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April 28, 1978

California Coastal Commission
631 Howard Street
San Francisco, California 94105

Attention: Mr. L. Thomas Tobin
Senior Engineer

Gentlemen:

Geotechnical Evaluation of
Five Potential Mainland California
LNG Import Terminal Sites

This report presents the results of our geotechnical evaluation of the five potential mainland California LNG import terminal sites retained from the previous report dated January 16, 1978. The sites, in north to south order, are Rattlesnake Canyon, Cojo Bay (Pt. Conception), Las Varas, Deer Creek and Canyon, and Camp Pendleton.

We have enjoyed working with the Coastal Commission, and feel that the combined efforts of the Commission and their consultants represents a significant milestone toward siting energy facilities in California.

Very truly yours,

Donald D. Treadwell

Donald D. Treadwell
Project Engineer

George E. Brogan

George E. Brogan
Project Geologist

DDT/GEB/lp

See Amdt. 17 -FSAR

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GEOTECHNICAL EVALUATION OF FIVE POTENTIAL MAINLAND CALIFORNIA LNG IMPORT TERMINAL SITES

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1.0 SUMMARY

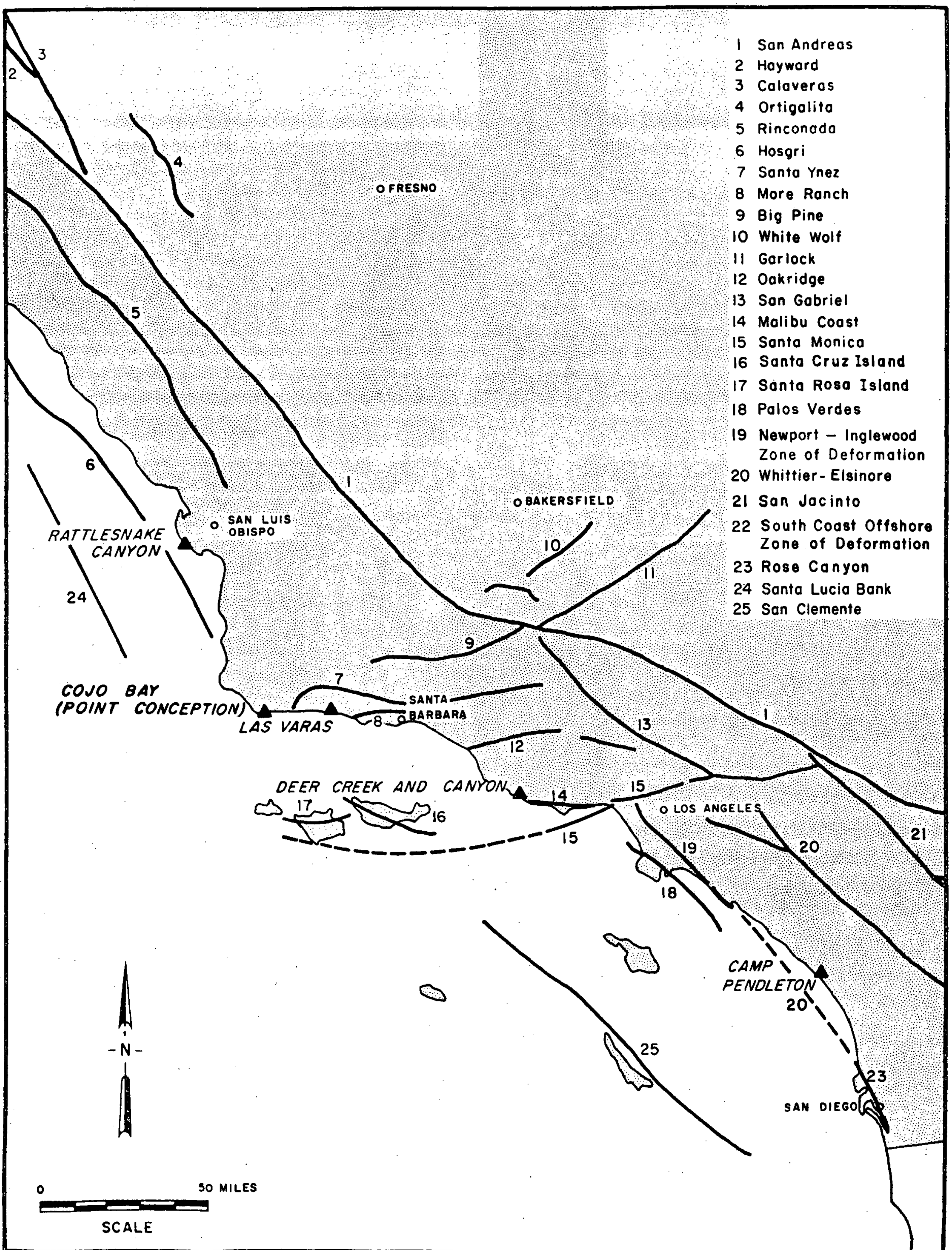
Five mainland California localities are being considered for an LNG import terminal (Figure 1.1). The Liquefied Natural Gas Act of 1977 requires the California Coastal Commission to make a recommendation to the California Public Utilities Commission regarding ranking of the potential sites. This report provides geotechnical information for the five sites for the Coastal Commission to consider in their ranking.

The level of knowledge for the five sites is not similar. The Rattlesnake Canyon and Camp Pendleton sites are each located a few miles from nuclear power plants, and geotechnical data developed in relation to these facilities is of benefit in evaluating potential LNG sites. The Deer Creek and Canyon site and the Las Varas site are in areas that have been mapped previously, with those data generally available. In addition, detailed subsurface investigations of the potential for on site faulting like those completed at the Las Varas site have not been attempted at any of the other sites. The Cojo Bay site is located in a remote area that is poorly known geologically relative to other areas of coastal California; the data available for this site were recently developed in relation to the proposed LNG site and have not been subjected to years of scrutiny as have the data for other sites. Comparisons of the data regarding each site should account for these different levels of knowledge.

All five of the sites appear to be feasible for construction of an LNG import terminal. Each site has both positive and negative geotechnical attributes that are summarized in the following subsections.

1.1 RATTLESNAKE CANYON LNG SITE

The proposed Rattlesnake Canyon LNG site is four miles south of the Diablo Canyon Nuclear Power Plant in San Luis Obispo County. It is situated on a 600- to 1,500-foot-wide, nearly flat coastal terrace with an average elevation of about 110 feet.



Project: LNG TERMINALS EVALUATION Project No: 41033I	PRINCIPAL FAULTS OF COASTAL CALIFORNIA	Fig: 1.1

The terrace surface is underlain by competent sands, silts, and clays to an average depth of approximately 75 feet and hard sandstone at greater depths. The sandstone is exposed in the lower portion of the sea cliff, in the hills inland from the site, and offshore where it is eroded into numerous pinnacles and rock islands. Landslides at the seaward margin of the coastal terrace in the southern portion of the site are active; landslides at the base of the hills along the access highway appear to be inactive.

The Hosgri fault is located 5 miles offshore and is interpreted as a potential source of earthquakes as large as magnitude 7-1/2. The San Andreas fault is 47 miles inland and may generate earthquakes as large as magnitude 8-1/2.

Major geotechnical considerations at the Rattlesnake Canyon site include the limited space available on the narrow terrace, competency of the terrace deposits, slope stability, the offshore rock pinnacles, and exposure to potentially damaging earthquakes.

1.2 COJO BAY (PT. CONCEPTION) LNG SITE

The proposed Cojo Bay LNG site is 3-1/2 miles east of Point Conception in western Santa Barbara County. It is situated on a gently sloping coastal terrace that is approximately 2,500 feet wide and 80 to 200 feet in elevation.

The terrace surface is underlain by competent sands, silts, and clays to an average depth of about 50 feet, with smaller areas of loose, compressible alluvium and hard shale and mudstone. Hard shale and mudstone are encountered beneath the entire site below the alluvium and terrace deposits. Shale is exposed offshore where it has been eroded into a gently sloping surface without significant relief.

Cojo Canyon intersects the terrace and contains a perennial stream of small discharge. Ground water is within the alluvium and bedrock at about sea level in the southern portion of the site, and near the surface in the northern portion underlain by bedrock and alluvium. The possibility of local, limited liquefaction is low within the terrace deposits, but needs further consideration in areas of high ground water.

A youthful fault located 2-3/4 miles offshore may or may not be associated with the South Branch of the Santa Ynez fault. If it is not associated with the Santa Ynez fault, it may be the source of earthquakes of moderate magnitude; however, if it is a part of the Santa Ynez fault, it may be associated with earthquakes as large as magnitude 7-1/2. Other inland branches of the Santa Ynez fault are also interpreted to be potential sources of nearby earthquakes. The San Andreas fault, 62 miles to the northeast, may produce earthquakes as large as magnitude 8-1/2.

