Woodside Natural Gas Inc.
OceanWay Secure Energy
Los Angeles, California

Exhibit B
Topic Report 6 – Geological Resources

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Acronyms and Abbreviations

ANSS	Advanced National Seismic System
Bgs	below ground surface
BTU	British thermal unit
C	Celsius
CBC	California Building Code
CCA	California Coastal Act
CCC	California Coastal Commission
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CGS	California Geological Survey
cm	Centimeter
CM	Conservation Measure
CPT	cone penetration test
CSLC	California State Lands Commission
DWP	Deepwater port
F	Fahrenheit
FEMA	Federal Emergency Management Agency
ft	Foot/feet
g	Gravity
GPS	global positioning system
HDD	Horizontal directional drilling
IGIF	Inert Gas Injection Facility
km	Kilometer
LAX	Los Angeles International Airport
LNG	Liquefied natural gas
M	Magnitude
m	Meter
mm	Millimeter
mm/yr	Millimeters per year
MMI	Modified Mercalli Intensity
Mw	Moment magnitude
NCEC	Northern California Earthquake Catalogue
NEIC	National Earthquake Information Center
NFPA	National Fire Protection Agency
NIFZ	Newport-Inglewood fault zone

Acronyms and Abbreviations (Cont'd)

NM	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NTHMP	National Tsunami Hazard Mitigation Program
OBE	Operating Basis Earthquake
ODP	Ocean Drilling Program
OES	Office of Emergency Services
PDE	Preliminary Determination of Epicenters
PFRHA	Probabilistic fault rupture hazard analysis
PGA	Peak ground acceleration
PLEM	Pipeline End Manifold
PSHA	Probabilistic Seismic Hazards Analysis
PVFZ	Palos Verdes fault zone
RCTS	Receiving and custody transfer station
RLNGC	Regasification LNG Carriers
SCEC	Southern California Earthquake Catalogs
SCG	Southern California Gas Company
SCV	Submerged Combustion Vaporization
SSE	Safe Shutdown Earthquake
UBC	Uniform Building Code
USGS	U.S. Geological Survey
Woodside	Woodside Natural Gas, Inc.

Geological Resources Topic Report Prologue

The following Geological Resources Topic Report was prepared in June and July 2006. This report is a synopsis of Fugro's Santa Monica Basin Desktop and Preliminary Seismic Hazard Analyses studies. At the time the Topic Report was prepared, some of the initial, preliminary results from Fugro's extensive spring 2006 marine survey and geotechnical investigation program were becoming available, and the insight from those preliminary results were included in the Topic Report.

The results and interpretations based on the spring 2006 field program have been published in three interpretive reports that are included as appendices to this Topic Report, as follows:

- HDD Site Characterization Report, published November 30, 2006, provided as **Appendix N**;
- Port Site Characterization Report, published November 30, 2006, provided as **Appendix O**; and
- Pipeline Route Site Characterization Report, published December 15, 2006, provided as **Appendix P**.

As discussed in the three site characterization reports, the results of the Spring 2006 field programs provide project-specific data that generally confirms the geologic interpretations and their implications to the project, as discussed in the July 2006 Topic Report.

Because the more definitive results provided in the three site characterization reports generally confirm the discussions in the Topic Report, the Geological Resources Topic Report is being submitted, as published in July 2006, with minor revisions reflecting changes in the Project description updated as of August 2007. Minor differences in detail between the Topic Report and the three site characterization reports, while important for project design, are not considered significant to the permit application.

6.0 Geological Resources

Woodside Natural Gas Inc. (Woodside) is proposing to bring natural gas into Southern California by using specially designed Liquefied Natural Gas (LNG) carriers that are equipped with regasification equipment on board, termed Regasification LNG Carriers (RLNGCs). At the offshore end of the deepwater port (DWP), the RLNGC will pick up a single point mooring (SPM) buoy, regasify the LNG using ambient air as a heating medium, and deliver the natural gas into dual subsea pipelines to shore. Woodside has named this project the OceanWay Secure Energy Project (OceanWay).

The port site will be located in the Santa Monica Basin, in approximately 3,000 feet (ft; 900 meters [m]) of water, over 21 miles[1] (34 kilometers [km]) from the nearest point on the mainland, and approximately 18 miles (29 km) from the western end of Santa Catalina Island. There will be two SPM buoys at the port site, located approximately 12,000 ft (3,600 m) apart. Each buoy will be connected to a subsea pipeline by a set of risers attached to a Pipeline End Manifold (PLEM) located on the seabed. The two PLEMs, one for each SPM buoy, will connect to separate but interconnected 24 inch (nominal 600 millimeter [mm]) outside diameter pipelines, and the two pipelines will be laid in parallel on the seafloor, nearly all the way to the shore.

The port site will be approximately 27 miles (44 km) southwest of Los Angeles International Airport (LAX) outside the 12 nautical mile (NM) limits of U.S. territorial waters of the West Coast and coastal islands. The landfall for the pipeline will be at the northern end of LAX and will be accomplished using horizontal directional drilling (HDD) with a seaward HDD of approximately 4,000 ft (1,200 m). The use of this technology will allow the pipelines to be placed beneath the seabed out to approximately 3,000 ft (900 m) from the shoreline in a water depth of approximately 37 ft (11 m) and will avoid disturbance to the beach. The overall length of the offshore pipeline route from the PLEM locations to the shoreline is approximately 35 miles (56 km). The two onshore pipelines will run approximately 4 miles (6 km) from the shoreline beneath the coastal dunes and under city streets to the Receiving and Custody Transfer Station (RCTS). The twin pipelines will be installed using conventional HDD methods approximately 2,500 feet (750 m) under the dunes and Pershing Drive from the shore crossing HDD drilling location to a receiving site within the secure area of LAX property. From the terminus of the dune crossing HDD, the pipelines will be installed using conventional trenching for the majority of the distance to the RCTS with boring at major intersections. Woodside has purchased a 3-acre (1.2 hectare) commercial property that includes an existing 57,000 square foot (5,300 square meter) warehouse / office building that will serve as the RCTS site. Downstream of the RCTS the gas distribution pipeline will continue exclusively under city streets and will begin as a single 36 inch (nominal 900 mm) pipeline extending approximately 0.25 miles (0.4 km) to the first tie-in point with the existing natural gas transmission grid of Southern California Gas Company (SCG). If market demand supports further expansion, the distribution pipeline will continue from the first tie-in point as a 24 inch (nominal 600 mm) diameter pipeline and extend an additional distance of approximately 12 miles (19 km), consisting of an 11 mile (18 km) mainline and 1 mile (1.6 km) lateral tying into the gas grid at two more locations for a total of three tie-ins. An Inert Gas Injection Facility (IGIF), comprised of nitrogen generation and compression equipment for Wobbe number control, will be housed inside the existing warehouse on the RCTS site.

Exhibit A/Project Description provides a comprehensive description of the proposed Project and should be consulted for additional Project-specific information and figures.

This Topic Report identifies the geological resources in the vicinity of the offshore and onshore components of the OceanWay DWP Project and discusses the key geological issues that may potentially affect this Project. It outlines the regulatory setting and identifies potential Project impacts resulting from the construction, installation, and operation of the DWP. It also presents conservation measures that Woodside will implement

[1] Note: mileages are presented as statute miles unless noted as nautical miles (NM).

during the life of the Project to minimize or eliminate impacts to or resulting from geological resources and constraints.

The majority of the information presented in this Topic Report has been taken from the Fugro Regional Geosciences Desktop Study, the Geosciences Desktop Study of Santa Monica Bay and Basin, and the Probabilistic Seismic Hazard Assessment (Fugro 2006a, 2006b, and 2006c) and included as **Appendices K, L,** and **M**. Information from the 2006 Fugro Desktop studies is supplemented by additional information and data examples from Spring 2006 offshore marine geotechnical and geophysical surveys performed in support of the OceanWay Project. The analysis of these is contained in three technical reports by Fugro West, included as **Appendices N, O,** and **P**.

The DWP and pipelines have been sited to avoid most areas where steep slopes and identified subsea landslides are present. In addition the pipelines have been routed around and to the north of Santa Monica Canyon to avoid turbidity currents and mass movements associated with that feature. However, the offshore pipelines will cross two active fault zones (the San Pedro Basin Fault zone and the Palos Verdes fault zone), and the onshore pipeline route will cross two active fault zones (the Charnoc fault zone and the Potrero fault zone), thus conservation measures such as crossing the identified fault traces at a high angle and application of current seismic design provisions will be implemented. As such, Woodside does not anticipate significant impacts on the OceanWay Project from the local geological features or on the geological resources.

6.1 Geologic Setting

The proposed OceanWay DWP will be located offshore of southern California, in the Santa Monica Basin. Section 6.1 presents a comprehensive discussion of the tectonic setting, physiography, regional geologic structure, seismicity, stratigraphy, geotechnical conditions, and anticipated geohazards. Additional information may be found in Fugro (2006, a, b, and c). A regional geosciences desktop study that was prepared for the proposed Project is provided as **Appendix K**

6.1.1 Tectonic Setting

The recent tectonic history of Southern California is defined by the interaction between the Pacific and North American tectonic plates. The resulting tectonic setting and deformational history of the region form the basis for interpreting the stratigraphy, geologic structures, and present seismotectonic environment of the Project study area (Fugro, 2006b).

Southern California has a long and complex geologic history. Atwater (1970) presented the first detailed models of the Cenozoic evolution of the Pacific margin of North America. In the Cretaceous and early Tertiary, the western side of the borderland was a convergent, subduction plate boundary (**Figure 6-1**). During Cretaceous and Paleogene time, the oceanic Farallon plate collided with and was subducted beneath the continental crust of western North America, resulting in a continental margin arc-trench system (**Figure 6-1**). The subduction-related geology of Central California, when reconstructed, includes the Sierra Nevada granite batholith that formed the roots of the magmatic arc, the metamorphic rocks along the arc front that form the foothills belt of the Sierra Nevada, the Great Valley Sequence of marine sedimentary rocks formed in the submarine fore-arc basin, the Coast Range ophiolite that was the oceanic floor of the fore-arc basin, and the Franciscan complex of metamorphic rocks formed in the accretionary wedge at the subduction front. These major geologic units are still recognizable in Southern and Central California (**Figure 6-2**), but have been broken up and re-organized by subsequent tectonic events (Atwater 1998).

Oblique extension began in the late Oligocene, or about 27 Ma, (million years ago) and continued into the middle Pliocene (**Figure 6-1**). The crustal slab that had been subducted beneath the western edge of the North American plate reversed direction, began moving generally northwest (N57°W) (Legg 1991), and started sliding out from under western North America. Extensive ridge and basin (horst and graben) morphology, similar to block faulting in the Basin and Range Province, occurred in the inner Continental Borderland as a result of the oblique extension, forming many of the generally northwest-trending basins and ridges of the margin that are apparent today.

During this time, various tectonic blocks along the North American margin became attached to the Pacific Plate (Atwater 1998). The Western Transverse Ranges was one of several crustal blocks that became attached to the northward moving Pacific Plate. As much as 90 to 110 degrees of clockwise rotation of the Western Transverse Range block occurred in the Neogene (Kamerling and Luyendyk 1985; Crouch and Suppe 1993). As the Western Transverse Range block rotated, the transform plate boundary continued to develop along the eastern edge of the rotating block, while the entire plate boundary became well-established by about 19 Ma (Nicholson et al. 1994).

Pliocene reorientation of the Pacific North American relative plate motion increased the component of convergence across a wide area of the Southern California margin (Clark et al. 1991; Wright 1991; Schneider et al. 1996; Sorlien et al. 1999; Seeber and Sorlien 2000). Since that time (about 5 Ma), the relative plate motion vector between the North American and Pacific plates has been oriented approximately N37°W (Cande et al. 1995; Atwater and Stock 1998). During this reorganization, Baja California became attached to the Pacific Plate, as the southern part of the plate boundary shifted eastward into the Gulf of California, and the northern part of the boundary shifted inland in Southern California.

Overall, the tectonic setting changed from a predominately extensional regime to a predominately transform regime. The increased convergence resulted in common reactivation of diversely-striking Miocene normal-separation faults as reverse-separation faults, and inversion of half-graben basins into anticlines in others (Yeats 1987; Clark et al. 1991; Seeber and Sorlien 2000). Baja California began to impinge on the continental blocks of Southern California, while rotation of the Western Transverse Ranges continued (**Figure 6-1**), in addition to significant contraction across the Western Transverse Ranges on numerous oblique reverse faults.

The present Pacific North American transform plate boundary is dominated by a broad zone of distributed right-lateral strike-slip motion. This motion affects an area extending from the San Andreas fault in the east to the offshore San Clemente fault in the west. Approximately 50 mm/year of right-lateral slip occurs across the southern California shear zone (Bennett et al. 1996). The San Andreas fault and several other fault zones accommodate most of the slip across the plate boundary (Jennings 1994; Petersen et al. 1996), but approximately 20 percent of the total slip (10 millimeters per year [mm/yr]) is accommodated by offshore structures. Quaternary to Holocene offsets on the major fault zones within the Continental Borderland are interpreted to be primarily right-lateral strike-slip with a lesser vertical slip component, which are commonly referred to as oblique slip faults.

Northeast of the eastern Santa Barbara Channel, or at the eastern boundary of the Transverse Ranges, the Mojave segment of the San Andreas fault strikes more westerly than the neighboring segments and relative plate motion. This change in fault orientation forms a restraining trend that is sometimes referred to as the "big bend." Despite the requirement for substantial convergence at the "big bend," this segment of the San Andreas fault carries nearly pure right-lateral slip (Huftile and Yeats 1995). The convergent component is partitioned into belts of thrust, or oblique-slip faults, striking nearly parallel to and directed away from the San Andreas fault on both sides. One system propagates and verges north-northeast into the Central Valley of California (Keller et al. 2000) and another south-southwest toward the Pacific Ocean. The Western Transverse Ranges are the south-verging part of this system, and the Northern Channel Islands are part of the southern range.

Within the rotated tectonic blocks of the Western Transverse Ranges, older faults that rotated from original north-northwest strikes have been reactivated, explaining the present orientation of structures and topography. Estimates of Cenozoic or Neogene left-lateral slip across faults separating the Western Transverse Ranges from the inner Continental Borderland vary between 20 and 55 miles (32 and 90 km) (Campbell and Yerkes 1976; Truex 1976; Dibblee 1982a and 1982b; Wright 1991). Therefore, most rotation models include left-lateral slip on faults that bound the Western Transverse Ranges to the north and south (Luyendyk et al. 1985). Santa Cruz and Santa Rosa Islands are each bisected by active left-lateral faults that are linked to each other and to the Santa Monica-Dume-Malibu Coast fault system (**Figure 6-3**) (Pinter et al. 1998).

The south-directed thrusts, and related folds and topography, terminate abruptly at a sharp mountain and structural front along the south flank of the Santa Monica Mountains and the Northern Channel Islands (**Figure**

6-3). The east-west onshore and offshore basins (including the Los Angeles, Santa Monica, and Santa Cruz Basins) mark the foredeep of this front. The ranges, islands, and offshore banks of the Western Transverse Ranges and California Continental Borderland have been interpreted as the result of complex interaction along the North American-Pacific Plate boundary (Namson and Davis 1990; Shaw and Suppe 1994; Seeber and Sorlien 2000, Sorlien et al. 2004).

Farther south, the transition between the Peninsular Ranges and the Catalina Schist belts occurs along a low-angle detachment fault within the eastern edge of the Gulf of Santa Catalina, near Oceanside. Northwest-southeast right-lateral faults slice across the inner and outer Continental Borderlands (**Figure 6-4**). These faults are, from east to west, the onshore-offshore Newport-Inglewood, Palos Verdes-Rose Canyon fault, the offshore San Pedro Basin fault, the San Clemente fault system, East Santa Cruz Basin fault and the Patton Ridge fault (**Figure 6-3**). All of these faults, except the Patton Ridge fault, project to intersect the Western Transverse Ranges front, but they generally seem to have little effect on it.

The right-slip character of these faults is evident in transpressional uplifts (pop-up structures) at left fault contractional bends, or fault offsets, and transtensional sags or pull-apart basins at right fault extensional bends, or stepovers. The Shelf Projection anticlinorium, expressed as a bathymetric high on the continental shelf of eastern Santa Monica Bay, appears to be cored by an active, blind, thrust structure that is interpreted as a restraining bend between the Palos Verdes and San Pedro Basin faults (Sorlien et al. 2004, Sorlien, personal communication, 2006). The San Pedro Basin fault is the only regionally continuous right-lateral fault between the Palos Verdes coastline and Catalina Island (**Figure 6-3**). The San Pedro Basin fault merges with the Catalina fault zone to form the San Diego Trough fault zone at a pull-apart basin adjacent to Crespi Knoll. Santa Catalina Island represents a major restraining bend along the San Diego Trough fault zone, and the southern portion of San Clemente Island represents a restraining bend along the San Clemente fault zone. These and other physiographic features are often controlled by regional structure and tectonics.

Northwest-southeast right-lateral faults slice across the Inner and Outer Continental Borderlands. These faults are, from east to west: Newport-Inglewood fault, THUMS-Huntington Beach fault, Palos Verdes fault, San Pedro Basin fault, Catalina Escarpment-San Diego Trough fault zone, Thirty Mile Bank fault, San Clemente fault, and Patton Ridge fault (**Figures 6-5** and **6-6**). The San Pedro Basin fault is the only regionally continuous right-lateral fault between Palos Verdes and Catalina Island. The southwest margin of Santa Monica Basin is defined by the Santa Cruz-Catalina Ridge fault, which is an active strand of the San Clemente fault system. Seafloor geologic evidence supports the San Clemente fault being an active right-lateral fault (Goldfinger et al. 2000). A magnitude (M) 5.3 earthquake occurred on the Santa Cruz-Catalina Ridge strand of this fault in 1981 (**Figure 6-6**).

6.1.2 Regional Physiography and Geomorphology

The Project area lies along the southern California coast, west of Los Angeles County. The proposed Project pipeline route crosses the continental shelf in an arcuate path that parallels Santa Monica Submarine Canyon and extends southwestward into Santa Monica Basin (**Figures 6-7** and **6-8**). Santa Monica Basin is one of a series of basins of the California Continental Borderland (Shepard and Emery 1941).

Southern California is divided into several geomorphic regions or provinces. The proposed Project area is located in the Inner Continental Borderland Province, which extends from offshore San Diego to the northern margin of Santa Monica Basin. The province is almost entirely an offshore area, but the onshore area includes a portion of the western Los Angeles basin, as well as Santa Catalina Island. The Inner Borderland Province is bounded on the east by the Peninsular Ranges Province, on the north by the Transverse Ranges Province, and on the west by the Outer Continental Borderland Province (MMS 1999) (F**igure 6-4**).

Some researchers have included the Borderland Provinces with the Peninsular Ranges. However, distinct differences in basement rock composition, structural relief, and geomorphology suggest that it is appropriate to separate the offshore areas into distinct geomorphic provinces. The Inner Continental Borderland Province generally comprises the area south of the Northern Channel Islands, from near the coastline westward to San Clemente Island. Structurally, it is bounded by the San Clemente-San Ysidro fault zone on the west and the

Newport-Inglewood-Rose Canyon-Descanso fault zone near the coast. It extends from the southern boundary of the Western Transverse Ranges southward to the Vizcaino Peninsula in Baja California, Mexico (Legg 1991). The Inner Borderland Province is underlain by Catalina Schist. The physiography of the Inner Borderland is composed of generally northwest-oriented faults, ridges and basins, with relative steeper slopes on the flanks of uplifted ridges.

The northern margin of Santa Monica Basin is narrow, and is dissected by several south-trending, submarine canyons (Fugro 2006b). These include the active Hueneme, Mugu, and Dume submarine canyons, all of which contribute sediment to Santa Monica Basin. The eastern margin of the basin is characterized by a broad continental slope, which is dissected by the inactive Santa Monica submarine canyon and the active Redondo submarine canyon.

The narrow shelf, narrow beaches, and steep coastal bluffs and rugged Santa Monica Mountains along this part of the shoreline result from active tectonism. The Malibu Coast fault that shapes the shoreline also forms part of the southern boundary of the Transverse Ranges province. The shelf widens from just over 1.1 mile (1.5 km) at Point Mugu to just over 4.5 miles (6 km) wide offshore Santa Monica. The undissected continental slope is moderate to steep, averaging about 12 degrees. Seabed gradients are steep on canyon margins.

The continental shelf widens dramatically between Santa Monica and the Palos Verdes Peninsula. This widening of the shelf is likely structurally controlled, and may be the result of faulting and folding along the Palos Verdes fault system. The very gently sloping shelf in Santa Monica Bay is 4.5 miles (6 km) wide at Santa Monica, and nearly 9.3 miles (15 km) wide offshore El Segundo, before narrowing again to less than 1.9 miles (2.5 km) wide offshore the Palos Verdes Peninsula. The shelfbreak occurs at approximately 200 to 300 ft (66 m to 91 m) water depth (**Figures 6-7** and **6-8**).

The continental shelf is cut by Santa Monica and Redondo Submarine Canyons. The Palos Verdes fault Zone (PVFZ) may partially control the orientation of the Santa Monica Canyon (Fisher et al. 2003). Redondo Canyon is controlled by the Redondo Canyon fault, which terminates near the shore. Gradients on the continental slope and the westward extension of the San Pedro Escarpment are moderate to steep south of Santa Monica Canyon, ranging from 13 degrees between Santa Monica and Redondo Canyons to 30 degrees off the Palos Verdes Peninsula (**Figure 6-9**). Beaches along Santa Monica Bay tend to be wide and flat, backed by alluvial lowlands, aeolian sand dunes, and locally uplifted low mesas.

At the base of the continental slope is the northwest-southeast trending Santa Monica basin. The floor of Santa Monica basin is a low-relief area between 2,900 and 3,000 ft deep. It is approximately 10 to 20 miles (15 to 30 km) wide and 50 miles (80 km) long. Other Inner Borderland basins and troughs exist offshore. From north to south, they are Santa Monica Basin, San Pedro Basin, Santa Catalina Trough, and San Diego Trough. The basins are bounded to the west by uplifted banks and ridges, including Santa Cruz-Catalina Ridge, Catalina Island, and Thirty Mile Bank. Santa Monica Basin and San Pedro Basin are separated by Redondo Knoll, a rise that lies about 11 miles southwest of the Palos Verdes Peninsula.

Portions of the onshore area are within the Peninsular Ranges Physiographic Province. The Peninsular Ranges Province is dominated by northwest-southeast trending mountain ranges that extend up from Mexico to the Los Angeles Basin (CGS, 2002b). Onshore, the Los Angeles Basin is a low-relief area that is 15 miles (24 km) wide and 60 miles (97 km) long, bounded by high-relief mountains to the north and east, the Palos Verdes Peninsula to the south, and the shoreline to the west.

6.1.3 Regional Geology and Stratigraphy

The primary tectonic fabric of the inner California Continental Borderland is characterized by a series of northwest-southeast elongated basins and ridges arranged en echelon and separated by faults along which lateral motions have occurred (Bohannon and Geist, 1998). Superimposed on these structures is a distinct secondary tectonic fabric of east-west trending features associated with the Santa Monica Mountains and the Northern Channel Islands that correspond to the westward extension of the Santa Monica Mountains, and a system of predominantly left-lateral strike-slip faults running from the Northern Channel Islands eastward to the mainland and along the northern margin of the Los Angeles and Santa Monica Basins.

The Project is located northwest of the Palos Verdes Peninsula. The Palos Verdes Hills on the Palos Verdes Peninsula are part of an uplift which includes five northwest-trending en echelon anticlinoria, extending from Santa Monica Bay southeast to Lausen Knoll and forming the southwestern edge of the Los Angeles Basin. The Palos Verdes Hills constitute the central and highest of these anticlinoria. In its core, Catalina Schist is exposed at the surface and is overlain by a 2,100-m thick sequence of middle Miocene to lower Pliocene sedimentary rocks and middle Miocene volcanic rocks. Uplift of the Palos Verdes Hills is recorded by thirteen major marine terraces, the highest being 1,348 ft (411 m) above sea level (Wright, 1991).

The proposed pipeline route initiates offshore in the western portion of the Santa Monica Basin, traverses NE through Santa Monica Bay, and extends onshore into Los Angeles Basin via a landfall at LAX. Santa Monica Shelf is the submerged portion of the Los Angeles coastal plain, and lies within the Los Angeles Basin. The stratigraphy of the onshore area in the vicinity of LAX and the offshore Santa Monica Basin is briefly described below.

6.1.3.1 Stratigraphy

Los Angeles Basin represents a deep structural depression that has been filled with marine and non-marine deposits over 2.5 miles (4 km) thick. These sequences unconformably overlie early Cretaceous to Jurassic Catalina Schist basement of unknown thickness, which outcrops locally on the Palos Verdes Peninsula and on Catalina Island. Pliocene marine sedimentary rocks (Pico and Repetto Formations), Miocene marine sedimentary (Monterey Formation) and volcanic rocks underlie the LAX/Ballona Gap area, and are locally exposed on the rugged slopes of the Santa Monica Mountains and the Palos Verdes Peninsula (Dibblee and Ehrenspeck 1993; **Figure 6-10**). These are overlain by Quaternary strata, which show a transition from marine to non-marine deposition as the basin was infilled and uplifted (Fisher et al. 2004). The non-marine strata include coarse fluvial (stream and river) deposits, as well as wind-blown (aeolian) sand dune deposits in the vicinity of LAX.

Santa Monica Basin is a tectonically active, deep, structural depression filled with unconsolidated Quaternary sediments of predominately mud, silt, and fine sand up to 500 ft (150 m) thick. The unconsolidated Quaternary sediments overlie marine sediments and sedimentary rocks that locally exceed 4,900 feet (1,500 m) thick (Shipboard Scientific Party 1997; Fisher et al., 2003; Normark and McGann 2004). The sediment infilling has occurred synchronously with the basin's subsidence during the Pliocene and Quaternary (Crouch and Suppe 1993). The sediments within the basin are thought to represent hemipelagic sediments and a thick accumulation of distal turbidite deposits, derived from periodic flows down the continental slope and through at least four submarine canyons that feed into the basin (Shipboard Scientific Party 1997; Normark and McGann 2004).

Surficial materials onshore in the Los Angeles basin consist of Quaternary and Holocene alluvial deposits consisting of unconsolidated sand, silts, and gravel (Thelen et al. 2004). Offshore the surficial geologic units consist of consolidated and unconsolidated Quaternary non-marine fluvial deposits, late Quaternary marine shelf, slope and basin deposits, Miocene and Pliocene sedimentary rocks, and Miocene volcanic rocks (Kennedy et al. 1987). **Figure 6-11** presents a portion of the regional geologic map (Saucedo and others, 2005) of Santa Monica Bay at the DWP and along the offshore pipeline route.

The only known deep exploration boring in the Santa Monica Basin is the Ocean Drilling Program (ODP) Site 1015 (**Figures 6-5** and **6-11**), located approximately 1.9 miles from the preferred PLEM location and about 1,600 feet from the proposed gas pipeline. This site records a sequence of fine- to medium-grained sands, hemipelagic muds and turbidite deposits interpreted to be of late Quaternary age to 150 meters (depth explored; Shipboard Scientific Party 1997). The sediment sequence is dominated by thin interbeds of quartz feldspar sand and clayey silt. The sand layers show sharp basal contacts and grade upwards into clayey silt, suggesting deposition by turbidity currents. Thin layers of nannofossil clays are frequently found to overlie the clayey silt and, in turn, are overlain by sand.

Santa Monica Basin is underlain by post-Miocene marine sedimentary rocks, Miocene sedimentary, volcanic and volcaniclastic rocks, and Jurassic metamorphic rocks of Catalina Schist (Vedder 1987; Fisher et al. 2003). Surficial sedimentary units in the basin (Qmb on **Figure 6-11**) are mapped as mostly thin, unconsolidated Holocene mud (mixed silt and clay) over older, silty, sandy turbidite and hemiplegic deposits (Normark et al. 1998; Piper et al. 1999).

Onshore, the coastal plain where the pipeline corridor is planned is comprised of thick eolian, alluvial and fluvial deposits. These deposits include active sand dunes, older dune sand, alluvium, terrace deposits, and portions of the San Pedro Formation. Due to extensive urbanization of the area, many areas have been disturbed and are presently composed of reworked native materials and/or artificial fill.

6.1.3.2 HDD Shore Crossing Soils and Stratigraphy

Geoscience considerations for HDD site selection focused on topography, local geology, and stratigraphy. The HDD site characterization report for the proposed Project is provided as **Appendix N**. At the shore crossing, the HDD entry locations are located on an elevated plain south of Ballona Creek. The HDD entry point is located on an approximately 100-foot-high, relatively flat-topped bluff overlooking a wide, flat, sandy beach to the west of LAX. The HDD is located in predominately late Quaternary sandy and sandy gravel soils that are likely at least 180 ft thick (**Figures 6-12** and **6-13**). Upper Pleistocene deposits underlie the elevated plain, and likely extend offshore. These include the San Pedro Formation, which overlies the late Pliocene Pico Formation (CDWR 1961). Onshore, the upper portion of the Pico Formation is over 1000 feet (300 m) thick, and consists of semiconsolidated silt, clay, sandy clay, and sand with interbeds of sandy gravel, mudstone, and sandstone. Near the coast, the base of the San Pedro Formation lies approximately 95 to 100 ft (30 m) below ground surface (bgs) (Poland et al., 1959). The San Pedro Formation consists primarily of interbedded sandy gravel and sand, with units ranging in thickness from a few feet to several tens of feet.

Overlying the San Pedro Formation are Pleistocene river deposits (Qoa) composed of dense to very dense, medium- to coarse-grained sands, with gravels that likely interfinger with nearshore marine sediments of similar compositions (**Figure 6-13**). This unit is overlain by Pleistocene-aged dune deposits (Qoe) composed mostly of dense to very dense, well-sorted, medium- to coarse-grained sands with minor lenses of sandy silt, clay, and gravel. Immediately shoreward of this unit is a quarter- to half-mile-wide strip of Holocene-aged dune deposits (Qe) that are adjacent to the modern beach. The younger dune deposits consist of very well-sorted, fine- to medium-grained sand typically less than 10 to 20 feet (6 m) thick.

Offshore Holocene strata are up to 30 feet (10 m) thick near the HDD exit, and are composed of interstratified sand and sandy gravel overlying upper Pleistocene strata (**Figure 6-14**). The upper Pleistocene sediments consist of intercalated, very thin to massive beds of moderately well- to well-sorted, fine- to medium-grained sand, and moderate- to poorly-sorted, pebbly, medium- to coarse-grained sand and gravel (Inset 3 **Figure 6-8**)(Osborne et al., 1983).

