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U.S. Nuclear Regulatory Commission
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Docket No. 50-275, OL-DPR-80
Docket No. 50-323, OL-DPR-82
Diablo Canyon Units 1 and 2
Progress Report: Shoreline Fault Zone, Central Coastal California

Dear Commissioners and Staff:

On January 5, 2010, representatives from Pacific Gas and Electric Company (PG&E) met with the NRC to discuss the analysis of the California Central Coast Shoreline Fault Zone that is in close proximity to the Diablo Canyon Power Plant.

Enclosure 1 provides the progress report for the Shoreline Fault Zone as discussed with the NRC.

PG&E makes no regulatory commitments as a part of this submittal.

Sincerely,

James R. Becker

swh
Enclosures
cc: Redacted
Elmo C. Collins, NRC Region IV
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Enclosure 1
PG&E Letter DCL-10-003

PROGRESS REPORT ON THE ANALYSIS OF THE SHORELINE FAULT ZONE, CENTRAL COASTAL CALIFORNIA

PROGRESS REPORT ON THE ANALYSIS OF THE SHORELINE FAULT ZONE, CENTRAL COASTAL CALIFORNIA

Report to the U.S. Nuclear Regulatory Commission
January 2010

1.0 INTRODUCTION

In November 2008, PG&E informed the NRC that preliminary results from the Diablo Canyon Power Plant (DCPP) Long Term Seismic Program (LTSP) seismic hazard update indicated that there was an alignment of microseismicity that may indicate a previously unidentified fault located about 1 km offshore of DCPP (Figure 1). This seismicity alignment was called the Shoreline fault zone.

PG&E conducted an initial sensitivity study to evaluate the potential impact of the Shoreline fault zone on the seismic safety of DCPP (PG&E, 2008) using a seismic margin approach. Using conservative assumptions about the total length of the fault zone, a magnitude 6.5 strike-slip earthquake at a distance of 1 km was considered. The results of this sensitivity study demonstrated that the 84th percentile ground motion from the Shoreline fault zone was lower than the 1991 LTSP ground motion for which the plant had been evaluated and shown to have adequate margin (NRC, 1991). Therefore, PG&E concluded that the plant had adequate seismic margin to withstand the ground motions from the Shoreline fault zone. In early 2009, the NRC conducted an independent study of the potential impacts of the Shoreline fault zone on DCPP (NRC, 2009) and they also concluded that there is adequate seismic margin.

Although these initial sensitivity studies show that the plant had adequate margin to withstand ground motion from the potential Shoreline fault zone, three main parameters of the Shoreline fault zone are not well constrained: geometry (length, width, dip) and segmentation, location offshore of DCPP and slip-rate. To reduce the uncertainties in these source parameters, PG&E prepared a 2-year Action Plan to collect additional data to better characterize the Shoreline fault zone. Once completed, the improved characterization will be used to update the ground motion hazard at DCPP and to also assess the potential for secondary deformation along the Auxiliary Salt Water (ASW) intake pipe corridor.

This report describes the data collection and initial results from new geologic interpretations for the first year of this study. This report distinguishes between the seismicity lineament as defined by Hardebeck (2009) and the Shoreline fault zone as currently defined by bathymetry and the interpretations presented in this report. The report is organized into the following sections:

2.0 Data Collection - describes the new geologic and geophysical data, including multibeam echo sounding (MBES) swath mapping and high resolution seismic reflection profiling, that were used to identify the surface expression of the Shoreline fault zone.

3.0 Seismicity Lineament - evaluates the Shoreline seismicity lineament including estimates of earthquake location uncertainty.

4.0 Initial Results - integrates the new geologic and geophysical data with the seismicity to improve the characterization of the Shoreline fault zone in terms of its geometry and segmentation, location offshore from DCPP, and activity rate.

5.0 Impacts at DCPP - presents an updated evaluation of the ground motion and initial evaluation of secondary fault deformation at DCPP related to surface faulting on the Shoreline fault zone.

6.0 Summary and Planned 2010 Studies - summarizes PG&E's conclusions to date and the research program that has been identified for 2010 to address unresolved issues and questions.

7.0 References

The study area addressed in this report is the offshore region between the Hosgri fault zone on the west, the Irish Hills on the east, Estero Bay on the north and San Luis Obispo Bay on the south (Figure 1). Tectonically the study area lies within the Pacific-North American transpressional plate margin between the San Simeon/Hosgri system of near-coastal faults to the west and the San Andreas fault system to the east in a region called the Los Osos-Santa Maria (LOSM) domain, as first described in the PG&E Long Term Seismic Program Final Report (PG&E, 1988) (Figure 1 inset). The domain consists of northwest-striking reverse and oblique slip faults that border intervening uplifted blocks and subsiding basins (PG&E, 1988, Lettis et al., 2004). The Shoreline fault zone is located within the San Luis Pismo block of the LOSM domain.

2.0 DATA COLLECTION

Modern high resolution potential field (magnetics and gravity) and bathymetric data have significantly improved the ability to resolve geologic structures in the vicinity of DCPP since the original LTSP (PG&E, 1988). During 2008 and 2009, new marine magnetic, high resolution seismic profiling, and multibeam echo sounding (MBES) data were collected offshore DCPP. New aeromagnetic data were collected onshore in 2008 and 2009, and new gravity measurements were collected in 2009 to update earlier models for the area (Figure 2).

2.1 Magnetics

Figure 2a shows the coverage of a fixed wing aeromagnetic survey that was flown in 2008 under the PG&E/USGS CRADA program. A total of 20,508 line-kilometers of data were collected at an altitude of 305 m (~1000 feet) with an 800 m line spacing using differential GPS navigation. A contour map of this aeromagnetic data was published as USGS Open File Report 2009-1044 (Langenheim et al., 2009).

Marine magnetic data were collected at 400 m line spacing during 2008 and 2009 as part of a joint marine magnetics and high resolution seismic reflection study as part of the PG&E/USGS CRADA and the California State Waters Mapping Program. The data collected in 2008 were published as USGS Open File Report 2009-1100 (Sliter et al., 2009). Figure 2b shows the track lines for both marine studies.

The USGS "merged" the marine magnetic data, collected at sea level, with the aeromagnetic data, collected at an altitude of 305 m above terrain, by applying a simple datum shift (Watt et al., 2009; see Figure 2c). The data "merge" quite well despite the difference in measurement height. This is confirmed by the similar magnetic character between the aeromagnetic data and the marine magnetic data that have been filtered to effectively place those data at the same height as that of the aeromagnetic data (upward continuation).

In order to capture the shorter wavelength features of the magnetic field in the vicinity of the Shoreline fault zone and fill the gap between the fixed wing and marine surveys, PG&E conducted a helicopter-based magnetic survey along the coast line in December 2009. An additional 933 line-kilometers of total field aeromagnetic data were collected between Pt. Buchon and Pt. San Luis along flight lines spaced 150 m apart and at a nominal altitude of ~100m above terrain (see Figure 2b for survey area). Processing of these data is in progress.

2.2 Gravity

The USGS compiled, edited and reprocessed nearly 30,000 gravity measurements to produce an isostatic residual gravity map for the region, spanning Monterey on the north to the Santa Barbara channel on the south (Langenheim et al., 2008). Data includes the PG&E LTSP offshore data base as well as data collected at ~ 1 mile spacing by NIMA (formerly the Defense Mapping Agency) for the area south of 36°15'N near Vandenberg Air Force Base. Terrain corrections were applied using 30 m DEMs to create a roughly 2 km grid over the central California coastal area The USGS also collected about 180 new gravity measurements in the Pt. Buchon /Pt. San Luis area and in the Santa Maria basin during 2009. Several older measurement sites were reoccupied to aid in editing the old data and highlighted the inaccuracy of the older data. Figure 2d shows the isostatic gravity anomalies in the vicinity of the DCPP at a grid spacing of 400 meters (Watt et al, 2009).

2.3 High Resolution Seismic Reflection Profiling

Single-channel seismic-reflection data were acquired in 2008 and 2009 by the U.S. Geological Survey between Piedras Blancas and Pismo Beach, along shore-perpendicular transects spaced 800 m apart extending from close to shore to beyond the 3-mile limit of California State waters (Figure 2b). Data were collected as part of the PG&E/USGS CRADA and the California State Waters Mapping Program. The 2008 data were published as USGS Open File Report 2009-1100 (Sliter et al., 2009). Data collected in 2009 are still being processed. In general, the USGS survey vessel was not able to approach as close to shore as the CSU Monterey Bay vessel (see below) due to the presence of shallow rocks and kelp. Specific attempts were made in 2009 to image portions of the Shoreline fault zone based on locations mapped by MBES; however, these attempts were not successful.

2.4 Multibeam Echo Sounding

Multibeam echo sounding (MBES) data for the Estero Bay to San Luis Bay nearshore region were acquired by the Seafloor Mapping Lab at California State University Monterey Bay during 2008 and 2009. Figure 2e shows the areas mapped in 2006 (Point Buchon- grey colored track lines) and 2009 (Point Buchon to San Luis Bay – red colored track lines). The acquired MBES bathymetry data are shown on Figure 2f. The spatial resolution in water depths less than 50 m is 1 m, and is 2 m for water depths greater than 50 m. Multibeam databases can be accessed at the CSU Sea Floor Mapping Lab Data Library http://seafloor.csumb.edu/SFMLwebDATA_c.htm. Data bases for 2006 Pt. Buchon survey are currently on line, and the databases for the 2009 Pt. Buchon to Avila Beach survey will be available at the end of 2009.

3.0 SEISMICITY LINEAMENT

3.1 Hardebeck Studies

In November 2008, Dr. Jeanne Hardebeck (USGS) presented relocations of earthquakes that have occurred from 1987 to 2007 in the south-central coastal region of California at a PG&E/USGS Cooperative Research and Development Agreement (CRADA) workshop. Dr. Hardebeck's study, supported by the CRADA as part of the regional LTSP Update program, used the Double Difference (DD) program, *hypoDD* (Waldhauser and

Ellsworth, 2000) and found a microseismicity lineament about one km offshore of DCPP.

In 2009, Hardebeck relocated the earthquakes through 2008 using a new relocation technique called *tomoDD* (Zhang and Thurber, 2003). *TomoDD* is a more robust program than *hypoDD* because it incorporates absolute and relative arrival time data from the phase picks and waveform cross correlations, respectively, and it uses DD tomography to determine a 3D velocity model jointly with absolute and relative event locations (Zhang and Thurber, 2003). Hardebeck's *tomoDD* results also show the Shoreline seismicity lineament (Figure 1). The seismicity lineament consists of approximately 50 microearthquakes of magnitude 0.8 to 3.5 located between 2 and 15 km depth.

We evaluated why the seismicity lineament was not previously visible using typical catalog locations based on a 1D velocity model. We found that a diffuse pattern of earthquakes between the shoreline and the Hosgri fault zone centered about 1½ km west of DCPP was visible, but they did not show a strong alignment (Figure 3, frame CAT08). The diffuse pattern was due primarily to imprecise locations of earthquakes occurring offshore and outside the seismic networks using a 1D velocity model.

During the 1988 through 2008 time period, the seismographic station coverage did not change. The yearly plots in Figure 3 show that during this time period the Shoreline microseismicity lineament began in the northern end and, in about 1992, the seismicity began to fill in the central and southern parts. Analysis of earlier seismicity data with less station coverage identified possibly 3 additional microearthquakes associated with the seismicity lineament (J. Hardebeck, personal communication, 2009).

3.2 Peer Review of Seismicity Lineament

Regardless of the location method used, hypocentral accuracy depends on several factors such as the quality of the *P*- and *S*- arrival time picks, an adequate velocity model and good station geometry (<180° azimuthal gap). The accuracy of the offshore Shoreline fault zone earthquake locations is likely affected by all of these factors.

Hardebeck's *tomoDD* location results for earthquakes within the study area were reviewed by Dr. Clifford Thurber, co-author of *tomoDD* (Zhang and Thurber, 2003). He first reproduced the *tomoDD* results of Hardebeck using her same assumptions, and then relocated the earthquakes using *tomoDD* with his preferred parameters and velocity model. Thurber also estimated the hypocentral location uncertainty for comparison with Hardebeck's uncertainty estimates (Hardebeck, 2009). Thurber concluded that the seismicity lineament identified by Hardebeck is a robust feature (Thurber, 2009).

Figure 4 shows both the Hardebeck and Thurber locations with the 2009 Shoreline fault zone interpretation (this study). The earthquakes that are associated with the seismicity lineament are defined here as those events whose 0.5 km uncertainty circles (buffers) intersect the mapped traces of the Shoreline fault zone (as described in Section 4.2) or the cross section line A-A' to the northwest. Thurber's locations are generally farther offshore than Hardebeck's and the difference in location generally increases with distance offshore (i.e., there is less offset between Thurber and Hardebeck along the seismicity lineament and more offset along the Hosgri fault zone). Thurber's locations are also approximately 1 km shallower than Hardebeck's locations (Figure 5).