Major geotechnical considerations at the Cojo Bay site include the foundation suitability of the terrace deposits and alluvium, dewatering of excavations, erosion control, slope stability and exposure to potentially damaging earthquakes.

1.3 LAS VARAS LNG SITE

The proposed Las Varas LNG site is on a broad coastal terrace 17 miles west of Santa Barbara. The site is nearly flat, with elevations ranging from 60 feet to 140 feet.

The terrace surface is underlain by 30 to 40 feet of easily excavatable terrace sands, silts and clays that cover bedrock shales exposed in the coastal bluffs and offshore where the sea bottom is generally smooth. Erosion of the coastal bluffs may be on the order of 2 to 10 inches per year.

An apparently youthful fault has been identified on the Las Varas site; the relationship of this feature to nearby faults, such as the Eagle fault, Dos Pueblos fault, or More Ranch fault, is unknown. The length and age of this feature are unknown, but it may trend westerly across the site, and may have ruptured within the past few tens of thousands of years. The Eagle fault is located adjacent to the site and is not known to have displaced units of Quaternary age.

The More Ranch fault may be 2 miles offshore and associated with earthquakes as large as magnitude 7-1/4. The San Andreas fault is 48 miles inland and may generate earthquakes as large as magnitude 8-1/2.

The major geotechnical considerations at the Las Varas site include the apparently youthful fault that may cross the site, and exposure to potentially damaging earthquakes.

1.4 DEER CREEK AND CANYON LNG SITE

The proposed Deer Creek and Canyon LNG site is in Ventura County 11 miles northwest of Point Dume and 5 miles southeast of Point Mugu. It is situated in a deeply incised, steep-sided canyon in the western Santa Monica Mountains. The canyon is approximately one-mile wide between the bounding ridges and contains an intermittent creek with many small tributaries. Sandstones and conglomerates with some interbedded shales, and Tertiary intrusive rock are the principal materials underlying the site. The Malibu Coast fault is interpreted to be approximately 2-1/2 miles offshore and may be a potential source of earthquakes as large as magnitude 6-3/4. The San Andreas fault, 52 miles to the northeast, may produce earthquakes as large as magnitude 8-1/2. Potentially active landslides are along the coast at Deer Canyon and apparently inactive landslides occur to a lesser extent inland.

Major geotechnical considerations include slope stability, the limited area and steep slopes in the canyon, the difficulty of site development and grading, and seismic exposure.

1.5 CAMP PENDLETON LNG SITE

The proposed Camp Pendleton LNG site is on a 4,000-foot-wide coastal terrace about 90 to 200 feet in elevation, 5 miles south of the San Onofre Nuclear Generating Station. The terrace deposits of clay, sand and gravel are approximately 70 feet thick and rest upon bedrock sandstone and shale exposed at the base of the coastal bluffs and offshore on a smoothly eroded sea floor.

Landslides are common along the coastal bluffs and affect the terrace surface as far as 450 feet inland. Significant erosion averaging 15 feet per year has occurred along Dead Dog Canyon through the center of the site. Erosion has also been significant but at a somewhat lower rate along Horno Canyon north of the site.

The South Coast offshore zone of deformation is 6 miles offshore and may be associated with earthquakes as large as magnitude 7-1/4; the Whittier-Elsinore, San Jacinto, and San Andreas faults are 22 to 60 miles distant from the site and may be associated with earthquakes larger than magnitude 7.

Major geotechnical considerations at the Camp Pendleton LNG site include the unstable coastal bluffs, erosion of Dead Dog Canyon through the site and Horno Canyon north of the site, and exposure to potentially damaging earthquakes.

2.0 INTRODUCTION

2.1 BACKGROUND INFORMATION

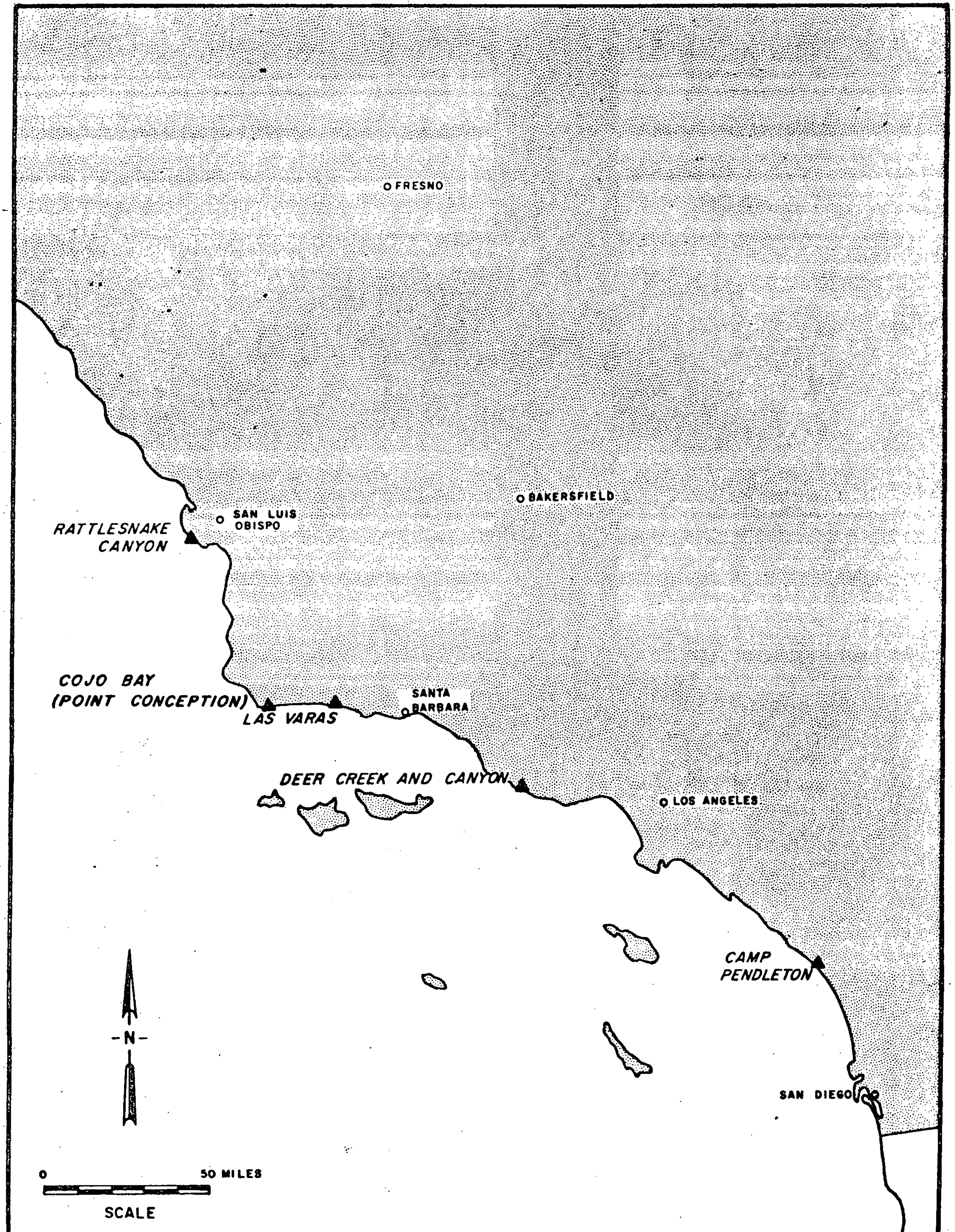
The Liquefied Natural Gas Act of 1977, requires the California Coastal Commission to identify and rank suitable sites along the California mainland coast for an LNG import terminal. From an original list of more than 80 nominated mainland sites, eleven sites were selected by the Commission for preliminary evaluation.

As part of the preliminary evaluation of the eleven selected sites, geotechnical factors influencing LNG terminal siting were assessed by Woodward-Clyde Consultants. The results of the preliminary geotechnical assessment were presented in a report (and supplement) entitled "Geotechnical Evaluation of Potential Mainland California LNG Terminal Import Sites," dated 16 January 1978. Based on the information contained in the referenced report and on information concerning population density, wind and wave conditions, land use, and other factors, the Commission retained five sites (Figure 2.1) for more thorough evaluation.

2.2 PURPOSE AND SCOPE

This report describes the results of a study of site-specific geotechnical information for the five retained mainland sites. The study included geological reconnaissance mapping, offshore geophysical investigations, the estimation of seismic exposure for four sites, and a summary based on a brief visit and available literature and reports for the fifth site.

