**BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA**

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| Application of Pacific Gas and Electric )<br>Company for Approval of Ratepayer )<br>Funding to Perform Additional Seismic )<br>Studies Recommended by the California )<br>Energy Commission. (U 39 E) | Application No. 10-01-014 |

**DIRECT TESTIMONY OF DOUGLAS H. HAMILTON**

The Alliance for Nuclear Responsibility hereby submits the attached testimony of Douglas H. Hamilton

/s/ ROCHELLE BECKER
Executive Director
Alliance for Nuclear Responsibility
PO 1328
San Luis Obispo, Ca 93406
rochelle@a4nr.org
(858) 337-2703

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## A. Introduction and Background

### 1. Summary and Recommendations

Q1. Please identify yourself and state your professional qualifications.

A.1. My name is Douglas H. Hamilton and my qualifications include BS, MS, and Ph D degrees, all from Stanford University, and more than fifty years of professional experience in engineering and seismic geology. My involvement as a consultant for PG&E's Diablo Canyon nuclear project began in 1971 when I was retained as a consultant to log the geologic features exposed in the foundation excavation for Unit 2 of the power plant, and ended in 1991. In those 20 years, I logged exploratory trenches at Diablo Canyon Nuclear Power Plant (DCNPP) and advised PG&E of the potential seismic significance of the large (later to be named Hosgri) fault located offshore near the powerplant site in 1972. I subsequently planned and directed offshore seismic reflection geophysical studies of this fault sponsored by PG&E between late 1973 and 1974. In 1978 I prepared most of PG&E's geology testimony for the NRC operating license Atomic Safety and Licensing Board (ASLB) hearing and testified during that hearing. I assisted in formulation of the geology component of PG&E's license-required "Long Term Seismic Program" (LTSP) and thereafter was involved in that program until 1988.

Q2. What is the purpose of your testimony in this proceeding?

A.2. My Testimony for this proceeding raises concerns regarding the seismic setting of the plant, both as it relates to public heath and safety, and to the reliability of its contribution to the electric power supply of California. My Testimony also questions relevance of much of PG&E's extremely costly program of geology, geophysics and seismology research, to resolving or even addressing the important seismic safety issues affecting DCNPP.

Q.3. Is there a reason to distrust PG&E's self-determination as to scope and format of seismic studies?

A.3. Historically, there have been numerous deficiencies and oversights in PG&E's previous seismic investigations, both pre-and post-licensing of the plant. Pre-licensing, PG&E failed to conduct any detailed geologic investigation outside of the DCNPP coastal terrace area. Consequently, much time and effort during construction were wasted when the Hosgri fault was later discovered, requiring costly and time-consuming retrofits. Post-licensing, the best known of the deficiencies from their Long Term Seismic Program findings is the failure to recognize the Shoreline fault, which they identified in 1991 as a harmless "lineament related to old shoreline" and in a response to an NRC inquiry argued that there was no fault along the shoreline. Another significant deficiency was PG&E's defense of its representation of the relationship of the offshore Hosgri to the onshore San Simeon faults as one of separation across the "Cambria Stepover." This misinterpretation was necessary to support PG&E's contention (since proven wrong) that this stepover limited the earthquake potential of the Hosgri fault.

Q.4. Does PG&E's proposed seismic scope of work, as outlined in this Application, lead you to any conclusions for which these historical antecedents may provide insight?

A.4. PG&E has failed to consider or acknowledge any seismic implication from the progressive late Quaternary uplift of the Irish Hills, and the occurrence of frequent small earthquakes in the crust beneath these hills as demonstrated by the absence of any meaningful discussion of this issue in any document or presentation known to the writer. This has resulted in non-recognition or non acknowledgement by PG&E of what may well be the controlling seismic hazard to the seismic safety of DCNPP. This seismically active thrust system impinges on the seismically active Shoreline fault at shallow crustal depths. Likewise, the Diablo Cove fault is of special interest in that it is a zone of north side up reverse faulting that displaces the Obispo Formation bedrock of the DCNPP Unit 1 Turbine-Generator and Reactor Containment foundations. This has the likely consequence of putting the safety of the plant, the electricity it provides to the state power grid, and potentially the health and property of the public at risk.

Q.5. Does PG&E's current proposed scope of work address the concerns you have expressed in Answer 4?

A.5. No. In fact, a good deal of their planned work includes offshore and onshore geophysical programs that duplicate existing investigations and analyses completed by the USGS and others (for the Shoreline fault, Cambria stepover, etc.). Rather, PG&E should develop a 3-D model of the tectonic structure beneath the Irish Hills based on uplift mechanism and earthquake hypocenters distribution; expand consideration of potential near field seismic sources to include faults underlying the Irish Hills in order to account for observed seismicity and level uplift of the hills; and investigate possible compressional interaction of thrust faults with the strike-slip Hosgri and Shoreline faults as a mechanism for the origin of prominent west-facing scarps along the Hosgri fault crossing of outer Estero Bay and the trace of the Shoreline fault opposite the Irish Hills southeastward from Diablo Cove.

## 2. Qualifications of Douglas H. Hamilton, Ph D, C.E.G.

My name is Douglas H. Hamilton and my office and residence address is 2 Bassett Lane, Atherton, California, 94027. I am presenting the following testimony on behalf of the Alliance for Nuclear Responsibility but I am not employed by nor otherwise affiliated with that organization. My qualifications include BS, MS, and Ph D degrees, all from Stanford University and more than fifty years of professional experience in engineering and seismic geology. During my career in this field I have worked on electric generation projects involving some 7600 MW of installed capacity and on proposed but not completed projects with a planned capacity of a further 8000 MW. Electric generation projects for which I have provided geoseismic consultation have included nuclear, conventional thermal, geothermal, and hydroelectric facilities, with regulation variously by the U.S. Nuclear Regulatory Commission, the Federal Energy Regulatory Commission, the U.S. Forest Service, and State agencies in California and Washington. Projects not involving electric power generation have included the Devils Slide Tunnel, numerous water supply dams, and a variety of other projects that entailed engineering geology and seismic issues. My involvement as a consultant for PG&E's Diablo Canyon nuclear project began in 1971 when I was retained as a consultant to log the geologic features exposed in the foundation excavation for Unit 2 of the power plant, and ended in 1991 with a study of the hydrogeologic and geochemical setting of the Diablo Canyon Wastewater Holding Pond facility. During the intervening twenty years I first made geologic logs of three large exploratory trenches at the power plant site and recognized and advised PG&E of the potential seismic significance of the large (later to be named Hosgri) fault located offshore near the powerplant site in 1972, and then planned and directed offshore seismic reflection geophysical studies of this fault sponsored by PG&E between late 1973 and 1974. I also prepared most of the geology sections of the FSAR as submitted to the NRC in 1973 and of supplements to it submitted in 1975, and participated on PG&E's behalf in numerous meetings with NRC staff and before the NRC Advisory Committee on Reactor Safeguards (ACRS). In 1978 I prepared most of PG&E's geology testimony for the NRC operating license Atomic Safety and Licensing Board (ASLB) hearing and testified during that hearing. I was subsequently called on to testify before the NRC Atomic Safety and Licensing Appeals Board (ALAB) in 1981. In 1985, after the low power test license for Diablo Canyon Unit 1 was restored following its having been suspended in connection with the "Diagram Error" issue between 1981 and 1984, I assisted in formulation of the geology component of PG&E's license-required "Long Term Seismic Program" (LTSP) and thereafter was involved in that program until I was reassigned by PG&E in 1988. Thereafter I assisted in preparation of PG&E's Rate Case testimony before the CPUC, with that assignment ending when the Rate Case ended with a negotiated settlement in 1989. I have had no involvement with PG&E since 1991 except for having been identified by them, unilaterally, as one of many "Resource Experts" for their recently initiated SSHAC program.

My interest in the geoseismic issues concerning PG&E's Diablo Canyon project was revived in 2004 by a plot I obtained from the University of Nevada Seismological Laboratory showing earthquake epicenters superimposed on a digital terrain map of the south central coastal region of California where the Diablo Canyon site is located. This plot dramatically illustrated the essentially 1:1 correlation between seismicity and mountain ranges in the region including the Irish Hills-San Luis Range, the site of the DCNPP. Since obtaining this plot I have carried out independent research about the seismic and fault hazard to the nuclear power plant and have submitted interim results at a briefing to the Seismic Advisory Panel of the California Energy Commission and a presentation at the Fall Meeting of the American Geophysical Union, both in 2010. Most recently I was an observer in my capacity as an invited "Resource Expert" at PG&E's Workshop No. 1 for its SSHAC process review of geologic and seismic issues deemed by PG&E to be relevant to the seismic safety of Diablo Canyon.

I hold California Professional Geologist license No. 56 and am Certified Engineering Geologist No.31, both licenses dating from 1970, and Washington Professional Geologist and Engineering Geologist license No. 1710, dating from 2002.

## B. Geologic and seismic Setting of the DCNPP

### 1. Regional Setting

The DCNPP site is located in coastal south central California along the shoreline of the Irish Hills of the San Luis Range. The site is directly on the margin between the two major tectonic domains of this region, where the right-lateral strike slip San Gregorio-Hosgri fault system truncates and locally interacts with the compressional crustal-shortening domain of the onshore Santa Lucia-Santa Maria neotectonic domain. The site is therefore subject to continuous low level seismicity engendered by the very limited ongoing partial release of accumulating tectonic strain, and to periodic much larger seismic releases of larger increments of accumulated strain from either, or both, the San Simeon-Hosgri fault and its south-easterly East Hosgri and Shoreline fault splays, and the reverse and thrust faults that border the Irish Hills.

### 2. The San Gregorio–Hosgri fault system

The San Gregorio–Hosgri fault system is the name commonly used for the series of large faults along the coast of central California that together form the only major west side branch of the San Andreas fault in this region (*Figures 1, 2*). This fault system splays southward from the San Andreas fault in the vicinity of Bolinas Lagoon, north of the Golden Gate, and continues for a distance of some 400 km, finally dying out in folds and thrust faults between Pt. Sal and Pt Arguello, a few km north of the Western Transverse Ranges. Although the Neogene San Gregorio-Hosgri fault system consists of discontinuous strands that exhibit varying styles and amounts of deformation, the fault system generally follows the basement rock trace of a Paleogene strike slip fault that was an important component of a proto San Andreas fault system.

Over its 400 km length the San Gregorio-Hosgri system is now the principal locus of right lateral strike-slip strain west of the San Andreas. This strain transfers from the northern San Andreas fault where the slip rate is 24 mm/yr to the northern San Gregorio where the slip rate is around 7 mm/yr.[1] That this actually occurs is confirmed by the corresponding decrease by 7 mm/yr in the slip rate of the San Andreas on the San Francisco Peninsula south of its junction with the San Gregorio fault, to 17 mm/yr.[2]

Southward from its onshore exposure between San Gregorio and Año Nuevo Bay the rate of slip along the modern San Gregorio-Hosgri fault system decreases by increments as right slip gradually transfers onto southeasterly splays and is absorbed in the local compressional antiformal structures around Point Sur and Point Piedras Blancas.

The principal eastward splay zones are, between Monterey Bay and Point Sur, the Monterey Bay-Northern Santa Lucia splay comprising the Monterey Bay–Navy fault zone, the Carmel Canyon fault, and the Church Creek and Palo Colorado faults, all of which carry some right slip from the San Gregorio fault into the northern Santa Lucia Range. At the south end of this region the Point Sur antiform must then additionally absorb some right slip by thrusting and uplift. Between the Point Sur and Point Piedras Blancas antiformal uplifts, the Coast Ridge fault probably conveys a small increment of right slip into the coastal front of the central Santa Lucia Range. The amount of right lateral strain available for strike slip faulting is probably further reduced by thrusting, slivering, and uplift of the Point Piedras Blancas antiform. This form of deformation in this area is confirmed both by the existence of the uplift itself, and by the occurrence of numerous thrust mechanism earthquakes in the area. Studies conducted under PG&E's **L**ong **T**erm **S**eismic **P**rogram (LTSP)[3] of the onshore strike slip faulting near San Simeon Bay where several major fault strands coalesce southward, resulted in a range of possible slip rates around an average of 3 mm/yr. This indicates a loss of about 4 mm/yr. right slip along the system going from the junction of the San Gregorio fault with the San Andreas southward to

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[1] Weber, G.E., 1990, Late Pleistocene slip rates on the San Gregorio fault zone at Point Ano Nuevo, San Mateo County, California, in Garrison, R.E., Greene, H.G., Hicks, R.R., Weber, G.E., and Wright, T.L. eds., Geology and tectonics of the central California coast region, San Francisco to Monterey: Pacific Section, American Association of Petroleum Geologists, Book GB67, p. 193-203.

[2] CDMG, 1996, California Fault Parameters.

[3] The requirement for PG&E to initiate a "Long Term Seismic Program" was a condition of their receiving an operating license from the Nuclear Regulatory Commission. *See*: Nuclear Regulatory Commission, Diablo Canyon Unit 1 Operating License, DPR-80, Item 2.c.(7), NRC Operating License Condition, November 2, 1984, Seismic Design Bases Reevaluation Program.

the San Simeon area. Southward from this area right slip continues along the San Simeon-Hosgri fault across the mouth of Estero Bay.

Southward from San Simeon Bay the San Simeon-Hosgri fault trace is entirely offshore, but it can be mapped with a high degree of confidence by geophysical means. The main fault trace between San Simeon Bay and Estero Bay is marked by a local landward facing scarp seen in multibeam sea floor imagery, as well as by its appearance on seismic reflection lines and effect on aeromagnetic data. In the approximate center of its crossing of outer Estero Bay the fault is marked locally by a very prominent seaward facing scarp.

Southward from Estero Bay in the vicinity of Point Buchon, several right slip faults apparently splay eastward from the main Hosgri trace beneath the sea floor along the seaward side of the Irish Hills. These include the East Hosgri fault and the newly recognized Shoreline fault. As with the main San Simeon-Hosgri faulting in Estero Bay, the right slip character of these faults is indicated by right lateral focal mechanism earthquakes along them (*Figure 7*).

Farther south along the central reach of the San Simeon-Hosgri fault and roughly opposite the Santa Maria Valley, the character of the fault gradually alters from that of a high angle strike slip fault to a more complex pattern of folds and faults of reverse to thrust configurations. Earthquake focal mechanisms from this reach of the San Simeon-Hosgri have reverse oblique or thrust focal mechanisms.

With regard to the pattern and tectonics of crustal deformation on either side of the San Simeon-Hosgri, there is a clear and striking difference between the regime of north-northwest-striking fold and thrust structures in the strata of the offshore basin on the west and the west-northwest-striking fold and thrust structures that characterize the near-offshore and onland region of the Santa Lucia-Santa Maria Valley province on the east (*Figures 6, 7*). The structures of the southern offshore Santa Maria Basin and of the southern Hosgri itself, reflect east-northeast-west-southwest compression and crustal shortening while the structures east of the San Simeon-Hosgri boundary reflect northeast-southwest to north northwest—south-southeast compression and crustal shortening. The San Simeon-Hosgri zone appears to form an interface between these provinces of differently oriented compression. One effect on the displacement along the Hosgri of the northeast-southwest directed crustal shortening along its east side is the accumulation of crustal shortening at a moderate to high angle to it on one side but not the other. This effect should introduce an apparent left lateral component of lateral displacement along what farther north is clearly a right lateral fault. The combination of splaying off of right slip from the Hosgri opposite from Point Buchon together with accumulation of crustal shortening in the neotectonic province on the east, giving an apparent component of left slip along the fault south of the area of splaying, may result in a nearly complete lack of lateral slip, but a progressively increasing amount of fault-normal compressive deformation going south as is indicated on seismic reflection profiles and discussed above. This tends to make the southern reach of the San Simeon-Hosgri fault resemble the model proposed in 1984 by Crouch et.al., even though their model clearly does not apply farther north as is demonstrated by the pattern of earthquake hypocenters downdip along the Hosgri fault plane.[4]

Overall the San Gregorio-Hosgri fault system evolves from a major San Andreas branch type of right lateral strike slip fault along its northerly reach, into a complex of folds and thrusts approaching its south end, with incremental losses of right slip into splay faults and upwarps along the way.

## 3. Structure, Seismicity and Neotectonics of the Irish Hills/San Luis Range

The structure of the Irish Hills (where DCNPP is located) comprises two separate domains. The first, and older domain is the Pismo syncline, including its boundary shoulders of Mesozoic "basement" rock and the two fault zones (Edna, San Miguelito) that form parts of the margins of the syncline. This domain is exposed at the surface and has been the subject of geological studies dating back to the late nineteenth century. Available geologic and seismologic evidence appears to indicate that this structural domain has not been active during late Quaternary time.

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[4] Crouch, J., Bachman, S.B., and Shay J.T., 1984, Post-Miocene compressional tectonics along the central California margin: in Crouch, J., and Bachman, S.B., eds., Tectonics and sedimentation Along the California Margin; Pacific Section, S.E.P.M., v. 38, p. 37-54.

The second domain encompasses the various structures that have been active during late Quaternary time and have created or influenced the present landform of the Irish Hills and adjacent offshore region. These structures include the San Luis Range/**I**nferred **O**ffshore **F**ault ("IOF") thrust (including the subsidiary San Luis Bay fault) and Los Osos fault backthrust, which together are responsible for the uplift of the San Luis Range generally and in particular, the Irish Hills, and the right slip Shoreline fault which appears to deflect movement along the west-vergent[5] San Luis Range/"IOF" fault to uplift as is illustrated on *Figure 4b*.

The name San Luis Range/"IOF" thrust is used herein because although the existence of such a fault was dismissed in PG&E's 1988 LTSP Final Report and the NRC's 2001 Safety Evaluation Report, such a fault was in fact recognized in letters commenting on the LTSP by R.D. Brown of the USGS and D.B. Slemmons of University of Nevada, Reno (UNR), addressed to the NRC and written in 1989.[6]

The term "IOF" (Inferred Offshore Fault) was employed for maps and text in articles by Vittorio et. al. and Nitchman and Slemmons published in Geological Society of America Special Paper 292 (1994) (*Figures 6a, 6b*).[7]

Evidence for active compressional deformation and uplift of the Irish Hills is of four types:

1. The steep high terrain, developed in relatively weak layered sedimentary rocks. The formation and current existence of such terrain suggests rapid, ongoing tectonic uplift.
2. Evidence, consisting of a flight of marine terraces, of incremental uplift during at least the last half million years, with a pronounced rejuvenation or acceleration of uplift circa

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[5] *Vergent*: geological term indicating a planar surface sloping upward or updip, "west-vergent" indicates a surface such as a fault inclined up towards the west.
[6] US NRC, Docket Nos. 50-275 and 50-323, Transmittal of Documents and Requests for Additional Information Relating to NRC Staff Review of Diablo Canyon Long Term Seismic Program (LTSP) (TAC Nos. 55305 and 68409), October 13, 1989.
[7] Vittori, E., Nitchman, S.P., and Slemmons, D.B., 1994, Stress Pattern from Late Pliocene and Quaternary Brittle Deformation in Coastal Central California in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B., eds., Seismotectonics of the central California Coast Ranges: Geological Society of America Special Paper 292, p. 133-150.

500 ka.[8] This approximately 500 ka event is represented by steep-walled V-notch drainage course incision of older broad-valley terrain present in the interior valleys of the Irish Hills (*Figures 4, 5*).

3. Presence of late Quaternary reverse and thrust faults along the margins of the Irish Hills. The thrust boundary along the inland Los Osos Valley margin of the hills is the Los Osos fault; the thrust boundary along the seaward side apparently impinges at depth on the east side of the adjacent "Shoreline" fault (*Figures 4a, 4b*). Onshore, southeast of Arroyo Grande, the southwest margin thrust is known as the Wilmar Avenue fault. Smaller late Quaternary faults, present in the leading edge of the southwest margin (San Luis Range/"IOF") thrust include the San Luis Bay, Rattlesnake, Olson, Diablo Cove and DCWHP faults (*Figures 3, 9, 13*).
4. High quality seismicity data obtained since 1987, including
   a. A pattern defined by hypocenters of small earthquakes recorded in the shallow crust beneath the Irish Hills and Los Osos Valley that appears to define a NE-dipping source structure that extends from an updip termination at the vertical "Shoreline" fault, downdip beneath the Los Osos Valley (*Figure 8*). This pattern closely resembles that of the post earthquake hypocenter patterns of well-recorded earthquakes in California including the 1971 San Fernando and 1994 Northridge events (e.g. *Figure* 15).[9]
   b. Focal mechanisms of numerous earthquakes showing compressional or reverse oblique compression faulting (*Figure 7*).

The down dip configurations of both the San Luis Range/"IOF" thrust and the Shoreline fault are clearly delineated by the hypocenters of numerous small earthquakes (*Figure8*). The near surface form of the Los Osos fault was established by LTSP trenching. Its downdip projection is not well controlled but has been drawn on *Figures 4* and *8* by analogy with the backthrusting imaged by hypocenters of aftershocks of the 2003 San Simeon earthquake (*Figure 8*).

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[8] 500 ka. In geological shorthand, the abbreviation “ka.” refers to “hundred thousand” and “ma.” to “millions” of years ago. Thus, “500 ka.” would represent “500,000 years ago.”

[9] Hauksson, E., 1995, Seismological Overview of the 1994 Northridge Earthquake sequence in California, in Mary C. Woods and W. Ray Seiple, Editors: The Northridge, California Earthquake of 17 January 1994, California Division of Mines and Geology Spec. Publ. 116.

The earthquake hypocenters that approximately define the San Luis Range/"IOF" thrust show it as a plane that is vergent to the southwest, sloping up to a subsurface intersection with the vertical Shoreline fault between Point Buchon and Point San Luis. The projected depth of intersection of the two fault planes is at a depth of approximately 1 to 2 km as interpreted from the hypocenter transect plots shown on *Figure 8*.

North-side up anomalies referred to in the LTSP as the Olson and Rattlesnake faults that interrupt the continuity of shoreline angles along the backedges of the lower uplifted marine terraces at two locations between Diablo Canyon and Point San Luis are minor features of apparent late Quaternary deformation. At the DCNPP site the Diablo Cove fault, although also located within the domain of late Quaternary activity, apparently does not displace the lowest marine terrace surface, but may increase in displacement and level of activity along its strike[10] offshore. The Diablo Cove fault is of special interest in that it is a zone of north side up reverse faulting that displaces the Obispo Formation bedrock of the DCNPP Unit 1 Turbine-Generator and Reactor Containment foundations. This zone of faulting is described and illustrated in detail in the following section.