6.1.4 Structure and Seismicity

Given the tectonically active environment, structure and seismicity are important considerations to the engineering design of the Project. Numerous active faults are located within 60 miles (100 km) of the Project area (**Figure 6-6**), and are addressed in Section 6.1.4.1. Characteristics of potential seismogenic sources are summarized in **Table 6-1**. These parameters were used in construction of a site-specific probabilistic seismic hazard assessment for the Project (Fugro, 2006c) (refer to **Appendix M**). Historic damaging earthquakes and seismicity are discussed in Section 6.1.4.2.

6.1.4.1 Active Faults

This section provides descriptions of the active faults located in the vicinity of the Project area, as well as of the San Andreas fault and blind faults under the Los Angeles Basin. Detailed descriptions of the other faults located within 60 miles (100 km) of the Project area are provided in Fugro (2006c).

Palos Verdes Fault

The Palos Verdes fault is a right-lateral strike-slip fault zone, with a minor component of oblique slip resulting from a restraining bend near the Palos Verdes Peninsula. The fault offsets Holocene sediments in the Port of Los Angeles, and is considered an active fault with an estimated slip rate of approximately 3 +/-1 mm/year, based on offset of a dated ancestral channel of the Los Angeles River (McNeilan et al., 1996; Stephenson et al., 1995). The fault extends for approximately 60 miles (96 km) southeastward from Santa Monica Bay across the northeast portion of the Palos Verdes Peninsula and across the San Pedro shelf to Lausen Knoll. The fault bifurcates around Lausen Knoll (Fisher et al., 2004), and then continues south, connecting with the Coronado Banks fault in the inner borderland northwest of La Jolla. The proposed LAX pipeline alignment crosses the projected location of the main trace in Santa Monica Bay.

The northwest part of the Palos Verdes fault, in Santa Monica Bay, has been modeled to lose slip into clockwise rotating blocks (Sorlien et al. 2004), and has been mapped to split into several strands (Bryant, 2005). These strands lose vertical separation in Pliocene strata towards the northwest, and the potential for seafloor rupture is debatable. Fisher et al. (2003) report that the fault segment that produces seafloor surface displacement dies out on the Santa Monica shelf northwest of the peninsula. They did not observe seafloor surface or shallow sediment displacement along the projected strike of the main fault trace in the data they collected (Fisher et al., 2003).

The 0.12 inch/yr (3 mm/yr) Holocene slip determined at Long Beach probably gradually decreases to near zero at the northwest terminations of the fault strands near the Santa Monica-Dume fault (Sorlien, personal communication 2006). This decrease in slip rate may be accommodated by the observed short-wavelength folding beneath the Santa Monica shelf (Fisher et al., 2003) and/or a transfer of slip onto the Redondo Canyon fault, as has been postulated by Nardin and Henyey (1978). We have segmented the fault into a northern segment and a southern segment. We have assigned a slip rate of 0.12 inch/yr (3 mm/year) for the southern segment, which extends through the Palos Verdes Peninsula and south toward the Coronado Banks fault. For the segment northwest of the peninsula, we have assigned a slip rate of 0.06 inch/yr (1.5 mm/year). We have included both single-segment and combined segment rupture scenarios in our seismotectonic model. We estimate the maximum earthquake magnitudes for the rupture scenarios range from M_w 6.6 to 7.3.

San Pedro Basin Fault Zone

The San Pedro Basin fault zone is parallel to, and located between, the Palos Verdes and San Clemente faults. This fault zone has been interpreted to die out near the Santa Monica-Dume fault in the north and to extend approximately 88 miles (142 km) southward, where it connects to the San Diego Trough fault at a pull-apart basin near Crespi Knoll (Legg and Goldfinger, 2002). The fault motion is thought to be predominantly right-lateral strike-slip based on “flower-structures” observed along the fault (Bohannon et al., 2004; Fisher et al., 2003). As is common in transpressional zones, high angle reverse and normal structures have also been observed along the fault (Bohannon et al., 2004; Fisher et al., 2003).

The San Pedro Basin fault zone is characterized by a series of en echelon fault splays, as opposed to one main trace (Legg and Goldfinger, 2002; Normark and Piper, 1998). In the Santa Monica Basin, the fault displays prominent seafloor expression (Legg and Goldfinger, 2002). Bohannon et al. (2004) interpret an anticlinal structure between Santa Monica and Dume Canyons to be potentially active during the Holocene. Post-50 ka strata correlated from ODP Site 1015 are locally folded and offset across and adjacent to the fault with 130 ft (40 m) of structural relief, suggesting significant young strike-slip motion and vertical motion in a restraining double-bend (Sorlien, personal communication 2006). The proposed LAX pipeline alignment option crosses several mapped fault splays of the San Pedro Basin fault zone. The surface fault rupture hazard is addressed in **Section 6.1.7.1** of this report.

In the San Pedro Channel, the San Pedro Basin fault zone displays well-defined offset of sub-seafloor acoustic horizons (Legg and Goldfinger, 2002). The database for the Quaternary fault in the Santa Monica Basin, shown in **Figure 6-6,** is compiled from Bryant (2005), Fisher et al. (2005), and Jennings (1994). Fault locations in the San Pedro Channel seismotectonic model are based upon the mapping by Legg and Goldfinger (2002).

The slip rate for the San Pedro Basin fault is currently unknown. However, it is likely that slip from the San Diego Trough fault is partitioned onto the San Pedro Basin fault zone. Based upon the regional slip budget in our seismotectonic model, we estimate that the slip rate is approximately 0.04 inch/yr (1 mm/year). Additionally, we estimate that a portion of the slip from the Palos Verdes fault is transferred through a left step-over zone in Santa Monica Bay and accommodated on the northern segment of the San Pedro Basin fault zone (Bohannon et al., 2004; Nardin and Henyey, 1978). Therefore, we estimate the slip rate on the northern fault segment to be 0.08 inch/yr (2 mm/year). A probability of rupture of 0.50 was assigned to this fault in the seismotectonic model because its recent activity rate is relatively uncertain. We divided the San Pedro Basin fault zone into four segments and developed both single-segment and multi-segment rupture scenarios. The segment boundaries are based upon fault intersection points, change in fault strike where the fault appears to bend at Avalon Knoll, and a pull-apart basin between the southern end of the San Pedro Basin fault zone and the San Diego Trough fault. The northern segment at the northern end of the San Pedro Basin fault appears to die out near the Dume fault. We estimate the maximum magnitudes of the various rupture scenarios to range from M_w 6.5 to 7.3. For more detailed information concerning our fault segmentation model for the San Pedro Basin fault zone, see Fugro (2006c).

<u>Dume Fault</u>

This fault is located at the northern margin of the Santa Monica Basin and, at its closest point, is mapped within about 5 miles (8 km) of the proposed LAX pipeline alignment. Studies of the focal mechanisms of the 1973 Point Mugu earthquake (magnitude 5.5) provided the first pertinent information about the dip and sense of movement on the three faults that all project towards the hypocenter. These faults include the Santa Monica Bay fault, the Dume fault, and the Malibu Coast fault. Analyses of the 1973 earthquake suggest reverse strike-slip motion, with a component of left-lateral strike-slip on an east-west trending fault. This motion is consistent with the geometry of the Dume fault (Lee et al., 1978; Stierman and Ellsworth, 1976).

In addition to the local tectonic information inferred from the 1973 earthquake, a review of industry seismic data that was recently made available has lead to an improved understanding of the Dume fault structure (Fisher et al, 2005; Sorlien et al., 2003 and submitted). The Dume fault is interpreted as a restraining double bend in a left-lateral strike-slip fault, with an oblique component that dips moderately to the north. The overall strike of the Dume fault is east-west, but it is arcuate and describes broad curves, as detailed in work by Sorlien et al. (2003 and submitted). Fisher et al. (2005) suggest that, based on the fault strike and its subsurface structure, the Dume fault system can be divided into three trends or segments: (1) the east-northeast Santa Monica trend between Sycamore Knoll and the shore (Segment D [B]), (2) the west-northwest Dume trend (Segment D[A]), and (3) the set of mostly blind northeast-southwest faults (Hueneme Segment D[H]) beneath the Hueneme Submarine Fan.

The Dume fault at the base and to the east of Sycamore Knoll disrupts the seafloor, indicating Holocene activity (Fisher et al., 2005 and 2003). West of Sycamore Knoll, the Dume fault changes in strike and several subvertical faults, with notably less structural relief than the main Dume fault east of Sycamore Knoll, are observed to trend toward the Malibu Coast fault (Fisher et al., 2005). The shallow subvertical faults that connect the Dume to the Malibu Coast fault have experienced little (tens of meters) vertical separation. It is unclear how much left-lateral slip they can carry. However, according to Dr. Sorlien it is likely that several km of post-~4 Ma left-lateral slip on the Dume fault is transferred to the Malibu Coast fault in this area. Thus, the Malibu Coast fault may have a larger left-lateral slip rate from this junction area to the west. Left deflections of submarine canyons near these connecting faults are noted by Fisher et al (2005). At the western end of the Dume trend, where part of the fault becomes blind under the Hueneme Fan, the fault is less likely to have a reverse component of slip because the strike of the fault changes and because regional contraction decreases to the west (Sorlien et al., submitted manuscript).

According to Dr. Sorlien, the estimated slip rate along the Dume fault is about 0.08 inch/yr (2 mm/year). We have included single-segment and multi-segment rupture scenarios in our seismotectonic model. A large onshore-offshore combined rupture of magnitude 7 or greater on the Santa Monica and Dume faults, while rare, is still possible (Dolan et al., 2000).

Malibu Coast Fault

The Malibu Coast fault is an integral part of the major east-west-trending zone of deformation that defines the transpressional features of the Transverse Ranges. This zone extends offshore up to 60 miles (100 km), and is composed of north-dipping left-oblique faults (Yerks and Lee, 1987). We include the onshore and offshore fault components within this discussion.

Offshore, the general fault pattern of the Malibu Coast fault is described by Fisher et al. (2005) and Sorlien et al. (2003). Authors describe the fault as a left-oblique reverse feature that runs from Point Mugu in a west-southwest direction across the Hueneme Fan, and projects to the west to connect directly with one or more of the northern strands of the Santa Cruz Island fault. It dips steeply to the north in the near-surface and flattens with depth. It likely merges at depth with the Dume and Santa Monica Bay faults (Sorlien et al., 2003). While offset of the fault is observed onshore, there is only about 200 m of vertical separation of ~4 Ma strata across the sub-vertical offshore part of the Malibu Coast fault across the Hueneme Fan (Sorlien et al., 2003). This does not preclude a much larger strike-slip offset.

At the western end of the Malibu Coast fault, studies on Santa Cruz Island suggest that the fault has been active during the Quaternary. Pinter et al. (1998) estimate that the left-lateral slip along that section of the fault has been 0.03 inch/yr (0.75 mm/year) during the Holocene. Their study has also inferred that the Santa Cruz Island fault last broke around 5,000 years ago. Data suggest that the average interval between earthquakes on the Santa Cruz Island fault is at least 2,700 years, and probably between 4,000 and 5,000 years, with a maximum magnitude earthquake M_w 7.3 to 7.4. These results closely match recent findings on the other faults mapped along the southern margin of the western Transverse Ranges.

Because the Malibu Coast fault connects with active onshore faults at both ends, i.e. on Santa Cruz Island and along the Malibu Coast, it is probable that the fault is also active offshore. Dr. Sorlien estimates that the Malibu Coast fault, east of its junction with the Dume fault (possibly beneath the Hueneme Fan), probably has a long-term post-Miocene slip rate of less than 1 millimeter per year. Various studies show minimal, or no, Holocene slip across onshore strands of the Malibu Coast fault.

We include a single-segment rupture and a combined rupture scenario for the Santa Cruz Island fault in our seismic source model. These rupture scenarios have magnitudes of M_w 7.15 and 7.25, respectively. We assign a conditional probability of 0.10 for the combined rupture of the Malibu Coast and Santa Cruz Island faults.

Redondo Canyon Fault

The Redondo Canyon fault is shown on published maps (e.g., Wright, 1991; Nardin and Henyey, 1978). It is, however, not a well-known fault. Bohannon et al (2004) indicate that it is a south-dipping reverse fault that trends north-northwest. Quaternary sediments up to a kilometer thick overlie basement strata (Monterey, Puente, and Repetto Formations) north of the fault. To the south, these strata are exposed in the Palos Verdes Hills (Bohannon et al., 2004). Nardin and Henyey (1978) suggest that the Redondo Canyon fault may connect to the Palos Verdes fault zone and may accommodate some of its slip. Currently, Holocene displacement rates are uncertain. However, we estimate that half of the 0.12 inch/yr (3 mm/year) of slip on Palos Verdes fault zone is distributed to the Redondo Canyon fault to the west, through a left step-over with the San Pedro Basin fault zone, and the other half is distributed to the north into Santa Monica Bay, among a northwesterly strand(s) of the Palos Verdes fault zone. We estimate that the Redondo Canyon fault is capable of generating a M_w 6.5 earthquake.

Santa Monica Bay Fault

The Santa Monica Bay fault is a gently north-dipping Miocene low-angle blind normal separation fault that is now part of the SCEC Community fault Model. Because it is a blind fault and does not manifest seafloor or shallow sediment deformation, we do not consider it to represent a surface fault rupture hazard. The tip line of the fault projects beneath the LAX Alternative proposed pipeline; therefore, the Santa Monica Bay fault may potentially produce seismic ground motions that could affect the Project.

The activity rate of this fault is still unknown. There is only minor folding of Pliocene strata above its southern, upper part, and can be considered inactive there. However, it projects downdip and north into seismicity, and may be reactivated as a thrust (Sorlien et al., 2003 and submitted). The Dume fault dips moderately north and thus projects downdip to intersect, and possibly merge with, the Santa Monica Bay fault. It is intersected to the east by the San Pedro Basin fault zone. We estimate this fault has a slip rate of 1 mm/year and has maximum earthquake magnitude of Mw 6.95. Because its activity rate is uncertain we assign a fault rupture probability of 0.50.

Compton Structure

The activity, structure, geometry, and relationship with other structures have been controversial topics in Southern California seismic hazard studies (Ward and Valensise 1994; Shaw and Suppe 1996; Mueller and Suppe 1997; Cao et al., 2003; Sorlien et a. 2003 and 2005). According to Bill Bryant (CGS), the Compton structure is currently being evaluated by the State to determine whether it will be re-incorporated as a source in the State's probabilistic seismic hazard analysis, scheduled to be released in 2007 (Bryant, personal communication 2006).

A recent study of global positioning system (GPS) data cannot rule out this deep, thrust structure being active. GPS data, modeled for locked faults and changes in fluid levels, were used to estimate 0.18 inch/yr (4.5 mm/yr) of current contraction and 0.32 inch/yr (8 mm/yr) of creep on low-angle faults near and north of downtown Los Angeles (Argus et al. 2005 and presentation at SCEC workshop Oct. 27, 2005). The proposed slip rate on the Puente Hills thrust accounts for less than a quarter of this, although the underlying lower Elysian Park thrust may carry additional slip (Shaw and Shearer, 1999). Shaw et al. (2002) show the lower Elysian Park and the Compton thrusts to be parts of the same faults, so contraction north of downtown L.A. may be expressed during earthquakes as uplift of the Torrance-Wilmington-Belmont trend and of the Palos Verdes anticlinorium.

There is direct local evidence that parts of the offshore Palos Verdes anticlinorium remain active. This evidence may not be sufficient to prove that the entire southwest limb of the anticlinorium is actively folding. Santa Cruz Basin and Santa Monica Basin have both subsided 2.5 miles (4 km) in the last 5 million years and the strata beneath most of Santa Barbara Channel have continued to subside through Quaternary time (Pinter et al., 2003; Sorlien et al., in review). The simplest interpretation is that Santa Monica and San Pedro basins continue to subside, and that active folding, faulting, and tectonic uplift is required to keep the shelf projection, Palos Verdes Hills, and San Pedro shelf from subsiding.

We acknowledge the possibility that the Compton Structure may be partly responsible for the activity of the Palos Verdes anticlinorium. We adopt a slip rate of 0.008 inch/yr (0.2 mm/yr) and fault geometry similar to those used by Savy and Foxall (2003). Due to the uncertainty in the fault activity we assign a rupture probability of 0.50.

Santa Cruz-Catalina Ridge Fault

The Santa Cruz-Catalina Ridge fault is a long linear right-lateral fault that produced a right-lateral earthquake in 1981 M_w 6.0 (Astiz and Shearer, 2000), based on the aftershock pattern that occurred along its trace. It likely connects to the San Clemente fault, and thus can be considered a part of that fault system (Legg, personal communication). This fault is a major contributor to the seismic hazard for the proposed LAX pipeline alternative evaluated in this study.

We divide the fault into two segments. At the segmentation point, the fault appears to split into multiple splays and it intersects with the East San Clemente fault. Aftershocks from the 1981 earthquake appear to be limited to the north segment and suggest that the north and south segments may rupture independently. The segment north of its intersection with the San Clemente fault most likely accommodates 0.16 inch/yr (4 mm/yr) of slip from the San Clemente fault (Legg, personal communication 2006). The activity rate of the southern segment is likely lower (Legg, personal communication 2006), therefore, we assign a slip rate of 0.04 inch/yr (1 mm/yr) to the southern segment. Evidence that the slip on the southern segment most likely becomes minimal further south is supported by mapping of the southern termination of the fault on Santa Catalina Island, where drainages and terraces are not offset by the fault (Legg, personal communication 2006). Based on this, we assign a conditional probability of 0.40 for the southern segment to rupture alone and 0.20 for a combined rupture with the northern segment.

San Clemente Fault

The San Clemente fault extends over 150 miles (250 km), from near Santa Catalina Island offshore of southern California southward to Ensenada, Baja California, where it most likely connects with the San Ysidro fault. To the north, it most likely continues as the Santa Catalina Ridge fault. This fault contributes to the seismic hazard of both the proposed LAX and AES Alternatives.

This fault is a mature borderland fault as evident by its very straight, well-defined, narrow, and continuous zones of faulting (Legg and Goldfinger 2002). Based on observations in seismic reflection data, and from its straight seafloor surface trace, it is interpreted to be a high angle fault (Bohannon and Geist 1998; Legg and Goldfinger 2002).

The fault morphology at fault bends and offsets indicate that this is a right strike-slip fault (Legg and Goldfinger 2002). Pull-apart or sag structures with secondary normal separation faulting, indicative of extensional or transtensional character, are observed at right steps or bends in the fault. Fault-normal shortening (pop-up structures), folding, secondary thrust or reverse faulting are observed at left-steps or bends.

Three moderately sized earthquakes have occurred on the San Clemente fault system during historical time. The 1981 M_w 6.0 Santa Barbara Island earthquake (Astiz and Shearer, 2000) occurred on the Santa Cruz - Catalina Ridge fault, a northern extension of the San Clemente fault. The 1951 M_L 5.9 San Clemente Island and the 1964 M_s 6.2 Offshore Ensenada earthquakes occurred on the San Clemente fault (Legg 1980; Cruces and Rebollar 1991). Legg and Goldfinger (2002) suggest that multi-segment ruptures on this fault have the potential to produce earthquakes up to M_w ~7.6.

Based on slip rate estimates in Legg and Goldfinger (2002), we assign a slip rate of 4 mm/year. We also consider the potential for single-segment and multi-segment ruptures that correspond to maximum earthquake magnitudes from 6.80 to 7.55.

THUMS-Huntington Beach Blind Thrust Fault

The THUMS-Huntington Beach fault is a blind thrust that was only recently recognized as being an active seismic source. It extends for about 23 miles (37 km) from its intersection with the Palos Verdes fault, southeast to where it intersects the Newport-Inglewood fault offshore Huntington Beach (Wright 1991; Williams 2003). Davis and Namson (1992) believe the fault is a high-angle reverse fault, but recent interpretation of 3D seismic data suggest that the dip of the fault is about 38 degrees to the northeast (Williams 2003). Deposition of syntectonic Pliocene Repetto Formation strata and gentle folding of overlying early Pleistocene strata clearly demonstrate fault movement. Late Pleistocene reactivation of the structure has been documented by the Unites States Geological Survey (USGS) (Edwards et al. 2001), based on seismic and borehole data, as well as on gentle surficial topographic relief. Early Holocene strata are gently folded, but late Holocene strata are flat-lying, suggesting that an earthquake event occurred on the fault in the early to mid-Holocene (Edwards, personal communication 2003).

Shaw (personal communication, 2003) suggests the recurrence interval for this fault is several thousands of years, comparable with other blind thrusts beneath the Los Angeles Basin. Williams (2003) suggests a Holocene slip rate of about 0.04 inch/yr (1 mm/yr) for this fault, but does not present data supporting this estimate.

Newport-Inglewood Fault Zone

See section 6.1.7.8 for a discussion of the onshore Newport-Inglewood fault zone.

San Andreas Fault Zone

The San Andreas is the primary tectonic structure defining the seismicity of California. The San Andreas fault forms a relatively narrow zone extending from Cape Mendocino in Northern California to the Salton Sea in Southern California, a distance of about 680 miles (1,100 km). Geologic mapping and paleoseismic studies along the fault zone have identified varying slip rates, earthquake recurrence intervals, and asperities that allow the fault system to be divided into several segments. Considered in this analysis are the southern segments that are within approximately 60 miles (100 km) of the proposed sites. These are the Coachella Valley, San Bernardino Mountains, and Mojave segments. The lengths of these segments are approximately 60 miles (96 km) for the Coachella segment, 64 miles (103 km) for the San Bernardino segment, and 84 miles (135 km) for the Mojave segment. Based on the rupture lengths of the 1857 Tejon earthquake and the 1906 San Francisco earthquake, a potential rupture of all three segments is possible. Ruptures are modeled on the separate segments as well as a single rupture combining the segments.

6.1.4.2 Historical Seismicity

The historical earthquake record in Southern California dates back about 200 years. Several significant, damaging earthquakes have occurred in the coastal region during that time (**Table 6-2**). However, far-field earthquakes, or earthquakes with epicenters outside of the study area, have also caused damage within the study area. These events include the great Fort Tejon earthquake (approximately moment magnitude [Mw] 8.0) of 1857 that ruptured over 224 miles (360 km) of the San Andreas fault, the Long Beach earthquake (Mw 6.4) of 1933 that occurred on the Newport-Inglewood fault zone (NIFZ), and the Northridge earthquake (Mw 6.7) of 1994 that occurred on a previously unmapped (or blind) thrust fault possibly related to the Oakridge fault (Fugro 2006c).

6.1.4.3 Seismicity Catalog

A composite seismicity catalog covering the period between 2150 B.C. to February 2006 was compiled. The majority of the data were acquired from the following agencies:

- USGS/National Earthquake Information Center (NEIC), Preliminary Determination of Epicenters (PDE) catalog, 1973 - present. This catalog is a listing of earthquakes located by the USGS/NEIC and its predecessors in the U.S. Coast and Geodetic Survey, the National Oceanic Survey, and the Environmental Research Laboratories of the Department of Commerce.
- CALIFORNIA, 1735 - 1974 (CGS). This catalog was compiled by Real et al. (1978) and Toppozada et al. (1984) at the California Division of Mines and Geology. This file includes hypocenters from catalogs of the Seismological Laboratory of the California Institute of Technology and the Seismological Stations of the University of California at Berkeley.
- Advanced National Seismic System (ANSS), 1898- present.
- Northern California Earthquake Catalogue Search (NCEC), NCSN catalog 1889 - present.
- National Earthquake Information Center (NEIC), Significant Earthquakes Worldwide catalog 2150 BC - 1994.
- NEIC, Significant U.S. Earthquakes catalog 1568 - 1989.

- Southern California Earthquake Catalogs (SCEC), SCSN catalog 1910 - present.

After the catalogs were merged, events of magnitude less than 5.0 and duplicate events were deleted. As a result of merging the catalogs, several events with conflicting magnitudes were encountered. An automated system was used to remove duplicate events, provided by different sources, from the catalog. The program looks for similarities in time, location, and magnitude to score successive events as duplicates. The final catalog includes 154 earthquakes ranging from M 5.0 to 8.3 for the period from 1769 A.D. to 2005. The epicenter locations from the declustered catalog are shown on **Figure 6-6**.

Magnitude 5.0 and larger earthquakes generally are associated with a few major fault zones. Onshore, the larger earthquakes are from five areas:

- the San Bernardino Mountains,
- the San Andreas fault zone,
- the San Jacinto-Imperial fault zone,
- the Whittier-Elsinore fault zone, and
- the onshore part of the Newport-Inglewood fault zone that was responsible for the 1933 magnitude 6.4 Long Beach earthquake.

Offshore, there are four areas with instrumental and/or historical seismicity:

- A prominent group of epicenters surrounds the northern end of the San Diego Trough fault zone, where a bend or offset occurs at the south end of the Catalina Escarpment. The majority of this cluster represents the 1986 magnitude 5.4 Oceanside earthquake and associated aftershocks that occurred about 30 miles (50 km) from the Project area.
- There is also a diffuse zone of smaller magnitude 4 to 5 earthquakes associated with the San Clemente fault zone, between San Clemente Island and the Mexican border. CDMG (2000) located the 1951 magnitude 5.9 earthquake at the southwestern tip of San Clemente Island along the San Clemente fault zone.
- The Coronado Banks-Palos Verdes fault zone is the reported source of several earthquakes of magnitudes 4.5 or greater, as well as of several lesser magnitude earthquakes.
- The Rose Canyon fault zone offshore from Encinitas is reported in CDMG (2000) as the probable source for a magnitude 6.5 earthquake that occurred in the early 1800s. Several smaller earthquakes have been recorded along this trend from Tijuana north.

6.1.4.4 Design Criteria for LNG Facilities

In general, the design of onshore LNG facilities within the United States is conducted in accordance with the 2001 version of the National Fire Protection Agency (NFPA) 59A code. In 2006, NFPA published an update to the NFPA 59A code. However, it is unlikely that the U.S. Maritime Administration and U.S. Coast Guard, who are responsible for the permitting of Deepwater Ports, will adopt the NFPA code for LNG import facilities permitted in accordance with the Deepwater Port Act.

The following description of the NFPA requirements is provided for perspective, although the actual design return periods for the DWP Project may vary from those required by NFPA.

According to NFPA, two levels of design ground motions are developed: 1) Operating Basis Earthquake (OBE), and 2) Safe Shutdown Earthquake (SSE). Additionally an Maximum Credible Earthquake (MCE) is developed to provide input to the calculation of the OBE and SSE.

6.1.4.5 NFPA Maximum Credible Earthquake (MCE)

According to both NFPA (2001) and NFPA (2006), the MCE response spectrum is defined as the probabilistically-estimated spectrum of ground motions that have a 2 percent probability of exceedance in a 50-year period (i.e., a return period of 2,475 years). This definition is subject to the requirement that the ordinates of the 2,475-year return period spectrum at structural periods of 0.2 and 1.0 second are smaller than those of a deterministic limit spectrum. The deterministic limit spectrum is defined as the spectrum determined in accordance with NEHRP (1997) or ASCE-7 (1998), using an importance factor of 1.0, Ss= 1.5g, S1= 0.6g and a site class representative of the site conditions where the LNG facility is located. If the deterministic limit spectra are exceeded at structural periods of 0.2 and 1.0 second, the MCE motions are calculated as the lesser of:

- the probabilistically estimated 2,475-year return period equal-hazard spectrum, or
- 150 percent of a deterministically estimated median response spectrum associated with the maximum magnitude earthquake on all known faults close to the site. However, the spectral ordinates of the deterministic spectrum should not be lower than the deterministic limit spectrum.

A similar procedure is used to develop the MCE vertical ground motions, with the exception that NEHRP/ASCE criteria are not available. NFPA (2001) requires that the vertical ground motions at all structural periods be above the ground motion level corresponding to two-thirds of the horizontal ground motion. However, NFPA (2006) allows for vertical ground motions to be as low as one-half of the horizontal ground motions if a seismic hazard analysis is conducted. **Table 6-3** presents the exceedance probabilities for different return periods at the DWP.

6.1.4.6 NFPA Operating Basis Earthquake (OBE)

The OBE is a mid-level design criterion. Qualitatively, LNG facilities are to be capable of remaining operational following OBE ground motions. According to NFPA (2001), the OBE horizontal ground motions are calculated as the acceleration response spectrum that is the lower of the following:

- two-thirds of the spectral accelerations resulting from an MCE, or
- the probabilistically estimated equal-hazard spectrum corresponding to ground motions that have a 10 percent probability of exceedance in a 50-year period (i.e., a return period of 475 years).

According to NFPA (2006), the OBE ground motions are directly estimated as the 475-year return period equal-hazard spectrum.

A similar procedure is used to develop the OBE vertical ground motions. NFPA (2001) requires that the vertical ground motions at all structural periods be above the ground motion level corresponding to two-thirds of the horizontal ground motion. However, NFPA (2006) allows for vertical ground motions to be as low as one-half of the horizontal ground motions if a seismic hazard analysis is conducted. **Table 6-3** presents the exceedance probabilities for different return periods at the DWP.

6.1.4.7 NFPA Safe Shutdown Earthquake (SSE)

The SSE is an upper-level design criterion. Qualitatively, LNG facilities are to be capable of being safely shut down with no loss of containment or loss of safety system functionality when subject to the SSE ground motions.

According to NFPA (2001), the SSE is calculated as the response spectrum that is the lower of:

- the probabilistically estimated equal-hazard spectrum associated with ground motions that have a 1 percent probability of exceedance in a 50-year period (i.e., a return period of 4,975 years); or
- two times the OBE response spectrum.

According to NFPA (2006), the SSE is equal to the MCE.

A similar procedure is used to develop the SSE vertical ground motions. NFPA (2001) requires that the vertical ground motions at all structural periods be above the ground motion level corresponding to two-thirds of the horizontal ground motion. However, NFPA (2006) allows for vertical ground motions to be as low as one-half of the horizontal ground motions if a seismic hazard analyses is conducted. **Table 6-3** presents the exceedance probabilities for different return periods at the DWP.