Aerial photographic interpretation, geologic mapping, and on-site materials evaluations were conducted over a period of 5 to 10 days per site. Faults on or in the vicinity of the sites were mapped and a preliminary analysis was made of their activity based on field evidence. Offshore geophysical investigations combined with published literature provided information about the area beyond the surf zone.



Project: LNG TERMINALS EVALUATION Project No: 410331	LOCATIONS OF LNG SITES CONSIDERED IN THIS STUDY	Fig: 2.1

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The results of this study provide a basis for assessing the relative geotechnical suitability of the five retained sites.

2.3 METHODS AND SCHEDULE

Data utilized were obtained mainly from the California Coastal Commission, the Californa Division of Mines and Geology, the California Public Utilities Commission, the U.S. Geological Survey, Pacific Gas and Electric Company, Southern California Edison Company, the Southern California Gas Company and other published geologic reports. In addition to the reports and maps obtained, vertical aerial photographs, some as old as 50 years taken in 1928, and oblique color transparencies of each site were obtained and interpreted. Data acquisition and evaluation were completed prior to the beginning of the field investigations, February 24, 1978. The offshore geophysical investigations began March 18, 1978 and continued through April 1, 1978. The limited time available precluded acquisition and evaluation of proprietary data.

2.4 GEOTECHNICAL SITING FACTORS

The assessment of the five retained sites included an evaluation of the geotechnical factors which affect the safety and cost of an LNG terminal facility. A brief description of these factors is given in the following paragraphs:

2.4.1 Seismicity and Faulting

The presence of faults represents a hazard and a cost and engineering factor that should be considered for critical structures in seismically active areas. Fault location is important for several reasons: recently active faults may generate future earthquakes, and distance from faulting allows ground accelerations to be estimated. The magnitude of these ground accelerations will have significant impacts on the engineering and construction costs necessary to mitigate the hazard.

Two principal factors are considered in evaluating seismicity: the possibility of active faulting (surface fault rupture) through the site, and the intensity of ground shaking due to earthquakes. No firm policies regarding the definition of an active fault have been established by regulatory agencies for LNG facilities. For the purposes of this report, known faults with evidence of Quaternary activity (approximately the past 2 to 3 million years) are included in this evaluation. Criteria for a fault considered to have a potential to cause earthquakes have been set by various agencies (Table 2.1). These criteria include evidence of faulting within the past 11,000 years for dwellings in California, evidence of faulting within the past 35,000 years for dams constructed by the Corps of Engineers and 100,000 years for dams constructed by the Bureau of Reclamation, and evidence of one event of faulting within the past 35,000 years or multiple events of faulting within the past 500,000 years for nuclear power plants.

2.4.2 Faulting Within a Site

Surface rupture within a site represents a hazard that may be difficult and costly to accommodate in design. The presence of a major fault on a site implies the potential for a hazard as well as possible difficulties securing regulatory approval. The presence of a minor fault on a site requires thorough geologic studies to identify the degree of hazard.

2.4.3 Faulting Within 5 Miles

Faults within 5 miles of a site represent a geotechnical factor because: (1) the fault may be associated with presently unknown branch faults that could cross a site, and (2) the fault may represent the source of an earthquake to be considered in design of the LNG terminal. The close proximity of a fault of Holocene or Quaternary age to a site suggests that further studies may be desirable to better define whether or not a fault trace may be located on a site.

2.4.4 Faulting More Than 5 Miles

Faulting at distances farther than 5 miles is a significant geotechnical factor because large faults at great distances may generate earthquakes that could affect LNG terminal facilities, such as large tanks or structures located upon deep fill.

2.4.5 Ground Shaking

The ground-shaking response of a site to an earthquake is a significant geotechnical factor for all coastal California LNG sites, because all the sites are likely to be exposed to earthquake shaking within the lifetime of an LNG terminal. This factor depends upon three variables:

- The type of fault generating the earthquake, and the size (magnitude) of the earthquake.

- Attenuation of the earthquake motions as the seismic waves propagate from the fault to the site.

- The characteristics of the site that may locally modify the earthquake motions.

This study considered the earthquake shaking response at each site for estimated 100-year earthquakes on a nearby fault (within 10 miles) and on a distant fault (45 to 60 miles distant). The 100-year earthquakes are utilized because they provide a measure of the seismic exposure to which an LNG import terminal may be subjected.

Bedrock accelerations are higher for nearby earthquakes than for distant earthquakes. Accordingly, accelerations are estimated for nearby earthquakes, considering the apparent soil characteristics at each site. The acceleration values have meaning only when considered in the context of the number of vibratory cycles per second and the overall site responses that are induced. The possible effects on acceleration of thick fill at a canyon site are also addressed.

The displacements of the ground caused by surface waves are also an important consideration for structural design of critical facilities, because different structural components may vibrate with motions that are out-of-phase with one another. These out-of-phase motions are estimated for each site, for the consideration of structural engineers.

2.4.6 Liquefaction

Liquefaction is the sudden loss of soil strength during seismic shaking; it has produced catastrophic damage to structures in past earthquakes. In this report, the potential for liquefaction is evaluated by considering the intensity of ground shaking and the soil and ground water conditions inferred from the ground reconnaissance efforts. Specific measures to reduce or eliminate the liquefaction potential have not been considered in this evaluation. Liquefaction potential in the intertidal zone and offshore areas has not been fully evaluated, but is a factor in all areas where sand beaches are found.

2.4.7 Geology

The regional geology is a guide to the rock types and their engineering properties, and provides important information to help identify problems which may not be readily apparent during a visit on the site. An assessment of the regional geology may also provide information on the susceptibility of the area to landsliding, mudsliding, or erosion.

The geology of each site provides information regarding the distribution and properties of rock types, depth to bedrock, and the potential for locally hazardous conditions. The local geology also affects factors such as grading, erosion, coastal erosion, and the stability of existing slopes.

2.4.8 Offshore Geology

Geophysical surveys and bottom soil surveys can be used as a guide to conditions in the offshore berthing area. The conditions along the pipeline to shore can also be evaluated from these data. Potential hazards such as offshore faults may require additional investigations but can be located and given a preliminary evaluation based on the surveys conducted. These data can be used to assess the pipeline location, alignment, construction procedures and relative cost required at each of the sites.

2.4.9 Topography

Topography is an important consideration in assessing grading costs, erosion potential, tsunami run-up, and potential for brush fires. Grading large volumes of material to develop a site requires significant engineering effort and costs. Tsunami run-up is a function of the tsunami height, and the local topography and bathymetry. It is assumed that the area between the berthing and onshore facilities will be prone to tsunami effects at all of the sites. The presence of vegetation which may fuel brush fires has been identified but the hazard of wild fires can be minimized by proper design of buffer zones and fire breaks.

2.4.10 Slope Stability

The stability of existing slopes reflects the potential for massive landsliding and the possible need for extensive engineering and large costs for remedial measures. The stability of temporary and permanent constructed slopes is based upon geology and bedrock types.

Landslides and unstable coastal bluffs could affect the cryogenic pipeline and could require protective measures. The rate of erosion of the coastal bluffs at most of the LNG sites is generally poorly known; in the judgments of our personnel, this erosion does not constitute a hazard as long as reasonable setback distances are established from steep slopes.

2.4.11 Hydrology

Ground-water levels affect the potential for liquefaction in unconsolidated sediments and shallow ground water may create construction difficulties, for example, during excavation for buried tanks. Site flooding is of concern in narrow canyons, where upstream dams exist, or where the upstream drainage basin is large. This potential is affected by the ability to provide for the conveyence of floods through or around a site. Canyon sites may require considerable design to provide for flood flows.

2.4.12 Engineering Properties and Foundation Conditions

The behavior of a given structure resting upon a soil or rock foundation depends largely on the underlying foundation material. Soil conditions at each site affect the design of structures and the cost of construction. Although poor soil conditions do not usually constitute a hazard, the engineering effort and construction costs may be significantly increased due to the presence of unfavorable soils. It has been found that rocks and soils can be classified into general groups within which significant engineering properties are somewhat similar. The primary engineering properties of concern for soils are the shear strength, compressibility, shrink/swell, permeability, and stress-strain. The engineering properties in turn influence such design considerations as bearing capacity, pile support capacity, settlement and heave. As no program of soil borings and laboratory testing has been conducted, these factors have been addressed qualitatively in the present report.

