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ABBREVIATIONS AND ACRONYMS

3D	three-dimensional
AMEC	AMEC Environment & Infrastructure, Inc.
ASME	American Society of Mechanical Engineers
AWD	accelerated weight drop
CDP	common depth point
CEC	California Energy Commission
cm	centimeter(s)
CSUMB	California State University, Monterey Bay
DCPP	Diablo Canyon Power Plant
DEM	digital elevation model
DOGGR	Division of Oil, Gas, and Geothermal Resources
DRG	Digital Raster Graphic
FCL	Fugro Consultants, Inc.
FGDC	Federal Geographic Data Committee
FSAR	final safety analysis report
FWLA	Fugro William Lettis & Associates, Inc.
GIS	geographic information system
GMP	Geologic Mapping Project
GPS	global positioning system
ISFSI	independent spent fuel storage installation
km	kilometer(s)
LCI	Lettis Consultants International, Inc.
LiDAR	light detection and ranging
LTSP	Long Term Seismic Program
m	meter(s)
MBES	multibeam echo sounder
MIS	marine isotopic stage
NAD 83	North American Datum of 1983
NAIP	National Agriculture Imagery Program
NAVD 88	North American Vertical Datum of 1988

NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
PG&E	Pacific Gas and Electric Company
QA	quality assurance
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WLA	William Lettis & Associates, Inc.
WSI	Watershed Sciences, Inc.

1.0 INTRODUCTION

This data report presents the results of a geologic mapping study in the onshore area surrounding the Diablo Canyon Power Plant (DCPP), located in San Luis Obispo County, California. The project, titled, “Geologic Mapping and Data Compilation for the Interpretation of Onshore Seismic-Reflection Data,” merged new onshore geologic data with previously collected and published geologic data. The project will be referred to herein as the “Geologic Mapping Project” or GMP.

This work is being done by Pacific Gas and Electric Company (PG&E) to comply with the California Energy Commission (CEC) recommendation, as reported in the CEC’s November 2008 report titled *An Assessment of California’s Nuclear Power Plants: AB 1632 Report*, that PG&E use three-dimensional (3D) seismic-reflection mapping and other advanced geophysical techniques to explore fault zones near the DCPP.

1.1 Purpose

The purpose of the GMP is to provide accurate geologic data to help with the interpretation of onshore seismic-reflection data collected in 2011 and 2012 by Fugro Consultants, Inc. (FCL) for PG&E (referred to herein as “seismic-reflection data”). The study area is shown on Figure 1-1 and generally consists of the Irish Hills and adjacent areas to the north and east, plus a smaller area within Price Canyon southeast of the Irish Hills. The geologic data are contained in a digital database and include surface (map) and subsurface (well) information on stratigraphy and geologic structure.

1.2 Intended Use of the Results

The intended use of the GMP results is to provide near-surface stratigraphic and structural constraints for the following types of activities:

- Assessment of the quality and interpretability of seismic-reflection data.
- Interpretation of the geologic history and 3D geologic structure of the study area, particularly in combination with the interpretation of seismic-reflection data.
- Evaluation of seismic sources for seismic hazard analysis.

1.3 Scope of Work

The project scope of work is explained in detail in the Project Planning Document, GEO.DCPP.PPD.13.01, Rev. 0, dated 4 March 2013. The technical scope consisted of the following tasks:

- Preliminary interpretation of provisional (non-QA) seismic-reflection profiles, existing geologic map data, oil and hydrogeologic well data, LiDAR topography, and multibeam echosounder (MBES) bathymetry. The primary purpose of the preliminary interpretation was to help establish field mapping priority areas. The field mapping priority areas were selected mainly as a result of evaluating previously published geologic maps. The use of non-QA seismic data as part of this assessment is justified because numerous data sets corroborated the field mapping priority areas and it was assumed that the non-QA seismic data would be sufficient to delineate any clear and obvious additional priority mapping targets.

- Field bedrock geologic mapping along and adjacent to the seismic-reflection profile lines.
- Processing of field data and integration of those data with previously collected and compiled geologic map data into a geographic information system (GIS) database.
- Construction of strip geologic maps and shallow geologic cross sections along the accelerated weight drop (AWD) subset of seismic-reflection profile lines, and geologic map plates of the broader study area and the DCPP site (Figure 1-1).
- Data report preparation.

During the course of the GMP project, it was decided that the strip geologic maps and shallow geologic sections were not as useful as originally envisioned for the interpretation of seismic-reflection data, and that the focus should change to developing geologic maps of the broader Irish Hills, DCPP, and Price Canyon study areas. The strip maps and shallow cross sections, which were completed in accordance with the originally issued work instruction, were not revised and are not included in this report.

1.4 Project QA Program, Participating Organizations, and Responsibilities

This project was conducted under PG&E's nuclear Quality Assurance (QA) program, with terms provided in Project Planning Document GEO.DCPP.PPD.13.01, Rev. 0 (dated 4 March 2013) and Project Instructions GEO.DCPP.PI.12.01, Rev. 1 (dated 11March 2013) and GEO.DCPP.PI.12.02, Rev. 2 (dated 11 March 2013).

The project Technical Coordinator is Stuart Nishenko (PG&E Geosciences). The QA Manager for the project is Marcia McLaren (PG&E Geosciences). The project Independent Technical Reviewer is William Page (PG&E Geosciences).

Geologists and GIS specialists from Lettis Consultants International, Inc. (LCI), AMEC Environment & Infrastructure, Inc. (AMEC), Fugro Consultants, Inc. (FCL), and InfraTerra, Inc., conducted the technical work. The Geologic mapping team for this project consisted of six geologists: Andrew Lutz (LCI before 16 February 2013; InfraTerra after 16 February 2013), Jeffrey Unruh (LCI), John Baldwin (LCI), Brian Gray (LCI), Josh Goodman (FCL), and Christopher Slack (AMEC). The Geologic Mapping Project manager was Stephen Thompson (LCI). The Database Manager for the project was Serkan Bozkurt (LCI). LCI has overall responsibility for the preparation and delivery of this data report with assistance from geologists and staff of AMEC, FCL, and InfraTerra. Janet Sowers of FCL headed the evaluation of oil exploration data presented in Appendix E.

2.0 ASSUMPTIONS

The primary assumption made in this data report is that previously collected and published geologic maps used in this compilation were done to a high technical standard, and thus the data from these maps provide useful constraints for the interpretation of seismic-reflection profiles. This assumption is generally supported by field observations made by the GMP team members during the course of the study and by the fact that all the previously published maps were peer-reviewed before publication and/or release as professional reports.

3.0 DATA

The data evaluated in this study consist of previously published geologic map data, previously collected (but unpublished) geologic map data, previously collected geospatial data, available deep well and borehole data, and new geologic map data. Figure 3-1 shows the locations of new geologic data observations and measurements relative to the seismic-reflection data. Figure 3-2 shows the locations of deep oil exploration wells and hydrogeologic boreholes that provide subsurface geologic and geophysical information for the study. Figures 3-3 through 3-8 show the sources of previously published and unpublished geologic data considered in the study. The base image for all map figures and plates in this report is an artificial hillshade image derived from a merged digital elevation model (DEM) consisting of onshore LiDAR and offshore MBES data. Both data sets were referenced to a zero elevation corresponding approximately to mean sea level. In the process of merging data sets, the GMP database manager noted discrepancies in the zero elevation reference that were on the order of several centimeters (cm) to a meter (m). It is recognized that although more work can be done to resolve the discrepancies, it is not required for this land-based study.

The newly acquired geologic data were collected under PG&E's nuclear QA program. However, with some exceptions, the previously collected data considered in this study were not collected under any nuclear QA program. The QA "pedigree" of all the data is discussed in this section, with those data collected under a nuclear QA program or accepted as QA by PG&E's nuclear QA program considered "qualified," and those data not collected or accepted as QA considered "not qualified." The procedures that were followed to qualify certain data sets are also described.

3.1 Previously Collected Geologic and Geospatial Map Data

Two types of previously collected map data are relevant to the study: geologic map data and other geospatial (mostly geographic) data. Well data are discussed in Section 3.2.

3.1.1 Previously Collected Geologic Map Data

Previously published and unpublished geologic map data were compiled at two scales. For the larger Irish Hills study area shown on Figure 1-1 and Plate 1, and for the adjacent Price Canyon study area shown on Figures 1-1 and 3-9, previous geologic map data were compiled from geologic maps at 1:12,000 to 1:48,000 scale. For the DCPP study area shown on Figure 1-1 and Plate 2, previous geologic map data were compiled from maps at approximately 1:3,000 to 1:10,000 scale. Data sources for the three maps are presented in Table 3-1 and shown on Figures 3-3 through 3-8. The geologic data compilation for the DCPP study area contained a greater number of unpublished data sources than the compilation for the larger GMP area, mainly due to the detailed mapping that was performed in and around the DCPP site.

Geologic map data considered "qualified" under PG&E's nuclear QA program are indicated in Table 3-1 in bold font. Qualified sources of map data include published maps that have undergone extensive peer review during the publication process (e.g., Hall et al., 1979), maps that were performed under a nuclear QA program (e.g., PG&E, 2004), and maps that were accepted by the U.S. Nuclear Regulatory Commission (NRC) previously and have undergone extensive scrutiny since release (e.g., PG&E, 1990).

Table 3-1. Sources of Previous Geologic Map Data Considered for the GMP

Name and Year	Data Source	Area of Relevance
AMEC (2012a)	Compilation of Geologic Maps and GIS Databases for the Irish Hills and Surrounding Areas (Draft Report)	Plates 1 and 2 and Figure 3-9
Dibblee (2004)	**Geologic Map of the San Luis Obispo Quadrangle**	Plate 1
Dibblee (2006a)	**Geologic Map of the Morro Bay South Quadrangle**	Plate 1
Dibblee (2006b)	**Geologic Map of the Pismo Beach Quadrangle**	Plate 1
Dibblee (2006c)	**Geologic Map of the Port San Luis Quadrangle**	Plate 1
FWLA (2009, 2010)	Unpublished geologic map data of the DCPP coastline	Plates 1 and 2
FWLA (2011)	Landslide maps for HAZUS / DCPP Evacuation Route Study	Plates 1 and 2
Hall (1973a)	**Geologic Map of the Morro Bay South and Port San Luis Quadrangles**	Plates 1 and 2
Hall (1973b)[†]	**Geology of the Arroyo Grande 15' Quadrangle**	Plate 1 and Figure 3-9
Hall and Prior (1975)	**Geologic Map of the Cayucos–San Luis Obispo Region**	Plate 1
Hall et al. (1979)[†]	**Geologic Map of the San Luis Obispo–San Simeon Region**	Plates 1 and 2
Hanson et al. (1994)	**Quaternary Geologic Map of Coastal California from Morro Bay to Shell Beach (Plate 2)**	Plate 1
Jahns et al. (1973)	Geology of the DCPP Site (stand-alone map)	Plates 1 and 2
Lettis and Hall (1994) [†]	**Map of the Los Osos Fault Zone (Plate 5)**	Plate 1 and Figure 3-9
PG&E (1974)	**Diablo Canyon Units 1 and 2 final safety analysis report (FSAR; selected figures)**	Plates 1 and 2
PG&E (1990)[†]	**Diablo Canyon Long Term Seismic Program, Response to Question GSG Q16 (Plates GSG Q16-1A and 1B)**	Plates 1 and 2
PG&E (2004)	**Diablo Canyon independent spent fuel storage installation (ISFSI) FSAR (selected figures)**	Plates 1 and 2
PG&E (2011)	Report on the Analysis of the Shoreline Fault Zone, figures and Appendix B plates	Plates 1 and 2
WLA (1996)	Diablo Canyon Dry Cask Facility Siting Study Geology Compilation Map (Plate 1)	Plates 1 and 2
WLA (1998–2001)	Diablo Canyon Dry Cask Facility Siting Study Geologic Map with Revisions	Plate 2

Name and Year	Data Source	Area of Relevance
Wiegers (2009)†	**Geologic Map of the Morro Bay South 7.5' Quadrangle**	Plate 1
Wiegers (2010)†	**Geologic Map of the San Luis Obispo 7.5' Quadrangle**	Plate 1
Wiegers (2011)	**Preliminary Geologic Map of the Pismo Beach 7.5' Quadrangle**	Plate 1

Note: Map data sources in bold are considered qualified by PG&E's nuclear QA program. Map data citations marked with a bold dagger (**†**) were used to corroborate the digital compilation by AMEC (2012a) and to initiate the data compilation effort.

The majority of previously published geologic map data in the study area were compiled for PG&E by AMEC Environment & Infrastructure (AMEC, 2012a) in ArcGIS shapefile and layer file format. This compilation was not performed under a nuclear QA program, but was conducted to a high standard of care, as described in the draft memorandum accompanying the AMEC (2012a) GIS database.

The AMEC compilation focused on previous mapping by C.A. Hall and colleagues (Hall, 1973a, 1973b; Hall and Prior, 1975; Hall et al., 1979) and by PG&E for the Diablo Canyon Long Term Seismic Program (LTSP; Lettis and Hall, 1994; PG&E, 1990) and the Shoreline Fault Zone Report (PG&E, 2011). The compilation also considered geologic maps by M.O. Wiegers for the Morro Bay South and San Luis Obispo 7.5-minute quadrangles (Wiegers, 2009, 2010). The AMEC compilation did not consider the quadrangle maps by T.W. Dibblee (2004, 2006a, 2006b, 2006c) published by the Santa Barbara Museum of Natural History, the Pismo Beach quadrangle map by Wiegers (2011), or detailed mapping of the DCPP site by PG&E and its consultants (Table 3-1).

In order to qualify the digital geologic map database under PG&E's nuclear QA program, the geologic map database compiled by AMEC (2012a) was reviewed, added to, and modified under procedures and guidelines described in PG&E's Quality Assurance Procedure QAP-015, "Qualification of Existing Data" and the American Society of Mechanical Engineers" (ASME) standard NQA-1-2008, Nonmandatory Appendix 3.1, "Guidance on Qualification of Existing Data." The qualification procedures, which used the approach of corroboration, were performed only *within* the three study areas defined on Figure 1-1; AMEC's digital compilation *outside* the study areas was not corroborated.

The AMEC (2012a) compilation was corroborated by the map sources in Table 3-1 that are listed with a dagger. Additional non-QA map data were compiled and qualified using the PG&E and ASME procedures mentioned above. All the data sources shown in Table 3-1 were considered for the compilation effort, but because many of the data sources are themselves compilations of earlier published map data (e.g., Dibblee, 2004, 2006a, 2006b, 2006c) and contain information that is redundant or not original, not all maps shown in Table 3-1 contributed data to the final map database.

3.1.2 Previously Collected Geospatial Data

In addition to geologic map data, other geospatial data sets were used in the study; these data sets are listed in Table 3-2.

Table 3-2. Sources of Previously Collected Geospatial Data

Organization and Year	Data Source	Area of Relevance
CSUMB (2007, 2009, 2010, 2011)	MBES bathymetry data from Estero Bay to San Luis Obispo Bay (described in PG&E, 2011)	Plates 1 and 2
TetraTech (2010)	LiDAR topographic data and aerial orthophoto data for the Diablo Canyon coastline	Plates 1 and 2
TetraTech (2011)	LiDAR topographic data for the Irish Hills and surrounding areas	Plate 1 and Figure 3-9

MBES bathymetry data were acquired from Estero Bay to San Luis Obispo Bay during 2007, 2009, 2010, and 2011 by the Seafloor Mapping Lab at California State University, Monterey Bay (CSUMB). The data sets were not collected under a nuclear QA program, but they were collected in accordance with industry standards and specifications. The data sets range from 1 m horizontal resolution for data from the 0 to 50 m depth range, to 2 m horizontal resolution for data from greater depths. The vertical precision of the data is ±10 cm (Appendix F of PG&E, 2011).

In 2011, following the release of the Shoreline Fault Zone Report (PG&E, 2011), the CSUMB Seafloor Mapping Lab collected new detailed MBES data from the nearshore environment in areas previously unreachable by the survey vessels, including in the DCPP Intake Cove and Discharge (Diablo) Cove. These new “Kelpfly” data (named for the small instrumented vessel used to collect the data) were merged with the previously collected MBES data.