## 4. Diablo Canyon site geology and the Diablo Cove fault zone

### Site geology

The geology of the Diablo Canyon NPP Units 1 and 2 area was initially explored by four large trenches and was later completely exposed in the foundation excavation for the two units, the cooling water intake conduits, and the outlet structure (*Figure 10*). The site geology encompasses three distinct domains:

1. A northwest domain consisting mostly of moderately to steeply dipping predominantly massive sandstone of the Obispo Formation. This domain includes the site of Units 1 and 2. Interruptions to the continuity of the sandstone bedding

[10] "Strike" is a geological term denoting the orientation of a horizontal line on an inclined or vertical planar surface.

in this domain consist of the small reverse-sense displacements along the Diablo Cove fault zone that cuts through the Obispo Formation foundation of Unit 1, and several local clastic volcanic tuff intrusions in the Unit 2 foundation. A claystone interbed present within the Unit 2 sandstone section is a few meters thick and is notable for being internally squeezed and sheared.

2. A southeast domain having more complex structure and more heterogeneous lithology than that in the northwest domain. The generally finer grain strata in this domain were tightly folded in several zones and were intruded by a number of clastic tuff sills and discordant plug-like masses. At least two faults with strike and dip roughly accordant with that of the generally near vertical bedding, were identified in the sea cliff exposure but despite the highly deformed condition of the Obispo Formation in the southeast domain, none of this deformation was observed to extend across the overlying uplifted wave cut platform surface.

3. A cross-cutting domain of cemented, highly resistant intrusive and locally faulted tuff breccia that forms ramparts protecting the coastal headlands as well as the offshore island rocks and apparently the rough sea floor outcrop between the shoreline and the trace of the near-shore Shoreline fault. Among the major components of the Units 1 and 2 power plant complex, only the intake structure and lower ends of the cooling water conduits are located on rocks of this domain. Even the relatively sound, massive sandstone of the Units 1 and 2 foundation is mostly highly fractured with the greatest deformation occurring in a north-northwest trending fracture zone that crosses the east side of the Unit 1 containment foundation, and the highly sheared claystone interlayer located beneath the central part of the Unit 2 half of the Turbine Generator Building, all as shown on the *Figure 10* map. The intricately carved in-place variously fractured and sheared remnants of the rocks of the plant foundation are now encased with formed and cast sheaths of reinforced concrete. It would be worth investigating whether the pervasive secondary fracturing of this rock degrades the strength of the complex of conduit and chambers walls, and pedestals, that form the plant foundation compared to what a foundation of the same layout but constructed of solid reinforced concrete would have.

The greatest uncertainty concerning the performance of the plant foundation, however consists of the remote but actual possibility of further movement along the Diablo Cove zone of faulting through the Unit 1 foundation. The geology and tectonics of this zone are discussed below.

**The Diablo Cove Fault**

**Overview and history**

The Diablo Cove fault is a local zone of faulting accompanied by closely spaced fracturing and some structural disruption that extends from offshore along an east-west trend into the southwest margin of the west-northwest - east-southeast-aligned San Luis Range (*Figures 3, 9* and *13*). The onshore faulting cuts sandstone of the mid-Miocene Obispo Formation bedrock but apparently, not the late Pleistocene (80,000 years) age marine terrace deposit that overlies its trace in the bedrock. Under pre-development site conditions, the faulting was exposed in the Diablo Creek south headland where it was first recognized and mapped in 1966 by PG&E's geologic consultant Professor R.H. Jahns. Subsequently when PG&E had excavated exploratory trenches crossing the Units 1 and 2 layout for the (then) proposed DCNPP complex, Jahns mapped faulting in the Obispo Formation bedrock exposed in the walls of the trenches in the Unit 1 area, and confirmed that the interface between faulted bedrock and overlying uplifted marine terrace deposits was not displaced by upward propagation of any of the bedrock faults. Detailed logs of the trench exposures and a map showing a plot of both the trench exposures and the Diablo Creek headland were then presented accompanying a supplemental report discussing the faulting as it was then known onshore. It was also noted that the strike of the sea cliff headland faulting "corresponds to the trace of the main break as observed in nearly horizontal outcrop within the tidal zone (i.e., the present wave-cut platform) west of the cliff."[11] Still later, in 1969 when the deep bedrock foundation for the Unit 1 facilities had been excavated, Jahns prepared an extremely detailed map of the exposed geology, using 7" x 9" black and white

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[11] Jahns, R.H., 1966, Geology of the Diablo Canyon Power Plant Site, San Luis Obispo County, California: 1967, Supplementary Reports I and II; 1968, Supplementary Report III, Diablo Canyon PSAR, Docket No. 50-275 (Main Report and Supplementary Report I); Diablo Canyon PSAR, Docket No. 50-323 (All reports).

photographs taken by PG&E that systematically covered the walls of the complicated excavation as his mapping base (eg: *Figure 11*). Jahns then transferred the data from the annotated photographs of the Unit 1 foundation, together with similar data from the writer's 1971 mapping of the Unit 2 foundation excavation to an overall base map of the Units 1 and 2 excavation (*Figure 10*).

Composite cross sections based on the Diablo Creek headland map, the Units 1 and 2 trench logs, and the foundation excavation logs are presented on *Figure 12*. Those cross sections show the profiles of natural ground, exploratory trenches, plant foundation excavations and the geology mapped in the trench walls and underlying foundation walls exposures.

During hearings before the CPUC and the Atomic Energy Commission (AEC) Construction Permit Atomic Safety and Licensing Board (ASLB), Jahns explained and defended his conclusion that the faulting he had meticulously documented at the DCNPP Unit 1 site was a minor "second order" feature and while clearly younger than the intense folding and volcanic intrusive activity that had affected parts of the site during mid Miocene time, was definitely older than the unbroken capping uplifted marine terrace deposits, and was therefore inactive and not a potential source of surface faulting dislocation of the Unit 1 foundation.[12]

Subsequently, small dislocations caused by north side up reverse faulting approximately along the trend of the headland and Unit 1 area faulting were mapped in the switchyard access road cut bank by the writer circa 1972. The overall length of the onshore expression of the Diablo Cove fault trend was thus extended to roughly 1,400 feet, with no known termination of the zone on the east and a clear continuation offshore on the west. However, the fault was not shown on the 1:24,000 geologic map released as a USGS open-file report by C.A. Hall in 1973. Hall had independently mapped the geology of the DCNPP site and region during the early 1970's but by then the Unit 1 structure was in place and the headland faulting exposure was obscured by an access road graded across it.

[12] Ibid.

Both the Jahns site-specific geologic data and the Hall open-file regional geologic map were presented in the 1973 DCNPP Final Safety Analysis Report (FSAR) and Supplements extending through 1975. The Units 1 and 2 foundation excavation geologic map was then included as a figure in the PG&E Direct Testimony for the 1978-79 Operating License ASLB hearing (*Figure 10*). This was the last presentation that included the Jahns geologic data or any mention of the Diablo Cove faulting. This information essentially vanished and might never have existed so far as the LTSP Final Report of 1988 was concerned.[13]

It should be noted that there were no official Atomic Energy Commission (AEC) criteria for establishing the activity and corresponding hazard of future movement of tectonic faults prior to 1973. In coastal California, at least, it was customary to consider faults to be "inactive" if it could be shown that they did not displace the lowest uplifted marine terrace, which was known to be circa 100,000 years old at several locations. But in November 1973, the AEC promulgated the regulation "Seismic and Geologic Siting Criteria for Nuclear Power Plants" as Appendix A to 10 CFR100. Appendix A listed criteria defining a fault as "capable," a specific AEC term for a critical level of fault activity. The criteria specified three conditions, any one of which would define a fault as "capable." The definition and three conditions were the following:

> "<u>A capable fault is a fault which has exhibited one or more of the following characteristics:</u>
>
> (1) Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
>
> (2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
>
> (3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other."

[13] Pacific Gas & Electric, 1988, Long Term Seismic Program, Final Report to U.S. Nuclear Regulatory Commission for Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323.

The effect of application of these criteria to the Diablo Cove fault was problematic, at least as the fault was known in 1973. The uncertainty, at that time, lay with the fact that while the zone of faulting did not displace the lowest uplifted terrace, hence satisfying the no movement within the past 35,000 years part of AEC criterion (1), there was no way of determining whether it might have experienced recurring movement between the 80,000 years age of the overlying marine terrace deposits and the arbitrary 500,000 years age limit. In 1973 the seismicity in the region of Diablo Canyon was poorly located especially at the lower limit of "macro seismicity" (circa $M \geq 3.0$) but in any case no epicenters had been plotted within about 10 miles of the site so AEC criterion (2) was not then known to be violated. AEC criterion (3) did not appear to apply prior to recognition of the offshore Hosgri fault in 1972 and the activity or "capability" of that fault was initially in doubt. In any case even though the Diablo Cove fault was last seen heading offshore toward the Hosgri, the latter was mapped by its discoverer Shell Oil Company as passing no closer than about 5 miles from Diablo Cove, seemingly a safe separation from minor faulting along the shoreline.

The result of all of this was that <u>no serious question regarding the apparent lack of conclusive evidence demonstrating the non-capability of the Diablo Cove fault was raised during the protracted AEC/NRC licensing process, or either during the conduct of the LTSP Program or of the external reviews of this program</u>. For the latter case the lack of further inquiry apparently resulted partly because PG&E largely avoided any update study of the DCNPP site itself during the LTSP program, and then argued forcefully against the possible existence of a "shoreline" fault paralleling the coastline in the near offshore region when reviewers from the University of Nevada, Reno, raised that question in 1989.[14] Further discussion of this chronology will be found in section C (3) on page 31 of this Testimony. Thus the "shoreline" fault issue remained dormant, at least regarding the potential for the existence of such a fault in fairly close proximity to the point where the Diablo Cove fault headed offshore, until PG&E-sponsored research by the USGS revealed in 2008 that a coastline-parallel offshore fault did exist and furthermore, was

[14] Pacific Gas & Electric, Response to Question 43e, January 1989. This volume is part of a set that responds to 47 questions asked of PG&E by the Nuclear Regulatory Commission (NRC) on December 13, 1988. The responses provided data requested to augment or clarify the Final Report of the Long Term Seismic Program submitted by PG&E to the NRC on July 31, 1988.

seismically active. And unlike the Hosgri, this fault was very close to the shoreline, passing within about 3000 feet from the Diablo Creek south headland outcrop of the Diablo Cove fault.

<u>In any case the geologic and seismologic data now available (eg. Figure 8) clearly show that the San Luis Range is a "pop-up" wedge being uplifted above a northeast-dipping master thrust and a southwest-dipping backthrust (the Los Osos fault) and that this seismically active thrust system impinges on the seismically active Shoreline fault at shallow crustal depths</u>. This means that the Diablo Cove fault and the DCNPP are situated above the leading edge of an active thrust fault and that the stress environment in this area is affected by both the San Luis Range/"IOF" thrust and the Shoreline fault. This in turn suggests that the Diablo Cove fault could be classified as "capable" according to the terms of NRC criterion (3), "A structural relationship to a capable fault" (ie, both the underlying San Luis Range thrust and the adjacent Shoreline fault, each of which exhibit instrumentally determined macro-seismicity and are therefore capable according to NRC criterion (3) – "such that movement on one could reasonably be expected to be accompanied by movement on the other".

**Geologic Description of Onshore Expression of the Diablo Cove Fault**

The onshore reach of the Diablo Cove zone of faulting was characterized in three stages by Professor Jahns. For the first stage Jahns performed a detailed investigation of the faulting exposed in the south headland of Diablo Creek based on mapping and petrographic studies, but without any subsurface exploration. The results of this initial work were described in a brief report to PG&E dated December 5, 1966. The second stage involved detailed mapping of the walls of four large trenches excavated with bulldozers and scrapers in the terrace where the Units 1 and 2 power plant complex was to be located. Trench logs, geologic observations, and conclusions were then presented in a further report dated July 8, 1967.[15]

[15] Jahns, R.H., 1966, Geology of the Diablo Canyon Power Plant Site, San Luis Obispo County, California: 1967, Supplementary Reports I and II; 1968, Supplementary Report III, Diablo Canyon PSAR, Docket No. 50-275 (Main Report and Supplementary Report I); Diablo Canyon PSAR, Docket No. 50-323 (All reports).

The third stage involved detailed mapping of the geologic features exposed in the walls and where accessible, the floors of the Unit 1 foundation excavation made in 1969. The results of this work consisted of the extremely detailed map (*Figure 10*) but without any written report. However the character of the bedding, joints, "crackled" zones, and faults that were mapped can be inferred from Jahns' annotations on black and white photographs of the excavation walls, examples of which are reproduced as *Figure 11*.

In the Unit 1 foundation excavation, faulting of the Obispo foundation sandstone bedrock was present in an east-west aligned zone exposed from the northwest corner of the turbine-generator building to the east wall of the containment structure (*Figure 12*). The overall length of this exposure was roughly 400 feet and it was aligned with the headland outcrop faulting located some 400 feet west of the west wall of the turbine generator building. The zone crossing the north end of the turbine-generator building was approximately 30 feet wide and consisted of three distinct strands, which dipped 45 to 50 degrees north. No distinct offsets were recognized among the many fractures mapped in the west wall and floor of the Unit 1 containment foundation, but two sets of faulting were mapped in the east wall, separated by about 100 feet and aligned with the zone seen crossing the turbine-generator building. These faults also dipped around 50 degrees north, with the strand on the north having a subsidiary antithetic break dipping toward and terminating against the main break, at a dip angle of 40 degrees (*Figure 12*). The dip slip displacement across the faults ranged between 1 and 5 feet. The principal break within each fault set consisted of multiple shears in a zone ranging from a few inches to roughly 2 feet wide.

The general aspect of the faulting exposed in the foundation excavation walls, which were mostly between 10 and 20 feet below the original rock surface, was one of several distinct breaks which were much more coherent than the rather diffuse breaks recognized in the near surface 5 to 8 feet of weathered bedrock seen in the overlying exploratory trenches (*e.g. Figure 12*).

The pattern of upward splaying and near-surface secondary antithetic fault-bounded "pop-up" wedges that characterizes the upper level of exposure of the Diablo Cove fault in both the natural headland exposure and the artificial exploratory trench and foundation excavation exposures suggests that the faulting now seen within this zone developed near a free surface rather than at depth where it would have been more confined. This impression is supported by the results of Jahns' petrographic study of the rock within the zone of faulting. This study revealed that "…nearly all of the samples were found to contain shards of volcanic glass and/or the tests of foraminifera; some of these delicate components showed effects of microfracturing and a few had been offset a millimeter or less along tiny shear surfaces, but none appeared to have been smeared out or partially obliterated by intense shearing or grinding." (Jahns, 1966). These observations suggest that the most recent faulting may have occurred when the now uplifted bedrock floor of the 80,000 year terrace surface was still the actively eroding surf zone platform. If this was the case, the faulting would have occurred long enough ago for its surface scarps to have been planed by marine erosion and the resulting planed surface covered by surf zone marine deposits and then uplifted to form the present terrace bench. The faulting would then be somewhat older than 80,000 years but possibly younger than the next older terrace level of around 120,000 years age.

**Offshore Expression; Apparent Relationship to Shoreline Fault**

As observed in available multibeam sea floor imaging, there is a definite zone of structural disturbance and terrain interruption along the approximately 200m. width of the elevated rough bathymetry along the strike of the onshore Diablo Cove fault. This terrain interruption terminates the linear scarp of the Shoreline fault in resistant Obispo Formation vitric tuff, that extends southeastward from the termination. The seaward projection of the Diablo Cove fault is marked by a channel-like eroded zone that separates the continuous sea floor outcrop on the landward side of the Shoreline fault scarp from an outcrop of similar elevated sea-floor terrain that steps east roughly 200 m toward the shoreline. The landward step in outcrop occurs at a point where the strike of the Shoreline fault bends abruptly from N48W on the NW to N68W on the southeast (*e.g. Figure 9*).

From the available multibeam imaging it is not clear whether the deflection in the strike of the Shoreline fault results from dislocation by movement along the Diablo Cove fault or instead from structural interaction with a pre existing fault structure by a developing Shoreline fault. But in either case the evidence strongly suggests some interaction between the known seismically active Shoreline fault and the seaward extension of the Diablo Cove fault.

**Tectonic Context of the Diablo Cove Fault**

The tectonic model of the San Luis Range and adjacent offshore area was described in Section B-3 of this report and illustrated diagrammatically (*Figure 6*). This model shows the region in the vicinity of the Hosgri fault and its Point Buchon splays, being subject to north-northwest shear while the adjacent San Luis Range is subject to north-northeast - south-southwest compression. The large-scale north-northwest right lateral shear along the San Simeon-Hosgri fault system includes its principal east-side splay, the Shoreline fault, to north-south compression. This compression apparently drives the east side up reverse movement of the east-west aligned Diablo Cove fault. The latter fault is clearly a planar surface along which north-south compression has previously resulted in reverse sense shear failure, probably during late Quaternary time. On the basis of its angle of intersection with the northerly N48W reach of the Shoreline fault, the east-west aligned Diablo Cove fault could have either a branch-splay or less probably, a conjugate structural relationship with the shoreline zone. That the compression is still active is abundantly demonstrated by the many right lateral mechanism earthquakes along the Shoreline fault, such that the Diablo Cove fault should probably be considered correspondingly subject to potential hazard of future additional movements.

A further suggestion of interaction between these faults is provided by a cluster of three epicenters of small earthquakes located 0.5 km NW of the offshore Diablo Cove fault. As determined by Hardebeck (2010)[16] the hypocenters of these events were between 4 and 6 km depth, and were slightly east of the surface trace of the vertical Shoreline fault. They were, however, approximately down dip from the surface trace of the north-dipping Diablo Cove fault. <u>This suggests that ongoing seismic adjustments at depth along the active Shoreline fault may trigger small seismic adjustments along the adjacent part of the Diablo Cove fault</u>.

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[16] Hardebeck, Jeanne L., Seismotectonics and Fault Structures of the California Central Coast, Bulleting of the Seismological Society of America, Vol. 100, No. 3, pp. 1031-1050, June 2010.

## 5. Shoreline Fault and Inferred Offshore Fault ("IOF")

Although PG&E's 1985-88 LTSP program provided essentially no significant new information about the geology of the DCNPP site (and no mention of that already available from its previous licensing studies), it did include installation and activation of a local seismograph network starting in late 1987, which resulted in a vastly improved capability to record earthquakes originating in the south central coastal region. This combined with the much refined local crustal model also developed in connection with the LTSP, allowed much more accurate determination of the location, depth, and for larger events, focal mechanism of earthquakes occurring in the region. The accumulating high-quality earthquake data then began to gradually define a much clearer image of the active tectonism in the region. By 2001, 14 years of such high quality earthquake records had been acquired and integrated into the Northern California Earthquake Data Center (NCEDC). This data set then provided the basis for a valuable article entitled "Seismicity of South-Central Coastal California" by PG&E's Marcia McLaren and William Savage and published in the Bulletin of the Seismological Society of America.[17]

Five years later, in 2006, the writer acquired the NCEDC epicenters plotted on the digital terrain image of *Figure 2*. On that plot a clustering of epicenters beneath the Irish Hills/San Luis Range is clearly evident, and more than half of the focal mechanisms shown by McLaren and Savage (2001) for this area were thrust or reverse oblique. In early 2008 the writer arranged to have several plots of the hypocenters of the Irish Hills/San Luis Range region earthquakes in the NCEDC catalogue made for transects through the range. The resulting plots, which provided seismicity cross sections "e" and "f" for *Figure 8*, clearly define a northeast dipping pattern that closely resembles the main shock and aftershock pattern of the destructive 2003 San Simeon earthquake (*Figure 8*). These plots also show the vertical zone of hypocenters that was part of the basis for the subsequent identification by the USGS of the actual Shoreline fault in October 2008. PG&E was advised of this discovery in November 2008 and shortly notified both the NRC and the San Luis Obispo area public, the latter at a press conference reported in the local

[17] McLaren, M.K, and Savage, W.H., 2001, Seismicity of South-Central Coastal California: October 1987 through January, 1997 Bull. Seismol. Soc. Am. V. 91, no. 6 pp.1629-1688.

newspaper on November 22, 2008.[18] The seismologic and geophysical bases for the USGS interpretation of the Shoreline fault were then formally presented to the scientific community in a special session entitled "Central California Coast Earthquake Hazards" at the annual meeting of the Seismological Society of America in March 2009.[19] Update presentations on progress in studying the newly recognized Shoreline fault both by the USGS (supported by PG&E) and by PG&E staff and private consultants were presented to the NRC in June of 2009 and on January 5 of 2010.[20] However all of these presentations either by inadvertent omission or design, avoided touching on the issue of the thrust fault-defining pattern of earthquake hypocenters beneath the Irish Hills immediately adjacent to the Shoreline fault as these are shown in the hypocenter cross sections of this Testimony (*Figure 8*).

## C. Seismic Source Faults and Their Estimated Earthquake Capability in the Vicinity of the DCNPP

The following is a discussion of the writer's proposed revised deterministic seismic hazard to the DCNPP. This revision modifies the deterministic hazard evaluation given in PG&E, 2011 to accord with several lines of geologic (including geomorphic) and seismologic evidence that have become available between 1981 and 2011 which are either not mentioned or are not accurately characterized in PG&E's seismic hazard evaluations of 1988, 1991, and 2011. The principal changes to PG&E's (and the NRC's) geoseismic characterizations that lead to this proposed revision of the seismic hazard to the DCNPP are discussed below.

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[18] Sneed, David, "Fault found near plant," San Luis Obispo Tribune, November 22, 2008, p. 1.
[19] Johnson, S.Y., Hart, P.E., Watt, J.T., and Slater, R.W., 2009, High Resolution Seismic Reflection Survey Offshore Central California Will Help Refine Regional Seismic Hazard Assessment, Abstracts, in Seismological Research Letters, vol. 80, No. 2, March-April 2009. and Hardebeck, J., Seismotectonics and Fault Structure of the Central Coast.
[20] Summary of January 5, 2010, Meeting with Pacific Gas and Electric Company Regarding Shoreline Fault, January 20, 2010, Nuclear Regulatory Commission, ADAMS number ML 100060063 and accompanying slides.

*Figure 14* shows the traces and a down dip projection of the faults identified by PG&E 2011a[21], 2011b[22] as defining the seismic hazard to DCNPP, together with the San Luis Range thrust/"IOF" fault identified in this writer's study. Table A lists the characteristics of the four faults the writer considers as defining most of the seismic hazard to DCNPP. Note that Table A does not list the San Luis Bay fault, which the writer does not consider as significant a threat.