3.0 RATTLESNAKE CANYON LNG SITE

3.1 SUMMARY

The proposed Rattlesnake Canyon LNG site is located four miles south of the Diablo Canyon Nuclear Power Plant in San Luis Obispo County. It is situated on a 600 to 1,500 foot wide, nearly flat coastal terrace with an average elevation of about 110 feet. The coastal terrace is underlain by competent sands, silts and clays to an average depth of approximately 75 feet and hard sandstone at greater depths. The sandstone is exposed in the lower portion of the sea cliff, in the hills inland from the site, and offshore where it is shaped by wave action into numerous pinnacles and rock islands. Two intermittent streams flow through the site in narrow canyons. Ground water occurs within older, deeper formations and within the base of the terrace deposits. The Hosgri fault is about 5 miles offshore and is a potential source of a magnitude 7-1/2 earthquake. The San Andreas fault, 47 miles northwest, may produce a magnitude 8-1/2 earthquake. Landslides at the seaward margin of the coastal terrace in the southern portion of the site are active; landslides at the base of the hills along the highway appear to be inactive.

Major geotechnical considerations include the limited space available on the narrow terrace, foundation suitability of the terrace deposits, slope stability, the removal of rock pinnacles offshore, and exposure to potentially damaging earthquakes. The terrace is only 600 feet wide in some areas where tanks may be located; set-back from the sea cliff to account for cliff recession and stability would confine LNG tank locations to the inland portions of the terrace. Based on limited data, the terrace deposits below the soil mantle are suitable for foundations. Landslides in the terrace margin in the southern third of the site and near the highway west of the unnamed creek should be avoided. If the tanks are buried, the Cretaceous sandstone slope above the excavations may be unstable and require special treatment during construction. Smaller cuts for surface tanks would require relatively less treatment. One alternative to accommodate these restrictions due to space and landslides includes siting three LNG tanks northwest and one southeast of Pecho Creek. In the berthing area, the irregular, rocky bottom may require removal of rocky shoals and pinnacles by blasting. Earthquakes from faults as near as 5 miles and as far as 47 miles are expected to cause severe ground shaking during the life of a terminal.

3.2 MAJOR GEOTECHNICAL CONSIDERATIONS

Geotechnical design considerations include the relatively narrow terrace, suitability of the terrace deposits as a foundation, slope instability, and seismic exposure.

3.2.1 Width of the Terrace

The nearly flat portion of marine coastal terrace is approximately 1,500 feet wide at the widest point near Pecho Creek. It rapidly narrows to a width of approximately 600 feet within about 1,000 feet along the coast in either direction, and maintains this width to the margin of the site. A setback from the sea cliff on the order of 200 feet and a setback of 100 feet from Pecho Creek and the other creeks that traverse the site may be required unless the canyons are filled. These setback considerations would confine the LNG tanks to the portion of the terrace adjacent to the existing paved road. There appears to be little flexibility in the locations available for tanks and other facilities.

3.2.1 Foundation Suitability

The foundation material most likely to be encountered at expected excavation depths for either surface or buried tanks is the terrace deposits. The terrace materials below surficial soils are generally suitable foundation material for the structures anticipated. Based on limited data, the clayey materials immediately below the soil to depths of about 25 feet are moderately expansive and very stiff to hard. Below 25 feet the terrace materials are very dense clayey sandy silts and sandy clays. These materials are not anticipated to exhibit significant settlement under expected static or seismic loads.

3.2.3 Slope Stability

Slope stability must be considered for the sea cliff, the canyon rims, and the existing landslides. The sea cliff in the northwestern portion of the site is nearly vertical and is affected by a few small slumps, a few erosional gullies, and no major landslides. A setback of about twice the height of the cliff (about 200 feet from the terrace margin) for critical facilities or large structures should be considered in order to avoid the effects of relatively slow cliff recession and minor instability of the terrace margin. In the southeastern third of the site, the terrace margin is subject to more instability, but is at a lower elevation; the 200-foot setback should be sufficient in this area as well. The canyons that traverse the site appear to have achieved stable channel configurations with ample capacity to confine their respective streams. A setback of 100 feet from the canyon rims appears to be sufficient, considering their depth and apparent stability.

The landslides in the seaward terrace margin in the southern third of the site do not appear to indicate a general condition of instability of the entire width of terrace. Rather, they appear to be related to ground water at the bedrock contact. The ground water could be drained and the landslide deposits removed and replaced with engineered fill. An additional margin of safety could result from limiting the southern third of the site to less critical facilities.

Landslides in the Cretaceous sandstone near the paved roadway appear to be confined between Pecho Creek and the unnamed creek 1,500 feet to the southeast. Of these, the largest is near the unnamed creek. It may be of particular concern if an LNG tank were buried near it because the terrace materials may be providing lateral support to the landslide. If the terrace material were removed, the landslide could be reactivated. However, it may be stable under present conditions, and a surface LNG tank may be preferable near the landslide. The other, smaller landslides should be evaluated for their present stability and treated if necessary, but these appear to represent relatively minor geotechnical considerations. They indicate the base of the hills must be carefully evaluated for slope stability. A preliminary plant configuration suggests three LNG tanks could be sited northwest of Pecho Creek and one to the southeast. This would avoid the large landslide near the unnamed creek.

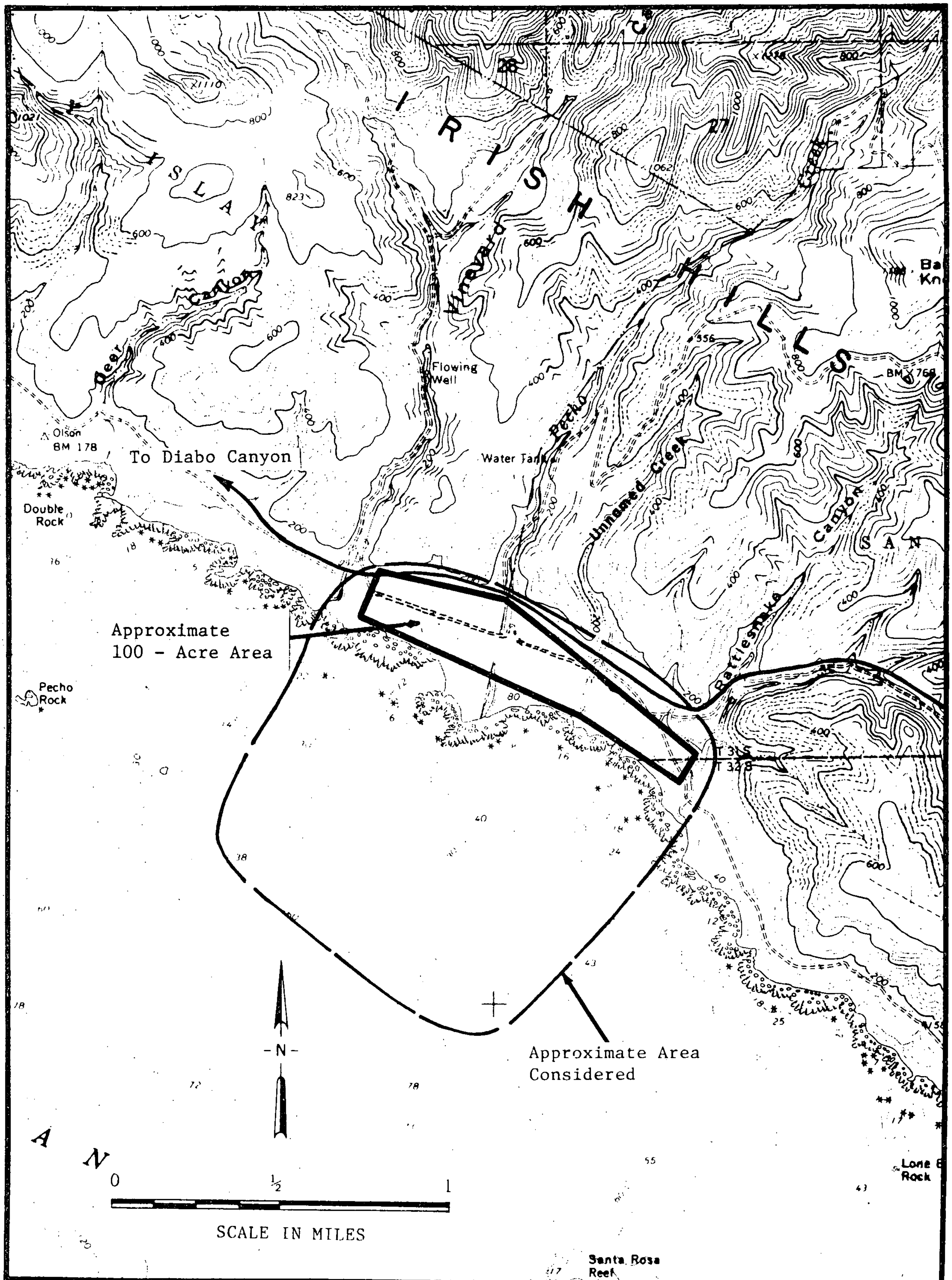
3.2.4 Seismic Exposure

Seismic shaking due to both nearby and distant earthquake sources is expected to be severe, although no more so than for the other potential LNG sites. The Hosgri fault is 5 miles offshore and may be the source of earthquakes as large as magnitude 7-1/2. The San Andreas fault is 47 miles to the northeast, and may be a potential source of earthquakes as large as magnitude 8-1/2.

