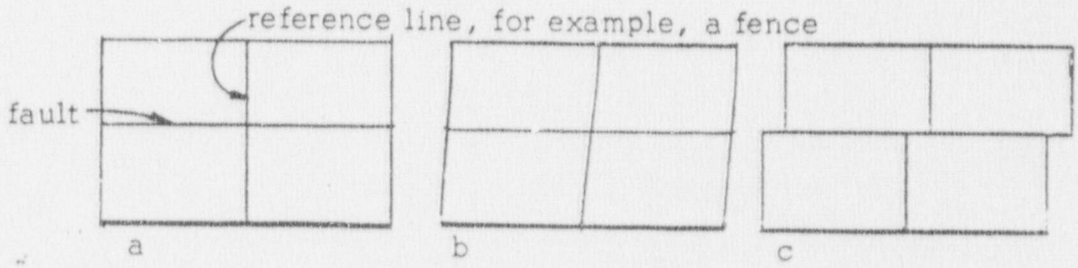

FIG. 12. Process of Strain Accumulation and Release (not to scale)
a. Field cut by a strike slip fault, before strain accumulation.
b. During strained condition and before an earthquake.
c. After an earthquake.

The Bodega Head reactor site is located in the zone of fling of the San Andreas fault and will probably undergo some 3 or 4 meters permanent horizontal displacement.

3 - 4. <u>Possible Fault Movement on the Head</u>. The most serious cause for concern at the reactor site would be the possibility of movement on a fault passing either through the power plant area or across the cooling-water system. This possibility is quite high. When a fault such as the San Andreas moves, it moves not on a single plane but on many fractures. There is usually one main plane of movement, but in many major earthquakes faulting has been found to have occurred over a large area. Some of the faults move during the main event while others move during the aftershock sequence. Numerous examples could be given

where movement took place on more than one fault. Richter (1958, pp. 476-487), in discussing the 1906 earthquake, shows rather clearly that that event was much more complex than a simple fault movement. Although the 1906 earthquake was accompanied by displacement along a fracture to the east of the Head it must be remembered that during an earthquake energy is suddenly released from a large volume of rock and movement can and does take place across many faults and fractures over a wide zone. Pre-existing faults, often considered "dead," joints, bedding planes and similar structures participate in the readjustments. The Chilean earthquakes of 1960 (Saint-Amand, 1961) produced movements on a plurality of faults spread over about 100 km of longitude. The Kern County earthquake of 1952 (Buwalda and Saint-Amand, 1955) had a zone of faulting of considerable width, with many minor faults and some clear-cut traces as far as 5 to 10 miles to the side. The list could continue indefinitely.

The hazard from movement is carefully pointed out by Housner, page 3, wherein he says that "Since it is quite impossible to design a power plant to survive without damage the large permanent ground surface displacements that might occur if the earthquake fault slippage occurred on the site, this possibility must be given special consideration."

While the whole slippage from a major earthquake will probably not occur on any one fault going through Bodega Head, it is quite likely that movement may occur on the big fault in the plant site, or on any of the several faults that cross the site of the cooling-water system.

3 - 5. Possible Changes of Land Elevation. One phenomenon that has been observed following all large earthquakes, when an attempt has been made to notice it, is a widespread change in elevation on both sides of the causative fault, even when the movement is mainly strike-slip. The land on either side is either raised or lowered, usually a matter of a meter or more for the larger earthquakes. Examples are the 1835 (Fitzroy, 1836) and 1960 (Saint-Amand, 1961) earthquakes in Chile, the Kern County earthquakes of 1952 (Whitten, 1955, p. 79), and the Yakutat Bay earthquake of 1899 (Tarr and Martin). This list could also be continued almost indefinitely. These changes are widespread and involve more than mere displacement on one fault. Many faults are involved, together with uplift and downbowing on a regional scale.

This raises the serious question of the effects of a change of level on an installation that draws cooling water from a shallow estuary.

Attempts were made in the year following the 1906 earthquake to detect changes in the level of Bodega Head on the basis of barnacle growth, but these were unsuccessful. The study was largely confined to the eastern shore, where such evidence would be difficult to find or to assess. The negative findings do not indicate that the Head will not change elevation--it has done so in the past, as evidenced by the wave-cut platform and by the elevated shorelines. In fact, the very existence of the promontory is due to continued uplift; no mass composed of such easily erodible rock could long withstand the assault of the sea were it not for continued rejuvenation.