3.3 Location Uncertainty

Hardebeck and Thurber each estimated location uncertainties for earthquakes within the Shoreline seismicity lineament. Their methods are described below. In this report, we estimate location uncertainty by comparing the individual Hardebeck and Thurber uncertainty estimate to our estimate based on a comparison of the two *tomoDD* results.

Hardebeck (2009) estimated the absolute earthquake location uncertainty by relocating shots with known locations. For 13 shots (Murphy and Walter, 1984; Sharpless and Walter, 1988) located inside her 3D velocity model, the RMS shift from the true location was 0.9 km horizontal and 1.3 km vertical. She concluded that the absolute uncertainty of the earthquake locations, which should be better located than the shots, was ≤ 0.9 km horizontal and ≤ 1.3 km vertical. She acknowledges that the offshore shot location errors are larger. The location errors in shots tend to be about twice the location errors for earthquakes because the ray path for shots samples the shallow surface structure twice.

Thurber assessed the relative and absolute location uncertainties. Using a jackknife approach, he estimated relative location uncertainties of 140 m in the direction parallel to the lineation, 190 m perpendicular to the lineation, and 280 m in depth. For the absolute location uncertainty he obtained a rough estimate by considering the variations in absolute locations resulting from the use of different starting velocity models and different control parameter settings. He considers 500 meters to be a reasonable estimate of the absolute location uncertainty (horizontal and vertical) for the Shoreline earthquakes within the Shoreline seismicity lineament.

Hardebeck (2009) also estimated uncertainties for the San Luis Obispo region based on the stability of the locations determined using various location methods. The median absolute shift between her *hypoDD* and 3D locations is 470 m horizontal and 450 m vertical. The median absolute location shift between her *hypoDD* and *tomoDD* locations is 390 m horizontal and 510 m vertical.

In a similar approach, we compared location results specifically between Hardebeck and Thurber's *tomoDD* earthquake locations. The average shift values between the two *tomoDD* runs are 0.50 ± 0.34 km (RMS 0.60 km) horizontal shift and 1.39 ± 0.82 km (RMS 1.61 km) vertical shift. Our results are consistent with the Hardebeck and Thurber error estimates. In this progress report, we use the Hardebeck locations with uncertainties of 0.50 km horizontal and 1.4 km vertical to study the relation of the seismicity lineament to the Shoreline fault zone.

4.0 INITIAL RESULTS

4.1 Geologic Setting

Identifying a potential candidate structure as the cause of the seismicity lineament requires an understanding of the geologic setting in terms of the geomorphology, stratigraphy, and structure of the offshore region west and southwest of the Irish Hills. The geologic setting of this offshore region is partly known from previous studies (e.g PG&E, 1988) but has been greatly improved by interpretation of the recently acquired MBES bathymetric, seismic reflection, and potential field data.

Geomorphology

The Shoreline seismicity lineament traverses the inner continental shelf west and south of the Irish Hills. The inner shelf in this area consists of a gentle, westward-sloping (less than 1 degree) bedrock platform between the coastline and a prominent break-in-slope coincident with the Hosgri fault zone. The bedrock platform is underlain by Cretaceous (~ 100 million years ago (mya)) and Tertiary rocks (~ 2 to 65 mya) that have undergone multiple phases of deformation (Hall 1978), and thus are extensively folded, fractured and faulted. In addition, the bedrock platform was eroded during multiple cycles of Pleistocene (~ 10,000 years to 2 mya) and Holocene (10,000 years ago to present) sea level rise and fall, producing both submerged paleo-seacliffs (former coastlines) and sea stacks, as well as enhanced lineaments along the previously folded and faulted strata. Locally, extensive thin mobile sand sheets veneer and obscure the bedrock surface.

Identification of a potential candidate structure associated with the Shoreline seismicity lineament, therefore, must consider several factors of the geologic, geomorphic, and structural setting:

(1) The multiple phases of Tertiary deformation have produced an inherited structural grain. Most (or all) of these structures are no longer active; however, current active faulting may locally re-activate a pre-existing structure.

(2) Many of the most prominent sea floor lineaments are the result of marine erosion, including multiple paleo-seacliffs and enhanced erosion along inherited, pre-existing geologic structures and bedding.

(3) Marine erosion likely obliterates or obscures subtle geomorphic features associated with low rates of fault activity.

(4) Drifting, mobile sand sheets of modern age cover not only large parts of the bedrock surface, but also locally infill many bathymetric lineaments and seafloor channels, obscuring subtle geomorphic evidence of active faulting.

(5) A potentially active fault must exhibit clear evidence of cross cutting, and thus post-dating, the inherited Tertiary stratigraphic and structural grain, and ideally would have geomorphic evidence of cross-cutting relationships to the Pleistocene erosion surfaces.

Stratigraphy and Structure

Rock strata on the offshore bedrock platform are identified through correlation to onshore stratigraphic units following the nomenclature of Hall (1973). The bedrock consists primarily of unnamed Cretaceous greywacke (sandstone) and Franciscan Mélange, and Tertiary Obispo, Monterey, and Pismo formations. These units are recognized and mapped based on changes in seafloor texture and structure seen on the MBES bathymetry and locally confirmed by cores and diver samples.

Understanding the distribution of stratigraphic units provides critical information for interpreting both the inherited Tertiary structural features on the inner shelf, as well as potential Quaternary structural features that either locally reactivate pre-existing structures, or "cross cut", and thus post-date, these earlier structural features.

During the Tertiary (~ 2 to 65 mya), northeast-southwest-directed compression produced the northwest-trending anticlines and synclines in the Irish Hills and the offshore inner shelf. Onshore deformation ended sometime in the late Tertiary (Pliocene (2 to 5 mya) and transitioned into uplift of the San Luis/Pismo structural block during the early Quaternary (Pleistocene) (Hanson et al., 1994; Lettis et al., 2004). We infer that offshore deformation also ended by the late Tertiary and was replaced by uplift of the offshore bedrock platform as an extension of the San Luis/Pismo structural block. MBES bathymetry and high resolution seismic reflection data clearly show folded and faulted Tertiary strata (Figure 6). The deformation also warps and folds pre-existing fault contacts or angular unconformities that separate the Tertiary section from the underlying Cretaceous basement section. This pre-existing stratigraphic and structural grain, therefore, provides the basis for identifying and characterizing potential faults that crosscut older structures.

Further to the west, the marine bedrock platform and geologic structures are truncated by the Hosgri fault zone (Figure 6). The Hosgri fault zone is an active transpressional right slip fault that forms one of the major strike slip faults separating the Pacific and North American tectonic plates. It is approximately 110 kilometers long, has a slip rate of 1 to 3 mm/yr, and lies approximately 4 kilometers offshore of the DCPP (Hanson et al., 2004; PG&E, 1988, 1990).

4.2 Potential Candidate Structure for the Shoreline Fault Zone

Based on our analysis of the MBES bathymetry and seismic reflection data and interpretation of offshore geology, we identify a candidate geologic structure that we call the Shoreline fault zone. The fault zone cuts across all Cretaceous and Miocene structures and, thus, is younger than the Miocene (5 to 24 mya). It consists of three distinct segments separated by right en echelon steps of several hundred meters width (Figure 6). The characteristics of these three segments are summarized in Table 1 and described below.

<u>Segmentation and Length</u>

The Shoreline fault zone consists of three segments: (1) a 6 to 9 km Northern Segment defined by a distinct N40W-trending escarpment that locally truncates Miocene bedding and structures; (2) a 8 km Central Segment expressed as a sharp bathymetric lineament and scarp that locally juxtaposes unlike bedrock lithologies, truncates bedding and structures (folds and faults), and has associated gas-related pock marks and mud extrusions; and (3) a 6 km Southern Segment expressed as a poor to moderate bathymetric lineament with local truncation of bedding. The geomorphology of all the segments shows that differential erosion is the primary cause of the bathymetric lineaments on the seafloor. Fault line scarps accentuated by wave erosion are common where faults juxtapose resistant and weak rock. The weaker materials in the fault zone are eroded into troughs.

The northern part of the seismicity lineament and the Central and Southern fault segments forms a right-stepping en echelon pattern with an overall strike of North 60° to 70° West. Within the Central Segment, the bathymetric lineament also shows a right-stepping en echelon pattern at both the kilometer scale and 10 to 100 meter scale. The en echelon right stepping fault pattern strongly suggests right-lateral strike-slip surface displacements consistent with the focal mechanisms of the recent microseismicity (Figure 7).

The Shoreline seismicity lineament coincides with the surface trace of the Central and Southern segments of the Shoreline fault zone, and thus these two segments of the fault zone appear to have been reactivated in the current tectonic setting. The alignment of seismicity with the fault zone occurs from directly west of the DCPP southward along the coastline to directly southwest of Point San Luis, where both the seismicity lineament and the Shoreline fault zone die out (Figure 4).

To the north, however, the seismicity lineament is more diffuse and diverges along a more westerly trend than the Northern segment of the Shoreline fault zone. No fault has been identified that can be associated with the northern part of the seismicity lineament. To the contrary, six shallow high resolution seismic reflection lines that cross the northern part of the seismicity lineament provide direct stratigraphic evidence showing the absence of faulting within the upper hundred meters of the bedrock platform and the Quaternary sediments that overly the platform (e.g., Figures 8 and 9a and 9b). It may be that this part of the seismicity lineament is associated with a fault that does not reach the surface. Some of the seismicity may be associated with the western trace of the Hosgri fault zone at depth.

The total length of the seismicity lineament is 22 to 23 kilometers (Table 1). The northern part that is not associated with a known fault extends from the Hosgri fault zone southward to near the discharge cove of DCPP for a distance of 8 to 9 kilometers.

The microseismicity defines nearly vertical fault planes (Figure 5) and the composite focal mechanisms indicate vertical strike-slip earthquakes. In the Central and Southern parts of the seismicity lineament, the seismicity reaches a depth of about 10 km. Along the northern part of the seismicity lineament, there is a change in the depth distribution with depths up to 15 km. The seismicity lineament appears to be most active near the Hosgri fault zone and decreases in activity to the southeast.

4.3 Location of the Shoreline Fault Zone with Respect to DCPP

Our analysis of the MBES data in the DCPP area (Figure 10a) locates the Central Segment of the Shoreline fault zone southwest of the Intake Cove breakwater, 600 meters from the Power Block and 300 meters from the intake structure (Figure 10b). The high quality of the MBES data clearly shows the Shoreline fault zone in this area as a sharp lineament whose northern end projects beneath the sand sheet west of the Discharge Cove.

4.4 Activity Rate of the Shoreline Fault Zone

<u>Evidence of Activity</u>

The offshore seismicity lineament correlates well with the Central and Southern segments of the Shoreline fault zone. As described previously, most of the microseismic events along the Central and Southern segments locate along the fault zone within the ½ kilometer uncertainty bound (Figure 4). Because of this direct association with microseismicity, we conclude that the Central and Southern segments of the Shoreline fault zone are active and that the evidence of activity is sufficient to warrant inclusion of the fault zone in sensitivity analyses to assess implications of ground motion and secondary deformation at the DCPP.

In contrast, the Northern part of the seismicity lineament is not associated with a mapped fault. Seismic reflection records confirm that the underlying wave cut platform and the overlying Quaternary sediments are not deformed (Figures 8 and 9a and 9b). The lack of coincidence of the seismicity with a mapped fault indicates that the northern part of the lineament should be considered separate from the Central and Southern segments of the Shoreline fault zone.

Our preliminary analysis of the MBES bathymetry and seismic reflection data along the Central and Southern segments of the Shoreline fault zone has not identified conclusive geologic, geomorphic, or geophysical evidence of late Quaternary (Holocene) fault activity; however, the prominent seafloor scarps, local gas pock marks, subtle geomorphic features that crosscut talus and colluvium are consistent with a late Quaternary active fault. Further analysis is required during 2010 to test these observations.

Slip Rate on the Shoreline Fault Zone

Slip rate on the Shoreline fault zone is poorly constrained at this point of our preliminary analysis. Several approaches are being used to constrain slip rate or activity rate on the Shoreline fault zone. Progress on each of these approaches is as follows:

(1) *Direct quantitative estimate of slip rate*. The Northern Segment of the Shoreline fault zone crosses numerous submerged marine terrace surfaces and paleo-coastlines. These marine terraces represent former still stands of sea level, and thus form an excellent strain gauge to assess the amount and age of late Quaternary deformation if they can be mapped and dated with confidence. A preliminary map of these terraces has been prepared, and work is in progress to correlate and assign ages to the terraces. At this point, our preliminary observation is that the Northern Segment of the Shoreline fault zone has not produced significant deformation (greater than one meter) of the 80,000 and 125,000 year old terrace sequences suggesting that the fault is not active or has a slip rate that is less than 0.01 mm/yr.