3.3 LOCATION

The proposed Rattlesnake Canyon LNG site is located in San Luis Obispo County approximately 11 miles southwest of San Luis Obispo. Point San Luis, 2 miles to the southeast and Point Buchon, 8 miles to the northwest, are the nearest prominent coastal landmarks. Access to the area is along a two-lane, paved private road that leaves public roads at Port San Luis. The road continues along the coast to the Diablo Canyon Nuclear Power Plant. Access is controlled by Pacific Gas and Electric Company.

The onshore portion of the site considered for development is situated on a coastal terrace between Rattlesnake Canyon and Vineyard Canyon (Figure 3.1). Existing land use is for crops and the private road along the inland limit of the terrace. The terrace north and south of the site is used mainly for grazing,



Project: LNG TERMINALS EVALUATION **Project No:** 41033I	LOCATION MAP OF THE RATTLESNAKE CANYON LNG SITE	**Fig:** 3.1

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as are the hills inland from the highway. The Diablo Canyon Nuclear Power Plant is four miles northwest of the site.

3.4 TOPOGRAPHY

The site is located on a marine coastal terrace adjacent to the Irish Hills, alternatively called the San Luis Range. These hills form a broad peninsula bounded by Estero Bay on the north and San Luis Bay on the south. The marine coastal terrace has a 50- to 100-foot-high coastal bluff on the southwest, and the base of the gently rolling Irish Hills on the northeast; the average elevation of the site is approximately 110 feet (Figure 3.1). Vineyard Creek forms the northwestern boundary and Rattlesnake Creek forms the southeastern boundary of the site.

The sea cliff has 10 to 40 feet of Cretaceous sandstone bedrock exposed at its base. A wave-cut platform was developed on the bedrock, and subsequently the Quaternary terrace materials were deposited on the platform. The platform and terrace deposits have since been gently warped and uplifted, resulting in a southeasterly rise of the bedrock surface and the variation in thickness of resistant sandstone at the base of the cliff.

The marine coastal terrace varies in elevation from approximately 50 feet near the mouth of Rattlesnake Creek to approximately 110 feet near Vineyard Canyon, where it crosses the highway. The terrace deposits thin to the southeast. The slope of the terrace is generally a few percent with slightly steeper slopes in the southeastern portion of the site. The terrace is approximately 1500 feet wide at its widest point near Pecho Creek, but averages approximately 600 feet wide elsewhere on the site.

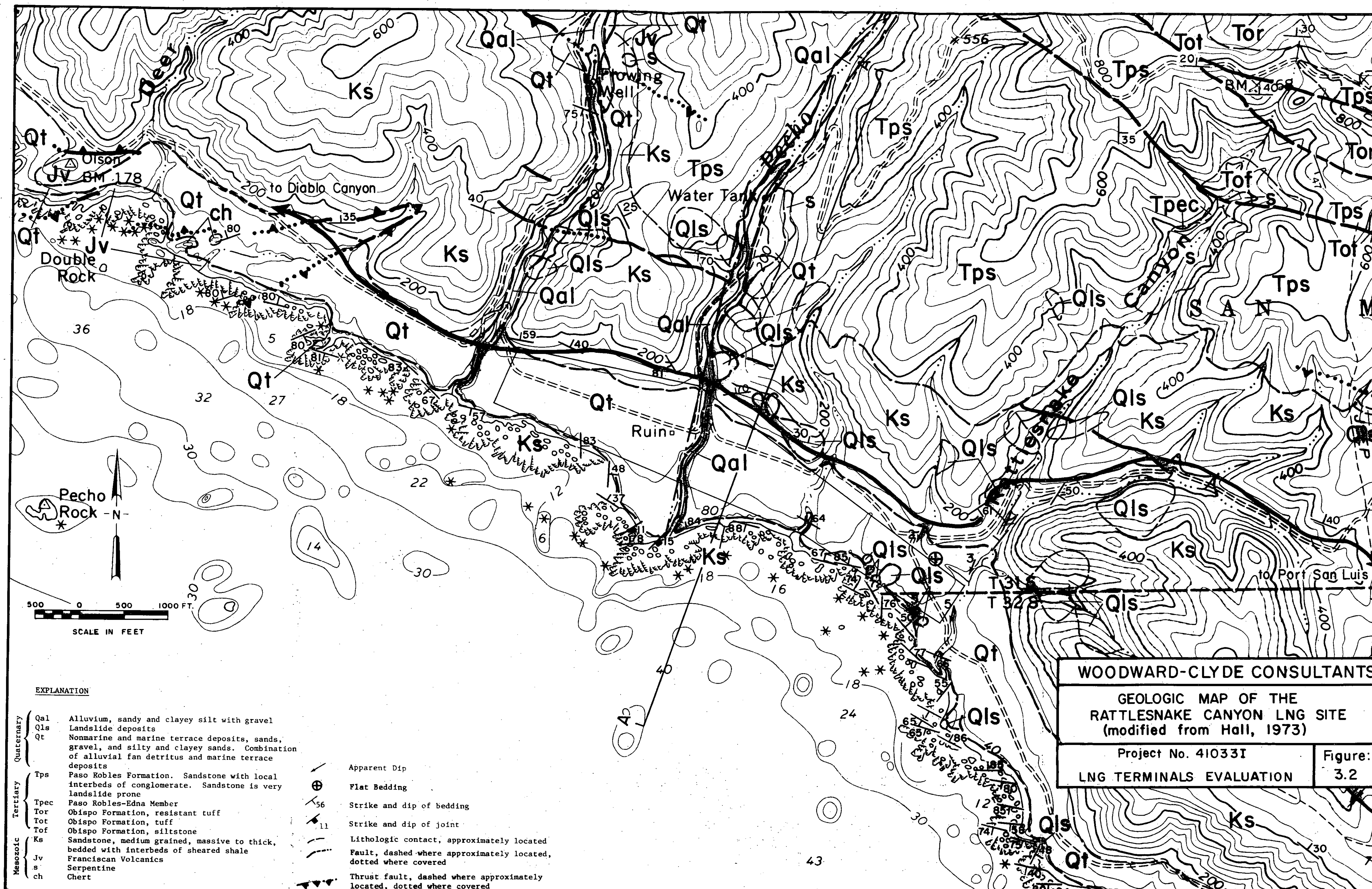
Canyons that traverse the terrace are incised nearly to sea level at the coast, yielding steep canyon sides as high as 80 feet. The canyons are progressively shallower inland, and at the inland limit of the terrace are about 30- to 40-feet deep. Two drainages in the southern third of the site traverse about one-half the width of the terrace (Figure 3.1). One of these drainages is a small, broad valley 500 feet north of Rattlesnake Creek. It appears to propagate headward by successive small landslides rather than by stream erosion. The floor of that valley is relatively flat and contained standing water after the heavy rains of January and February, 1978.

The Irish Hills rise to a general elevation of 500 feet somewhat less than one-mile inland, and a maximum elevation of 1819 feet three miles to the north at Saddle Peak. Relatively flat areas occur on the ridge tops inland from the site. They occur at several different elevations and record progressive uplift of the Irish Hills during the past few million years, indicating that the uplift that created the coastal terrace is a continuing process over geological time.

3.5 GEOLOGIC UNITS

Geologic units in the vicinity of Rattlesnake Canyon range in age from Jurassic to Holocene. Their distribution is shown on Figure 3.2. The rock unit of Jurassic age is the Franciscan Formation, which crops out extensively in the Coast Ranges. This formation is present only in the extreme northwest portion of the area mapped (Figure 3.2). The primary bedrock formation at the site is a Cretaceous sandstone exposed along the base of the sea cliff and at the foot of the Irish Hills. Stratigraphic formations of Tertiary age crop out in the inland portion of the Irish Hills. The Tertiary formations include the Paso Robles Formation sandstone and conglomerate, and the Monterey Formation shales. The near-surface deposits at the site are Quaternary marine and nonmarine terrace materials of sandy clay, sand, and gravel. Quaternary landslide deposits are derived from the terrace materials along the bluff at the site and from Cretaceous and Tertiary formations in the Irish Hills.