3 - 6. Tectonic Movement in the Absence of a Major Earthquake. Even if no major earthquake occurs in the area concerned, the possibility of large-scale warping or slippage is present and should be considered. While there is no clear-cut evidence at Bodega Head for other than catastrophic changes, it seems appropriate to recount one or two cases of this sort. Perhaps the most notable case is that of the W.A. Taylor Winery, near Hollister (Steinbrugge, et al., 1960), where damage has occurred from a slow slippage on a portion of the San Andreas fault. Concrete floors have been broken and walls displaced at a rate

of one centimeter per year.

A thrust fault in the Buena Vista Hills, near Bakersfield (Wilt, 1958), has been moving without earthquakes for a number of years, deforming roads and bending pipelines.

On another scale, widespread changes of considerable rapidity are taking place in many places, such as across the San Andreas fault near Cajon Pass or along the southern and southeastern coast of Alaska (Saint-Amand, 1957, pp. 1360-1364).

Changes of this sort are large enough to cause trouble, and a study to identify any such changes should be made before construction begins.

3 - 7. Foundation Considerations. It is generally thought that it is better to build upon solid rock than upon alluvium. This is certainly true at a distance from the causative fault. However, at near-fault distances, where fling is important, rock may be as bad or worse. Clearly the worst possible situation is to build upon a combination of the two. At the Bodega Head site the rock is severely crushed, broken, and mylonitized. It could scarcely be classed as good foundational material. It will transmit well high-frequency vibrations, and then plastically deform in response to regional readjustment of strain; it will probably also undergo mass movement due to its own weight during the long-period oscillations. In addition, the alluvium, a loosely aggregated clay-rich soil, will certainly yield at a different rate than the rock, subjecting the installation to widely varying dynamic loads and permitting the several parts of the installation to settle different amounts, probably resulting in serious damage from changes in level and position to interconnecting structures, to the cooling system, and to the reactor itself.

A worse foundation situation would be difficult to envision.

3 - 8. Transmission Lines. The transmission lines which will stretch across the fault zone will probably be destroyed by the fault movement, after first possibly having been shorted by swinging together. While damage to the power lines could be repaired easily enough, such activity is certain to put a severe load on the power plant.

3 - 9. Tsunamis. Since California has never suffered extensively from tsunamis (seismic seawaves) produced by its own earthquakes, this does not seem a serious cause for concern.

3 - 10. General Observations. It is difficult to conceive all the trouble that a great earthquake can cause. Accounts of these events are always condensed, and hence a mere perusal of the literature, often after it has been digested and edited in the interests of economy, does not convey a very graphic impression of the extent of disruption of the normal human activities. Not only are there the usual concomitants of fire and occasionally flood, but widespread disruption of water supply and sewage disposal occur. One of the most serious losses is that of electricity; this loss is invariably felt during the period it is most needed for emergency service.

Loss of electricity leads to shortages of water, hospital facilities, elevator service, street signals, lights, etc. The most serious loss is in communications--especially radio, television, and the press, which in turn leads to public panic and the spread of groundless rumors and exaggerations. The latter tend to include misinformation regarding installations known to have a damageproducing potential such as dams, and in the future would inevitably involve atomic reactors--especially any known to be precariously located.

For the above reasons it is absolutely essential that electrical power plants be so situated that they are as invulnerable as possible to disruption by seismic causes. The presently announced plans for the PG&E installation include eventual construction of several units on Bodega Head. Considering the extreme vulnerability of any plant on the site, it seems highly imprudent to lump such an essential service in such a poor locality.

Eventually the United States will have to turn to atomic energy to fulfill its power requirements. The future development of atomic energy will hinge upon the safety of the first reactors! Reactors must be carefully sited in order that an accident does not so alarm, discourage, and dishearten the public that widespread mistrust will prevent the deliberate, careful, and competent development of this energy source.

4. CONCLUSIONS

Bodega Head is a very poor location for a reactor for the following reasons:

a. The probability of a great earthquake is at least one per century; over half a century has elapsed since the last one, hence another may be expected within the lifetime of the plant.

b. The extensive faulting on the head has rendered the rock a poor foundational material. The combination of an unstable alluvium and crushed rock is especially unsuited to heavy construction.

c. The plant is located in the region of permanent distortion, or fling--a region where exceptionally high earthquake intensities will develop.

d. The probability of actual fault displacement on or near the site is high. The large fault exposed in the present excavation is of special concern, and is itself sufficient reason to discontinue construction. The presence of faults crossing the site of the cooling water tunnel is another serious aspect.

e. The abundant evidence for recent uplift causes concern for the cooling water system because of the possibility of change in elevation of the plant with respect to the water source.