(2) *Qualitative estimate of slip rate*. Many active faults with known slip rates cross the inner continental shelf of California. Comparing the geomorphic, geologic, and geophysical signature of these faults to the Shoreline fault zone provides a qualitative estimate of slip rate. We compare the Shoreline fault zone to the Hosgri fault zone that has a known slip rate of 1 to 3 mm/yr. The Hosgri fault zone forms a prominent geomorphic break-in-slope, clearly deforms late Pleistocene and Holocene marine deposits, and is associated with a prominent gravity and magnetic anomaly (Figures 6 and 11). In contrast, the Shoreline fault zone does not form a prominent break-in-slope and does not appear to significantly offset offshore submerged marine terraces. It is also not associated with a major geophysical anomaly indicating that it has had relatively minor cumulative bedrock offset. We interpret the contrast between theses faults to show that the slip rate on the Shoreline fault zone is one to two orders of magnitude lower than the Hosgri fault zone. Hence, our preliminary qualitative estimate of slip rate on the Shoreline fault zone using this approach is 0.01 to 0.3 mm/yr.

Table 1 Characteristics of the Shoreline Fault Zone and the Northern Microseismicity Lineament

Segment	Location Strike	Length Width Dip	Geomorphic (bathymetric) Expression	Lithology	Structure	Microseismicity	Seismic Reflection
SHORELINE FAULT ZONE							
North Segment	Offshore of Point Buchon to Lion Rock N40°W	6 km; may extend north additional 3km Not known* 90° (?)	Moderate geomorphic expression with fault line scarps in resistant rock in contact with sand sheets. Strong morphology where not covered by sand sheet. Wave-cut platform not displaced across fault.	Locally Sharp lithologic contacts (Obispo/Monterey)	Strong; south end changes strike and trends onshore as 'horsetail' strands south of Lion Rock and may connect with bedrock faults mapped onshore	A few microseismic events	No deformation of wavecut terraces within 1 meter resolution
Central Segment	Lion Rock to Rattlesnake Creek N65°W	8 km 2 to 10 km* 90°	Strong geomorphic expression, with fault line scarps in resistant rock units. Locally sharp morphology with en echelon offsets C-1 moderately prominent C-2 prominent; particularly where not covered by sand sheet C-3 moderately prominent	C-1 contact within Obispo rocks but covered by sand sheet C-2 sharp lithologic contact (Obispo/Franciscan?) C-3 sharp contact in Franciscan	Strong with 100 to 500 m stepover between segments C-1 Strong; truncated bedding, no onshore connection (?) C-2 Very strong; may connect to Olson fault C-3 Locally strong; truncated bedding; may connect to Rattlesnake fault	Best expression 3 to 8 km deep No differentiation of geologic segments C1, C-2, C-3 Right lateral focal mechanisms	No reflection data due to proximity to shore Acoustically opaque basement
South Segment	Rattlesnake Creek to end of seismicity lineament south of Point San Luis N50°W	5 to 5 ½ km 2 to 10 km* 90°	Weak to moderate; local fault line scarps in resistant rocks in contact with sand sheets	Sharp lithologic contact in Franciscan	Locally strong; truncated bedding	Weakest expression With cluster and largest earthquake at marking the southern end Right lateral focal mechanisms	Wavecut platform and overlying Quaternary sediments not deformed
MICROSEISMICITY LINEAMENT							
Northern Micro-seismicity trend	Hosgri fault to Lion Rock N45°W	9 km 2 to 15 km* 90°	No surface expression	No lithologic contact	No structural offsets No association with North Segment of Shoreline fault 'Blind'?	Locally diffuse toward north 3 to 15 km deep Right lateral focal mechanisms	Wavecut platform and overlying Quaternary sediments not deformed

Footnote: * Width of fault zone is estimated from the depth of the microseismic events

5.0 IMPACTS AT DCPP

5.1 Ground Motion

The previous analysis of the impacts of the ground motion at DCPP assumed a M6.5 strike-slip earthquake at a distance of 1 km. The results from the 2009 studies indicate that the length of the combined central and southern segments corresponds to a magnitude 6.25 earthquake. The distance from DCPP to the power block is 0.6 km, not 1 km as previously assumed.

For the same magnitude, the change from 1 km to 0.6 km distance leads to about a 4% increase in the 84th percentile ground motions. Reducing the magnitude from 6.5 to 6.25 leads to a 5-10% reduction in the 84th percentile ground motions. As shown in Figure 12, the spectrum from the Shoreline fault zone remains lower than the LTSP spectrum. In the frequency range of 3-8.5 Hz used for the fragility curves, the Shoreline fault spectra are 10-30 percent lower than the LTSP. Therefore, using the new results, the deterministic ground motion will remain smaller than the LTSP spectrum and there is adequate seismic margin.

5.2 Potential for Secondary Fault Deformation

The central segment of the Shoreline fault zone is 600 meters from the Power Block and 300 meters from the cooling water intake. Given this short distance, the potential for secondary fault deformation is evaluated. The geology in the plant region is shown in Figure 10b. There is a unit labeled Tofc, consisting of shale, claystone and siltstone that is a weaker rock material. If secondary fault ruptures occur, they would most likely occur in the weaker Tofc unit.

The Auxiliary Salt Water (ASW) pipes are the only safety related Structures, Systems and Components (SSC) that could be affected by small fault deformations in the Tofc unit. A study of the deformation capacity of the ASW pipes found that there are eight 1-ft long Dresser coupling sections that are susceptible to small ground deformations.

An initial probabilistic analysis of the secondary fault deformation occurring at any of the eight Dresser coupling sections was conducted following the method of Petersen et al (2004). Two rupture segmentation models are considered; rupture of the Central segment by itself (M6.0) and rupture of the combined Central and Southern segments (6.25). As described in Section 4.4, the slip-rate is uncertain but is judged to be between 0.01 and 0.3 mm/yr. The hazard for secondary fault deformation occurring at any of the eight Dresser couplings is shown in Table 2 for the two rupture models. The range of values for each case represents the range of slip rates. The probability of 1 cm or larger occurring is very small: between 4.2E-9 to 2.4E-7. The NRC allows for events with less than 1E-8 to be excluded from the risk assessment for Yucca Mountain (10-CFR.63-342).

This screening level falls within the lower range of the probabilities of secondary fault deformation.

Secondary fault deformation was not previously considered in the license of DCPP. The potential impacts are evaluated in terms of the potential change in the seismic Core Damage Frequency (CDF). The seismic CDF at DCPP is 3.7 E-5 (LTSP, 1988). Therefore, with the probability of secondary fault rupture in the range of 4.2E-9 to 2.4E-7, the increase in seismic CDF due to secondary fault deformation will be much less than 1%. We conclude that secondary fault deformation impacting the ASW pipes leads to a negligible change in the seismic CDF and does not affect the seismic safety of DCPP.

Table 2. Annual probability of secondary fault rupture at any of the eight Dresser couplings of the ASW in the Tofc unit.

Secondary Deformation	Central (M6.0)	Central & Southern (M6.25)
>1.0 cm	4.2E-9 - 1.3E-7	8.0E-9 - 2.4E-7
>2.0 cm	1.7E-11 -5.1E-10	2.3E-9 - 6.9E-8

6.0 SUMMARY AND PLANNED 2010 STUDIES

6.1 Summary

Initial analyses of the seismicity, multibeam (MBES) bathymetry, and high resolution seismic profiles collected to date allow for several preliminary observations and conclusions as summarized below. These preliminary conclusions will be further evaluated during Year 2 (2010) of our planned Investigation Program.

<u>Seismicity Lineament</u>

1. The seismicity lineament as defined by Hardebeck (2009) is a robust feature and consists of approximately 50 events from 1988 to 2008. All of the events are small (most are in the M 1 to 2 range) with the largest being a M3.5 in 2000. Horizontal location uncertainty is approximately ± 0.5 km, vertical uncertainty is ±1.4 km.

2. Seismicity generally becomes more diffuse spatially and extends to greater depths (2 to 15 kilometers) along the northern part of the lineament as it approaches the Hosgri fault zone. The depth range of the seismicity along the central and southern parts of the lineament extends from 2 to 10 kilometers. The seismicity

along the entire lineament defines a nearly vertical zone. Focal mechanisms indicate primarily right lateral strike slip movement.

Shoreline Fault Zone

1. The Shoreline fault zone has been identified based on MBES and high resolution seismic profiling data The Shoreline fault zone displaces Tertiary and older geologic structures, and thus is younger. The fault zone consists of three distinct segments, the Northern, Central and Southern segments. These segments are well expressed in the sea floor bathymetry as the result of differential marine erosion along the fault trace.

2. The total length of the active portions of the Shoreline fault zone is 13 to 14 km: 8 km for the Central segment and 5- to 5 1/2 km for the Southern Segment. The Northern segment is 6 to 9 km long and is not considered active.

3. The seismicity lineament is coincident with and indicates reactivation of the Central and Southern segments of the Shoreline fault zone. The seismicity lineament diverges northward away from the Northern Shoreline fault zone segment. Therefore, we consider the Northern Shoreline fault zone segment to be a separate structure in the current tectonic setting.

4. Seismic reflection lines across the northern part of the seismicity lineament provide direct stratigraphic evidence that demonstrates the lineament is not associated with surface faulting. The northern part of the seismicity lineament may be occurring on a buried fault in the crust between the Shoreline and the Hosgri fault zones or it may be occurring on faults at depth within the Hosgri fault zone.

Location with Respect to DCPP

1. The Central segment of the Shoreline fault zone is 300 meters southwest of the Intake structure and 600 meters southwest of the Power Block.

Activity Rate

1. Currently, the activity or slip rate on the Shoreline fault is poorly constrained. Developing constraints on the slip rate will be a focus of our 2010 investigations. Qualitative comparison of the Shoreline fault zone to the more prominent Hosgri fault zone suggests a slip rate one to two orders of magnitude less than the Hosgri fault zone, or approximately 0.01 to 0.3 mm/yr. At this time, we believe that this qualitative assessment bounds the range of uncertainty in slip rate on the Shoreline fault zone.

<u>Implications to DCPP</u>

1. The vibratory ground motion impacts were evaluated using a margin approach. The 84th percentile ground motions from the Central and Southern segments of the Shoreline fault zone are bounded by the LTSP. Therefore, there is adequate seismic margin due to vibratory ground motion.

   The secondary fault deformation impacts were evaluated using a Probabilistic Risk Assessment (PRA) approach. The probability of 1 cm or larger deformation at any of the eight Dresser coupling ranges from 4E-9 to 2E-7 depending on the slip-rate (0.01 to 0.3 mm/yr) and rupture segmentation (Central segment versus combined Central and Southern segments). The potential change in the seismic CDF is much less than 1%. Therefore, we conclude that the secondary deformation leads to a negligible change in the seismic CDF.

6.2 Planned 2010 studies

PG&E's research program for 2010 will focus on integrating and interpreting the geologic and geophysical data sets collected in 2008 and 2009 in a regional context. A high priority task is to better characterize the slip rate, long-term style of deformation, and slip along the Shoreline fault zone. This will involve completion of our interpretations of the marine multibeam survey and, working with the USGS, completion of the processing and interpretation of the high resolution marine reflection, magnetics, and gravity data. Specific geologic studies to asses the possible relationship of the Shoreline fault zone to the Southwestern Boundary Zone and to improve our estimates of the slip rate for the Shoreline fault will also be conducted.

All of the geologic and geophysical information collected to date will be integrated to develop an initial three dimensional tectonic model of the region in 2010. This compilation will be used as input to a 3-D finite element model to evaluate various kinematic interpretations of crustal deformation in the central California coastal region. The characterization of the Shoreline fault zone will be incorporated into the seismic hazard update being conducted as part of the LTSP. This complete seismic hazard update is scheduled to be completed in 2013.