The Franciscan Formation exhibits a wide variety of lithologies in the Coast Ranges. These lithologic units, while recognizable



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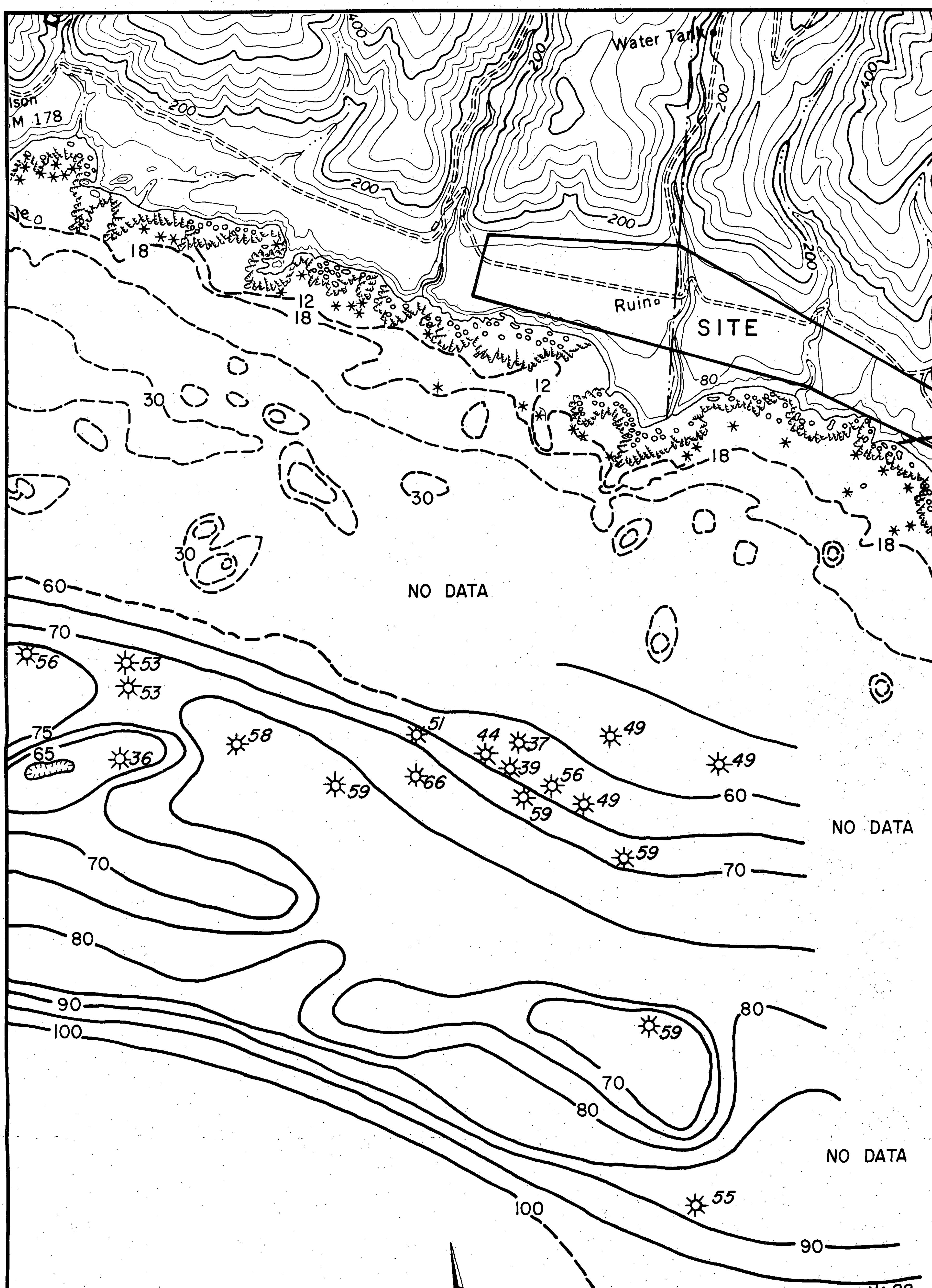
GEOLOGIC MAP OF THE RATTLESNAKE CANYON LNG SITE (modified from Hall, 1973)

Project No. 41033I

LNG TERMINALS EVALUATION

Figure: 3.2



EXPLANATION:

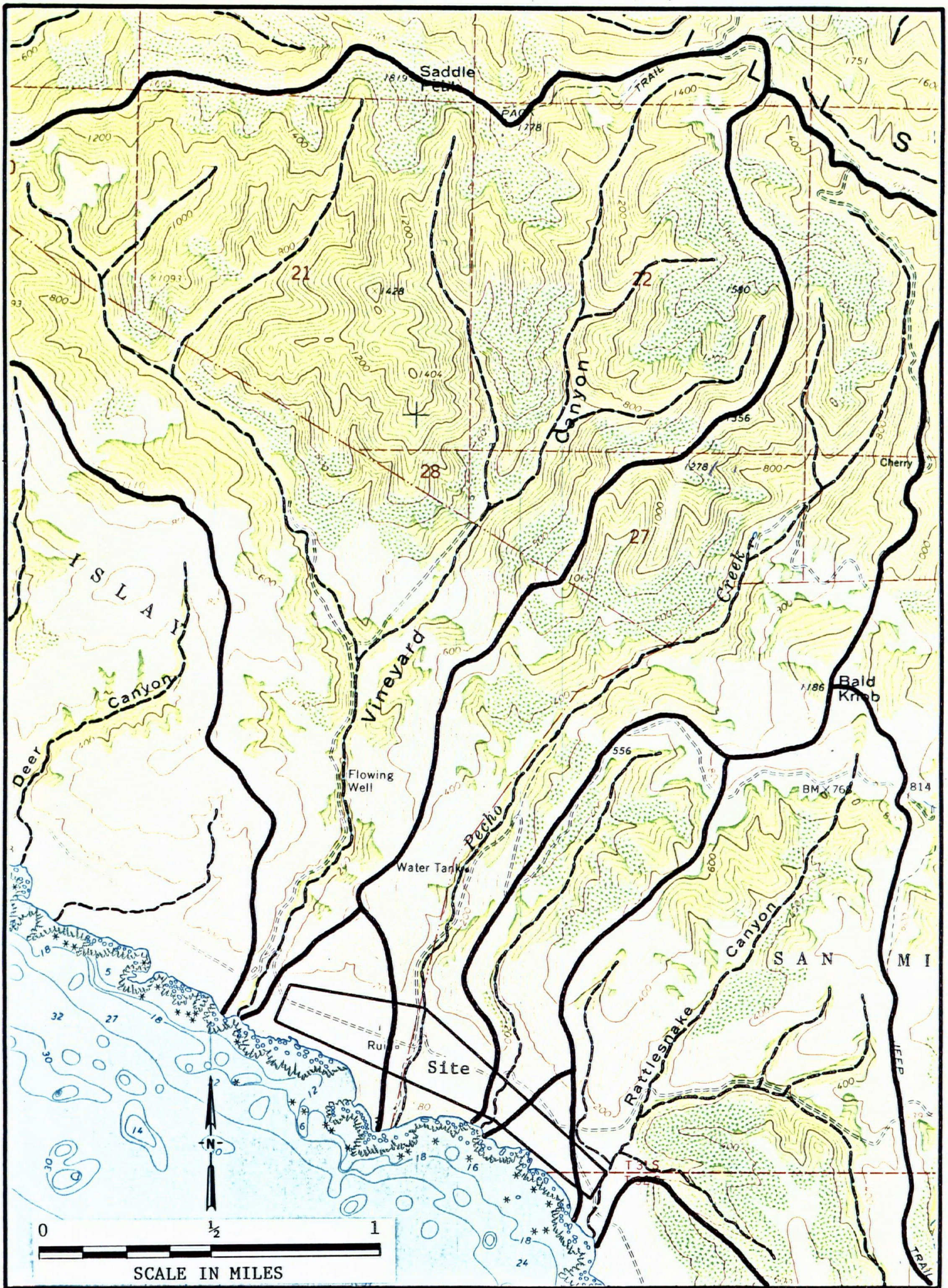
47 Submerged rock or pinnacle with depth below sea level from Woodward-Clyde Consultants survey.

Depth from USGS 7 1/2 minute quadrangle.

Depth from Woodward-Clyde Consultants survey.

