REPORT ON THE ANALYSIS OF THE SHORELINE FAULT ZONE, CENTRAL COASTAL CALIFORNIA
Report to the U.S. Nuclear Regulatory Commission
January 2011

1.0 INTRODUCTION

This report presents the results of a two-year Pacific Gas and Electric (PG&E) study of the Shoreline fault zone, which is located offshore of the Diablo Canyon Power Plant (DCPP). In November 2008, PG&E informed the U.S. Nuclear Regulatory Commission (NRC) that preliminary results from the DCPP Long Term Seismic Program (LTSP) seismic hazard update showed an alignment of seismicity that suggested the presence of a previously unidentified fault approximately 1 kilometer (km) offshore of DCPP. This previously unidentified fault was subsequently named the Shoreline fault zone by PG&E.

Using a seismic margin approach, 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). PG&E used conservative assumptions about the total length of the fault zone to consider a magnitude 6.5 strike-slip earthquake at a distance of 1 km from DCPP. 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 and also concluded that there was adequate seismic margin (NRC, 2009).

Although these initial sensitivity studies show that the plant has adequate margin to withstand ground motion from the potential Shoreline fault zone, four main parameters of the Shoreline fault zone were not well constrained: geometry (length, width, dip); segmentation; location offshore of DCPP; and slip rate. To address the uncertainties in these source parameters and analyze the earthquake relocations, PG&E prepared a two-year Action Plan in 2009 (Appendix A1) to collect additional data to better characterize the Shoreline fault zone. Figure 1-1 shows the location of the Shoreline fault zone study area. A Progress Report was issued in January of 2010 that summarized the first-year activities (see PG&E, 2010a, Appendix A).

1.1 Organization of This Report

This report presents the results of the two-year study and comprises the following:

- A more complete evaluation of the geologic and seismologic characteristics of the Shoreline fault zone (geometry, location, segmentation, and slip rate).
- An assessment of the ground motion hazard at the DCPP that includes the Shoreline fault zone.

- An assessment of the potential for secondary fault deformation on the DCPP site.

Section 1 provides background on prior coastal investigations and the LTSP. Section 2 summarizes the geologic; geophysical (gravity and magnetic surveys, multibeam echo sounding [MBES], and seismic reflection profiling); and seismicity data that were collected from 2008 to 2010 for this report. More detailed descriptions of specific data sets are presented in Appendices B through I. Independent reviews of the Hardebeck earthquake relocations are in Appendices C1 and C2. Section 3 discusses the tectonic, geologic, and seismologic setting of the Shoreline fault zone study area. Section 4 describes the geological, seismological, and geophysical characteristics of the Shoreline fault zone. Section 5 presents the source characterization of the Shoreline fault zone, and Section 6 describes the ground-motion impacts to DCPP. Further details are provided in Appendices J and K. Section 7 describes the potential for secondary fault deformation at the DCPP site. Section 8 summarizes the findings of this report and presents PG&E's conclusions. Finally, Section 9 contains the references cited in this report.

1.2 Background

The existence of an offshore fault zone between Point Buchon and Point San Luis was discussed by NRC staff in 1989 and was based on the linear nature of the coastline in this area and the presence of lineaments and escarpments parallel to the coast, as well as a postulated slip deficit across the San Luis–Pismo structural block. Nitchman (1988) described the San Luis Range as being bounded by the Los Osos fault to the north, the Hosgri fault to the west, and several reverse faults to the south. The southern boundary included the Wilmar Avenue fault, the San Luis Bay fault, and an inferred northeast-dipping reverse fault that Nitchman called the Inferred Offshore fault. The basis for Nitchman's (1988) interpretation was the observation that the shoreline was parallel to the N60°W trending San Luis Range, and the lack of tilting of marine terraces (Killeen, 1988). This suggested that the range is uplifting as a block and, he thought, is probably bounded to the southwest by a matching reverse fault that is a mirror image of the Los Osos fault.