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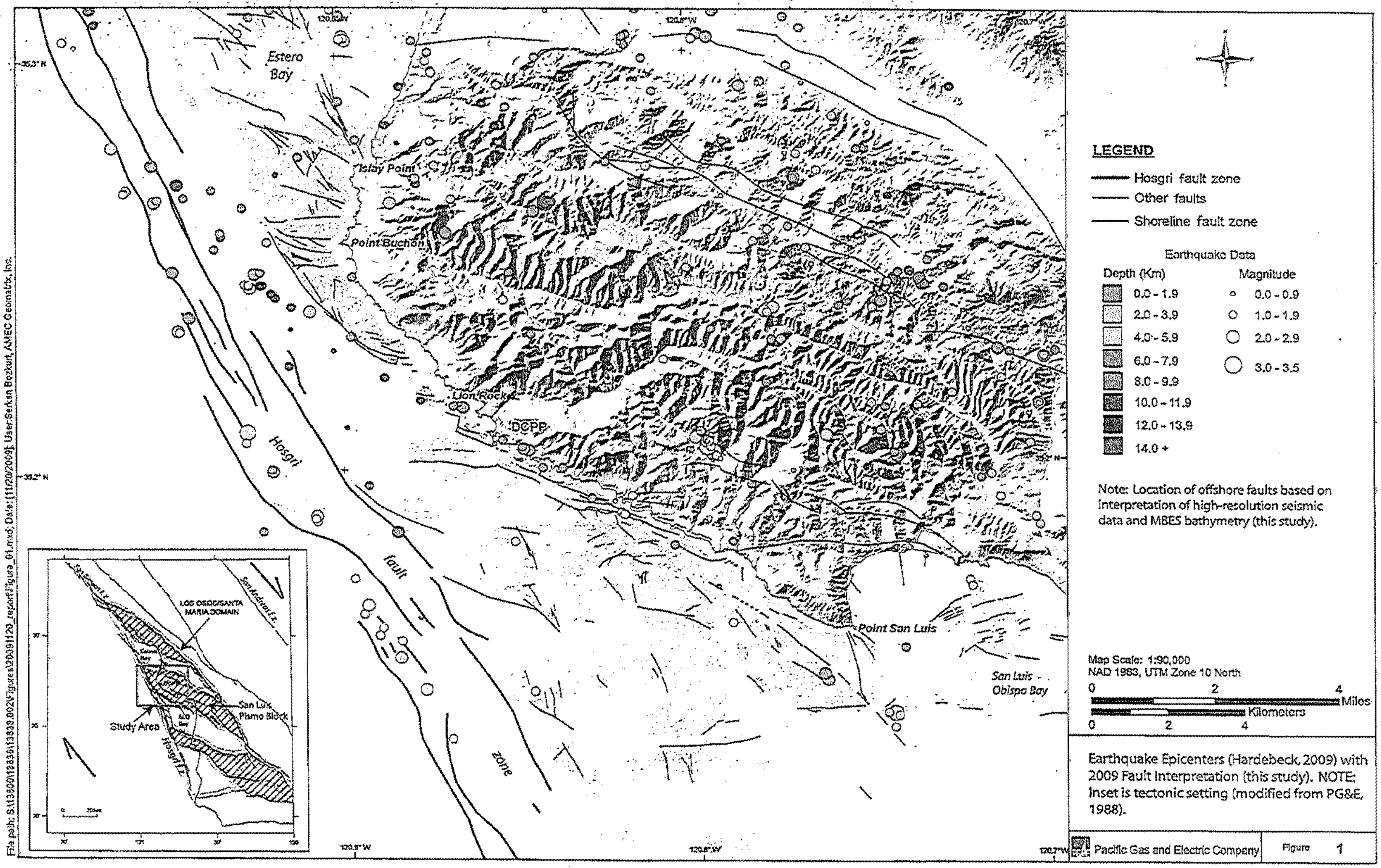

Earthquake Epicenters (Hardebeck, 2009) with 2009 Fault Interpretation (this study). NOTE: Inset is tectonic setting (modified from PG&E, 1988).

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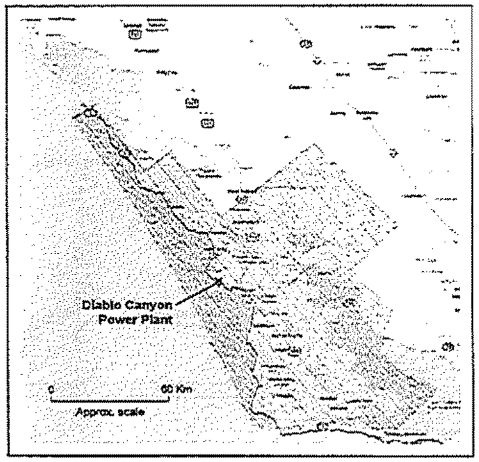
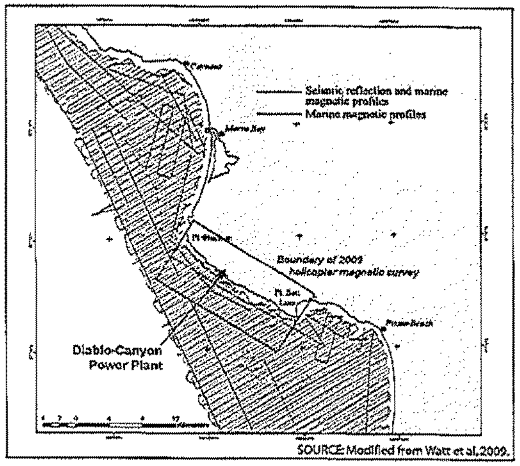
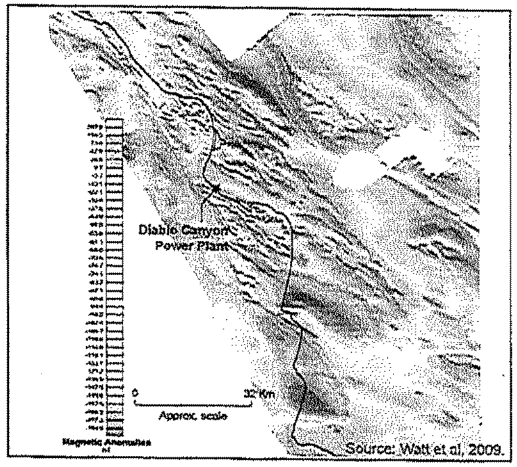


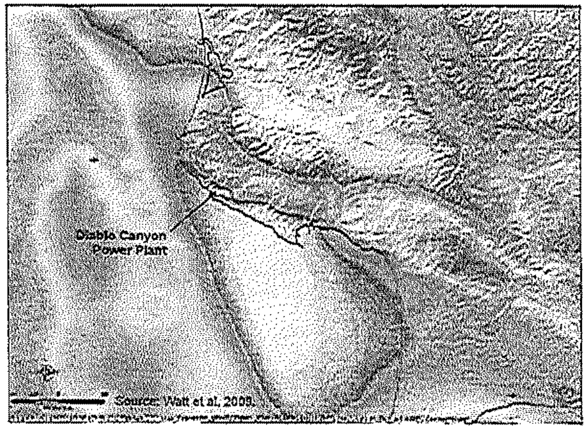
a. Aeromagnetic Survey Area 2008



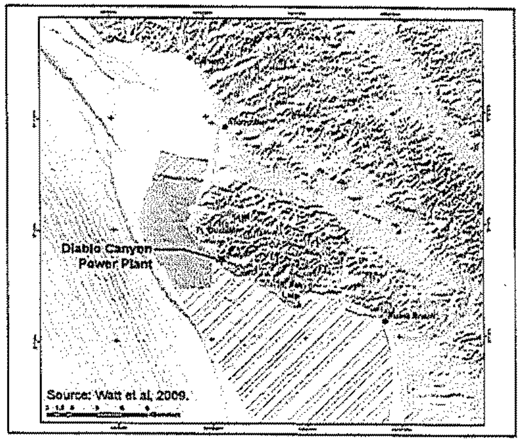
b. New Marine Geophysical Data Collected in 2008-2009



c. Regional Magnetic Anomalies



d. Regional Isostatic Gravity Anomalies



e. Multibeam Echo Sounding Bathymetry Data Coverage 2006 and 2009

Maps Showing Aeromagnetic, Gravity, Seismic Reflection, and Bathymetry Survey Areas and Data Examples

NOTE: See next page for 2f.

Pacific Gas and Electric Company | Figure 2

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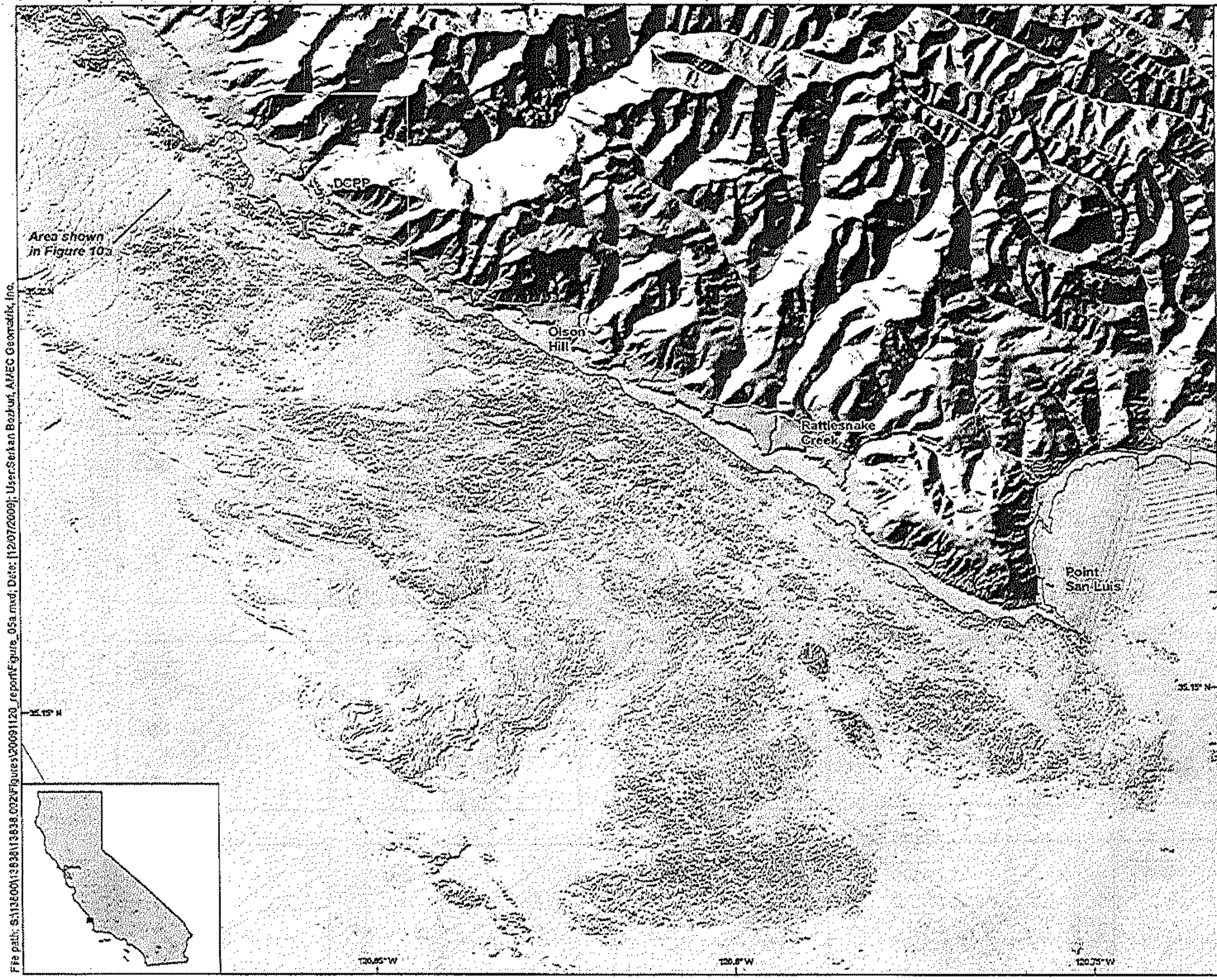

