Independent Peer Review Panel

A multi-agency panel of seismic hazard specialists
established by the California Public Utilities Commission

CALIFORNIA GEOLOGICAL SURVEY, CALIFORNIA COASTAL COMMISSION
CALIFORNIA PUBLIC UTILITIES COMMISSION, CALIFORNIA ENERGY COMMISSION
CALIFORNIA SEISMIC SAFETY COMMISSION, COUNTY OF SAN LUIS OBISPO

IPRP Report No. 8, December 17, 2014

Comments on PG&E's Central Coastal California Seismic Imaging Project Report part 2: onshore seismic studies intended to reduce the uncertainty in seismic hazard at Diablo Canyon Power Plant

BACKGROUND

In 2006, the California Legislature enacted Assembly Bill (AB) 1632, which was codified as Public Resources Code Section 25303. AB 1632 directed the California Energy Commission (CEC) to assess the potential vulnerability of California's largest baseload power plants, which includes Diablo Canyon Power Plant (DCPP), to a major disruption due to a major seismic event and other issues. In response to AB 1632, in November 2008 the CEC issued its findings and recommendations in its AB 1632 Report, which was part of its 2008 Integrated Energy Policy Report Update.

In Pacific Gas and Electric Company's (PG&E) 2007 General Rate Case decision D.07-03-044, the California Public Utilities Commission (CPUC) directed PG&E to address and incorporate the recommendations from the AB 1632 Report into its feasibility study to extend the operating licenses of its Diablo Canyon Units 1 and 2 for an additional 20 years.

In November 2009, PG&E submitted its formal application with the Nuclear Regulatory Commission to extend the licenses of DCPP Units 1 and 2. In 2010 PG&E filed for cost recovery with the CPUC for expenditures associated with the enhanced seismic studies recommended by the CEC's AB 1632 Report. The motions for cost recovery were subsequently approved in 2010 and 2011. CPUC Decision D.10-08-003, issued on August 16, 2010, established that the CPUC would convene its own Independent Peer Review Panel (IPRP) and invite the CEC, the California Geological Survey, the California Coastal Commission, and the California Seismic Safety Commission to participate on the panel. Under the auspices of the CPUC, the IPRP is conducting an independent review of PG&E's seismic studies including independently reviewing and commenting on PG&E's study plans and the findings of the studies.

The comprehensiveness, completeness, and timeliness of these studies will be critical to the CPUC's ability to assess the cost-effectiveness of Diablo Canyon's proposed license renewal. As noted in the CEC's AB 1632 Report, a major disruption because of an earthquake or plant aging could result in a shutdown of several months or even cause the retirement of one or more of the plants' reactors. A long-term plant shutdown would have economic, environmental and reliability implications for California ratepayers.

This report by the IPRP responds to reports released by PG&E on September 10, 2014. Those reports are collectively referred to as the Central Coastal California Seismic Imaging Project (CCCSIP) report. The CCCSIP report is divided into 14 chapters focused on individual studies. This review, and subsequent reviews of the CCCSIP, are divided into sections based on factors that are important to seismic hazard analysis and the studies intended to help constrain those factors.

In this organization and emphasis, these reports by the IPRP follow the format of IPRP Reports No. 2 and 3 and refer to investigation "targets" described in a memo report "Response to IPRP Request for Hazard Sensitivity for Targets for the DCPP Geophysical Surveys," that was prepared by the PG&E Geosciences Department and dated August 8, 2011. Due to the large volume of information in the CCCSIP report, the IPRP chose to review it in three parts.

The second part includes onshore seismic studies and the hazard parameters that they are designed to study. These studies, Chapters 7, 8, 9 and 12 of the CCCSIP report, were the subject of a public meeting on November 17, 2014 and of this report.