PG&E presented evidence supporting its conclusion that there was no significant undetected fault paralleling the coast in the zone from the shore out to a distance of 1–2 km, within which shallow water precluded obtaining seismic reflection profiles (PG&E, 1989a, Response to Question 43e; 1990). This evidence consisted of seismic reflection data that covered the area offshore of the shallow water zone, and seismic reflection lines that would have crossed any significant coast-parallel faulting extending into Estero Bay. PG&E recognized the difficulties of identifying faults in shallow water with an acoustic basement characterized by steeply dipping structures, and examined other lines of evidence, mainly bathymetric data in the near shore from Morro Bay to Point San Luis. Prominent bathymetric escarpments that could be traced from Point Buchon to Point San Luis were identified and interpreted to be a series of closely spaced shoreline features that formed during previous low sea-level conditions (PG&E, 1990). Although the general trend of these escarpments appeared to cut obliquely across bathymetric contours, each individual slope break was subparallel to the bathymetric contours, sinuous and irregular,

indicating that the breaks in slope were not tectonically controlled. NRC staff concluded that while the evidence presented by PG&E supported the absence of a coast-parallel fault, the presence of such a fault could not be completely ruled out (NRC, 1991, pp. 2-29 to 2-30).

PG&E established the LTSP in 1984, and assembled a robust geosciences and engineering program to support licensing and operation of DCPP. Following the success of the LTSP in satisfying the NRC's licensing requirements for DCPP, this program has grown to include partnerships with the U.S. Geological Survey (USGS) as well as state, local, and academic institutions such as the Seafloor Mapping Lab at the California State University Monterey Bay and the Pacific Earthquake Engineering Research Center at the University of California, Berkeley.

Long Term Seismic Program

Following the successful completion of the LTSP in 1991, PG&E maintained the LTSP staff of geoscience and engineering experts to keep abreast of new geological, geophysical, seismological, and seismic engineering information that might apply to Diablo Canyon. PG&E recognized that some issues (e.g., the type of fault motion on the Hosgri fault, the characterization of the Southwestern Boundary zone, and ground motion estimates for oblique-slip earthquakes) were controversial due to lack of definitive evidence, and assumed that future geoscience discoveries would bring these issues to a firm conclusion. As a result, PG&E made a commitment to continue LTSP activities for the life of the plant (PG&E, 1991b; NRC, 1991, p. 1-7).

PG&E–USGS Cooperative Research and Development Agreement

Both the 2003 San Simeon and 2004 Parkfield earthquakes provided extensive data and new opportunities to better understand and more accurately characterize details of the tectonic environment in the central coastal California region and to compare this new information with existing knowledge. PG&E and USGS have collaborated on studies of the San Simeon and Parkfield earthquakes as part of a Cooperative Research and Development Agreement (CRADA) that was established in 1992 to improve rapid earthquake notifications and develop new geoscience data and advanced analysis methods leading to reducing earthquake risks in PG&E's service territory in northern and central California. The PG&E–USGS CRADA has provided a unique and productive opportunity to conduct collaborative research that is of mutual interest to both PG&E and the USGS.

Examples of CRADA-supported mutual-interest research include fixed-wing and marine geomagnetic surveys that were conducted in 2008 and 2009, as well as high-resolution marine seismic reflection profiles that were collected as part of the California Seafloor Mapping Program (http://walrus.wr.usgs.gov/mapping/csmp/). The advent of differential GPS navigation and improvements in offshore geophysical mapping technology have enabled higher-resolution imaging of the shallow water areas along the California coast. These modern geologic and geophysical data have helped to improve the regional tectonic characterization in south-central coastal California.

LTSP Update

Beginning in 2006, PG&E embarked on an effort, called the LTSP Update, to update its geological geophysical, and seismological databases and to incorporate new scientific information and emerging tectonic concepts to advance the understanding of earthquake hazards in the south-central coastal region. One of the initial tasks in this plan was to combine the occurrence of additional seismicity since the original LTSP with the development and application of recently-developed advanced earthquake location techniques (tomoDD [Zhang and Thurber, 2003] and hypoDD [Waldhauser, 2001]). This work led to identifying a seismicity lineament that parallels the coast between Point Buchon and Point San Luis (Hardebeck, 2010). This lineament was not apparent at the time of completion of the original LTSP in 1991. While these newer data appear to confirm the location, orientation, and approximate length of Nitchman's reverse-slip Inferred Offshore fault, the focal mechanisms of earthquakes that have occurred along the Shoreline fault zone from 1988 to 2008 are more consistent with right-lateral strike-slip motion than reverse motion. The new geologic and geophysical data that have been collected as part of the LTSP Update are being used in conjunction with the earthquake locations to constrain the geometry, segmentation, location, and slip rate of the Shoreline fault zone for this report.