LiDAR topographic data were acquired over the Irish Hills and surrounding areas by PG&E in 2010 and 2011 (TetraTech, 2010, 2011). The surveys were performed by Watershed Sciences, Inc. (WSI), in collaboration with TetraTech in accordance with industry standards and specifications. These data were collected in Universal Transverse Mercator (UTM) Zone 10 North projection using the North American Datum of 1983 (NAD 83) horizontal datum and the North American Vertical Datum of 1988 (NAVD 88) vertical datum. Stated absolute accuracy in the 2010 and 2011 LiDAR surveys is less than 10 cm (TetraTech, 2010; WSI, 2011).

The GMP database manager evaluated the raw binary files (in industry-standard LAS format) from the 2010 and 2011 LiDAR surveys and found that bare-earth ground-surface point spacing averaged between 0.5 m and 1 m. Raster DEMs of the LiDAR data were created for cell sizes of 0.5 and 1 m using the original LiDAR survey projection system. The raster DEM base map allowed the field geologists to locate geologic measurements more precisely than previous mapping efforts, which used 7.5-minute topographic maps with relatively coarse elevation contours.

The LiDAR data sets were qualified under procedures and guidelines described in PG&E's Quality Assurance Procedure QAP-015, "Qualification of Existing Data" and in American Society of Mechanical Engineers standard ASME NQA-1-2008, Nonmandatory Appendix 3.1, "Guidance on Qualification of Existing Data."

The LiDAR data for the study areas defined on Figure 1-1 was corroborated by checking elevation and latitude and longitude values of the LiDAR against survey benchmarks contained within the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey (NGS) online survey mark database on 10 August 2012 (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl). Elevation values of the DEM were compared to elevation values from a subset of survey marks. The latitude and longitude values of the DEM were compared to digital raster graphic (DRG) versions of topographic quadrangles produced by the U.S. Geological Survey (USGS), and to aerial imagery acquired by the U.S. Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP). Each of the NGS survey marks used to evaluate elevation values was used as an arbitrary location to compare the DEM to the appropriate USGS DRG and the USDA NAIP imagery by visually confirming the position of terrain and cultural features common to all data sets.

For both the vertical elevation values and horizontal values, the corroboration exercise found that the DEM values are within 5 m of the control reference markers, which we conclude is sufficiently accurate and precise for the intended use of the data in the GMP. Evaluation of the exact data accuracy, and the possible explanations for differences between the survey mark locations and the DEM-derived locations, is beyond the scope of this study.

The GMP database manager merged the offshore MBES data (including the 2011 Kelpfly data) and the LiDAR data to produce a seamless onshore-offshore DEM. The estimated absolute accuracy of the combined onshore-offshore DEM is less than 2 m vertical and horizontal near the DCPP and estimated to be within 5 m over the entire study area. For purposes of the GMP, which include providing a high-resolution topographic base for collecting and analyzing geologic data, these uncertainties are considered adequate. In addition, we note that most of the map priority areas where new data were collected are sparsely vegetated and thus in areas where the LiDAR-derived DEM is very accurate. Areas of dense vegetation, which in the GMP study area typically coincide with stream valleys, are likely to have higher DEM uncertainties. These densely vegetated areas were less common locations of geologic study sites for the GMP.

3.2 Available Deep Well and Borehole Data

Appendix E to this data report presents information about 26 oil exploration wells and 8 hydrogeologic boreholes considered relevant for this study. The locations of 29 of the deep wells and boreholes are shown on Figure 3-2, and wells and boreholes within the Irish Hills and Price Canyon study areas are shown on Plate 1 and Figure 3-9, respectively. As explained in more detail in the Appendix E, 18 deep wells or boreholes are located along seismic-reflection profile lines, and additional boreholes located in the study area vicinity provided velocity log data and other information that were considered for processing the seismic-reflection data. Information about the wells and boreholes was obtained from various sources. The primary source for the deep oil exploration wells was the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR). Supplemental information for the Honolulu-Tidewater well was obtained from Mr. Larry Knauer of Chevron Corporation in Bakersfield, California, via written communication in 2013. Supplemental paleontological data for 3 other wells (the Maino-Gonzales, Pecho, and Spooner wells) were obtained from the California Well Sample Repository at California State University, Bakersfield. Data for 8 hydrogeologic boreholes were obtained from a technical report by geologic consultants Cleath & Associates (2003).

The compilation and review of the well and borehole data and the data uncertainties were performed under procedures and guidelines described in Pacific Gas & Electric Company (PG&E) Quality Assurance Procedure QAP-015, “Qualification of Existing Data,” as well as American Society of Mechanical Engineers standard ASME NQA-1-2008, Nonmandatory Appendix 3.1, “Guidance on Qualification of Existing Data.” The qualification of the well and borehole data is described in Appendix E.

3.3 New Geologic Map Data

The locations of geologic observations and field data collected by the geologic mapping team for this investigation are shown on Figure 3-1. The field data consist of “stations” where structural measurements (bedding attitudes, faults, shears, folds, etc.); stratigraphic observations (characterizations of geologic contacts, unit descriptions); photographs; and samples were collected. Appendices A through D contain information related to the collection of new data at field stations. Appendix A contains electronic copies of the daily field reports by the geologic map team members. Appendix B contains electronic copies of photographs taken at stations. Appendix C contains a list of geologic hand samples that were collected in the field. These samples are being kept in a basement storage space at LCI’s office in Walnut Creek, California. The hand samples will be kept at LCI through the duration of the seismic interpretation project, and will then be discarded. This approach is justified as all sample locations are archived in the GIS shapefile of field station data and are easily revisited at a later time should the need arise.

Appendix D contains the GIS database produced for this study. Among these data is a shapefile containing the information collected at each field station. The attribute table of the shapefile includes the following information:

- Station name and ID
- Location
- Unit description
- Formation name
- Type of structural measurement and the structural orientation (strike/trend, dip/plunge, and dip/plunge directions)
- Quality of the measurement
- Sample collection method (e.g., hand sample)
- File names of photographs

As explained in the next section, these data were collected in the field on tablet computers and paper maps, and later merged and synthesized with previously collected map data.

4.0 METHODOLOGY

The approach taken to produce the geologic data set involved the following steps:

1. Review of onshore seismic-reflection data collection extent and preliminary (non-QA) seismic profiles and identification of priority areas for the collection of new data.
2. Compilation of previously published geologic data, including geologic maps and deep borings.
3. Field mapping and collection of new data.
4. Integration of new geologic data with previously published data.
5. Analysis of the geologic data to produce updated geologic maps.

Each of these steps is described further in this section.

4.1 Preliminary Review and Identification of Priority Areas

Before the field mapping began, the GMP team members reviewed existing geologic maps and preliminary (non-QA) seismic-reflection profiles to identify a set of priority mapping areas. Two types of seismic-reflection data had been collected previously at the time of field mapping: higher-resolution, shallower-penetrating AWD data and lower-resolution, deeper-penetrating Vibroseis data. The extent of the two types of seismic-reflection data is shown on Figure 3-1. At the time, preliminary two-dimensional profiles were available for AWD data. Priority areas were identified to accomplish the main objectives, as follows:

- To corroborate or update geologic mapping along specific AWD and Vibroseis seismic lines.
- To fill in key data gaps or areas of uncertainty not covered by seismic-reflection profiles but deemed relevant to understanding the geologic structure of the Irish Hills.

Given the onshore extent of the project area of approximately 330 square kilometers (km^2), prioritizing mapping areas was a necessity to accomplish the project objectives. Once identified, mapping areas were prioritized by geologic importance, presumed relevance of the data to be collected with respect to the structure of the Irish Hills, and constraints to road access and land access. Areas selected are indicated by the data collection sites shown on Figure 3-1.

4.2 Compilation of Previously Collected Geologic Data

The types and sources of previously collected geologic data considered in this study are listed and described in Sections 3.1 and 3.2.

Data compilation was conducted by the geologic mapping team members in collaboration with the GMP database manager and other qualified GIS specialists working under the supervision of the database manager. All relevant geospatial data were organized in a designated electronic location using a clear file structure and ensuring that each data set is adequately documented with regard to data origin and projection and datum.

The following types of activities were performed as part of the data compilation:

- Organizing raster and vector geospatial files.
- Defining or redefining the projection of geospatial data sets.
- Scanning and georeferencing of hard-copy geologic maps (Table 3-1).
- Qualifying map data that was not previously qualified under PG&E's nuclear QA program.
- Digitizing relevant geologic data from hard-copy maps (as recommended by the GMP project manager and other mapping team members).
- Reviewing the georeferencing and digitizing of data and comparing them to the original maps and to other geospatial data sets.
- Assessing the technical quality of the data.

4.3 Field Mapping and Collection of New Data

Geologic mapping was performed to confirm, supplement, and/or supersede geologic data available from existing geologic maps (Table 3-1 and Figures 3-3 through 3-8). The mapping was conducted by geologic mapping team members (Section 1.3) who were already familiar with the general geology and environment of the project area. Mapping was conducted in pairs of two geologists, and up to three mapping pairs collected geologic data at any given time. The following types of activities were performed as part of the data collection for the field geologic mapping, each of which resulted in generated data considered field records:

- Checking calibration of field equipment.
- Recording data collection locations.
- Describing rock type.
- Measuring bedding attitude and estimating uncertainty.
- Measuring and describing outcrop-scale faults or folds.
- Photographing relevant outcrops and features.
- Collecting geologic samples.

Selected outcrops were located and described in two formats: electronically on tablet computers (Apple iPads) with GIS software installed, and manually on hard-copy field maps and field notebooks or field sheets (collectively called field notes). The primary method of recording field geologic data was using the electronic format, and hard-copy records complemented the information gathered on the tablet computers.

Station location information was recorded on a tablet computer that uses GIS software and/or on a hard-copy map base at an appropriate scale. A global positioning system (GPS) receiver was used to generally locate the position of each data point relevant to base data, though the saved location was entered manually using standard geologic practice field location methods (Compton, 1985; Lisle et al., 2011). Both members of a mapping pair agreed on the data location before moving to the next task. Each data collection point was assigned a unique station ID.

Rock unit descriptions were recorded using standard geologic practice methods (Compton, 1985; Lisle et al., 2011). Descriptions included information about rock type, color, and texture (grain size), with additional comments describing rock structure (e.g., bedding, jointing, and foliation) and other information that the field geologists considered necessary. The rock unit descriptions included the unit name, where possible. Both members of a mapping pair conferred and agreed on the rock type description before moving to the next task.

Structural orientations, including planar features such as bedding, faults, foliations, and shears, and linear features such as striations or fold hinge lines, were measured and recorded using standard geologic practice methods (Compton, 1985; Lisle et al., 2011). For planar features, the strike direction, dip angle, and dip direction were recorded. The strike directions were recorded using the right-hand-rule convention, whereby the recorded strike direction is the value 90 degrees counterclockwise to the dip direction. For linear features, azimuthal trend direction, plunge angle, and plunge direction were recorded. Before entering a field record, both members of a mapping pair had to agree on the interpretation of the planar and linear features and their measurements to values within 5 degrees.

An estimate of the uncertainty associated with each individual bedding attitude measurement was noted with the measurement values. The uncertainty estimate was made at the time of collection using the grading criteria in Table 4-1 as a guideline.

An important component of the field data collection was an outcrop-by-outcrop evaluation of which data were deemed relevant to the production of the 1:32,000 scale Plate 1 or other maps that may be needed for the evaluation of seismic-reflection data at 1:12,000 or 1:24,000 scale. In other words, data collection was focused on mapping structures relevant to the scale of the geologic maps and not to the finer scales of small outcrops. To that end, small-scale structures such as parasitic folds and faults with little offset were generally excluded from the field structural measurements. However, these complexities were commonly noted in the handwritten and iPad field notes.

4.4 Integration of New Geologic Map Data with Previously Collected Data

Data integration activities were performed by the geologic mapping team members in collaboration with the GMP database manager and with other qualified GIS specialists working under the supervision of the database manager. Compiled and newly acquired geologic data were integrated into a single internally consistent database after identifying and resolving relationships between conflicting or spurious data. Where conflicting data were identified in different data sets (e.g., co-located bedding attitudes from published geologic maps that conflicted with new data), the GMP project manager or a geologic mapping team member judged which data were representative of the local conditions and should be included and which data were not representative and should be discarded from the integrated data set.

Table 4-1. Guidelines for Describing Structural Measurement Uncertainty

Measurement Certainty Level	Description
A	Extremely confident—sufficient rock material is exposed to ascertain that measured feature(s) are representative within 5° of strike (or trend) and 5° of dip (or plunge). Other features similar to those measured are abundantly present for use in differentiating the measured feature from other planar or linear features.
B	Very confident—sufficient rock material is exposed to ascertain that the measured feature(s) are representative within 10° of strike (or trend) and 10° of dip (or plunge). Other features similar to those measured are commonly present for use in differentiating the measured feature from other planar or linear features.
C	Moderately confident—sufficient rock material is exposed to ascertain that measured feature(s) are representative within 20° of strike (or trend) and 20° of dip (or plunge). Other features similar to those measured are rarely present for use in differentiating the measured feature from other types of planar or linear features.
D	Probable—sufficient rock material is exposed to ascertain that the measured feature(s) are representative within 40° of strike (or trend) and 40° of dip (or plunge). Other features similar to those measured are rarely present for use in differentiating the measured feature from other types of planar or linear features.

The process of integrating new and existing data also included new interpretation of the geology mapped directly offshore of the DCPP. This new mapping consisted of an update of the offshore mapping conducted for the Shoreline Fault Zone Report (PG&E, 2011) based on the following three pieces of information:

1. The Kelpfly MBES data offshore that became available after the Shoreline Fault Zone Report (PG&E, 2011) was released.
2. Additional consideration of helicopter magnetic susceptibility data (Appendix D of PG&E, 2011) in delineating probable offshore contacts.
3. Additional constraints on probable offshore structures in light of further compilation of onshore data.

The results of these integration and new mapping activities are presented in Sections 6.2 and 7.5. The following metadata were generated for each geospatial data file created as a product of data integration activities:

- Data file type
- Purpose of the data file
- Date of file creation
- Description of the data file
- Credits for the source of the data file
- Limitations for data use
- Data file projection

4.5 Analysis of the Geologic Data for Production of Geologic Maps

Geologic maps for the study areas were developed using the integrated geologic database. The base images shown on figures and plates in this report are artificial hillshades developed from the onshore-offshore DEM. Topographic contours derived from the DEM are also available within the geospatial database for use as base data.

4.5.1 Selection of Map Units and Symbols

Unit subdivisions for the maps and database were based on recently produced maps by PG&E (e.g., PG&E, 2011) that also followed the major unit subdivisions identified by C.A. Hall (e.g., Hall, 1973b; Hall et al., 1979) and adopted by the most recently published geologic maps (Wiegers, 2009, 2010, 2011). Alternative stratigraphic schemes for Neogene rocks (e.g., those proposed by Dibblee, 2004, 2006a, 2006b, 2006c) were considered but ultimately rejected based on precedent, the body of the published literature, and consideration of key Neogene stratigraphic relationships near the DCPP. Plate 2, which is presented at a much larger scale than Plate 1, contains additional stratigraphic subdivisions that have been recognized during previous DCPP mapping efforts (PG&E, 2004).

Structural features on the maps, such as bedding attitudes, faults, and folds, were symbolized using standard symbols and patterns recommended by the Federal Geographic Data Committee (FGDC) and accessed online at http://ngmdb.usgs.gov/fgdc_gds/geolsymstd/download.php. New structural measurements that were given an uncertainty grade of "D" according to the criteria in Table 4-1 were kept in the database but are not shown on the geologic maps.

The geologic maps of the Irish Hills and Price Canyon study areas (Plate 1 and Figure 3-9, respectively) do not symbolize unit contacts according to common map standards. The primary reason for this is inefficiency in creating and updating unit contacts in GIS with minimal improvement in map quality. The method used to compile the map units in GIS was to create and attribute map unit polygons based on original mapping and then modify the polygons based on new information or compilation. Due to the compilation nature of the database and the development of a uniform stratigraphic column, many of the mapped units were modified and reclassified in GIS during the mapmaking process, beginning before the AMEC (2012a) compilation. The database tracks the original source(s) of the mapping, and contiguous polygons of the same compilation stratigraphic unit were systematically merged in the GIS. A "unit contacts" polygon layer was created using this approach and is displayed on Plate 1 and Figure 3-9 as a solid dark gray line.