At the IPRP meeting on November 17, 2014, PG&E project manager Stuart Nishenko presented an update of the "tornado diagram" from the August 11, 2011 memo report. In the updated "tornado diagram" (Figure 1), the distance between points related to a hazard parameter represents the uncertainty in seismic hazard resulting from that parameter. In this type of diagram, parameters that are poorly constrained and have a

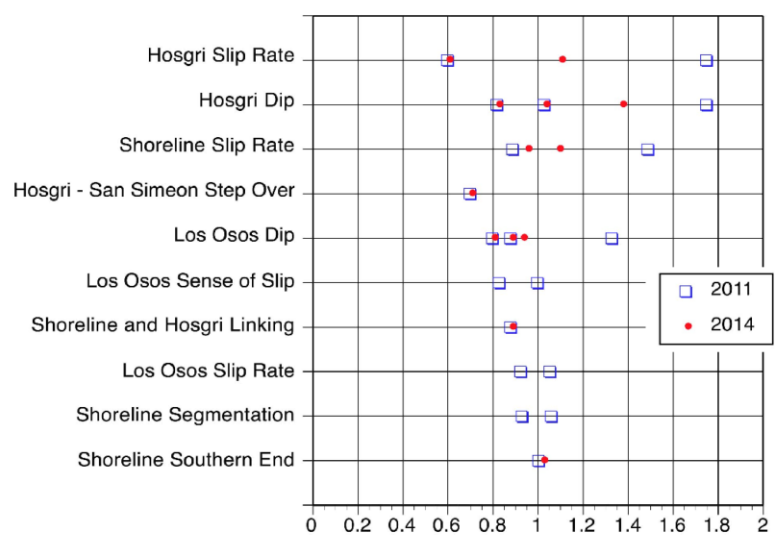

Figure 1. "Tornado diagram" from CCCSIP report, chapter 14, showing seismic hazard parameters and related uncertainty in seismic hazard. Values depicting state of knowledge in 2011 and 2014 show reduction in uncertainty related, in part, to CCCSIP studies.

large effect on hazard are shown as widely separated points at the top of the diagram. Closely spaced points shown near the base of the diagram can be either parameters that are well-constrained or parameters that are poorly-constrained but have slight effect on hazard.

As stated by Dr. Nishenko, reducing the uncertainty in the parameters near the top of the “tornado” will have the greatest effect in reducing the uncertainty in hazard. The depiction of uncertainty in 2011 and 2014, particularly the lower uncertainty for the parameters at the top of the “tornado” show PG&E’s estimate of how much uncertainty in seismic hazard has decreased due to studies described in the CCCSIP report. The parameter with the greatest impact on seismic hazard, slip rate on the Hosgri fault, was the main subject of IPRP Report No. 7.

This report includes discussion of seismic hazard parameters including dip and sense of slip on the Los Osos fault (fourth and fifth from the top of the “tornado”). The IPRP notes that the parameters shown on the “tornado diagram” are the parameters included in the 2011 seismic hazard analysis. As stated in IPRP Reports No. 2 and 3, an important emphasis of on-land seismic surveys should be to determine if there are additional faults that should be considered and an overall “tectonic model” describing the location, sense of slip, and level of activity on faults within the Irish Hills.

As in IPRP Report No. 7, the IPRP notes that the parameters shown on the “tornado diagram” are all “seismic source characterization” parameters. Other parameters, especially “site conditions” or “site amplification” parameters can have equal or greater impact on seismic hazard calculations as any shown on Figure 1. Site conditions and seismic amplification factors were the subject of IPRP Report No. 6 and are discussed in other sections of the CCCSIP report. These factors will be addressed in a subsequent IPRP report.

Seismic hazard parameters addressed in Chapters 7, 8, 9 and 12 of the CCCSIP report and discussed here are:

- Los Osos dip
- Los Osos sense of slip
- Tectonic model of the Irish Hills
- Evaluation of hazard related to the Diablo Cove fault and the San Luis Range Fault.

The major emphasis of this part of the CCCSIP is to develop a complete and consistent tectonic model of the Irish Hills, which includes dip and sense of slip on all faults, including the Los Osos fault. This review, therefore, follows the general organization of the CCCSIP report and presentations at the IPRP meeting on November 17, 2014, beginning with, 1) a discussion of studies intended to develop tectonic models of the Irish Hills, 2) how well those studies constrain seismic hazard parameters, (e.g.,dip of the Los Osos fault), and 3) use of those models in seismic hazard analysis. A separate section discusses Chapter 12 of the CCCSIP report, which is an evaluation of faults and tectonic models proposed by Dr. Douglas Hamilton and presented by Dr. Hamilton at the IPRP meeting on November 17, 2014.