As part of the ongoing LTSP Update, continued investigation of the DCPP region in general and the Shoreline fault zone in particular plan to include three-dimensional (3-D) marine and two-dimensional (2-D) onshore seismic reflection profiling, additional potential field mapping, GPS monitoring, and the installation of an ocean bottom seismograph network.

1.3 Acknowledgments

This study originated as part of the Diablo Canyon LTSP Update conducted by PG&E under the direction of Mr. Lloyd S. Cluff. The PG&E Staff who contributed to this study include Dr. Norman Abrahamson, Mr. Kent Ferré, Mr. William Horstman, Ms. Debbie Kwok, Ms. Marcia McLaren, Dr. Stuart Nishenko, Dr. William Page, Ms. Megan Stanton, Mr. Richard Van der Linden, and Ms. Katie Wooddell.

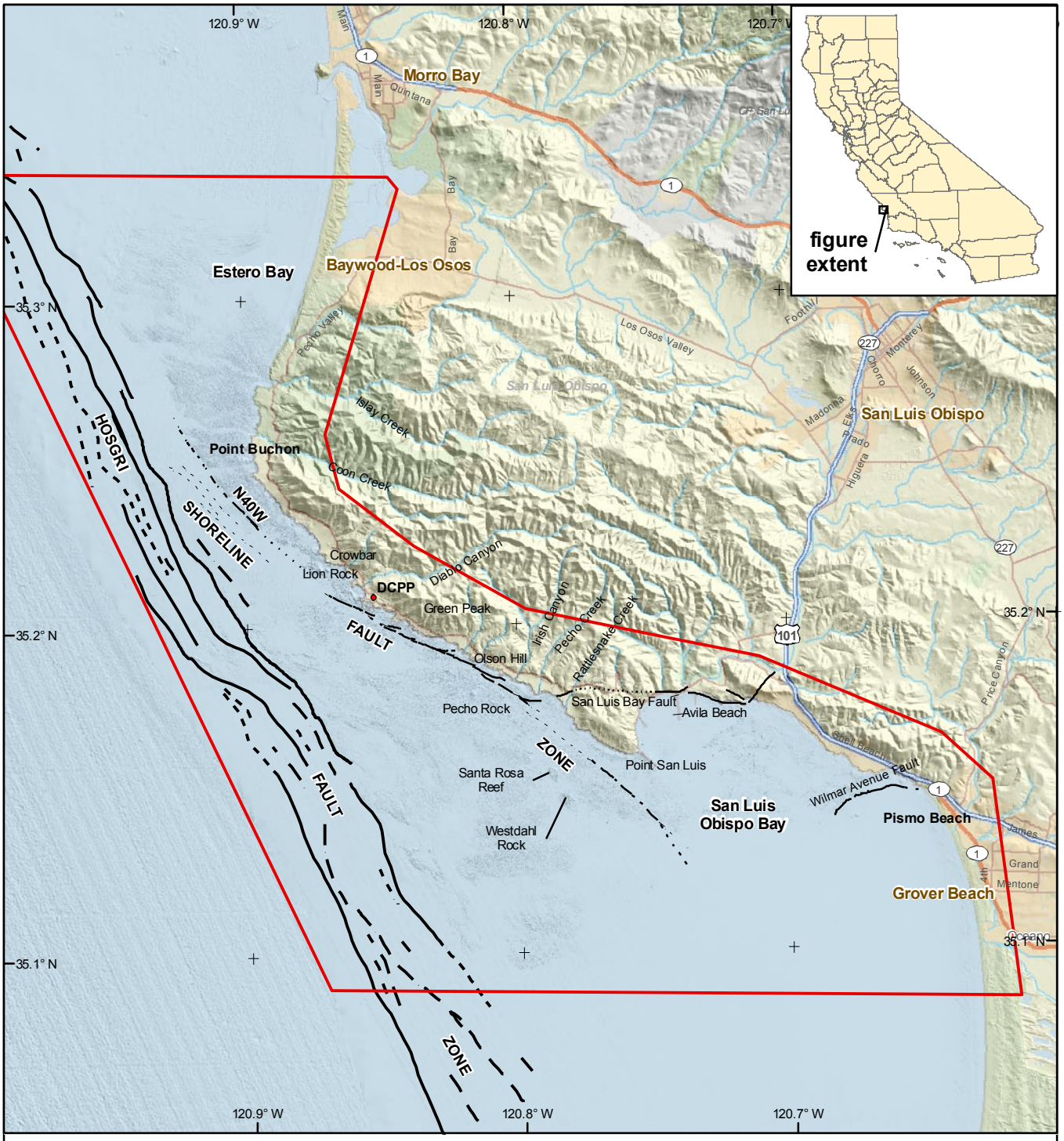
A study of this scope and complexity would not have been possible without the cooperation of numerous individuals and organizations outside of PG&E. In particular, the excellent efforts of PG&E's CRADA partners at the USGS are acknowledged. Much of the new geophysical data used in this report were collected under the PG&E–USGS CRADA as part of the LTSP Update. PG&E thanks Dr. Thomas Brocher, Dr. William Ellsworth, Dr. Jeanne Hardebeck, Ms. Vickie Langenheim, Dr. Robert Jachens, Dr. William Savage, Dr. Carl Wentworth, Dr. Samuel Johnson, Ms. Janet Watt, and the crew of the *R/V Parke Snavely*.