In order to correctly display unit contacts on the geologic map, which would include solid, dashed, and dotted depositional contacts or solid, dashed, and dotted fault contacts, further parsing and editing of the contacts polygon shapefile into an attributed line shapefile would be required. We decided not to do this for the Plate 1 and Figure 3-9 areas because an intended use of the geologic database is to re-display the data at different scales and with alternative stratigraphic subdivisions. The solid, dark gray unit contacts line symbolizes an approximately located contact on Plate 1 and Figure 3-9. The

DCPP study area map (Plate 2) follows FGDC map standards for symbolizing unit contacts.

4.5.2 Selection of Map Scale and Extent

The size, scale, and extent of the geologic maps were selected based on considerations of the scale of the seismic-reflection data acquisition, ease of use by the interpretation team, and level of detail of the compiled and integrated data set. The Plate 1 extent includes the contiguous area of the Irish Hills at 1:32,000 scale. At this scale, many of the bedding attitudes collected by the GMP or digitized bedding attitudes from previous large-scale mapping efforts are too closely spaced to be decipherable. To facilitate the interpretability of the map, geologic mapping team members and the GMP project manager selected a subset of the structural data considered to be redundant or otherwise unnecessary in areas of dense measurements. These redundant data points, along with the structural measurements given a grade of D according to the criteria in Table 4-1, were attributed in the database and not displayed on Plate 1. The display definition query is preserved in the ArcGIS layer file (Appendix D). Thus, the seismic interpretation team and other evaluators of the data are able to add or omit structural information from the map display as required for ease of use.

Plate 2, which is presented at 1:3,000 scale, contains a higher density of structural measurements. However, as much of the mapping was compiled from maps as large as 1:500 scale, some of the digitized structural data are also overly dense, and similar attributes and definition queries were developed to prevent overcrowding of redundant data on the maps.

Figure 3-9 is a geologic map of the northeast end of Price Canyon at 1:12,000 scale. This geologic map is a representation of previous mapping by Hall (1973b) and Lettis and Hall (1994) at 1:48,000 and 1:24,000 scales, respectively, in the area surrounding the approximately 9 km long AWD line 145. The available strike and dip and fold and fault data are readily displayed at 1:12,000 scale. The available geology was deemed adequate for purposes of interpreting the seismic-reflection data, so no field station activities were necessary in this area.

5.0 SOFTWARE

This project has no software validation requirements.

Three software programs (GIS Pro, ESRI ArcGIS, and Adobe Illustrator) were used to collect, compile, integrate, and analyze the geologic data set and to prepare figures and plates for this report.

GIS Pro, a GIS software application developed by Garafa for the iPad, was used to collect and store field data generated during GMP field mapping. This software was loaded with aerial imagery, high-resolution topography, geologic maps, and other geospatial data sets (shapefiles of faults, trenches, boreholes, seismic lines, field stations, etc.) to aid in the field mapping effort. GIS Pro uses the iPad's GPS satellite and cellular triangulation capabilities to accurately (within several meters) pinpoint the location of the device in the field, allowing the user to accurately locate and map geologic data, including structural measurements, contacts, outcrops, and field stations. Field data can be transferred from GIS Pro to ArcGIS using a number of geospatial formats, including shapefile (.shp), comma-separated values files (.csv), and handheld GPS (.gpx) formats.

ArcGIS, developed by ESRI, is a software package used by industry, government, and academia to collate and map spatial data in an accurate georeferenced manner. This software (ArcMAP version 10.1) was used to compile, integrate, and evaluate, and edit the geologic data and construct the technical information in all maps in this report. An earlier version of ArcGIS was used to construct maps for the Shoreline Fault Zone Report (PG&E, 2011).

Adobe Illustrator (Creative Suite 6) was used for computer drafting of the map explanations. Illustrator is a graphical illustration software package that is widely used by the earth sciences community.

6.0 RESULTS

The results of the GMP are compiled in the GIS database. Portions of the data are presented on geologic maps of the three study areas: Irish Hills (Plate 1), DCPP (Plate 2), and Price Canyon (Figure 3-9). Additional information is provided in the appendices, including field records, the GIS database, and a description of the deep oil well and hydrogeologic borehole data.

6.1 Irish Hills Study Area

Plate 1 is the 1:32,000-scale geologic map for the Irish Hills study area. The map is intended to be used as a direct aid to interpretation of the onshore seismic-reflection data by the interpretation team. The seismic-reflection interpretation team is able to add to the geologic map the common depth point (CDP) lines of the AWD or Vibroseis data and/or shotpoint and receiver data locations as needed in GIS or the seismic-reflection visualization software. New bedding attitudes collected in the field for the GMP are differentiated on the map from the previously collected data with a white halo; this feature allows the interpretation team to distinguish the areas where new observations in the field were made by GMP geologists from areas where previous data were collected. Plate 1 also shows compiled oil exploration wells and hydrogeologic boreholes.

In general, Plate 1 and the geospatial database containing the Plate 1 data are intended to supersede the older geologic maps within the Irish Hills study area. However, the older geologic maps may still be useful to the seismic-reflection interpretation team, even given the changes and uncertainties that are explained in this data report. The geology shown on Plate 1 is significantly different from previously published maps in certain areas, as discussed in Section 7.5 below. Data layers that comprise this map are described briefly below in Section 6.7 and Appendix D.

The map emphasizes bedrock units and structure but provides a depiction of Quaternary units, including previously recognized landslides (Qls), alluvium (Qal), and marine terrace deposits overlain by variable amounts of alluvium and colluvium (Qm).

6.2 DCPP Study Area

Plate 2 is the GMP geologic map of the DCPP study area at 1:3,000 scale. The map shows a compilation of extensive detailed mapping and reconnaissance mapping of the DCPP site, from the initial siting studies (Jahns et al., 1973) to recent mapping that was performed as part of the Shoreline fault zone investigation (PG&E, 2011; FWLA, 2009, 2010). The map also shows new geologic mapping offshore based on interpretation of the Kelpfly MBES data in Discharge Cove and Intake Cove, and revised mapping of the offshore contact between Obispo Formation diabase (Tmod) and resistant tuffaceous Obispo Formation (Tmor). A white line on Plate 2 represents an approximate mean-lower-low tide limit separating areas that can be directly viewed and described by a geologist from offshore areas that must be mapped based on limited dive samples, seafloor texture as imaged by MBES data, and other geophysical data.

The map emphasizes bedrock units and structure but provides a depiction of Quaternary units, including previously recognized landslides (Qls), alluvium and colluvium (Qal), and marine terrace deposits overlain by variable amounts of alluvium and colluvium (Qm). The map depicts areas of artificial fill (af) placed above natural grade (e.g., underlying the switchyards), but does not provide a comprehensive depiction of all placed fill in and around DCPP structures and other facilities. Furthermore, the map shows bedrock lithology and structural information beneath the current facilities as documented during trenching and excavation mapping prior to construction (Jahns et al., 1973; PG&E, 1974).

The geology shown on Plate 2 is significantly different from previously published maps in certain areas, as discussed in Section 7.5 below. Data layers that comprise this map are described briefly below in Section 6.7 and Appendix D.

6.3 Price Canyon Study Area

Figure 3-9 is the geologic map of the Price Canyon study area at 1:12,000 scale. The geologic map of the Price Canyon study area is entirely a compilation of previous mapping by Hall (1973b) and Lettis and Hall (1994); no new observations from the GMP have been added to the map. Lettis and Hall (1994) mapped the northern portion of the Price Canyon study area (Figure 3-5) and focused on Quaternary stratigraphy. Accordingly, in the northern portion of the map where the geologic maps of Hall (1973b) and Lettis and Hall (1994) were both available, preference was given to Lettis and Hall (1994) for defining the Quaternary units and the Quaternary/pre-Quaternary contact. Preference was given to Hall (1973b) for defining pre-Quaternary unit contacts and faults and folds within pre-Quaternary units.

Figure 3-9 shows a simplified Neogene stratigraphy from that of Hall (1973b) by combining several sub-members of the Edna Member of the Pismo Formation into a single Edna Member unit. This is performed in GIS by symbolizing on the “Comp_unit” attribute field in the “Geology_Compilation_GMP_2013” layer. The simplified stratigraphy shown on Figure 3-9 is consistent with the stratigraphic framework of the adjacent Irish Hills study area. Whereas dividing the Edna Member into separate sub-members has not been shown to be useful in the Irish Hills study area, the seismic-reflection interpretation team may consider consulting the original mapping of Hall (1973b) in their work, and may select alternative stratigraphic subdivisions from the GIS database. This may be performed by symbolizing on the “Src_unit” attribute field.

6.4 Appendix A: Daily Field Reports

Appendix A includes digital copies of handwritten daily field reports generated by GMP teams during field exercises in July and August 2012 and February 2013. Field reports include notes for the day’s geologic mapping exercise(s) and documentation of daily field equipment verification. Files are labeled with the field work instruction number “WI.XX” and the month/day date.

6.5 Appendix B: Field Photographs

Appendix B contains field photographs taken by GMP geologists during field mapping in July and August 2012 and February 2013. A GIS shapefile of all GMP field stations (GMP_FieldStations_All_2013.shp) contains links between field station locations and photographs. Photographs are named by the last initials of the mapping group members followed by the photo number assigned by the camera. A duplicate set of photographs is included and is grouped by work instruction number followed by year/month/day date for cross-referencing with the daily field reports in Appendix A. Appendix B includes a Readme text file with instructions for linking field photographs to GIS field station points.

6.6 Appendix C: Field Samples

Appendix C contains a spreadsheet of field samples collected by GMP geologists during field mapping in July and August 2012 and February 2013. The GIS shapefile of GMP field stations (GMP_FieldStations_All_2013.shp) includes in the attribute table whether a sample was collected. All field hand samples are being kept in the basement storage space at LCI's offices in Walnut Creek, California. The hand samples will be kept for the duration of the seismic interpretation project, and will then be discarded.

6.7 Appendix D: GIS Files and Layers

Appendix D consists of electronic files and documentation summarizing the GIS data. The electronic GIS files are those used to make the geologic maps for the Irish Hills (Plate 1), DCPP (Plate 2), and Price Canyon study area (Figure 3-9). Appendix D describes the GIS files (ArcGIS map document files (*.mxd), shapefiles (*.shp), geodatabase files (*.gdb), and georeferenced raster files (*.tif and *.jp2) and GIS layers (manipulations of the shapefiles, geodatabase files, and raster files) used to create the three maps.

6.8 Appendix E: Well Data Report

Appendix E presents information about the 18 deep oil exploration wells and hydrogeologic boreholes that are located within the map area and near the onshore seismic-reflection lines. The report includes original geologic, drilling, and geophysical data; summary geologic descriptions; evaluations of location and interpretation uncertainties; and summary plates for selected wells.

7.0 ANALYSIS

The GMP yielded additional insights into the geology of the project study areas that are summarized below. The analysis consists of a review of the nature and quality of geologic mapping (Section 7.1), summary descriptions of and observations about the stratigraphy and geologic structure (Sections 7.2 and 7.3, respectively), and descriptions of areas where the GMP interpretations and mapping deviated significantly from previous geologic mapping (Section 7.4).

7.1 Nature and Quality of Geologic Mapping in the Study Area

The Irish Hills (Plate 1) and Price Canyon (Figure 3-9) study areas are moderately challenging for field mapping, partially because bedrock underlying much of the study area is either obscured or inaccessible. The limited exposure of rock in many areas is due to a combination of factors, but mostly to the presence of surficial soils that cover bedrock. Thus, outcrops in the area are limited, but where present are located either in areas of high rates of erosion (e.g., coastline, stream beds) and artificial exposure (e.g., road cuts) or on highly resistant units or beds (e.g., tuffaceous sandstones of the Obispo Formation).

To ensure consistent mapping quality, the geologic mapping team members identified and recorded outcrops and locations of structural measurements in accordance with the grading system outlined in Table 4-1.

Because of the lack of continuous exposure of rock, many parts of the geologic map are subject to interpretation by the geology team members and previous field geologists responsible for map making. This is the nature of field geologic mapping and is nothing unusual, but it must be kept in mind that most of the mapped contacts, fold traces, and fault traces are best interpretations only and are seldom, if ever, constrained by continuous, or even multiple, observations. For fold and fault traces, dashed lines to indicate “approximately located” are in common use. For purposes of interpreting the geologic maps of the three study areas, users should consider every unit contact on Plate 1 and Figure 3-9 to be approximately located, with an estimated uncertainty of approximately 5 to 15 m. This uncertainty estimate is based on a combined uncertainty on the part of the geologist locating the contact in the field, the GIS specialist georeferencing the previously published map, and the geologist or GIS specialist digitizing the data from the previously published map, and on the integration of various maps into a single compilation geologic map. It can be inferred that uncertainties are less where several bedding attitudes are shown close to unit boundaries, and greater where few or no bedding attitudes are shown.

In many areas, especially where the maps show few or no structural measurements, the unit contacts should be considered to be approximately located to within 20 or 30 m, or even inferred (i.e., reflecting the field geologist’s preferred interpretation given limited information). The location uncertainty in bedding attitudes themselves also varies. For the GMP, geologists had access to high-resolution hillshade images and GPS that resulted in very precise locations with low location uncertainties. In contrast, most prior mapping represented in the compilation data was performed using 7.5-minute topographic quadrangle maps. Location uncertainties for bedding attitudes using these techniques are probably much higher, on the order of 5 to 10 m or so depending on the topography and proximity to landmarks. Geologists reviewing and interpreting the geologic maps of the site areas should be aware of such uncertainties based on prior experience and are encouraged to practice standard levels of care and judgment. For purposes of using the geologic maps to aid in the interpretation of seismic-reflection data, these uncertainties in the data are considered within the error from the seismic data and, hence, are acceptable.

Within the DCPP study area (Plate 2), more precise data are available within the areas of focused investigations (e.g., PG&E, 1974, 2004) and sea cliff and artificial exposures. The density of bedding attitudes reflects these areas of greater and lesser data availability, and hence, precision. Unit boundaries on Plate 2 are shown with standard map symbols, and in this study area, the interpreter should be able to distinguish more readily well-located contacts and structures from those that are approximately located or inferred. Within the Plate 2 area, we consider a well-located contact to be within approximately 5 m and an approximately located contact to be within approximately 10 to 15 m.

7.2 Stratigraphy of the Study Area

The following subsections describe the stratigraphic units of the map area and the nature of the contacts between those units.

7.2.1 Franciscan Complex Rocks

The Cretaceous to Jurassic Franciscan Complex (unit symbol KJf where undifferentiated) in the project area consists of multiple lithologies. The most widespread Franciscan Complex unit is mélange (unit symbol KJfm) with knockers of graywacke (gw); shale (sh); schist (sch); blueschist (bs); conglomerate (cg); metavolcanic rocks (mv); silica carbonate (sc); and green, white, or red chert (ch). Also widespread are mapped bodies of metavolcanic rocks (KJfmv); serpentinite (s); and graywacke (KJfg). In one area—Port San Luis—a mappable body of ophiolite is categorized as part of the Franciscan Complex (KJfo), reflecting its emplacement history and honoring the original age designation of these rocks by Hall (1973a).

Lithologic contacts within the Franciscan Complex are almost exclusively faulted. In contrast, unit boundaries between the Franciscan Complex and younger units are a mixture of unconformable contacts and fault contacts. At the surface, the size distribution of sub-units within the Franciscan Complex is considerable, ranging in scale from several meters to several kilometers; it is likely that such a size distribution is present at depth. Within any given sub-unit, the size and density distribution of fracturing and other rock discontinuities is also variable between scales of tens to hundreds of meters. This results in frequent juxtaposition of highly fractured and competent bedrock. Such complex stratigraphic and discontinuity juxtaposition should be considered during interpretation of seismic-reflection profiles through Franciscan Complex rocks.

An isolated body approximately 8,000 m^2 in areal extent within Franciscan mélange was mapped by Hall and Prior (1975) and Hall et al. (1979) as queried Toro Formation marine shale and sandstone (their unit symbol KJt?) in the northeastern Irish Hills (Figure 7-1).

Due to its comparable size to other mapped sub-units within the mélange, we recharacterize this sub-unit as shale (sh) on Plate 1. The attribute table in the GIS shapefile includes a record of the original map designation.