**1. Hosgri fault**

Length is 150 km plus since there is no interruption in the continuity of the San Simeon and Hosgri faults,[23] rather than the 110 maximum Hosgri length stated in PG&E 1988[24] and 2011,[25] based on a northern termination of this fault at a "Cambria Stepover" structure. The continuity of the Hosgri and San Simeon faults was demonstrated by the marine geophysical study reported in USGS OFR 81-430,[26] and recently confirmed by multibeam sea floor imaging interpreted by Johnson (2011)[27] and the writer (*Figure 2*). San Simeon and Hosgri are therefore merely different names given to reaches of the same 150 plus km long fault, as described both by Leslie in OFR-81-430 and by McColloch, 1987. The $M_{max}$ for this fault is $\geq$M7.5, not M7.1 as listed in

[21] PG&E, Report on the Analysis of the Shoreline Fault Zone, Central Coastal California, Report to the US Nuclear regulatory Commission, January 2011.
[22] PG&E, Report on the Analysis of the Shoreline Fault Zone, Central Coastal California, Report to the US Nuclear regulatory Commission, Section 5, Seismic Source Model Map, Traces of Hosgri, Los Osos, San Luis Bay, and Shoreline Fault sources, p. 5-24, January 2011.
[23] McCulloch, S.S., 1987, Regional geology and hydrocarbon potential of offshore central California: in Scholl, D.W., Grantz, A., and Vedder, J., eds., Geology and Resource Potential of the Continental Margin of Western North America and the Adjacent Ocean Basins, Beaufort Seat to Baja California; American Association of Petroleum Geologists Circum. Pacific Earth Science, v. 6, p. 353-401.
[24] PG&E, 1988, Long Term Seismic Program, Final Report to U.S. Nuclear Regulatory Commission for Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323.
[25] PG&E, Report on the Analysis of the Shoreline Fault Zone, Central Coastal California, Report to the US Nuclear regulator.
[26] Leslie, R.B., 1981, Continuity and tectonic implications of the San Simeon - Hosgri fault zone, central California: U.S. Geological Survey Open-File Report 81-430, 59 p.
[27] Johnson, Samuel Y., USGS offshore, low-energy seismic-reflection data, USGS Pacific Coastal and Marine Science Center, Diablo Canyon SSHAC Workshop 1, November 29, 2011.

PG&E 2011 or "closer to M6.0" as stated in a communication released by PG&E spokesman Kory Rafftery in January 2011.[28]

## 2. Shoreline fault

Following its recognition by Hardebeck[29] of the USGS 20 years after PG&E failed to recognize that seismologic and sea floor geomorphic evidence contained in its 1988 LTSP final Report indicated the existence of a shoreline fault, the Shoreline fault has been characterized in PG&E 2011 as a structurally isolated, segmented strike slip fault with a maximum seismic capability of a M6.5 earthquake. The writer (Hamilton 2010a,[30] b[31]) and more definitively Hardebeck et. al. (2011)[32] show that the Shoreline fault is structurally linked to the Hosgri fault. The writer further presents geophysical evidence from PG&E 1975[33] and 1988[34] that strongly suggests a southeasterly continuation of the Shoreline fault across San Luis Obispo Bay toward the Santa Maria Valley. The dimensions and characteristics of the Shoreline fault as thus characterized are similar to those of the Greendale fault that ruptured during the M7.1 2010 "Canterbury" earthquake in New Zealand. The appropriate magnitude for a conservative evaluation of a potential earthquake on the Shoreline fault is therefore circa M7.0 although a splay onto it from a long rupture along the San Simeon-Hosgri fault to the north, could give rise to a M$\geq$7.0 earthquake along the Shoreline fault.

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[28] Sneed, David, San Luis Obispo Tribune, January 15, 2011, p. 1.
[29] Hardebeck, Jeanne L., Seismotectonics and Fault Structures of the California Central Coast, Bulletin of the Seismological Society of America, Vol. 100, No. 3, pp. 1031-1050, June 2010.
[30] Hamilton, Douglas H., Earthquake and Fault Hazard in the area of the Diablo Canyon Nuclear Power Plant, san Luis Obispo, California, March 2010
[31] Hamilton, Douglas H., Dual-System Tectonics of the San Luis Range and Vicinity, Coastal Central California, poster session, 2010 American Geophysical Union Fall Meeting, San Francisco, California, December 15, 2010.
[32] Hardebeck, J.L., Objective Determination Of The Geometry Of The Shoreline And Hosgri Faults, Near Point Buchon, California, From Seismicity Relocations, U.S. Geological Survey, Menlo Park, CA April 15, 2011
[33] PG&E, 1975, Appendix 2.5 E, Final Safety Analysis Report for Diablo Canyon Nuclear Power Plant: U.S. Atomic Energy Commission Docket Nos. 50-275 and 50-323.
[34] PG&E, 1988, Long Term Seismic Program, Final Report to U.S. Nuclear Regulatory Commission for Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323

**3. San Luis Range/"IOF" thrust** (the southwest range-front uplift structure for the Irish Hills - San Luis Range wedge uplift, consisting primarily of the Wilmar Avenue fault on the southeast and the "Inferred Offshore Fault" ("IOF") of Nitchman, 1988,[35] Nitchman and Slemmons (1994)[36] and Vittorio et al (1994)[37] opposite the Irish Hills.

The existence of this structure is required in order to account for the level uplift of the Irish Hills/San Luis Range, as was noted by both the USGS's Brown[38] and UNR's Slemmons each in both 1989[39] and 1991[40] and by Slemmon's student Nitchman in 1988 and (with Slemmons) in 1994. Seismologic evidence suggestive of the existence of a thrust fault underlying the Irish Hills was presented but not discussed, both in PG&E's 1988 LTSP Final Report and in McLaren and Savage (2001). Additional hypocenter data available from the Northern California Earthquake Data Center (NCEDC) in 2008 and plots by Hardebeck (2009) and PG&E (2011), (*Figure 8*) clearly delineates the northeast dipping thrust structure present beneath the Irish Hills, but has not, to this writer's knowledge, been acknowledged by either the USGS, PG&E, or the

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[35] Nitchman, S.P., 1988, Tectonic geomorphology and neotectonics of the San Luis Range, San Luis Obispo County, California: University of Nevada, Reno, M.S., thesis, 120 p.
[36] Nitchman and Slemmons, D.B., 1994, The Wilmar Avenue Fault: A Late Quaternary Reverse Fault Near Pismo Beach, California, in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B., eds., Seismotectonics of the central California Coast Ranges: Geological Society of America Special Paper 292, p. 133-150.
[37] Vittori, E., Nitchman, S.P., and Slemmons, D.B., 1994, Stress Pattern from Late Pliocene and Quaternary Brittle Deformation in Coastal Central California in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B., eds., Seismotectonics of the central California Coast Ranges: Geological Society of America Special Paper 292, p. 133-150.
[38] Brown, Robert, Letter to US Nuclear Regulatory Commission, September 25, 1989 as collected by the NRC in the "Transmittal of Documents and Requests for Additional Information Relating to NRC Staff Reviw of Diablo Canyon Long Term Seismic Program (LTSP) (TAC NOS. 55305 and 68049).
[39] Slemmons, D.B., Letter to US Nuclear Regulatory Commission, September 25, 1989 as collected by the NRC in the "Transmittal of Documents and Requests for Additional Information Relating to NRC Staff Reviw of Diablo Canyon Long Term Seismic Program (LTSP) (TAC NOS. 55305 and 68049).
[40] Slemmons, D.B., and Clark, D.G., 1991, Independent Assessment of the Earthquake Potential at the Diablo Canyon Power Plant, San Luis Obispo County, CA., Center for Neotectonic Studies, Mackay School of Mines, University of Nevada, Reno, NV, Appendix D in Safety Evaluation Report related to the operation of Diablo Canyon Nuclear Power Plant, Units 1 and 2 Docket Nos. 50-275 and 50-323, Pacific Gas and Electric Company.

NRC even though the data as illustrated in Hamilton (2010a, b) have been made available, as requested, to seismologists on the staffs of all three organizations.

The San Luis Range/"IOF" thrust has a length of as much as 80 km and a down dip width of approximately 20 km. It reaches the surface along the southwest margin of the "Pecho Shelf," Irish Hills, and San Luis Range as, respectively, the "N40W" fault of PG&E (2011)[41], the scarp along the trace of the central reach of the Shoreline fault, and the Wilmar Avenue fault. Its leading edge passes beneath the DCNPP at a depth of approximately 1 to 2 km, within Franciscan Formation or Cretaceous sedimentary rock. Both PG&E (2011) and the CDMG (1998)[42] assign a magnitude potential of M7.0 to the Wilmar Avenue fault. A calculation based on NGA[43] (Next Generation Attenuation) attenuation relationships indicates a maximum spectral acceleration of 2.35g for ground motion at the DCNPP site resulting from a M7.0 earthquake on the San Luis Range/"IOF" thrust fault. This value considerably exceeds the ground motion from maximum earthquakes on either the Hosgri or the (separate) Shoreline fault.

**4. Los Osos fault.** This topographically prominent late Quaternary reverse or thrust fault provides the structure for the uplift of the northeast side of the Irish Hills and San Luis Range. However the available NCEDC, USGS, and PG&E hypocenter data (*Figure 8*) shows that the Los Osos fault must be a large backthrust of the underlying San Luis Range thrust. This indicates a down dip width limited by the down dip intersection of the Los Osos fault plane with the plane of the underlying San Luis Range "master" thrust. This width is circa 7 km, so the maximum earthquake on the Los Osos fault should not exceed circa M6.5. Additionally it seems likely that significant movements along the Los Osos fault can occur only as back thrust events linked to movements along the San Luis Range/"IOF" thrust. The Los Osos fault, by itself, would therefore appear to provide very little contribution to the seismic hazard to the DCNPP.

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[41] PG&E, Report on the Analysis of the Shoreline Fault Zone, Central Coastal California, Report to the US Nuclear regulatory Commission, January 2011.

[42] California Department of Mines and Geology Seismology Committee, "Maps of Known Active Fault Near-Source Zones in California and Adjacent Portions of Nevada", International Conference of Building Officials, 1998.

[43] NGA, data available at: www.peer.berkeley.edu/ngawest/nga_models.html

**5. San Luis Bay fault**. This reverse or thrust fault present along the shoreline of Avila Bay and continuing northwest through the pass between San Luis Hill and the main body of the Irish Hills, appears to be an upward splay from the underlying San Luis Range/"IOF" thrust. As such it has a limited down-dip width and consequently a limited earthquake potential, probably not exceeding a maximum of M6.0. As with the Los Osos fault, movement along the San Luis Bay fault appears to be linked with the San Luis Range/"IOF" fault and so this fault is unlikely to provide a significant independent seismic source affecting the seismic hazard to the DCNPP. Note that PG&E's interpretations have indicated an offshore extension of the San Luis Bay fault into the terrane of the Point San Luis high. This may or may not exist, but if it does it is now structurally and tectonically disconnected from the onshore San Luis Bay and San Luis Range/"IOF" faults by the cross cutting Shoreline fault.

The attached illustration (*Figure 14*) shows a mark-up of PG&E's (2011) Figure 5-8 to delineate the map traces and down-dip surfaces that this writer considers provides the actual seismic source model for the Diablo Canyon area. Earthquake hypocenter cross sections based on PG&E, USGS, and NCEDC data, with interpreted geologic structure are shown as well in *Figure 8*.

## D. Comparison of Diablo Canyon's PG&E-estimated maximum earthquakes with recent well-recorded distinctive earthquakes elsewhere

### 1. The Diablo Canyon – Christchurch New Zealand Analogy

There are several notable similarities between the tectonic setting of Diablo Canyon and that of the city and region of Christchurch in New Zealand. The obvious difference between the two sites is that no strong earthquake has occurred close enough to Diablo Canyon to give rise to intense vibratory ground motion in that area during the roughly two hundred years of historic record there, whereas Christchurch was partially destroyed by intense vibratory ground motion generated by an earthquake of moderate (M6.3) strength, in February of 2011. The M6.3 event centered near Christchurch proper was an aftershock of the main M7.1 earthquake that had originated about 40 km west of that city on a previously unknown strike slip that reached as close as about 20 km west of Christchurch. The M6.3 aftershock was a shallow event on a smaller and also unknown fault centered approximately 5 km south of the center of Christchurch. The pga in Christchurch was around 1.0g on rock, and over 1.0g on many soil sites.[44]

The analogy with Diablo Canyon is that the original Design Basis (DB) for the AEC-permitted OBE (Operating Basis Earthquake) and SSE (Safe Shutdown Earthquake) for the two units, as postulated by PG&E's original seismic consultants Benioff and Smith and structural engineer John Blume, involve a hypothetical earthquake with characteristics similar to those experienced in Christchurch. Benioff and Smith determined that, based on their work in the mid- 1960s, there were four possible earthquake scenarios for Diablo Canyon:[45]

Earthquake A: A magnitude 8 and 1/2 along the San Andreas fault 48 miles away

Earthquake B: A magnitude 7 and 1/4 along the Nacimiento Fault 20 miles away

Earthquake C: A magnitude 7 and 1/2 along the offshore Santa Ynez fault, 50 miles away

Earthquake D: An aftershock of magnitude 6 and 3/4 at 6 miles *directly beneath* the site, associated with earthquake A listed above.

The location of these earthquakes is shown on *Figure 1*.

The AEC accepted a combination of postulated earthquakes "B" and "D" as determining the design basis of the plant. However, as the writer has demonstrated in the preceding sections, the San Luis Range/"IOF" thrust, located directly beneath the plant, is *the* source of Earthquake "D," the basis of the plant's licensed OBE and SSE. Correspondingly, Earthquake "B" is no longer the M7.25 along the Nacimiento Fault 20 miles away, but conceivably the strike slip Hosgri fault at less than 3 miles from the plant and therefore the potential source of either a main shock or a large aftershock affecting the San Luis Range/"IOF" thrust fault beneath the plant site. Seemingly the seismic hazard to the plant based on its tectonic setting is much greater than the unrecognized Greendale fault and aftershock zone was to Christchurch. Knowledge of earthquake ground motion acquired since John Blume assigned .4g as the presumed doubled ground acceleration for the above referenced Earthquake D has greatly improved. It is

[44] Anderson, R., and Stirling, M., "Preliminary Information on the M7.1 September 4, 2010 Darfield Canterbury Earthquake and Mw 6.3 February 22, 2011 Christchurch Aftershock, New Zealand," AEG News 54 (3), September 2011.

[45] US Atomic Energy Commission, Division of Reactor Licensing, Report to the Advisory Committee on Reactor Safeguards, In the Matter of Pacific Gas and Electric Company Diablo Canyon Nuclear Plant, Report No. 1 September 20, 1967, pp. 6-7.

conceivable that subject to contemporary interpretation in a post-San Fernando, post-Northridge environment (in which instrumentally recorded "g" forces of 1.25g exceeded previously accepted maxima by a factor of three), the ground motion that could be expected from the combination of a Hosgri *plus* San Luis Range/"IOF" event may well exceed the original estimate, and a reinterpretation subject to contemporary understanding is overdue. <u>PG&E's current Application for seismic studies does not adequately recognize this deficiency</u>.

## 2. The Diablo Canyon – Fukushima Analogy

Unlike the analogy based on tectonic setting similarity between the Diablo Canyon site and Christchurch, New Zealand, a Diablo Canyon – Fukushima, Japan analogy is based on the attitudes of the owner-operator and regulators of the DCNPP and the Fukushima Daichi and Daini nuclear generation complex. In the Fukushima case the fact that the owners and regulators had grossly underestimated both the potential vibratory ground motion and especially, the magnitude of the potential tsunami was made immediately evident by the shaking followed by inundation that resulted in one of the two worst non military nuclear disasters that have ever occurred. But the Fukushima disaster resulted from a replay of a tsunami event recorded both in the annals of Japanese history and in the sedimentary deposits that provided evidence of a tsunami inundation that extended as far inland as, and therefore resulted from a wave and causative offshore earthquake like, the one of April 2011. This had been documented based on an investigation by Japanese geoscientists in an article published in 1991 (Minouru and Nakata, 1999).

The date of publication of this particular article was some thirteen years after the first of the six plants of the Fukushima complex was completed, but twenty years before it was destroyed along with a large tract of the surrounding countryside. During those twenty years following publication of this study—that provided the historic and geologic evidence of an earthquake and tsunami many times greater than what had been accounted for in the design of the Fukushima complex—apparently there was no move on the part of the plant's owner Tokyo Electric Power (TEPCO) or regulators to undertake any upgrade of its seismic/tsunami resistance. Instead TEPCO sought validation of its inadequate design mathematically with a Probabilistic Seismic

Hazard Assessment (PSHA) but one with input parameters that, viewed in post disaster retrospect, were grossly low.

At Diablo Canyon conditions are certainly better than at Fukushima so far as tsunami hazard is concerned, but the potential for the occurrence of vibratory ground motion exceeding that for which the plant has been designed and analyzed is probably greater. As in the analogy of Christchurch, PG&E's current Application for seismic studies does not adequately recognize nor address this deficiency.

### 3. The Diablo Canyon – San Simeon Analogy

The well documented 2003 San Simeon M6.5 earthquake provides a direct analogue of a potential large earthquake involving the San Luis Range/"IOF" thrust and Los Osos fault backthrust system. Geologically the thrust and reverse fault system that gave rise to the San Simeon earthquake and its thousands of aftershocks forms the structural and tectonic root of the southern Santa Lucia Range "pop-up" just as the San Luis Range/"IOF" thrust and Los Osos fault backthrust form the structural and tectonic root of the similarly situated San Luis Range. The two ranges are adjacent, separated only by the Los Osos Valley antiform, and both root in major structures accommodating northeast-southwest crustal shortening by thrust faulting and uplift within the Santa Lucia Range-Santa Maria neotectonic province of the southern Coast Ranges, as is discussed in preceding Section B-3. Both ranges are the sites of abundant seismicity (*Figure 2*), much of it arising from thrust-mechanism earthquakes (*Figure 7*), even discounting the seismicity in the southern Santa Lucia Range that was generated by the 2003 San Simeon earthquake. Both ranges are undergoing geologically rapid uplift, which results in the steep rugged terrain of each. Seemingly all that is lacking in the comparison is a contemporary earthquake in the San Luis Range larger than the locally damaging one that occurred in 1916.[46]

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[46] Pacific Gas & Electric, 1988, Long Term Seismic Program, Final Report to U.S. Nuclear Regulatory Commission for Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323.

Figure 12 in McLaren et. al; 2008,[47] entitled "Summary model for the complex faulting in the 2003 San Simeon earthquake" which is based on the main shock and aftershock hypocenter patterns along three transects of this earthquake zone, provides the basis for a structural and seismicity comparison. Such a comparison of similar hypocenter distribution patterns is visibly comparable and evident on *Figure 8*, which reproduces the McLaren et. al. 2008 Figure 12 for comparison with the San Luis Range seismicity and structural cross sections also shown on *Figure 8*. In short, the earthquake aftershock distribution pattern generated by the blind thrust fault that caused the San Simeon event of 2003 is uncannily similar to the pattern emerging in the San Luis Range nearest to Diablo Canyon, and is a likely precursor of similar larger thrust mechanism earthquakes there.

**4. The 1971 San Fernando Earthquake comparison**

In 1971, a M.6.7 on the San Fernando segment of the San Gabriel frontal fault system, ruptured a thrust fault plane of 15 km strike length, 20 km up dip from the earthquake main shock hypocenter near the lower end of rupture (*Figure 15*).

This seismic event involved nearly pure updip thrust movement, which created a zone of surface scarps some 13 km long. Ground motion at the Pacoima Dam strong motion seismograph on the hanging wall upper plate was the strongest ever recorded when the earthquake occurred in 1971, and damage above the leading edge (e.g. Sylmar Hospital) was intense (MM IX)[48]. The San Fernando earthquake provides a fairly close analogue for a large earthquake on the San Luis Range/"IOF" thrust as can be seen on the plot of aftershock hypocenters (*Figure 15*). An earthquake that involved most of the Irish Hills section of this thrust, with dimensions of circa 20 km strike length and circa 18 km down dip width, would be somewhat larger than the San Fernando event, perhaps around M~6.8. An earthquake that involved greater strike length of

[47] McLaren, M.K., Hardebeck, J.L., VanderElst, N., Unruh, J.R., Bawden, G.W., and Blair, J.L., 2008, Complex Faulting Associated with the 22 December 2003 Mw6.5 San Simeon, California, Earthquake, Aftershocks and Post Seismic Surface Deformation, Bull. Seismol. Soc. Am., v. 98, No. 4, pp 1659-1680.

[48] MM (Modified Mercalli) scale is a measure of locally experienced earthquake effects and damage ranked on an overall scale of I (least) to XII (greatest)

fault rupture, extending southeastward to include part of the Wilmar Avenue fault, could reach a magnitude of around 7.0. The increased magnitude potential is due to the overall increased total area of the rupture. Two differences between the historic San Fernando earthquake and a potential Irish Hills-San Luis Range earthquake are first, that the leading edge of the Irish Hills part of the San Luis Range thrust appears to terminate updip against the vertical strike slip Shoreline fault (as discussed in Section B-3 and illustrated conceptually on *Figure 4b*). The second difference is that there is no Los Osos fault type backthrust for the San Fernando fault. The combination of a partially blocked leading edge and a backthrust with unimpeded continuity to the surface for the San Luis Range/"IOF" could potentially result in there being an even higher proportion of vertical motion associated with a large earthquake beneath the Irish Hills compared with the San Fernando ground motion.

**5. The 1994 Northridge Earthquake comparison**

The 1994 Northridge earthquake, M6.7, on a blind thrust beneath the San Fernando Valley north of Los Angeles, ruptured a fault plane of 15 km strike length, 22 km down dip width like the nearby previous San Fernando earthquake, with the earthquake main shock hypocenter near the bottom of the zone of fault rupture (*Figure 15*).

The Northridge earthquake provides another form of analogue with a potential large seismic event on the San Luis Range/"IOF" thrust or thrust plus Los Osos fault backthrust system. This analogy comes from the condition that, like the Irish Hills section of the San Luis Range thrust, the leading edge of the Northridge source structure is blocked from reaching the surface by a subsurface termination against another fault. The horizontal energy, unable to be dissipated updip because of the blockage, is in turn forced into a near vertical expression. This may well have been a factor in the strong motion recordings from this earthquake at two sites showing a component of vertical motion equal to or greater than the largest component of horizontal motion. This accentuation of vertical motion could be an important analogue of potential ground motion induced by a large earthquake on the San Luis Range/IOF thrust or thrust and Los Osos fault backthrust system.

## E. Calculated Response Spectra for DCNPP, PG&E versus this testimony

Response spectra for potential earthquakes on the four faults that appear to define the earthquake hazard to the DCNPP, (Hosgri, Shoreline, Los Osos, San Luis Range/"IOF" thrust) as calculated using an average of the five 2008 NGA attenuation relationships and the seismic parameters shown on Table A, together with the Hosgri response spectrum presented in the PG&E Long Term Seismic Program report, are shown on *Figure 16*. It will be noted that the spectral acceleration for a near maximum M 6.7 earthquake on the Shoreline fault is nearly the same as the 1988 LTSP Hosgri M 7.2 earthquake spectral acceleration (determined using the attenuation relationships available at that time), and that spectral acceleration for a M 7.2 Hosgri earthquake occurring at 4 km distance on the Hosgri, calculated using the current NGA relationships, is substantially lower. However the spectral acceleration for an earthquake even as small as M6.5 on the underlying San Luis Range/"IOF" thrust is substantially higher than for an earthquake as large as M6.7 on the Shoreline fault (or 7.2 on the Hosgri fault), and the exceedance of the spectral acceleration of San Luis Range/IOF thrust events increases progressively, with the spectral acceleration reaching 2.36 g for a 7.0 magnitude event on that thrust, using the "averaged" NGA results.[49]

This response spectra plot computed using straight NGA relationships and the formulas contained therein may be compared with the plot shown by PG&E in its "Shoreline Fault Investigation Final Report" issued in January, 2011 (*Figure 16*).