PG&E also gratefully acknowledges the assistance of Prof. Rikk Kvitek and the crew of the *R/V Ven Tresca* from the Seafloor Mapping Lab at the California State University of Monterey Bay with collecting and processing the MBES bathymetry data offshore of DCPP.

PG&E's Interpretation Team reviewed and interpreted the newly collected multibeam bathymetry and high-resolution seismic reflection data, as well as older geophysical and geological data sets, to develop the geologic maps in this report. The Interpretation Team includes Dr. Gary Greene (consultant); Mr. Serkan Bozkurt, Ms. Kathryn Hanson, Mr. Hans AbramsonWard, Ms. Alexis Lavine (AMEC Geomatrix); Dr. William Lettis, Mr. Michael Angell, Dr. Daniel O'Connell, Dr. Stephen Thompson, Mr. Andrew Lutz (FUGRO-William Lettis & Associates); and Dr. Jan Rietman and Dr. Phillip Hogan (Fugro West, Inc.).

PG&E also established an Advisory Board to provide an independent review of the data and conclusions developed in the LTSP Update, including the Shoreline fault zone study. Members of the Advisory Board are Prof. Julian Bommer (Imperial College); Dr. Kevin Coppersmith (Coppersmith Consulting, Inc.); Prof. Steven Day (San Diego State University); Dr. Robert Kennedy (RPK Structural Mechanics Consulting, Inc.); and Prof. Raymond Weldon (University of Oregon).

Additional consultants who assisted in addressing specific issues for this report include Dr. Gary Carver (Carver Geologic Inc.); Mr. Lew Rosenberg (Consulting Geologist to San Luis Obispo County); Prof. Clifford Thurber (University of Wisconsin–Madison); and Dr. Felix Waldhauser (Lamont-Doherty Earth Observatory).



LEGEND

Study area

Shoreline, Hosgri, San Luis Bay, and Wilmar Avenue faults, dashed where approximate, dotted where concealed

N W E S

0 1 2 Miles

0 2 4 Kilometers

Map projection and scale: NAD 1983, UTM Zone 10N, 1:200,000

Map of Shoreline fault zone study area

SHORELINE FAULT ZONE STUDY

Pacific Gas and Electric Company

Figure **1-1**

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