7.2.2 Cretaceous Sandstone

Cretaceous sandstones (Ks) in the project area are arkosic to lithic sandstones, brown, well-bedded, well-lithified, and fine- to coarse-grained, and include minor shale. Contacts with Franciscan Complex rocks are almost exclusively faulted. Contacts with overlying Tertiary (Paleogene and Neogene) units may be unconformable (e.g., with Squire Formation, Tpps); intrusive (with diabase, Tmod); or faulted (e.g., with Obispo Formation, Tmo, along the San Miguelito fault zone).

7.2.3 Morro Rock–Islay Hill Volcanic Intrusive Complex

The Oligocene Morro Rock–Islay Hill volcanic intrusive complex (Tom) defines a northwest-trending alignment of lava domes, intrusive sheets, and felsic-rhyolite dacite. Dacite plugs on Plate 1 are located between eastern San Luis Obispo and Morro Rock at the mouth of Morro Bay (Morro Rock is located outside the Irish Hills study area but within the base image of Plate 1). Potassium/argon dates from multiple samples range from approximately 23 to 28 million years ago (Ma; Cole and Stanley, 1998). Although the surficial distribution of plugs is well constrained by the mapping, the subsurface extent and depth of the intrusive bodies are unknown and possibly may be imaged in the seismic-reflection data.

7.2.4 Cambria Felsite

The Oligocene Cambria Felsite (Tocf) has been mapped in a small area near the northern edge of the Irish Hills study area. This light gray felsite is deposited unconformably on Franciscan Complex mélange. Due to its limited extent and location at the northern edge of the map area, this unit has minimal importance for the interpretation of seismic-reflection data.

7.2.5 Vaqueros Formation

The Oligocene Vaqueros Formation (Tov) defines the base of Tertiary (Paleogene and Neogene) sedimentary section in the project area. The Vaqueros Formation in the Pismo syncline and surrounding vicinity is characterized by tan to gray, nonvolcanic, nonmarine conglomerate and shallow marine, locally fossiliferous conglomerate and sandstone. It is inferred to postdate the Morro Rock–Islay Hill intrusive complex and Cambria Felsite, and has been dated at approximately 24 to 26 Ma using strontium isotope ratios on bivalves in near-basal strata (Keller et al., 1996).

Within the north-central Irish Hills, along the northeast limb of the Pismo syncline, the Vaqueros Formation is faulted against the Franciscan Complex in some places and unconformably overlies the Franciscan Complex in other places. The resistant nature of the Vaqueros Formation commonly results in ridge-forming outcrops, particularly along the Edna fault zone on the northeast side of the Pismo syncline. On the south side of the

Irish Hills, along the southern margin of the Pismo syncline and the San Miguelito fault zone, a few discontinuous areas are mapped as Vaqueros Formation and overlying Rincon Formation. Outcrops of Vaqueros sandstone in these areas were studied by Keller et al. (1996), but the exposures are poor, and the areal distributions shown on Plate 1 should be considered approximate. The interpretation team should consider the mapped distribution of Vaqueros Formation along the San Miguelito fault zone to be moderately to poorly constrained. The limited outcrops in this area imply that additional field investigations may be unable to reduce this uncertainty.

7.2.6 Rincon Formation

The Miocene Rincon Formation (Tmr) is observed in the north-central Irish Hills in road-cut exposures along the Edna fault zone to be a siltstone and silty claystone, dark brown, and thinly bedded to massive. The Rincon Formation is commonly mappable because of its propensity for landsliding. In drill logs for oil exploration wells (e.g., Honolulu-Tidewater 1 and Montadoro 1; see Appendix E), the Rincon Formation is commonly described as including intervals of dolomitic sandstone and volcanic tuff. This contrasts with published descriptions of Rincon Formation as a deep marine argillaceous mudstone and shale (Keller et al., 1996), with no mention of volcanic facies, although Hall and Corbato (1967) describe local interfingering of Obispo and Rincon Formations in the Nipomo Quadrangle area southeast of the Irish Hills. The interbedded sequence of dolomitic sandstone, siltstone-shale, and tuff noted in the drill logs of these local oil exploration wells is consistent with natural coastline exposures near the DCPP, where Hall (1973a) and, later, PG&E (1990, 2004, 2011) mapped these exposures as Obispo Formation. The seismic interpretation team should consider that the sequences of shale, dolomitic sandstone, and tuff recorded in the drill logs and originally classified as Rincon Formation may instead correlate with Obispo Formation mapped at the surface near the DCPP.

Where unfaulted, Rincon Formation is commonly found overlying Oligocene Vaqueros Formation. As mentioned above, the Rincon Formation mapped in the southern Irish Hills along the San Miguelito fault zone on the south side of the Pismo syncline appears to be based on a few exposures of Vaqueros sandstone, and its areal distribution shown on Plate 1 should be considered approximate. The interpretation team should consider the mapped distribution of Rincon Formation along the San Miguelito fault zone to be moderately to poorly constrained.

7.2.7 Obispo Formation

The Miocene Obispo Formation is a volcanic and volcaniclastic unit within the Pismo Basin and portions of the Santa Maria Basin (Hall et al., 1966; Hall and Corbato, 1967; Schneider and Fisher, 1996). Regionally, the formation consists of white tuff, mafic lava flows, intrusive dikes and sills, and volcanic shales and sandstones. The formation thickness cited in the literature ranges from less than 400 m to as much as approximately 1,300 m (Hall and Corbato, 1967; Schneider and Fisher, 1996). Radiometric dates obtained from tuffs in the lower part of the Obispo Formation range from approximately

15 to 18 Ma (Cole and Stanley, 1998), and sparse marine fauna indicate a Saucesian to Relizian age (Hall et al., 1966).

The Obispo Formation thickness varies considerably within the Irish Hills study area. In the southwestern Irish Hills, and specifically in the DCPP study area, the Obispo Formation is approximately 1,500 m thick. Similar thicknesses are suggestive at depth within the Honolulu-Tidewater well (Appendix E). In the central Irish Hills, along the northeastern margin of the Pismo syncline, the Obispo Formation is less than 100 m thick, with an exposure on the order of 40 m thick adjacent to U.S. Highway 101 (Schneider and Fisher, 1996). The subsections below describe the Obispo Formation within the Irish Hills study area in more detail.

7.2.7.1 Volcaniclastic and Clastic Sub-units

The volcaniclastic sub-units of the Miocene Obispo Formation (Tmo where undifferentiated) are composed of welded tuffs and tuffaceous to diatomaceous and dolomitic siltstones and fine sandstones. On Plate 1, all clastic sub-units of Obispo Formation are shown as a similar light blue color (Tmo). Within the DCPP study area (Plate 2), sub-units of the volcaniclastic Obispo Formation are shown. The tuffaceous sub-unit (Tmor), which includes zeolitized, white silicic tuff, tuffaceous sandstone, and peperite, is resistant to erosion. The resistant nature of this sub-unit results in prominent ridge-forming outcrops inland and steep sea cliffs and seastacks along the coastline. Within the mostly tuffaceous, resistant Tmor sub-unit in southern Discharge Cove and east of Intake Cove are indurated very fine sandstone and siltstone beds that ring with a hammer when hit. It is unclear whether these fine-grained but resistant beds are stratigraphically equivalent to the Rincon Formation mapped elsewhere in the Pismo Basin (suggesting interfingering of the lower Obispo and Rincon Formations), or whether these beds interspersed with tuffaceous rocks are stratigraphically higher in the section.

The fine-grained sub-unit (Tmof) is a fining-upward sequence of dolomitized, tuffaceous to diatomaceous sandstone and shale. The fine-grained sub-unit is commonly in fault contact with Tmor along the coast, but generally appears to overlie it and interfinger with it elsewhere along the eastern margin of the Pismo syncline. Plate 2 further distinguishes the lower silt and shale fine-grained sub-unit Tmofc from the more common coarser-grained siltstone and fine sandstone sub-unit Tmofb that underlies the Diablo Canyon power block and the ISFSI (PG&E, 2004). The Tmofc sub-unit is intensely folded where observed in Discharge Cove, and is mapped in fault contact with the resistant, tuffaceous Tmor (Plate 2). The Tmofc sub-unit is in fault contact with Tmofb in northern Discharge Cove but conformably underlies the Tmofb sub-unit in southern Discharge Cove (in a gradational contact).

The Honolulu-Tidewater well (Appendix E), drilled in the central Irish Hills, includes an interval approximately 100 m thick between Obispo tuff and Monterey Formation that was logged as Point Sal Formation. Point Sal Formation is regionally mapped in the Huasna Basin by Hall and Corbato (1967) and Hall (1973b), but has not been mapped in the Pismo syncline by Hall (1973b), Hall et al. (1979), or more recent authors. In

Appendix E we propose a reinterpretation of the interval as belonging to the fine-grained sub-unit of the Obispo Formation, based on the mapping within the Irish Hills study area.

7.2.7.2 Obispo Formation, Diabase Sub-unit

The intrusive sub-unit of the Obispo Formation (Tmod) is aphanitic to phaneritic, brown to dark gray diabase that has intruded into the tuff and volcaniclastic Obispo Formation in dikes and sills. South of the DCPP, at the base of Green Peak, the mafic volcanics occur at the base of the Obispo Formation, where they are juxtaposed against pre-Cenozoic rock (Plate 1). Because the contact is inaccessible from land, its exact nature has not been examined in detail and remains uncertain. Here, the seismic-reflection interpretation team should consider whether additional Obispo Formation and lower Neogene and Paleogene units may be stratigraphically below the diabase where the Obispo Formation lies in possible fault contact with Franciscan Complex rocks. Higher up on the hillside of Green Peak, additional lens-shaped exposures of mafic volcanic rock have been identified, suggesting that sills intruded higher into the Obispo section.

Within the DCPP site area (Plate 2), the diabase sub-unit is exposed adjacent to the breakwater of Intake Cove and within the hillside northwest of Diablo Canyon Creek. The expansive diabase mapped offshore of the DCPP—extending southwest to the Shoreline fault zone—is uncertain but suggested, based on considering the following information:

- Mapping the diabase off the Intake Cove breakwater and along the coastline southeast of the DCPP.
- The texture of the submerged rocks imaged from the MBES data.
- High magnetic susceptibility values from the helicopter magnetic survey (PG&E, 2011, Appendix D).

The diabase map pattern suggests dike and sill relationships to the top of the Obispo Formation (Plates 1 and 2). This provides evidence that the mafic intrusions postdated or occurred episodically during deposition of the volcaniclastic sub-units.

7.2.8 Monterey Formation

The Miocene Monterey Formation (Tmm) is a tuffaceous, siliceous, and diatomaceous siltstone and porcelaneous shale. It is brown (weathers to chalky white), thinly bedded and well lithified, and includes common chert laminations. Where exposed, its basal contact with the Obispo Formation is commonly a subtle angular unconformity. The map relations suggest that the diabase sub-unit of the Obispo Formation does not extend upsection to intrude into the Monterey Formation, and diabase appears to be truncated along an angular unconformity at the base of the Monterey Formation directly north of the DCPP switchyards (Plate 2). Mapping for the GMP indicates that the Monterey Formation is largely absent in the northern part of the Irish Hills, along the northeastern margin of the Pismo syncline (Plate 1). This contrasts with the southwestern Irish Hills, where the Monterey Formation is approximately 1,000 m thick along the southwestern margin of the Pismo syncline.

7.2.9 Pismo Formation

The upper Miocene to Pliocene Pismo Formation can be subdivided into a lower and an upper part. The lower Pismo Formation has two members described by Hall (1973a, 1973b): the Edna (Tmpe) and the Miguelito (Tmpm) Members. Both members are mapped in the central Irish Hills within the Pismo syncline. The Edna Member is more prevalent within the Price Canyon study area (Figure 3-9), and the Miguelito Member is more prevalent within the Irish Hills study area (Plate 1). As mapped within the Irish Hills study area, localized interfingering between the members occurs in the eastern Irish Hills, near San Luis Obispo Creek, although the Edna Member is more commonly mapped as the basal member, including along the northwest end of the Edna fault zone (Plate 1). The Edna Member is a fine-to-medium lithic to arkosic sandstone, thinly bedded to unstratified, weakly to moderately indurated, and includes bituminous intervals (Hall, 1973b). The Miguelito Member is dominantly siltstone to claystone, with localized fine sandstones and rare gravelly sands. It is brown, thinly bedded, and moderately well lithified, and includes rare to common intervals of siliceous and dolomitic siltstone, opaline and porcelaneous shale, and bituminous sandy siltstone.

Alternative stratigraphic schemes put the lower Pismo Formation within the Monterey Formation (e.g., Dibblee, 2006a, 2006b, 2006c), and historically, geologists logging oil and gas exploration wells likely considered the lower Pismo Formation as part of the Monterey Formation (Appendix E). The basal contact of the Pismo Formation appears conformable on Monterey Formation where mapped near Point Buchon, where it has been dated at approximately 9 to 10 Ma (Schwalbach and Bohacs, 1996). In contrast, the basal contact of the Pismo Formation is clearly unconformable in the northwestern Irish Hills along the northeastern margin of the Pismo syncline where Monterey Formation and Obispo Formation are progressively cut out (Plate 1). An angular unconformity with the Monterey Formation along the southwest limb of the Pismo syncline in the southwestern Irish Hills is suggested from bedding attitudes on either side of the contact (Plate 1) but is not obvious in the field.

The upper Pismo Formation unconformably overlies the lower Pismo Formation and other Tertiary and pre-Tertiary units within the Irish Hills study area. Of probable Pliocene age, it consists of the Gragg (Tppg), Belleview (Tppb), and Squire (Tpps) Members, from oldest to youngest, respectively. Distribution of the upper Pismo Formation is largely limited to the southeastern portion of the Irish Hills study area and areas adjacent to the Price Canyon study area. The Gragg Member is a fine-to-medium sandstone with rare diatomaceous siltstone, pebble conglomerate, and bituminous sandstone. The Belleview Member is composed of sandy claystone, siltstone, claystone, and fine-grained sandstone. Localized diatomaceous horizons are also present. The Squire Member represents the last major episode of marine deposition recorded by rocks of the Irish Hills and adjacent areas. It is locally benched into pre-Tertiary rocks in the southern Irish Hills southwest of the San Miguelito fault zone. The Squire Member is composed of unstratified white to tan medium-to-coarse-grained sandstone.

7.2.10 Quaternary Deposits

Quaternary deposits within the Irish Hills, DCPP, and Price Canyon study areas include terrestrial deposits of alluvium (Qal), alluvial fan deposits (Qaf), fluvial terrace deposits (Qt), colluvium (Qc), landslides (Qls), aeolian sands (Qe), marine terrace deposits (Qm), and older deposits of weakly lithified alluvium (Qoa). In general, the Quaternary mapping of terrestrial deposits across the study areas is of varied quality, mainly due to the bedrock-oriented nature of most maps considered in the compilation. The mapping of marine terraces along the coast (PG&E, 1990; Hanson et al., 1994; Wiegers, 2009) and Quaternary deposits along Los Osos Valley (Lettis and Hall, 1994; Wiegers, 2009, 2010) were performed with a careful consideration of Quaternary deposits and Quaternary stratigraphic relations.

The Quaternary stratigraphic schemes and criteria for defining a bedrock-Quaternary contact in these studies differed from the bedrock-focused maps of C.A. Hall and colleagues. The geologic mapping of Wiegers (2009, 2010) combined elements of both bedrock- and Quaternary-focused stratigraphic schemes that resulted in alternative depictions of Quaternary units and Quaternary/pre-Quaternary boundaries from those of Lettis and Hall (1994). The general approach taken for the Irish Hills and Price Canyon study areas was to consider first the Quaternary contacts and stratigraphy of Lettis and Hall (1994) and PG&E (1990), second to consider alternative interpretations by Wiegers (2009, 2010), and lastly take contacts and stratigraphy by C.A. Hall. In parts of the study areas not covered by Lettis and Hall (1994) or Wiegers (2009, 2010, 2011), the boundaries and stratigraphy of maps by C.A. Hall were used.