## F. Potential Earthquake Hazards Including Strong Ground Motion, Ground Deformation, Ground Failure, and Local Tsunami Generation

The earthquake hazard potential from seismic source structures present in the south central coastal region derives from either, or a combination of, offshore earthquakes of predominantly strike slip mechanism, and nearshore/onshore earthquakes of predominantly reverse or thrust mechanism.

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[49] These spectral accelerations were computed by Dr. Robert Pyke using an Excel spreadsheet for NGA spectral acceleration values developed by Dr Norman Abrahamson.

**Seismic strong ground motion:** This hazard exists throughout the region but would appear to be greatest, based on proximity to known active seismic source structures, along and within around 20 km inland from the coastline, at least as far south as Arroyo Grande. The principal seismic source structures that give rise to this hazard are the strike slip San Simeon-Hosgri and Shoreline faults, and the San Luis Range/"IOF" and Los Osos thrust faults. Possibly the Oceanic – West Huasna fault should also be included although its distance of some 20 km from the DCNPP limits the effects of even a large earthquake from this source originating at its closest approach to the plant site.

As part of PG&E's presentation for the California Energy Commission Workshop of July 26, 2011, they show slides entitled "Spent Fuel Pool Supplemental Water Sources" and "DCPP Design Overview."[50] Each slide presents information concerning the DCNPP emergency cooling systems, and each identifies the two 2.5 million gallon raw water storage reservoirs at the site as supplemental or backup sources of emergency cooling water. The two reservoirs are broad, relatively shallow basins located on the graded off top of a topographic knob near the base of the ridge behind the DCNPP. The effect of earthquake-induced seiches that were widespread in the San Francisco Bay area as effects of the 1989 M6.9 Loma Prieta earthquake was that swimming pools and other open-water basins lost much of their water as it sloshed out of the basin. This occurred not only in close proximity to the earthquake epicenter in the Santa Cruz Mountains west of San Jose, but at points at least as far distant as Walnut Creek, nearly 100 km from the epicenter. The likely occurrence of similar seiche-induced loss of water from the two open raw water storage basins identified as sources of 5 million gallons of cooling water by PG&E would appear to cast some doubt on the validity of this aspect of its emergency planning.

An aerial photo (*Figure 20*) of the DCNPP included in the same Nuclear Workshop presentation clearly shows the proximity of the Dry Cask Spent Fuel storage pad to the two raw water reservoir basins. The close proximity of the two facilities suggests that a seiche surge from the basins, in addition to reducing the amount of stored water available for emergency cooling in the

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[50] Sharp, L., Pacific Gas & Electric, Diablo Canyon Power Plant, presentation to California Energy Commission workshop on nuclear power, Integrated Energy Policy Report, Sacramento, California, July 26, 2011.

plant, could temporarily but violently flood the spent fuel Dry Cask pad. The writer is not aware of whether this has been considered in connection with a hazards evaluation of this facility. The writer would also note that the oblique aerial photo referenced above appears to show the Dry Cask pad being located more or less directly under the power line from Unit 1 to the substation in Diablo Canyon, seemingly another potentially hazardous situation.

**Ground Deformation:** This hazard category includes seismic uplift, subsidence, and surface faulting; tsunami generation results from seismic uplift of the sea floor but is here listed as a separate category of hazard. Surface uplift has clearly affected the Irish Hills especially during the last 500 ka, and the southern Santa Lucia Range underwent measurable tectonic uplift during and following the 2003 San Simeon earthquake. The lagoon of Morro Bay owes its existence to tectonic subsidence and there is certainly potential for this to continue in recurrent episodes. Surface faulting can be expected to occur along the submerged traces of both the strike slip and reverse faults but only faulting involving vertical uplift of the sea floor is likely to produce directly damaging effects. However changes in shoreline elevation could impact seawater DCNPP cooling water intake hydraulics vital to nuclear reactor operation.

Onshore surface faulting, most probably related to "popup" fault wedge uplift of the Irish Hills, could occur along both their landward boundary Los Osos fault, and along smaller faults in the hanging wall leading edge of the underlying San Luis Range/"IOF" thrust such as the Diablo Cove fault along the seaward shoreline of the Irish Hills

**Ground Failure:** This general category of earthquake-related effects includes soil liquefaction, landsliding, rockfalls, and cliff failures. With the exception of soil liquefaction, all of these phenomena occur in the south coastal region even in the absence of triggering earthquakes, but their occurrence is certain to be enhanced by earthquake strong motion. Liquefaction of water saturated sandy soils along the coastline occurred as far south as Arroyo Grande during the M6.5 San Simeon earthquake, which was centered 50 km northwest of Morro Bay and 90 km NW of Arroyo Grande. Large historically dormant slump and earthflow landslides, present at various locations in the Irish Hills and elsewhere in the region, are susceptible to reactivation and could be damaging to roads, power transmission facilities and other infrastructure—including routes necessary for emergency preparedness or evacuation and communication towers. Rockfalls from the fractured volcanic rock cores of the steep hills between Morro Rock and Islay Hill, have yielded marginal boulder fields with blocks as large as small houses. Rockfalls similar to those that have occurred at intervals throughout late Quaternary time could again be triggered by strong earthquake showing.

**Tsunami Generation:** The issue of central California coast tsunami hazards has recently been the subject of extensive studies by the Pacific Gas and Electric Company (eg: Nishenko et. al., 2009) but we are not aware that their studies have included the potential occurrence and effects of tsunamis generated by local sea floor uplift in Estero and/or San Luis Obispo bays. The interpretation presented herein suggests that some tens of square km of shallow sea floor in either or both Estero Bay and San Luis Obispo Bay could be subject to seismic uplift ranging up to one meter or more in amount. The effects of local tsunamis generated by such uplift on shoreline developments could be severe, especially since unlike with tsunamis originating in distant locations, there would be no more advance warning than the immediately preceding occurrence of the causative local earthquake.

**Surface Faulting:** Onshore surface faulting, most probably related to "popup" fault wedge uplift of the Irish Hills, could occur along both their landward boundary Los Osos fault, and along smaller faults in the hanging wall leading edge of the underlying San Luis Range/"IOF" thrust along the seaward shoreline of the Irish Hills. The most important such fault relative to the safety of the DCNPP is the Diablo Cove fault, which extends through the bedrock of the central foundation of Unit 1 and appears to have characteristics corresponding to at least 2 of the 3 NRC criteria for a "capable" fault.

## G. Deficiencies in PG&E's Submittals to the NRC, Including Omissions, Mischaracterizations and Apparent Evasions 1968 PSAR- 2011 SSHAC

### 1. Current Deficiencies

a. PG&E has failed to consider or acknowledge any seismic implication from the progressive late Quaternary uplift of the Irish Hills, and the occurrence of frequent small earthquakes in the crust beneath these hills, as is demonstrated by the absence of any meaningful discussion of this issue in any document or presentation known to the writer. This has resulted in non-recognition or non acknowledgement by PG&E of what may well be the controlling seismic hazard to the seismic safety of DCNPP, i.e., the southwest vergent San Luis Range/"IOF" active thrust fault that available seismologic data suggests underlies the DCNPP site at shallow depth. This has the likely consequence of putting the safety of the plant, the electricity it provides to the State power grid, and potentially the health and safety of the public and its property at risk.

b. PG&E has sponsored the collection of various forms of high and low energy seismic reflection data, according to a program of its own design that apparently partly responded to the requirement mandated by AB1632 for a 3D seismic reflection survey. Some of the high energy data collected to date (January 2012)[51] was displayed at and made available to the public following, the SSHAC workshop of 29 November-1 December, 2011. None of this data provided any information useful for significantly improving understanding of the seismic hazard to the DCNPP and nothing in the planned additional surveys, both onshore and offshore, offers any prospect for any result beyond marginal improvement to what is already known. In particular the 2D and 3D high energy seismic reflection surveys apparently have not yielded useful data at depths much exceeding 3 km on the Los Osos Valley side of the Irish Hills and line 112 crossing San Luis Hill, as released, shows no useful data at all. Line 115,

[51] O'Connell, D., Turner, J., Central California Coast Seismic Imaging Project, Diablo Canyon SSHAC Workshop 1, 2011 DCPP Onshore Seismic Reflection Data Acquisition, Fugro Consultants, November 30, 2011.

acquired extending from the shoreline into the southwest flank of the Irish Hills 2 km up coast from the DCNPP, appears to provide some data down to 7.5 km depth, and this line may image the San Luis Range/IOF thrust structure. If it does it will confirm the existence of this potential seismic threat, but if it does not image such a structure, the seismologic and uplift evidence for it will remain unanswered. It is this writer's opinion that the only component of the PG&E updated LTSP Program as now set forth that has the potential to significantly improve understanding of the seismogenic structures that constitute the potential seismic hazard to DCNPP, is the installation of at least 4 ocean bottom seismometers on the sea floor offshore from the vicinity of the DCNPP.

## 2. Historic Deficiencies - overview

During the 43 years since PG&E submitted the PSAR for a Construction Permit for DCNPP Unit 1 to the AEC, it has made a series of submittals with representations regarding geologic and seismic conditions that concern the seismic safety of the nuclear power plant. The submittals and testimony during ACRS, ASLB and ALAB (Atomic Safety and Licensing Appeals Board) hearings concerned with geology and seismology submitted between the original PSAR in 1968 and the ALAB Hearing in 1981 essentially all originated with PG&E's consultants, since PG&E had no staff with expertise in these fields and had always relied on consultants for such expertise, which was and has largely remained standard practice for most of the industry. During this 13-year period, culminating with the NRC's issuance of a low power test operating license for Unit 1 in the Fall of 1981, PG&E was guided by and relied on several consultants, one of whom was the writer. This period was a time of great advances in knowledge of geology, tectonics, and earthquake effects, and of a corresponding strengthening of regulatory oversight of such issues as they related to the seismic safety of nuclear power plants. To the writer's knowledge PG&E complied with all recommendations regarding geology, seismicity and seismic design made by its consultants in those areas, also with all requests made by the ACRS and AEC/NRC. Representations of potentially more adverse seismic conditions presented by intervenors and some academics, however were generally countered by PG&E with support by the AEC/NRC even though with 20/20 hindsight it has since become evident that many of those intervenor concerns were valid. Among the deficiencies, large and small, in the consultants' approaches and findings adopted by PG&E during this period, the most notable in the writer's opinion are mentioned below.

**Pre-Operating License Deficiencies:**

1. Initial failure to conduct any geologic investigation outside of the DCNPP coastal terrace area beyond the extremely detailed and thorough Jahns investigation of that area, which ended at the shoreline. This failure applied to both the onshore and more particularly, the offshore regions. The failure was partly mitigated by the insightful brief report on potential seismic hazards to the Diablo Canyon site in which consultants Professors Benioff and Smith made allowance for the then-prevailing very sketchy knowledge of the tectonics of the south central coastal region by hypothesizing the potential occurrence of a M 6-3/4 earthquake directly beneath the proposed DCNPP site.[52]

2. Disregarding evidence presented at the Unit 2 Construction Permit ASLB Hearing in January 1970 by intervenors regarding offshore seismicity and the existence of an onshore fault subsequently rediscovered during PG&E'S LTSP and named the Los Osos fault. The tectonic model proposed by intervenor Scenic Shoreline Preservation Council witness Cal Poly Professor Ralph Vrana was investigated by the USGS at the request of the AEC and found not to be possible given the offshore structural pattern mapped by the USGS, and so was not considered credible or a factor in granting the Unit 2 Construction Permit license.[53] But one year later Shell Oil Company allowed publication of offshore data it had acquired at great expense during the preceding decade, which revealed the same large offshore fault that had been mapped but not publicly reported during the brief

[52] Pacific Gas & Electric, Preliminary Safety Analysis Report for Diablo Canyon Power Plant, US Atomic Energy Comm., Docket Nos. 40-275 and 50-323, Appendix Section 2.5 E, 1968.
[53] USGS Internal Memo from J.E. Schoellhamer to H.H. Waldron; Subject: Administrative report on marine geology between Santa Lucia Banks and Point Buchon California, May 15, 1970 by S.C. Wolf and H.C. Wagner, 1970, "Preliminary Reconnaissance Marine Geology of Area Between Santa Lucia Escarpment and Point Buchon, California."

USGS investigation in 1970[54] responding to the AEC request in 1970. This fault was given the name "Hosgri" by the USGS in a 1974 report.[55]

3. Arguing (with AEC concurrence), against the applicability to the Diablo Canyon setting of the 1.25 pga (peak ground acceleration) from the M6.5 (now evaluated as 6.7) 1971 San Fernando earthquake. The magnitude (M6.7) was essentially the same magnitude earthquake as the postulated Benioff and Smith/Blume OBE/SSE event at Diablo Canyon, for which their original calculation of predicted ground motion was (and still is) in DCNPP's license as 0.2pga for the OBE. The 0.4pga specified for the DCNPP SSE was estimated by PG&E's structural engineering consultant as a conservative doubling of the seismologist's 0.2pga estimate.

4. Initially underestimating the potential maximum magnitude of an earthquake originating on the Hosgri fault as M6-1/2, even while continuing to support the (then) hypothetical M6-3/4 event in the much less extensive space available for a fault beneath the Irish Hills.[56]

5. Mapping the southeastward splay from the Hosgri fault offshore from Point Buchon and its southerly in-line continuation beneath San Luis Obispo Bay, but not the intervening connecting link along the Irish Hills shoreline, of the fault subsequently recognized on the basis of associated earthquakes by the USGS in 2008 and now called the Shoreline fault. This retrospective deficiency, for which the writer must accept a large measure of blame having been in charge of PG&E's offshore geophysical surveys during 1973-1974,

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[54] Hoskins, E.G. and Griffiths, J.R., 1971, Hydrocarbon potential of northern and central California offshore: in Cram, I.H., ed., Future petroleum provinces of the United States – their geology and potential: American Association of Petroleum Geologists Memoir 15, p. 212-228.
[55] Wagner, H.C., 1974, "Marine Geology Between Cape San Martin and Point Sal, South Central California Offshore;" US Geological Survey Open File Report, 74-252.
[56] Pacific Gas & Electric, 1975, Appendix 2.5 E, Final Safety Analysis Report for Diablo Canyon Nuclear Power Plant: U.S. Atomic Energy Commission Docket Nos. 50-275 and 50-323.

only received attention during PG&E's 1988 LTSP studies, in connection with which PG&E represented—and the NRC accepted—that no such fault existed.[57]

6. No attention was given to the tectonic/seismic implications of the progressive uplift of the Irish Hills/San Luis Range, and the evidence for an acceleration in the rate of uplift of the ranges observable within the interior of the Irish Hills, especially in the incised V-shaped inner canyon of Coon Creek (*Figures 4 and 5*) which was not recognized during the 1974 FSAR supplemental investigations. As with deficiency (5) above, in retrospect, this represents an omission on the part of the writer.

**Operating Stage Deficiencies:**

**1. Long Term Seismic Program (LTSP)**

The initial primary assignment of the new Geosciences Department was to conduct the DCNPP's NRC-mandated Long Term Seismic Program (LTSP), which needed to be completed by mid 1988.

In 1985, with its Unit 1 operating license restored after successfully dealing with its "Diagram Error" problem, PG&E established its own Geosciences Department and hired geologist Lloyd Cluff to recruit staff and manage the new department, reporting directly to PG&E's Vice President of Engineering Donald A. Brand. Cluff lost no time in filling several key staff positions with former co-workers from his previous employment with the consulting firm Woodward Clyde Consultants, and also retaining the services of a new consulting firm, Geomatrix, owned and largely staffed by others of his former Woodward Clyde co-workers. Several other consultants (including this writer, initially) and firms were also retained in order to meet the LTSP submittal timetable in 1988. Cluff in the meantime managed his department, oversaw the conduct of the LTSP, and established and cultivated a close working relationship

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[57] US Nuclear Regulatory Commission, Safety Evaluation Report related to the operation of Diablo Canyon Nuclear Power Plant Units 1 and 2, Docket Nos. 50-275 and 50-323. NUREG-0675, Supplement 34, June 1991, p. 2-4.

with the NRC. The LTSP interval in the history of the DCNPP extended from around mid 1985 when Cluff was on board and the Geosciences Department became operational, to 1991, when the post 1988 submittal of the Final Report responses to additional questions by the NRC were all submitted and the NRC issued its official SER (Safety Evaluation Report) bestowing its regulatory blessing on PG&E and its LTSP representations.

The LTSP was a massive report that covered not only the geology and seismology of the DCNPP site at least to the degree PG&E was interested in addressing geology and seismology issues, but also derivative earthquake engineering considerations including seismic strong ground motion, soil structure interaction, probabilistic risk analysis, deterministic risk evaluations, and finally, assessment of the adequacy of seismic margins. From its inception the LTSP was very tightly controlled by Cluff and his principal lieutenants. This resulted in a study that was wide ranging and impressive, with the benefit to PG&E that nothing in it indicated any hazard to the seismic safety of the DCNPP that exceeded that already accounted for. The LTSP results thus fulfilled the license condition that had mandated the program, validated the seismic safety of the plant to the satisfaction of the NRC, and showed PG&E to be on the cutting edge of state-of-the art geologic and seismic research. Or so it appeared. However, retrospective review reveals several noteworthy deficiencies in the LTSP, as are described below.

1. The best known of the deficiencies in the LTSP findings is the failure to recognize the Shoreline fault. In PG&E's defense it could be argued that the earthquake epicenters alignment that led Dr. Jeanne Hardebeck of the USGS to recognize that an active strike slip fault extended along the Irish Hills shoreline had mostly not been detected at the time the LTSP studies were underway, since the seismograph network that existed prior to November of 1987 when PG&E's improved local network went online purportedly was not good enough to accurately locate the small earthquakes involved. The epicenter plot in the LTSP Figure 2-35 appears to support this but the hypocenter cross section B-B' in the same figure (*Figure 8c*) clearly shows a vertical train of hypocenters along the shoreline, where no fault was mapped. This hypocenter plot is actually very similar to plots attributed to Hardebeck in PG&E's 2011 Shoreline Fault Investigation Final Report, so much of the seismologic evidence

used by Hardebeck to identify the Shoreline fault in 2008 was available to but not acknowledged as significant by PG&E in 1988. In addition to this seismologic evidence, PG&E prepared an Onshore-Offshore Geologic Correlation Map (LTSP Plate 19)[58] which included exact delineations of the scarp along the Shoreline fault as it is now known and the offshore trace of the Diablo Cove fault (but not the onshore trace as precisely delineated on PG&E's previous PSAR and FSAR submittals). The Shoreline fault scarp however was represented by a symbol for "Lineament related to old shoreline" and the Diablo Cove offshore trace by a symbol simply described as "Moderately defined lineament." Both features were therefore conveniently harmless, and the Plate 19 map was later cited by PG&E in its response to an NRC Request for Information, arguing that there was no fault along the shoreline.[59]

2. The real basis for this request by the NRC reviewers was an interpretation by a participant with the NRC-sponsored UNR (University of Nevada at Reno) team directed by UNR Professor David "Burt" Slemmons, also by Dr. Robert Brown of the USGS, to the effect that the neotectonics of the Irish Hills/San Luis Range required the existence of a fault in the near offshore parallel to the Irish Hills range front. This interpretation was documented in an MS thesis completed by UNR graduate student Steven Nitchman in May 1988, but was known by PG&E several months earlier. However, Nitchman's shoreline-parallel reverse (thrust) fault, later referred to as an Inferred Offshore Fault – "IOF", was dismissed by PG&E. Instead, the undeniable tectonic requirement to explain the level uplift of the Irish Hills was replaced with a vaguely defined "Southwest Boundary Zone" consisting of a "—diffuse complex zone of northwest-trending reverse faults and flexures. Principal structures within the zone include the San Luis Bay, Wilmar Avenue, Pecho and Oceano faults". This zone conveniently omitted any "IOF" and its only component extending into the

[58] Pacific Gas & Electric, 1988, Long Term Seismic Program, Final Report to U.S. Nuclear Regulatory Commission for Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323.
[59] Pacific Gas & Electric, Response to Question 43e, January 1989. This volume is part of a set that responds to 47 questions asked of PG&E by the Nuclear Regulatory Commission (NRCO on December 13, 1988. The responses provided data requested to augment or clarify the Final Report of the Long Term Seismic Program submitted by PG&E to the NRC on July 31, 1988.

offshore opposite the DCNPP site was the "Pecho" fault which was shown (LTSP Figure 2.53) as parallel to but slightly more than 4 km from the Irish Hills shoreline. This safely distant “Pecho” fault—PG&E’s rationlization for the southwest side level uplift of the Irish Hills—was not accorded the importance of an earthquake magnitude assignment. By ignoring Nitchman’s “IOF,” PG&E deprived the real life tectonic model of undeniable uplift of the mechanism along its necessary southwest side reverse fault. But PG&E’s avoidance of this issue and instead calling on the 4km distant “Pecho” fault solved the problem only to the extent that the NRC accepted this story and the LTSP was subsequently regarded as the “gold standard” for seismic hazard studies. The LTSP “Pecho” fault then began to appear on other geologic maps, many still in use by various other agencies.[60] However, when the Shoreline fault was identified in 2008, *part of the data used to define the surface expression of the Shoreline Fault also showed that there was no “Pecho” fault.*[61] <u>So, with the “Pecho” fault now “disappeared,” PG&E has yet to provide a replacement tectonic explanation for the southwest side level uplift of the Irish Hills</u>. Additionally, to the best of this writer’s knowledge, PG&E has never acknowledged either in the 1988 LTSP or the 2011 Shoreline fault investigation, even a possibility that the pattern of earthquake hypocenters beneath the Irish Hills has any implications for either the uplift of the hills, or the earthquake hazard to the DCNPP.

**2. The "Cambria Stepover"**

During the LTSP of 1985-1991 and the following Shoreline fault investigation of 2008-2011, this relic of the 1971 Hoskins and Griffiths map, which was drawn to show basin-margin structures, not faults per se, was preserved in PG&E's representations of the relationship between the purportedly separate San Simeon and Hosgri segments of an overall San Gregorio-Hosgri regional fault. This interpretation well suited PG&E's

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[60] California Geological Survey, 2010, Fault Activity Maps of California, California Geologic Data Map Series, Map No. 6, 2010.