6.1.4.8 Pipeline Route and Other Facilities

The pipelines between the DWP and the California shoreline and other appurtenant facilities will not be carrying LNG. Consequently, they likely need not be designed in accordance with NFPA 59A. Other design guidelines, such as those suggested by the American Petroleum Institute (API) can likely be considered for the design of these facilities. In general, the criteria specified in these design codes and several others give consideration to ground motions with return periods ranging from about 200 years to about 5,000 years. Thus, in addition to the detailed NFPA-based ground motion criteria for the DWP location, results are presented for five different return periods. Tabulations of the return periods and associated probabilities of exceedance for exposure periods (design life) of 25 and 50 years are presented in **Table 6-3**. Estimated peak ground accelerations (PGAs) at the DWP site and along the gas pipeline routes are presented in **Figures 6-19** and **6-20**, and are discussed in Fugro (2006c) and Section 6.1.7 of this report. A pipeline route site characterization report is provided as **Appendix P**.

6.1.5 Sediment Transport and Depositional Environments

6.1.5.1 Sediment Transport

Sedimentary processes are controlled by the water depth, proximity to detrital sources, and water column biological productivity. On the California Continental Margin, marine deposits are often hemipelagic sediments, i.e. a mixture of terrigenous sediment (derived from land) and biogenic material (consisting largely of skeletal debris of microorganisms). The terrigenous components (transported by rivers, winds, and turbidity flows) total about 80 percent of the annual influx to the Continental Borderland Basins. Biogenic carbonate, silica, and organic matter primarily originated from the water column contribute the remaining 20 percent.

The narrow continental shelf along the northern margin of Santa Monica Basin receives predominantly sandy sediments from ephemeral rivers (Schwalbach and Gorsline 1985). The Ventura and Santa Clara River systems are the primary source of sediment supply to the Basin (Normark et al., 2005). Sediments from these two rivers are transported southeastward in longshore drift until intercepted by the Hueneme and Mugu Submarine Canyons.

The inner shelf is largely a zone of sediment bypassing at current sea-level high stands. However, significant amounts of sediment were trapped in this area during the earliest stages of the Holocene marine transgression (Nardin, 1983). Periodically, these shelf deposits are re-suspended by storm waves and advected over the slope or down the canyons into the Santa Monica Basin as turbidity flows (Gorsline 1996). Fine-grained sediments are also transported to the basin by hemipelagic processes (Thornton 1984).

Storm-generated sediment flows constitute an important sediment transport mechanism into the Santa Monica Basin. Today, the Santa Clara River discharge is likely to produce such flows primarily during major flood events (Schwalbach et al. 1996), during episodes of storm surge at the head of Hueneme Canyon, and as a consequence of ground shaking during seismic events (Normark et al. 1998).

Other important sources of sediment in Santa Monica Basin include local slope failures on the steep sections of the continental margin, particularly on the sidewalls of the canyons and channels mapped in the area. Slope failures in the upper channels of the Hueneme Fan are also a source of sediment in the basin.

Turbidity currents are a dilute mixture of sediment and water. The density of turbidity currents is commonly 3 to 6 percent higher than that of ambient seawater. Maximum turbidity current velocities often range from 4 to 6 m/second, while average velocities are commonly 2 to 3 m/second. Maximum velocities are attained several meters above the seafloor. In some large turbidity current events, granular materials are also transported near the seafloor as bedload sediment, concurrent with and as a direct consequence of turbidity current events.

Rates of sedimentation in the Santa Monica Basin have been estimated from 18 radiocarbon-dated cores and average 0.12 inch/yr (3.1 mm/year) for the last 32,000 years (Normark and McGann 2004). Rates of sediment accumulation on the continental shelf and slope in Santa Monica Bay average 0.006 to 0.035 inch/yr (0.15 to 0.88 mm/year) (Sommerfield and Lee 2003).

6.1.5.2 Depositional Environments

The depositional environments traversed by the offshore pipeline are highly variable, and include:

- Santa Monica Basin
- Lower Slope Apron
- Continental Slope
- Shelfbreak
- Continental Shelf

The depositional environments associated with each of these areas are described in the following subsections. Supporting **Figure**s include **Figures 6-11** through **6-16**. Additional geotechnical information on these depositional environments is presented in **Figures 6-17** and **6-18**, and is discussed in Section 6.1.5.2. Data examples of seismic profiles collected in the 2006 offshore surveys of basin, slope, and shelf depositional environments are presented in **Figures 6-22** through **6-25**. Known locations of oil seeps and methane hydrates in Santa Monica Bay are shown on **Figure 6-26**.

<u>Santa Monica Basin</u>

Santa Monica Basin is an elongated (in a northwest-southeast direction), fault-bounded basin that is about 40 by 20 nautical miles (75 by 37 km) in dimension. The water depth in the basin is approximately 3,000 feet (900 m). Regionally, the basin is flat, although past regional mapping (conducted with surface mounted instruments) have suggested the presence of low-relief levee-channel systems extending from northwest to southeast across the basin floor. Except for the extreme southeast corner of the Deepwater Port survey area, no relief was measured in the basin (using deep-tow survey instruments) within the survey area of the Basin. A geosciences desktop study of the Santa Monica Basin is presented in **Appendix L**.

Normally, the deep-tow systems used for the 2006 field survey of the Project area (**Figure 6-7**) can resolve objects as small as 3 by 3 by 3 feet (1 by 1 by 1 m). However, in some portions of the basin, the bottom is extremely soft, and a significant portion of the survey beam energy was absorbed. Therefore, we consider the survey to have been capable of resolving objects larger than about 5 by 5 by 5 feet (1.5 by 1.5 by 1.5 m). Sometimes suggestions of linear seafloor features that are smaller than the resolution of the survey system can be apparent in the side scan sonar data. The data from the Project survey did not suggest such features on the surface. The sub-bottom Chirp profiler data, however, does show evidence of northwest to southeast linearly-trending sediment sequences in some areas.

Four main submarine canyons supply sediment to the basin: Hueneme, Mugu, Dume and Santa Monica (Plate 1). A fifth submarine canyon, Redondo Submarine Canyon, is located within Santa Monica Bay, but presently feeds into San Pedro Basin to the south. The Hueneme Submarine Fan has formed at the mouth of the Hueneme Canyon, where the canyon opens into Santa Monica Basin. The fan occupies the northwestern half of the Santa Monica Basin and is the largest submarine fan in the Continental Borderland (Gorsline 1992). The main source of sediment in the Hueneme and Mugu Canyons is the Ventura-Santa Clara River system and adjacent drainages (Schwalbach et al. 1996). The fan is supplied by sediment that is transported along the coast by the Santa Barbara littoral cell (Nardin 1981), and then from the continental shelf to the basin floor by mass-wasting and turbidity currents primarily channeled through Hueneme Canyon (Gorsline 1992). In contrast, Dume Canyon traps generally lower volumes of sediment from littoral drift on the continental shelf and feeds a smaller fan. Santa Monica Canyon is the longest canyon feeding the basin but is not a major conduit, and its associated fan has the most limited expression of any in the basin.

Santa Monica basin has been infilled by both turbidity current flows and hemiplegic deposits. The turbidites have been deposited episodically as turbid, sediment-laden waters transport particles down one, or more, of the canyons that border the basin and out into the basin. Turbidite flows can be produced by sediment-laden floods or by landslides and slumping along the canyon walls. The largest source of turbidite flows to the basin is from the Hueneme and Mugu Submarine Canyons at the northwest corner of the basin. Thus, turbidity current deposition in the Deepwater Port area and along the pipeline route occurs on the distal portions of the Hueneme fan and on the basin floor.

Piston Cores collected for Woodside by Fugro in the 2006 field survey area (**Figure 6.7**) in support of the OceanWay Project, numerous box cores (which typically penetrate 1/2 to 1 foot below the seafloor) that have previously been collected in the basin by the University of Southern California, and one ODP boring (near the southern buoy location) provide information on the sediment layering. The piston cores, box cores, and boring indicate that the basin floor is underlain by repeated sequences of clays, silts, and sands. The thickness of individual sand layers is quite variable, but typically ranges from fractions of an inch to slightly more than 1 foot. In the ODP boring, occasional sand layers are 3 to 5 feet (1 to 1.5 m) thick.

Examination of the age dates of the layers in the box cores and ODP boring suggest that, in the Deepwater Port area, turbidity current flows deposit sand thusly:

- thin layers [less than 1 or 2 inches (2.5 or 5 cm) of sediment one or twice per century,
- several inches to a half-foot (150 mm) of sediment possibly every 2 centuries,
- approximately a foot (0.3 m) of sediment every 1,000 years, and
- several feet (1 to 2 m) of sediment every 2,000 to 3,000 years.

Hueneme Submarine Fan

The Hueneme Submarine Canyon/Fan system is widely-recognized as an important source of granular and fine-grained sediment in the deepest parts of the Santa Monica Basin. Hueneme Fan, and to a lesser extent Mugu submarine fan, are the primary source of sediment to the basin.

Bathymetric, side scan sonar (GLORIA) and sampling data collected across Hueneme Fan revealed that the morphology and the sediment distribution of the fan can be divided into three distinct regions (Normark et al., 1998). These include:

- sandy channel and muddy levee facies in the proximal (upper) fan;
- lenticular sand sheets on the middle fan; and
- thinly bedded turbidite and hemipelagic facies in the distal (lower) fan.

The upper Hueneme Fan consists of a set of wide valleys, bounded by high levees (up to 650 feet [200 m high]), which gradually increase in width and decrease in depth toward a down-slope termination. These valleys were active sequentially through the late Quaternary. Typically the channels have muddy levees and are floored by thick acoustically reflective deposits of sand (Normark et al. 1998). The Hueneme Fan Valley, at the NW end of the basin, contains a 0.6-mile- (1-km-) wide inner channel that is itself bounded by 165-feet- (50-m-) high, muddy levees.

Abundant near-surface sand deposits forming gently-sloping, convex-upward lobes characterize the middle fan. Shallow channels with low or no levees (15 to 50 feet [5 to 15 m] in height) locally cut these lobes. In addition, irregular hummocky elements, interpreted as sand lenses and irregular sheet sands (Piper et al. 1999), a few meters thick and spaced by hundreds of meters, are widespread on the middle fan.

Farther down the fan, the architecture of Hueneme/Mugu Fan is complicated by the fact that the various channels and upper-fan valleys that fed the Hueneme/Mugu Fan system were active at different times during the Quaternary. Seismic reflection profiles over the fan structure, tied to the chronology available from the ODP Site 1015 in the Santa Monica Basin, suggest several phases of growth in the last 12,000 years and were used to map channel and levee sediments extending out from the fan margin (Piper and Normark 2001). Sediments in the areas surrounding the channels have silt contents of over 70 percent, and clay contents of about 20 to 30 percent. Distal channels are acting as conduits for coarse sediments transported through the fan channels to the lower fan. Areas between the channels have sediments with clay contents above 40 percent and silt content less than 60 percent. In contrast, basin floor sediments far from the fan margin have over 50 percent clay content and less than 50 percent silt content.

Anoxic Conditions

Santa Monica basin, below a depth of about 2,650 feet (800 m), is currently anoxic. This condition commenced about 350 years before present (Gorsline 1996). Anoxic conditions are not conducive to the existence of bottom-dwelling life forms, and preclude bioturbation of sediments by most known life forms.

Anticipated Conditions at the Deepwater Port and PLEM Site

The site is located on the distal portion of the Hueneme Submarine Fan system, on the floor of the basin (**Figures 6-21** and **6-22**).

The only known deep exploration boring in the Santa Monica Basin is the ODP Site 1015 which is located approximately 1.9 miles (3 km) from the preferred PLEM location and about 1,600 feet (490 m) from the proposed gas pipeline. This site records a sequence of fine- to medium-grained sands, hemipelagic muds, and turbidite deposits interpreted to be of late Quaternary age to 500 feet (150 m) (depth explored; Shipboard Scientific Party 1997). The sediments were dominated by thin interbeds of quartz feldspar sand and clayey silt. The sand layers showed sharp basal contacts and they grade upwards into clayey silt, suggesting deposition by turbidity currents. Thin layers of nannofossil clays were frequently found to overlie the clayey silt and, in turn, were overlain by the sand. Preservation and interpretation of these structures is possible because anoxic (oxygen-poor) bottom waters in the basin mean that the sediments are undisturbed by burrowing marine organisms. Turbidite deposits at ODP Site 1015 are interpreted to have extended from the Hueneme/Mugu and Dume Fans, with other possible minor contributions from basin rim failures. Some of the laterally continuous turbidite deposits can be correlated nearly basin-wide in seismic data and from core data (Normark and McGann 2004; Gorsline 1996).

The stratigraphic sequence and sediment characteristics down to about 26-ft (8-m) depth at the proposed DWP, as documented by piston cores and Cone Penetration test (CPT) soundings (performed in spring 2006 in support of the OceanWay Project), are described in Section 6.1.6.3.

<u>Lower Slope Apron</u>

Seafloor sediments that underlie the lower slope and fan are variable. Both clay sediments, similar to those on the middle and upper slope to the east, and granular sediments may underlie the lower slope and fan. The stratigraphic sequence and sediment characteristics down to about 26-ft (8-m) depth at the proposed DWP, as documented by piston cores and Cone Penetration test (CPT) soundings (performed in spring 2006 in support of the OceanWay Project), are described in Section 6.1.6.4.

The lower portion of the slope forms the submarine slope apron that may occasionally be affected by turbidity currents. The turbidites on the lower slope area are greatly reduced in thickness when compared to those deposited on the floor of the basin. The turbidites on the lower slope are thought to represent the larger turbidite events recorded on the floor of the basin, but are highly condensed because the turbidity currents that deposited these units were less dense and carried less sediment up the lower portion of the basin slopes. Piper and Normark (2001) suggest that the larger turbidity current events carried sediments in suspension in a turbid cloud up to about 200 to 330 feet (60 to 100m) thick. Thus, only the lower portions of the continental slopes surrounding the basin may be expected to be affected by turbidity currents.

Continental Slope

Above the basin and below the shelfbreak, the sediments that underlie the lower slope apron and continental slope are predominately unconsolidated mud (mixed silt and clay of Qmf on F**igure 6-15**). Normark and McGann (2004) sampled five locations along the lower continental slope north of Santa Monica Canyon that contained predominately hemipelagic muds, with occasional turbidite sand interbeds in cores that penetrated to a maximum subsea depth of 15 feet (4.5 m). Most of the continental slope is covered by a blanket of unconsolidated silt and clay, with possibly trace-to-little fine sand. The middle and upper Continental Slope is incised by elongate downslope-trending gullies (**Figures 6-8** and **6-15).** The gullies on the upper slope near the shelfbreak may contain relict gravel deposits. These gullies are 10 to 20 feet (3 to 6 m) deep and 200 to 500 feet (60 to 150 m) wide. Elongate shallow gullies and slope gullies are also found further downslope, but are more widely spaced. The stratigraphic sequence and sediment characteristics down to about 26-ft (8-m) depth at the proposed DWP, as documented by piston cores and Cone Penetration test (CPT) soundings (performed in spring 2006 in support of the OceanWay Project), are described in Section 6.1.6.5.

Other important units are rocks of Miocene and Pliocene (Tmp) that crop out in the submarine canyons, and in isolated areas on the continental slope to the north and south of the proposed pipeline route. Current geophysical surveys in support of the Project confirm the presence of low-relief rock outcrops northwest of the proposed pipeline route in one portion of the slope, in approximately 1,800 feet (550 m) of water (Inset 1 on **Figure 6-8**). These isolated rock exposures will be avoided during final pipeline route selection.

A possible shipwreck located on the middle slope near the area of rock outcrop is shown on **Figure 6-27**.

Shelfbreak

The continental shelfbreak occurs along the northern edge of the Santa Monica Bay at about a 200-foot (60-m) water depth. The shelfbreak is a higher energy environment than the slope or middle shelf areas to the east and west. Active tidal and internal wave currents likely affect this area. Consequently, seafloor sediments at the shelfbreak are often granular materials consisting of fine- and medium-sand, with some silt and possibly some coarse sand and gravel.

Although bedrock is often exposed locally at the shelfbreak in the Continental Borderland and in southern Santa Monica Bay, bedrock exposures are not found in Santa Monica Bay at the location where the proposed pipeline crosses the shelfbreak. Some relict fluvial gravel deposits were sampled from upper slope channels located near the shelfbreak during the spring 2006 field program for the OceanWay Project. These deposits are visible on the 2006 bathymetry and side scan sonar data (**Figures 6-8** and **6-16**). Detailed mapping and interpretations of the 2006 data are currently taking place.

Continental Shelf

Between Point Mugu and Point Dume, the shelf has a thin (0 to 130 feet [0 to 40 m]), discontinuous Holocene sediment cover (Fischer et al. 1983, and refs. therein). Sediment thickness on the shelf increases southward toward Redondo Canyon to at least 165 feet (50 m).

The Continental Shelf to the west of LAX extends about 4.5 nautical miles (8.3 km) offshore to the shelfbreak, in about 200-foot (60-m) water depth. Seafloor slopes typically are less than 1 percent out to the shelfbreak and increase to more than 2 percent beyond the shelfbreak. Along the planned pipeline routes, the seafloor is generally featureless, although an area of reef and debris is present about 1 nautical mile (1.8 km) offshore to the north of Marina del Rey.

Surface sediments on the shelf should be relatively uniform at any water depth, but there may be more variability in the underlying sediments. Although the Los Angeles River now discharges to the south of the Palos Verdes Peninsula, the river has also periodically discharged in the area that is presently Marina del Rey. The head of the Santa Monica Submarine Canyon is about 4.5 nautical miles (8.3 km) offshore from Marina del Rey. Although the seafloor is flat between the coast and the head of the canyon, during periods of lower sea level, the drainage from onshore would have extended out onto what is now the Continental Shelf and connected with the current submarine canyon. Thus, a large infilled paleochannel system (possibly infilled with sediments of different grain size or density) could underlie the shelf between LAX and the head of the present submarine canyon. Further consideration of that possibility will be evaluated while interpreting the recently acquired marine geophysical survey data.

Along the selected pipeline route north of Santa Monica Canyon, the surficial shelf sediments are predominately unconsolidated sand and silt (Qms on **Figure 6-11**). Relict fluvial gravels are present at the seafloor at the shelfbreak and on the inner shelf (**Figures 6-8**, **6-14** and **6-16**). Based on 2006 vibrocores and seismic reflection survey data (F**igure 6-25**), these fluvial gravels also appear to be present in the subsurface across most of the shelf. Sediments on the inner and outer shelf typically have a higher percentage of granular materials, whereas the middle shelf area is commonly dominated by middle to late Holocene silts and clays (mid-shelf mud belt). Most of the surficial sediments on the shelf consist of silty sands and sandy silts. The inner shelf, particularly the nearshore zone in water depths of less than 50 feet (15 m), is a high-energy environment and is dominated by granular materials. The stratigraphic sequence and sediment characteristics down to about 26-ft (8-m) depth at the proposed DWP, as documented by piston cores and Cone Penetration test (CPT) soundings (performed in spring 2006 in support of the OceanWay Project), are described in Section 6.1.6.6.

Nearshore and Onshore Zone

The nearshore area is a high-energy, wave-dominated environment. Granular materials are found in this area. The beach and wave zone consists primarily of fine and medium sand with little-to-some coarse sand. Outside of the surf zone, in water depths of 30 to 100 feet (10 to 30 m), modern seafloor sediments have a progressively higher percentage of fine grained sand and silt. Similar deposits may be expected in the shallow subsurface, although more granular materials may be expected with increasing depth as a consequence of the pre- and early-Holocene transgression. A layer of relict late Pleistocene gravel deposits outcrops locally on the inner shelf (**Figure 6-14**)

At the shore crossing, the HDD entry location is on an elevated plain south of Ballona Creek (**Figures 6-12** and **6-13**). Quaternary sediments underlying the elevated plain include Pleistocene river deposits (Qoa) composed of medium- to coarse-grained sands and gravels that interfinger with nearshore marine sediments of similar composition (**Figures 6-10**, **6-12** and **6-13**). This unit is overlain by Pleistocene-aged dune deposits (Qoe) composed mostly of dense to very dense, well-sorted, medium- to coarse-grained sands. Immediately shoreward of this unit is a quarter-mile-wide strip of Holocene-aged dune deposits (Qe) that are adjacent to the modern beach. The younger dune deposits consist of very well-sorted, fine- to coarse-grained sand. Because these units occur on the elevated plain above the local water table, they have low susceptibility to liquefaction (Wills et al. 1998). Along the beach are modern, unconsolidated sandy beach deposits (Qb) that may be susceptible to liquefaction due to loose, young, unconsolidated, granular materials and shallow groundwater conditions (**Figure 6-13**).

6.1.6 Geotechnical Conditions

6.1.6.1 Geotechnical Areas

For descriptive purposes, the DWP and its pipelines to shore can be divided into four areas.

- Santa Monica Basin: the Deepwater Port and the first 10.2 nautical miles (19 km) of the pipeline route are in the deepwater Santa Monica Basin.
- Lower Slope Apron: the next 4.5 nautical miles (8.3 km) of the pipeline route ascend across the Lower Slope Apron of the Continental Slope.
- Continental Slope: the pipeline route ascends the upper Continental Slope for about 8 nautical miles (15 km).
- Continental Shelf: the final 7 nautical miles (13 km) of the pipeline route cross the Continental Shelf that rims Santa Monica Bay.

The seafloor characteristics and sediments that underlie each of these areas are described below. In addition, the geotechnical character of the near-surface sediments that underlie each area is also discussed.

6.1.6.2 Basis of Interpretation

This section describes some of the preliminary interpretations from the Spring 2006 marine geotechnical and geophysical surveys conducted in support of the OceanWay Project. **Figure 6-7** shows the approximately 80-square-mile survey area. Those site-specific data are supplemented by regional studies, as described in the Geologic and Geohazards Desktop Study for the Santa Monica Basin – LAX Project (Fugro, 2006b) (refer to **Appendix L**). A site characterization report for the OceanWay port site is provided as **Appendix O**.

The marine geophysical survey included collection of multi-beam bathymetry, side scan sonar, sub-bottom profiler, and seismic reflection data throughout the survey area. The multi-beam and side scan sonar data were collected at line spacings that provided full coverage overlap throughout the survey area. The sub-bottom profiler data, collected with a Chirp system, and the seismic reflection data, collected using a triple-plate boomer source and geo-eel hydrophone cable, were generally collected along survey tracklines at less than 500-foot (150-m) spacing. In addition, magnetometer data were collected on the shelf.

The geotechnical sampling and in situ testing program included the following types and numbers of explorations:

- piston cores: 62 samples, on the slope and in the basin, to 8-foot (2.4-m) (maximum) depth;
- vibracores: 16 samples, on the shelf, to 9-foot (2.7-m) (maximum) depth; and
- Seascout Cone Penetration Test (CPT) soundings: 152 tests, through survey area, to 26-foot (8-m) (maximum) penetration.

Those results have been used to prepare the plan and cross-section interpretations shown in **Figures 6-18a** through **6-18d**, while **Figure 6-18e** provides a key to the symbolism on those figures. **Figure 6-17** provides a map showing the locations of the Geotechnical Plans and Profiles presented in **Figures 6-18a-d**. Note that the vibracores are not shown on **Figures 18a-d** because they have not yet been logged.

6.1.6.3 Santa Monica Basin

The Santa Monica Basin is an elongated (in a northwest-southeast direction), fault-bound basin that is about 40 by 20 nautical miles in dimension. The water depth in the basin is about 2,950 to 2,960 feet (900 m).

Regionally, the basin is flat, although past regional mapping (conducted with surface mounted instruments) has suggested the presence of low-relief levee-channel systems extending from northwest to southeast across the basin floor. Except for the extreme southeast corner of the Deepwater Port survey area, little relief was measured in the basin (using deep-tow survey instruments) within the survey area of the Basin during the 2006 Woodside OceanWay surveys.

Normally, the deep-tow systems used for the survey can resolve objects as small as 3 by 3 by 3 feet (1 by 1 by 1 m). However, in some portions of the basin, the bottom is extremely soft and a significant portion of the survey beam energy was absorbed. Therefore, we consider the survey to have been capable of resolving objects larger than about 5 by 5 by 5 feet (1.5 by 1.5 by 1.5 m). Sometimes suggestions of linear seafloor features that are smaller than the resolution of the survey system can be apparent in the side scan sonar data. The data from the Project survey did not suggest such features on the surface. The sub-bottom Chirp profiler data, however, does show evidence of northwest to southeast linearly-trending sediment sequences in some areas.

In the southeast corner of the Deepwater Port survey area, the seafloor begins to slope upward, at a slope of about 5 percent. The transition from a flat seafloor to a sloping seafloor corresponds to two local areas of hard bottom that are observed on the survey data. This area is outside of the planned footprint of the Deepwater Port moorings.

The basin has been infilled by turbidity flows and hemiplegic deposition. The turbidites have been deposited episodically as turbid, sediment-laden waters transport particles down one, or more, of the canyons that border the basin and out into the basin. Turbidite flows can be produced by sediment-laden flood events, or by landslides and slumping along canyon walls. As discussed in Section 6.1.5, the largest source of turbidite flows originate in the Hueneme and Mugu canyons at the northwest corner of the basin. Thus, these deposits generally extend across the basin floor from northwest to southeast. Deposition in the Deepwater Port area and along the pipeline route typically occurs near the distal limits of the turbidity flows, although numerous flows during the past 500 years have been documented across the entire basin (Gorsline, 1996). Basin-wide turbidite events extending beyond the DWP site occurred 100, 180, 280, and 400 years ago (**Figure 6-21**).

Thirty-six piston cores and sixty-five CPT soundings have been collected in the basin. In addition, numerous box cores (which typically penetrate one-half to one foot below the seafloor) previously collected throughout the basin and one ODP boring (near the southern buoy location) provide information on the sediment layering. All of the data show that the basin floor is underlain by repeated sequences of clays, silts, and sands.

The CPT and piston core data show that, throughout the Project area, the basin sediments (down to at least 26-foot [8-m] depth) consist of extremely soft to very soft clay with intermittent sand and silt layers. Globally, the CPT data suggest that about three-fourths of the sediments are clays and fine silts, while one-fourth of the sediments are fines sands and coarse silts. The spacing interval between adjacent sand layers is relatively consistent down the length of each individual sounding. The sand and coarse silt layers are inferred to be turbidity flow deposits. In some soundings, the top of the sand layer is overlain by a transitional silt layer. Examination of the piston core samples indicates that the sand and silt layers show the distinctive characteristics of turbidity flow deposits.

The soundings show that the shear strength of the clay sediments increases linearly with depth from near zero at the seafloor. The data suggest that the rate at which the undrained shear strength increases is less beneath the center of the basin than near the northeastern margin of the basin.

The frequency and thickness of the sand layers is variable within the buoy area and along the pipeline route. In general, the frequency and thickness of sand layers is greater in the central portion of the basin (i.e., the Deepwater Port area), less so beneath the northeastern portion of the basin (i.e., pipeline route to the north of the Deep Water Port). In the far southeastern corner of the buoy area, the occurrence and thickness of the sand layers decreases.

Examination of the detailed stratigraphic sequence identified by the CPT soundings provides valuable information on the distribution of turbidite deposits in the upper 26 feet (8 m) of the stratigraphic sequence. The data suggests that 8 to 10 events have deposited sand and/or coarse silt layers and seams, which are traceable, across much of the basin floor that was investigated during the spring 2006 geotechnical and geophysical surveys (conducted in support of the OceanWay Project).

6.1.6.4 Lower Slope Apron

The planned pipeline route crosses the edge of the Santa Monica Basin about 8.5 nautical miles (15.7 km) to the south of Point Dume. For the next 4.5 nautical miles (8.3 km), the pipeline route ascends the slope apron and lower slope along the margin of the basin. Both borders of this reach of seafloor are fault controlled. The lower slope apron is underlain by very soft to firm clay.

Several areas of steeper seafloor define the lower portion of the slope. The slope of these steeper areas is locally on the order of 12 to 20 percent. These areas of steeper seafloor may be underlain by older sediments or rock, although the CPT soundings and piston cores within the survey corridor did not encounter rock.

An area of resistant rock outcrop is present along the western portion of the survey corridor at the top of the lower slope apron. This area extends into the western portion of the pipeline survey corridor. The 2006 multi-beam bathymetry and side scan sonar records show evidence of bedding, and suggest that this area is an anticline of Miocene age rock. The outcrop is covered by an easterly-thickening wedge of clay in the eastern portion of the survey corridor. Although regional geologic maps suggest that a similar older outcrop is present at the base of the lower slope apron, the CPT and piston cores encountered very soft to soft clay.

The proposed pipeline route has been planned to avoid these areas of steeper seafloor and possible older outcrops. Along the proposed pipeline route, the average seafloor slope is between 2.5 and 10 percent. The seafloor slopes over the various depth intervals along the planned route average are:

- Water depth interval from 2,900 to 2,600 feet (884 to 793 m), the average slope is 8.5 percent.
- Water depth interval from 2,600 to 2,500 feet (793 to 762 m), the average slope is 20 percent.
- Water depth interval from 2,500 to 2,400 feet (762 to 732 m), the average slope is 6.5 percent.
- Water depth interval from 2,400 to 2,200 feet (732 to 671 m), the average slope is 3.5 percent.
- Water depth interval from 2,200 to 2,000 feet (671 to 610 m), the average slope is 6 percent.
- Water depth interval from 2,000 to 1,800 feet (610 to 549 m), the average slope is 4.5 percent.
- Water depth interval from 1,800 to 1,700 feet (549 to 518 m), the average slope is 2.5 percent.

Much of the lower slope and slope apron is underlain by very soft to firm clay. In some areas, the shear strength of the clay increases more or less linearly with depth. Elsewhere, there is a 2- to 3-foot- (0.6- to 1-m-) thick layer of very soft clay that directly overlies clay with a shear strength that increases from firm to stiff with depth (**Figure 6-18b,c**).

6.1.6.5 Continental Slope

Along the planned pipeline route, the upper and middle Continental Slope is about 8 nautical miles (15 km) wide. In this area, the water depth deepens from about 200 feet (60 m) at the shelfbreak to about 1,700 feet (518 m) at the base of the middle slope. The seafloor slope is a relatively uniform 3.5 to 4 percent down to about 1,500-foot (457-m) water depth. At the bottom of the middle slope, the slope flattens to about 3 percent.

Numerous downslope, southwesterly-trending gullies are present on the upper slope. The downslope-trending gullies at the top of the slope can contain granular sediments, including coarse sand and gravel. These gullies are pervasive from the shelfbreak down to about the 500-to 600-foot (150- to 180-m) water depth contour. The V-shaped gullies are commonly about 300 to 500 feet (90 to 150 m) wide and 10 to 25 feet (3 to 8 m) deep. The gullies immediately below the edge of the shelf are less prevalent at the northwestern limit of the survey area. A pipeline route through this portion of the survey area can largely avoid the edges of slope gullies.