Because of the GMP's focus on bedrock mapping that is most useful for the interpretation of seismic-reflection data, the Quaternary stratigraphic scheme was simplified (e.g., nested terrace deposits are not differentiated by relative age). Also, the Quaternary units remain somewhat inconsistently mapped across the study areas (e.g., alluvial fans (Qaf) and colluvium (Qc) are inconsistently delineated and differentiated from alluvium (Qal). We note that deposits mapped as Paso Robles Formation by C.A. Hall and colleagues are symbolized as Quaternary older alluvium (Qoa), generally following the stratigraphic scheme of Lettis and Hall (1994) and Wiegers (2009, 2010). Implications of the simplified and inconsistent Quaternary mapping for the interpretation of seismic-reflection data are few, with the exception that careful mapping of Quaternary deposits may yield insight into the location and activity of active structures bordering the Irish Hills (e.g., Hanson et al., 1994).

Additional Quaternary deposits shown on the geologic map of the Irish Hills study area include estuarine deposits in Morro Bay (Qes) and offshore marine sediments (Qs), sand wave deposits (Qsw), and offshore channel fill deposits (Qcs). The mapping of offshore deposits is based on PG&E (2011).

7.3 Geologic Structure of the Study Areas

Faults and folds within the GMP study areas reflect a prolonged geologic history of tectonic deformation. This data report does not attempt to unravel that history, but rather describes the general characteristics of the folding and faulting that are observed in the field and portrayed on the maps. The following subsections address folding, then faulting.

7.3.1 Folding

The Pismo syncline is a regional structure that trends northwest-southeast across the Irish Hills and Price Canyon study areas (Hall and Corbato, 1967; Hall, 1973a, 1973b; Hall and Prior, 1975). Within the Irish Hills, the Pismo syncline is synonymous with the limits of the Tertiary Pismo Basin, which is bounded to the northeast and southwest by faults, including the Edna and San Miguelito fault zones (Plate 1). West of the northwest end of the San Miguelito fault zone, the southwestern margin of Tertiary strata steps west and follows the base of Green Peak before going offshore southeast of the DCPP. Offshore of the DCPP, it is probable that the Shoreline fault zone coincides with the southwestern margin of the Pismo syncline.

The entire Tertiary stratigraphy is involved in the generally synclinal folding, with moderately southwest-dipping Vaqueros, Rincon, Obispo, Monterey, and lower Pismo Formations on the northeast side of the fold, and moderately north- to northeast-dipping Vaqueros, Rincon(?), Obispo, Monterey, and lower Pismo Formations on the southwest side of the fold. Thicknesses of Tertiary (especially Miocene) strata differ on either side of the fold, with substantially greater thicknesses of Pismo and Monterey Formations exposed along the southwest limb of the syncline than along the northeast limb, and pinch-outs of Obispo and Monterey Formations along the northeast limb from southeast to northwest.

Within the Pismo Basin are numerous second-order (herein defined as “map-scale”) and third-order (herein defined as “outcrop-scale”) anticlines and synclines that trend northwest-southeast. The GMP geologists were instructed to take bedding measurements that were representative of larger, map-scale fold limbs, so the attitudes on Plate 1 from the GMP data are intended to represent map-scale, and not outcrop-scale, structures. Bedding attitudes compiled from other maps are probably representative of map-scale features as well. The collection of bedding attitudes and interpretation of fold axial traces suggest that the Pismo syncline is not defined by a single continuous axial trace, but rather by a zone of smaller folds several hundred meters wide (Plate 1).

Other map observations suggest that the Pismo syncline changes structure across San Luis Obispo Creek. Bedding attitudes in the Irish Hills west of San Luis Obispo Creek (Plate 1) show generally steeper dips and delineate more closely spaced, tighter folding compared to the San Luis Range east of San Luis Obispo Creek, including the Price Canyon study area (Figure 3-9; Hall, 1973b). The tighter folding within the Irish Hills block may reflect greater amounts of shortening there compared with the syncline to the southeast; this difference should be considered when interpreting seismic-reflection data in the Price Canyon study area and comparing results to seismic-reflection interpretations in the Irish Hills study area. Additionally, the syncline recorded within the upper Pismo Formation located across the lower reaches of Pismo Creek in the southeast corner of Plate 1 suggests that deformation of the Pismo syncline has developed and continued into Pliocene time. The axial trace of this part of the syncline is oriented almost east-west, in contrast to the more northwest-southeast trend of the syncline through the rest of the Irish Hills.

The major bedded units within the Neogene section—the Obispo, Monterey, and lower Pismo Formations—were all observed locally to record considerable shortening, including recumbent folding and chaotic, refolded folds. One example of recumbent folding is within the clastic units of the Obispo Formation near Diablo Canyon, along the ridgeline between Green Peak and the plant within Tmofb (Plate 2). Isoclinal folding is present in the sea-cliff exposures at the south end of Discharge Cove within fine-grained Tmofc (Plate 2). Interpreters of seismic-reflection data should consider the impact that this folding style, and resulting amounts of shortening and thickening, may have on the interpretation of reflectors in the seismic-reflection data and restorability of geologic cross sections.

In the well-bedded Monterey Formation and Miguelito Member of the Pismo Formation, folding is the predominant deformation style. This folding is likely associated with bedding-parallel slip and contraction within the limbs of larger-scale folds, including the Pismo syncline. These folds likely root into small out-of-syncline thrusts and detachment surfaces along mechanically weaker beds that do not project to substantial depths. This deformation style should be considered during interpretation of seismic-reflection data and cross-section construction.

Folding and tilting within the pre-Tertiary Franciscan Complex and Cretaceous sandstone record the prolonged tectonic history of subduction and accretion prior to Miocene basin formation. Much of the folding in these rocks pre-dates the deformation associated with the Pismo syncline. Generally, the attitudes measured along the outer coast from the south flank of Green Peak to San Luis Hill show moderate to steep dips to the north and south, particularly within the extensive Cretaceous sandstone. The overturned beds near Rattlesnake Creek (Plate 1) suggest that, at least locally, stratigraphic up faces south. This facing direction is opposite the north-side-up facing direction within Tertiary strata along the margin of the Pismo syncline. Franciscan Complex rocks exposed along the northeast flank of the Irish Hills, and northeast of the Pismo Basin, have few measured bedding or foliation attitudes (Plate 1). The outcrop pattern of contacts between graywacke (KJfg), metavolcanics (KJfmv), and other Franciscan lithologies suggests possible gently dipping fabrics. Elongate bodies of serpentinite with relatively straight fault-bounded margins along the Los Osos and Edna fault zones, however, suggest steep fabrics within the Franciscan Complex along and parallel to fault zones.

7.3.2 Faulting

Like folding, faulting is observed at all scales and in all pre-Quaternary rock units across the Irish Hills study area (Plate 1). Most commonly, faults at the outcrop scale are consistent with bedding-parallel shear and suggest minimal cumulative displacement based on visible offset beds or similar strata. In general, few conclusive observations of fault kinematic indicators (to provide slip direction) were made in the field. No new faults of appreciable scale or displacement were identified in the field effort.

The prominent faults within the Irish Hills study area are the Los Osos, Edna, San Miguelito, San Luis Bay, and Shoreline fault zones. Because the characterization of these fault zones is one of the primary objectives for the seismic-reflection survey, map evidence for each fault zone is discussed in the following separate subsections.

7.3.2.1 Los Osos Fault Zone

The Los Osos fault zone was characterized by the LTSP (PG&E, 1988) and Lettis and Hall (1994) as a late Quaternary reverse fault that defines the northern and northeastern margin of the San Luis Range. Primary evidence for late Quaternary activity came from topographic observations of an uplift-rate boundary across the San Luis Range front, mapping aerial photo lineaments along the range front, paleoseismic trenches across a few of the lineaments approximately half a kilometer south of the intersection of Los Osos Valley Road and West Foothill Boulevard, and the abrupt change in structural relief at the northern edge of the Irish Hills between uplifted late Quaternary terraces benched into the Irish Hills and Quaternary stratigraphy encountered in hydrogeologic wells within the Morro Bay basin (Lettis and Hall, 1994).

Lettis and Hall (1994) defined three onshore segments of the Los Osos fault zone:

- The Irish Hills segment, located between the coastline south of Morro Bay and San Luis Obispo Creek (i.e., within the Irish Hills study area on Plate 1).
- The Lopez Reservoir segment, located between San Luis Obispo Creek and Arroyo Grande Creek, including across the Price Canyon study area on Figure 3-9.
- The Newsome Ridge segment, located between Arroyo Grande and the intersection of the Los Osos fault zone with the West Huasna fault zone.

The Los Osos fault zone was not a widely recognized Quaternary structure prior to the LTSP. Subparallel to the northeastern margin of the Irish Hills, and mostly southwest of the lineament zone identified by PG&E (1988) and Treiman (1989), mapping by Hall (1973a) and Hall et al. (1979) characterized the Los Osos fault zone as a subvertical zone of faults bounding serpentinite within Franciscan Complex metavolcanic rocks (Plate 1). Lettis and Hall (1994) highlighted that this serpentinite-defined part of the Los Osos fault zone locally cuts older alluvium (Paso Robles Formation?) and includes lineaments that may be indicative of late Quaternary activity. Lettis and Hall (1994) re-defined the Los Osos fault zone in two main ways. First, they broadened the fault zone to encompass the zone of lineaments in Franciscan Complex rocks and Quaternary deposits northeast of the bedrock fault zone. Second, they lengthened the fault zone to follow the northeastern and northern topographic front of the entire San Luis Range. This included lengthening the fault to the west to follow the boundary between the Irish Hills and Morro Bay basin, and lengthening the fault to the southeast to follow the boundary between the Tertiary rocks exposed in the San Luis Range and the Quaternary deposits in Edna Valley.

The GMP geologists performed reconnaissance mapping along the Los Osos fault zone between Highway 101 and Montaña de Oro State Park and where the fault zone crosses seismic-reflection lines (Figure 3-1; Plate 1). The lineaments identified by Lettis and Hall (1994) and the California Geological Survey (Treiman, 1989; Wiegers, 2010) and the previously mapped serpentinite-defined Los Osos fault zone were reviewed on LiDAR data and in the field with a focus on testing multiple hypotheses. Four alternative hypotheses were proposed for the Los Osos fault zone as an active fault within the current tectonic regime:

1. The interpretation by Lettis and Hall (1994) that the Los Osos fault zone is a zone of continuously emergent reverse faults across the entire northern and northeastern margins of the Irish Hills.
2. The Los Osos fault zone is a northeast-vergent blind thrust or reverse fault that locally is emergent.
3. The Los Osos fault zone along the northeastern margin of the Irish Hills is a late Quaternary right-lateral or right-lateral-oblique fault zone, with the steeply dipping serpentinite-defined Los Osos fault perhaps accommodating the majority of the right-lateral strike-slip movement.
4. The northeastern front of the Irish Hills is not bordered by an emergent late Quaternary active fault, but rather is bounded by a fold hinge that may be locally breached by secondary faulting.

General findings of the reconnaissance by GMP geologists are as follows:

- No new exposures of the Los Osos fault zone were found, including within Quaternary deposits and along the serpentinite-defined Los Osos fault strands.
- No wells clearly penetrate or uniquely constrain the location and dip of the Los Osos fault zone.
- Modern streams crossing the serpentinite-defined or lineament-defined Los Osos fault zone were not found to be systematically offset either in a right-lateral or left-lateral sense.
- Lineaments identified by Lettis and Hall (1994) and Wiegers (2010) in Los Osos Valley are consistent with either a fluvial or tectonic origin.
- Mapping near the northeast end of the Irish Hills, approximately half a kilometer southeast of the intersection of Los Osos Valley Road and Turri Road, revealed a prominent ridge extending into Los Osos Valley that is underlain by chert. This chert ridge constrains the location of an emergent Quaternary fault (if present) to be north or south of the chert outcrop (see also Section 7.4.4).
- Sharply defined geomorphic expression consistent with late Quaternary faulting along the Los Osos fault zone is limited to two reaches approximately 4 km apart along the northeast side of the Irish Hills. The northwestern reach is directly south and southeast of the above-mentioned chert ridge, and is a narrow zone of low, northeast-facing scarps within and adjacent to an elongate band of serpentinite. The southeastern reach is within the approximately 1-km-wide zone of bedrock faults and range-front lineaments that were mapped in detail and trenched by PG&E (1988) and documented by Lettis and Hall (1994).

- Outcrops of probable Edna Member of the lower Pismo Formation were observed adjacent to the Los Osos fault zone overlying Franciscan Complex metavolcanic rocks along the northeast side of the Irish Hills. The presence of these outcrops, located approximately 1 and 2 km west of the intersection between Los Osos Valley Road and West Foothill Boulevard, suggests that southwest-side-up vertical offset across an emergent Los Osos fault zone at the margin of the Irish Hills may be limited.

In addition to the findings and observations made in the field during the GMP, evidence from recent compilations of borehole data (Cleath & Associates, 2003, 2005; AMEC, 2012b) provides additional information about the Los Osos fault zone that is reflected on the Plate 1 and may be considered when interpreting the seismic-reflection data and evaluating alternative hypotheses for the Los Osos fault zone. First, Cleath & Associates (2005) reviewed the basis for a northwest-trending splay of the Los Osos fault zone underlying the Morro Bay basin (called the Los Osos Valley groundwater basin in Cleath & Associates (2003, 2005)) that was mapped by PG&E (1988) and Lettis and Hall (1994). An evaluation of a larger set of hydrogeologic wells drilled throughout the basin concluded that the stratigraphic associations interpreted by PG&E (1988) that were the basis for identifying a fault were probably incorrect, and a preferred stratigraphic interpretation of the larger set of wells does not support a Quaternary fault through the basin. On this basis, Plate 1 does not show a northwest-trending splay beneath the Morro Bay basin.

Additionally, the review and evaluation of borehole data by Cleath & Associates (2005) conclude that there is general support for the presence of a concealed Los Osos fault zone (that locally includes a buried, subparallel fault splay) along the southern margin of the Morro Bay basin based on the top-of-rock elevations encountered in borings and outcrop locations. Plate 1 adopts the general location of the concealed Los Osos fault zone by Wiegers (2011) with the splay mapped by Cleath & Associates (2005) here. Lastly, Cleath & Associates (2005) included two north- to northeast-trending faults within the southern portion of the Morro Bay basin directly west of Los Osos Creek that are the northern continuation of two north-trending strands of the Edna fault. Cleath & Associates (2005) describe the rationale for mapping these structures and inferring Quaternary activity on them north of the Los Osos fault. Because their existence north of the Los Osos fault is not supported by map relations or stratigraphic observations in borings, and there are alternative explanations for the observed changes in groundwater elevation, we do not display the continuation of the north-trending faults north of the Los Osos fault on Plate 1.

The second result from recent borehole compilations is confirmation of the general finding of Lettis and Hall (1994) that appreciable aggradation of Quaternary deposits northeast of the Los Osos fault zone is restricted to two isolated locations: the Morro Bay basin and a smaller basin south of San Luis Obispo across San Luis Obispo Creek. Elsewhere, bedrock in the Los Osos and Edna Valleys is shallow, suggesting the absence of a footwall basin that would be predicted from a simple northeast-vergent thrust or reverse Los Osos fault zone.

The above findings can inform the four alternative hypotheses posed for the Los Osos fault zone, and provide information for the seismic-reflection interpretation team to consider when investigating the Los Osos fault zone in the geophysical data. None of the findings by the GMP are sufficient to rule out any of the alternative hypotheses.

As a result of the reconnaissance mapping, borehole review, and interpretation, an updated map of the Los Osos fault zone is presented on Plate 1. The Los Osos fault zone (or alternative range-bounding structure) bounding the northern and northeastern margins of the Irish Hills is shown on Plate 1 as concealed and queried fault traces, lineaments, and faults that mark the approximate boundary between the Irish Hills and adjacent, lower-lying areas. This zone can be subdivided into four reaches, which are described from west to east-southeast.

The westernmost reach of the Los Osos fault zone, which we informally name the western reach, is between the coastline south of Morro Bay and approximately where Los Osos Creek crosses the northern front of the Irish Hills. The western reach strikes east-west for a distance of 4 to 5 km and juxtaposes the uplifted Irish Hills to the south and the subsiding Morro Bay Basin to the north (Lettis and Hall, 1994). The abrupt change from uplift to subsidence is constrained by bedrock and marine terrace mapping and borehole logs (Hanson et al., 1994; Lettis and Hall, 1994; Cleath & Associates, 2003. 2005; see Appendix E).