[61] Summary of January 5, 2010, Meeting with Pacific Gas and Electric Company Regarding Shoreline Fault, January 20, 2010, Nuclear Regulatory Commission, ADAMS number ML 100060063 and accompanying slides.

evident need to constrain the length, hence the magnitude capability and possibly also the slip rate, of the Hosgri fault. By ending the north end of their representation of the Hosgri at a point opposite the "stepover" area they were able to limit its overall length to around 110 km and therewith its maximum magnitude to M7.2 and when, during its review of the LTSP report the NRC asked for documentation of the existence and nature of the Cambria Stepover, PG&E responded with a supplemental study that showed an extensional pullapart basin bounded by the Hosgri on the west and the San Simeon fault on the east, opposite the shoreline south of Cambria.[62] This was clearly at odds with a USGS-backed investigation by (then) UC Santa Cruz graduate geophysics student Rob Leslie conducted using the R.V. (Research Vessel) Scammon to perform a geophysical investigation of this same area. Leslie's results, published as USGS Open File Report 81-430 in 1981, were that there was no "stepover" structure and that since there was unbroken continuity between the San Simeon and Hosgri faults, these fault names simply referred to northerly and southerly reaches of the same approximately 150 km long fault. Twenty years on, USGS marine geologist/geophysicist S.Y. Johnson released preliminary results of his own investigations now based on a new close-spaced low energy seismic reflection survey, newly available multibeam sea floor imagery, and both aeromagnetic and gravity data. His results as presented at PG&E'S SSHAC Workshop held in late 2011, confirm Leslie's 1981 results and disprove PG&E's 1991 supplemental study.[63] PG&E's application requesting ratepayer funding to conduct yet another investigation of the "Cambria Stepover" by its geology and geophysics consultants is an unnecessary expenditure given the exhaustive body of work in this area already completed by the USGS, and represents resources that could better be focused on the under-explored areas of concern previously identified in this Testimony.

[62] Pacific Gas & Electric, Response to Question 41, January 1989. This volume is part of a set that responds to 47 questions asked of PG&E by the Nuclear Regulatory Commission (NRC on December 13, 1988. The responses provided data requested to augment or clarify the Final Report of the Long Term Seismic Program submitted by PG&E to the NRC on July 31, 1988.
[63] Johnson, Samuel Y., USGS offshore, low-energy seismic-reflection data, USGS Pacific Coastal and Marine Science Center, Diablo Canyon SSHAC Workshop 1, November 29, 2011.

**3. The Diablo Cove fault.**

From the establishment of PG&E's Geosciences Department in 1985 through its presentations at its SSHAC workshop in late 2011, this previously well-documented zone of faulting extending through the foundation of DCNPP Unit 1 has never been mentioned.

## H. Recommendations

1. Re evaluate PG&E-originated list of seismic sources significant to the seismic hazard to DCNPP for SSHAC, deterministic, and PSHA evaluations.
2. Re evaluate PG&E program of geologic, geophysical and seismologic studies
   - (a) Put offshore (Ocean Bottom Seismometers-OBS) seismograph program into operation as soon as practicable
   - (b) Eliminate PG&E (ratepayer) sponsored offshore and onshore geophysical programs, especially those duplicating investigations by USGS and others (Shoreline fault, Cambria stepover, etc.)
   - (c) Develop 3-D model of structure beneath the Irish Hills based on uplift mechanism and earthquake hypocenters distribution.
   - (d) Expand consideration of potential near field seismic sources to include faults underlying the Irish Hills that must exist in order to account for observed seismicity and level uplift of the hills.
   - (e) Investigate possible compressional interaction of thrust faults with the strike-slip Hosgri and Shoreline faults as a mechanism for the origin of prominent west-facing scarps along the Hosgri fault crossing of outer Estero Bay and the trace of the Shoreline fault opposite the Irish Hills southeastward from Diablo Cove.
   - (f) Evaluate the feasibility and possible merits of continuous coring at one or more sites in the Morro Bay structural depression, with regard to the possibility of learning more about earthquake and tsunami recurrence in the area.
3. Initiate a program of reviewing and as appropriate, recalculating seismic margins of components of the DCNPP critical to safe shutdown of the plant, as well as safe storage of highly radioactive spent fuel, using SSE pga values based on current knowledge of the potential pga from the license-specified M6-3/4 earthquake originating directly beneath the plant, according to the structure indicated from the results of recommendation 2-(c) above.

4. Place both the SSHAC and the seismic margins review program recommended in (3.) above, under the oversight of an entity independent from PG&E and the NRC.

## TABLE A

### Seismic Source Parameters of Faults Significant to Seismic Hazard at DCNPP

| **Fault Name**<br><br><br>**Source parameter** | **Hosgri**<br><br>Source of "Hosgri Earthquake" for DCNPP license | **Shoreline** | **Los Osos** | **San Luis Range "IOF"**<br><br>Source of OBE/SSE for DCNPP License |
|---|---|---|---|---|
| **Sense of slip** | Strike slip | Strike slip | Reverse/thrust | Reverse/thrust |
| **Length** | c.150 km | ≥30 km | 35-50 km | 60 km<br>(Irish Hills segment 40 km) |
| **Dip** | 90º-80ºNE | 90º | 35-40º SW | 35º NE |
| **Down dip width** | 15 km | 13-15 km | 6-8 km | 20km<br>(ramp to surface of Shoreline fault plane intersection) |
| **Distance, DCNPP to nearest point on fault surface** | 4.0 km | 0.5 km | 5.5-6.5 km subsurface | 1.0 km subsurface |
| **Est. slip rate** | 2-5 mm/yr | <<mm/yr | 0.6-0.9 mm/yr | 0.6-0.9 mm/yr |
| **Est $M_{max}$** | M7.5 | M6_-7.0 | M6.5 | M6_-7.0 |
| **DCNPP geometric relationship to fault** | adjacent to vertical/near vertical fault | adjacent to vertical fault | on hanging wall wedge, fault vergent away from DCNPP | on hanging wall over leading edge, fault vergent toward DCNPP |


Figure 1. Regional setting of DCNPP, Central California, showing regional and local faults, also locations estimated by Benioff and Smith (1968) for controlling earthquakes A, B, C, and D for DCNPP.

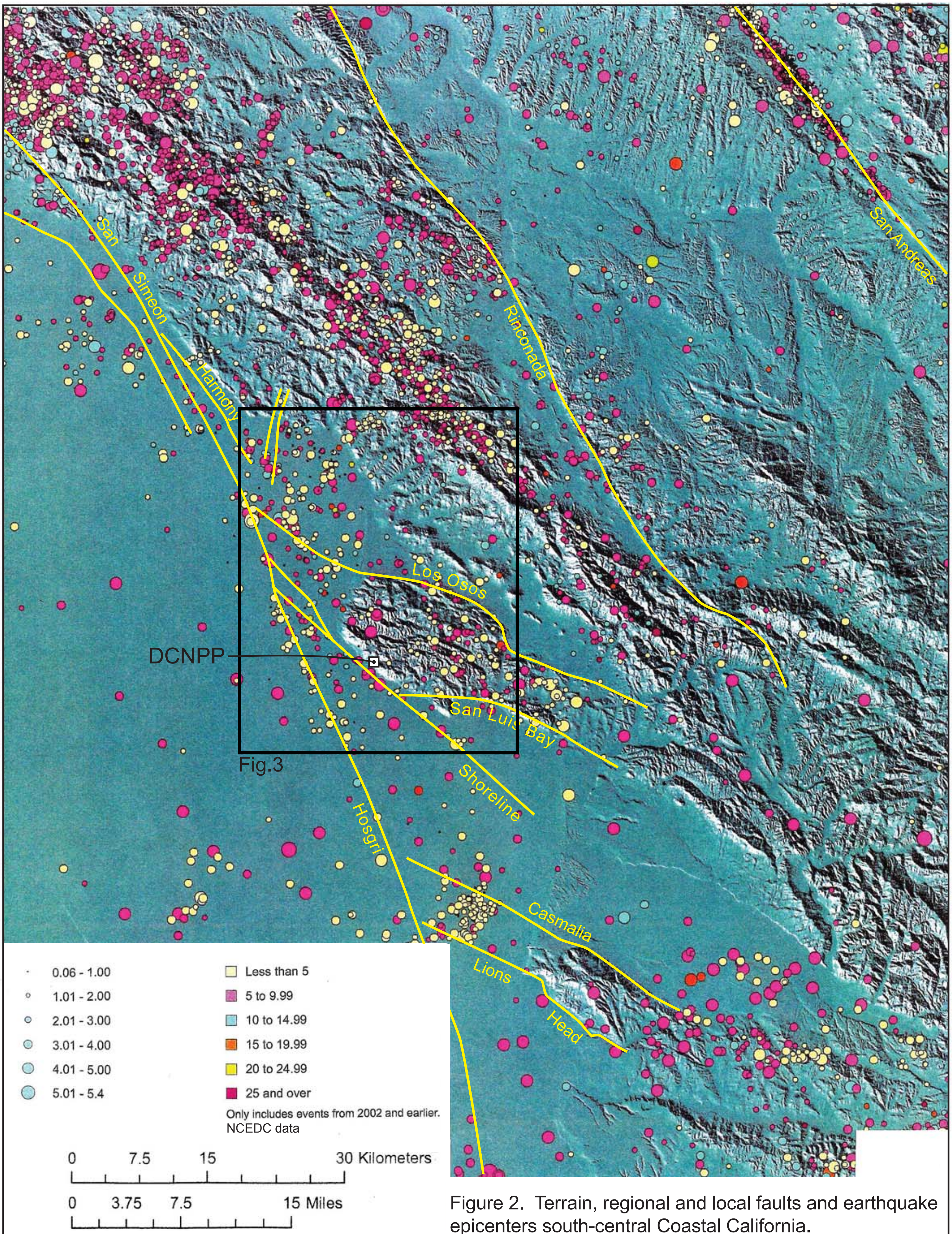



Figure 2. Terrain, regional and local faults and earthquake epicenters south-central Coastal California.

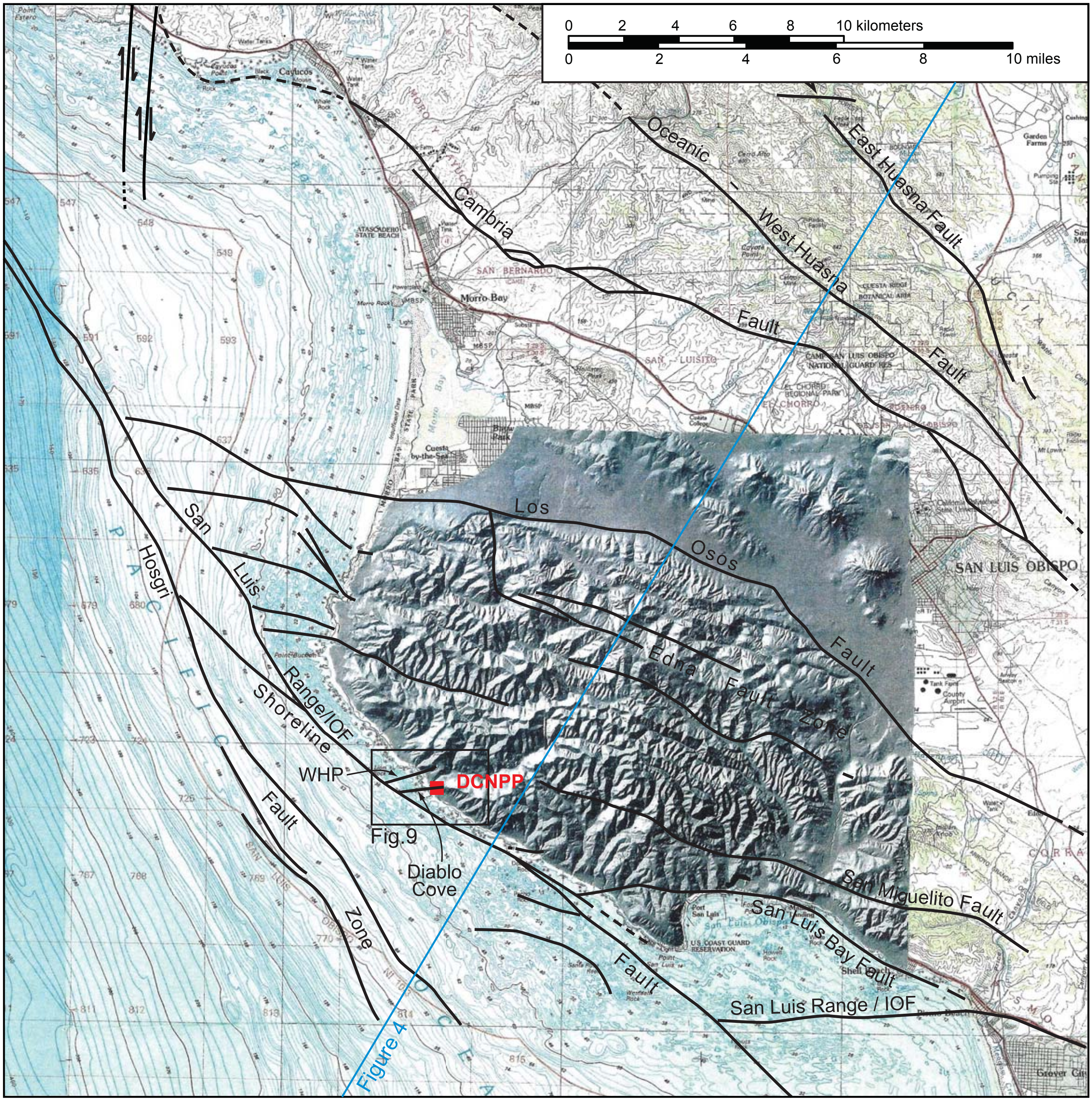
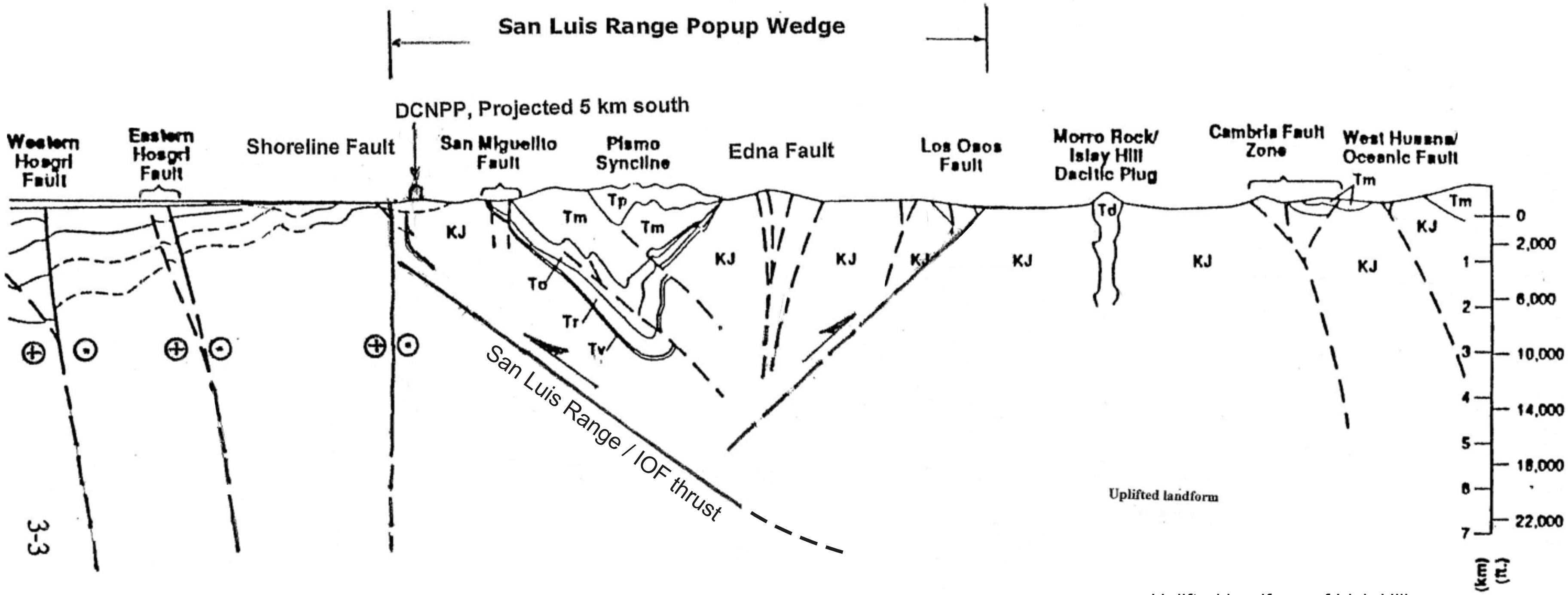
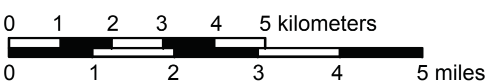


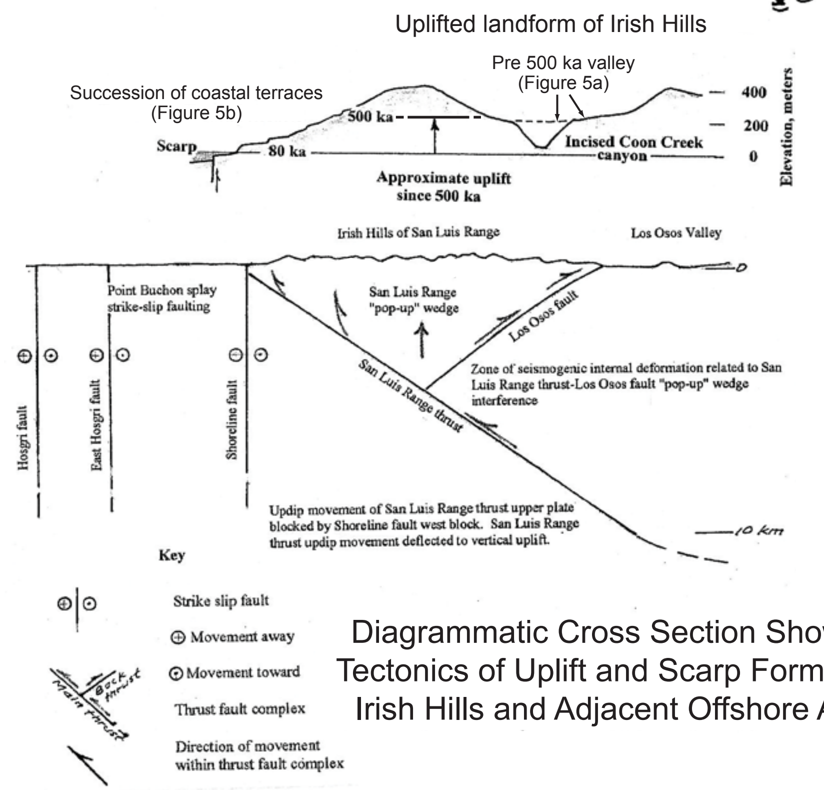

Figure 3. Terrain and faults in the Estero Bay - Irish Hills (Diablo Canyon) - San Luis Obispo region.




## Geologic Units

| | |
|---|---|
| Tp | Pismo Formation |
| Tm | Monterey Formation |
| To | Obispo Formation |
| Tr | Rincon Formation |
| Tv | Vaqueros Formation |
| Td | Morro Rock / Islay Hill dacitic intrusive plug complex |
| KJ | Franciscan and unnamed Cretaceous rocks, undifferentiated |

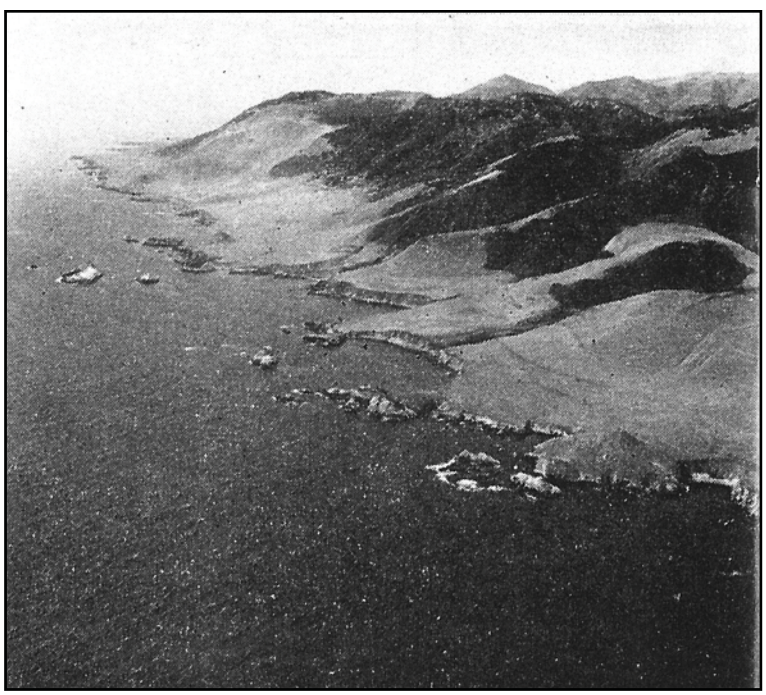



Diagrammatic Cross Section Showing Tectonics of Uplift and Scarp Formation, Irish Hills and Adjacent Offshore Area

Figure 4. Interpreted geologic cross section through the Irish Hills and adjacent areas

a. View northwest, looking downstream along the canyon of Coon Creek. Note the incised steep walled canyon of the modern drainage. (Photo by Martin Litton, 1966)



b. View northwest, showing uplifted wave-cut platform along the coastline. (Photo by Martin Litton, 1966)

Figure 5. Photographs showing terrain features resulting from progressive late Quaternary uplift of the Irish Hills.