Onshore seismic interpretation program (ONSIP)

The major data collection efforts described in Chapters 7, 8 and 9 of the CCCSIP report were seismic surveys of the area surrounding the DCPP, including the Irish Hills collectively referred to as the onshore seismic interpretation program (ONSIP). This effort was supplemented by updated geologic mapping, new surveys of gravity and magnetics, and interpretation of available data from previous oil and water wells. Seismic surveys were conducted in 2011 and 2012 and consisted of two types of seismic sources and arrays of receivers. The sources, truck-mounted Accelerated Weight Drop (AWD) and Vibroseis vehicles, were deployed along roads throughout the Irish Hills and receivers were deployed on the roads and in grid arrays where allowed by the terrain and landowners. As described in the CCCSIP report and in the November 17, 2014 IPRP meeting by Dr. Daniel O'Connell of Fugro Consultants, the highly irregular source and receiver layout posed challenges for processing, hence all data were processed with 3D methods.

Processed seismic survey data were presented in the CCCSIP report and at the IPRP meeting as 2-dimensional cross sections along the lines where surveys were conducted, mainly along roads across the hills. In general, AWD surveys produced relatively high resolution to shallow depths and Vibroseis surveys produced lower resolution to greater depth. The surveys show "reflections" related to changes in seismic velocity of the materials.

The processed seismic reflection data were interpreted by a team from PG&E and their consultants. The CCCSIP report (Chapter 7, page 25) lists assumptions upon which the team's interpretations are based, including: "We assume that variations in the acoustic properties of the rocks that give rise to the seismic reflectors directly or indirectly represent real geologic structure". In practice, observed reflections generally are assumed to represent bedding or other geologic fabric. The reflections further arre assumed to be caused by contrasts in acoustic impedance (the product of acoustic velocity and rock density) between adjacent geologic features. Faults are assumed to truncate or offset otherwise continuous geologic units, and thus are interpreted from related changes in observed reflections. Note also that the interpretation of seismic sections needs to take into account the possibility that some observed events are artifacts. On a given 2D section, observed reflections may come from features that are not in the plane of the cross-section. Observed events may also be artifacts created by assumptions built into the seismic data processing. Use of the sections derived from the seismic survey data to develop a tectonic model of the Irish Hills is described in Chapter 7 of the CCCSIP report. This chapter and the presentation by Dr. Jeff Unruh at the IPRP meeting on November 17, 2014 describe the evidence for the Los Osos, Edna, San Miguelito, San Luis Bay and additional un-named faults. Chapter 7 and the presentation emphasized the seismic surveys, but also described the use of geologic mapping, surveys of the gravity and magnetic fields, and well data in developing a tectonic model for the Irish Hills.

The tectonic model described in Chapter 7 of the CCCSIP report includes a series of faults, generally dipping steeply toward the center of the hills (Figures 5-30, 5-31 and 5-32 of the CCCSIP report). The major faults are interpreted as having formed as extensional faults (normal faults) during Miocene time. Movement on these faults formed a deep basin that was filled with sediment that became the Obispo, Monterey, and Pismo Formations. In this model, faults formed as normal faults, possibly with some lateral displacement, in the Miocene then were reactivated as reverse faults, also possibly with some lateral displacement, in the Quaternary. This model is consistent with 1) potential field (gravity and magnetic) data, 2) the great thickness of Miocene sedimentary rocks encountered in the "Honolulu-Tidewater 1" oil well in the central Irish Hills, and 3) surface geologic mapping. The CCCSIP report does not thoroughly address the extent to which the geologists who developed this model considered alternative models which match the observed data equally well. Neither does the CCCSIP quantify the impact of potential alternative models on the seismic hazard. These issues were the subject of discussion at the IPRP meeting on November 17, 2014, which is summarized below.

There are two types of questions about the faults that are included in the tectonic model: How well documented are they? And how much do they contribute to seismic hazard? Some faults, such as the Edna and San Luis Bay faults, are known from surface geologic mapping and can be projected some distance into the subsurface using the seismic reflection data. In some instances, truncated reflections in seismic sections presented in the CCCSIP report can reasonably be attributed to the downward extension of known surface faults. Such correlation of truncated reflections with surface faults can be accomplished with some confidence in the shallow subsurface, but becomes increasingly difficult with depth.