Farther down the slope, the gullies are less frequent but individual gullies can extend as much as two nautical miles (3.7 km). Two of these gullies cross the survey corridor. Some of the gullies are slightly chevron-shaped in plan with their apex pointed to the southeast. The V-shaped gullies, on this portion of the slope, are about 1,000 feet (300 m) wide and 10 to 15 feet (3 to 4.5 m) deep. The upper slope generally is underlain by clay sediments. From the edge of the shelf down to about 500-foot water depth, the clays are locally interbedded with sand. The bases of the downslope-trending gullies at the top of the slope can contain coarse sand and gravel.

From about 500-foot (150-m) water depth down to the area of Miocene outcrop, at about 1700-foot (518-m) water depth, very soft to soft clay was typically encountered for the full sample and CPT sounding depths. In the lower portion of the upper slope, sand layers were encountered below about 25-foot (8-m) depth in several CPT soundings. The CPT data show some indication of layering, although within the depth sampled by the piston cores, the clay is generally uniform in composition.

The undrained strength of the clay generally increases with depth, although the rate of increase is not always uniform. The clay sediments frequently include a thin surface layer of extremely fine sand. Below the surface layer, the clay sediments are very soft to soft with an undrained shear strength that increases with depth. The clay sediments trend to become finer and more plastic with increasing water depth.

6.1.6.6 Continental Shelf

The Continental Shelf to the southwest of Marina del Rey and LAX extends about 4.5 to 5 nautical miles (8 to 9 km) offshore to the edge of the shelf at about 200-foot (60-m) water depth. The seafloor slopes to the southwest at an azimuth of about 210 degrees. The 40-foot (12-m) isobath is located about 0.5 nautical miles (1 km) offshore.

Between the 40- and 140-foot (12- and 43-m) contours, the seafloor slopes at a relatively uniform 0.7 percent. Between the 140- and 180-foot (43- and 55-m) contours, the slope flattens to abut 0.5 percent, before steepening to about 0.7 percent between the 180- and 200-foot (55- and 60-m) contours. Seaward of the shelf edge at 200-foot (60-m) water depth, the slope steepens to about 2 percent between the 200- and 220-foot (60- and 67-m) contours.

The shelf is relatively smooth and featureless except for numerous, minor irregularities between the 60- and 80-foot (18- and 24-m) contours. In that area, the bathymetry is uniformly irregular, but the depths of the local irregularities are less than 1 to 2 feet (0.3 to 0.6 m). Along the pipeline approach to the alternative LAX-South HDD exit, the irregularities locally extend inshore to the inner limit of the survey data (at about the 26-foot [8-m] isobath). There are some minor (1-foot maximum depth) pockmarks seaward of the 170-foot contour. Three subtle, downslope-trending ridges are present between the 130- and 170-foot (40- and 52-m) contours. The relief across these ridges is generally limited to several feet.

There are several rocks or mounds about one nautical mile (2 km) to the southeast of the head of the Santa Monica Canyon. These features, however, will be outside any possible pipeline alignments. An area of reef and debris is shown on the nautical charts about one nautical mile (2 km) offshore, to the northwest of the entrance to Marina del Rey. That area is outside the pipeline survey corridor, which was established to avoid the potential hazards associated with those conditions.

The sediments that underlie the Continental Shelf are composed primarily of medium dense to dense granular sediments. Along the coast, the nearshore area is a high-energy, wave-dominated environment, and the sediments are primarily fine to coarse sand, with little or no fines. On the middle shelf, the wave energy decreases, and the sediments are typically slightly finer and include some percentage of fines. In the higher energy environment at the edge of the shelf, the seafloor sediments are coarser and include lesser percentages of fines.

Vibracores and CPT soundings encountered coarse sand and gravel in the area of irregular seafloor between the 60- and 80-foot (18- and 24-m) contours and near the shelf edge. Some of the other explorations encountered refusal at depths above the maximum penetration capabilities of the corer and CPT, which may suggest that a discontinuous layer with gravel semi-continuously underlies portions of the shelf.

6.1.7 Geologic Hazards

Several potential geohazards and constraints have been identified that could affect the DWP and the proposed pipeline route. Geologic hazards include seismic hazards such as strong ground motions, active surface fault ground rupture, lateral spreading, liquefaction mass movement (slides, slumps, debris flows, or other), and tsunamis, as well as other geologic phenomena such as flooding, sedimentation and erosion, volcanism, methane hydrates, mud volcanoes, shallow gas, gas seeps, oil seeps, steep terrain, slope channels and gullies, and turbidity currents. Onshore and offshore geohazards will be described in this section.

6.1.7.1 Surface Fault Rupture Hazard

Ground surface displacement, or rupture, caused by an earthquake is a major design consideration for onshore and offshore pipelines that cross faults. Southern California is structurally complex and seismically active. The State of California defines a fault as historically active if it has generated earthquakes, accompanied by surface rupture, in the last approximately 200 years. Any fault that shows evidence of surface displacement in the last 11,000 years (Holocene time) is considered active (Hart and Bryant 1997). The State of California has mapped known faults in inhabited areas onshore as part of the Alquist-Priolo Earthquake Fault Zoning Act (www.consrv.ca.gov/CGS/rghm/ap/). Faults of concern include those that are known to be active or potentially active and are capable of surface rupture. However, while individual, localized, high-resolution studies may provide information about some offshore faults (for example, Goldfinger et al. 2000; Marlow et al. 2000), there is no comprehensive source of information regarding submarine faults.

The active Palos Verdes and San Pedro Basin faults both cross the proposed pipeline route. A preliminary probabilistic fault rupture hazard analysis (PFRHA) for these faults is presented in Fugro (2006c). The location of individual fault splays associated with these two fault systems, and their orientation with respect to the proposed pipeline route, is currently being evaluated based on the results of site-specific seismic reflection surveys performed for Woodside's OceanWay Project. Local faulting and the potential for surface fault rupture will be considered in subsequent revisions to Fugro (2006c).

The CGS and the USGS have periodically updated fault databases that include nearly 100 years of detailed study and mapping (for example, Petersen et al. 1996; Frankel et al. 1996; Jennings 1994; Cao et al. 2003; Bryant 2005). The best studied faults and structures are onshore, and the digital databases reflect this bias. Detailed studies of offshore structures are expensive and increasingly complicated by regulatory restrictions, so the data coverage is generally incomplete and concentrated near shore. Investigation of potential seismic hazards has moved in new directions in the past decade, with studies addressing the concerns about "blind" structures (i.e. Source of 1994 Northridge EQ), which have been mapped only by studying subsurface data in heavily urbanized areas such as the Los Angeles Basin. Consequently, many active and potentially active faults and structures are mapped only at depths well below the surface (or seabed).

A separate Probabilistic Seismic Hazard Analysis (Fugro 2006c) addresses the known, significant, active faults in the region of the Project, as well as seismic ground accelerations. The offshore active Palos Verdes and San Pedro Basin faults are crossed by the proposed pipeline from the DWP to shore. These faults have been described in section 6.1.4.1. Probabilistic and deterministic estimates of surface rupture ground displacement on these two faults zones are presented in Fugro (2006c), and are summarized herein.

<u>Palos Verdes Fault Zone</u>

Some deep seismic data were collected before modern restrictions on the power of seismic sources. From these data, mapping extends the fault zone deep under the western Santa Monica shelf (Yerkes et al. 1965; Nardin and Henyey 1978; Junger and Wagner 1977). In contrast, high-resolution bathymetry and shallow seismic surveys have found no evidence of fault displacement of Quaternary sediments on the Santa Monica shelf west of the Palos Verdes Peninsula (Nardin and Henyey 1978; Fisher et al. 2003; Sorlien et al. 2003). Fisher et al. (2003) had limited success even trying to align the projected location of the Palos Verdes fault using the occurrence of shallow subsurface folds that are considered to be secondary features of faulting.

Disagreement about the Palos Verdes fault geometry in the area has led to the development of some models favoring transfer of strike-slip displacement to reverse faults and transpressional folds as the fault terminates in Santa Monica Bay (Nardin and Heyney 1978; Wright 1991; Legg et al. 2001; Fisher et al. 2003; Bohannon et al. 2004; Sorlien et al. 2004). Another model proposes that the Palos Verdes fault north of the Palos Verdes Peninsula is predominately a back-thrust on the deeper Compton-Los Alamitos blind thrust that underlies the regional structures of the Palos Verdes uplift (Shaw and Suppe 1996).

An all-encompassing solution for the complex geometry of the structures under the Santa Monica shelf might be a two-level model that incorporates both deep movement along low-angle detachments and steeply-dipping reverse faults, and an upper level regime of shallow, predominantly aseismic strike-slip faulting (Fisher et al. 2003). This model may also accommodate the termination of the Palos Verdes fault into a complex series of strike-slip and reverse faults, accompanied by folds, as the fault approaches the southern boundary of the western Transverse Ranges. The most conservative approach in modeling hazards associated with these structures would consider the potential for both surface rupture and ground shaking along the Palos Verdes fault zone and for ground shaking associated with an active blind thrust underlying Santa Monica Bay. This is the approach taken in the Probabilistic Seismic Hazards Analysis (PSHA) (Fugro 2006c) (refer to **Appendix M**).

San Pedro Basin Fault Zone

The San Pedro Basin fault zone is a northwest-trending 12-mile- (20-km-) wide zone of nearly vertical en echelon faults, extending through the study area from Dume Canyon to the flanks of Redondo Knoll. Deformation along the San Pedro Basin fault zone is complex, with flower structures observed in seismic sections that result from transpressional strike-slip displacement (Bohannon et al. 2004; Fisher et al. 2003). The segment of the fault within the Santa Monica Basin is somewhat unique in the inner Continental Borderland for being located in the interior of a basin (Junger and Wagner 1977). In the southwestern part of San Pedro Basin, the fault zone lies along or near the subsurface contact between basement rocks and basin fill sediments (Bohannon et al., 2004; Fisher et al. 2003). Evidence of fault activity includes deformed seabed sediments in shallow seismic sections (Normark and Piper 1998; Bohannon et al., 2004), hills and ridges on the seafloor that are aligned along the fault, (Fisher et al. 2003) and microseismicity along the fault trace (Legg and Goldfinger 2002).

Surface Fault Displacement Estimates

The Fault displacement hazard estimated for each of the fault crossings is summarized in **Table 6-4**. Deterministic fault displacement estimates were calculated based on the characteristic magnitude on each fault and the relationship proposed by Wells and Coppersmith (1994). For both the Palos Verdes and the San Pedro Basin faults, the mean characteristic magnitude is 7.3. Probabilistic estimates of surface fault displacements are presented in Fugro's draft PSHA **(Appendix M).**

We consider these preliminary results to be conservative. The northern segment of the Palos Verdes fault may not be active and the pipeline fault crossing is near the northern terminus of the fault. These average and maximum fault displacement values represent displacement estimates calculated using regressions of earthquake magnitudes, fault length, and observed surface fault displacements compiled by Wells and Coppersmith (1994). These estimates are averages for entire fault systems, whereas the proposed pipeline fault crossings of the Palos Verdes and San Pedro Basin faults are either proximal to or within fault stepover zones, or are near the termini of mapped strike-slip fault rupture segments.

Detailed studies of slip distribution along fault rupture segments from the 1940 Ms 7.1 and 1979 Ml 6.6 Imperial Valley earthquakes on the Imperial fault, the 1992 Mw=7.3 Landers earthquake on Camp Rock and Emerson faults, the 1987 Mw=6.6 Superstition Hills earthquake on the Superstition Hills fault, and the 1931 Mw=8.0 Great China earthquake demonstrate that the magnitude of slip significantly decreases towards the ends of individual fault rupture segments. Observed slip near the ends of fault rupture segments often range from about 10 percent to 50 percent of the maximum observed displacement. The proposed pipeline fault crossings are located near the northern termini of the Palos Verdes and San Pedro Basin fault systems.

Therefore, it is probable that fault surface rupture displacements at the proposed fault crossings will be significantly less than the maximum estimated displacement presented in **Table 6-4**. Moreover, these estimates of surface displacements will be refined after site-specific high-resolution geophysical field surveys are completed. Data acquired during these surveys will be interpreted to better locate faults, and to evaluate fault geometry, length, segment boundaries, activity, and surface or shallow subsurface fault displacements.

For preliminary pipeline feasibility studies, we recommend assuming that both the Palos Verdes and San Pedro Basin faults are pure right-lateral strike-slip faults. Conservative, preliminary estimates of surface fault rupture displacement on the north segment of the Palos Verdes fault range from an average 2.3 feet (0.7 m) to a maximum of 4.3 feet (1.3 m) (Wells and Coppersmith, 1994). Preliminary estimates of surface fault rupture displacement on a combined rupture of the northern and central segments of the San Pedro Basin fault range from an average 6 feet (1.8 m) to a maximum of 12 feet (3.6 m) (Wells and Coppersmith, 1994). The results of this preliminary study will be revised after new site-specific, high-resolution, geophysical data allow for a better understanding of fault activity, location, and geometry. The revised values will likely be less than these preliminary estimates of fault displacement. In general, well-designed pipelines that are either laid at the seafloor or buried at shallow depths in soft sediments have significant structural capacity to withstand fault displacements.

6.1.7.2 Strong Ground Motions

Any Deepwater Port location is within a seismically active area, and the potential exists for strong ground motion to affect the facility. In general, the primary effects will be those associated with shaking and/or ground accelerations. In addition, ground shaking due to earthquakes can cause potential loss of bearing capacity of seafloor structures or holding capacity of anchors, due to liquefaction or cyclic degradation of the strength or stiffness of the foundation soils.

Santa Monica Bay and Basin are seismically active areas with the potential for seismically-generated strong ground motions. Fugro has separately conducted a PSHA for the Project **(Appendix M).** Seismicity and the basis for the seismic source model are summarized in Section 6.1.4.2 of this report.

The effects of earthquake-related ground displacement and strong ground motions are a significant regional geohazard. Strong ground motions and fault displacements are a lesser risk to floating offshore facilities, but a greater risk to onshore or fixed offshore facilities, like pipelines. Secondary hazards to offshore facilities that may result from strong ground motion or fault displacement include mass movement (slumps, landslides, debris flows, turbidity currents) and liquefaction that may affect fixed anchors and pipelines.

The historical earthquake record in Southern California dates back about 200 years. Several significant and/or damaging earthquakes have occurred within the study area during that time (**Table 6-2**). However, far-field earthquakes, or earthquakes with epicenters outside of the study area, have also caused damage within the study area. These events include the great Fort Tejon earthquake (approximately M_w 8.0) of 1857 that ruptured over 225 miles (360 km) of the San Andreas fault, the Long Beach earthquake (M_w 6.4) of 1933 that occurred on the Newport-Inglewood fault zone, the San Fernando earthquake (M_w 6.4) of 1971 that occurred on the San Fernando fault, the Whittier-Narrows earthquake (M_w 5.9) of 1987 that occurred on the Elysian Park fault, and the Northridge earthquake (M_w 6.7) of 1994 that occurred on a previously unmapped (or blind) thrust fault possibly related to the eastward projection of the Oakridge fault.

Earthquakes in the area (**Figure 6-6**) are directly related to the active tectonic setting of Southern California, where the Pacific plate is sliding northwestward relative to the North American tectonic plate along the San Andreas transform boundary. The overwhelming style of faulting in this province is right-lateral strike-slip, where the ground displacement is generally parallel to the fault surface. The resulting earthquakes commonly have right-lateral, strike-slip focal mechanisms. There is still, however, a strong component of horizontal compression in the system, resulting in the many active west and northwest-trending thrust faults in the region. Earthquakes along these reverse, or thrust, faults have focal mechanisms that indicate vertical or near vertical ground displacements along the fault surface.

Earthquake locations and focal mechanisms are easier to resolve for onshore events because of the extensive, widespread network of recording devices. Locations and focal mechanisms for offshore events tend to be less certain because of the complexity of the borderland geology, the lack of nearby recording stations, and the inherent asymmetry of the onshore network relative to the offshore area. Still, a few significant, damaging events have been attributed to mapped, offshore tectonic structures with high confidence (Astiz and Shearer, 2000).

The USGS Open File Report 2004-1286 addresses the probability of a damaging earthquake (defined therein with a magnitude of 6.5 or greater) occurring in the area for specific existing and proposed facilities in Ventura County (Ross et al. 2004). The estimated probability of such an event in the next 30 years is highest (70 to 80 percent) in the Southern California (plate boundary) shear zone extending westward of the San Andreas fault. In this area, many active faults and many faults capable of generating damaging earthquakes result in an increased overall probability of an event, compared to areas with fewer active faults.

Estimated PGAs as a percent of gravity, with a 2 percent chance of being exceeded in 50 years, are presented in the USGS Earthquake Hazards Program at http://earthquake.usgs.gov/hazmaps/. The model represented in the map includes few offshore faults, but does take into account the offshore Channel Islands Thrust, Palos Verdes-Coronado Bank fault zone, and the Newport-Inglewood-Rose Canyon fault zones. This level of ground motion represents the basis for the USGS recommended mid-level design criterion for an LNG facility (NFPA, 2001).

The USGS study suggests that there is, in 50 years, a 2 percent chance that there will be ground shaking of greater than 0.8 times the acceleration of gravity (80 percent gravity) along the Palos Verdes fault Zone and in western Santa Monica Bay. Values for the Deepwater Port mooring area in Santa Monica Basin are lower, with a 2 percent chance of ground shaking of greater than between 40 and 60 percent g in 50 years. However, these conservative estimates are the hazard levels for firm rock sites rather than for sediment basins according to the USGS National Seismic Hazard Maps (Frankel et al. 1997, 2002). For example, ground shaking may be greater due to the amplification effects of the relatively soft Hueneme Fan sediments in the western Santa Monica Basin, or other areas filled with soft sediments. The effects of "basin waves" (long period seismic waves that resonate within bedrock basins) are not included in the USGS National Seismic Hazard Maps (Ross et al. 2004).

Figures 6-19 and **6-20** show Fugro's estimates of ground accelerations and fault hazards for the proposed facilities. PGAs for a 2,475-year return period equate to a 2 percent chance of an earthquake producing, in the next 50 years, an estimated level of ground motion expressed in terms of exceeding the acceleration of gravity. For the Deepwater Port area, these data suggest that there is a 2 percent chance that there will be ground shaking of greater than 0.7 times the acceleration of gravity (70 percent g) in 50 years. Along the proposed pipeline route, values range from approximately 0.65 to 1.05 times the acceleration of gravity (**Figure 6-20**). Fugro's PSHA presents more detailed analysis and discussion of site-specific estimates of seismicity and ground motions for the OceanWay Secure Energy facilities (Fugro 2006c).

6.1.7.3 Liquefaction and Lateral Spreading

Liquefaction is the phenomenon in which saturated, cohesionless sediments temporarily lose their shear strength due to increased pore pressures during periods of dynamic loading. During strong ground shaking, liquefaction commonly occurs in granular soils with high pore pressures. The susceptibility of granular soils to liquefaction is a function of the distribution of grain sizes (gradation), soil density, cementation, total fines content, and plasticity characteristics of the fines. The resistance to liquefaction increases with increasing grain size distribution, soil density, cementation, fines content, and plasticity characteristics of the fines.

Onshore, liquefaction hazard is higher in areas with granular soils (sands and silty sands), a shallow water table, and the potential for strong ground shaking. Low-lying, unconsolidated, modern beach deposits are especially susceptible to liquefaction as a result of ground shaking. Sandy soils in the low-lying areas around Ballona Creek and beach sands along the coast have been identified as a liquefaction hazard zone.

Offshore, where seabed sediments at the sediment-water interface are always saturated, hazards are higher where unconsolidated, coarser-grained sediments (sands and silty sands) predominate, and the potential for strong ground shaking exists (Qp and Qms on **Figure 6-11**). For example, areas near shore and near river mouths may have higher liquefaction potential as a result of local accumulations of clean, sandy sediments of uniform grain size. Liquefaction in seabed sediments may be initiated by ground shaking, or by variation in pore pressure caused by wave activity, like deep storm waves.

Generally speaking, clayey soils commonly deposited on continental slopes and in deeper ocean basins do not liquefy, but may be displaced by strong ground shaking. Lateral downslope displacement of submerged clay soils on slopes, while not liquefaction-induced, is similar to lateral spreading. Soil displacement and cracking may also occur at soil-type boundaries, or at the boundary between soil and rock units. These boundaries are usually apparent in high-resolution subsurface geophysical survey data. Subsurface data available from seismic lines in the vicinity of OPD Site 1015 suggest relatively uniform soil layering. Additionally, even the limited seabed sample data available indicate silty and sandy soils are present at the Deepwater Port mooring site (Shipboard Scientific Party 1997). Geotechnical studies of local soil characteristics are required to fully assess the liquefaction hazard for the site.

The Seismic Hazard Mapping Program of the California Geological Survey systematically maps onshore areas where liquefaction could occur during a strong earthquake (http://gmw.consrv.ca.gov/shmp/). However, there is no systematic program for mapping offshore areas. Geotechnical studies of local soil characteristics are required to fully assess the liquefaction potential for a specific site. **Figure 6-28** shows a geologic map of the onshore area, and **Figure 6-29** shows the areas susceptible to liquefaction and earthquake-induced landslides.

Along the beach lie modern, unconsolidated beach deposits (Qb) consisting of loose to moderately dense coarse sand and gravelly sand over 20 feet (6 m) thick (Wills et al. 1998). Due to the loose, young unconsolidated granular materials and shallow groundwater conditions, CGS (1999b) has placed the modern beach deposits in a liquefaction hazard zone. CGS defines a liquefaction hazard zone as an area where historic occurrence of liquefaction, or where local geological, geotechnical, and ground water conditions, indicate a potential for permanent ground displacements as a consequence of seismic shaking.

6.1.7.4 Sediment Transport and Mass Movement

Submarine landslides on the steep slopes of the offshore California Continental Borderland are widespread. The documented evidence of offshore landslides includes the large landslide failure along the Palos Verdes Peninsula slope (Bohannon and Gardner 2004), offshore Goleta in the Santa Barbara Channel, and along the Thirtymile and Fortymile Banks near San Clemente Island (Legg and Kamerling 2003). The distribution of mass movement deposits in the Borderland is summarized in Hogan (1986).

Turbidity currents and debris flows are potential hazards wherever loose sediment is deposited on steep submarine slopes. Turbidity currents are a type of gravity-driven, density current laden with clay, silt, and sand. Debris flows are dense slurries of fluidized sediments, rocks, and other debris. Turbidity currents and debris flows have been studied along the continental margin and are known to occur in the study area (Normark et al. 2003, 1998) **Figure 6-21** shows the interpreted distribution of turbidites in Santa Monica Basin from numerous events over the past 500 years.

Submarine slumps and slides (down-slope slip of coherent blocks of sediment and/or rock) are triggered by a variety of mechanisms, including strong ground shaking, fluid or gas expulsion in seabed sediments, and sediment loading and collapse in areas of high rates of sediment accumulation. These types of mass movement occur at a variety of scales and on slopes with even relatively low gradients, depending on local conditions.

Sediment transport can affect pipeline design when considering whether a pipeline may become undermined or impacted by mobile sediments. Sediment mass movement in the form of slides, slumps, and fluidized flows may catastrophically damage pipelines and other seabed installations, and are an important design consideration.

Along many narrow, active continental margins, where the seafloor slope increases at the shelf break, gravity-driven processes become an important mode of sediment transport. These processes include turbidity currents, debris flows, and mass failures such as slumps and slides. These types of mass failure are generally triggered by a seismic event, but also can be initiated by storm waves, gas expulsion, over-steepening from tectonic uplift, or sediment loading (rapid deposition of high-volumes of sediment).

Submarine slumps and slides are important modes of mass movement on the tectonically active, often steep continental margin. Submarine landslides involve the movement of rocks and sediments, either their moving under sea or their sliding into the sea. Slides are defined as movement of coherent blocks of material parallel to planes of weakness, often parallel to the slope of the seabed. Slumps involve more complex movement of materials that may include block rotation in addition to slip down slope.

Sediment mass flows are also widely mapped on the continental margin. These types of transport, such as turbidity currents and debris flows, have been classified by Middleton and Hampton (1976). According to this classification, sediment gravity flows are distinguished from fluid gravity flows by the relative importance of sediment and fluid in driving the motion. Particles are kept in motion by mechanisms such as turbulence, saltation and traction (by dragging or rolling along the seafloor). Other possible mechanisms which can keep particles in suspension include upward intergranular fluid flow, direct interaction between grains, and matrix strength. On the basis of the predominant support mechanism for the sediment flow, Middleton and Hampton (1976) defined basic flow types as follows:

- turbidity currents in which sediment particles are kept aloft in the body of the flow by the upward component of fluid turbulence;
- fluidized flows in which sediment particles are supported mainly by the upward flow of water escaping from between the grains as the grains settle out by gravity;
- grain flows in which sediment particles are supported by direct grain-to-grain interaction; and
- debris flows in which the larger grains and clasts are supported by the strength of the soil matrix in slurry-like flows.

Several types of mass-sediment transport phenomena may thus evolve from a single slope failure, as proposed by Mulder and Cochonat (1996). Following the initial slope failure, the sediments slide down the slope and degrade into three major components, including (1) a debris flow moving along the seafloor, (2) a secondary dense turbid-flow “plume” separate from the debris flow, and (3) a tertiary low density “ignitive plume” that moves downslope as a turbidity current.

A single slope failure can thereby create three very different types of mass-sediment transport phenomena, each with physical characteristics which will determine how far and how fast it will travel across the seafloor. Thus, turbidity flows might be created during landslides that also create debris flows.

Alternatively, “classic” turbidity currents result from cross-shelf transport of sediments that are eroded and stirred up into the water column during large storms. Often these turbulent clouds of fine-grained sediments are captured at the heads of submarine canyons, where they develop into turbidity currents that move down the canyons and sometimes out into the deepwater plain.

Turbidity Currents

Turbidity currents are a type of gravity-driven, bottom-flowing density flow composed of clay, silt, and sand in turbulent suspension. These flows can be initiated by a number of occurrences such as landslides, storm waves, tsunamis, sediment loading and subsequent collapse, or density differences due to the introduction of dense, bottom-flowing, sediment-laden water from heavily charged rivers (hyperpycnal flow). Offshore coastal

California, the risk of submarine sediment slumps or slides initiating turbidity currents and debris flows is enhanced by the fact that the region is subject to earthquake activity.

Turbidity currents moving down relatively steep slopes tend to be governed by somewhat different parameters than flows that are passing over relatively flat seafloor. Turbidity flows on steep slopes are influenced by the erosion of sediment from the seafloor, and its inclusion into the flow, as well as by the inclusion of large volumes of water into the head of the flow. This steep-slope flow may change greatly in density and height during its passage down slope. In contrast, slow-moving flows over relatively flat seafloor are more constant in size and density, and are governed by the accumulated effects of internal and external resistance to flow and to effects such as Coriolis Forces.

The development of turbidity flows has long been described in terms of submarine fan models and has largely contributed to the formation of the Hueneme Fan in the western part of the Santa Monica Basin (Normark 1970; Walker 1978; Bouma et al. 1985; Shanmugan et al. 1985).

Researchers conclude that turbidity flows in the Hueneme Fan and Santa Monica Basin were more widespread and common during times of low sea level during the last glacial period, when rates of sediment supply to the Santa Monica Basin were at a maximum (Normark et al. 1998; Piper et al. 1999). These studies indicate that turbidity flows were more frequent and larger in the submarine canyons of the upper and middle Hueneme Fan during lower sea level. Even so, turbidity flows regularly reached other portions of the basin as well (Gorsline 1996; Schwalbach et al. 1996). Sediments in ODP Site 1015, in the eastern Santa Monica Basin, are interpreted to be related to turbidity flows emanating from the Hueneme Fan in the western part of the basin (Normark and Piper 1991; Normark and McGann 2004). Individual seismic reflectors interpreted as discrete turbidite deposits have been interpreted to extend to elevations up to 130 feet (40 m) above the basin floor (Piper et al. 2003).

Studies of recent (sea level high-stand) deposits on the Hueneme Fan suggest that during the last 500 years (**Figure 6-21**) several turbidite events occurred as a result of earthquake activity, exceptional river floods and probably failure of sediments accumulated in canyon-heads (Reynolds 1987; Gorsline 1996; Piper et al. 1999; Piper and Normark 2001; Piper et al. 2003). Events that generated turbidity flows capable of reaching the basin margins have been interpreted by Gorsline (1996) to have a recurrence interval of about 100 years. The most recent turbidite event correlates with a major flood during the winter of 1969 to 1970. Other recent events (approximately 280, 400, and 560 years ago) may have been the products of large earthquakes, since they contain the largest volumes of material and would require massive slope failures. Several of the events within the last 500 years (Plate 26) have had depositional areas of 193 to almost 580 square miles (500 to almost 1,500 square-km), have contained sediment volumes ranging from about 10,000,000 to 100,000,000 tons, and have had depositional “outcrop” thicknesses of up to 3.9 inches (10 centimeter [cm]) thick (Gorsline, 1996). Based on studies of several turbidity current events, turbidite deposits appear to be preferentially deposited along the southern basin margin.

It is possible to recognize and map the occurrence of turbidites from marine borings, core, and geophysical survey data. In sub-bottom profiler and high-resolution seismic data, turbidites characteristically manifest as laterally continuous, relatively thin, acoustic layers (**Figure 6-23**). Turbidites are not typically mapped from side scan sonar, but it is possible to identify active channels based on seabed reflectivity as a measure of relative grain size. Active channels usually contain coarser grained sediments than the surrounding seabed, while inactive channels and the surrounding seafloor usually are draped with an acoustically uniform layer of fine-grained sediments. The correct interpretation of these data requires ground-truthing in the form of seabed samples. Turbidites are identified in cores by specific characteristics such as characteristically fining-upward sediment sequences, terrestrial or shelf sediments in sequences deposited far from shore, and evidence of current scour.

Based on review of available information, turbidity flows occur in the Santa Monica Basin and occasionally have been massive enough to encompass much of the basin floor, including the Deepwater Port mooring location and portions of the pipeline route across the basin. Gorsline (1996) concluded that earthquake-induced mass movements are the most probable sources for initiating such basin-wide events and that they occur about every 100 years.