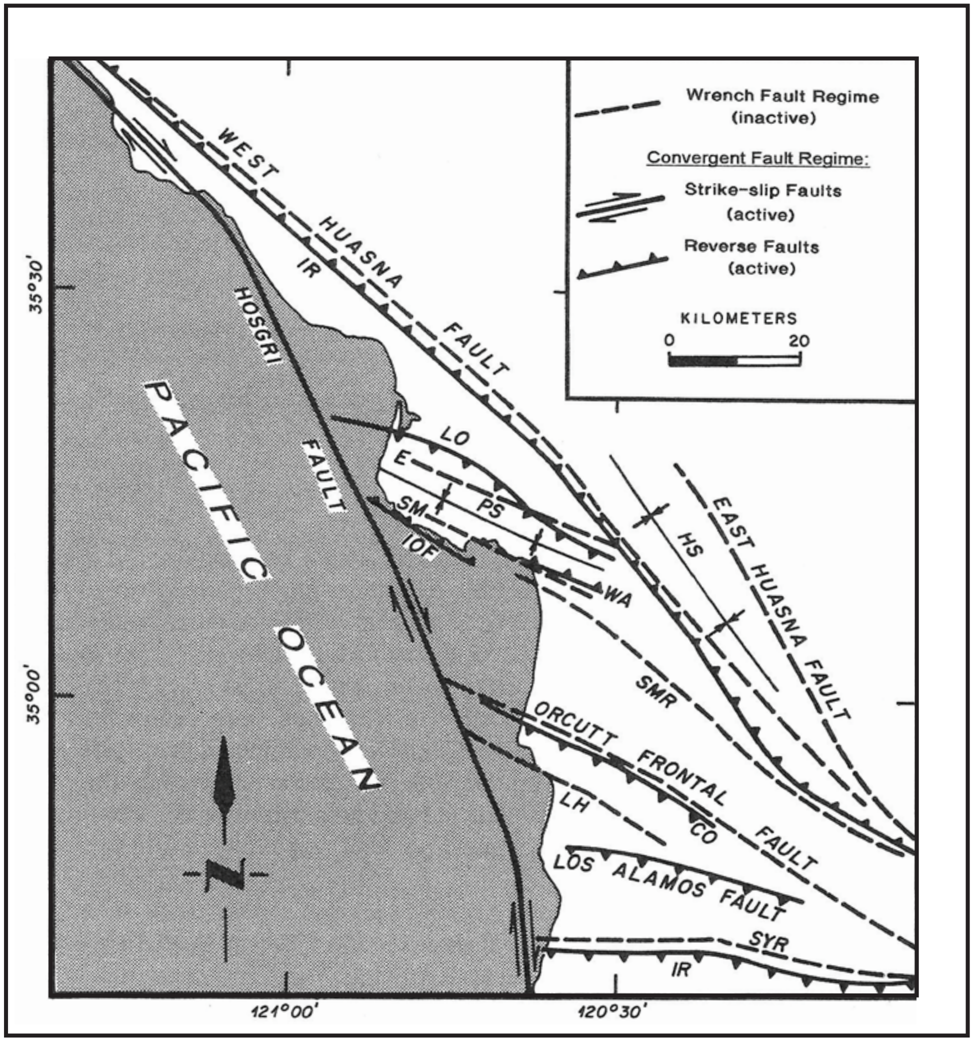



Figure 1. Compilation map showing principal structures in the San Luis Obispo–Santa Maria area. Inactive Tertiary wrench faults shown as dashed lines; Quaternary convergent regime faults shown as solid lines. Co = Casmalia = Orcutt blind thrust fault (Clark, 1991); E = Edna fault; HS = Huasna syncline; IOF = inferred offshore fault (Nitchman, 1988); IR = inferred range-front faults at base of Santa Lucia–San Rafael and Santa Ynez Ranges; LH = Lions Head fault; LO = Los Osos fault; PS = Pismo syncline; SM = San Miguelito fault; SMR = Santa Maria River fault; SYR = Santa Ynez River fault; WA = Wilmar Avenue fault.

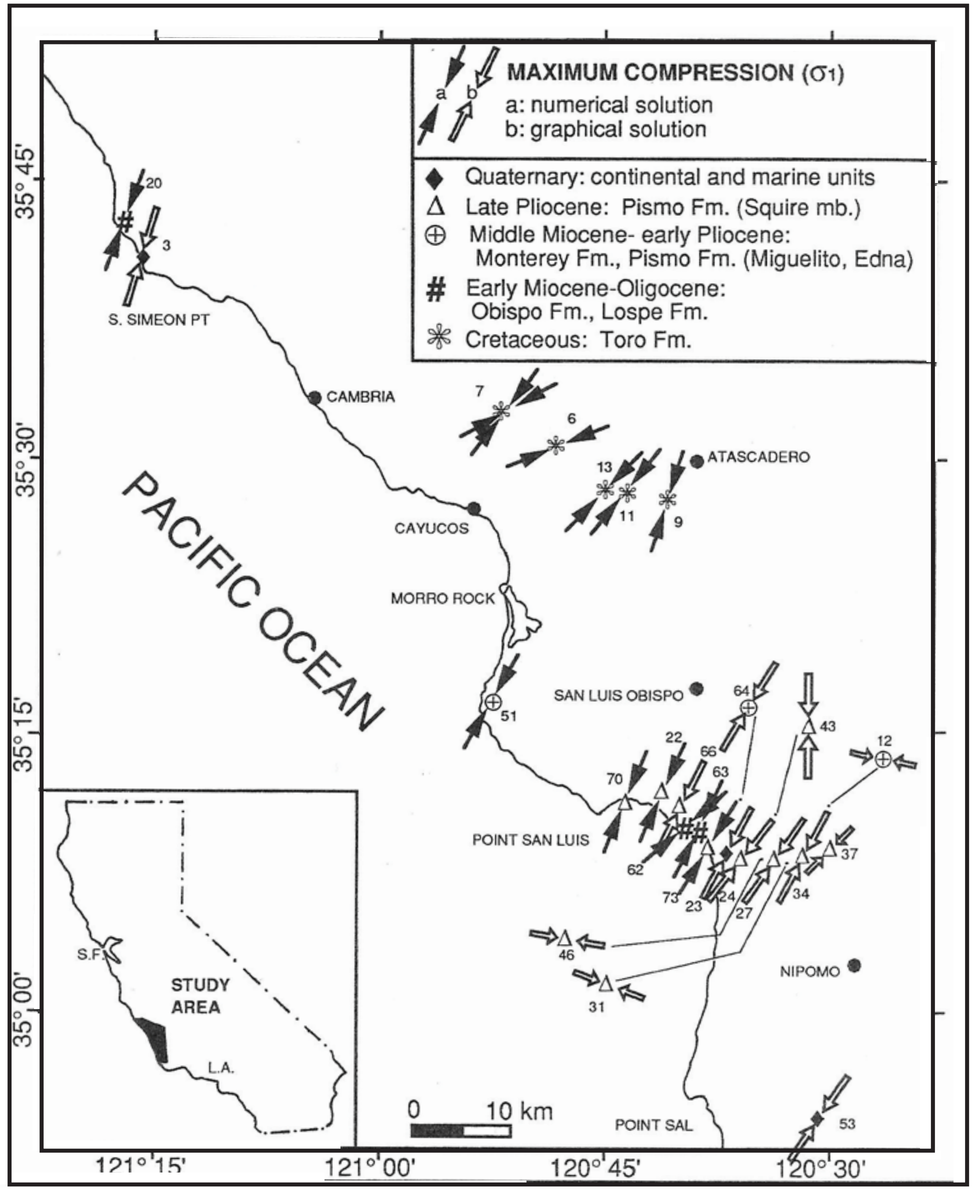



Figure 2. Directions of maximum compression ($\sigma_1$) inferred from kinematics of mesoscale faults. Numbers refer to the sites listed in Table 1. Stress solutions derive either by numerical inversion following the method of Carey (1979) (solid arrows) or by graphical analysis of conjugate sets of faults (empty arrows).

*Figures 1 and 2 from Vittorio et al, 1994*

Figure 6. Principal structures and direction of maximum compression, Irish Hills, Southern Santa Lucia Range, and San Simeon region.

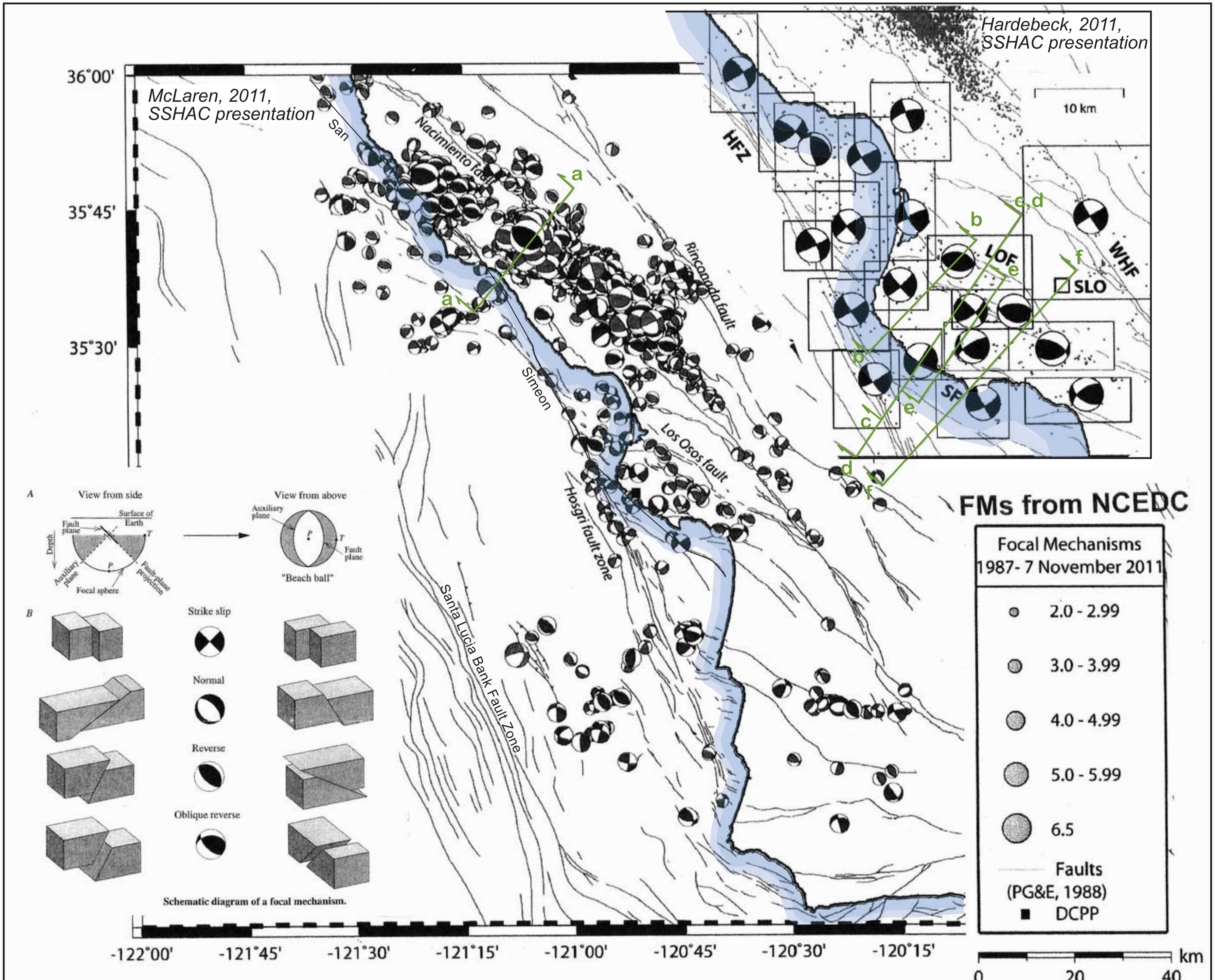
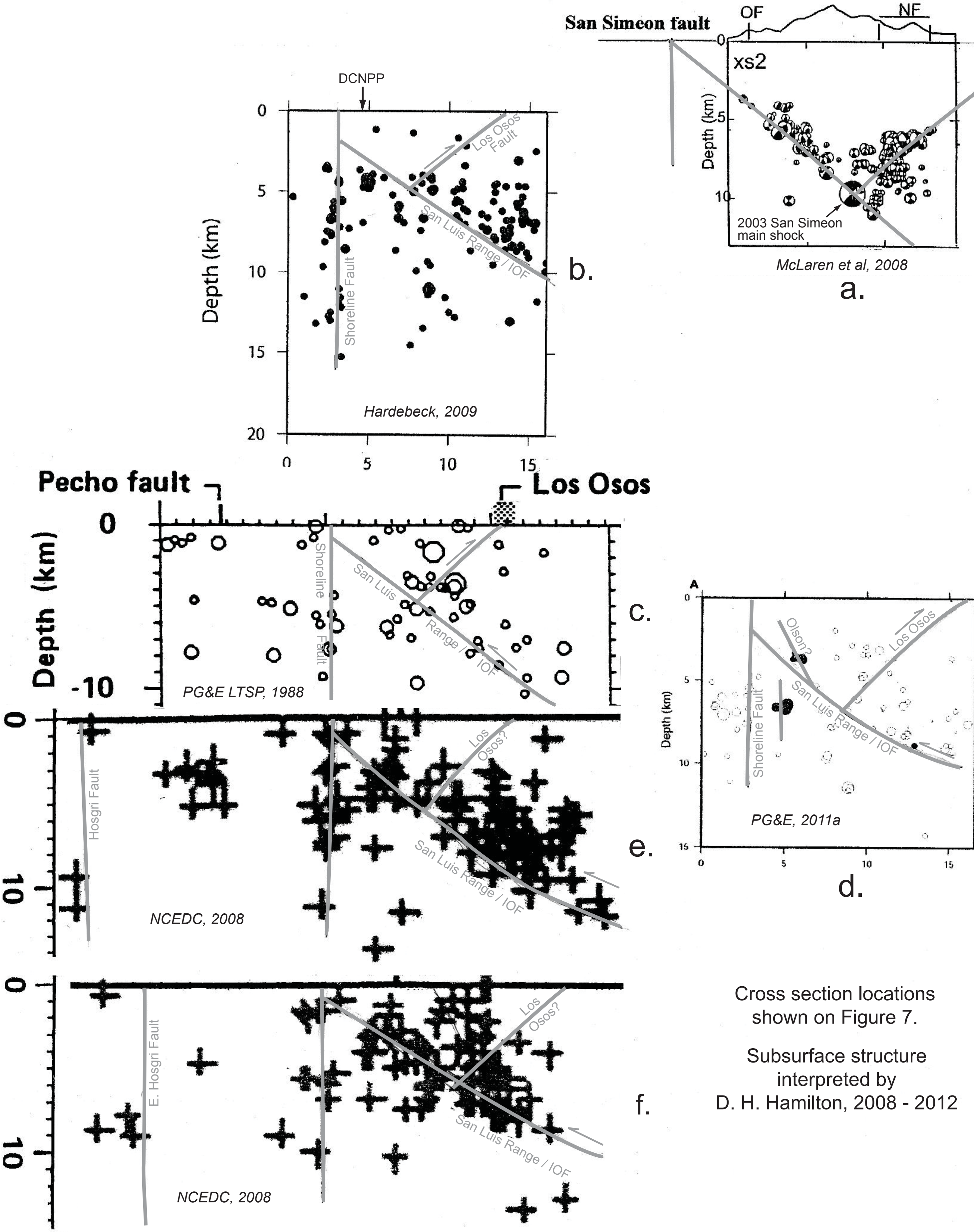



Figure 7. Earthquake focal mechanisms, Irish Hills and adjacent offshore region, 1987 - 2011, and location of Figure 8 earthquake hypocenter cross sections




8. Figure 8. Earthquake hypocenter cross sections through the Irish Hills and adjacent areas; 1988, 2008, 2009, 2011, and 2003 San Simeon earthquake epicentral area.

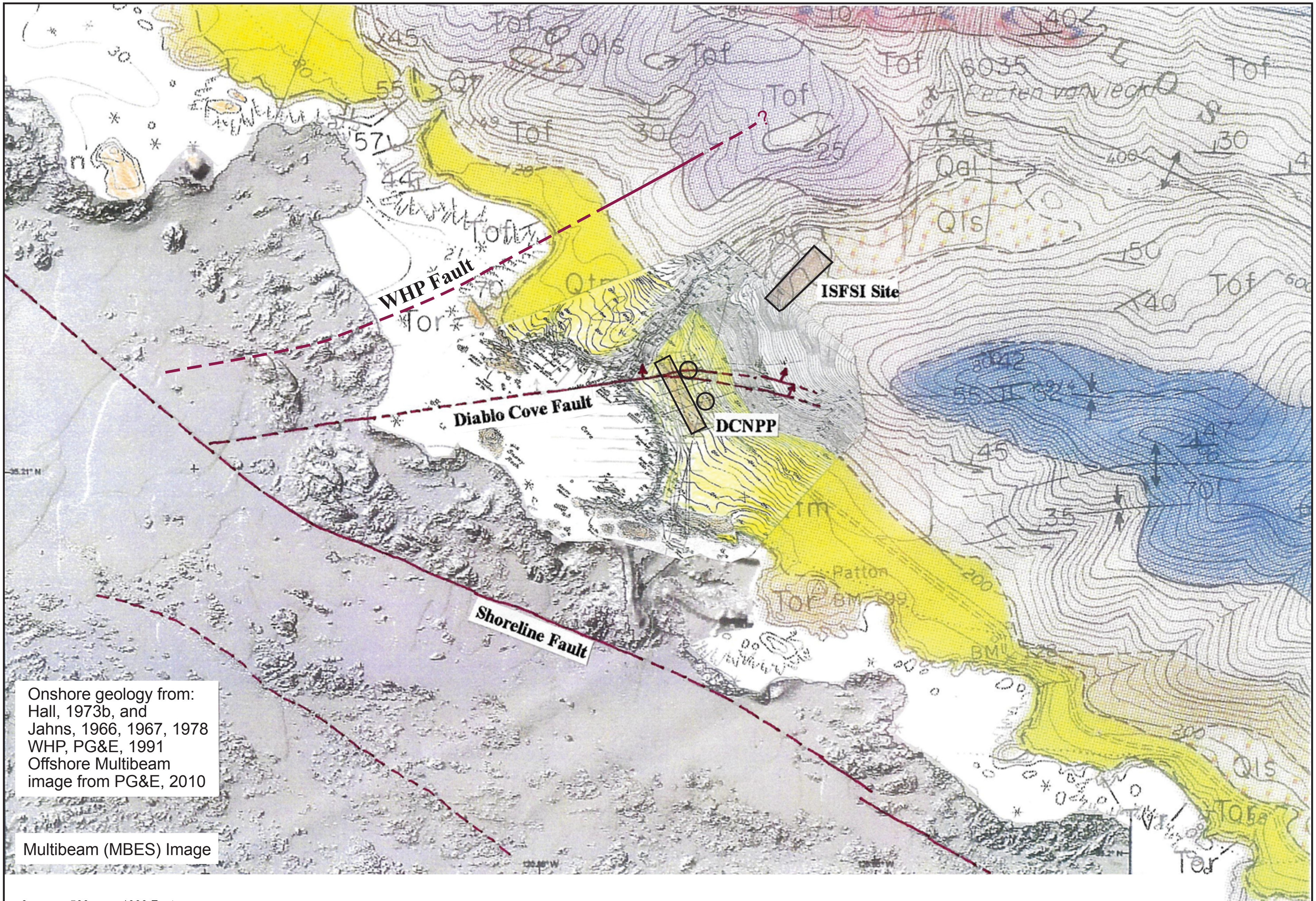
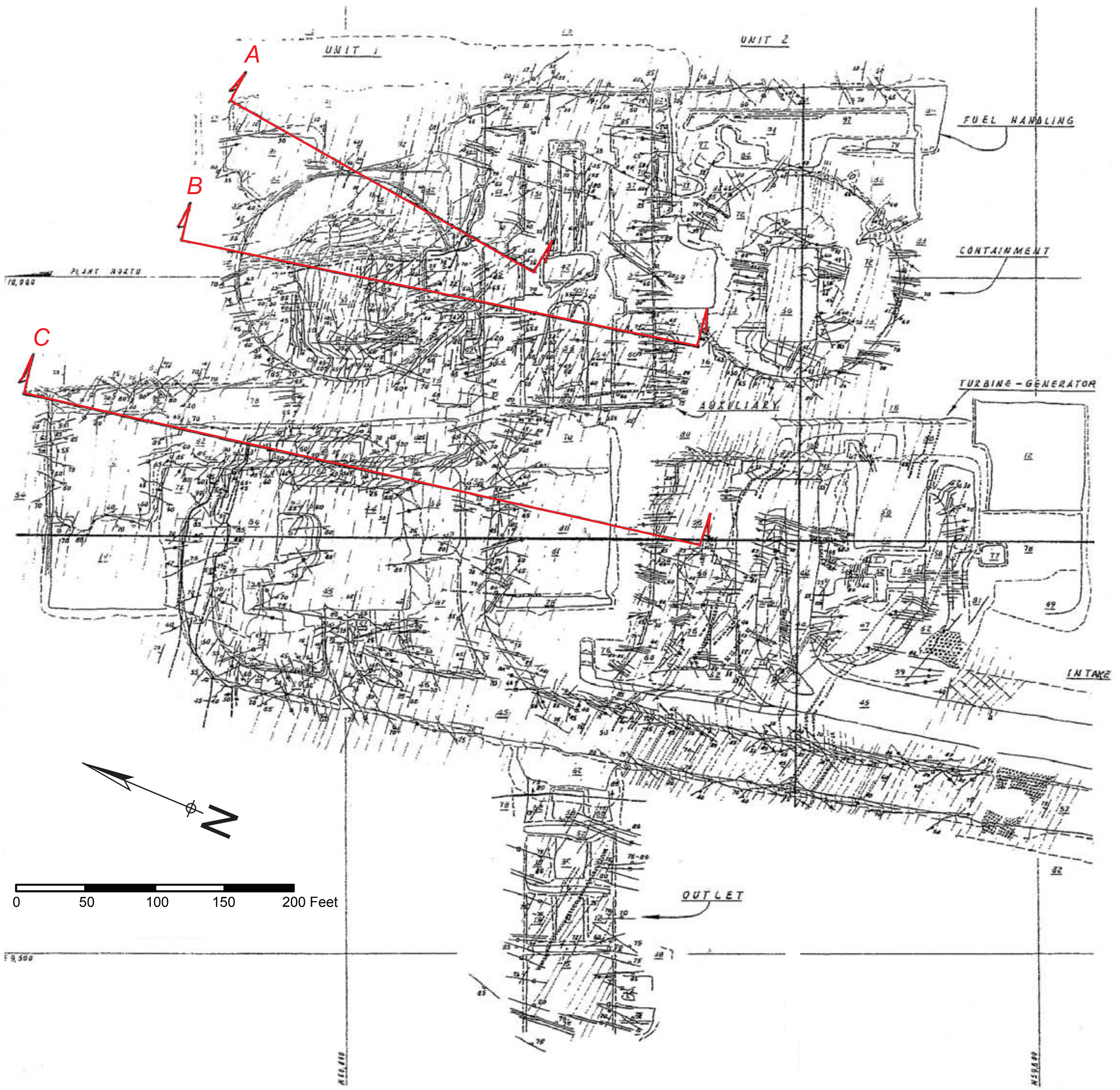



Figure 9. Geologic map of the Diablo Cove Fault Area.