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LEGEND

—— Limits of MBES data

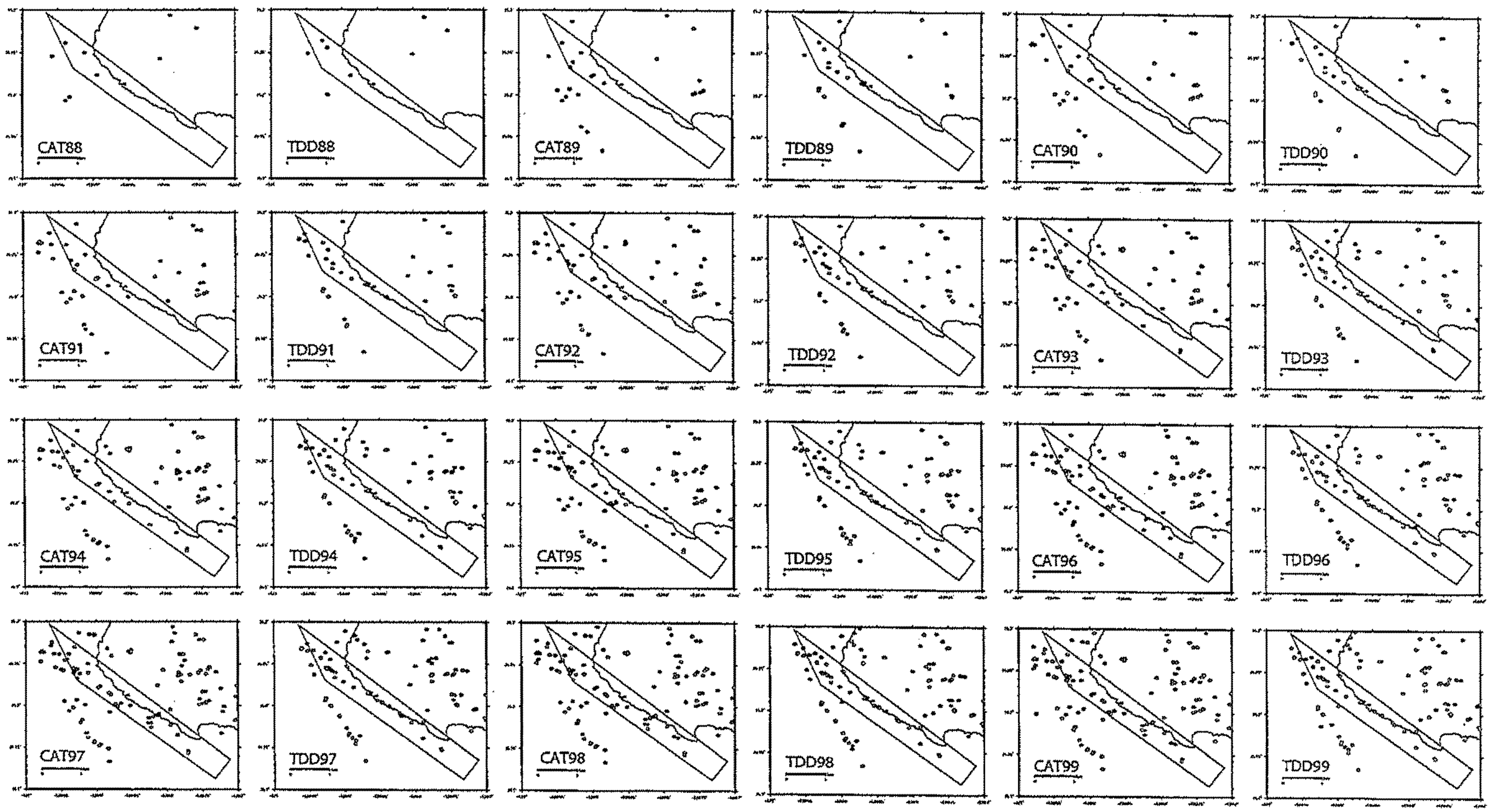
Map Scale: 1:50,000
NAD 1983, UTM Zone 10 North

0 1 2 Miles

0 1 2 3 Kilometers

Multibeam (MBES) Bathymetry Image Obtained for Analysis of Offshore Geology within the Shoreline Fault Zone Area

Pacific Gas and Electric Company | Figure 2f

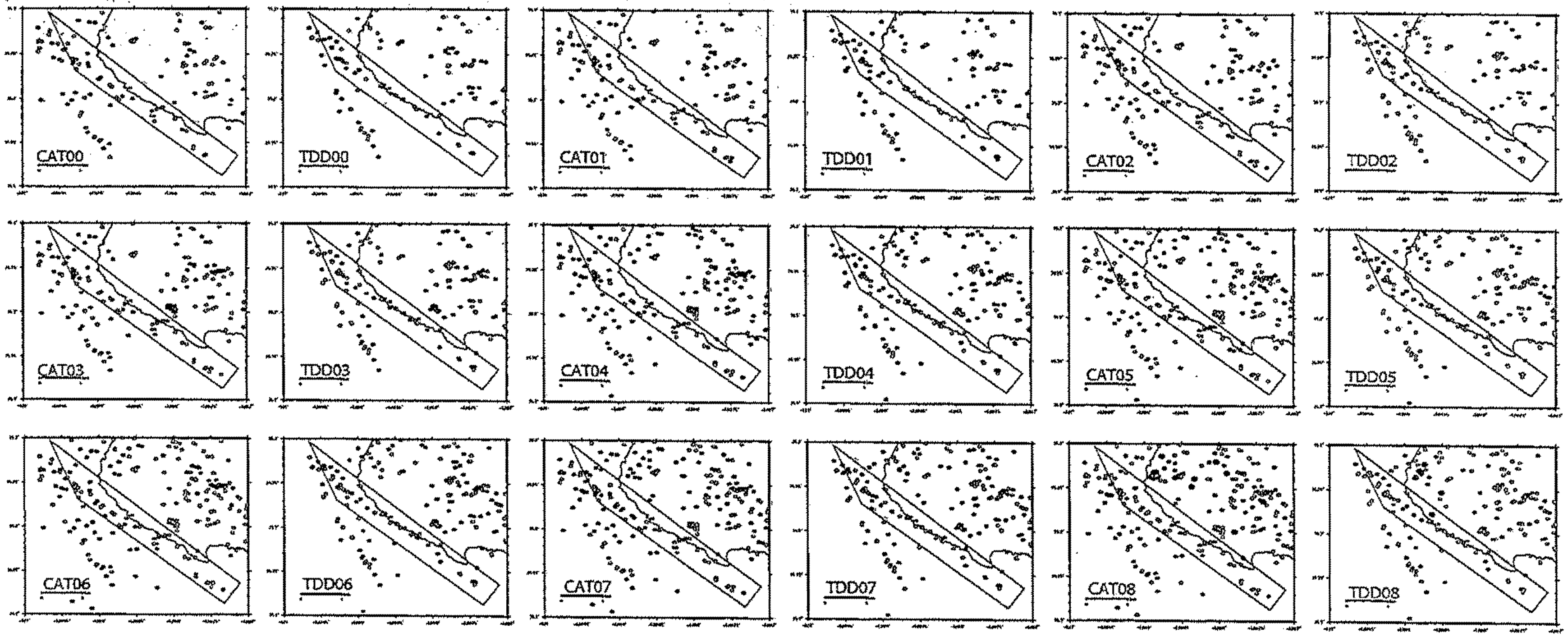


Current year earthquake locations
Previous year(s) earthquake locations

Yearly Seismicity Plots from 1988 to 1999, Comparing USGS/PGE Catalog (CAT) Locations to Hardebeck tomoDD (TDD) Locations.

NOTE: Polygon encloses general area of the Shoreline fault zone. See Figure 3b for plots from 2000 to 2008.

Pacific Gas and Electric Company | Figure 3a

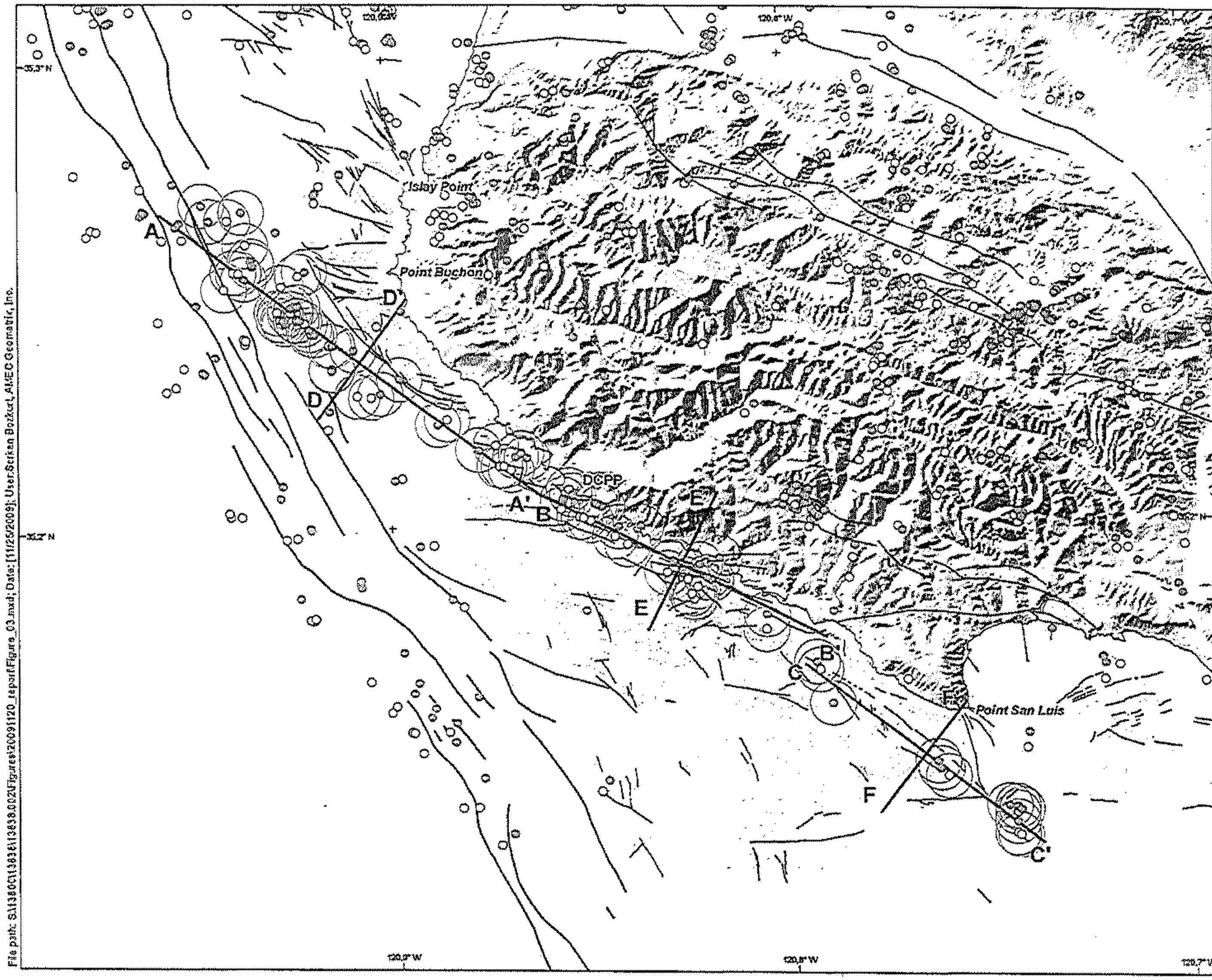


Current year earthquake locations
Previous year(s) earthquake locations

Yearly Seismicity Plots from 2000 to 2008, Comparing USGS/PGE Catalog (CAT) Locations to Hardebeck tomoDD (TDD) Locations.

NOTE: Polygon encloses general area of the Shoreline fault zone. See Figure 3a for plots from 1988 to 1999.

Pacific Gas and Electric Company | Figure 3b



LEGEND

- Hosgri fault zone
- Other faults
- Shoreline fault zone

Earthquake Data

- TomoDD (Thurber)
- TomoDD (Hardebeck)

500m buffers represent the average epicentral uncertainty. Colors denote possible association with the NW (red), Central (green) and SE (blue) segments of the Shoreline fault zone.

Note: See Figure 1 for fault descriptions

Map Scale: 1:90,000
NAD 1983, UTM Zone 10 North

0 2 4 Miles
0 2 4 Kilometers

Earthquake Epicenters from Hardebeck and Thurber tomoDD Inversions with 2009 Fault Interpretation and 2009 MBES data.