While the DWP and at least portions of the pipeline route across the basin will be subject to turbidity flows, the pipeline should be relatively insensitive to such future events. Several or more feet of extremely soft sediments blanket the basin floor throughout most of the DWP area and along the pipeline route. Thus, the pipeline is expected to settle into the subsurface and be largely, if not totally, buried beneath the basin floor. Hence, the highest velocity portion of a turbidity flow will be above the pipeline. Nevertheless, the design of the pipeline will need to consider possible bed scouring and lateral displacement should a turbidity flow extend out into the basin and beyond the planned pipeline route. In addition, the connections of the moorings to their foundations will need to consider the potential forces produced by possible future turbidity flows.

Slumps and Slides

Submarine landslides and slumps (down-slope slip of coherent blocks of sediment and/or rock) have been mapped all along the California Continental Borderland and in the offshore Central California Province (Kennedy et al. 1987; Field and Edwards 1980). Submarine landslides have been mapped in detail in several areas of the Santa Barbara Channel (Eichubl et al. 2002), at the base of the slope offshore of the Palos Verdes Peninsula (Bohannon and Gardner 2004; Normark et al. 2004, see Plate 27), and in the Santa Maria Basin (Hogan 1986).

While the occurrence of these larger-scale features appears to be fairly common (in a geologic time frame), the frequency of occurrence is much less well known. Only the Palos Verdes slide (7,500 years ago), and the Gaviota slide (200 to 300 years ago) and parts of the Goleta complex (8,000 to 10,000 years ago) have been dated (Normark et al. 2004; Lee et al. 2004; Fisher et al. 2004).

Submarine slumps and slides are triggered by a variety of mechanisms, including strong ground shaking, fluid or gas expulsion in seabed sediments, and sediment loading and collapse in areas of high rates of sediment accumulation. These types of mass movement occur at a variety of scales and on slopes with relatively low gradients, depending on local conditions.

Evidence of slumps and slides is normally apparent in high-resolution marine geophysical survey data. Additional subsurface geotechnical and geophysical survey data may further define areas with potential for slope displacement along a planned pipeline route. The site-specific surveys completed for the OceanWay Project suggest that slumps and slides are not occurring on the continental slope, and that it is stable.

Geologic maps and geohazard maps of onshore areas are presented in **Figures 6-28** and **6-29**. Onshore areas susceptible to mass movement, flooding, liquefaction, and other geohazards are presented on these maps and are discussed in Section 6.1.7.8.

6.1.7.5 Volcanism

There are no active volcanoes, seamounts, volcanic vents or rifts in the region.

6.1.7.6 Tsunami

A tsunami is a series of sea waves generated by rapid displacement of a large volume of sea water. The displacement may result from vertical warping of the seabed, large scale submarine or coastal landslides, or volcanic eruptions in or near ocean basins. Tsunamis are usually described as local or distant-sourced.

In the open ocean, distant-source tsunami waves have a very long period and wavelength and can travel at speeds of greater than 300 miles (500 km) per hour. As a tsunami moves into shallow water, however, wave height increases and wavelength and speed decrease. Historical records indicate that the character of tsunami waves varies greatly depending on factors such as the shape of the coastline, coastal seafloor topography, the existence of offshore islands, and the direction of the incoming waves.

Tsunami waves are produced by displacement of the seafloor. Uplift of the seafloor elevates the sea surface upwards, while subsidence of the seafloor produces a drawdown of the sea surface. Numerical studies (Todorovska et al. 2001) of local tsunamis produced by faulting and landslides show that, at the source, the initial tsunami wave amplitude approximates the uplift or subsidence of the seafloor. Thus, if the Channel Islands Thrust fault were to rupture and the seafloor across the entire 1,900-square-km area were to be displaced about 7 to 10 feet (2 to 3 meters) upward, it would produce a tsunami with an initial amplitude of 7 to 10 feet (2 to 3 meters).

The amplitude of the tsunami wave quickly dissipates to one-half the initial uplift or subsidence as the wave propagates away from the source region. For earthquake-induced tsunamis, the tsunami wave amplitude quickly dissipates to about one-half the maximum as the tsunami propagates away from the source in directions orthogonal to the elongate fault rupture zone. In directions parallel, or slightly oblique, to the zone of tectonic uplift or subsidence, the tsunami wave amplitudes are substantially reduced due to defocusing and wave spreading (diffraction) effects. Further dissipation of the amplitudes occurs more slowly in deep water. Amplification of the wave height may occur where the water shoals on basin margins. Thus, wave amplitude will increase when a tsunami crosses the shelf break. Further increases in wave amplitude will occur as the wave crosses the shelf toward the shoreline. While some amplification occurs due to refraction effects above shallow ridges, banks, and seafloor peaks, those effects are less in deep water than in shallow water along the coast.

Offshore landslides triggered by earthquakes are frequently large-scale features, and the localized displacement of the seafloor at the landslide is often greater than the offset produced by coseismic fault rupture. This occurred in Papua New Guinea in 1998, when a moderately sized M_w 6.8 earthquake triggered a submarine landslide that resulted in a large tsunami with localized run-up of approximately 50 feet (15 m). The tsunami wave amplitudes in numerical simulations (Legg et al. 2003) produced by landslides are typically larger than the tsunami wave amplitudes produced by earthquakes.

In the shallow waters of bays and harbors, a tsunami may initiate a seiche, which is a resonant oscillation wave within a harbor or basin. If the tsunami period is related closely to that of the bay, the seiche is amplified by the succeeding waves. Under these circumstances, maximum wave activity often is observed much later than the arrival of the first wave.

Local Tsunami Sources

Thrust or reverse faulting associated with major faults of the Western Transverse Ranges are known sources of local tsunamis in southern California (McCulloch 1985; McCarthy et al. 1993; Borrero et al. 2001). In the Santa Barbara Basin to the NW of the Project area, earthquake sources that could generate a tsunami include the Channel Islands Thrust fault, the North Channel and Pitas Point fault, Red Mountain fault, and Oak Ridge fault.

In addition, transpressional uplift associated with restraining bends (also called "pop-ups") develop tsunami potential due to fault rupture along the major offshore strike-slip fault zones. The Santa Catalina Island uplift, to the southeast of the Santa Monica Basin, is the largest "pop-up" in the Southern California offshore area (Legg et al. 2004). Other restraining bends include: the Oceanside and Dana Point segments of the Newport-Inglewood fault zone, offshore Palos Verdes anticlinorium, Lausen Knoll along the Palos Verdes fault zone, and the southern half of San Clemente Island and the “Bend Region” of the San Clemente fault zone (Legg and Goldfinger 2002).

Submarine landslides on the steep slopes of the offshore inner California Continental Borderland are widespread. The documented evidence of offshore landslides includes some very large landslide failures such as those mapped offshore Goleta (Eichubl et al. 2002), offshore the Palos Verdes peninsula (Bohannon and Gardner 2004), and along the Thirtymile and Fortymile Banks near San Clemente Island (Legg and Kamerling 2003).

Historical Tsunami Data

Several damaging tsunamis generated by distant earthquakes have reached the southern coastal California region in the past century (**Table 6-5**). Historically, these distant-source events have caused the most damage in California. The 1964 Pacific basin-wide tsunami generated by the great Alaskan earthquake is the most damaging tsunami to date, with significant damage in Crescent City and Santa Cruz Harbor, and lesser damage in Los Angeles and Long Beach Harbors (Tudor 1964). As instrumentation has improved, it's become clear that distant-source tsunamis affect California every few years on average, but they are rarely damaging (Lander et al. 1993; Lander et al. 2003; NOAA 2005b). To our knowledge, no accurate estimate of a return period for distant-sourced tsunamis affecting California has been compiled.

Locally-generated tsunamis are also a hazard. Local tsunamis may be generated by seismic displacement of the seabed, or by a submarine landslide triggered by ground shaking from even a moderate earthquake in the coastal region. In 1927, an earthquake offshore of Point Arguello produced run-up of 6 feet (1.8 m) at Surf, near Guadalupe (Lander et al. 1993). In December 1812, historical accounts record several local earthquakes near Santa Barbara causing significant damage to structures, and were associated with sea waves of several meters recorded in Gaviota, Santa Barbara and Ventura (McCulloch 1985; Lander et al. 1993). In 1930, an M 5.2 earthquake off of Redondo Beach may have triggered a landslide that generated unusually large waves (Legg et al., 2004) or a local tsunami (Lander et al., 1993) with a 6-foot (1.8-m) run-up resulting in serious damage and one fatality in Santa Monica. Recurrence intervals for local events will be similar to the recurrence intervals for large, offshore earthquakes, generally hundreds to thousands of years or, in the case of large offshore landslides, on the order of hundreds of years (Legg et al., 2003).

Tsunami Hazard Planning

In deep water far from shore, a passing distant-source tsunami would have little effect on a floating structure or a submarine pipeline, although locally sourced tsunamis may pose a greater threat to offshore facilities, depending on the proximity and magnitude of the source. Tsunami hazards are particularly important in shallow water and in coastal areas. In some cases, the advancing turbulent front is the most destructive part of the wave with regard to damage of coastal facilities. Even where the rise is quiet, the outflow of water to the sea between crests may be rapid and destructive, sweeping debris offshore, and undermining roads, buildings, and other structures.

Coastal tsunami hazards are generally discussed in terms of "run-up," which is the elevation above sea level of a tsunami at the limit of penetration, and "inundation," which is the lateral distance from the shoreline to the limit of tsunami penetration. There is considerable variability in these measures for both historical and modeled events caused by a number of factors, including slope of the land (lower run-up elevations and greater inundation distances in flatter areas), underwater topography, and orientation of the coastline.

In addition to reviewing historical records, agencies use tsunami modeling to plan for potential events. Many groups are involved in the process of generating tsunami inundation maps for coastal California, including the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory, NOAA National Tsunami Hazard Mitigation Program, USACE, California Office of Emergency Services, and the University of Southern California Tsunami Research Center, to name a few. The National Tsunami Hazard Mitigation Program (NTHMP) promotes planning and design principles to reduce the risk of tsunami damage in coastal communities, but ultimately the design of coastal facilities is regulated by state and local building codes (NTHMP 2001).

Legg et al., (2003) examined the Santa Catalina Island platform and its potential for generating local tsunamis that would threaten coastal areas near Los Angeles. With a simulated earthquake of M_w7.6, their models generated wave heights up to 4.9 feet (1.5 m). Coastal run-up of about 3 to 7 feet (1 to 2 meters) was predicted over most of the region from Point Dume to San Onofre for the largest scenario modeled. Their run-up values compared well to those observed following the 1927 Lompoc earthquake (5 to 6 feet [1.5 to 1.8 m]). However, they noted that their model predictions may understate the hazard.

At the time of this report (March 2006), Los Angeles County had not yet publicly released updated inundation maps. The County has adopted a criteria of 40 feet (12 m) run-up in all coastal areas, with latest mapped inundation areas defined by the 42-foot (12.8-m) elevation contour. It should be noted that the map is based on worst case scenario models, and is used for emergency preparedness and evacuation planning rather than for engineering guidelines (Eisner et al. 2001). These data indicate that the flat-lying areas along Ballona Creek and in Marina del Rey are at greatest risk for large tsunami run-ups (**Figure 6-30**). The HDD entry is above this elevation.

Additionally, the Marine Oil Terminal Engineering and Maintenance Standards (CSLC 2005) outline tsunami design considerations for marine oil terminal structures and moored vessels, providing estimated tsunami run-up values for the Ports of Long Beach and Los Angeles of 8 feet (2.4 m) (100-year return period) to 15 feet (4.6 m) (500-year return period).

6.1.7.7 Methane Hydrates, Shallow Gas and Seeps

Gas hydrates (also known as clathrates) comprise gas molecules, usually methane, surrounded by a cage of water molecules. Methane hydrates are stable as a crystalline solid in seafloor sediments at high pressures, such as those below 985 feet (300 m) water depth, and low temperatures (near 0°C). Methane hydrates pose a hazard to seafloor installations where they may become destabilized and disturb overlying sediments. Methane hydrates may become unstable as a result of pressure drops (for example, if sea level drops) or heating (from rising ocean temperatures, or geologic or man-made heat sources).

Sources of shallow gas include disassociated hydrates, free gas migrating along fractures or faults from deeper reservoirs, and gas resulting from biogenic activity in shallow sediments. Evidence of methane gas expulsion in sediments includes gas bubbles or plumes in the water column and gas-blanking of gas charged sediments in sub-bottom profiler and seismic survey data. Biologic communities of chemosynthetic organisms that grow up around "cold seeps" may form acoustically reflective hard-grounds (shell beds), detectable with side-scan sonar. Methane seeps are also commonly the site of authigenic carbonate production that leads to formation of localized hard grounds. Methane gas is known to be discharging from a mud volcano in water 2,667 feet (813 m) deep, located approximately 15 miles (24 km) southwest of Redondo Beach. The source of the gas is thought to be methane hydrate-laden sediments that have become destabilized by faulting along the edge of the Santa Monica Basin. Piston cores taken near the summit of the structure in the Santa Monica Basin recovered shells, authigenic carbonate and methane hydrate (Normark et al. 2003; Hein et al. 2005), the first methane hydrates to be found offshore Southern California. Recovered samples also contained shells with specific carbonate chemistry *and Vesicomya (sp.)* worms, indicating an active methane seep at the seabed. **Figure 6-26** shows the natural seeps and methane hydrate locations in Santa Monica Bay.

Gas in shallow seabed sediments occurs throughout Santa Monica Bay and in Santa Monica Basin (Normark et al. 2003; Normark and McGann 2004; Shipboard Scientific Party 1997). A temporary biogenic gas seep observed by swimmers and divers approximately 600 feet (183 m) offshore Malibu Pier was probably initiated by an earthquake in 1971 (Wilkinson 1972).

Evidence of methane gas expulsion in sediments, whether from disassociated hydrates or other sources, includes gas bubbles in the water column, and biologic communities of chemosynthetic organisms that grow up around "cold seeps." Conduits for gas and gas-water mixtures, such as faults, mud volcanoes, and mud diapirs, may be apparent on the seafloor imagery or in subsurface data. Other geologic expressions of gas expulsion include seafloor subsidence, pockmarks, sediment slumps, and landslides.

The potential impact of gas seeps include the occurrence of hard grounds and the possibility of sediment displacement during gas expulsion that may lead to post-installation pipeline spans. Marine survey data should be carefully examined for any evidence of the occurrence of shallow gas along the pipeline route.

Several oil and gas seeps are mapped along the projected trend of the Palos Verdes fault zone in Santa Monica Bay (**Figure 6-26**). Two well-known natural oil seeps are located near shore: one is located near the head of Redondo Canyon and the other is located approximately 4.6 miles (7.4 km) offshore Manhattan

Beach. Some of the oil dissipates before reaching the surface, but oil globules and tar balls from these seeps, and seeps in the Santa Barbara Channel, occur along local beaches (Hartmond and Hammond 1981).

Potential geohazards of relevance to the Project are summarized in **Table 6-6**.

6.1.7.8 Onshore Geologic Hazards

Fault Zones and Seismicity

The onshore proposed pipeline route crosses the Charnock and Potrero faults. The Potrero fault is considered to be a splay of the Newport-Inglewood fault zone (NIFZ)(**Figures 6-28** and **6-29**; SCEC 2006), whereas the Charnock fault is a separate structure located to the west.

Newport-Inglewood (Los Angeles Basin) Fault

This NIFZ is a right-lateral strike-slip fault located in the Los Angeles Basin. The NIFZ comprises a closely spaced system of NW-trending active strike-slip and oblique-slip faults. Onshore, it is marked by a chain of low hills extending from the Santa Monica Mountains to Newport Beach. Based on historical seismicity and structural differences (SCECWG 1995; Grant and Rockwell 2002), some workers have segmented the fault into northern and southern segments. The southern section of this fault, which last ruptured in the Mw 6.4 Long Beach earthquake of 1933, is about 24 miles (38 km) long and runs parallel to the coast, then heads offshore at Newport Beach. The northern (Baldwin Hills) segment of the fault is about 17 miles (28 km) long and has not ruptured in historical time. The date of most recent rupture is unknown. The combined length of the two segments is about 41 miles (66 km), and is treated as a single fault segment by Cao et al. (2003).

Historical earthquakes have been most common on the southern part of the onshore portion of the fault zone; most were aftershocks of the 1933 Mw 6.4 Long Beach earthquake. Subsurface paleoseismic investigations of the fault zone in the vicinity of Newport Bay demonstrated evidence of three to five surface rupture events in the past 11,700 years (Grant et al. 1997). Paleoseismic data and historical seismicity indicate a sequential northward propagation of ruptures since about 1650 A.D. on a 300+ series of kinematically linked active faults extending from Baja California to Southern California (Grant and Rockwell 2002). There is no evidence that the northernmost portion of the Newport-Inglewood fault has ruptured during this time.

Slip rates for this fault are poorly constrained, and estimates vary from 0.004 inch/yr (0.1 mm/yr) to about 0.06 inch/yr (1.5 mm/yr) (Petersen and Wesnousky 1994; SCECWG 1995). The slip rate on the fault zone cannot be precisely estimated from available surface data because of the many uncertainties regarding interpreted offsets and ages of geomorphic features. For the purposes of this investigation, a slip rate of 0.04 +/- 0.02 inch/yr (1+/-0.5 mm/yr) and an estimated maximum magnitude of M_w 7.1 earthquake are assigned to this fault (Cao et al. 2003).

Charnock Fault

The Charnock fault does not show evidence for Holocene activity and is thus not considered active (Poland et al., 1959; Jennings, 1994). It is located parallel to and lies west of the NIFZ (**Figure 6-28**). Poland et al. (1959) report that the Charnock fault acts as a groundwater barrier, as evidenced by observed different groundwater levels on either side of the inferred fault trace. Based on well log data, they infer that the base of the lower Pleistocene San Pedro Formation is offset by about 140 feet (43 m) with offset down to the east. However, they noted that the pre-Holocene to early Holocene “50-foot [15-m] gravel” in the Ballona Gap does not appear to be offset by the Charnock fault (Poland at al., 1959). Additionally, Poland et al. (1959) report that there is no evidence of ground surface displacement along the fault. The lack of reported Holocene activity and the offset of late Pleistocene units suggest that this fault is not currently active.

The orientation of the fault plane is unknown, but is believed to be very steep to vertical. Due to its parallelism and proximity to the NIFZ, its predominant sense of displacement is believed to be strike-slip. However, the down-to-the-east vertical displacement reported by Poland et al. (1959) indicates a presence of vertical component to its displacement.

A more complete discussion of faulting, seismicity, and surface fault rupture is presented in Section 6.1.4 and in the draft Probabilistic Seismic Hazard Assessment (Fugro, 2006c).

Landslide and Slope Instability

About 2,000 ft (610 m) inland from the coast, a terrace bluff creates an area of potential slope instability (CGS 2006). **Figure 6-29** shows geohazards along the onshore pipeline route.

Areas Prone to Liquefaction

Where the pipeline makes landfall, the beach to 1,500 ft (457 m) inland may be subject to liquefaction effects from earthquake-induced strong ground motions (Fugro 2006b; CGS 2006). The eastern portions of the onshore pipeline route traverses areas of potential soil liquefaction **(Figure 6-29**).

Areas Prone to Flooding

Portions of the LA Basin are subject to periodic storm-induced flooding. The Federal Emergency Management Agency (FEMA) 100-year flood zone map of the onshore pipeline area shows areas subject to flooding (**Figure 6-29**).

6.1.7.9 Mineral Resources

The major mineral resources in the Los Angeles Basin are oil and natural gas. The basin has 3 super giant oil fields (greater than 1 billion barrels [1 barrel=42 gallons/159 liters] of reserves), namely Wilmington, Huntington Beach, and Long Beach (Montgomery 1998). In addition, there are more than a dozen giant fields with reserves of greater than 100 million barrels. The total recoverable reserve of the Los Angeles Basin is 9.1 billion barrels of oil and 7.6 trillion cubic feet of natural gas. Although most of the production has come from onshore areas, potential oil and gas reservoirs extend out onto the shelves in Santa Monica Bay and San Pedro Bay. The Wilmington and Huntington Beach structures extend offshore (CDOGG 2006). One wholly offshore field is Beta Field, 6 miles (10 km) southwest of Huntington Beach, in Federal waters. The only active Federal leases in the Project area are the lease blocks associated with Beta Field (MMS 2006). The onshore pipeline crosses near the Playa del Rey oil field. The Hyperion oil field is south of the pipeline.

The Pacific Offshore Continental Shelf Region, administered by the U.S. Minerals Management Service, has 79 active leases offshore California. Of those leases, 39 developed leases lie between Point Arguello and Point Vicente. The CSLC also administers oil and gas leasing inside the Three Nautical Mile Limit. Currently in the state, there are 31 total leases, of which 17 are producing, 11 are not producing, and 3 are undeveloped. Seven of the producing state leases lie between Point Arguello and Point Vicente. Permission to locate an infrastructure (platform, pipeline, etc.) in an active lease may require permission from the lease operator as well as from the administering government agencies.

Natural oil seeps are locally present in the offshore Project area. Seeps have been identified in Santa Monica Bay along the Palos Verdes fault in relatively shallow water from 1 mile (1.6 km) to 6 miles (9.6 km) from the shore (CDOGG 1972). Some of the seeps closest to shore are located at the head of Redondo Canyon. Another seep has been identified about halfway between the mainland coast and Santa Catalina Island, near the base of the continental slope just south of the San Pedro Sea Valley. Other seeps in the area are located south of Long Beach, and are associated with the Wilmington oil field structure that extends offshore.

Other minerals that are mined and produced in the Los Angeles Basin include sand and gravel, gypsum, and clay (USGS 2003).

The offshore pipeline route does not cross the areas of active oil production. However, the pipeline route crosses the Palos Verdes fault to the north of where active oil seeps have been reported (CDOGG 1972; 2006).

The proposed onshore pipeline route crosses near two oil fields: the Playa del Rey field and the Potrero field (CDOGG 2006). These fields were active producers as of 2004 (CDOGG 2004).

Review of aerial photographs indicated that no active quarries or mines were identified along the proposed LAX pipeline route. The areas crossed are entirely residential-commercial in nature.

6.1.7.10 Paleontological Resources

Significant paleontologic resources are fossils or assemblages of fossils that are unique, unusual, rare, uncommon, diagnostically or stratigraphically important, and those that add to the existing body of knowledge in specific areas. They include fossil remains of large to very small aquatic and terrestrial plants and animals. In general, all vertebrate fossils are considered significant.

Approximately 4.5 miles (7.2 km) north of the proposed pipeline route is the La Brea Tar Pits, a unique fossil locality that contains the fossilized remains of a diverse assemblage of 660 bird and mammal species (Harris and Jefferson 1985). In addition, some sedimentary deposits within the Los Angeles Basin contain fossil remains of marine plants and animals.

<u>Offshore Pipeline Routes</u>

A site-specific paleontology investigation has not been conducted of the offshore areas; however, identification and/or recovery of fossils from the seafloor are not routinely performed. The marine pipeline is expected to be surface laid on the seafloor, so no dredging or significant disturbance of the seafloor is anticipated.

<u>Onshore Pipeline Routes</u>

A site-specific paleontology investigation has not been conducted of the onshore areas; however, the onshore pipeline crosses highly urbanized ground and most areas have been disturbed.

6.2 Regulatory Setting

As a highly geologically active area, California has promulgated substantial regulatory requirements. **Table 6-7** provides a listing and description of regulatory programs and policy relevant to this Project.

6.3 Impact Analysis and Conservation Measures

The geologic setting, faults, seismicity, landslides, turbidity currents, and other geologic considerations and resources in the Project area have been examined. This section describes the potential impacts of the OceanWay Secure Energy Project to geologic resources. This section also identifies Conservation Measures (CM) that will be implemented by Woodside to reduce or eliminate potential impacts. The potential impacts of construction are discussed first, followed by the potential impacts of operations.

6.3.1 Offshore Construction

Offshore construction includes the anchor buoys for the DWP and the pipelines. The pipelines will be on the seafloor except near the shore where they will be threaded through buried casing pipelines to the landfall location. Offshore construction can be susceptible to the following geologic impacts.

Impact

GEO-1[2]: Damage to Offshore Pipelines Resulting from Surface Fault Rupture

Offshore pipelines would be susceptible to damage resulting from surface fault rupture.

There is potential for permanent ground displacement across active faults. A pipeline crossing an active fault is susceptible to bending or rupture if ground displacement is severe enough.

Conservation Measure

CM-GEO-1: Avoid laying pipelines over active faults

Avoid crossing active faults where possible; place the pipelines on the surface of the seafloor for greater flexibility; cross fault traces at an appropriate angle; apply appropriate seismic design criteria to pipeline engineering and design.

The DWP is located outside of areas where active faults have been identified and so will avoid exposure to this impact. The pipelines cross two active fault zones, the San Pedro Basin fault zone and the Palos Verdes fault zone. Conservation measures applied to the pipelines include crossing the identified fault traces at an appropriate angle and applying current seismic design provisions. Except for the shore crossing, or where shallow burial might be appropriate to mitigate other potential impacts, the pipelines will be installed directly on the seabed surface to allow enhanced flexibility and to help the pipelines withstand movement caused by fault rupture.

Pipeline routes will also be designed to cross potential faults at as optimal an orientation as possible based on fault style and fault geometry. Offset of pipelines crossing normal faults at right angles will induce tension in pipes, rather than compression. Pipelines can withstand more offset when in tension than when in compression. If future fault motions exceed allowable stresses in the pipelines, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system.

Impact

GEO-2: Damage to Offshore Pipelines From Soil Liquefaction or Lateral Spreading

Offshore pipelines may be damaged by earthquake-induced liquefaction or lateral spreading.

Liquefaction causes the soil to lose strength and compact or settle. This can cause the ground surface to settle, and buried pipelines can become buoyant. Liquefaction on a slope may cause earth materials to flow downhill. Lateral spreading is another liquefaction hazard in which blocks of competent soil are displaced horizontally over liquefied strata (Pelmulder 1995). Earthquake-induced liquefaction can cause loss of pipeline support and result in bending or rupture.

Conservation Measure

CM-GEO-2: Avoid areas prone to liquefaction and lateral spreading, and apply seismic design to pipeline.

Liquefaction impacts are limited to the areas underlain by loose, non-cemented sands. These areas may underlay portions of the DWP buoys and pipeline. Conservation measures to accommodate the effects of soil

[2] Note that Impacts have been identified in this section using a "GEO" (i.e., "geological resources" impact) designation, while the associated conservation measures have been identified using a "CM-GEO" (i.e., "conservation measure" to address the "geological resources" impact) designation.

liquefaction are application of current seismic design provisions. The pipelines will be buried beneath the nearshore, beach, and dune sand areas most susceptible to liquefaction. If liquefaction were to cause the pipelines to settle or become buoyant to the extent that allowable stresses were exceeded, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system, and natural gas would rise to the surface. However, well-engineered pipelines generally withstand liquefaction, so pipeline rupture as a direct consequence of liquefaction is considered highly unlikely.

Impact

GEO-3: Damage to DWP Facilities, Anchors or Offshore Pipelines From Mass Movement

DWP facilities, anchors, or offshore pipelines may be damaged by mass movement.

Landslides, debris flows, or turbidity currents can cause bending or rupture of pipelines laid on the seafloor surface, or of buried pipelines, due to loss of support or lateral movement of soils and pipe. Mass movements can also bury seafloor pipelines.

Conservation Measure

CM-GEO-3: Avoid areas of steep slopes and mass movement, and design the pipelines to accommodate or withstand some ground movement and turbidity flows.

The DWP and pipeline have been sited to avoid most areas where steep slopes and identified subsea landslides are present. In addition, the pipelines have been routed around and to the north of Santa Monica Canyon to avoid any turbidity currents and mass movements associated with that feature.

As shown on **Figure 6-21,** the DWP is within a turbidity current flow channel where an event occurred approximately 100 years ago (Gorsline, 1996). Design criteria for the pipeline and subsea facilities will allow them to withstand anticipated forces from turbidity currents during their respective design lives. Preliminary engineering analysis based on measured soil strength conditions along the pipeline route in Santa Monica Basin suggests that the pipeline will sink into the soft seafloor soils and at least partially self-bury, affording some protection from turbidity currents.

If mass movements occurred that were to exceed allowable stresses in the pipelines, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system, and natural gas would rise to the surface.

Impact

GEO-4: Damage to Pipelines or DWP from a Tsunami

DWP facilities or offshore pipelines may be damaged by the effects of a tsunami.

The effects of a tsunami are generally not significant until the tsunami waves reach shallow water. As described previously, these waves can be very destructive of the nearshore environment, causing erosion and triggering both surface and subsurface mass movements.

Conservation Measure

CM-GEO-4: Avoid exposure to wave action from tsunami, and design the pipeline to withstand uplift and/or erosion.

As stated above, the offshore effects of a tsunami are limited to the near shore and shallow water areas. The DWP is in water that is too deep to be impacted by the effects of a tsunami. Within the anticipated tsunami impact area near shore, the pipeline will be buried. The pipeline will be constructed of steel capable of resisting significant erosion should portions of the pipeline be exposed following a tsunami.

Impact

GEO-5: Damage to Pipelines from Ground Shaking

Offshore Pipelines may be damaged from earthquaking-generated ground shaking.

Earthquake-generated ground shaking can damage pipelines. The Modified Mercalli Intensity (MMI) Scale is a good indicator of earthquake effects. **Table 6-8** presents the MMI Scale as modified to describe possible effects to natural gas pipeline facilities (McDonough 1995).

Conservation Measure

CM-GEO-5: Design and construct the DWP and pipelines to meet or exceed the current seismic design standards.

The conservation measure for ground shaking for the DWP and pipeline is application of current seismic design provisions. The offshore gas pipelines will be designed to accommodate anticipated maximum horizontal and vertical ground motions from earthquakes. A preliminary PSHA has already been performed for the Project (Fugro, 2006c). The preliminary PSHA will be updated based on seismic surveys and geotechnical data. A Final PSHA will be used for final pipeline design.

If seafloor ground motions were to exceed allowable stresses in the pipelines, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system, and natural gas would rise to the surface.

Impact

GEO-6: Loss of Access to Offshore Oil and Gas Resources

Construction and operation of the DWP and offshore pipelines may interfere with exploration and/or development of offshore oil and gas resources.

Although there are no active oil or gas leases in the DWP area or along the offshore pipeline route, the potential to find new resources in the area is recognized.

Conservation Measure

CM-GEO-6: Use of standard drilling and/or exploration techniques.

If an oil or gas deposit should be discovered in the future within the DWP area or along the pipeline route, the presence of the DWP and pipeline would not preclude exploration of, or development of, the resource using standard drilling and exploration techniques.