The IPRP is not convinced that the interpretations of the down-dip extensions of faults are well constrained, even in the case of well-documented surface faults. Similarly, faults interpreted from the seismic sections, but not corroborated by surface mapping, (e.g. faults interpreted between the San Miguelito and Edna faults) are possible, but are by no means unique interpretations of the data. Overall, the IPRP is not convinced that projections of faults beyond the very shallow subsurface represented unique interpretations of the data.

Projections of faults to depth in “basement” rocks of the Franciscan complex appear to be even more problematic. As discussed at the IPRP meeting on November 17, 2014, the Franciscan complex is known to be a mixture of different rock types pervasively sheared at a variety of scales and is not expected to produce reflectors that are extensive over broad areas. The majority of seismic sections, (e.g. AWD line 150 as presented on Chapter 7, Figure 5-25) show prominent, continuous reflectors at relatively great depths in material that is assumed to be bedrock of the Franciscan complex.

Most deep reflectors shown on Figure 5-25, and in many other sections are arranged in groups of concave-upward, gently curved reflectors. These reflectors are interpreted in the CCCSIP report as representing geological structure. The IPRP, however, regards this pattern of concave-upward sets of reflectors as difficult to explain geologically, but not difficult to envision as artifacts from the data processing. If the continuous reflectors in Franciscan complex bedrock are artifacts of data processing, rather than representing geologic structure, then the seismic reflection surveys provide no constraint on the down-dip geometry of faults in the Franciscan Complex. The Los Osos fault, in particular, is entirely within Franciscan Complex rocks from very shallow depths. If the reflection surveys do not show real geologic structure along the down-dip extension of this fault, then dip of the fault remains essentially unconstrained.

The question of how important the faults included in the tectonic model of the Irish Hills are in terms of seismic hazard is not addressed in the CCCSIP report, but was partly addressed in a presentation by Dr. Steve Thompson of Lettis Consultants International at the IPRP meeting on November 17, 2014. In that presentation, Dr. Thompson explained how the “Technical Integration (TI) Team” working within the U.S. Nuclear Regulatory Commission’s Senior Seismic Hazard Analysis Committee (SSHAC) process is developing input to the seismic hazard analysis.

In contrast to the CCCSIP report, which attempts to present a single tectonic model as a unique result of the geophysical surveys, Dr. Thompson reports that the SSHAC “TI team” is developing three alternative tectonic models for input into their seismic hazard analysis. One of these models is similar to the model described in the CCCSIP report, with faults that dip steeply toward the center of the Irish Hills, the two others are dominated by more gently dipping faults that dip either to the northeast or to the southwest.

All else being equal, a tectonic model with relatively gently dipping thrust faults may result in higher hazard at Diablo Canyon for two reasons: the known vertical uplift of the Irish Hills requires a higher slip rate on a gently dipping reverse fault than on a steeply dipping one and most ground motion prediction equations predict higher ground motion for sites above (on the hanging wall of) thrust faults.

The CCCSIP report describes some of the data to support a tectonic model including thrust faulting in discussion of the Honolulu-Tidewater 1 well (Chapter 7, page 43). It also presents analysis of seismicity that can be used to support a tectonic model that includes thrust faulting, based on the work presented by Dr. Jeanne Hardebeck (SSHAC workshop in San Luis Obispo, March, 2014, see (Chapter 12, Figure 6-47). The CCCSIP report does not, however, present a tectonic model with gently dipping thrust faults.

Dr. Thompson's presentation indicates that the SSHAC seismic hazard analysis will consider three alternative tectonic models of the Irish Hills, including two with gently dipping thrust faults. The IPRP supports the concept of including three different tectonic models in seismic hazard analysis and has not seen a compelling reason to favor the model presented in the CCCSIP report over the other two described by Dr. Thompson.