Clear observations of a surface-fault trace are lacking along the western reach, although there are candidate lineaments locally (Plate 1; Lettis and Hall, 1994), and a surface trace may be obscured by Quaternary aeolian deposits (Qe) that blanket the range front (Plate 1). A surface trace does not appear in the offshore MBES data along this same strike (PG&E, 2011a), suggesting that if a strand of the Los Osos fault zone is emergent along the northern margin of the Irish Hills it ends at or near the coastline. Possible secondary fault traces near the coastline north of the range front were interpreted from geophysical data; these traces, adopted from Wiegers (2009), are shown as short, concealed faults beneath the beach and dunes in southern Morro Bay (Plate 1). As described above, a concealed, subparallel splay of the Los Osos fault zone is mapped near Los Osos creek based on changes in depth to top of bedrock between closely spaced boreholes by Cleath & Associates (2005). Based on the abrupt change in vertical rate but the lack of evidence for a surface trace, the entire western reach of the Los Osos fault zone is mapped as a concealed fault. This interpretation suggests the change in uplift rate is accommodated by a fault that is either blind or buried, although we acknowledge that the data are consistent with the change in uplift rate being accommodated by an abrupt fold hinge that is not necessarily cored by a fault.

The reach of the Los Osos fault zone east of Morro Bay—informally named the west-central reach—is approximately 4 km long between Los Osos Creek and a location where the trend of the Irish Hills range front changes from east-west to northwest-southeast (Plate 1). The west-central reach trends east-west like the west reach, but unlike southern Morro Bay, the crust north of the Irish Hills here does not appear to be subsiding. Borings show thin Plio-Pleistocene deposits (Cleath & Associates, 2003), and the distance between the Irish Hills and the adjacent hills to the north diminishes abruptly (Plate 1).

No clear candidate fault traces and few lineaments have been identified along this reach (Plate 1; Lettis and Hall, 1994). Based on the less abrupt nature of the Irish Hills range front and a lack of evidence for a surface fault, the west-central reach is mapped with a concealed and queried fault coinciding with the topographic range front. This map pattern suggests that the change in uplift rate may be accommodated by a blind or buried fault, but it is equally permissible that the change in uplift rate is accommodated by a fold hinge.

The boundary between the west-central and west reaches coincides approximately with previously mapped concealed faults beneath the Morro Bay basin, including northwest-trending faults (e.g., Lettis and Hall, 1994) and north to northeast-trending faults (Cleath & Associates (2005). As described above, we do not show any north or northwest-trending faults beneath the Morro Bay basin based on the lack of supporting geologic data for their existence. Independent observations in seismic-reflection, seismicity, or other geophysical data may help evaluate the presence or absence and nature of structures in this area.

The reach of the Los Osos fault zone east of the west-central reach is informally named the east-central reach. The east-central reach trends northwest-southeast and is located between the change in trend of the Irish Hills range front and a location approximately 2 km west-northwest of the intersection of West Foothill Boulevard and Los Osos Valley Road (Plate 1). The northwest end of this approximately 4 km long reach coincides with a ridge underlain by continuous chert (ch) near Turri Road that protrudes north across the projection of the range front. Mapped faults in Franciscan Complex rocks (mostly serpentinite and metavolcanics in addition to the chert) south of the chert are linear across small drainages within the foothills of the Irish Hills. Low, northeast-facing scarps and tonal lineaments within the serpentinite are semi-continuous over approximately 1.5 km, and are possible indicators of late Quaternary surface faulting southwest of the range front (although differential erosion in Franciscan Complex bedrock cannot be precluded). No systematic lateral deflection of streams crossing the lineaments or bedrock fault traces was noted from LiDAR or field evaluation.

The east-central reach of the Los Osos fault zone coincides with a narrow (typically 1 km wide or less) Los Osos Valley floored by thin Quaternary deposits, indicating little to no subsidence of the crust north of the Irish Hills. Additional lineaments mapped along this reach are within Quaternary deposits or at the Quaternary-pre-Quaternary contact. These lineaments are mostly tonal or vegetative, confined to valley-axis alluvium, and/or are subparallel to the drainage. The field evaluation of the lineaments was equivocal, with the interpretation that the lineaments may be fault related or stratigraphic and related to buried channel alluvium, with equal likelihood. At the southeast end of the east-central reach, small bodies of the Edna Member of the Pismo Formation are mapped overlying Franciscan Complex rocks near the range front (Plate 1). The presence of upper Miocene strata on pre-Tertiary rocks is suggestive of little post-Pliocene erosion of the range front, and therefore, limited throw on a postulated range front Los Osos fault zone. On the basis of geologic mapping, lack of a footwall basin, and the lineament evaluation, the east-central reach does not express conclusive evidence for an emergent, laterally continuous, active range-front Los Osos fault zone. Alternatively, the change in uplift rate between the Los Osos Valley and northeastern Irish Hills may be accommodated by a blind fault (that may or may not be locally emergent with splay faults). It is equally permissible that the change in uplift rate is accommodated by a fold hinge.

The southeasternmost reach of the Los Osos fault zone within the Irish Hills study area—informally named the east reach—is approximately 6 to 7 km long and is located between San Luis Obispo Creek and a point approximately 2 km west-northwest of the intersection of West Foothill Boulevard and Los Osos Valley Road (Plate 1). This reach includes abrupt scarps and tonal and vegetative lineaments at and near the range front and a linear fault zone within Franciscan Complex serpentinite along the foothills south of the range front (Lettis and Hall, 1994). No systematic lateral deflection of streams crossing the lineaments or bedrock fault traces was noted from LiDAR or field evaluation.

Paleoseismic trenches across several lineaments and the bedrock fault zone revealed evidence for late Quaternary faulting along the east reach, although the relationships between faulting, scarp formation, and differential uplift of the Irish Hills relative to the Los Osos Valley were locally unclear and conflicting (Lettis and Hall, 1994). The northeastern-most trench—Ingley trench T-2— crossed a northeast-facing, 6-m-high topographic scarp near Los Osos Valley Road and contained evidence for a gently (22 to 29°) southwest dipping zone of thrust faults within alluvium that shortened and repeated a prominent soil horizon. Slickensides were consistent with dip-slip faulting and a left-lateral component. The faulting exposed here was interpreted to be the range front Los Osos fault. Other trenches upslope of the Ingley trench T-2 were less straightforward. For example, a trench across the bedrock fault zone (Ellsworth trench T-1) exposed evidence for faulted Quaternary gravels along a steeply northeast-dipping fault with southwest-side-down vertical separation. Striations and folding of Quaternary strata were consistent with northeast- (valley-) side-up reverse faulting. Trenches across prominent scarps farther downslope (at the Cuesta and Ingley sites) exposed evidence that some scarps were not associated with faulting and thus were most likely erosional (Cuesta trench T-1), some faults offsetting Quaternary alluvium did not have recognizable geomorphic expression (Cuesta trench T-3), and a prominent northeast- (valley-) side-down scarp was underlain by a northeast-dipping fault placing Franciscan Complex mélange in the hanging wall against Quaternary alluvium in the footwall (indicating valley-side up faulting) with slickensides consistent with pure dip slip (Cuesta trenches T-2 and T-3). Other faults with geomorphic expression similarly showed evidence for northeast- (valley-) side-up reverse displacement with Franciscan Complex rocks faulted against late Quaternary deposits (Ingley trench T-1).

Lettis and Hall (1994) proposed alternative explanations for the unexpected observations, including scarp formation by erosional (as opposed to tectonic) processes, and normal reactivation of earlier Quaternary reverse faults. The preferred interpretation in general was that deformation observed in trenches in the foothills and near the range front was secondary, hanging-wall deformation above an underlying, southwest-dipping thrust or reverse fault that projected up dip to the range front of the Irish Hills (e.g., such as at Ingley trench T-2). Alternative interpretations to explain the conflicting relationship between the geomorphic scarps and faulting observed in the trenches were proposed with implications for possible changes in dip with depth on an underlying range-front fault (Lettis and Hall, 1994).

Although the east reach of the Los Osos fault zone within the Irish Hills segment includes the strongest evidence for a shallow or emergent, southwest-dipping Los Osos reverse fault, the absence of a footwall basin, and the lack of a compelling, laterally-continuous fault (or fault scarp) at the surface is also consistent with a mostly blind Los Osos reverse fault or a fold hinge at the range front that is locally broken by discontinuous faults. Interpretations of seismic-reflection data across the east and east-central reaches of the Irish Hills should consider the observations of steep faulting in Franciscan Complex rocks at the surface (particularly the serpentinite-defined fault zone along the foothills sub-parallel to the range front), a locally observed southwest-dipping thrust fault at the range front, possible changes in fault dip with depth beneath the foothills, and alternative hypotheses for active structures that can accommodate differential uplift of the Irish Hills relative to the Los Osos Valley.

The Lopez Reservoir segment of the Los Osos fault zone defined by Lettis and Hall (1994) crosses the northern margin of the Price Canyon study area (Figure 3-9). Within the map extent, Lettis and Hall (1994) do not recognize any aerial photo lineaments. The concealed fault traces shown crossing Pismo Creek near the head of Price Canyon are traces of the Edna fault zone mapped by Hall (1973b). The northernmost of these traces, which are located approximately coincident with the northeastern margin of the San Luis Range, may be considered equivalent, within uncertainties, to the Los Osos fault zone of Lettis and Hall (1994).

7.3.2.2 Edna Fault Zone

The Edna fault zone is the set of west-northwest-trending faults that offset and juxtapose Tertiary and pre-Tertiary rocks along the northeast limb of the Pismo syncline within the Irish Hills study area (Plate 1). The Edna fault zone cuts across considerable topographic relief, indicating a steep dip. The map relations across the fault suggest the Edna fault zone originated as a southwest-side-down, southwest-dipping normal fault bounding the Tertiary Pismo Basin. Later reactivation of the Edna fault zone as a northeast-vergent reverse fault during the contractional phase of deformation that produced the Pismo syncline is a hypothesis that may be tested with the seismic-reflection data. The steeply dipping Edna fault zone is hypothesized to intersect at depth with the less steeply dipping Los Osos fault zone beneath the Irish Hills. The seismic-reflection data may also provide constraints on the presence or absence and depth of this fault intersection.

Southeast of the Irish Hills and San Luis Obispo Creek, the Edna fault zone is located closer to the northeastern topographic front of the San Luis Range and has very little map separation from the subparallel Los Osos fault zone as mapped by Lettis and Hall (1994). As mentioned above, this characterizes the faulting at the north end of the Price Canyon study area (Figure 3-9).

The northwest end of the Edna fault zone within the northern Irish Hills is near AWD seismic-reflection lines 204 and 207. Near the east end of Islay Creek Road and AWD seismic-reflection line 204, the fault zone appears to branch into two structures:

- A set of north-trending faults that may extend to the northern limit of pre-Quaternary rock exposures (Plate 1).
- A northwest-trending fault that terminates adjacent to a west-northwest-trending anticline.

The west-northwest-trending anticline is cored by serpentinite and folds a Tertiary sequence of Pismo Formation unconformably overlying early Miocene Rincon Formation and Oligocene Vaqueros Formation. The north-trending set of faults juxtaposes Pismo Formation to the west against Pismo Formation and Franciscan Complex rocks to the east. This relation is consistent with west-side-down, west-dipping normal faults. The truncation of the Monterey and Obispo Formation strata along the margin of the Edna fault zone is consistent with fold growth and erosion during lower Pismo time.

The GMP geologists performed reconnaissance mapping along the Edna fault zone within the central Irish Hills. Mapping along the Edna fault zone generally confirmed the presence of a major fault within Tertiary deposits, and the fault was readily visible at the surface, based on distribution of rock units, local bedrock escarpments, and alignment of springs. The absence of Monterey Formation along the fault was noted near AWD seismic-reflection line 204, where strata change abruptly from Obispo to Pismo Formation. This change from previous mapping is described in Section 7.4 below, and the identification of this unconformity may be visible in the seismic-reflection data. No direct measurements of the Edna fault zone or kinematic indicators on faults adjacent to it were found that could be used to infer slip directions.

The Edna fault zone in the Irish Hills was characterized as inactive by the LTSP (PG&E, 1988), based on limited fault trenching that did not show any evidence for late Quaternary activity and on marine terrace profiles that showed the absence of vertical separation along the northwest projection of the fault zone to the coast. No observations were made during the GMP that provided additional evidence for or against late Quaternary activity.

7.3.2.3 San Miguelito Fault Zone

The San Miguelito fault zone is located along the southern limb of the Pismo syncline within the Irish Hills study area between Avila Beach to the southeast and Deer Creek canyon on the northwest (Plate 1). The fault zone consists of numerous strands that strike west-northwest and cut Tertiary and pre-Tertiary rocks, including the latest Pliocene Squire Member of the Pismo Formation west of Avila Beach. Resistant, steeply dipping beds of Obispo Formation hold up prominent ridges along the fault zone that are visible from Avila Beach. Near the north end of the mapped fault, the Tertiary–pre-Tertiary contact abruptly changes trend to the southwest and continues to the coastline (Plate 1). Offshore, dive samples and seafloor morphology suggest the Tertiary–pre-Tertiary contact trends east-west, where it is locally defined by the west-northwest-trending Shoreline fault zone (Plate 1 and PG&E, 2011). Interpretation of the seismic-reflection data across the San Miguelito fault zone (AWD lines 114 and 112-140) and west-trending fault that connects the San Miguelito and Shoreline fault zones (AWD line 102) may help characterize this structural bend or step in the southwestern margin of the Pismo Basin.

The San Miguelito fault zone in the Irish Hills was characterized as inactive by the LTSP (PG&E, 1988), based on limited fault trenching that did not show any evidence for late Quaternary activity and on marine terrace profiles that showed the absence of vertical separation across the fault across Avila Beach. Similar to the hypothesized relation between the Los Osos and Edna fault zones along the northeastern margin of the Pismo syncline, it is permissible that the steeply dipping San Miguelito fault intersects a less steeply north-dipping San Luis Bay fault at depth. Interpretation of AWD line 112-140 and deeper Vibroseis data along this trend have the potential to constrain the presence or absence and location of this intersection.

The GMP geologists performed reconnaissance mapping along the San Miguelito fault zone within the Irish Hills near where the fault zone crosses AWD seismic-reflection CDP lines 112-140 and 114 (Plate 1). Mapping along the San Miguelito fault zone generally confirmed the presence of a major fault within Tertiary formations. Interpretation of the lidar topography by GMP geologists along the San Miguelito fault zone and along its mapped termination within Monterey Formation did not reveal any lineaments or features indicative of late Quaternary activity or additional traces not previously recognized.

7.3.2.4 San Luis Bay Fault Zone

The late Quaternary San Luis Bay fault zone was discovered during the LTSP (PG&E, 1990; Lettis et al., 1994). The fault zone is located onshore between approximately Olson Hill (south of Green Peak) to the west and Port San Luis to the east (PG&E, 1990). The fault zone is interpreted to be primarily offshore between Port San Luis and Avila Beach (Lettis et al., 1994). The fault zone was recognized based on south-side-down changes in elevation of late Pleistocene coastal marine terraces (Hanson et al., 1994), steps in Squire Formation inferred to be due to faulting in boreholes along the Union 76 pier (Lettis et al., 1994), and exposures of the fault along the road directly north of the San Luis Obispo Creek bridge at Avila Beach (Lettis et al., 1994). Late Quaternary surface-fault rupture was observed adjacent to the west bridge abutment. The overall depiction of the San Luis Bay fault zone from the LTSP was a broad zone of distributed faulting, with a general north-side-up reverse sense of displacement (Lettis et al., 1994; PG&E, 2011).

The San Luis Bay fault zone was not a focus of the GMP because the fault zone was examined extensively in 2009 and 2010 as part of the Shoreline fault zone investigation (PG&E, 2011). No new mapping was performed along the San Luis Bay fault zone for the GMP with the exception of new bedding attitudes measured along AWD seismic-reflection line 112-140.