It is surprising, in view of the expert advice given by Tocher and Quaide, and by Housner, that another site was not chosen and that construction has gone ahead. The erection of a device not in itself dangerous except to its occupants is not a cause for great public concern. The erection of a device that in itself <u>is</u> hazardous to others is a matter for public concern, and the builders have a grave moral responsibility to be certain that harm to others will not result from failure of the device. The location on Bodega Head is hazardous from a geological and seismic point of view.

Because the San Andreas fault runs parallel to and forms the coast from San Francisco northward, it seems that the nearest safe locality near the sea would lie north of Point Arenas or south of Monterey Bay, and even then the site selected should be carefully and prudently examined from all points of view before beginning construction.

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BEFORE THE UNITED STATES ATOMIC ENERGY COMMISSION

In the Matter of PACIFIC GAS AND ELECTRIC COMPANY	Docket No. 50-205 Amendment No. 4

Now comes PACIFIC GAS AND ELECTRIC COMPANY (the Company) and amends its above-numbered application by submitting herewith Amendment No. 4. This amendment sets forth further details with regard to the earthquake design criteria for Unit No. 1 of the Company's Bodega Bay Atomic Park and supersedes the material set forth on page 8 of Section V of the Preliminary Hazards Summary Report (PHSR), paragraph 21 of Amendment No. 2 to the application, and paragraphs 2 and 3a of Part III of Amendment No. 3 to the application.

The Company has established earthquake design criteria for the Unit based upon the recommendations of Dr. George W. Housner. In general, the usual methods of earthquake resistant design will be followed except that the lateral force factor which will be assumed as a basis for designing each critical structure, equipment or system will vary with the natural period and damping characteristics of the particular structure, equipment, or system.

The earthquake design criteria for all critical structures, equipment and systems are based on the maximum credible earthquake ground motion on the granite at Bodega Head.

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0.33g on granite is an earthquake 2 to 3 times as great in intensity as a 0.33g earthquake giving 0.33g on alluvium.

1. As set forth in the PHSR, this is equal in intensity to the ground motion recorded on deep alluvium at El Centro, California, on May 18, 1940, which had a maximum acceleration of 33% of gravity. (This is estimated to be one and one-half times the intensity of the 1906 San Francisco earthquake at Bodega Head.)

The specific earthquake ground motions upon which the design of critical structures, equipment, and systems will be based are, for acceleration, the spectra shown in Figure 10, Appendix V, of the PHSR, converted for the maximum credible earthquake ground motion at Bodega Head by multiplying by 2.7. The corresponding velocity and displacement spectra are obtained by multiplying the acceleration spectra by T/2 pi and $T^2/4pi^2$, respectively. (T = natural period.) Stress levels to be used in design will conform, where applicable, to the ASME Boiler and Pressure Vessel Code, Section VIII, including applicable nuclear code cases, the ASA Code for Pressure Piping, and the Uniform Building Code of the International Conference of Building Officials, 1961 Edition (except that the usual one-third allowable over-stress for structures during earthquakes will not be applied).

The above design will be based on the following damping factors:

Structure	% of Critical Damping
Steel frame structures	2.5
Reinforced concrete frame structures	4.5
Reactor structure	(See attached curve)

In the event of earthquake ground motion equivalent to 66% of gravity critical, equipment and systems will be capable of bringing the Unit to a safe shutdown. For example, particular items of equipment important to safety shall be designed to withstand such earthquake ground motion without deflection or distortion which would impair their functioning.

Critical structures (referred to as Class 1 Structures in Appendix V to the PHSR) include the reactor containment structure, reactor refueling building, control building, and ventilation stack. Critical equipment and systems include the nuclear steam supply system inside containment, isolation valves, liquid poison system, emergency cooling systems, emergency electrical power system, and the necessary associated instrumentation and controls.

All noncritical structures, equipment, and systems will be designed in accordance with applicable Company seismic design practices.

Subscribed in San Francisco, California, this 9th day of August, 1963.