CONCLUSIONS

IPRP review of the tectonic model is based on the CCCSIP report and presentation. The IPRP has not had time, to review the seismic data processing in detail. In addition, a full auditing of the seismic data acquisition and processing sequence would require the IPRP to retain outside consulting services. Evaluation of the figures showing seismic sections, however, has led to the following general conclusions:

- Seismic imaging of geologic structures deep beneath the Irish Hills was expected to present a significant challenge for both data acquisition and interpretation. The data and interpretations presented in the CCCSIP report increase our knowledge of several faults in the Irish Hills, particularly in the shallow subsurface. With increasing depth, however, there appears to be less support for the assumption that the "reflectors" shown in seismic sections represent "real geologic structure". As noted at the IPRP meeting, the most prominent, continuous reflectors in many sections are from relatively great depth in material that is assumed to be bedrock of the Franciscan complex. Since the Franciscan complex is known to be a mixture of different rock types pervasively sheared at a variety of scales, continuous, gently dipping layers are not expected. The overall arrangement of the gently dipping "reflectors" also raises questions that are not addressed in the report. In several sections, the arrangement of reflectors does not resemble a cross-section of folded or faulted rock. The pattern of concave-upward sets of reflectors seen in many sections does not have an obvious geological explanation, leading the IPRP to question whether they represent real geologic structure.
- Even if all reflectors shown in the seismic sections are images of geologic features, the interpretations of various faults are inconsistent and not unique: 1) In many cases, faults are interpreted based on a series of truncated reflectors,

but are shown to pass through other reflectors that are not truncated; 2) In some seismic sections, it appears that additional faults are permitted by the data. It is not clear how the stated interpretation methodology allowed the interpretation team to draw some faults and not others; and 3) Alternate interpretations of the dip of most faults are possible. This concern applies to the dip of the Los Osos fault. Alternate dips, including relatively low-angle dips, of the Los Osos fault appear to be possible through sections 138-149 and 150 as shown on Figures 5-24 and 5-25 of the CCCSIP report. The reduction in uncertainty in seismic hazard depicted on the "tornado diagram" for dip of the Los Osos fault appears to be based on the CCCSIP report conclusion that the new data precludes low-angle dips. The IPRP does not concur that low-angle dips are precluded by this new data and therefore does not believe that these studies have resulted in reduced uncertainty in seismic hazard related to this parameter.

- Considering significant uncertainties in whether the seismic sections presented in the CCCSIP report represent "real geologic structure" and whether the faults shown on those sections represent preferred interpretations, the IPRP is not confident that the tectonic model described as being developed from these surveys is well constrained.

- The newly acquired seismic data may contain valuable new information that bears on the seismic hazard. However the interpretation process that resulted in a single tectonic model is hampered by significant data quality issues (associated in part with the irregular acquisition geometry) and a lack of significant subsurface control (see Ch. 7, page 70). An alternative approach exploring the full range of models allowed by the uncertainties of the data is preferable.

- The IPRP does not see a strong reason to favor the single tectonic model presented in the CCCSIP report over the two alternative models presented by Dr. Thompson at the IPRP meeting on November 17, 2014.

CCCSIP Chapter 12: Response to Administrative Law Judge's Decision D.12-09-008 Regarding Dr. Douglas Hamilton's Concerns

The CCCSIP report's Chapter 12 addresses elements of tectonic models of the Irish Hills advanced by Dr. Douglas Hamilton. We focus on the two elements with clear hazard implications: 1) The San Luis Range Fault (SLRF), originally based on the Inferred Offshore Fault (IOF), as a major seismic source, and 2) The Diablo Cove Fault as a surface rupture hazard. In this review we focus on Dr. Hamilton's presentations at SSHAC and IPRP meetings and other references upon which the CCCSIP report is based. At this point we are not commenting on details of his presentation at the

November 17, 2014 IPRP meeting, as this presentation included a preliminary new model for which no documentation has been provided.

The model explaining the tectonic uplift of the Irish Hills hypothesized by Dr. Hamilton consists of a low-angle northeast-dipping thrust fault, the SLRF (Figure 6-12), underlying the Irish Hills with a postulated surface trace almost entirely offshore. This inferred fault, would have a length of 60-80 km extending from an intersection with the Hosgri fault, about 8 km south of Point Estero in the north, to the onshore mapped Wilmar Ave fault to the south (Figure 6-21). The SLRF proposed by Dr. Hamilton appears to be a variation of the Inferred Offshore Fault of Nitchman and Slemmons (1994), Figure 6-23 in Chapter 12. Along the central portion this inferred fault is coincident with the mapped Shoreline fault. The SLRF is interpreted by Dr. Hamilton to be a thrust fault dipping to the northeast that intersects the Shoreline fault at a depth of 1 to 2 km. He hypothesizes that this is the main structure accommodating regional northeast to southwest compression, which ultimately results in uplift of the Irish Hills.