Impact

GEO-7: Damage to the DWP or the Offshore Pipelines from Natural Seeps and Methane Hydrates

Oil, gas, or methane hydrate seeps have the potential to cause damage to the DWP or offshore pipelines.

Natural seeps and methane hydrate locations may be identified in the vicinity of the DWP. There may also be natural seeps on the Palos Verdes fault along the offshore pipeline route.

Conservation Measure

CM-GEO-7: Design the pipeline to withstand the effects of natural oil, gas, or methane hydrate seeps.

The pipeline will be designed to withstand physical and chemical effects of oil, gas and methane hydrate seeps, if such seeps are identified or anticipated along the proposed pipeline route and DWP site.

Impact

GEO-8: Seafloor Erosion or Sedimentation Related to Construction of the DWP site

Localized or temporary disturbances to the seafloor will occur from the installation of the DWP.

Where the pipeline is buried near shore, depending on the construction method used, drill cuttings or fluids may be deposited on the seafloor. Localized or temporary disturbances to the seafloor will occur from the installation of the DWP. Disturbance of the seafloor from anchors and construction activities is expected to be very localized. Vibrations due to drilling may disturb seafloor sediments locally. Anchor penetration of the seafloor, anchor embedment, anchor dragging, and breaking out the anchor on removal will locally impact the seafloor.

Conservation Measure

CM GEO-8: Use drilling methods to minimize seafloor disturbance.

Where the pipeline is buried near shore, drill cuttings may be generated. Drill cuttings management will evaluate the necessity of using a drilling method that minimizes cuttings on the seafloor or the possibility that drilling mud is expelled to the seafloor from the pipeline bore.

Impact

GEO-9: Offshore Pipeline Rupture from Geologic Processes Exceeding Design of Pipeline

During operation of the proposed Project, offshore pipeline rupture could result from a significant geologic event that exceeds the design limits of the pipeline.

As identified above, it is possible that, during the lifetime of the Project, one or more significant geologic events could occur with potential to exceed the design limits of the pipeline. This may cause an undersea pipeline rupture.

Conservation Measure

CM-GEO-9: Safe shutdown of pipeline.

If geologic events occur that cause the pipeline to fail, the loss of pressure would induce the safe shutdown of the system, and natural gas would rise to the surface.

6.3.2 Onshore Construction

The following section discusses onshore construction impacts and conservation measures. The onshore construction includes the pipelines and the RCTS/IGIF. The pipelines will be along existing utility rights-of-way and along roadways, except near the shore where they will be buried. Onshore construction can be susceptible to some of the same impacts as those identified for offshore construction.

Impact

GEO-10: Damage to Onshore Pipelines Resulting from Surface Fault Ground Displacement

Offshore pipelines which cross an active fault are susceptible to bending or rupture from severe surface ground displacement

There is potential for permanent surface ground displacement across active faults. Offshore pipelines crossing an active fault are susceptible to bending or rupture if surface ground displacement is severe enough.

Conservation Measure

CM-GEO-10: Cross active fault traces at an appropriate angle, apply seismic design to the pipeline, and use safe shut-off valves.

The proposed onshore pipeline crosses the Potrero fault splay of the active NIFZ. Conservation measures applied to the pipeline include crossing the identified fault traces at an appropriate angle and application of current seismic design provisions. Site-specific seismic hazard studies will be conducted prior to construction. The studies will cover suspected active fault crossings to accurately define the fault plane location, orientation, and vector of anticipated offset, and will include estimates of the amount of anticipated offset at the fault locations. This information will be used to refine fault crossing pipeline design parameters.

If the fault motion were to exceed allowable stresses in the pipelines, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system.

Impact

GEO-11: Damage to Onshore Pipelines Resulting from Soil Liquefaction

Onshore pipelines may bend or rupture as a result of soil liquefaction.

Liquefaction causes the soil to lose strength and compact, settle, or flow. This can cause the ground surface to settle. Buried pipelines can become buoyant. Liquefaction on a slope may cause earth materials to move downhill as a lateral spread. Lateral spreading is a hazard in which blocks of competent soil are displaced horizontally over liquefied strata (Pelmulder 1995). Earthquake-induced liquefaction can cause loss of pipeline support, resulting in bending or rupture.

Conservation Measure

CM-GEO-11: Apply appropriate seismic design to pipeline.

Liquefaction impacts are limited to the areas underlain by loose, non-cemented sands below the groundwater table. Liquefaction is much more likely in areas where the groundwater table is less than 16 feet (5 m) below ground surface. Conservation measures to accommodate the effects of soil liquefaction are application of current seismic design provisions. The pipeline is buried beneath the nearshore, beach, and dune sand areas most susceptible to liquefaction. If liquefaction were to cause the pipeline to settle or become buoyant to the extent that allowable stresses were exceeded, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system.

Impact

GEO-12: Damage to Onshore Pipelines from Mass Movement.

Mass movements have the potential to bend or rupture onshore pipelines.

Landslides, debris flows, and mud flows can cause bending or rupture of buried pipelines due to loss of support or movement of pipe. Mass movements can also expose formerly buried pipelines.

Conservation Measure

CM-GEO-12: Avoid areas of steep slopes and identified mass movement.

The pipeline has been sited to avoid most areas where steep slopes and identified landslides are present. If mass movements occurred that were to exceed allowable stresses in the pipelines, pipelines could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system, and natural gas would rise to the surface.

Impact

GEO-13: Damage to Onshore Pipelines from a Tsunami

Tsunamis have the potential to damage onshore pipelines nearshore.

The effects of a tsunami are generally not significant until the tsunami waves reach shallow water. As described above, these waves can be very destructive of the near shore environment, causing erosion and triggering both surface and subsurface mass movements.

Conservation Measure

CM-GEO-13: Avoid exposure to tsunami wave effects in onshore tsunami run-up zone by burying the pipeline beneath the ground surface.

As stated above, the effects of a tsunami are limited to the nearshore and run-up areas. Within the anticipated tsunami impact area, the pipeline will be buried and anchored, and therefore should avoid most impacts. If the pipeline were significantly damaged or subject to stresses causing rupture, safe shutdown would occur.

Impact

GEO-14: Damage to Onshore Pipelines from Strong Earthquake-Induced Ground Motions

Earthquake-generated ground shaking can damage pipelines.

Onshore pipelines would be susceptible to damage from earthquake-generated ground shaking. If ground motions exceed allowable stresses in the pipelines, then the pipelines could rupture and cause a leak.

Conservation Measure

CM-GEO-14: Design and construct the pipelines to meet or exceed the current seismic design standards.

The conservation measure for ground shaking for the pipeline is application of current seismic design provisions. The onshore gas pipelines would be designed to accommodate anticipated maximum lateral/vertical motion from earthquakes. If ground motions were to exceed allowable stresses in the pipelines and a rupture occurred, then the loss of pressure would induce the safe shutdown of the system.

Impact

GEO-15: Loss of Access to Onshore Oil and Gas Resources

Construction and operation of the onshore pipelines may restrict access to onshore oil and gas resources.

The onshore pipeline route crosses approximately 0.25 miles (0.4 km) south of the Playa del Rey Oil field. The presence of the pipeline in this location will not preclude exploration or development of oil and gas resources, should they be discovered beneath the pipeline route.

Conservation Measure

CM-GEO-15: Use of standard drilling and/or exploration techniques.

If an oil or gas deposit should be discovered in the future beneath the onshore pipeline route, the presence of the pipeline will not preclude exploration or development of the resource using standard drilling and exploration techniques.

Impact

GEO-16: Loss of Unique Geologic or Paleontologic Resources

Excavation for onshore pipeline placement has the potential to uncover unique geologic or paleontologic resources.

The potential exists for encountering unique geologic or paleontologic resources along the onshore pipeline route. The onshore routes cross areas that are urbanized, with little or no original surface remaining. Because pipeline construction will be confined to the roadway or utility easement, there is a low probability that scientifically important geologic features or fossils will be found within the excavation for pipeline placement.

Conservation Measure

CM-GEO 16: Assess any unique geologic or paleontologic resource uncovered during excavation.

Qualified geologists and paleontologists will be available to assess any unique geologic or paleontologic resource uncovered during excavation.

Impact

GEO-17: Short-Term Soil Erosion Related to Construction Activities

Trenching for the onshore pipeline burial could result in soil erosion.

Soil disturbance during trenching for the onshore pipeline burial could destabilize the soil and result in soil erosion. Some disturbance of soil during construction is unavoidable.

Conservation Measure

CM-GEO-17: Use best management practices consistent with local, State and Federal grading requirements to minimize erosion.

As most of the trenching is within highly urbanized areas and along roadways, management of soil, dust, and erosion will be closely monitored.

Impact

GEO-18: Flooding of the Area Above the Buried Pipeline

Portions of the buried onshore pipeline could be subject to flooding.

Portions of the pipeline route are within the 100-year flood zone, specifically the area within 550 ft (138 m) of the shoreline. Although the pipeline will be buried throughout this area, it could be subject to inundation and erosion during a 100-year flood.

Conservation Measure

CM-GEO-18: Implement design provisions for flood-prone areas.

In areas identified as subject to flooding, the pipeline will be designed to withstand the effects in inundation and/or erosion. If events occurred to exceed the allowable stresses in the pipelines, they could rupture and cause a leak. The loss of pressure would induce the safe shutdown of the system.

Impact

GEO-19: Onshore Pipeline Rupture from Geologic Activities Exceeding Design of Pipeline

During operation of the proposed Project, a significant geologic event could cause onshore pipeline rupture.

It is possible that during the lifetime of the Project, one or more significant geologic events will occur that have the potential to exceed the design limits of the pipeline. This may cause a pipeline rupture.

Conservation Measure

CM-GEO-19: Safe shutdown of pipeline.

If geologic events occur that cause the pipeline to fail, then the loss of pressure will induce the safe shutdown of the system and natural gas will be released to the surface.

6.3.3 Offshore and Onshore Operation

The impacts and conservation measures for both offshore and onshore operations are the same as the construction impacts, with the exception that construction-related erosion and sedimentation and the potential for encountering unique geologic or paleontologic resources do not apply.

6.4 Alternatives

Consistent with good engineering and business practices, and to facilitate the environmental review under NEPA and CEQA, Woodside considered a variety of alternatives when developing the OceanWay Project. This section discusses the impacts to geologic resources caused by the nine alternatives to the proposed Project. Project alternatives include: No Action alternative (no Project); AES Alternative DWP and associated onshore pipeline routes; LAX south shore crossing; onshore pipeline route alternatives; Submerged Combustion Vaporization (SCV) as an alternative vaporization technology; burying segments of the pipelines on the ocean floor; an alternate site for the RCTS; an alternate method for installing the pipeline across the dunes; and refilling the pit excavated for the seaward end of the HDD. Each of these alternatives is summarized below. **Topic Report 13/Alternatives** presents a more comprehensive discussion of each of these alternatives.

6.4.1 No Action Alternative

The No Action Alternative means that the OceanWay Project would not go forward and that none of its associated facilities would be installed. Accordingly, none of the environmental impacts identified for the construction and operation of the proposed Project would occur. In the event that energy needs of the region must be satisfied by other LNG or natural gas pipeline projects, the impacts of such projects are likely to be comparable in nature and magnitude to the impacts associated with the OceanWay Project.

6.4.2 AES Alternative DWP with Associated Onshore Pipeline Route

The proposed AES Alternative DWP would be located approximately 20 miles (32 km) offshore of Orange County, with the offshore pipeline making landfall in Orange County at Huntington Beach, near the south end of Newland Street. The onshore pipeline would run approximately 24 miles (39 km) to the north and east across city streets of Orange County, making a connection with the SCG transmission system near the city of Orange.

The tectonic setting, regional structure, and seismicity of the AES Alternative (**Figure 6-37**) are similar to the proposed Project in Santa Monica Bay (Section 6.1.1). The AES alternative DWP would be located in a water depth of approximately 2,700 feet (820 m) (**Figure 6-38**). The AES alternative offshore pipeline route (twin 24-inch [nominal 600 mm] diameter pipelines) would be approximately 31 miles (50 km) in length. **Figures 6-39** through **6-42** provide additional information about the offshore portions of the AES Alternative. **Figures 6-43** and **6-44** present information concerning the geologic conditions at the AES Alternative HDD. The landfall would be in Orange County at Huntington Beach, near the south end of Newland Street (**Figure 6-45**). The onshore route of the AES alternative pipeline (36-inches [91-cm] inches diameter) would extend approximately 19.5 miles (31 km) to the north and east beneath city streets of Orange County, making a connection with the SCG transmission system near the city of Orange. **Figures 6-45** through **6-47** provide additional geologic and geohazards information concerning the onshore portions of the AES Alternative.

6.4.2.1 Geologic Setting

The tectonic setting for the AES Alternative is the same as that for the Project. Regional physiography and geology will be discussed below.

<u>Regional Physiography</u>

The AES study area includes portions of the Peninsular Ranges, and the (offshore) Inner Continental Borderland geomorphic provinces of Southern California. The AES study area is located within San Pedro Bay and the adjacent, deep water Gulf of Santa Catalina. This area encompasses the tectonic boundary between the offshore southern margin of the LA Basin and the inner Continental Borderland. The dominant physiographic features of the study area include the San Pedro shelf, the Newport Trough, Lausen Knoll, and the Gulf of Santa Catalina (**Figure 6-38**).

The northwest-trending shoreline of eastern San Pedro Bay lies near the boundary between the Peninsular Ranges to the east and the Inner Continental Borderland to the west. The topography on land to the north of the Long Beach coastal plain is smooth, with the exception of low folded hills that mark the inland trace of the Newport Inglewood fault Zone (NIFZ) (Bohannon et al. 2004). The San Pedro Shelf, underlying San Pedro Bay, extends out to the shelfbreak at about 200 to 300 feet (60 to 90 m) water depth and is relatively flat-lying and featureless. Laterally, the shelf extends southeast from Point Fermin about 22 miles (35 km) to Newport Beach. The width of the shelf varies from about 14 miles (23 km) south of Long Beach, narrowing to about 5.5 miles (9 km) near Newport Beach (**Figure 6-38**).

The southeastern slope of the San Pedro shelf slopes southeast, at about 2 degrees, to the Newport Trough. The southern shelf slope is incised by two major submarine drainage features northwest of Lausen Knoll. San Gabriel Canyon, which is likely related to the Palos Verdes Fault Zone (PVFZ), is a prominent drainage feature located on the southern portion of the shelf. San Gabriel Canyon is incised into the shelf slope and extends southwestward toward Lausen Knoll. North of the knoll, the drainage bifurcates, with the east fork traversing adjacent to the northwestern portion of the knoll, somewhat coincident with the mapped trace of the PVFZ. The second drainage system, Newport Canyon submarine drainage, is likely associated with the THUMS-Huntington Beach fault and/or the NIFZ. Newport Canyon is located east of San Gabriel Canyon, consisting of a series of smaller tributary drainages that incise the shelf slope and extend southwestward toward the eastern side of Lausen Knoll (**Figure 6-38**).

Lausen Knoll is an asymmetrical mound that is oriented roughly northwest, consistent with the structural grain of the Peninsular Ranges geomorphic province. It is a geomorphic expression of the PVFZ scarp. The southwestern slope is fairly linear, about 1,700 feet (518 m) high, and steeply inclined at about 14 degrees. The slopes that form the northern, eastern, and southern sides of the Knoll are about 1,100 feet (335 m) high, and are less steeply inclined at about 3.5 to 5 degrees. Irregularities within the topographic contours are suggestive of possible wave-cut terraces (created during glacially-induced lower sea-level stands) and landsliding/slope instability.

Southeast of the San Pedro shelf and west of the continental shelf, from Newport Beach to La Jolla in the Gulf of Santa Catalina, the seafloor topography is varied, with small mounds oriented in northwest trends. Between the continental shelf and Crespi Knoll, the basin is rather flat with water depths greater than 2,600 feet (793 km).

6.4.2.2 Structure and Seismicity

Geologic structure and seismicity for the Project is addressed in Section 6.1.4, and is very similar to that of the AES Alternative. The PVFZ and NIFZ are the two structures that control the ground motions at the AES Alternative site. The THUMS-Huntington Beach fault is a blind structure located beneath the AES Alternative Project area. The faults affecting the site are summarized in the following section. A more complete description of faulting and seismicity is presented in Fugro (2006c) and in Section 6.1.4.

<u>Active Fault Zones</u>

There are three fault zones of primary concern along the AES Alternative pipeline route: the PVFZ, the THUMS-Huntington Beach fault Zone, and the NIFZ (Fugro 2006c).

Palos Verdes Fault (PVFZ)

The PVFZ and other offshore faults to the south form a nearly continuous fault zone that connects with the Agua Blanca fault south of Ensenada. In total, it extends over a mapped distance of approximately 270 miles (430 km), from Los Angeles southward into Baja California (Figure 6-37).

The PVFZ is a right-lateral strike-slip fault zone, with a minor component of oblique slip resulting from a restraining bend near the Palos Verdes Peninsula. The fault offsets Holocene sediments in the Port of Los Angeles, and is considered an active fault with a slip rate of 0.12 +/- 0.04 inch/yr (3 +/-1 mm/yr), based on offset of a dated ancestral channel of the Los Angeles River (McNeilan et al., 1996; Stephenson et al., 1995). A series of 13 uplifted marine terraces document the late Quaternary tectonic history of the Palos Verdes fault. The fault extends south from Santa Monica Bay across the NE portion of the Palos Verdes Peninsula, and across the San Pedro shelf to Lausen Knoll. The fault bifurcates around Lausen Knoll (Fisher et al., 2004), then continues south, connecting with the Coronado Banks fault in the inner borderland northwest of La Jolla.

A slip rate of 0.12 +/- 0.04 inch/yr (3 +/- 1 mm/yr) has been assigned to the PVFZ on the basis of discussions with Dr. Thomas Rockwell of San Diego State University, and Mr. Tom McNeilan of Fugro West, Inc.

THUMS-Huntington Beach Fault

The THUMS-Huntington Beach fault is a blind thrust that was only recently recognized as being an active seismic source. A blind thrust fault is a shallow-dipping reverse fault that does not reach the surface (SCEC 2006). When the fault moves, it may cause uplift but does not cause surface rupture. The existence of blind thrust faults in Southern California is problematic and potentially very damaging. The Elysian Park Thrust that lies beneath downtown Los Angeles and the Northridge Thrust fault, which caused the 1994 Northridge quake, are examples of blind thrust faults.

The THUMS-Huntington Beach fault extends for about 23 miles (37 km), from its intersection with the PVFZ southeast to where it intersects the NIFZ offshore Huntington Beach (**Figure 6-37**) (Wright 1991; Williams

2003). Davis and Namson (1992) believe the fault is a high-angle reverse fault, but recent interpretation of 3D seismic data suggests that the dip of the fault is about 38 degrees to the northeast (Williams 2003). Deposition of syntectonic Pliocene Repetto Formation strata and gentle folding of overlying early Pleistocene strata clearly demonstrate fault movement. Late Pleistocene reactivation of the structure has been documented by the USGS (Edwards et al. 2001), based on seismic and borehole data, as well as gentle surficial topographic relief. Early Holocene strata are gently folded, but late Holocene strata are flat-lying, suggesting that an earthquake event occurred on the fault in the early to mid-Holocene (Fugro 2006c).

Shaw (personal communication, 2003) suggests that the recurrence interval for this fault is several thousands of years, comparable with other blind thrusts beneath the Los Angeles Basin. Williams (2003) suggests a Holocene slip rate of about 1 mm/yr for this fault, but does not present data supporting this estimate.

Newport Inglewood Fault (NIFZ)

This fault is a right-lateral strike-slip fault located in the Los Angeles Basin (Figure 6-37). The NIFZ comprises a closely spaced system of northwest-trending active strike-slip and oblique-slip faults. Onshore, it is marked by a chain of low hills extending from the Santa Monica Mountains to Newport Beach. Based on historical seismicity and structural differences (SCECWG, 1995; Grant and Rockwell, 2002), some workers have segmented the fault into northern and southern segments. The southern section of this fault, which last ruptured in the Mw 6.4 Long Beach earthquake in 1933, is about 24 miles (38 km) long and runs parallel to the coast, then heads offshore at Newport Beach. The northern (Baldwin Hills) segment of the fault is about 17 miles (28 km) long and has not ruptured in historical time. The date of the most recent rupture is unknown. The combined length of the two segments is about 40 miles (66 km).

Historical earthquakes have been most common on the southern part of the onshore portion of the fault zone; most were aftershocks of the 1933 Mw 6.4 Long Beach Earthquake. Subsurface paleoseismic investigations of the fault zone in the vicinity of Newport Bay demonstrated evidence for three to five surface rupture events in the past 11,700 years (Grant et al., 1997). Paleoseismic data and historical seismicity indicate a sequential northward propagation of ruptures since about 1650 A.D. on a 300+ series of kinematically linked active faults extending from Baja California to Southern California (Grant and Rockwell, 2002). There is no evidence that the northernmost portion of the Newport-Inglewood fault has ruptured during this time. Slip rates for this fault are poorly constrained, and estimates vary from 0.004 inch/yr (0.1 mm/yr) to about 0.06 inch/yr (1.5 mm/yr) (Petersen and Wesnousky, 1994; SCECWG, 1995). The slip rate on the fault zone cannot be precisely estimated from available surface data because of the many uncertainties regarding interpreted offsets and ages of geomorphic features.

Offshore, the Newport-Inglewood and Rose Canyon faults form an approximately 125 mile- (200-km-) long fault zone extending from the Santa Monica Mountains in the north to San Diego Bay in the south. A wide stepover, south of San Diego, may transfer slip onto the Descanso fault, which extends as far south as the active Aqua Blanca fault south of Ensenada. The entire fault system is about 185 miles (300 km) long.

The offshore segment of the Newport-Inglewood fault extends from Newport Beach to near Carlsbad, where an approximately 3-mile (5-km) stepover exists between the Newport-Inglewood fault and the Rose Canyon fault. South of Mount Soledad in San Diego, the northwest-striking Rose Canyon fault appears to diverge into a series of north-south-striking faults referred to as the Silver Strand fault zone. The approximately 6-mile- (10-km-) wide stepover created by the Silver Strand fault zone occurs in the vicinity of San Diego Bay. South of the Silver Strand fault zone, the Descanso fault forms a nearshore zone of faulting that strikes northwest and extends from near the U.S./Mexican border southward to the Aqua Blanca fault on Punta Banda, near Ensenada. The 1933 Long Beach earthquake is thought to have occurred on the Newport-Inglewood fault in the vicinity of Newport Beach. Data from CGS (Cao et al., 2003) indicate that the offshore Newport-Inglewood fault also has a length of 40 miles (66 km) and a slip rate of 0.06 +/- 0.02 inch/yr (1.5 +/- 0.5 mm/yr). Data by Lindvall and Rockwell (1995) indicate that the Rose Canyon fault has a length of 44 miles (70 km) and a slip rate of 0.06 +/- 0.02 inch/yr (1.5 +/- 0.5 mm/yr). Ongoing research and GPS data suggest that the Rose Canyon fault may have a slightly higher slip rate, but conclusive results are not yet available. We assign the NIFZ a slip rate of 0.04 inch/yr (1 mm/yr) in the LA Basin.

6.4.2.3 Anticipated Conditions at the HDD for the AES Alternative

The AES HDD shore crossing, located in the Santa Ana Gap near Huntington Beach, would lie within the broad southern margin of the Los Angeles Basin (**Figures 6-43** and **6-44**). The southern margin of the Los Angeles Basin culminates abruptly with the NIFZ Uplift. This Uplift is characterized by broadly warped coastal mesas comprised of late Miocene to early Pleistocene marine sediments, overlain by late Pleistocene marine terrace deposits. The Newport-Inglewood Uplift formed as a result of movement on the active NIFZ. The nearest actively mapped fault splay of the NIFZ, the North Branch fault, lies approximately 2,500 feet (760 m) northeast of the HDD entry location (**Figure 6-43**).

The mesas of the Newport-Inglewood Uplift are cut by six gaps through which tongues of the lowland to the north extend to the coast. The Santa Ana Gap is incised in the late Pleistocene terrace surface, and is floored by alluvium of the ancestral Santa Ana River system of latest Pleistocene to earliest Holocene age.

Surficial deposits near the HDD entry location consist primarily of unconsolidated lagoonal and alluvial fan deposits of interbedded clay, silt, silty sand and, near the coast, of fine to medium sand overlain by late Holocene sand dune deposits and sandy beach deposits. Due to the alluvial and lenticular nature of the deposits, individual sediment layers within the unit may be of variable thickness and may not be laterally continuous. Within the Santa Ana Gap, a bed of peat ranging in thickness from a few inches to many feet (locally up to 50 feet [15 m]) has been observed (Poland et al., 1956). The stratigraphy of the area is discussed in greater detail in section 6.5.4.4 below.

6.4.2.4 Stratigraphy

At a depth of approximately 150 feet ((46 m) bgs near the coast, late Pleistocene deposits within the Santa Ana Gap include the San Pedro Formation. The San Pedro Formation overlies the late Pliocene Pico Formation (**Figure 6-44**). Within the Santa Ana Gap, the San Pedro Formation is between 125 and 275 feet (38 and 84 m) thick, and consists of equal proportions of sand, gravel, silt, and clay. Units range in thickness from a few feet to several tens of feet. Commonly, the sand and gravel layers are clean and well sorted, with gravel ranging in the pebble size. However, cobbles 3 to 4 inches (76 to 100 mm) in diameter are common. Silt and clay deposits are reported as gray-blue, brown, or green, and may contain fragments of carbonized wood along with layers of peat (Poland et al. 1956).

Overlying the San Pedro Formation, the stratigraphic base of the Holocene interval is related to the late Pleistocene rise in sea level. Elevated sea levels raised stream-base levels, which led to the deposition of fan sediments. This fluvial backfilling of incised drainages controlled the initial distribution of coarse-grained sediments, locally named the Talbert aquifer (Mendenhall 1905). The Talbert aquifer consists primarily of gravel with sand and cobbles up to 5 inches in diameter. The Talbert aquifer extends offshore and is up to 60 feet (18 m) thick (**Figure 6-44**), with its base approximately 150 feet (46 m) below sea level at the coast (Poland et al. 1956). Mid-Holocene to modern sediments overlie the Talbert aquifer.

The surface distribution of Holocene sediments, as recorded in early editions of regional soil survey maps (Eckmann and others 1919), suggests that the Santa Ana River has avulsed (wandered back and forth) across the Orange County coastal plain, from Alamitos Bay to Newport Bay, through geologic time. Historical accounts and documents further support the process of widespread sheet flooding being the dominant depositional process associated with the Santa Ana River, prior to the construction of Prado Dam in 1941 (California Department of Water Resources, 1959). Poland et al. (1956) report that prior to the flood of 1825, the Santa Ana River entered the ocean several miles to the northwest of its present channel, and infer that, prior to that date, the Santa Ana River discharged through Bolsa Gap. Topographic maps of the Anaheim and Downey quadrangles, surveyed in 1894, show that a former channel of the Santa Ana River passed to the north of Anaheim and continued westerly nearly to Los Alamitos. Floods passing down this channel occasionally discharged to the ocean through Alamitos and Sunset Gaps (Poland et al., 1956).

Offshore, the Holocene alluvial sediments interfinger with marine sediments consisting primarily of fine to medium sand nearshore, increasing in fines content further offshore. The subsurface geologic relationships offshore are poorly known (**Figure 6-44**).

6.4.2.5 Geologic Hazards

Strong Ground Motions

The Gulf of Santa Catalina and onshore Orange County are seismically active areas with the potential for seismically-generated strong ground motions. Fugro has separately conducted a PSHA for the Project (Fugro 2006c). Seismicity and the basis for the seismic source model are summarized in Sections 6.1.4 and 6.5.4.2 of this report.

The effects of earthquake-related ground displacement and strong ground motions are a significant regional geohazard. Strong ground motions and fault displacements are a lesser risk to floating offshore facilities, but a greater risk to onshore or fixed offshore facilities, like pipelines. Secondary hazards to offshore facilities that may result from strong ground motion or fault displacement include mass movement (slumps, landslides, debris flows, turbidity currents) and liquefaction that may affect fixed anchors and pipelines.

The historical earthquake record in Southern California dates back about 200 years. Several significant and/or damaging earthquakes have occurred within the study area during that time (**Table 6-2**). However, far-field earthquakes, or earthquakes with epicenters outside of the study area, have also caused damage within the study area. These events include the great Fort Tejon earthquake (approximately M_w 8.0) of 1857 that ruptured over 225 miles (360 km) of the San Andreas fault, the Long Beach earthquake (M_w 6.4) of 1933 that occurred on the Newport-Inglewood fault zone, the San Fernando earthquake (M_w 6.4) of 1971 that occurred on the San Fernando fault, the Whittier-Narrows earthquake (M_w 5.9) of 1987 that occurred on the Elysian Park fault, and the Northridge earthquake (M_w 6.7) of 1994 that occurred on a previously unmapped (or blind) thrust fault possibly related to the eastward projection of the Oakridge fault.

Earthquakes in the area (**Figure 6-37**) are directly related to the active tectonic setting of Southern California, where the Pacific plate is sliding northwestward relative to the North American tectonic plate along the San Andreas transform boundary. The overwhelming style of faulting in this province is right-lateral "strike-slip," where the ground displacement is generally parallel to the fault surface. The resulting earthquakes commonly have right-lateral, strike-slip focal mechanisms.

Figure 6-41 shows Fugro's estimates of ground accelerations and fault hazards for the proposed alternative facilities. For the Deepwater Port area, these data suggest that there is a 2 percent chance, in 50 years, that there will be ground shaking of greater than 0.7 times the acceleration of gravity (70 percent g). Along the proposed alternative pipeline route, values range from approximately 0.6 to 0.8 times the acceleration of gravity. See Fugro's PSHA for site-specific estimates of seismicity and ground motions for OceanWay Secure Energy facilities (Fugro 2006c).

Surface Fault Rupture

As discussed in section 6.1.7.1, ground surface displacement, or rupture, caused by an earthquake is a major design consideration for onshore and offshore pipelines that cross faults. Southern California is structurally complex and seismically active. The State of California defines a fault as historically active if it has generated earthquakes, accompanied by surface rupture, in the last approximately 200 years. Any fault that shows evidence of surface displacement in the last 11,000 years (Holocene time) is considered active (Hart and Bryant 1997). The State of California has mapped known faults in inhabited areas onshore as part of the Alquist-Priolo Earthquake Fault Zoning Act (www.consrv.ca.gov/CGS/rghm/ap/). Faults of concern include those that are known to be active or potentially active and are capable of surface rupture. However, while individual, localized, high-resolution studies may provide information about some offshore faults (for example, Goldfinger et al. 2000; Marlow et al. 2000), there is no comprehensive source of information regarding submarine faults.