Respectfully submitted,

PACIFIC GAS AND ELECTRIC COMPANY

By ROBERT H. GERDES
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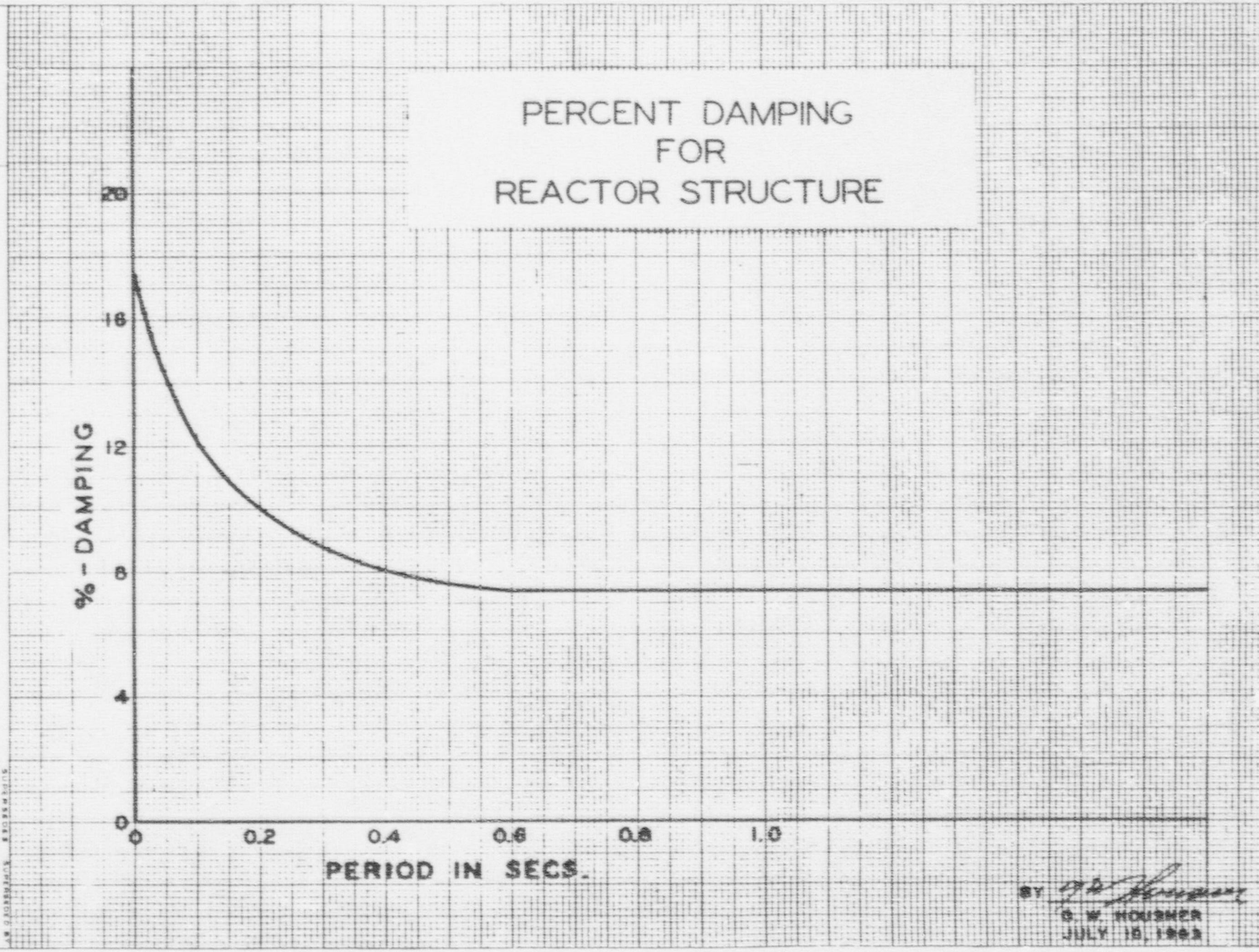
By PHILIP A. CRANE, JR.
Philip A. Crane, Jr.

Subscribed and sworn to before me this 9th day of August, 1963.

RITA J. GREEN (SEAL)
Rita J. Green, Notary Public in and for the City and County of San Francisco, State of California

My Commission Expires July 16, 1967.



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R. Lowenstein, Director
Division of Licensing & Regulation

AUG 5 1963

H. L. Price (Signed) H. L. Price
Director of Regulation

PREPARATION FOR BODEGA HEAD HEARING

I have on my desk a draft hazards analysis on the Bodega Head case dated June 21, 1963. It uses up 56 pages.

Without prejudice to any changes that may need to be made in this draft, I want you to have prepared a separate summary statement which deals with the merits of this case in the manner described in the licensing board procedures discussed with the licensing board panel at the recent meeting.

What the Commission wants from the boards is very clear on this point, but there is no hope that the licensing boards can, as a practical matter, carry out the Commission's wishes unless the staff work puts them in an easy position to do so.

Preparation of a safety analysis along the lines described above should be begun immediately so that it will be ready in ample time for the hearing.

For your guidance, I enclose a rough outline prepared by Dr. Beck of the basic elements to be considered in this case, and at least some, or most, of the judgment positions we must support. What we eventually decide to say on earthquakes can very logically follow the treatment of the items contained herein.

Enclosure:
As above

cc: Dr. C. K. Beck

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