Cross sections *A, B,* and *C* shown on Figure 11

*Unit 1 mapped by Dr. R.H. Jahns, 1969*

*Unit 2 mapped by D.H. Hamilton, 1971*

Figure 10. Geologic Map of Units 1 and 2 Construction Excavations

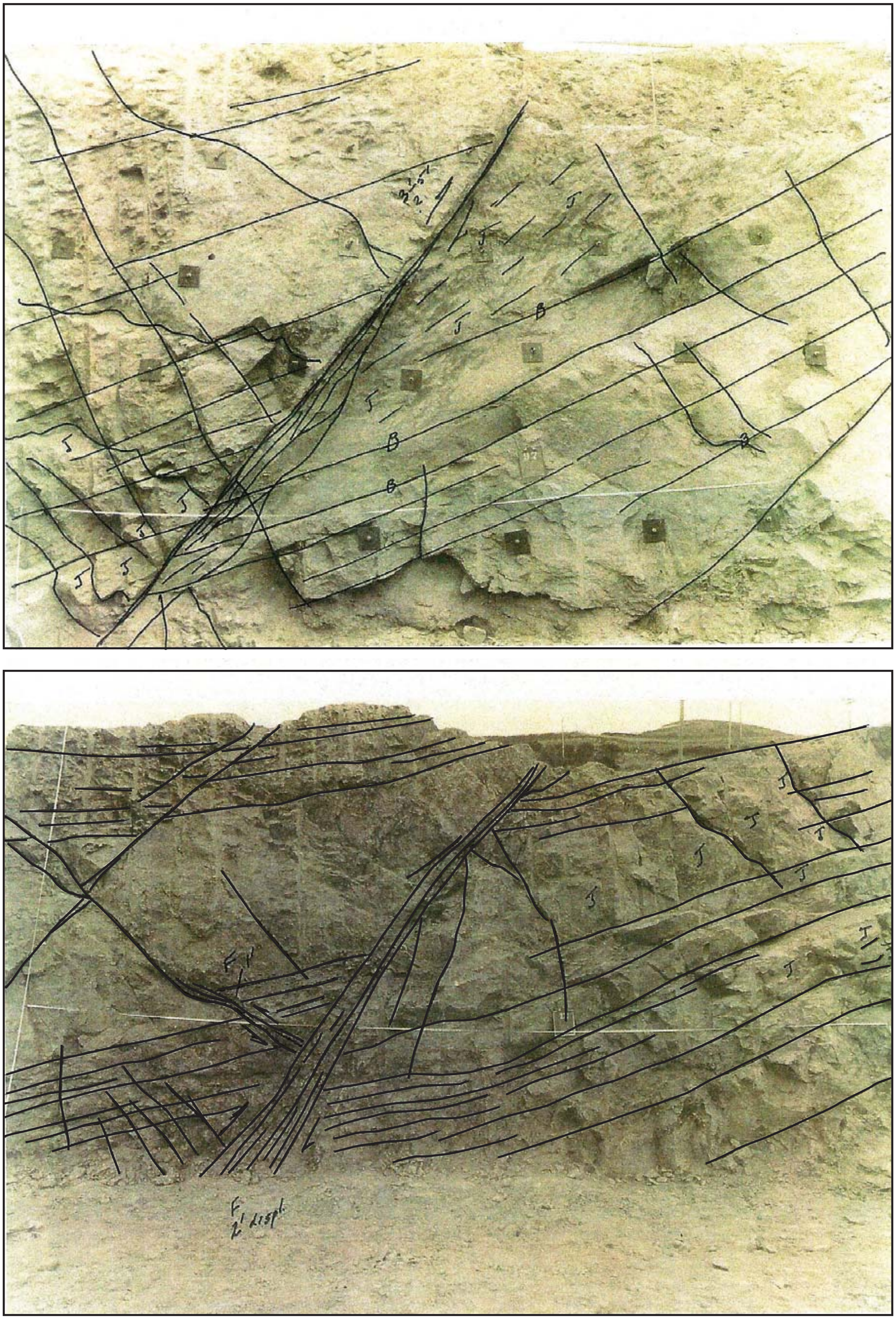



Figure 11. Photographs showing fault features exposed in walls of DCNPP power block and containment foundations excavation.

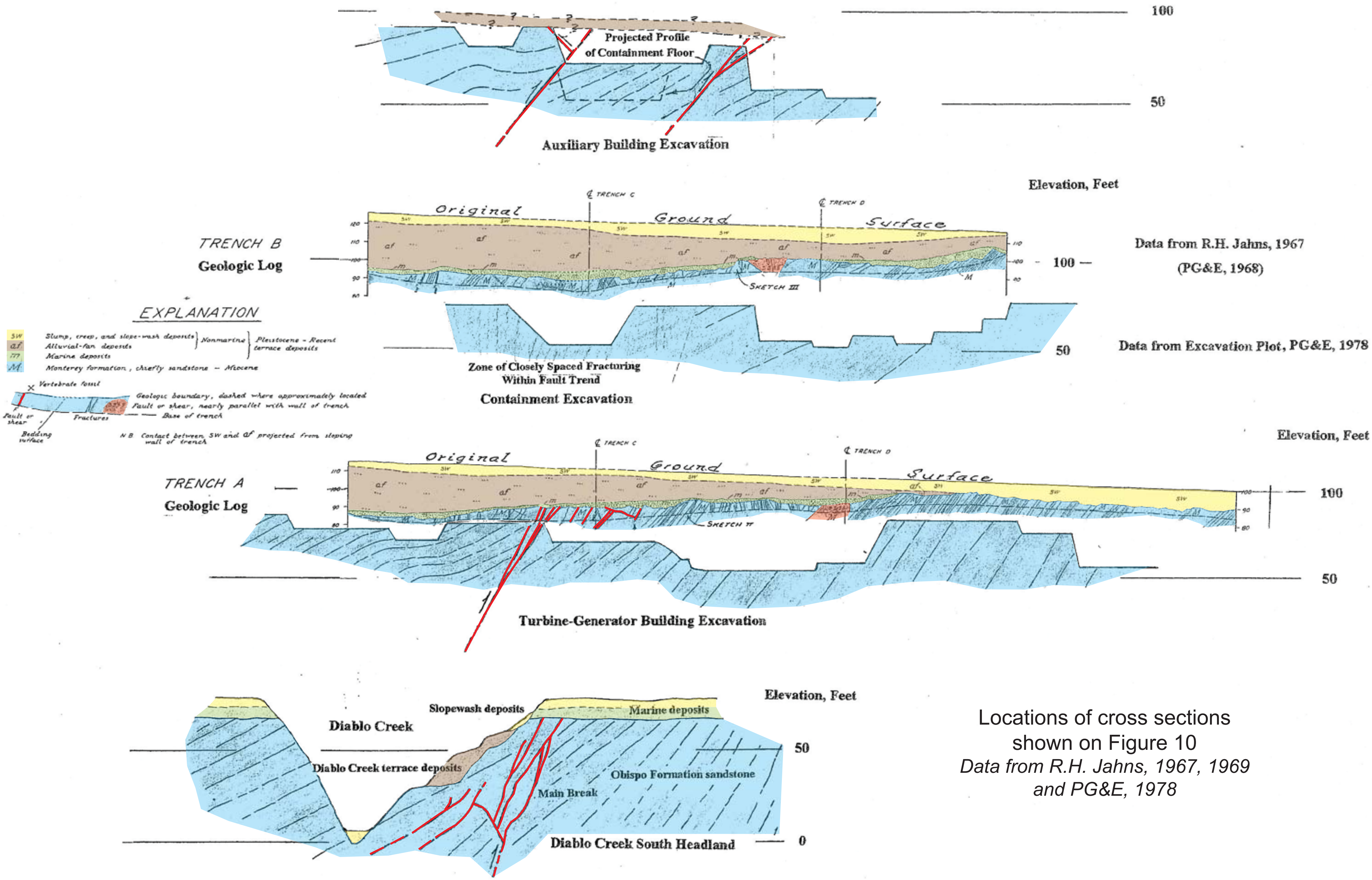



Figure 12. Geologic cross sections across Diablo Cove fault zone logged as exposed on Diablo Creek south headland, in Trenches A and B, and in DCNPP Unit 1 foundation excavation.

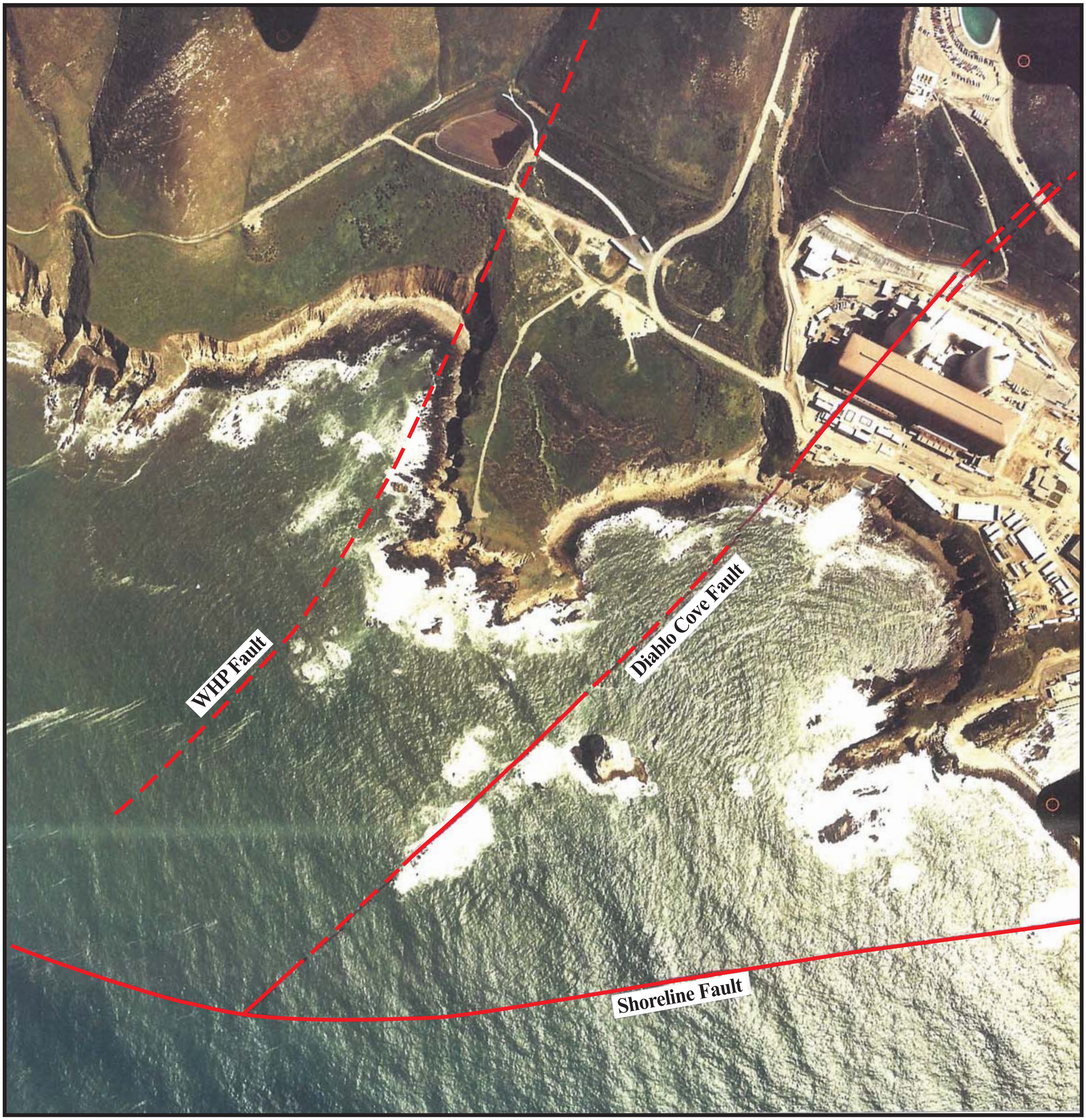
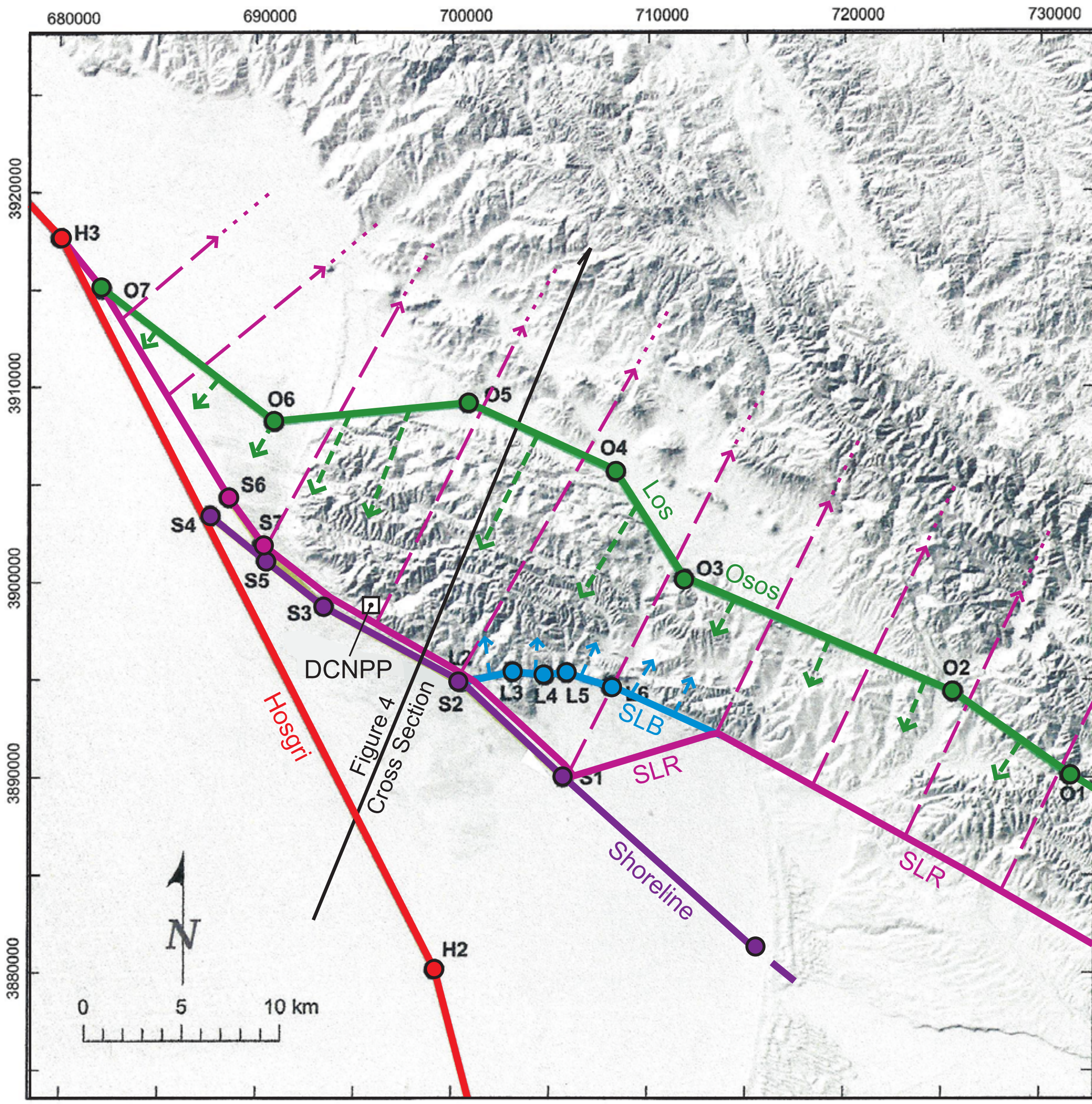



Figure 13. Aerial photo showing traces of Diablo Cove Fault, Wastwater Holding Pond Fault, and Shoreline Fault relative to DCNPP




Note: Coordinates of fault sources are in Table 5-1

*Base map from PG&E 2011.*

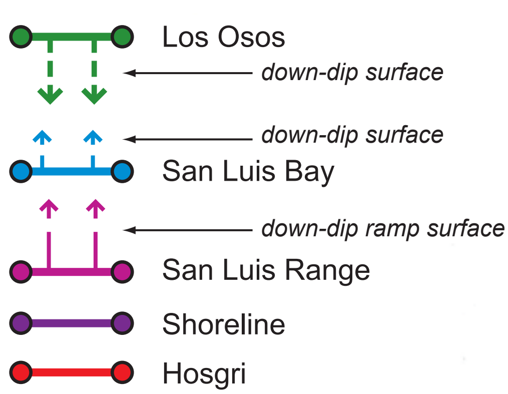
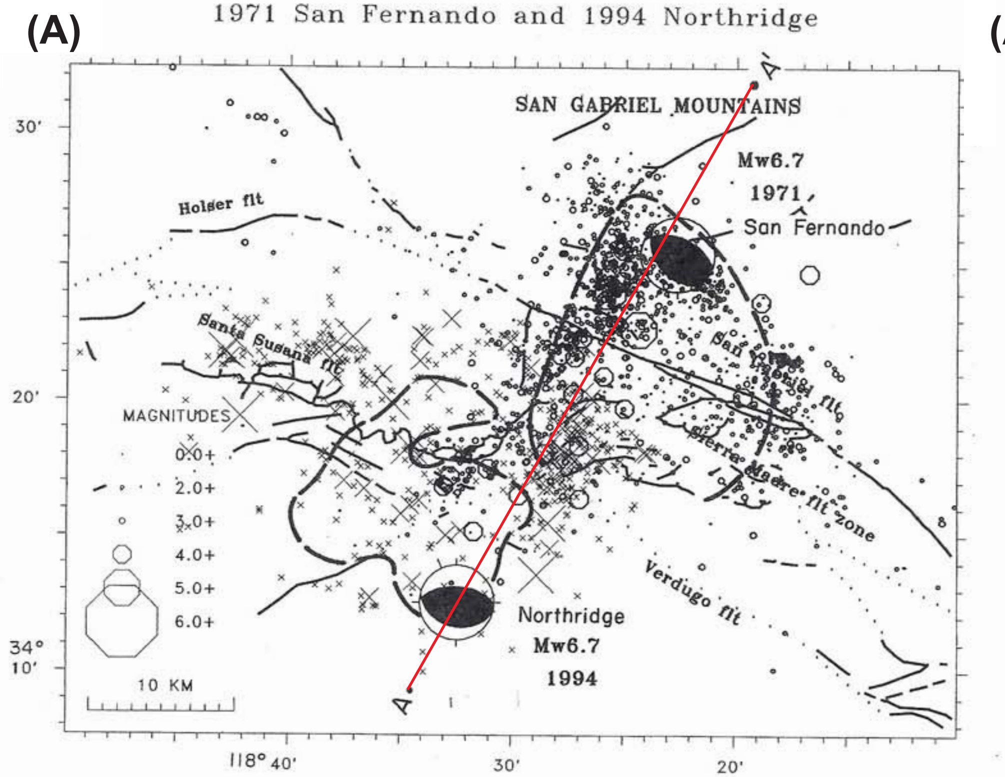
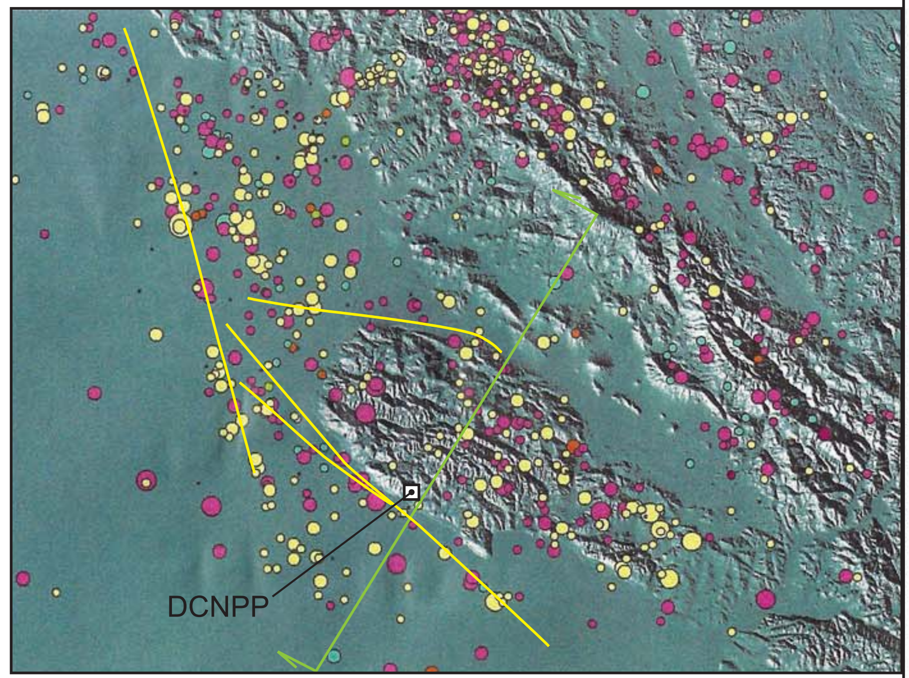



Figure 14. Plot showing traces and down dip projections of seismogenic faults near the DCNPP

(A)




(A)




*Terrain from UNR, 2010. Epicenters from NCEDC, 1987 - 2002*

(B)

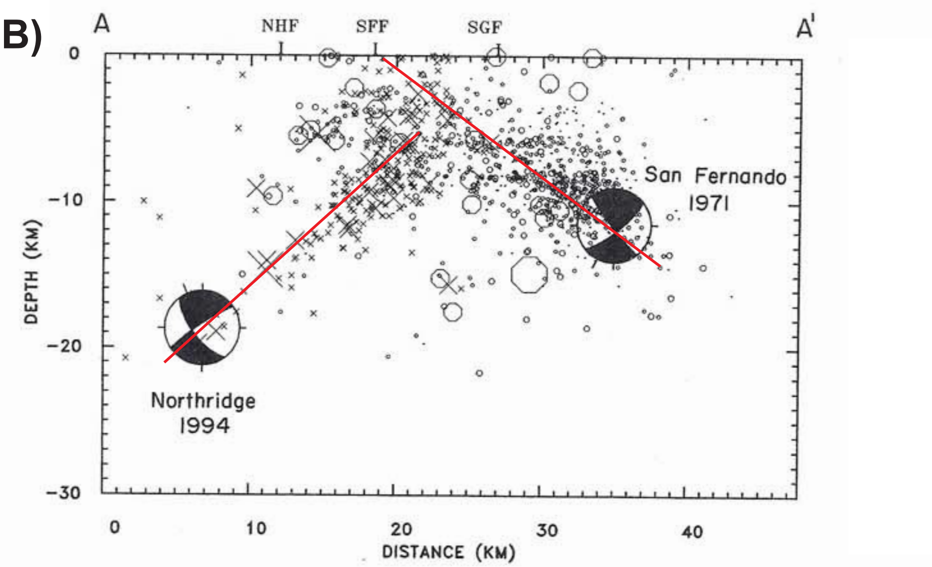
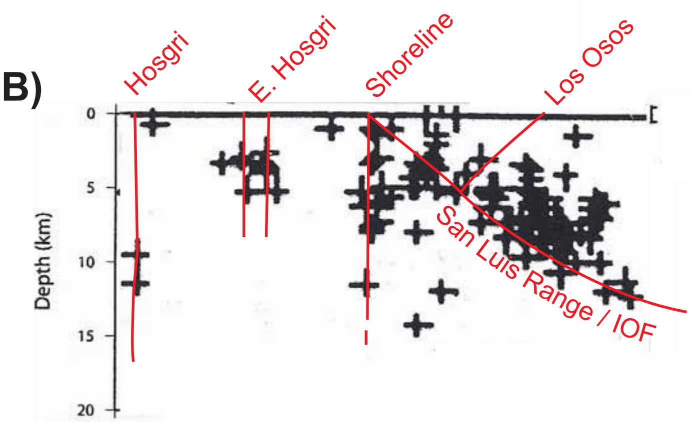