500 0 500 1000
SCALE IN FEET
DEPTH IN FEET

WOODWARD-CLYDE CONSULTANTS	
BATHYMETRY OF THE RATTLESNAKE CANYON LNG SITE	
Project No. 41033I	Figure:
LNG TERMINALS EVALUATION	3.4



Project: LNG TERMINALS EVALUATION Project No: 410331	DRAINAGE MAP OF THE RATTLESNAKE CANYON LNG SITE	Fig: 3.5

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Vineyard Canyon, with a drainage basin of approximately 3-1/2 square miles, and Pecho Creek, with a drainage basin of approximately 1-3/4 square miles. Rattlesnake Canyon is smaller, with a drainage basin slightly larger than one square mile. A small unnamed drainage between Rattlesnake Canyon and Pecho Creek drains approximately 1/3 square mile. The streams are intermittent except for Vineyard Creek, which is perennially fed by a flowing well and ground water that appears to surface at a fault-controlled ground-water barrier. All of these streams were flowing at the time of field investigation, with flow volumes estimated to be between a few hundred and a few thousand gallons per minute in the larger drainages. During peak storm flows, discharge in excess of 10,000 gallons per minute may occur in Vineyard Canyon, Pecho Creek, and Rattlesnake Canyon. No exact figures are available as the streams are not known to be gauged.

Four streams drain the area inland from the site. Their channels appear to be sufficiently incised to contain any flows that may occur. The principal hazard from these streams may result from the road embankments that block the canyons. The entrances to the culverts could become partially blocked in heavy storms and cause the embankment to function as a dam. In this unlikely event, the embankment could be overtopped, eroded, and fail. This worst case may cause a surge that the incised channels across the terrace could not contain, and some water could flow across the terrace surface. Detailed design studies could show a possible flood across the site to be unlikely or might indicate the need for modification of the culverts at some stream crossings.

3.7.2 Stream Erosion

The canyons that traverse the site appear to have stable channels. Those that extend only partly across the terrace are eroding in a headward direction. One of these was reported by a rancher to have eroded an additional five feet into the terrace during the storms of January and February of 1978. Surface drainage should be diverted to the four larger canyons to control headward erosion. If not controlled, these features may eventually erode farther into the terrace.

3.7.3 Ground Water

During field reconnaissance in March 1978, some of the gravelly channel deposits within the terrace materials exposed in the sea cliff south of Vineyard Canyon fed springs with flows estimated to be approximately 20 gallons per minute. These springs were located in the Quaternary terrace materials about 20 feet above the bedrock. Elsewhere, seeps below gravels were of very low flow and in general only dampened the underlying material. Seeps were common at the bedrock-terrace contact. At the time of field studies, there was a small amount of standing water on the terrace surface, probably confined by local clayey soils.

Ground water was not observed either as seeps along the sea cliff or elsewhere in the area considered during reconnaissance in December 1977. The height of the sea cliff and its proximity to the mountain front suggests that the sea cliff acts as a free drainage face to any ground water that may accumulate in the terrace deposits. Consequently it is anticipated that, under normal conditions, the depth to ground water is near the interface between terrace deposits and underlying bedrock. Seeps and springs observed during March are attributed to heavy rains during the early months of 1978.

3.7.4 Fresh Water Supply

Fresh water supply in the study area is restricted to ground water. Although Vineyard Creek is shown as perennial near the site, it is fed by a flowing well upstream. It may be possible to develop this as a source of water for the LNG site. The water table appears to be low at the site, perhaps near sea level, due to the near-vertical sea cliffs and canyons. No springs or seeps not attributed to the heavy rains were noted in the sea cliffs or in drainages cut into the terraces. Ground water may occur near the base of the terrace deposits or within the Cretaceous sandstone. Present development of the ground water in the immediate study area consists of the flowing well approximately one mile upstream in Vineyard Canyon.

3.8 FAULTING AND SEISMICITY

3.8.1 Inactive Faults

Active faults are not known on the site or in the immediate vicinity of the site; however, inactive faults have been mapped inland from the terrace within the Irish Hills (Hall, 1973). The northern fault of the San Miguelito fault zone has the greatest stratigraphic displacement, but the stratigraphic displacement is less than 1,000 feet as shown on the cross-sections of Hall (1973). The San Miguelito fault zone (Figure 3.2) displaces the Tertiary formations and is therefore younger than these formations. There is no evidence, however, that it has displaced units of Quaternary age. Two discontinuous fault traces trend approximately east-west about one-half mile inland (Figure 3.2). These fault traces are apparently overlain by Paso Robles Formation of Tertiary age. They may be typical of the ancient faults found along the coast that occur entirely within the Cretaceous sandstone. Ancient faults with a few feet of displacement are common in the Cretaceous sandstone but do not affect the terrace deposits. Inactive faults older than the Cretaceous sandstone occur as thrust faults within the Franciscian Formation.

3.8.2 Active Faults

The active fault nearest to the area is the Hosgri fault, situated 5 miles offshore. This is the fault closest to the area which may generate the strongest seismic shaking at the site. Earthquakes expected from the Hosgri and other faults in the region are shown on Table 3.1; other active faults are known (Pacific Gas and Electric, 1975) but are believed to be less significant than the faults listed.

Table 3.1

FAULTS IN PROXIMITY TO THE RATTLESNAKE CANYON LNG SITE[1]

Fault Name	Distance From Site[1] (Miles)	Fault Type[1]	Fault Length[1] (Miles)	Age Category[1]	Estimated 100-year Earthquake[2]	Estimated Maximum Credible Earthquake[3]
Hosgri	5	Normal w/ Strike-slip	80	Quaternary Historic	6-1/4 to 6-3/4	7-1/2
Rinconada	17	Strike-Slip	85	Quaternary	5 to 6	7-1/2
La Panza	25	?	43	Quaternary	5 to 5-1/2	6-3/4
Santa Lucia Bank	33	Strike-Slip	60	Historic	5-3/4 to 6-1/4	7
San Juan	36	Strike-Slip	40	Quaternary	5 to 5-1/2	6-1/4
San Andreas	47	Strike-Slip	>500	Historic	7-1/2 to 8-1/4	8-1/2

[1] Data from Jennings (1975) unless otherwise noted.

[2] Estimated earthquake activity is a judgment based upon knowledge of the historical seismicity of the region and local area, and upon the recent geological history of the faults considered. These estimates are considered to be conservative, especially in the upper rnagesof magnitude.

[3] Based upon one-half the fault length rupturing to produce an earthquake of given magnitude, as shown by Patwardhan and others (1975). Estimates are to the nearest 1/4 magnitude value.

3.8.3 Seismicity

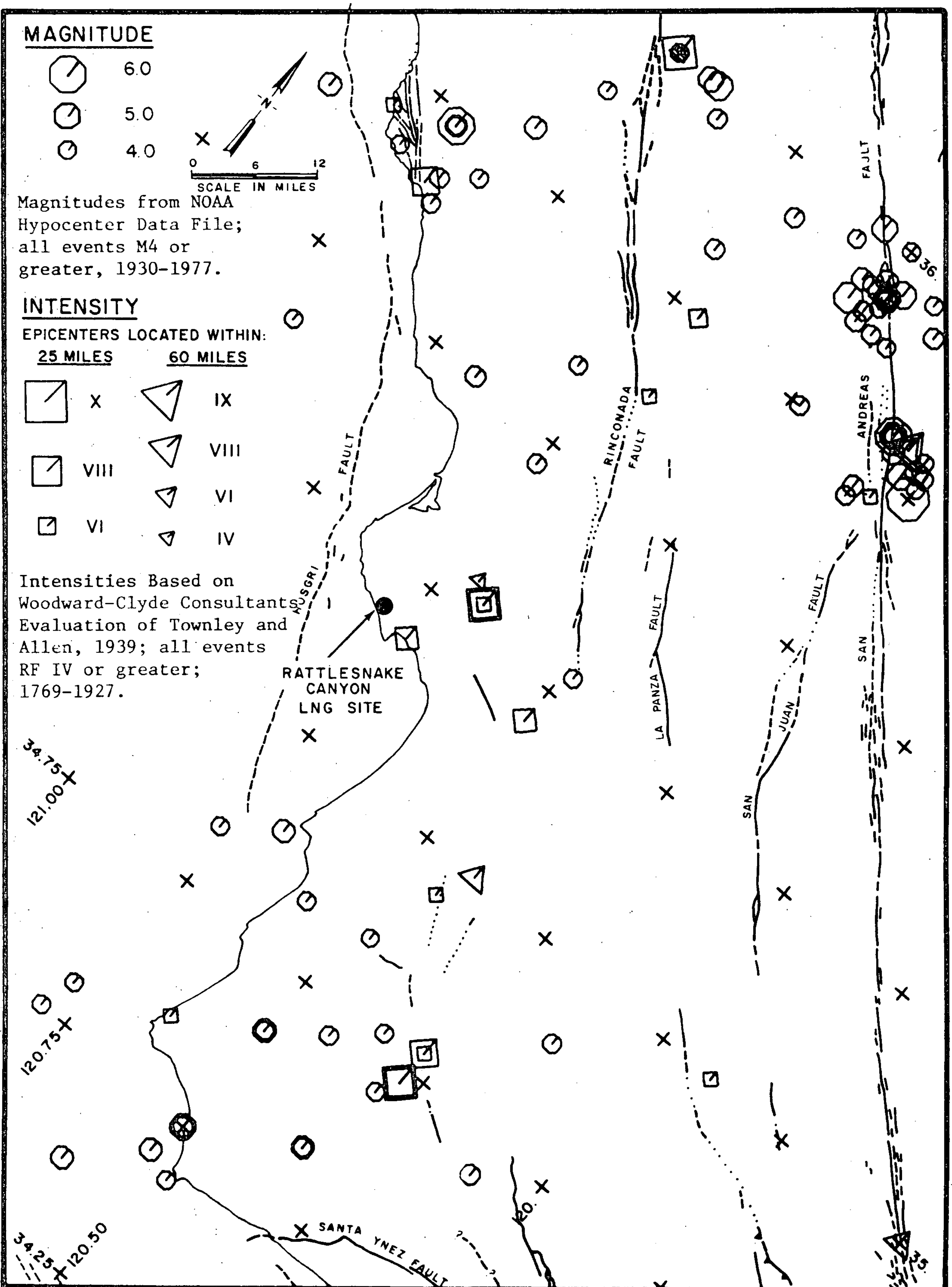
The central California coastal region has a lower level of historic seismic activity than the regions of the other sites (Figure 3.6). The 1952 Bryson (magnitude 6), and 1902 and 1915 Los Alamos (intensity VIII) earthquakes are the largest known historic onshore seismic events except for those associated with the San Andreas fault. The Point Arguello earthquake of 1927 (magnitude 7.3), as located by Byerly (1930), lies offshore and beyond the edge of Figure 3.6, but may have occurred on the Hosgri fault (Gawthrop, 1975) or some other nearshore fault. Scattered seismic activity that cannot be attributed to any single fault is located west of the San Andreas fault, both onshore and offshore.