A fault Displacement Hazard Analysis, addressing the active faults that the AES Alternative pipeline route would cross, has not been performed for the AES Alternative. The offshore active PVFZ and potentially active THUMS-Huntington Beach faults would be crossed by the proposed pipeline from the DWP to shore. These faults have been described in section 6.5.4.2. Onshore, the AES Alternative pipeline route would cross active, potentially active, and inactive splays of the NIFZ (**Figure 6-47**), described in section 6.5.4.2. The proposed onshore pipeline route would also cross (according to Bryant 2005): the active North Branch and Indianapolis splays of the NIFZ; the potentially active South Branch, Adams Avenue fault, and Bolsa-Fairview fault splays of the NIFZ; and three additional inactive, unnamed splays of the NIFZ (**Figure 6-47**). As seen on **Figure 6-46**, only the North Branch fault has been zoned by the State as an Alquist-Priolo special study zone.

Liquefaction/Lateral Spreading

According to the seismic hazard zone maps of the Newport Beach, Tustin, Anaheim and Orange quadrangles, the HDD entry location and approximately 13 miles of the proposed onshore pipeline route would be located within a liquefaction hazard zone (**Figure 6-46**). CGS (formerly CDMG) defines a liquefaction hazard zone as an area where historic occurrence of liquefaction, or local geological, geotechnical, and ground water conditions indicate a potential for permanent ground displacements as a direct result of liquefaction.

Mass Movement: Slumps, Slides, Debris Flows, Turbidity Currents

Sediment transport and mass movement are discussed in section 6.1.7.4 of this report. For the AES Alternative, the offshore pipeline would cross the continental shelf prior to traversing the continental slope. While the anticipated seafloor conditions on the shelf are stable, there is the possibility for seafloor instability on the slope within the Newport Trough, between the San Gabriel and Newport canyons. Kennedy et al., 1987 has mapped areas of slumps, block glides, creep, and sediment flow within the study area north and to the east of Lausen Knoll (**Figure 6-40**).

The alternative onshore route would cross the base of Las Bolsas Mesa along Newland Street where, according to CGS, there may be a potential for permanent ground displacement along the base of the slope (**Figure 6-46**).

Volcanism

There are no active volcanoes, seamounts, volcanic vents or rifts in the region.

Tsunami

Tsunamis and tsunami sources are discussed in section 6.1.7.6 of this report. For the AES Alternative study area, tsunami run-up maps were obtained from the Orange County Sheriff's Department. The tsunami hazard map is presented in **Figure 6-45**. The figure shows tsunami run-up impact areas produced by the California Office of Emergency Services (OES) and the City of Huntington Beach. Discussions with the Orange County Sheriff's Department and the City of Huntington Beach reveal that the OES 33-ft (10-m) impact zone shown on the map lies below the 33-ft (10-m) elevation contour. Therefore, the City of Huntington Beach has undertaken its own, more detailed, tsunami impact mapping, which shows zones of 0 to 15, 0 to 25, and 0 to 50 feet (0 to 4.5, 0 to 7.6, and 0 to 15 m) elevation possible run-up impact areas. The AES Alternative HDD entry location would lie outside of the OES 33-ft (10-m) run-up impact area; however, it would lie within the 0 to 15 feet (0 to 4.5 m) elevation possible run-up impact area as mapped by the City of Huntington Beach.

Shallow Gas, Oil and Gas Seeps, Methane Hydrates

Shallow gas, oil and gas seeps, and methane hydrates are discussed in section 6.1.7.7 of this report. **Figure 6-42** shows the natural oil and gas seeps within San Pedro Bay and the AES Alternative study area. One gas seep is located just offshore of Huntington Beach, approximately 3.6 miles (6 km) from the AES Alternative, and is likely associated with the NIFZ. Another oil/gas seep is located approximately 5.5 miles (9 km) to the west of the AES Alternative, at the head of San Gabriel Canyon, and is likely associated with the Palos Verdes fault Zone.

River and Stream Crossings and Flood Hazards

The proposed AES route would cross several stream channels, including the East Garden Grove Channel, Winterberg Channel, Huntington Channel, Santa Ana River, and Santiago Creek. Approximately 9.5 miles (15 km) of the onshore pipeline areas would lie within the FEMA 100-year flood zone.

6.4.2.6 Mineral Resources

The alternative offshore route would not cross active oil and gas production areas or areas of identified oil seeps. There are no active leases along the alternative pipeline route (MMS 2006). The proposed offshore pipeline route is about 7 miles (11 km) from the oil production infrastructure of the Beta Field. The AES alternative onshore route would cross the active West Newport and Huntington Beach oil fields. Both fields are active producers (CDOGG 2004, 2006).

Review of aerial photographs indicates that there are no active quarries or mines along the AES Alternative route. The areas crossed are entirely residential-commercial in nature.

6.4.2.7 Unique Geologic or Paleontological Resources

A site-specific paleontology investigation has not been conducted of the offshore areas. However, identification and/or recovery of unique geologic features or fossils from the sea floor are not routinely performed.

A site-specific paleontology investigation has not been conducted of the alternative onshore pipeline route, which would cross highly urbanized ground with mostly disturbed areas. The potential to encounter unique geologic or paleontologic resources would be recognized along the onshore pipeline route. However, because the onshore route would cross urbanized areas with little or no original surface remaining, and because the effect of the pipeline construction would be confined to roadways or utility easements, there is a low probability that scientifically important geologic features or fossils would be found within the excavation for pipeline placement.

6.4.2.8 Impacts Analysis and Conservation Measures

Impacts Analysis and Conservation Measures – Offshore

Geologic impacts associated with the construction and operation of the DWP and offshore pipelines at the AES alternative location would be similar to those described for the proposed Project location. Offshore impacts would be similar because the geology and seismology at the two sites are not significantly different. The potential for mass movement on the slope for the AES Alternative is considered greater than for the Project. Nearshore, impacts would be very similar. Implementation of conservation measures similar to those called out for the proposed Project would be expected to similarly reduce potential impacts for the AES alternative.

Impacts Analysis and Conservation Measures – Onshore

Impacts associated with the construction and operation of the AES alternative onshore pipeline would be similar to those described for the proposed Project. The multiple stream crossings of the AES alternative would present additional flood impacts that are not as extensive for the proposed Project. Implementation of conservation measures similar to those called out for the proposed Project would be expected to similarly reduce potential impacts for the AES alternative.

6.4.3 LAX South Shore Crossing Alternative

The LAX south shore crossing would involve a more southerly route for the offshore pipelines, and offshore and onshore HDD entry points approximately a mile (1.6 km) and 1.2 miles (1.9 km) respectively, south of the proposed routing. (**Figures 6-31** through **6-35a through c**).

The bathymetry, geology, and seismicity (**Figure 6-36**) along the LAX South Alternative are similar to those for the Project. **Figure 6-31** shows bathymetry for the LAX South Alternative, and **Figure 6-32** shows the offshore geology on the route. This alternative crosses upper slope channels and Inner Shelf areas where relict Late Quaternary gravels may be exposed at the seafloor (**Figures 6-33** and **6-14**). The upper slope channels are approximately 200 to 500 feet (60 to 150 m) wide and 10 to 20 feet (3 to 6 m) deep. Given that relict fluvial gravels deposited during the last low sea-level stand 18,000 years ago are exposed at the seafloor, it is likely that active nearbottom metocean currents have resulted in non-deposition or erosion of the seafloor in this area.

From a geological resources perspective, the environmental setting associated with this alternative route is slightly different from that of the proposed route. The southern route alternative crosses potential hardbottom areas offshore, on the inner shelf and near the shelfbreak (**Figure 6-14** and **6-16**), where sand and gravel are exposed on the seafloor. Thus, impacts to potential hardbottom communities, and to sand and gravel geologic resources, may occur should the LAX South shore crossing alternative be pursued.

6.4.4 Onshore Pipeline Alternatives

From the onshore end of the HDD pipeline segment there are multiple alternative routes to the identified tie-in point with SCG's Line 765 near the intersection of Otis and Santa Ana in South Gate. The alternative onshore pipeline routes do not encounter substantially different geological conditions from the proposed route. Impacts associated with these pipeline route alternatives would be similar to those associated with the proposed pipeline route, and the conservation measures presented above would be applicable.

The LAX South shore crossing option connects onshore with the proposed pipeline route 1 that crosses near the Hyperion, El Segundo, and Potrero oil fields (**Figure 6-28**). The Hyperion Field is abandoned, and El Segundo was active as of 2004.

6.4.5 Alternative Vaporization Technologies

Submerged Combustion Vaporization (SCV) is a commonly used technology for regasification of LNG and heating of natural gas for LNG projects. There would be no geologic impacts from the use of an alternative vaporization technology versus the proposed air vaporization system.

6.4.6 Burying of Pipeline on the Ocean Floor

Under this alternative, one or more sections of the offshore pipeline would be buried where conflicts with the fishing industry might occur as a result of the pipeline installation or operation. As currently proposed, the offshore pipelines will be concrete-coated steel pipelines placed directly on the sea floor. It is expected that these pipelines will settle somewhat due to their weight such that, eventually, they will be at least partially buried beneath the sea floor.

The standard of practice for the installation of pipelines in California nearshore waters is to not bury them. Buried pipelines are subject, as surface-laid pipelines are not, to shear forces in the event of ground movement. If Woodside were required to bury the pipelines offshore, the following impact could occur.

Impact

Alt-GEO-20: Offshore Pipeline Rupture from Geologic Activities Exceeding Design of Pipeline Due to Burial

Burial of offshore pipelines would increase the risk of rupture resulting from significant geologic events.

It is possible that during the lifetime of the Project, one or more significant geologic events will occur that have the potential to exceed the design limits of the pipeline because it was buried. This may cause a pipeline rupture.

Conservation Measure

CM-Alt-GEO-20: Do not actively bury the pipeline offshore except where other safety concerns outweigh the issues of pipeline burial.

6.4.7 Alternative RCTS Location

The alternative RCTS site would be constructed and operated between Belford Avenue and Airport south of 93rd Street, approximately two blocks west of the proposed site. Geologic impacts associated with the construction and operation of the RCTS at the alternative location would be similar to those described for the proposed Project location.

6.4.8 Open Trenching Alternative for Dunes Crossing

The dual 24 inch (600 mm) pipelines would be installed across the coastal dunes between the HDD work area and just east of Pershing Drive using open trenching. Soil disturbance during open trenching for the onshore pipeline burial could destabilize the soil and result in soil erosion. This alternative would result in increased potential for soil erosion compared to the proposed Project. However, this impact would be minimal with the implementation of best management practices as a conservation measure consistent with those outlined for the proposed Project.

6.4.9 Active Backfilling Alternative for Shore Crossing HDD Material

The dredge material that will be removed from the shore crossing HDD receiving pit would be actively returned into the excavation under this alternative. The trench would be backfilled with the sidecast dredged material using a reverse of the dredging operation. The backfilling operation is anticipated to take approximately 60 days to complete, about the same amount of time as the original dredging and sidecasting. Backfilling the trench would restore the dredge site to close to pre-dredging bathymetry. However, some surface relief would be created in the temporary staging area from clamshell incisions and bulking of the material during dredging is likely to create a small mound at either the dredging site or temporary staging area, at least until the material consolidates. Backfilling would necessitate deployment of vessels and dredging equipment for approximately an additional two months, resulting in a doubling of the length of deployment time compared to natural infilling. This deployment would result in approximately doubled turbidity impacts compared with the proposed Project. However, the turbidity impacts of backfilling are expected to be minimal and less than those created during excavation since the dredge material is coarse-grained and many of the finer materials would have been removed during the original dredging activity.

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TABLES

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources

Fault Zone	Fault Type	Probability	Rupture Length (km)	Down-dip Length (km)	Dip (degrees)	Slip Rate (mm/y)	M_W
ONSHORE-OFFSHORE CHANNEL FAULTS							
DUME-SANTA MONICA SYSTEM							
DUME FAULT (D) Segment A	Oblique	0.65	10	20	45	2.0	6.30
DUME FAULT (D) Segment B	Oblique	0.33	34	20	45	2.0	6.85
DUME-HUENEME SEGMENT D(H)	Blind Thrust	0.18	50	20	45	1.0	7.00
Combined rupture of D(A) + D(B) segments	Oblique	0.25	44	20	45	2.0	6.95
Combined rupture of D(B) + SANTA MONICA FAULT (SM) segments	Oblique	0.20	63	20	45	2.0	7.10
Combined rupture of D(H) + D(B) segments	Oblique	0.08	84	20	45	2.0	7.25
Combined rupture of D(A) + D(B) + SM segments	Oblique	0.10	73	20	45	2.0	7.20
Combined rupture of D(H) +D(B) + SM segments	Oblique	0.04	112	20	45	2.0	7.35
MALIBU COAST FAULT	Oblique	0.90	106	13	75	1.0	7.15
Combined rupture of MALIBU COAST + SANTA CRUZ ISLAND segments	Oblique	0.10	144	13	75	1.0	7.25
COASTAL FAULTS							
PALOS VERDES (Onshore-Offshore)							
North segment alone	Strike-slip	0.50	29	13	70	1.5	6.60
South segment alone	Strike-slip	0.50	67	13	70	3.0	7.00
Combined rupture of North + South segments	Strike-slip	0.50	96	13	70	3.0	7.30

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)

Fault Zone	Fault Type	Probability	Rupture Length (km)	Down-dip Length (km)	Dip (degrees)	Slip Rate (mm/y)	M_W
COASTAL FAULT							
REDONDO CANYON FAULT	Dip-slip	1.00	15	18	45	1.5	6.50
COMPTON STRUCTURE							
Segment A alone	Blind Thrust	0.16	18	13	25	0.2	6.40
Segment B alone	Blind Thrust	0.10	40	13	25	0.2	6.75
Segment C alone	Blind Thrust	0.16	21	13	25	0.2	6.45
Combined rupture of A + B segments	Blind Thrust	0.06	58	13	25	0.2	6.90
Combined rupture of B + C segments	Blind Thrust	0.06	61	13	25	0.2	6.90
Combined rupture of A + B + C segments	Blind Thrust	0.03	79	15	25	0.2	7.00
SAN PEDRO ESCARPMENT	Blind Thrust	0.25	33	13	25	0.2	6.65
OAK RIDGE (Onshore)	Dip-slip	1.00	49	14	65	4.0	7.00
OAK RIDGE MID CHANNEL STRUCTURE (MONTALVO-OAK RIDGE TREND)	Blind Thrust	0.25	63	10	70	1.0	6.80
VENTURA-PITA POINT	Oblique	1.00	72	13	75	1.0	7.00
SAN CAYETANO FAULT	Dip-slip	1.00	42	15	60	6.0	7.00
M. RIDGE-ARROYO PARIDA-SANTA ANA	Dip-slip	1.00	69	15	60	0.4	7.20
OFFSHORE NEWPORT-INGLEWOOD FAULT ALONE	Strike-slip	1.00	66	13	90	1.55	7.10
ROSE CANYON ALONE	Strike-slip	1.00	70	13	90	1.55	7.20
THUMS-HUNTINGTON BEACH	Oblique	1.00	37	17	37	1.0	7.00

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)							
Fault Zone	**Fault Type**	**Probability**	**Rupture Length (km)**	**Down-dip Length (km)**	**Dip (degrees)**	**Slip Rate (mm/y)**	**M_W**
OFFSHORE FAULTS							
SANTA MONICA BAY FAULT	Blind Thrust	0.50	44	19.8	20	1.0	6.95
ANACAPA FAULT	Dip-slip	1.0	20	19.8	45	1.0	6.60
SANTA CRUZ-CATALINA RIDGE FAULT							
North segment Alone	Strike-slip	0.80	58	15	90	4.0	6.95
South segment alone	Strike-slip	0.40	53	15	90	1.0	6.90
Combined rupture of North + South segments	Strike-slip	0.20	111	15	90	1.0	7.20
SANTA CATALINA (ESCARPMENT)							
North segment alone	Strike-slip	0.40	77	15	70	1.0+/-0.5	7.05
South segment alone	Strike-slip	0.40	27	15	70	1.0+/-0.5	6.60
Combined rupture of North + South segments	Strike-slip	0.10	104	15	70	1.0	7.25
SAN PEDRO BASIN FAULT	Strike-slip						
North (A) segment alone	Strike-slip	0.425	20	15	90	2.0	6.50
North (B) segment alone	Strike-slip	0.425	19	15	90	1.0	6.50
Central (C) segment alone	Strike-slip	0.25	60	15	90	1.0	6.95
Southern (S) segment alone	Strike-slip	0.35	62	15	90	1.0	7.00
Combined rupture of N(A) + C segments	Strike-slip	0.05	80	15	90	1.0	7.10
Combined rupture of N(B) + C segments	Strike-slip	0.05	79	15	90	1.0	7.10
Combined rupture of C + S segments	Strike-slip	0.10	122	15	90	1.0	7.25
Combined rupture of N(A) + C +S segments	Strike-slip	0.025	142	15	90	1.0	7.30
Combined rupture of N(B) + C + S segments	Strike-slip	0.025	141	15	90	1.0	7.30

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)							
Fault Zone	**Fault Type**	**Probability**	**Rupture Length (km)**	**Down-dip Length (km)**	**Dip (degrees)**	**Slip Rate (mm/y)**	**M_W**
Avalon Knoll segment alone	Strike-slip	0.50	15	15	90	1.0	6.40
SAN CLEMENTE FAULT							
Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)							
OFFSHORE FAULTS - CONTINUED							
Pilgrim Banks (PB) segment alone	Strike-slip	0.90	76	15	90	1.0	7.05
Segment A alone	Strike-slip	0.75	41	15	90	3.0	6.80
Segment B alone	Strike-slip	0.45	114	15	90	4.0	7.20
Segment C alone	Strike-slip	0.75	93	15	90	4.0	7.15
Combined rupture of PB + B segments	Strike-slip	0.10	190	15	90	1.0	7.45
Combined rupture of A + B segments	Strike-slip	0.20	155	15	90	4.0	7.35
Combined rupture of B + C segments	Strike-slip	0.20	207	15	90	4.0	7.50
Combined rupture of A + B + C segments	Strike-slip	0.05	248	15	90	4.0	7.55
OAK RIDGE (Blind Thrust Offshore)	Blind Thrust	0.25	33	20	30	3.0	6.85
NORTH CHANNEL SLOPE FAULT	Dip-slip	0.50	68	23	26	2.0	7.40
CORONADO BANKS FAULT (Offshore)							
North segment alone	Strike-slip	0.50	115	13	90	3	7.30
South segment alone	Strike-slip	0.50	70	13	90	3	7.10
Combined rupture of North + South segments	Strike-slip	0.50	185	13	90	3	7.60
SAN DIEGO TROUGH FAULT							
North (N) segment alone	Strike-slip	0.70	74	12	90	2.0	6.95
Central (C) segment alone	Strike-slip	0.50	50	12	90	2.0	6.80
South (S) segment alone	Strike-slip	0.70	65	12	90	2.0	6.90

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)							
Fault Zone	**Fault Type**	**Probability**	**Rupture Length (km)**	**Down-dip Length (km)**	**Dip (degrees)**	**Slip Rate (mm/y)**	**M_W**
Combined rupture of N + C segments	Strike-slip	0.20	124	12	90	2.0	7.15
Combined rupture of C + S segments	Strike-slip	0.20	115	12	90	2.0	7.15
Combined rupture of N + C + S segments	Strike-slip	0.10	189	12	90	2.0	7.35
SANTA CRUZ BASIN FAULTS	Strike-slip	0.50	52	15	90	1.0	6.90
CORTEZ BANKS FAULTS	Strike-slip	0.50	18	15	90	1.0	6.50
ISLAND FAULTS							
CHANNEL ISLAND THRUST (EASTERN)	Blind Thrust	0.50	63	34	15	1.5	7.50
SANTA CRUZ ISLAND FAULT	Oblique	0.90	50	13	70	1.0	7.00
SANTA ROSA ISLAND FAULT	Oblique	1.00	57	13	90	1.0	7.10
INLAND FAULTS							
SANTA MONICA FAULT	Oblique	0.66	28	13	75	2.0	6.60
HOLLYWOOD FAULT	Oblique	1.00	17	14	70	1.0	6.40
RAYMOND FAULT	Oblique	1.00	23	13	75	1.5	6.50
SIMI-SANTA ROSA FAULT	Oblique	1.00	40	15	60	1.0	7.00
RED MOUNTAIN FAULT	Dip-slip	1.00	66	15	60	2.0	7.00
SANTA MONICA MOUNTAINS THRUST	Blind Thrust	0.50	90	23.4	20	0.4	7.30
SANTA SUSANA FAULT	Dip-slip	1.00	27	16	55	5.0	6.70
NEWPORT-INGLEWOOD (L.A.Basin)	Strike-slip	1.00	66	13	90	1.0	7.10
NORTHRIDGE (E. Oak Ridge)	Dip-slip	1.00	31	22	42	1.5	7.00
SAN JOSE FAULT	Oblique	1.00	20	13	75	0.5	6.40
SIERRA MADRE FAULT	Reverse	1.00	57	18	45	2.0	7.20
SIERRA MADRE (San Fernando)	Reverse	1.00	18	18	45	2.0	6.70

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)							
Fault Zone	**Fault Type**	**Probability**	**Rupture Length (km)**	**Down-dip Length (km)**	**Dip (degrees)**	**Slip Rate (mm/y)**	**M_W**
HOLSER FAULT	Reverse	1.00	20	14	65	0.4	6.50
CUCAMONGA FAULT	Reverse	1.00	28	18	45	5.0	6.90
SANTA YNEZ FAULT (East)	Strike-slip	1.00	68	13	80	2.0	7.10
VERDUGO FAULT	Reverse	1.00	29	18	45	0.5	6.90
SAN GABRIEL FAULT	Strike-slip	1.00	72	13	90	1.0	7.20
PUENTE HILLS BLIND THRUST	Reverse	1.00	44	19	25	0.7	7.10
INLAND FAULTS – CONTINUED							
UPPER ELYSIAN PARK BLIND THRUST	Reverse	0.50	20	13	50	1.3	6.40
BIG PINE FAULT	--	1.00	41	13	90	0.8	6.90
SAN JOAQUIN HILLS BLIND THRUST	Blind Thrust	0.50	28	15	23	0.5	6.60
CHINO-CENTRAL AVE. FAULT (Elsinore Fault Zone)	Oblique	1.00	28	17	65	3	6.70
WHITTIER+GLEN IVY+TEMECULA FAULTS							
Whittier (W) fault alone	Strike-slip	0.70	38	15	90	2.5	6.80
Glen Ivy (GI) segment alone	Strike-slip	0.50	36	15	90	5	6.80
Temecula (T) segment alone	Strike-slip	0.70	43	15	90	5	6.80
Combined rupture of W + GI segments	Strike-slip	0.20	74	15	90	2.5	7.10
Combined rupture of GI +T segments	Strike-slip	0.20	79	15	90	5	7.10
Combined rupture of W + GI + T segments	Strike-slip	0.10	117	15	90	5	7.30
SAN JACINTO-IMPERIAL FAULT ZONE: NORTHERN THREE SEGMENTS							
San Bernardino (SB) segment alone	Strike-slip	0.70	36	15	90	12	6.70
San Jacinto Valley (SVJ) segment	Strike-slip	0.70	43	18	90	12	6.90

Table 6-1 Estimated Characteristics of Potential Seismogenic Sources (Cont'd)

Fault Zone	Fault Type	Probability	Rupture Length (km)	Down-dip Length (km)	Dip (degrees)	Slip Rate (mm/y)	M_W
Alone							
Combined rupture of SB + SJV Segments	Strike-slip	0.20	79+/-8	15	90	12	7.10
Combined rupture of SB + SJV + Anza segments	Strike-slip	0.10	170	15	90	12	7.40
SAN ANDREAS-SAN BERNARDINO SEGMENT	Strike-slip	1.00	103	18	90	24	7.50
SAN ANDREAS-MOJAVE SEGMENT	Strike-slip	1.00	103	12	90	30	7.40
SAN ANDREAS-COACHELLA VALLEY SEGMENT	Strike-slip	1.00	96	12	90	25	7.20

Table 6-2 Damaging historical earthquakes offshore Southern California

Date	Earthquake and/or Fault Name	Location	Magnitude
29 June 1925	fault unknown	12 km southwest of Santa Barbara	ML 6.3
4 November 1927	Lompoc earthquake, Santa Lucia (?) fault	25 km southwest of Point Arguello	ML 7.3
13 August 1978	fault unknown	1 km southeast of Santa Barbara	ML 5.1
30 June 1941	fault unknown	10 km ESE of Santa Barbara, 7 km WSW of Carpinteria	ML 5.5
21 February 1973	Point Mugu earthquake, Malibu Coast fault	14 km southwest of Oxnard, 64 km west of Los Angeles	Mw 5.3
1 January 1979	Malibu earthquake, fault unknown	13 km south of Malibu, 37 km west of Los Angeles	ML 5.2
8 January 1989	Malibu earthquake, fault unknown	16 km south of Malibu, 32 km WSW of Los Angeles	ML 5.0
21 October 1941	Torrance - Gardenia earthquakes, fault unknown	Onshore, east of Carson, near the present-day interchange of the 405 and 710 freeways	ML 4.8
14 November 1941	Torrance - Gardenia earthquakes, fault unknown	Onshore, near Wilmington	ML 4.8
10 March 1933	Long Beach earthquake, NIFZ	5 km south of present-day Huntington Beach	Mw 6.4
7 April 1989	Newport Beach earthquake, fault unknown	Onshore, directly below the town of Newport Beach	ML 4.7
13 July 1986	Oceanside earthquake, San Diego Trough fault zone	51 km WSW of the city of Oceanside, 55 km NW of San Diego	ML 5.4

Key:

km = kilometer; ML = local magnitude; Mw =moment magnitude; NE = Northeast; SW = Southwest; NIFZ = Newport-Inglewood fault Zone.

Sources: Fugro 2006; SCEC (www.data.scec.org/index.htm); and Astiz and Shearer 2000.

Table 6-3 Exceedance Probabilities for Different Return Periods at DWP

Return Period (years)	Design Life (years)	Probability of Exceedance (%)	Design Life (years)	Probability of Exceedance (%)
200	25	11.8	50	22.1
475	25	5.1	50	10.0
975	25	2.5	50	5.0
2475	25	1.0	50	2.0
4975	50	0.5	50	1.0

Table 6-4 Estimated Fault Surface Displacements

Fault[1] Crossing	Fault Zone	Fault Rupture Length (km)	Average Displace ment (meters) [3]	Maximum Displacement (meters)[2, 3]	Estimated Fault Dip	Style	Mw	Average Estimated Ratio of Horizontal to Vertical Slip[3]
1	***Palos Verdes North***	***29***	***0.7***	***1.3***	***60° - 90°***	***Strike-slip***	***6.6***	***5:1 to 10:1***
1	Palos Verdes North + South	96	2.1	4.4	60° - 90°	Strike-slip	7.3	***5:1 to 10:1***
2	San Pedro Basin North A	20	0.5	0.9	60° - 90°	Oblique: right-lateral reverse	6.5	2:1 to 5:1
2	***San Pedro Basin North A + Central***	***80***	***1.8***	***3.6***	***60° - 90°***	***Oblique: right-lateral reverse***	***7.1***	***2:1 to 5:1***
2	San Pedro Basin North A + Central + South	142	2.9	6.5	60° - 90°	Oblique: right-lateral reverse	7.3	2:1 to 5:1
3	San Pedro Basin North B1	6.2	0.2	0.3	60° - 90°	Oblique: right-lateral reverse	6.0	2:1 to 5:1
3	***San Pedro Basin North B1 + Central***	***79***	***1.7***	***3.6***	***60° - 90°***	***Oblique: right-lateral reverse***	***7.1***	***2:1 to 5:1***
3	San Pedro Basin North B1 + Central + South	141	2.9	6.5	60° - 90°	Oblique: right-lateral reverse	7.3	2:1 to 5:1
4	San Pedro Basin North B2	14.6	0.4	0.6	60° - 90°	Oblique: right-lateral revserse	6.35	2:1 to 5:1
4	***San Pedro Basin North B2 + Central***	***79***	***1.7***	***3.6***	***60° - 90°***	***Oblique: right-lateral revserse***	***7.1***	***2:1 to 5:1***
4	San Pedro Basin North B2 + Central+ South	141	2.9	6.5	60° - 90°	Oblique: right-lateral revserse	7.3	2:1 to 5:1

Notes:

a. Refer to Fugro 2006c for fault crossing locations.

b. The average and maximum surface displacement values are calculated from equations relating fault length and magnitude to surface rupture presented in Wells and Coppersmith (1994).

These maximum displacement values represent conservative displacement estimates for fault crossings near the end of strike slip fault rupture segments. Detailed studies of slip distribution along fault rupture segments from the 1940 Ms 7.1 and 1979 Ml 6.6 Imperial Valley earthquakes on the Imperial fault; 1992 Mw 7.3 Landers earthquake on Camp Rock and Emerson faults; 1987 Mw 6.6 Superstition Hills earthquake on the Superstition Hills fault; and 1931 Mw 8.0 Great China earthquake that the magnitude of slip decreased towards the ends of fault rupture segments. Observed slip near the ends of the fault rupture segments range from 10 percent to 50 percent of the maximum observed displacement. The proposed pipeline fault crossings are located near the ends of the Palos Verdes and San Pedro Basin faults. Therefore, it is probable that fault surface rupture displacements at the proposed fault crossings will likely be less than the maximum estimated displacement. Moreover, these estimates of surface displacements will be refined after site-specific high-resolution geophysical data are completed. These data will be interpreted to better locate faults, and to evaluate fault geometry, activity, and surface or shallow subsurface fault displacements.