Uplift Boundary and SLRF Location

Dr. Hamilton's proposed SLRF and Irish Hills uplift model are based on uplifted landforms, especially the well-documented series of Quaternary marine terraces (Hanson et al, 1994) and the longer term uplift of the Irish Hills block. Nitchman and Slemmons (1994), proposed the IOF to explain the uplift of the Irish Hills as well as the linear range front and coastline.

The discovery of the now well-documented Shoreline fault along this section of the coast provides an explanation for the striking linearity of the coastline. Dr. Hamilton's model requires uplift to be localized at the trace of the SLRF, either at or near the surface. Therefore, because the SLRF is co-located along the central portion of the Shoreline fault, it follows that the Shoreline fault should exhibit signs of vertical movement. The series of uplifted coastal terraces provide vertical uplift rates of approximately 0.2 mm/yr, which should be expressed as vertical uplift located on, or in close proximity to the Shoreline fault. The newly acquired multibeam echosounder (MBES) high resolution bathymetry data, however, show no evidence of any vertical fault slip on the Shoreline fault (Chapter 12, Figure 6-28). Hence, along this section of the inferred SLRF, where the highest vertical fault slip rates are predicted as indicated by the uplifted terraces, the Hamilton model is not consistent with observations. Rather, the relatively straight trace and a level marine shelf strongly suggests that the Shoreline fault is a nearly vertical strike-slip fault.

Implications of Seismic Imaging on the SLRF

Near-surface faults can be found along the length of much of the proposed the SLRF but do not support the model of a major thrust fault. New high-resolution offshore seismic data from the Point Buchon area, where the proposed SLRF diverges from the Shoreline fault, confirm the existence of faults shown in Figure 6-21. Along the central portion of the Shoreline fault the SLRF is coincident with the Shoreline fault. In San Luis Obispo Bay, seismic reflection data also confirms the existence of near surface faults. These surface fault traces, however, have been explained in existing models that interpret the Shoreline fault as a near vertical strike-slip fault, secondary eastern splays along its northernmost reach off of Point Buchon, and a series of strike-slip and reverse fault crossing San Luis Obispo Bay. Although surface faults recognized to date appear to be consistent with strike-slip faulting on the Shoreline fault, rather than thrusting on the SLRF, the possibility of thrust faults in the subsurface is not ruled out by on-land seismic survey data. The interpretation of the ONSIP data is far from unique and allows one to interpret a low angle reverse fault at the proposed location, contrary to what is stated in the CCCSIP report (p.70 Figure 6-54). The CCCSIP interpretation criteria are not clearly defined and do not appear consistent in terms of selections made when seismic reflections are truncated.

Does Seismicity Support the Existence of the SLRF?

Seismicity can be correlated with active faults; however, many active faults have little to no seismicity during the interseismic period. Further complicating the matter of using seismicity to characterize faults is the observation that microseismicity often occurs in a large volume surrounding the fault rather than on a localized fault plane. Despite these complications, the Shoreline fault was discovered by Hardebeck (2010, 2013) based on a seismicity trend and later confirmed by MBES surveys.

The assertion by Dr. Hamilton that seismicity beneath the Irish Hills shows an alignment that indicates the SLRF location and activity at depth is not confirmed by the more rigorous seismicity analysis performed by Hardebeck (2010, 2013, 2014a, 2014b). Hardebeck has shown convincingly that these data do not allow a unique interpretation and clearly do not strongly favor any Irish Hills uplift model. However, as previously implied, the interpretation of microseismicity has clear limitations in mapping faults and in this case also cannot be used to rule out the existence of the proposed SLRF.