The western part of the San Luis Bay fault zone was mapped during the LTSP (PG&E, 1990) as having two branches: the more northerly Olson fault and the Rattlesnake fault. The Rattlesnake fault is shown on Plate 1 as an approximately 1 km long dashed fault that trends west-southwest/east-northeast between the coast and the saddle between San Luis Hill and the main Irish Hills. Geologic mapping along the coastline performed by members of the GMP mapping team as part of the Shoreline fault investigations constrained the location of the Rattlesnake trace of the San Luis Bay fault zone within

Cretaceous sandstone near where it was mapped during the LTSP (PG&E, 1990; Plate 1). The Rattlesnake fault is crossed by AWD seismic-reflection line 101 and is covered by a high-resolution 3D seismic-reflection survey conducted in 2012 (Figure 3-1). The key geologic observation is that the fault separates similar facies of Cretaceous sandstone with little to no recognizable dip discordance. Thus, seismic-reflection profiles of AWD line 101 may not be able to recognize the Rattlesnake fault based on its apparent limited amount of cumulative slip.

The high-resolution 3D survey data may, however, better resolve the top-of-rock surface beneath the alluvium covering the marine terrace (mapped as Qm on Plate 1). Shallow auger borings conducted for the LTSP delineated a buried south-facing scarp in the top-of-rock surface and interpreted it to be the buried Rattlesnake fault scarp formed on an originally planar wave-cut platform surface formed during the marine isotopic stage (MIS) 5e sea-level highstand approximately 125,000 years ago (Lettis et al., 1994; Hanson et al., 1994). Mapping and analysis of the MBES data offshore suggest the 5a wave-cut platform is also offset by the Rattlesnake fault (PG&E, 2011). The fault was not directly viewed in outcrop at the coastline, so there is no information about surface-fault dip.

The westernmost part of the San Luis Bay fault zone has been called the Olson fault (PG&E, 1990) or the Olson Hill deformation zone (PG&E, 2011). The north and south Olson faults identified by the LTSP at the coast as possible structures accommodating surface-fault rupture was disproven by detailed bedrock mapping along the coast in 2010 as part of the Shoreline fault investigation (PG&E, 2011). Thus, bedrock mapping has not found a fault at the surface that accommodates the south-side-down vertical separation of MIS 5e and 5a marine terraces that occurs north and south of Olson Hill between the base of Green Peak and the Rattlesnake fault. We represent this broad folding on Plate 1 with a dotted and queried fault trace between a location directly north of Olson Hill and the saddle between San Luis Hill and the main Irish Hills. This dotted and queried fault represents an inferred fault zone that is partially or completely blind, or perhaps a fold hinge that is not cored by a fault. The inferred location of the concealed fault trace landward of the back edge of the prominent marine terraces is based on a permissible location identified during the LTSP (PG&E, 1990).

Similar to the description of the Los Osos fault zone (Section 7.3.2.1), the Olson Hill deformation zone (and the entire San Luis Bay fault zone) has been interpreted as a steeply north-dipping, south-vergent reverse fault. Within uncertainty, the terrace deformation may result from an active fold hinge that is locally broken through by faulting. The seismic-reflection interpretation team should keep in mind that no specific structure west of Avila Beach (other than the narrow constraints on the Rattlesnake fault at the coastline) has been identified in the bedrock geology that is conclusively the San Luis Bay fault zone.

7.3.2.5 Shoreline Fault Zone

The Shoreline fault zone is located entirely offshore and was not a focus of the GMP because no onshore seismic-reflection profile lines cross it. However, minor changes to the bedrock units adjacent to the Shoreline fault zone were made. These changes included minor revisions to faulting northeast of the fault between Olson Hill and Double Rock, an editorial correction to a fault-bounded section of rock that was reclassified as Cretaceous sandstone from Franciscan Complex based on a dive sample, and changes to the contact between diabase (Tmod) and resistant clastic Obispo Formation (Tmor) northeast of the fault near the DCPP based on interpretation of the helicopter magnetic data (PG&E, 2011; see Section 7.4.6).

7.4 Changes to Previous Geologic Maps and Compilation Efforts

Most of the mapping conducted by the GMP confirmed previously published map data and verified or added to the data set of bedding attitude and fold and fault information. Review of the AMEC (2012a) map during the qualification effort and during subsequent work on the overall map found a few editorial mistakes, and these were corrected. Besides the new map data, the GMP compilation effort added structural (bedding attitude) information from portions of the Irish Hills and Price Canyon study areas and detailed stratigraphic and structural information from the DCPP study area that were not compiled in the AMEC (2012a) effort.

At several locations the geologic maps of the Irish Hills and DCPP study areas (Plate 1 and Plate 2, respectively) differ from previous mapping. Some of these changes were recognized and made during the new field mapping for the GMP. Other changes were made during the compilation of previously collected data and new interpretation of existing information. These changes and a brief description of their significance are summarized in the following subsections. The locations of these changes are outlined on Figure 7-1. Figures 7-2 through 7-5 and Figure 7-8 show a frame “(a)” representing the current Irish Hills or DCPP study area geologic map and a frame “(b)” representing the prior compilation geologic map (from AMEC, 2012a or PG&E, 2011).

7.4.1 Northeastern Margin of the Pismo Syncline

Data collected during field reconnaissance for the GMP documents the absence of Monterey Formation strata within the Edna fault zone on the northeastern margin of the Pismo syncline (Figure 7-2). Three mapping transects across the Edna fault zone and the north limb of the Pismo syncline revealed that outcrops located within areas previously mapped as Monterey Formation (Figure 7-2b) exposed strata with lithostratigraphic affiliations closer to the Pismo Formation (i.e., Pismo-like tan sandy siltstone instead of Monterey-like thinly bedded chert/siliceous shale) and Obispo Formation (i.e., Obispo-like tuffaceous and laminated sandstone instead of Monterey-like thinly bedded chert/siliceous shale). These transects were performed across the western (Read property), center (Sinsheimer property), and eastern (Andre property) portions of Figure 7-2, as indicated by the white-outlined bedding attitudes on Figure 7-2a. No thinly bedded siliceous shale or other similar facies typically associated with the Monterey Formation were observed along any of the three transects, indicating that Monterey Formation strata—at least facies that typify the Monterey Formation elsewhere in the Irish Hills study area—are absent here. This conclusion does not exclude the possibility that Monterey Formation strata are present as mapped southeast of the figure extent along the north side of See Canyon, south of the Edna fault zone (Plate 1).

The GMP geologic map (Figure 7-2a) was revised by including some of the area mapped as Monterey Formation into the Edna Member of the Pismo Formation, and some into the Obispo Formation, with the contact generally following form lines inherited from existing mapping. The location of the resulting Pismo Formation/Obispo Formation contact is assumed to be generally correct, but could be refined further with additional mapping. This map revision is based on lithostratigraphic criteria from examination of outcrops and hand samples only, and has not been tested with biostratigraphy or other techniques.

This revision is considered significant for interpretation of seismic-reflection data because the absence of Monterey Formation implies that the Pismo Formation unconformably overlies the Obispo Formation along the northeast limb of the Pismo syncline and adjacent to the Edna fault zone. As discussed above, near the northwest end of the Edna fault zone, Pismo Formation unconformably overlies Rincon Formation. The seismic-reflection data may provide information to develop or test alternative models to explain the transition from the absence of Monterey Formation along the Edna fault zone, to the presence of Monterey Formation in the Honolulu-Tidewater well (Appendix E) and the southwest limb of the Pismo syncline.

7.4.2 Southwest Limb of the Pismo Syncline, Monterey Formation/ Pismo Formation Contact

Data collected during field reconnaissance for the GMP constrain the contact between the Monterey Formation and the Miguelito Member of the Pismo Formation north of the DCPP as closer to Coon Creek than previously mapped (Figure 7-3). Strata exposed along the ridge between the Coon Creek and Diablo Canyon Creek watersheds show an interval of the Monterey Formation that, though folded, has a consistent strike approximately N60°W across previously mapped unit contacts.

This revision is considered significant for the interpretation of seismic-reflection data primarily because of the shift in contact location at the ground surface. The revision does not provide any additional constraints on the nature of the Monterey-Pismo Formation contact at this location (assumed to be either conformable, paraconformable, or a low-angle unconformity).

7.4.3 Southwest Limb of the Pismo Syncline, Obispo Formation/ Monterey Formation Contact

Data collected during field reconnaissance for the GMP constrain the location of the contact between the Monterey Formation and the Obispo Formation to the south side of the mouth of Crowbar Canyon (Figure 7-4a), rather than along the north side as previously mapped (Figure 7-4b). Exposures on the north side of the mouth of Crowbar Canyon show tuffaceous and/or diatomaceous strata of the Monterey Formation, and outcrops on the south side of the mouth of Crowbar Canyon expose tuffaceous sandstone strata of the volcaniclastic Obispo Formation instead of the previously mapped diabase sub-unit of the Obispo Formation.

This revision is considered significant for interpretation of seismic-reflection data because the location of a major unit contact has changed and, at this location, the Obispo Formation diabase does not unconformably underlie Monterey Formation strata.

7.4.4 Franciscan Chert and Serpentinite, Los Osos Fault Zone

Data collected during field reconnaissance for the GMP indicate that the Franciscan Complex metavolcanic unit (KJfmv) is less extensive than shown on earlier geologic maps along the Irish Hills range front and along the east-central reach of the Los Osos fault zone (Figure 7-5). Most notably, red and green brecciated chert is observed along much of the range-front bedrock/Quaternary contact south of the intersection of Los Osos Valley Road and Turri Road (Figure 7-5a). Chert is observed in outcrop in stream cuts and as bedrock highs, as float on range-front ridges, and as a significant fraction of alluvial gravels emanating from small range-front drainages. GMP reconnaissance was generally confined to areas within and north of the serpentinite-defined traces of the Los Osos fault zone, but given the high chert content of observed fluvial gravels, it is likely that additional unmapped chert bodies are present at higher elevations along the foothills, south of the Los Osos fault zone. Additionally, the southwestern contact of the northwest-southeast-trending serpentinite body within the Los Osos fault zone mapped during the GMP reconnaissance southeast of the Turri Road intersection (between coordinate easting values 702000 and 704000 m; Figure 7-5a) is located as much as 90 m south of the contact provided in the AMEC (2012a) compilation (Figure 7-5b).

These map changes are considered significant for interpretation of seismic-reflection data because both the chert and serpentinite bodies may be associated with high impedance contrasts along their contacts, resulting in relatively high-amplitude seismic reflectors. Because of the apparent chaotic distribution of Franciscan lithologies, laterally extensive high-amplitude reflectors are of special significance for the interpretation of seismic-reflection data and may help better define structure within the Franciscan Complex.

7.4.5 Neogene Marine Deposits Within Western Los Osos Valley

Data collected during field reconnaissance for the GMP indicate the presence of marine sands along the Irish Hills range front southwest and west of the Turri Road intersection (between coordinate easting values 700000 and 702000 m; Figure 7-5a). Marine sands (mapped as Quaternary marine terrace deposits, Qm, on Plate 1 and Figure 7-5a) are exposed within and along the range-front contact of previously mapped laterally extensive Quaternary aeolian (Qe) deposits. Exposures of the presumed marine deposits (dominantly fine-to-medium sand with rounded gravels) are limited, and therefore, the lateral extents of the Qm units on Plate 1 are approximately located.

This revision is not considered significant for interpretation of onshore seismic-reflection data, as these surficial deposits would not be imaged in the seismic-reflection data. However, the presence, elevation, and age of these deposits have relevance to understanding the Quaternary uplift history of the northern Irish Hills.

7.4.6 New Mapping Offshore of the DCPP

Interpretation of the new Kelpfly MBES data in Discharge Cove resulted in improvements to previous mapping that was presented in the Shoreline Fault Zone Report (PG&E, 2011). Figure 7-6 shows the revised map portion of the DCPP study area map Plate 2 (Figure 7-6a) compared with the Shoreline Fault Zone Report map of the same area (Figure 7-6b). Figure 7-7 shows the two versions of the offshore-onshore artificial hillshade image after (Figure 7-7a) and before (Figure 7-7b) the Kelpfly data to highlight the difference in interpretability. The textural information in the Kelpfly data permitted clear delineation between bedded Obispo Formation (Tmofb) and massive to fractured resistant Obispo Formation (Tmor). Truncation of the beds showed this to be a fault contact striking slightly more northwesterly than inferred previously, before the Kelpfly data were obtained. The Kelpfly data indicated complexities in the fault geometry separating Tmor on the west from bedded Obispo Tmofb and Tmofc on the east.

Other changes to the mapping in the area offshore of the DCPP include the location of the contact between Obispo Formation diabase (Tmod) and resistant Obispo Formation (Tmor; Figure 7-6). As the two sub-units appear texturally similar on the seafloor, the contact was revised based on following the abrupt gradient in magnetic susceptibility from the helicopter magnetic survey data (PG&E, 2011; Appendix D; Langenheim et al., 2012) with secondary attention to seafloor texture. Figure 7-8 shows the total magnetic intensity data from Langenheim et al. (2012) that was used to help draw the revised contact. The revised contact is shown on the map as a boundary defined by helicopter magnetics (dash-dot line labeled “HM”) to emphasize that shallowly buried boundaries between the magnetic diabase and nonmagnetic tuff may be misinterpreted as the contact exposed at the seafloor (i.e., the diabase may be covered by thin Obispo Formation tuff). We are also mindful that these data are close to the magnetic dipole created by the DCPP facilities (Figure 7-8), and thus the magnetic intensity gradient that is used to delineate the contact may be partially or entirely an artifact. Nevertheless, the revised mapping (Figure 7-6a) is drawn more systematically than the previous effort (Figure 7-6b).

8.0 CONCLUSIONS

The Geologic Mapping Project provides revised and updated geologic maps of the Irish Hills, DCPP, and Price Canyon study areas that are sufficiently detailed to constrain the interpretation of recently collected onshore seismic-reflection data. These new geologic maps and data emphasize bedrock stratigraphic and structural relations. The geodatabase and this data report explain how the map was constructed, what the map contains, what additional geologic information is available (e.g., deep well data), and what uncertainties in the data the interpreters of seismic-reflection data should consider. The geologic map of the DCPP site has been updated with a more comprehensive compilation of available stratigraphic and structural data and with the addition of new mapping based on recently acquired offshore data.

Additional field work in the study areas to further check or improve the bedrock mapping should be motivated by specific questions from the seismic-reflection interpretation team and evaluators of seismic sources for seismic hazard analysis, and by questions concerning site conditions for DCPP facilities.

The GMP also provides a compilation of available well data from oil and gas wells and the deeper hydrogeologic boreholes located adjacent to seismic-reflection profile lines. These data, compiled in Appendix E, provide limited constraints regarding lithology, biostratigraphic information, downhole geophysical data, and stratigraphic interpretations. The well information and its uncertainty should be considered during interpretation of seismic-reflection data.

As a result of this study, several changes were made to the mapping of previously recognized faults in the Irish Hills study area (Plate 1). Changes to faults or to the geology directly adjacent to faults included the following:

- Edna and San Miguelito fault zones—minor changes to the geologic units adjacent to the faults.
- Los Osos fault zone—minor changes to the geologic units adjacent to the fault zone, and changes to the depiction of the fault zone along the northern margin of the Irish Hills (including removal of the concealed, northwest-trending fault across southern Morro Bay).
- Shoreline fault zone—minor changes to the geologic units and bedrock faults adjacent to the fault zone for the reaches opposite Olson Hill and the DCPP.
- San Luis Bay fault zone—minor changes to the geology adjacent to the fault zone along the outer coast from Olson Hill to Rattlesnake Creek, and the addition of a generalized, concealed, and locally queried trace in San Luis Obispo Bay and on the outer coast between the Rattlesnake fault and the Olson Hill deformation zone.

Based on this assessment, none of the changes made to the above-mentioned faults represent a significant change from previously considered fault characterizations. The new mapping in the vicinity of the Edna, Los Osos, San Luis Bay, San Miguelito, and

Shoreline fault zones do not introduce any new hard constraints on fault location, dip, slip direction, or slip rate.

The location of the Los Osos fault zone presented on Plate 1 is essentially unchanged from the characterization that has been used in seismic source models since the LTSP (PG&E, 1988). The removal of the concealed, northwest-trending fault splay beneath Morro Bay does not affect, in our judgment, the possible linkages between the Irish Hills and offshore Estero Bay fault segments defined by Lettis and Hall (1994). Mapping and analysis for the GMP has recognized the alternative interpretations that the Los Osos fault zone may be a mostly blind reverse fault or a fold hinge. The seismic-reflection data may provide the opportunity to test these alternative hypotheses.