Pacific Gas and Electric Company | Figure 4

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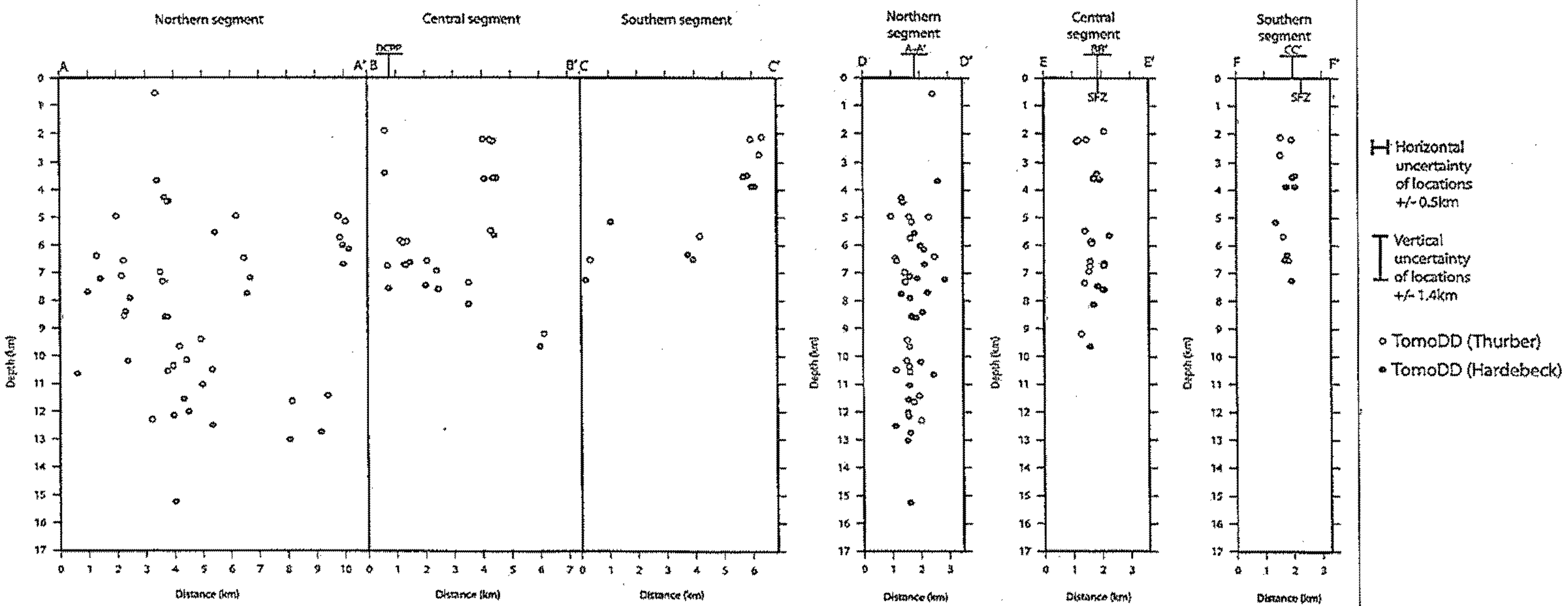
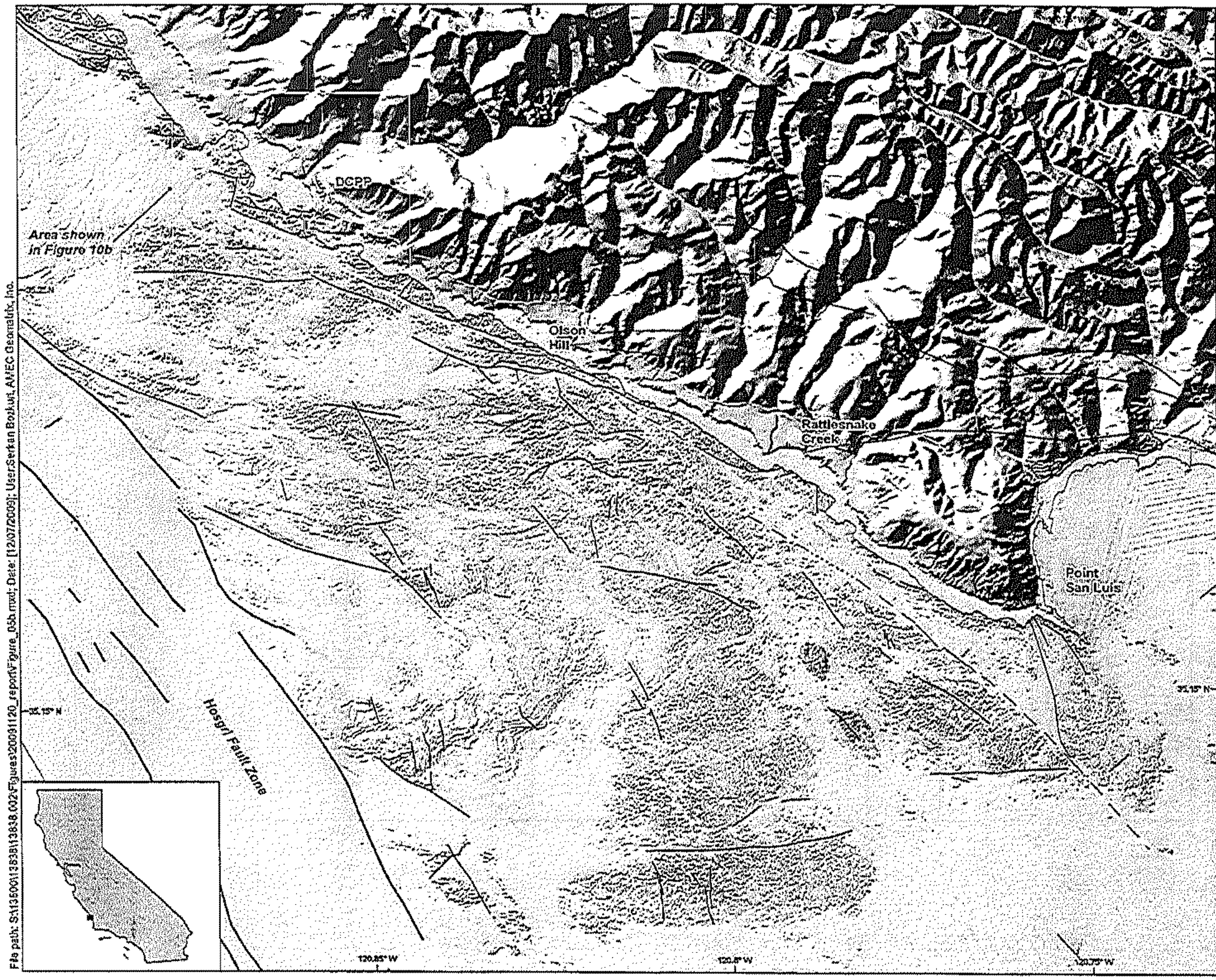


Seismicity Cross Sections Projecting Hardebeck and Thurber Locations.

NOTE: Cross sections AA', BB' and CC' are seamed together. See Figure 4 for cross section locations; SFZ=Shoreline fault zone.

Pacific Gas and Electric Company | Figure 5



LEGEND

- Hosgri fault zone
- Other faults
- Shoreline fault zone
- Limits of MBES data

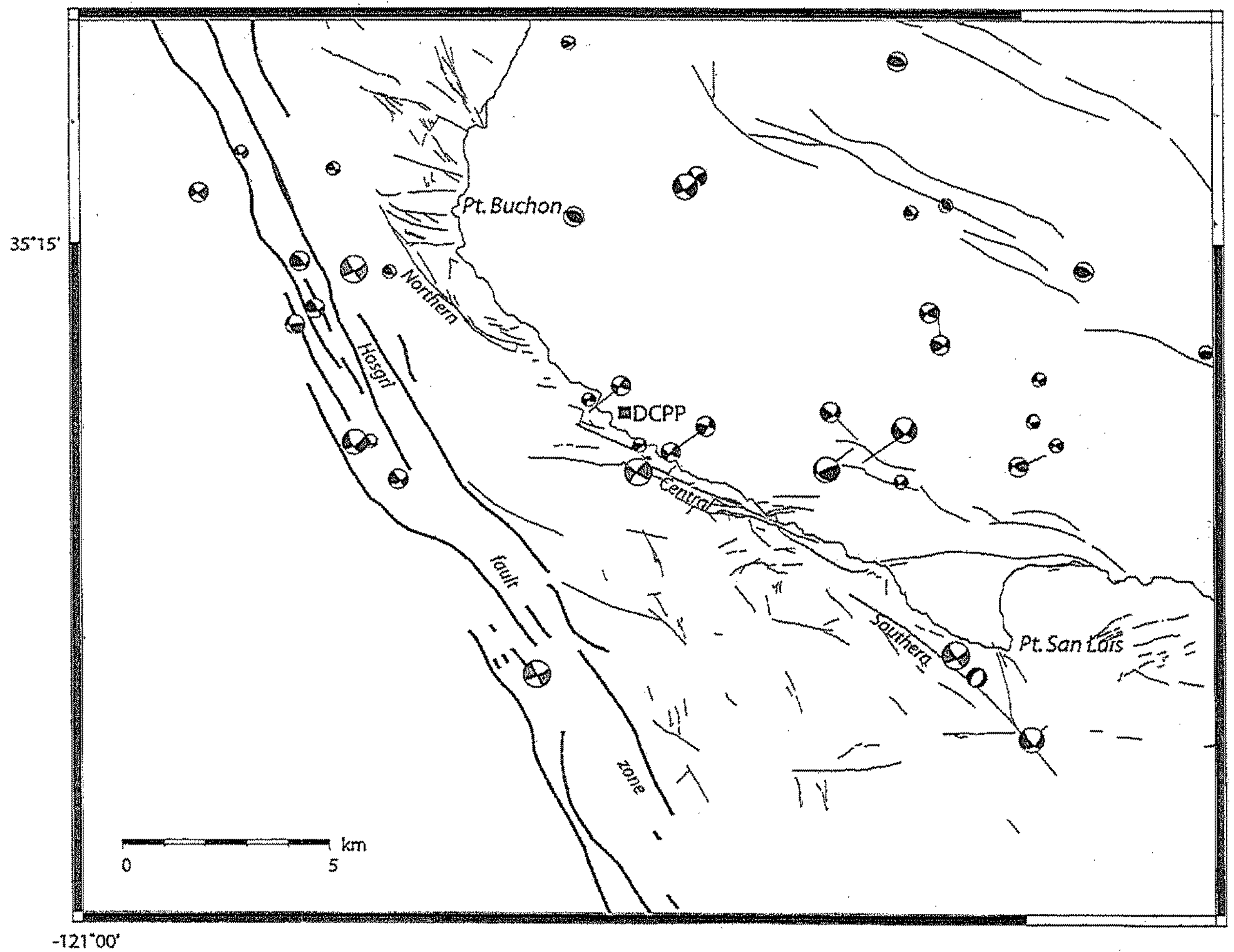
Note: See Figure 1 for fault description

Map Scale: 1:50,000
NAD 1983, UTM Zone 10 North

0 1 2 Miles
0 1 2 3 Kilometers

Shoreline Fault Zone and other Faults Interpreted from the MBES Image and from Shallow Seismic Reflection Profiles within the Shoreline Fault Zone Area

Pacific Gas and Electric Company | Figure 6



LEGEND

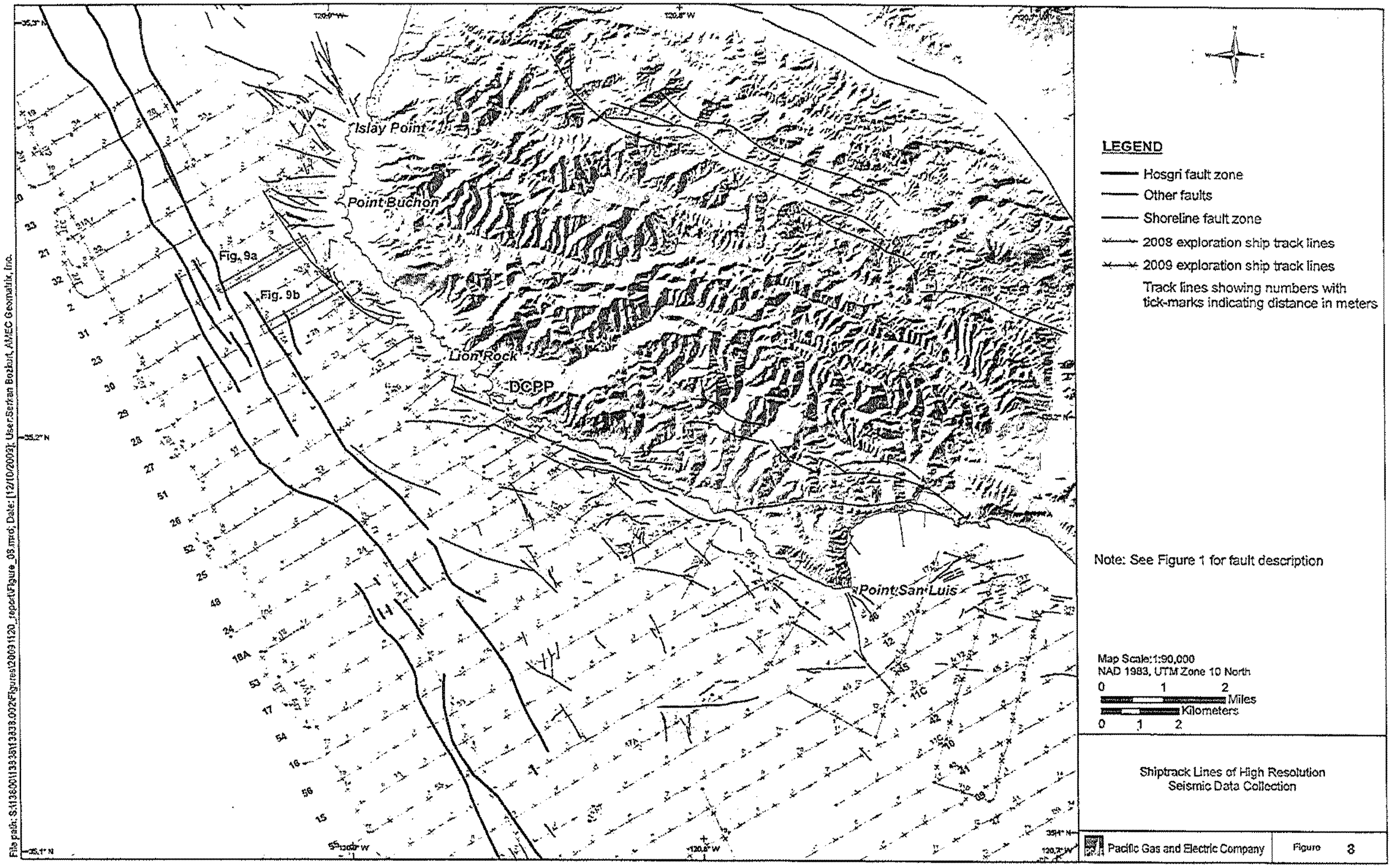
Focal Mechanisms
- M1-1.99
- M2-2.99
- M3-3.99
- Composite Focal Mechanisms

See Figure 1 for fault desriptions.