Conclusions

Although specific details of the Hamilton SLRF Irish Hills uplift model are inconsistent with several observations, the overall model that explains the uplift of the Irish Hills via a northward-dipping fault underlying the Irish Hills is a viable alternative model given the uncertainties in the existing data sets. As presented by Dr. Steve Thompson at the November 17, 2014 IPRP meeting, the SSHAC process is considering an alternative model that includes northeast-dipping thrust faults to explain the uplift of the Irish Hills which largely encompasses the hazard implications of the SLRF model.

Diablo Cove Fault

The Diablo Cove fault has been proposed by Dr. Hamilton as presenting a surface rupture hazard to DCPP. The basis for this proposed fault consists of on- and offshore bedrock mapping (Figure 6-3, 6-4, 6-5, 6-8, 6-9,6-10). The mapped faulting has been shown to be discontinuous (Figure 6-6, 6-17, 6-18) and limited in extent. Specifically, there are four locations where faulting was observed during the original DCPP construction between 1966 and 1973 (Figure 6-5, 6-6, 6-9): 1.) In the sea cliff south of the outlet of Diablo Creek (Figure 6-8, 6-10); 2.) In the turbine building foundation excavation; 3.) In the Unit 1 containment structure excavation; and 4.) In a road cut for the switchyard access road east of the DCPP power block.

At the turbine building the faulting consists of a zone of faulting extending 70 m in length. Under the Unit 1 containment structure the faulting consists of two discontinuous zones of faulting 10 to 20 m in length. Between these two areas the bedrock was continuously exposed and there is a 50 m-long area where no faulting in the bedrock was observed.

Perhaps the most significant exposure of the Diablo Cove fault exists in the sea cliff and was described in detail by Jahns (1966, 67a, 67b). The faulting was observed in thinly bedded sandstone originally classified as Tertiary-age Monterrey Formation (Jahns, 1967b), and later reclassified as Obispo Formation (Hall, 1973). Jahns noted that the fault planes in the sea cliff and on the adjacent modern wave cut platform project eastward north of the DCPP site. Figs. 6-3, and 6-4 show this fault zone to strike N55°-60°E with a steep dip to the north.

The original investigation by Jahns (1966) notes: "*None of the faults observed in the mapped area extends upward from the bedrock section into the overlying terrace deposits, nor have any of the wave-cut benches beneath these deposits been offset by such faults*". Since the original investigation and additional studies, this key observation has never been disputed. The age of this marine terrace is firmly established at 120 ka by correlation and nearby directly-dated U-series dating with a back edge at an elevation of 30-32 m (Hanson et al, 1994). No support for Dr. Hamilton's age assertion of 80-105 ka has been provided. Furthermore Jahns (1967b) reasonably states that the maximum age of faulting is millions of years. The discontinuous, minor faulting, with on the order of a few meters of total offset has been interpreted by the CCCSIP authors as most likely related to contractional deformation and folding (Figure 6-17), and as such could be late Miocene to Pliocene in age (Luyendyk, 1991).

Dr. Hamilton provides a cross section that extrapolates the Diablo Cove fault to seismogenic depths below 4 km and attempts to correlate the location with microseismicity (Figure 6-12). No basis for this correlation can be found, as the seismicity appears almost randomly distributed and provides little basis for any preferred fault selection. We refer to rigorous microseismicity analyses by Hardebeck (2010, 2013, 2014a, 2014b), who quantifies a wide range of possible fault orientations. The CCCSIP report makes the reasonable point that simple scaling relationships makes it unlikely that these short, discontinuous near-surface faults, with minor meter-scale displacements can reasonably be extended to depths of kilometers, where seismogenic processes occur.

Offshore Dr. Hamilton has mapped the Diablo Cove fault extending to the Shoreline fault on the basis of interpreted bedding disruptions observed in the Kelpfly MBES image (Figure 6-4, 6-11). The CCCSIP authors appear to have optimized the MBES imagery to assess NW trends of faults (Figure 6-8, 6-9), and they can only identify a possible lineament that does not extend continuously to the Shoreline fault, but rather is cut by a more northerly trending “Headland fault” (Figure 6-18).

Conclusions

Based on the characterization of the minor faulting activity as older than 120 thousand years and very possibly in the millions-ot-years age range, we find that the CCCSIP has reasonably assessed the Diablo Cove fault as not presenting a seismic hazard in terms of surface faulting or increased ground motions at DCPP.