Table 6-5 Damaging Tsunamis in Southern California

Date	Source Location	Source	Damage Location	Run-up	Comment
December 21, 1812	Southern California	Earthquake, Landslide	El Refugio	11 feet (?) (3.4m (?))	Anchored ship drifted up canyon
August 31, 1930*	Southern California	Earthquake, Landslide (?), unusual wave activity	Santa Monica	20 feet (6.1m)	1 fatality, 16 rescued, boat/pier damage
April 1, 1946	Aleutian Islands	Landslide (triggered by earthquake)	Avila	4.2 feet (1.3m)	A small island submerged, boats sank
			Catalina Island	6.0 (1.8m)	Small pier washed away
			Port Hueneme	2.6 feet (0.8m)	Sand deposited on railroad track
			San Luis Obispo	3.9 feet (1.2m)	Tanker torn from mooring lines
			San Pedro	1.3 feet (0.4m)	Tender and 2 cargo ships broke lines
			Santa Cruz	4.9 feet (1.5m)	1 fatality (drowned)
November 4, 1952	Kamchatka Peninsula	Earthquake	Santa Cruz	Observed	Boat damaged, sand washed away
March 9, 1957	Central Aleutian Islands	Earthquake	La Jolla	0.9 feet (0.3m)	Minor damage
			San Diego	0.7 feet (0.2m)	US$5,000 damage, wall of water 1 m high reported at Shelter Island.

Table 6-5 Damaging Tsunamis in Southern California (Cont'd)

Date	Source Location	Source	Damage Location	Run-up	Comment
May 22, 1960	South Central Chile	Earthquake	Pismo Beach	4.6 feet (1.4m)	Concession stand dislocated
			Santa Barbara	4.6 feet (1.4m)	US$20,000 damage
			Port Hueneme	4.2 feet (1.3m)	Dock damaged, boats broke mooring
			Santa Barbara	4.6 feet (1.4m)	US$20,000 damage
			Santa Monica	5.2 feet (1.6m)	Boats broke moorings
			Long Beach	0.7 feet (0.2m)	US$500,000 to 1,000,000 damage
			Los Angeles	2.6 feet (0.8m)	1 drowned, 1 injured
			San Diego	2.3 feet (0.7m)	80 m of dock destroyed, bridge damaged, barge sunk, 8 slips destroyed
October 13, 1963	Kuril Island	Earthquake	Avila	0.9 feet (0.3m)	Fishing boat broke mooring
March 28,1964	Gulf of Alaska	Earthquake	Avila	5.2 feet (1.6m)	US$2,000 damage, boats broke moorings
			Long Beach	Observed	US$100,000 damage, 8 docks destroyed
			Los Angeles	1.6 feet (0.5m)	US$200,000 damage
			Morro Bay	Observed	US$10,000 damage, fuel dock lost
			Santa Catalina	Observed	Minor damage
November 29, 1975	Hawaii	Earthquake	Santa Catalina	4.6 feet (1.4m)	US$1,000 damage to 2 docks
November 4, 2000*	Point Arguello	Landslide (?) or rogue wave	Point Arguello	16.4 feet (5.0m)	Sank 17 m vessel nearshore.
Source: Lander et al., 1993. *No confirmed tsunami wave data.					

Table 6-6 Geologic and geotechnical conditions and constraints

Geoscience Constraint / Condition	Areas Affected*	Status	Mitigation Measures	Studies
Soft Soils Conditions	Santa Monica Basin, Lower Slope Apron, and Slope	Geotechnical Testing and Study in progress	Pipeline and PLEM Design	Offshore geotechnical studies (CPTs, Borings, Vibrocores, Drop Cores, box cores) Offshore geophysical studies (sidescan sonar, multibeam backscatter data, high-resolution subbottom profiles) completed. Data Analysis in progress.
Loose Soils Conditions	Shelfbreak, Outer Shelf, Inner Shelf, Nearshore, Beach, Onshore and Offshore HDD (Aeolian sand dune and relict nearshore/beach deposits)	Geotechnical Testing and Studies in progress	Pipeline and HDD Design	Offshore geotechnical studies (CPTs, Borings, Vibrocores, Drop Cores, box cores) Offshore geophysical studies (sidescan sonar, multibeam backscatter data, high-resolution subbottom profiles) Onshore geotechnical studies (CPTs, Borings) for HDD design
Seismicity, strong ground motions, Liquefaction, Lateral Spreading	All Areas	Preliminary PSHA completed. Update PSHA based on seismic surveys for Final Facility Design	Shore facility design Pipeline design PLEM and DEEP WATER PORT mooring anchor design	Marine geophysical surveys, data acquisition, and interpretation Geotechnical sampling and evaluation of soils Liquefaction Study/Analysis
Active faults, surface fault displacement/ground rupture	San Pedro Basin fault zone crossing at base of Santa Monica slope, Palos Verdes fault zone crossing (?) on Santa Monica Bay shelf.	Project Desktop Study and PSHA completed. Update for final design	Route pipeline around active fault traces, if possible Optimally orient pipeline to withstand displacement Pipeline design at fault crossings.	Marine survey data interpretation, fault mapping and characterization Final fault displacement hazard study

Table 6-6 Geologic and geotechnical conditions and constraints (Cont'd)				
Geoscience Constraint / Condition	**Areas Affected***	**Status**	**Mitigation Measures**	**Studies**
Turbidity currents	Santa Monica Basin	Desktop Study and PSHA completed Forces to be evaluated and mitigation measures proposed during Pipeline and Mooring Engineering Design	Pipelines and Moorings designed for estimated loads	Interpret marine survey data to identify turbidity current channels and extent Geotechnical sampling and evaluation of sediments Turbidity current modeling studies based on survey results
Slope stability	Santa Monica slope	Project Desktop Study completed. Surveys completed, no evidence for Slope Instability on Pipeline Route	Avoid steep slopes, where possible Avoid areas slides, slumps, etc. Route perpendicular to slopes where possible	Marine survey data interpretation to identify areas of mass movement
Seafloor erosion/scour	Predominately Santa Monica shelf	Project desktop study completed. Preliminary metocean study completed. Forces to be evaluated and mitigation measures proposed during Pipeline and HDD Engineering Design	Pipeline design Pipeline burial or trenching in areas of damaging currents	Marine survey and metocean studies to identify current scour or sediment waves Metocean studies (current meters) Geotechnical sampling and evaluation of sediments for mobility
Tsunami	Santa Monica Bay	Project Desktop Study in completed (Published models for the LA Basin and POLA/POLB reviewed.)	Shore facility and pipeline design Pipeline burial at shore crossing (HDD)	

Table 6-6 Geologic and geotechnical conditions and constraints (Cont'd)				
Geoscience Constraint / Condition	**Areas Affected***	**Status**	**Mitigation Measures**	**Studies**
Methane Hydrates, shallow gas, gas seeps	Santa Monica shelf in areas of Palos Verdes anticlinorium Base of Redondo Slope	Project Desktop Study in completed. Data interpretation in progress	Avoid areas of gas expulsion	Marine survey to identify areas of gas expulsion, shallow gas and possibly methane hydrate deposits in the subsurface.
Seafloor Anchor Holding Capacity	DEEP WATER PORT Mooring	Project Desktop Study in completed. Data interpretation and Geotech testing in progress	Anchor Type Selection Anchor Layout Anchor Design Capacity	Geotechnical sampling and evaluation of Soil

*Areas listed for Santa Monica Basin-LAX Option: Equivalent areas are present for Santa Catalina Trough-AES Alternative

Table 6-7 Major laws, regulatory requirements, and plans for geologic resources

Law/Regulation/Standard/ Agency	Key Elements and Thresholds; Applicable Permits
Federal	
Federal Hazards Analysis, (30 CFR 250.204 (b)(1)(viii) and 30 CFR 250.1007 (a)(5) and shallow hazards survey (30 CFR 250.204(a)(17) and CFR 250.909) – *MMS* 49 CFR 192	Requires an analysis of seafloor and subsurface geologic and manmade hazards of the areas considered for oil and gas pipelines. This includes identifying and evaluating conditions that might affect the safety of proposed operations or that might be affected by the proposed operations. This evaluation process depends primarily on interpretation of data obtained from appropriately designed and executed high-resolution geophysical surveys. While the Project is not required to meet most MMS regulations, the Federal government intends to rely on MMS regulations and expertise as much as practicable to ensure application of appropriate, consistent standards: A shallow hazards survey and a geotechnical analysis of foundation soils/sediments underlying the proposed pipeline route must be performed. Outside of State waters, surveying must meet applicable MMS regulations and policy, as far as practicable. Minimum design standards for natural and other gas pipelines.
State	
California Seismic Hazards Mapping Act of 1990 (Public Resources Code § 2690 and following as Division 2, Chapter 7.8) and the Seismic Hazards Mapping Regulations (CCR Title 14, Division 2, Chapter 8, Article 10)	Designed to protect the public from the effects of strong ground shaking, liquefaction, landslides, other ground failures, or other hazards caused by earthquakes. The act requires that site-specific geotechnical investigations be conducted identifying the hazard and formulating mitigation measures prior to permitting most developments designed for human occupancy. Special Publication 117, Guidelines for Evaluating and Mitigating Seismic Hazards in California (CDMG 1997), constitutes the guidelines for evaluating seismic hazards other than surface fault rupture and for recommending mitigation measures as required by Public Resources Code § 2695(a)
The California Coastal Act (CCA) of 1976, as amended - *California Coastal Commission (CCC)*	Preserves, enhances, and restores coastal resources. Requires protection against loss of life and property from coastal hazards, including geologic hazards.
California State Lands Commission	Requires that the pipelines meet current seismic guidelines such as American Lifeline Alliance, July 2001, Guidelines for the Design of Buried Steel Pipe; American Lifeline Alliance, April 2004, Draft Guideline for Assessing the Performance of Oil and Natural Gas Pipeline Systems in Natural Hazard and Human Threat Events; and American Society of Civil Engineers, 1984, Guidelines for the Seismic Design of Oil and Gas Pipeline Systems.
California Public Resources Code § 5097.5 (Stats. 1965, c. 1136, p. 2792)	Defines an unauthorized disturbance or removal of fossil sites or remains on public land as a misdemeanor.

Table 6-7 Major laws, regulatory requirements, and plans for geologic resources (Cont'd)

Law/Regulation/Standard/ Agency	Key Elements and Thresholds; Applicable Permits
Uniform Building Code (UBC) and the California Building Code (CBC)	Contains requirements related to excavation, grading, and construction. Applicable codes and industry standards related to various geologic and soil features are identified in Appendix 8-3, Civil Engineering Design Criteria, UBC. The Project site is in the UBC and CBC Seismic Zone 4; the requirements included in the UBC and CBC for Zone 4 shall apply to the Project, including consideration for ground acceleration in structural design to provide earthquake-resistant design. According to the CBC, a grading permit is required if more than 50 yd^3 (38.2 m^3) of soil is moved. Chapter 33 of the CBC contains requirements relevant to the construction of pipelines alongside existing structures. CCR Title 23, §§ 3301.2 and 3301.3, contain the provision requiring protection of the adjacent property during excavations and require 10 days written notice and access agreements with the adjacent property owners. The UBC and CBC do not specifically apply to below-ground gas transmission pipelines operated by public utilities.
Alquist-Priolo Special Studies Zones Act of 1972 (California Public Resources Code §§ 2621-2630).	Requires that "sufficiently active" and "well-defined" earthquake fault zones be delineated by the State geologists. Prohibits locating structures for human occupancy across the trace of an active fault. Does not specifically regulate pipelines, but it does help define areas where fault rupture is most likely to occur.
Local	
Grading Permits - Local City or County Other	Required when more than 50 yd^3 (38.2 m^3) of soil is moved. No local regulations or codes are applicable beyond those identified in the UBC Appendix, Chapter 33, related to excavation, grading, and construction.

Key:

CCA = California Coastal Act; CCC = California Coastal Commission; CCR = California Code of Regulations; CFR = Code of Federal Regulations; m^3 = cubic meter; MMS = Minerals Management Service; UBC = Uniform Building Code; yd^3 = cubic yards.

Source: Ventura and Los Angeles Counties 2006.

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Table 6-8 Abridged Modified Mercalli Intensity Scale with possible natural gas facility response

Intensity	Definition	Gas Facility Response
I	Not normally felt.	Probably no failures.
II	Felt by a few persons at rest.	Probably no failures.
III	Felt indoors. Hanging objects swing. Vibration similar to a truck passing by.	Probably no failures.
IV	Felt indoors by many, outdoors by a few.	Probably no failures.
V	Felt by nearly everyone. Some dishes, windows broken. Unstable objects overturned.	Probably no failures.
VI	Felt by all, many frightened. Furniture moves. Weak plaster cracks.	Possible meter set or appliance shifting or damage, particularly at mobile homes.
VII	Difficult to stand. Weak chimneys break. Plaster and tiles fall. Some masonry cracks. Small gravel bank slides.	Possible cast iron damage, probably in smaller sizes with constrained joints. Some meter set, appliance, or connector damage.
VIII	Twisting or fall of chimneys, factory stacks, elevated tanks. Tree branches break. Cracks in wet ground or steep slopes. Damage great in poorly built structures.	Probable significant cast iron damage. Possible steel pipe damage, probably in old or uncoated pipe, possible polyethylene pipe damage at fusions.
IX	General panic. Buildings shifted off foundations, masonry destroyed or damaged. Reservoirs damaged. Partial collapse of substantial buildings. Conspicuous ground cracking. Sand and mud ejected in alluvial areas.	Probable damage to steel pipe system. Metering equipment impacted by masonry or shifting buildings.
X	Most masonry and frame structures destroyed. Large landslides.	Probable significant damage to some well-built wood structures
XI	Bridges destroyed. Few masonry structures remain.	Underground pipelines out of service.
XII	Total Damage. Objects thrown into the air.	
Source: McDonough 1995.		

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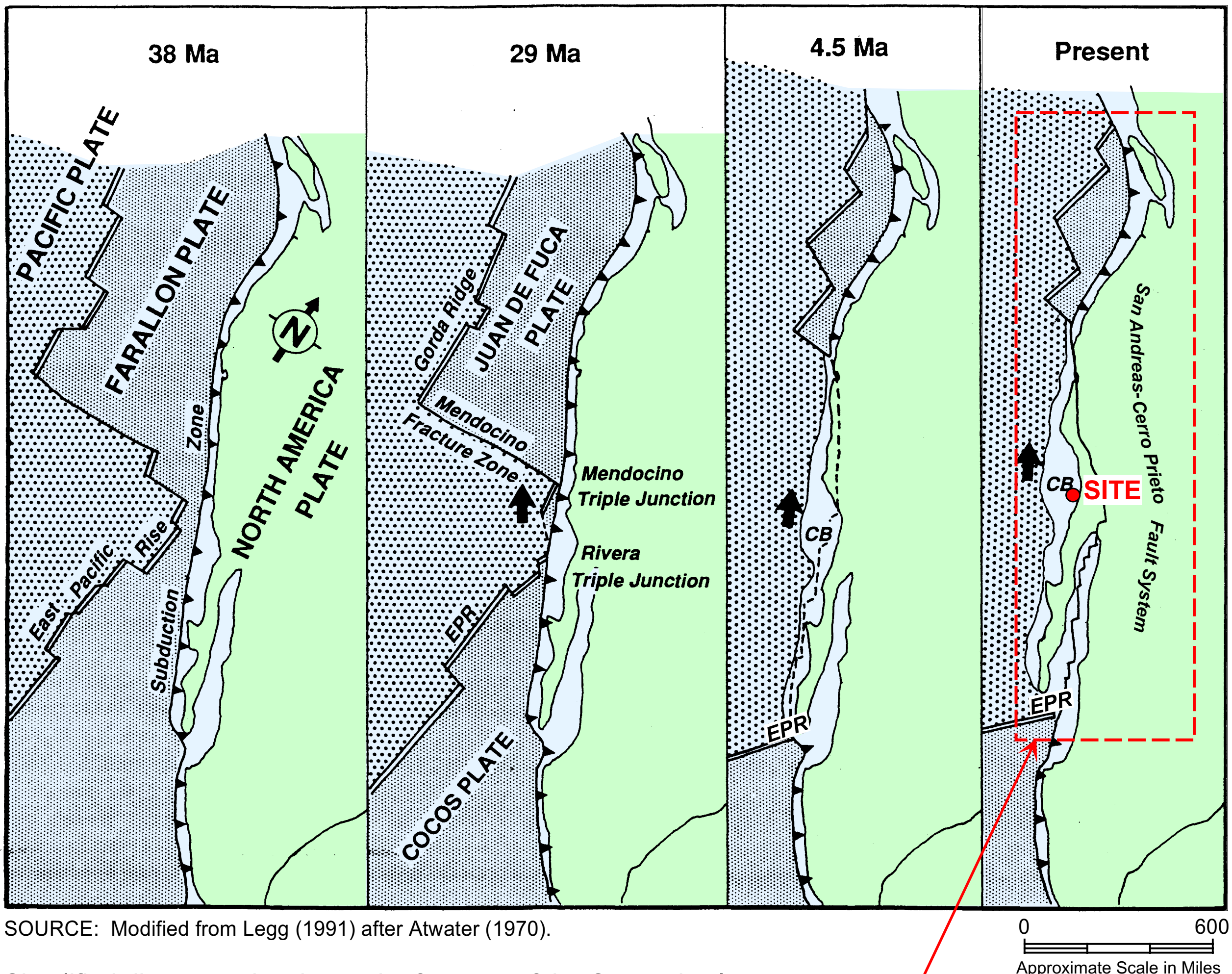
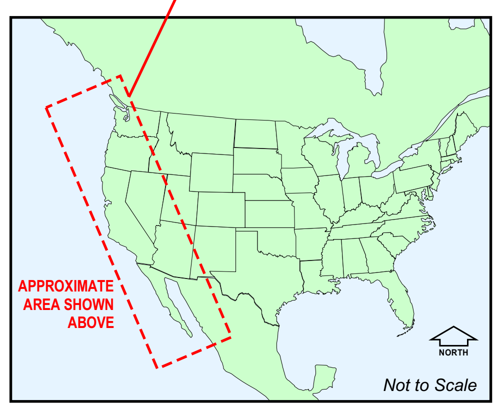
FIGURES

A B C D



SOURCE: Modified from Legg (1991) after Atwater (1970).

Simplified diagrams showing major features of the Cenozoic plate tectonic evolution of western North America. CB = Continental Borderland, EPR = East Pacific Rise.



A. 38 Ma, early Oligocene, subduction continuing from Cretaceous.
B. 29 Ma, late Oligocene, beginning of extension as Mendocino triple junction moves north and Rivera triple junction moves south.
C. 4.5 Ma, middle Pliocene, begin rifting of Baja California from mainland and transform plate margin.
D. Present day, Holocene, transform plate margin.

FUGRO

Locus Map

Figure: 6-1
Date: June 2006

Cenozoic Plate Tectonic Evolution of Western North America

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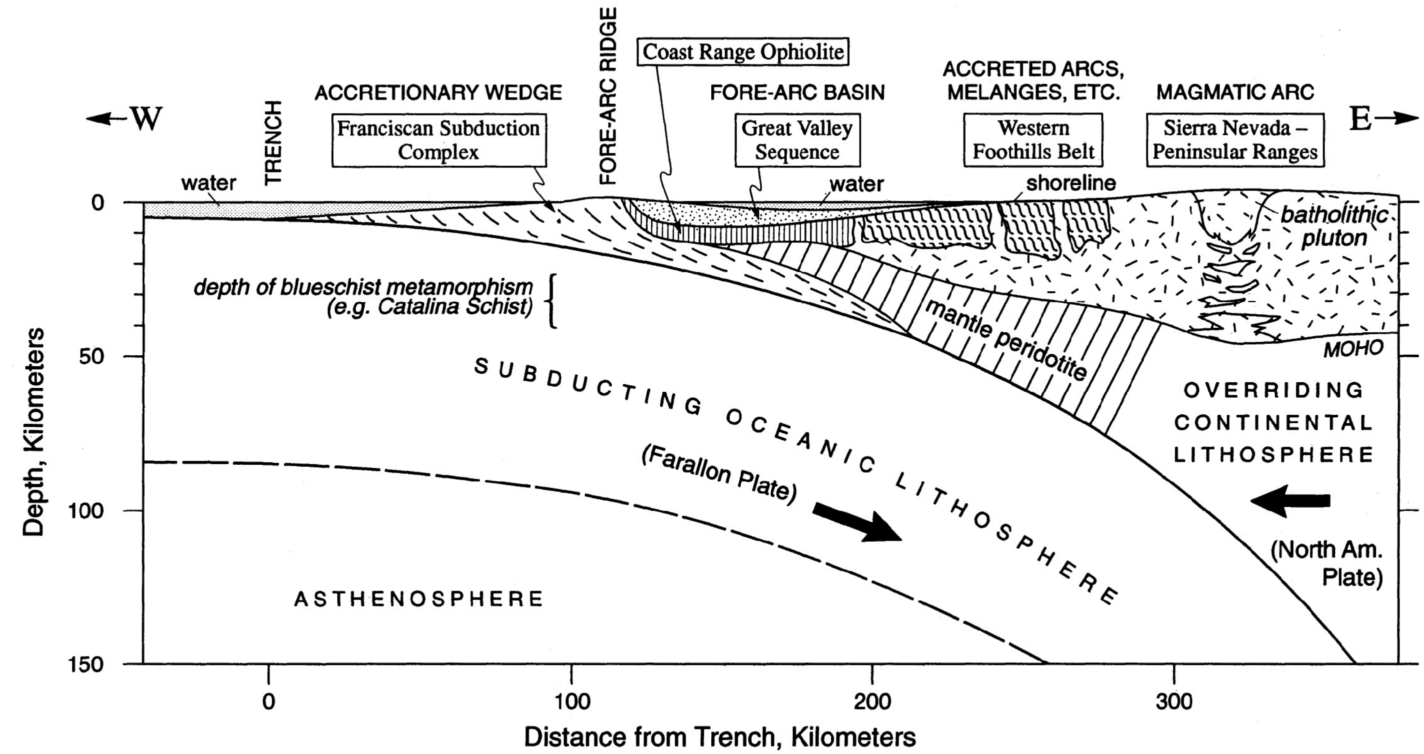

SOURCE: Modified from Crouch and Suppe (1993).

Cross section of a continental-margin subduction system. Key dimensions of the model are derived from Sumatra but are quantitatively like those of teh middle Cretaceous of California. The Mesozoic and Mesozoic-Paleogene lithotectonic belts of California (boxes) are shown in accordance with their inferred tectonic settings following the emplacement of the Coast Range ophiolite and Western Foothill belts.

Locus Map

Figure: 6-2
Date: June 2006

Cross Section of a Continental Margin Subduction System

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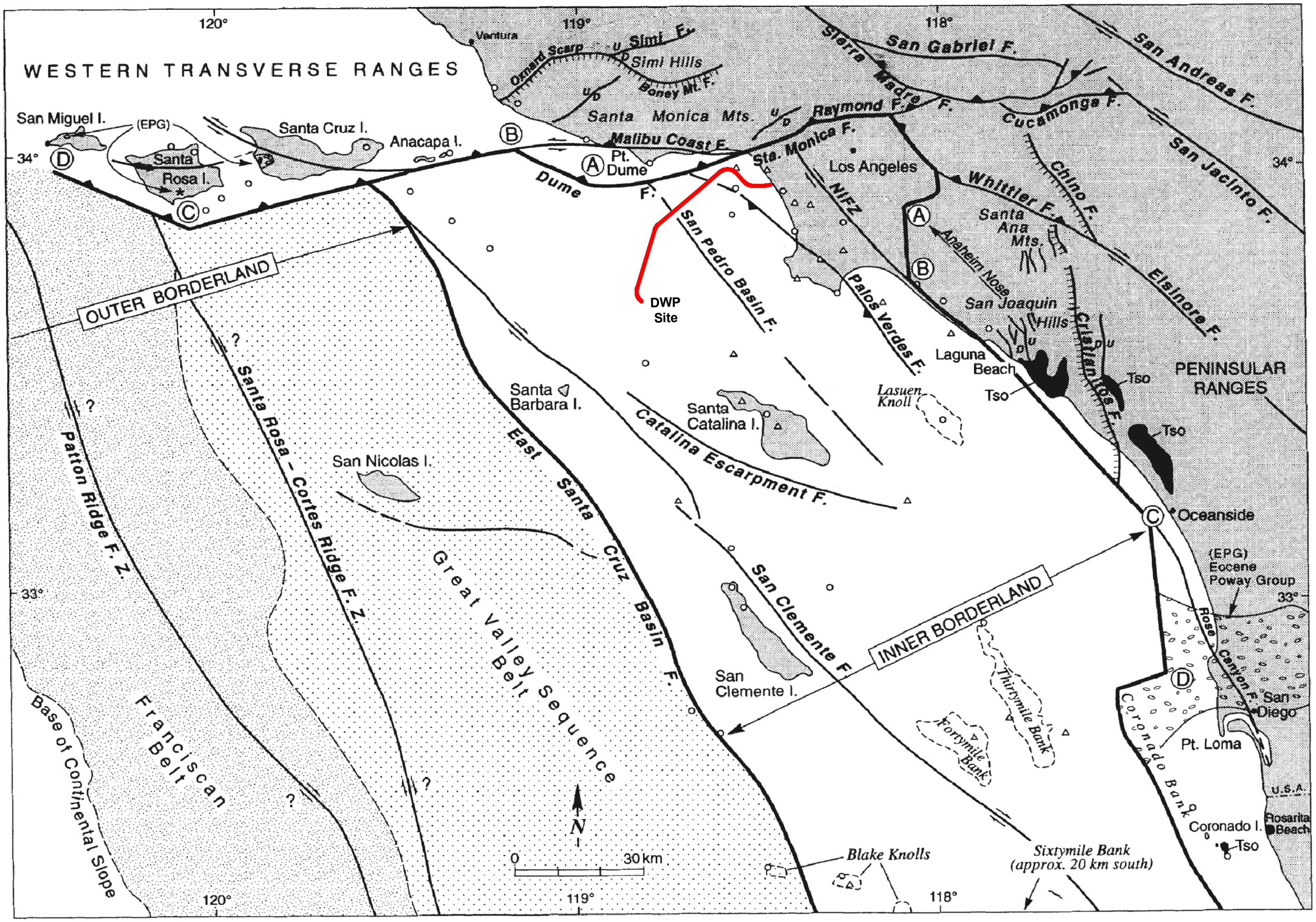

SOURCE: Crouch and Suppe (1993)

Locus Map

N
S

Legend

Proposed Pipeline Alignment

Abbreviations

F. = Fault
Z. = Zone
NIFZ = Newport Inglewood Fault Zone

Figure: 6-3
Date: June 2006

Fault and Geographic Map of Onshore and Offshore Southern California

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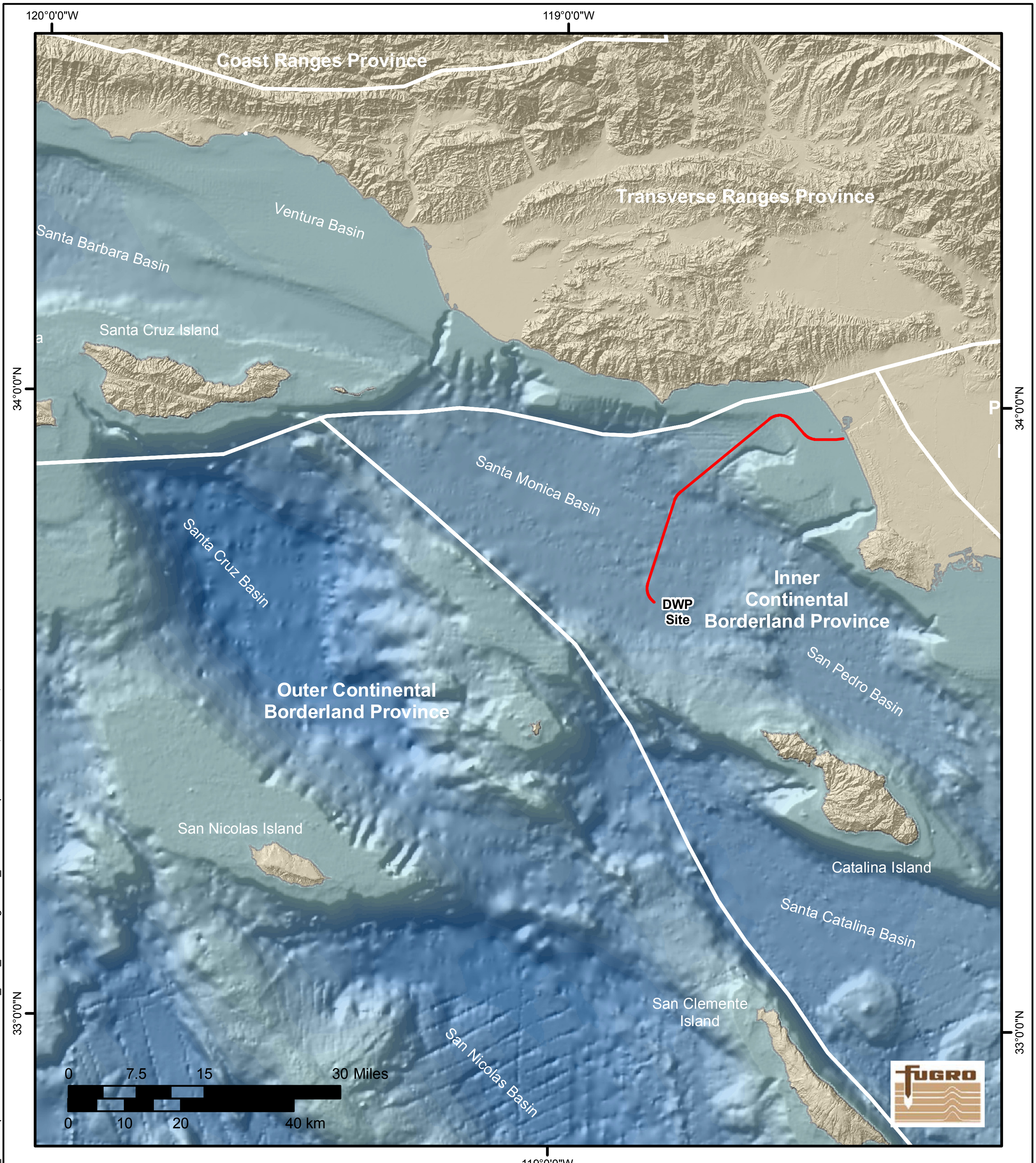
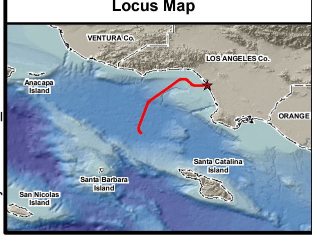


SOURCE: Province boundaries modified from California Geomorphic Provinces, California Geological Survey Note 36, www.consrv.ca.gov/CGS/information/publications/cgs_notes/note_36/note_36.pdf>

Locus Map



Legend

Proposed Pipeline Alignment

Geomorphic Provinces of Southern California

OceanWay Secure Energy

Figure: 6-4
Date: June 2006

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