Focal Mechanisms from Hardebeck (2009)

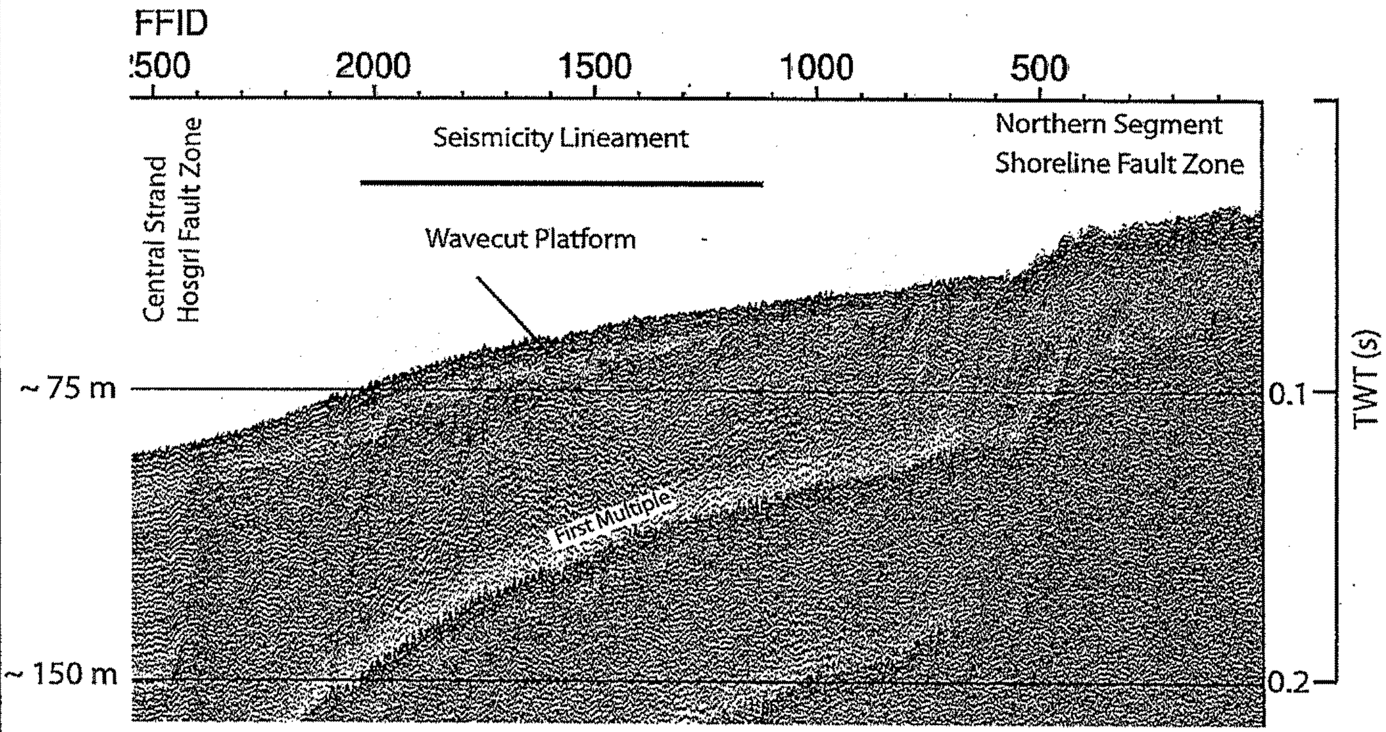
NOTE: Shoreline fault zone segments are labeled.

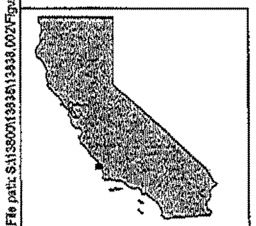
Pacific Gas and Electric Company | Figure 7



Shiptrack Lines of High Resolution Seismic Data Collection

Pacific Gas and Electric Company — Figure 3





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NOTE: See Figure 8 for location of seismic line.

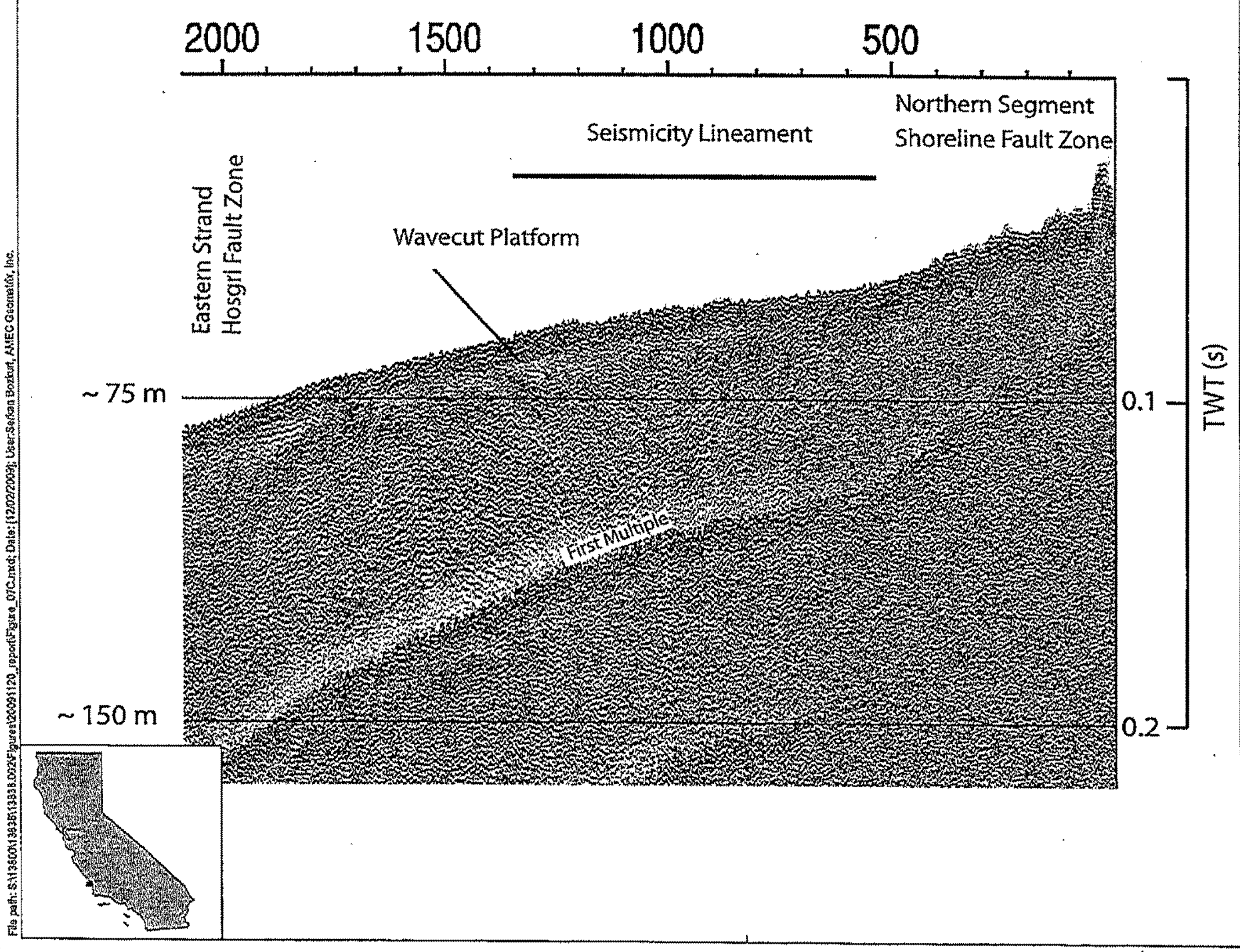
Vertical Exaggeration ~ 10: 1

Meters

0 100 200 500

High Resolution Seismic Reflection Profile
PBS-23

Pacific Gas and Electric Company | Figure 9A



NOTE: See Figure 8 for location of seismic line.