Figure 12. (A) Map and (B) northeast striking cross section (A-A') showing both the 1971 San Fernando (open symbols) and the 1994 Northridge aftershocks (x symbols). Aftershock data is from portable instruments, February to April 1971, (Mori and others 1994), and SCSN data from 1971 and 1972. Approximate rupture surfaces for the 1971 (Heaton, 1982) and 1994 (Wald and Heaton, 1994) earthquakes are also shown.
*(from Hauksson, 1995)*

(B)




**A.** Terrain with epicenters map of Irish Hills and Vicinity

**B.** Earthquake hypocenters and faults, cross section A-A' across Irish Hills and vicinity. Data from NCEDC, 2008

Figure 15. San Fernando and 1994 Northridge earthquakes - Irish Hills / San Luis Range seismicity comparison

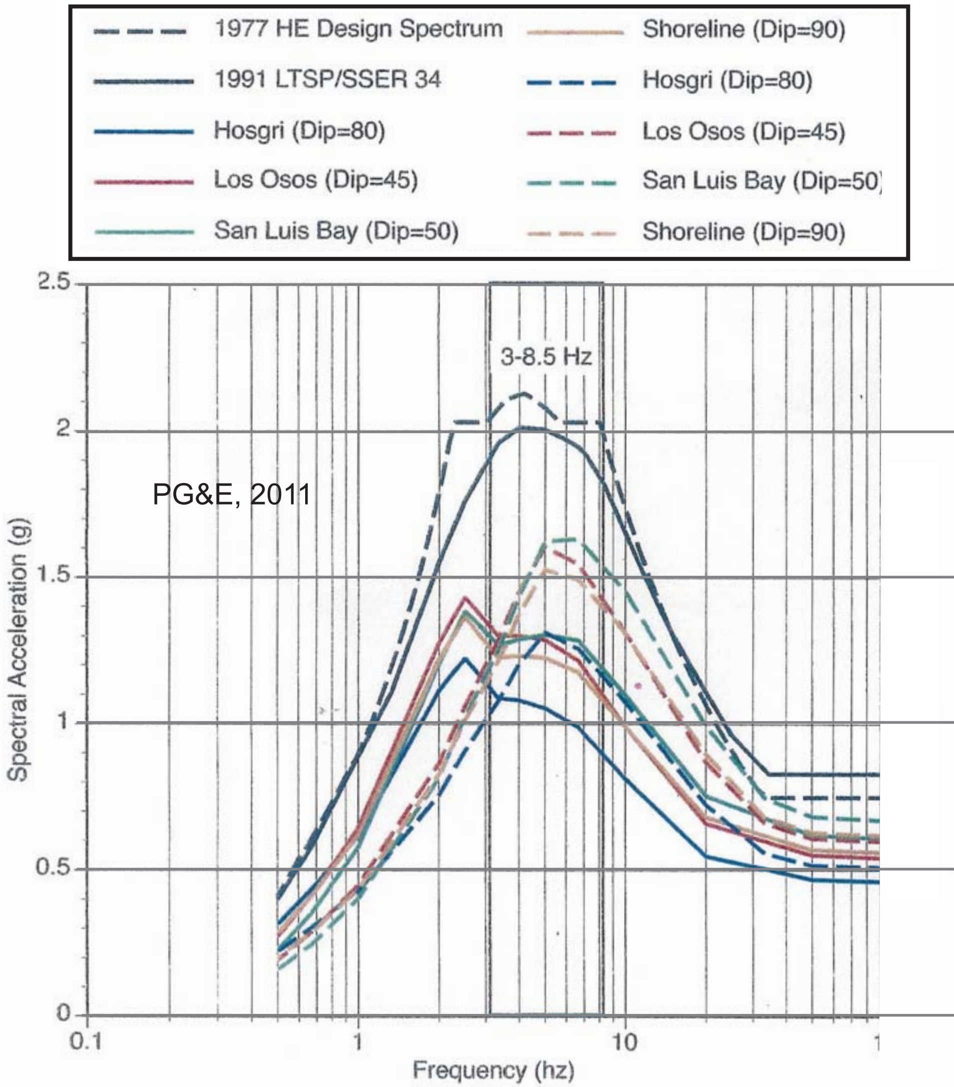



**Figure 6-19.** 84th percentile ground motion from the four nearby fault sources using the site-specific single-station sigma approach (solid lines) and the traditional ergodic approach (dashed lines). The 2.5 Hz peak in the site-specific spectrum reflects the DCPP site amplification.

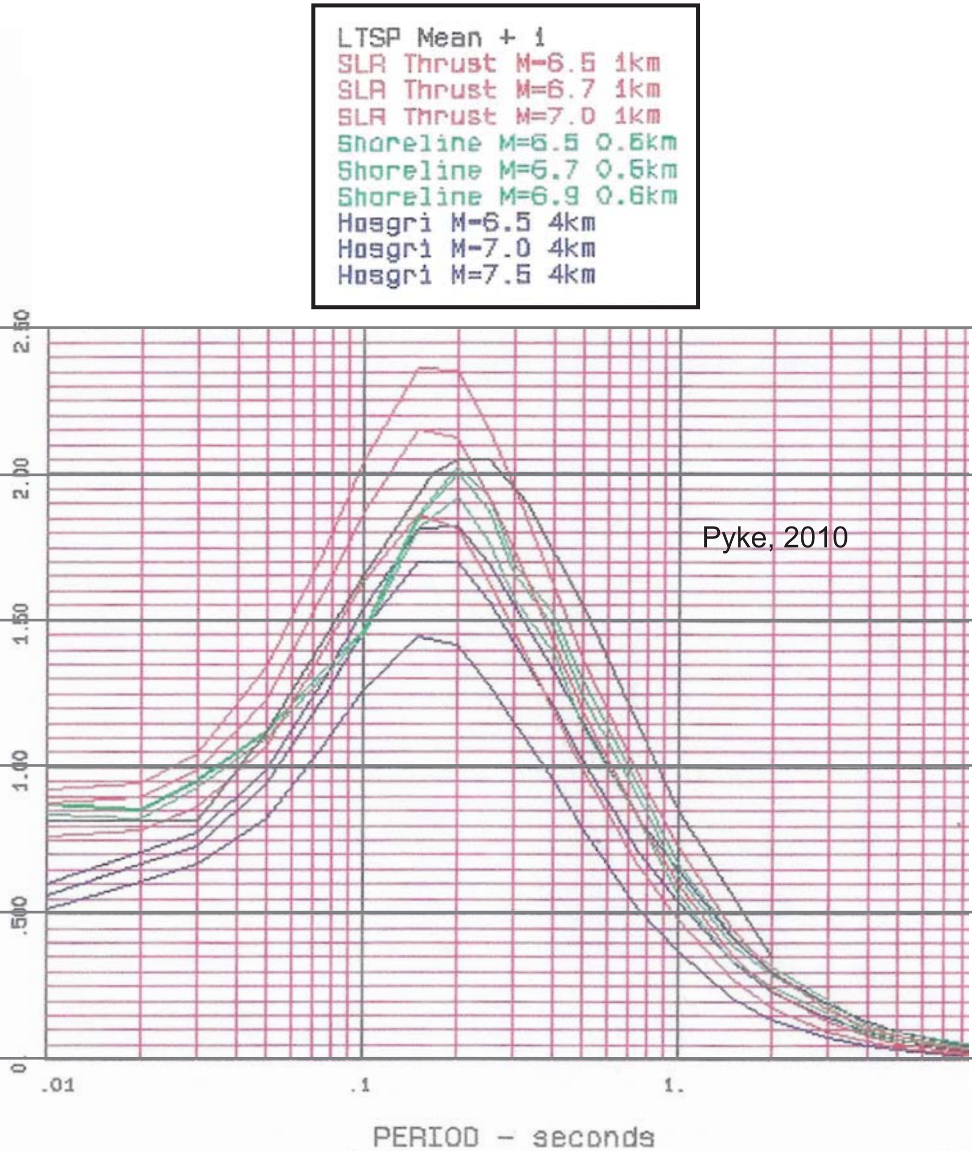



Figure 16 PG&E and this testimony plots of DCNPP site spectra, Hosgri, Shoreline, Los Osos and San Luis Range thrust earthquakes

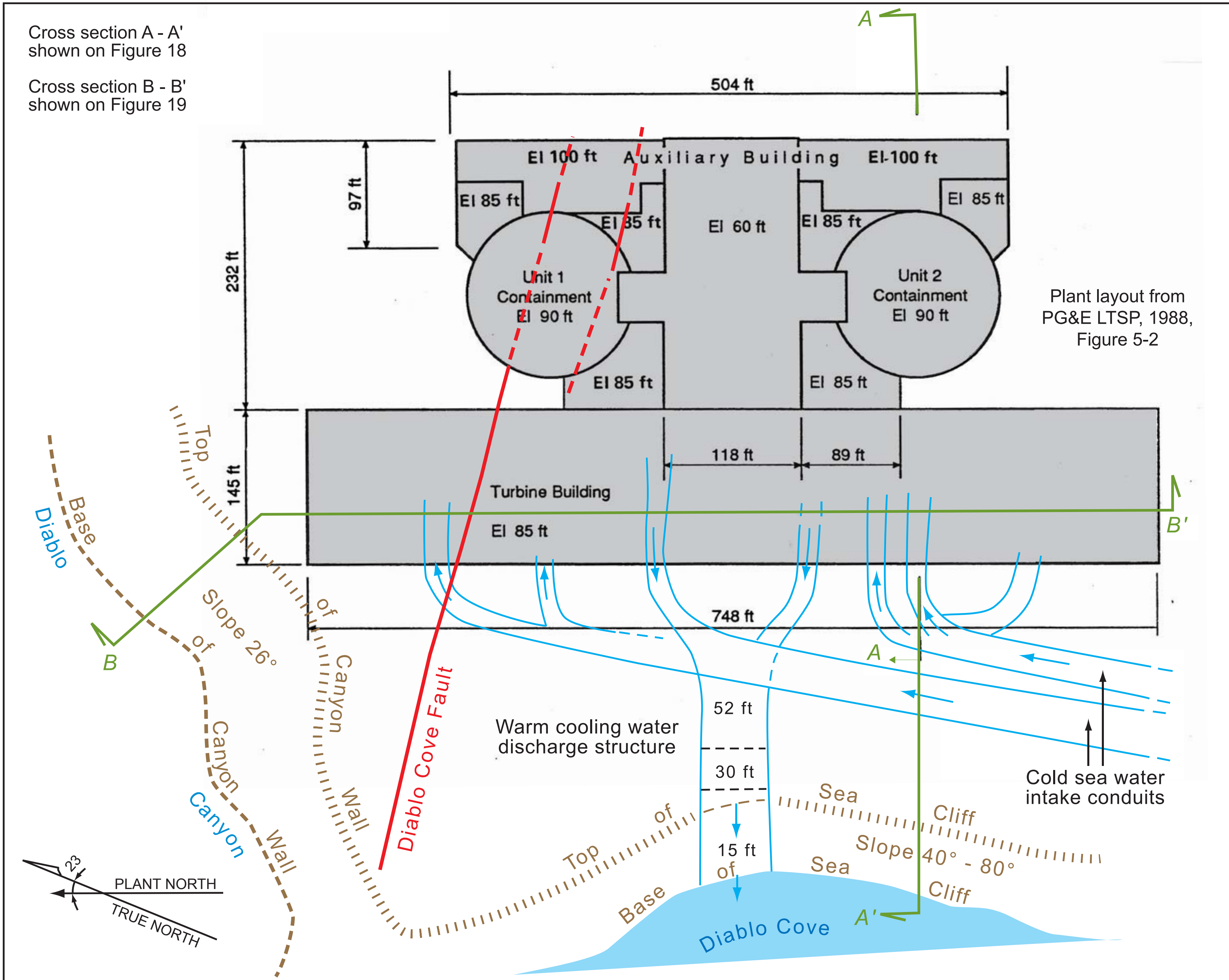



Figure 17. Foundation configuration of power block, containment, and spent fuel storage structures, DCNPP

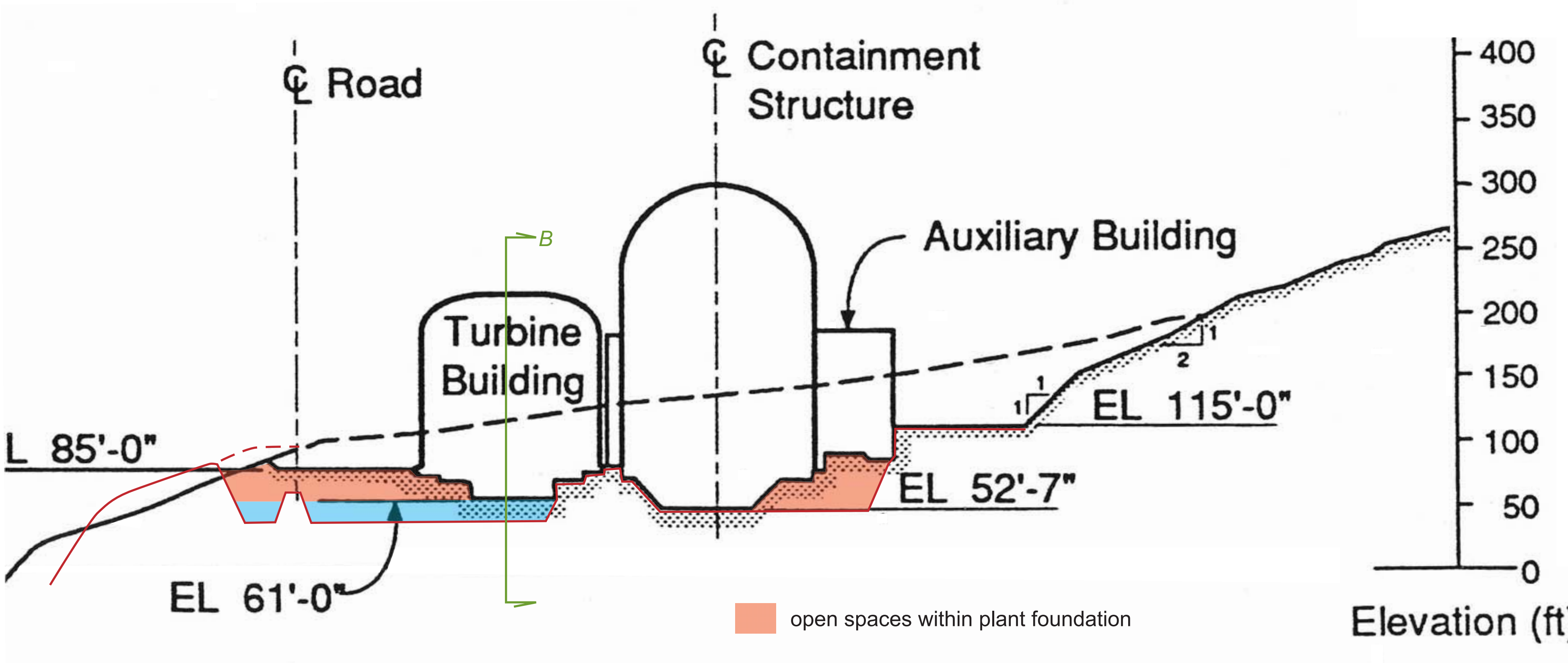



Figure 18. DCNPP foundation excavation profile modified from LTSP Figure 5-3.

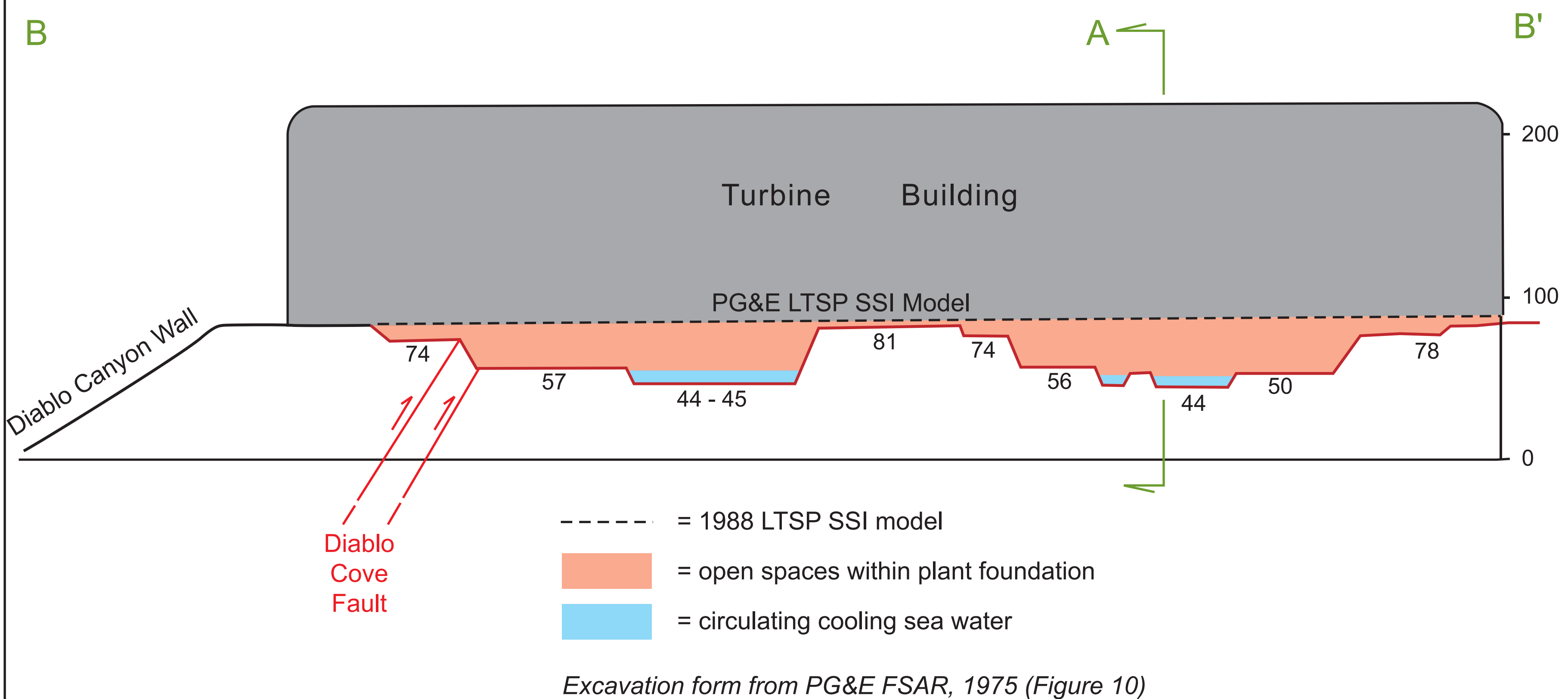



Figure 19 DCNPP foundation excavation profile, along longitudinal axis of turbine generator building

California Energy Commission

# Diablo Canyon Nuclear Power Plant

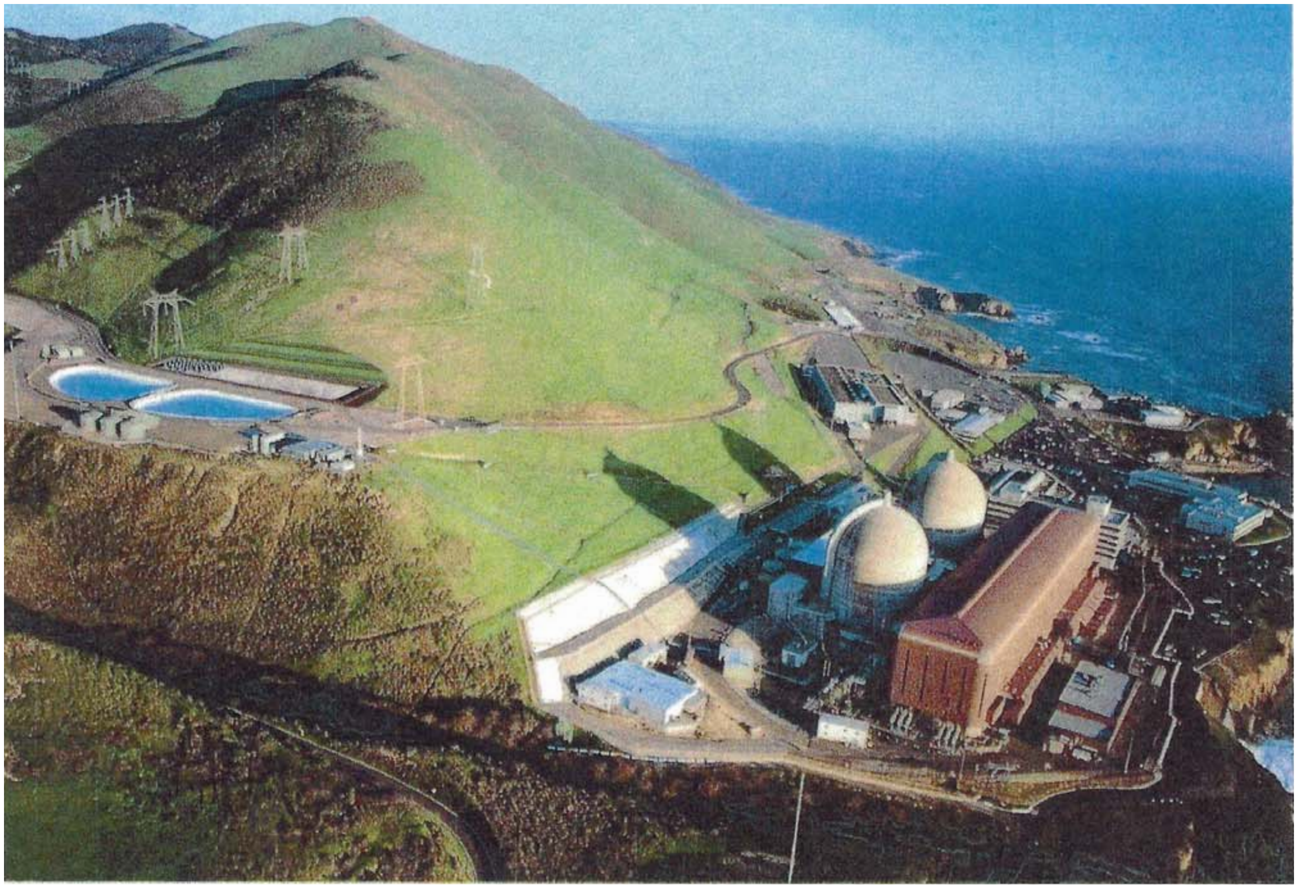


Figure 20.  Oblique aerial photo of DCNPP, showing power plant buildings, raw water storage basins and ISFSI pad (from B. Byron, CEC, July 2011)