The location and depiction of the San Luis Bay fault zone differs slightly from earlier maps that have been considered in seismic hazard assessments for the DCPP. The San Luis Bay fault zone northwest of the Rattlesnake fault is generally consistent with one of the alternative pathways considered for the Olson fault (PG&E, 1990). The main differences are that the north end of the fault trace, where it goes offshore, is located slightly to the north of Olson Hill, rather than through it. This difference is less than 400 m. The other minor difference is the interpretation that the northern portion of the San Luis Bay fault zone is partially or entirely blind, meaning that the top of the fault is located at depth and the surface expression is fold deformation rather than fault deformation. The new alternative interpretations for the geometry of the San Luis Bay and Los Osos fault zones are currently being incorporated in the probabilistic seismic hazard analysis update study for the DCPP.

The geologic map of the DCPP site area (Plate 2) is the first comprehensive geologic map of the entire site area since the original mapping described in the FSAR for Units 1 and 2 (PG&E, 1974). Most, but not all, of the information comes from these three studies:

- The original studies for the FSAR for DCPP Units 1 and 2 (PG&E, 1974).
- The FSAR for the ISFSI (PG&E, 2004).
- Detailed mapping of the coast between Islay Creek and Point San Luis (FWLA, 2009, 2010).
- The Shoreline fault zone investigation (PG&E, 2011).

Specific geologic units and structures located directly beneath the DCPP facilities have not changed, as the key information used in the Plate 2 compilation was derived from the original siting studies (e.g., PG&E, 1974, 2004). The incorporation and interpretation of the Kelpfly MBES data within Discharge and Intake Coves that has become available since the Shoreline Fault Zone Report (PG&E, 2011) represents new map information that has not been presented previously. While the Kelpfly data significantly improve the interpretation of the strata and structures offshore in Discharge Cove, the basic assessment of geologic conditions beneath the DCPP is unchanged from the Shoreline Fault Zone Report (PG&E, 2011).

9.0 LIMITATIONS

The geologic information provided represents the best information available from known previous work and new data collected for this project. This information is suitable for use as geologic constraints for the interpretation of seismic-reflection data given certain limitations. As shown on Figure 3-1, only a portion of the area was reviewed in the field for the mapping project; for the remaining area the interpretations shown on previously published maps were accepted. Based on the generally minor discrepancies between newly collected data and data compiled from previous mapping, these differences should be small.

The discrimination of geologic units and structures during geologic field study may or may not coincide with units and structures observable in seismic-reflection data. Likewise, incomplete exposure of the geology implies that mapped unit contacts and structures drawn between specific observations represent interpretations that are subject to model uncertainty. These limitations should be kept in mind when considering the extent to which the provided geologic maps and data represent hard data constraints for the interpretation of the onshore seismic-reflection data.

The geologic maps and data herein do not represent mapping suitable for purposes of engineering geology or geotechnical evaluations beyond a reconnaissance-level assessment.

10.0 IMPACT EVALUATION

This data report does not have any direct impacts on the DCPP. As stated previously, the information provided in this report is intended to help with the following types of activities:

- Assessment of the quality and interpretability of seismic-reflection data.
- Interpretation of the geologic history and 3D geologic structure of the study area, particularly in combination with the interpretation of seismic-reflection data.
- Evaluation of seismic sources for seismic hazard analysis.

11.0 REFERENCES

AMEC Environment & Infrastructure (AMEC), 2012a. Compilation of Geologic Maps and GIS Databases for the Irish Hills and Surrounding Areas, Diablo Canyon Power Plant, LTSP Update: Draft Consultants Report to PG&E, AMEC project 13838C01.CWA172, January 3.

AMEC Environment & Infrastructure (AMEC), 2012b. *Summary of Southwest Boundary Zone Preliminary Geomorphic Studies and Subsurface Data Compilation, Diablo Canyon Power Plant, San Luis Obispo, California*, prepared for PG&E, San Francisco, Calif.

American Society of Mechanical Engineers (ASME), 2008. Standard NQA-1-2008, Part III, Non-mandatory Appendix 3.1, "Guidance on Qualification of Existing Data."

California Energy Commission (CEC), 2008. *An Assessment of California's Operating Nuclear Power Plants: AB 1632 Committee Report*, CEC-100-2008-108-CTF, November.

California State University, Monterey Bay (CSUMB), 2007, 2009, 2010, and 2011. Multibeam echosounder (MBES) data for the California Central Coast; http://seafloor.csumb.edu/SFMLwebDATA_c.htm; accessed 16 May 2013.

Cleath & Associates, 2003. *Geologic Structure of the Los Osos Valley Ground Water Basin*, unpublished consulting report: prepared for the Los Osos Community Services District, November.

Cleath & Associates, 2005. *Sea Water Intrusion Assessment and Lower Aquifer Source Investigation of the Los Osos Valley Ground Water Basin, San Luis Obispo County, California*, unpublished consulting report prepared for the Los Osos Community Services District, October.

Cole, R.B., and Stanley, R.G., 1998. Volcanic Rocks of the Santa Maria Province, California: in Keller, M.A. (editor), *Evolution of Sedimentary Basins/Onshore Oil and Gas Investigations—Santa Maria Province*, U.S. Geological Survey Bulletin 1995-R, 35 pp.

Compton, R.R., 1985. *Geology in the Field*, John Wiley & Sons, 416 pp.

Dibblee, T.W. Jr., 2004. Geologic Map of the San Luis Obispo Quadrangle, San Luis Obispo County, California, Dibblee Geology Center Map #DF-129, Santa Barbara Museum of Natural History, Santa Barbara, CA, scale 1:24,000.

Dibblee, T.W. Jr., 2006a. Geologic Map of the Morro Bay South Quadrangle, San Luis Obispo County, California, Dibblee Geology Center Map #DF-214, Santa Barbara Museum of Natural History, Santa Barbara, CA, scale 1:24,000.

Dibblee, T.W. Jr., 2006b. Geologic Map of the Pismo Beach Quadrangle, San Luis Obispo County, California, Dibblee Geology Center Map #DF-212, Santa Barbara Museum of Natural History, Santa Barbara, CA, scale 1:24,000.

Dibblee, T.W. Jr., 2006c. Geologic Map of the Port San Luis Quadrangle, San Luis Obispo County, California, Dibblee Geology Center Map #DF-213, Santa Barbara Museum of Natural History, Santa Barbara, CA, scale 1:24,000.

Fugro William Lettis & Associates (FWLA), 2009. Unpublished field maps from coastline mapping at Diablo Canyon Power Plant site, scale 1:2400 to 1:1200.

Fugro William Lettis & Associates (FWLA), 2010. Unpublished field maps from coastline mapping, Rattlesnake Creek to the Diablo Canyon Power Plant, scales include 1:1200, 1:2400, and 1:4800.

Fugro William Lettis & Associates (FWLA), 2011. Transmittal and Documentation of GIS Shape Files of Landslides, Landslide Susceptibility, and Liquefaction Susceptibility for HAZUS Input to Diablo Canyon Power Plant Evacuation Plan, Letter Report and Data CD, February 18.

Hall, C.A., 1973a. Geologic Map of the Morro Bay South and Port San Luis Quadrangles, California, U.S. Geological Survey Miscellaneous Field Studies Map FM-511, scale 1:24,000.

Hall, C.A., 1973b. Geology of the Arroyo Grande 15' Quadrangle, California, California Division of Mines and Geology Map Sheet 24, scale 1:48,000.

Hall, C.A., and Corbato, E.E., 1967. Stratigraphy and sedimentology of Mesozoic and Cenozoic rocks, Nipomo quadrangle, southern Coast Ranges, California, *Geological Society of America Bulletin* **78**: 559–582.

Hall, C.A., and Prior, S.W., 1975. Geologic Map of the Cayucos-San Luis Obispo Region, San Luis Obispo County, California, U.S. Geological Survey Miscellaneous Field Studies Map MF-686 (two sheets), scale 1:24,000.

Hall, C.A., Jr., Ernst, W.G., Prior, S.W., and Wiese, J.W., 1979. Geologic Map of the San Luis Obispo-San Simeon Region, California, U.S. Geological Survey Miscellaneous Investigation Series Map I-1097 (three sheets), scale 1:48,000.

Hall, C.A., Jr., Turner, D.L., and Surdam, R.C., 1966. Potassium-argon age of the Obispo Formation with *Pecten lompocensis* Arnold, southern Coast Ranges, California: *Geological Society of America Bulletin* **77** (4): 443–446.

Hanson, K.L., Wesling, J.R., Lettis, W.R., Kelson, K.I., and Mezger, L., 1994. Correlation, ages, and uplift rates of Quaternary marine terraces, south-central California: in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B. (editors), *Seismotectonics of the Central California Coast Ranges*, Geological Society of America Special Paper 292, pp. 45–72 and 2 plates.

Jahns, R.H., and others, 1973. Geology of the Diablo Canyon Power Plant Site, San Luis Obispo County, California, unpublished(?) map for Pacific Gas & Electric Company, iterations of map used in PG&E (1974) FSAR for Units 1 and 2, approximate scale 1:500.

Keller, M.A., Tennyson, M.E., and Denison, R.E., 1996. Strontium isotope evidence for the age of the Vaqueros Formation and latest Oligocene marine transgression in the northern Santa Maria province, central California: in Keller, M.A. (editor), *Evolution of Sedimentary Basins/Onshore Oil and Gas Investigations—Santa Maria Province*, U.S. Geological Survey Bulletin 1995-P, 8 pp.

Langenheim, V.E., Watt, J.T., and Denton, K.M., 2012, Magnetic map of the Irish Hills and surrounding areas, San Luis Obispo County, central California: U.S. Geological Survey Open-File Report 2012-1080, scale 1:24,000; http://pubs.usgs.gov/of/2012/1080/.

Lettis, W.R., and Hall, N.T., 1994. Los Osos fault zone, San Luis Obispo County, California: in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B. (editors), *Seismotectonics of the Central California Coast Ranges*, Geological Society of America Special Paper 292, pp. 73–102 and Plate 5.

Lettis, W.R., Kelson, K.I., Wesling, J.R., Angell, M., Hanson, K.L., and Hall, N.T., 1994. Quaternary deformation of the San Luis Range, San Luis Obispo County, California: in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B. (editors), *Seismotectonics of the Central California Coast Ranges*, Geological Society of America Special Paper 292, pp. 111–132.

Lisle, R.J., Brabham, P., and Barnes, J., 2011. *Basic Geological Mapping*, Fifth Edition, John Wiley & Sons, 217 pp.

Pacific Gas and Electric Company (PG&E), 1974. Units 1 and 2 Diablo Canyon Power Plant, Final Safety Analysis Report, Update 20, U.S. Nuclear Regulatory Commission Docket Nos. 50-275 and 50-323, Figures 2.5-5, 2.5-6, 2.5-8, and 2.5-12. Also includes Earth Science Associates, 1974, Geologic Map of the Morro Bay South and Point San Luis Quadrangles, San Luis Obispo County, California, and Adjacent Offshore Area, Plate VIII, Appendix 2.5D, scale 1:24,000.

Pacific Gas and Electric Company (PG&E), 1988. Final Report of the Diablo Canyon Long Term Seismic Program, Diablo Canyon Power Plant, U.S. Nuclear Regulatory Commission Docket Nos. 50-275 and 50-323, July 1988.

Pacific Gas and Electric Company (PG&E), 1990. Response to Question GSG Q16, Diablo Canyon Long Term Seismic Program, Diablo Canyon Power Plant, U.S. Nuclear Regulatory Commission Docket No. 50-275 and No. 50-323, Plate GSG Q16-1.

Pacific Gas and Electric Company (PG&E), 2004. Final safety analysis report of the Diablo Canyon independent spent fuel storage installation, U.S. Nuclear Regulatory Commission Docket No. 72-26, Figures 2-6.6, 2.6-7, and 2.6-8.

Pacific Gas and Electric Company (PG&E), 2011. *Report on the Analysis of the Shoreline Fault Zone, Central Coastal California*, submitted to the U.S. Nuclear Regulatory Commission, January; www.pge.com/myhome/edusafety/systemworks/dcpp/shorelinereport/.

Schneider, J.L., and Fisher, R.V., 1996. Obispo Formation, California: Remobilized pyroclastic material: in Keller, M.A. (editor), *Evolution of Sedimentary Basins/Onshore Oil and Gas Investigations—Santa Maria Province*, U.S. Geological Survey Bulletin 1995-O, 21 pp.

Schwalbach, J.R., and Bohacs, K.M., 1996. Stratigraphic sections and gamma-ray spectrometry from five outcrops of the Monterey Formation in southwestern California: Naples Beach, Point Pedernales, Lion’s Head, Shell Beach, and Point Buchon: in Keller, M.A. (editor), *Evolution of Sedimentary Basins/Onshore Oil and Gas Investigations—Santa Maria Province*, U.S. Geological Survey Bulletin 1995-Q, 39 pp.

TetraTech, Inc., 2010. *Diablo Canyon Power Plant Coastline Survey*, technical report accompanying lidar survey and aerial photo digital data, prepared for PG&E, March 31.

TetraTech, Inc., 2011. *San Luis Range and Los Osos-Edna Valleys LiDAR Survey*, technical report accompanying lidar survey digital data, prepared for PG&E, July 8.

Treiman, J.A., 1989. *Los Osos Fault Zone, San Luis Obispo County*, California Division of Mines and Geology Fault Evaluation Report FER-200.

Watershed Sciences, Inc. (WSI), 2011. LiDAR Remote Sensing, Los Osos, California, Technical Report submitted to TetraTech, Lafayette, California, May 18.

Wiegers, M.O., 2009. Geologic Map of the Morro Bay South 7.5' Quadrangle, San Luis Obispo County, California: A Digital Database, Version 1.0, scale 1:24,000.

Wiegers, M.O., 2010. Geologic Map of the San Luis Obispo 7.5' Quadrangle, San Luis Obispo County, California: A Digital Database, Version 1.0, scale 1:24,000.

Wiegers, M.O., 2011. Preliminary Geologic Map of the Pismo Beach 7.5' Quadrangle, San Luis Obispo County, California: A Digital Database, Version 1.0, scale 1:24,000.

William Lettis & Associates (WLA), 1996. Unpublished geology compilation map produced for the DCPP Dry Cask Facility, Geologic/Geotechnical Siting Study, Plate 1, February, scale 1:2400.

William Lettis & Associates (WLA), 1998. Unpublished geologic map for the PG&E Diablo Canyon Power Plant Dry Cask Storage Facility Siting Study: prepared in April and May 1998, with revisions in May 1998 and February 2001, scale 1:2400.

VERIFICATION SUMMARY REPORT

Item	Parameter	Yes	No*	N/A*
1	Purpose is clearly stated and the report satisfies the Purpose.	X		
2	Data to be interpreted and/or analyzed are included or referenced.	X		
3	Methodology is appropriate and properly applied.	X		
4	Assumptions are reasonable, adequately described, and based upon sound geotechnical principles and practices.	X		
5	Software is identified and properly applied. Validation is referenced or included, and is acceptable. Input files are correct.	X		
6	Interpretation and/or Analysis is complete, accurate, and leads logically to Results and Conclusions.	X		
7	Results and Conclusions are accurate, acceptable, and reasonable compared to the Data, interpretation and/or analysis, and Assumptions.	X		
8	The Limitation on the use of the Results has been addressed and is accurate and complete.	X		
9	The Impact Evaluation has been included and is accurate and complete.	X		
10	References are valid for intended use.	X		
11	Appendices are complete, accurate, and support text.	X		

* Explain "No" or "N/A" entries. (For example, Items 3 thru 7 would be N/A for a data report that simply presents the collected data.)

As the ITR I spent two days in the field with a different mapping team each day and confirmed that the project plan and instructions were being followed implemented correctly. The overheating of the electronic field notepads (iPads) on hot days was corrected.

After completion of the initial draft report, my review found a number of inconsistencies that were noted by the PI, Steve Thompson, and then addressed. In particular, the planned specific cross sections were found not to be a valuable deliverable so we agreed to revise the work plan to change the deliverable to be the detailed geologic map so the interpretation team combining the geophysical data with the geology could construct cross sections at better locations.

For my second review of the report I confirmed that all the previous issues had been corrected. During this review I found a few minor things that needed to be changed or revised. These have been completed as requested.

Verifier (ITR): William D. Page [signature] June 20, 2014
(name/signature) (date)