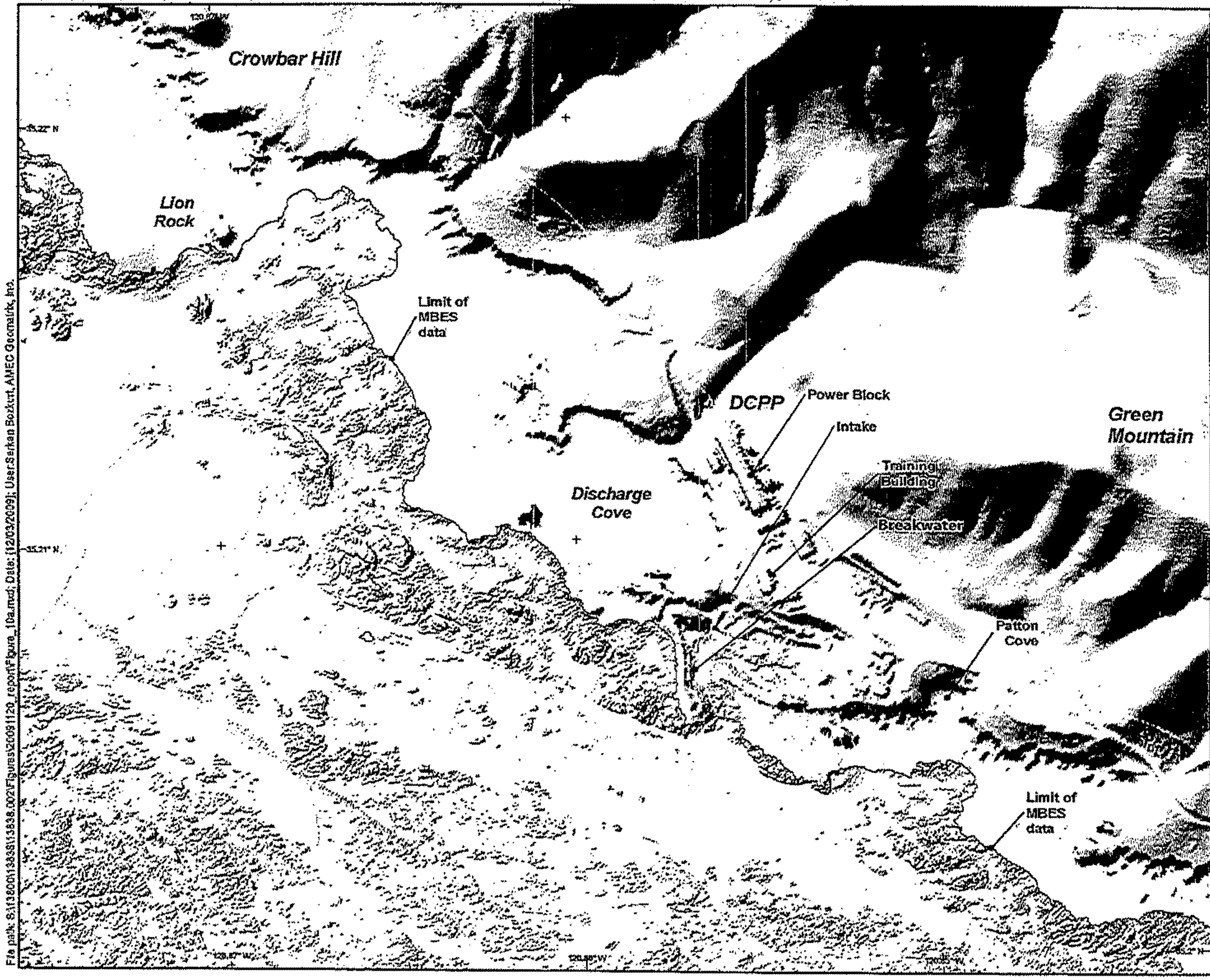
Vertical Exaggeration ~ 10: 1

Meters

0 100 200 500

High Resolution Seismic Reflection Profile PBS-29

Pacific Gas and Electric Company | Figure 9B

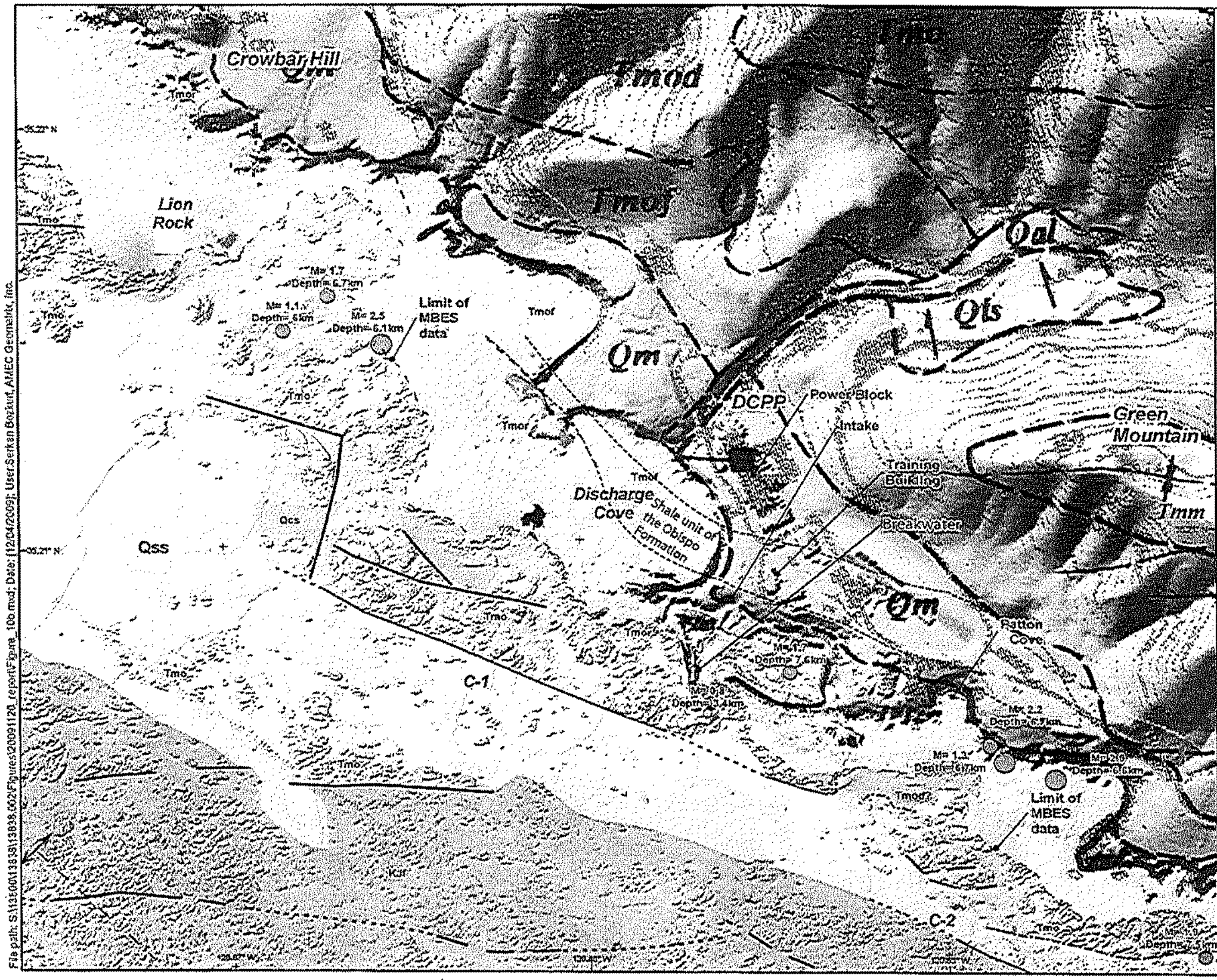


Map Scale: 1:10,000
NAD 1983, UTM Zone 10 North
0 500 1,000 Feet
0 200 400 Meters

Multibeam (MBES) Image and Digital Elevation Model (DEM) for the DCPP Area

Pacific Gas and Electric Company | Figure 10a

SB_GT&S_0759832



LEGEND

- Other faults
- Shoreline fault zone
- Earthquakes associated with the Shoreline fault zone (Hardebeck, 2009)
- Shale unit as shown in Figure 2.3-6, PG&E (2004)

Qss	Offshore mobile sand sheets that are activated by currents generated during large storms
Qcs	Sand deposits filling offshore paleo-stream channels that were cut into bedrock during Pleistocene low sea levels. Remnants of alluvium may underlie the sand deposits
Qal	Onshore alluvium; unconsolidated gravel, sand, silt and clay; locally includes older alluvium
Qls	Onshore landslide deposits
Qm	Onshore 80,000- to-120,000-year-old marine terrace deposits; generally covered by colluvium and alluvial fan deposits.
Tmm	Monterey Formation – siltstone or chert, dolomitic claystone or siltstone, diatomite, some tuff and opaline or cherty sandstone; offshore generally distinctly bedded
Tmo	Obispo Formation (undifferentiated)
Tmod	Diabase sill and dike
Tmof	Dolomitic sandstone and shale, tuffaceous
Tmor	Zeolotized and silicified tuff

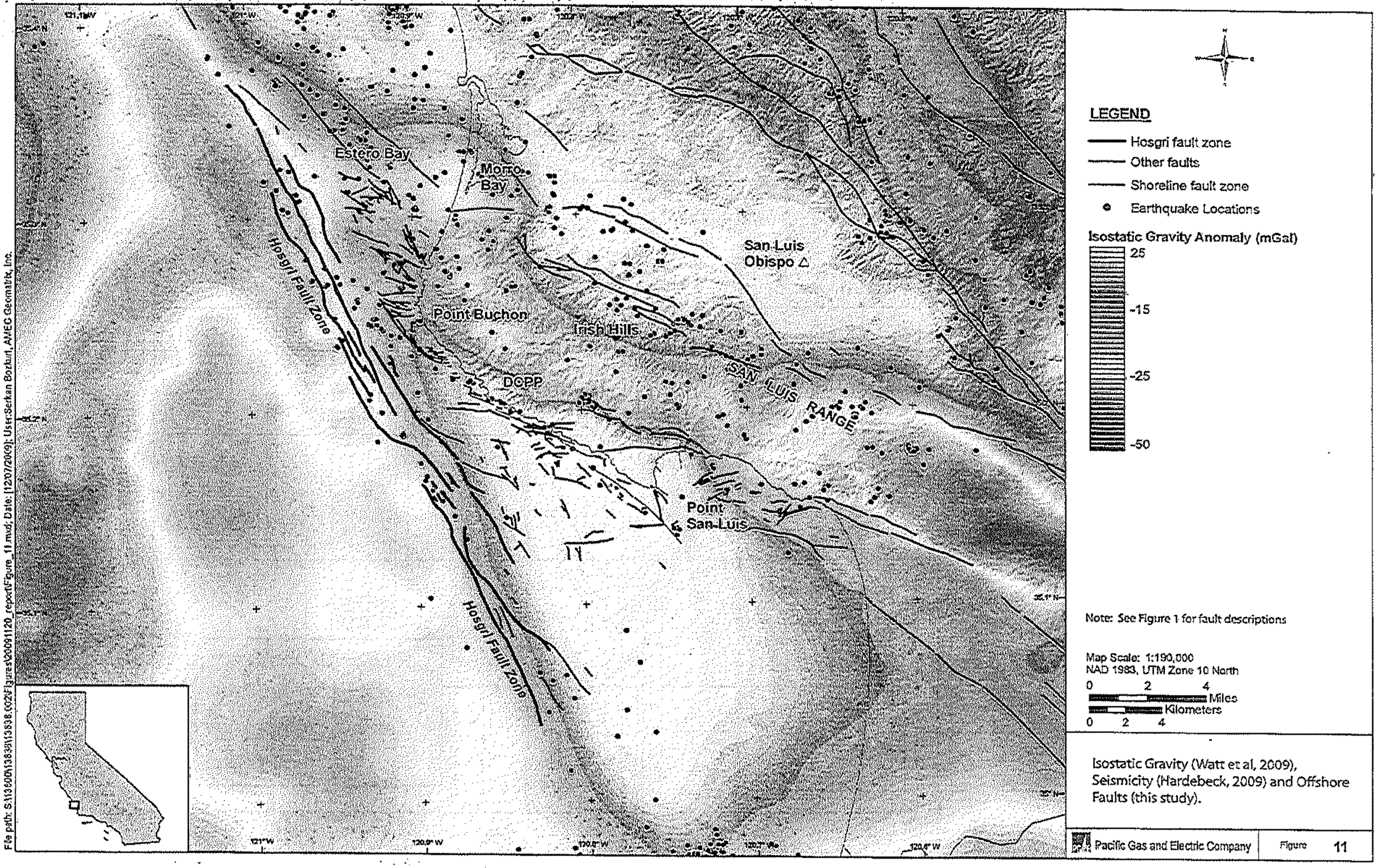
NOTE: Onshore geology from Hall (1973).

Map Scale: 1:10,000
NAD 1983, UTM Zone 10 North

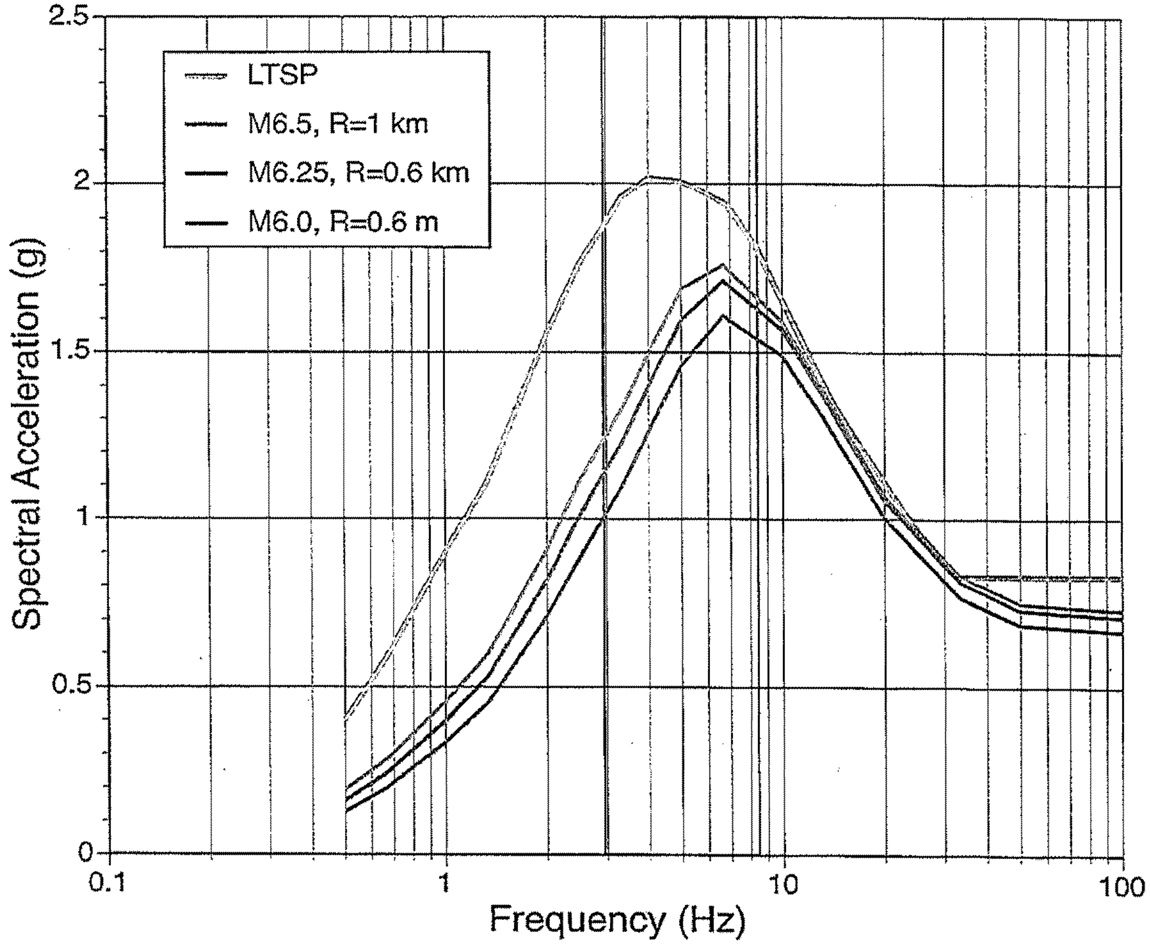
0 500 1,000 Feet
0 200 400 Meters

Geologic Map
of the DCPP Area

Pacific Gas and Electric Company | Figure 10b



Isostatic Gravity (Watt et al, 2009), Seismicity (Hardebeck, 2009) and Offshore Faults (this study).



NOTE: The red curve shows the spectrum from a M6.5 earthquake at a distance of 1 km assumed in the 2008 evaluation. The green and purple curves show the spectra used the updated values for either the central segment (M6.0) or the central and southern segments together (M6.25) and with the shorter distance of 0.6 km.

Comparison of the 84th Percentile Ground Motion Spectra from the Shoreline fault zone with the LTSP Spectrum.

Pacific Gas and Electric Company | Figure 12