3.8.4 Sources of Significant Earthquakes

Gawthrop (1975) re-evaluated seismographic records of the Point Arguello earthquake of 1927 and concluded it occurred on the Hosgri fault or on some other nearshore fault. Thus, the Hosgri fault has become a major design consideration for coastal structures in this region. The maximum credible earthquake for the Hosgri fault is estimated to be of magnitude 7-1/2 (D. Hamilton, personal communication, 1977).

The northern and southern terminations of the Hosgri fault are poorly known; some researchers believe that the Hosgri fault may be longer than is presently known. This greater length could affect the size of the estimated maximum credible earthquake, but changes of this nature are of minor consequence to this study.

The San Andreas fault lies 47 miles to the northwest, and is considered a potential source of earthquakes as large as magnitude 8-1/2. Smaller events may be expected for a 100-year period; magnitude 6-1/4 to 6-3/4 is estimated for the Hosgri fault, and magnitude 7-1/2 to 8-1/4 is estimated for the San Andreas fault.



Project: LNG TERMINALS EVALUATION **Project No**: 41033I	REGIONAL FAULT AND SEISMICITY MAP OF THE RATTLESNAKE CANYON LNG SITE	**Fig**: 3.6

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3.8.5 Seismic Hazards

The potential for seismically induced liquefaction appears to be low because of the limited water in the terrace deposits under normal conditions and the graded, granular and probably dense nature of the deeper terrace deposits. Surface rupture from faulting on the site does not appear to be a hazard, because active faults are several miles or more from the site. The height of the sea cliff (approximately 80 feet) protects the terrace surface from tsunami inundation, but the beach areas at the base of the sea cliff are susceptible to inundation. Zero-period ground accelerations as high as 0.4 g may result from a magnitude 6-3/4 earthquake on the Hosgri fault.

3.9 SLOPE STABILITY

3.9.1 Landslides

Quaternary landslides occur on or near the site at the seaward margin of the terrace in the southeastern portion of the site and at the base of the hills between Pecho Creek and the unnamed creek to the southeast (Figure 3.2). Many other landslides occur further inland. Small landslides or slumps affect much of the coastal bluff and are part of the normal erosion of the cliffs.

The landslides at the seaward margin of the terrace in the southeastern portion of the site appear to involve failure of the terrace deposits along the contact with the bedrock and do not appear to involve the bedrock. They indicate a local potential for instability. The largest of these landslides is located about 500 feet northwest of Rattlesnake Canyon. It is a broad, shallow depression in the terrace margin that opens to the sea through a narrow gap in undisturbed terrace deposits. This feature appears to have been formed by progressive movement of small landslides and mudflows. At the time of field studies, water was standing in the bottom of the depression. The source of the water is apparently underflow along the basal contact of the terrace deposits with bedrock.

The mechanism for the occurrence of this landslide may involve the presence of locally greater volumes of water within the terrace materials and perhaps a steeper gradient of the bedrock surface on which the terrace materials are situated. The shallow, perched groundwater may enter the terrace materials from the small tributary creek to Rattlesnake Canyon, located just inland at the foot of the Irish Hills, and flow toward the coast in buried gravel channels. It may be possible to stabilize the landslide by controlling the drainage upstream from the site. Significantly, no failures occured in early 1978 in this landslide, despite the unusually wet year, although some downslope motion may have occurred. The existence of these landslides in the margin of the terrace suggests that landslides may affect the terrace elsewhere. This condition may not be easily recognized, suggesting that this portion of the terrace might be sliding toward the sea cliff.

Elsewhere in the area of the site, failures of the terrace margin generally occur as small slumps rather than larger landslides. The small slumps are part of the normal process of cliff retreat and do not suggest massive failures. The exceptions are the landslides present southeast of the site where the terrace continues to narrow and steepen, and an incipient failure of the terrace margin immediately to the southeast of the largest mapped landslide. The incipient failure appears to affect a roughly equidimensional area about 100 feet across. It is manifest as a gentle, shallow depression a few feet deep. Inland from the landslides on the terrace margin the terrace surface exhibits its normal planar surface. At the base of the hills, Slossen and Associates (1978) report a flatter than normal terrace surface that may suggest landslide failure but could also be due to several other causes which they cite. In addition a small creek tributary to Rattlesnake Canyon flows a short distance parallel to topographic contours in a deeply incised channel within the terrace rather than down the slope. This channel could be inferred to be a pull-apart structure at the head of a landslide;

however, the tributary creek flows directly upon and through apparently undisturbed terrace deposits over its entire length, with no deformation of the terrace deposits observed. Therefore, it is unlikely that the tributary flows in a pull-apart structure. While there appears to be no general instability of the terrace, this southeastern portion of the terrace would require special investigation before placing critical facilities there.

Landslides in the Cretaceous sandstone near the paved roadway appear to be confined between Pecho Creek and the unnamed creek 1,500 feet to the southeast (Figure 3.2). Of these, the largest is near the unnamed creek. It may be of particular concern if an LNG tank were buried near it because the terrace materials may be providing lateral support to the landslide. If the terrace material were removed, the landslide could be reactivated. However, it may be stable under present conditions, and a surface LNG tank may be preferable if siting a tank near the landslide is necessary. The other, smaller landslides should be evaluated for their present stability and treated if necessary, but these appear to represent relatively minor geotechnical considerations. They indicate the base of the hills must be carefully evaluated for slope stability. A preliminary plant configuration suggests three LNG tanks could be sited northwest of Pecho Creek and one to the southeast. This would avoid the large landslide near the unnamed creek.

3.9.2 Cliff and Canyon Rim Recession

Sea cliff recession is controlled by the rate at which the sandstone at the base of the cliffs is eroded by wave action. The coastline is relatively stable because earlier erosion has aligned the coast approximately parallel to bedding. The orientation and steep dip of bedding (Figure 3.2) and the well consolidated nature of the sandstone appears to offer high resistance to erosion along the local coastline compared to areas such as Las Varas and Cojo Bay. Coastal recession that does occur leaves numerous rocks and sea stacks that absorb some of the wave energy and reduce the erosive power of the waves.

Slope stability must be considered for the sea cliff, the canyon rims, and the existing landslides. The sea cliff in the northwestern portion of the site is nearly vertical and is affected by a few small slumps and erosional gullies, and no major landslides. A setback of twice the approximate height of the cliff (about 200 feet from the terrace margin) for critical facilities or large structures should be considered in order to avoid the effects of relatively slow cliff recession and minor instability of the terrace margin. In the southeastern third of the site, the terrace margin is subject to more instability, but is at a lower elevation; the 200-foot setback should be sufficient in this area as well. The canyons that traverse the site appear to have achieved stable channel configurations with ample capacity to confine their respective streams. A setback of 100 feet from the canyon rims appears to be sufficient, considering their depth and apparent stability.

3.10 ENGINEERNG PROPERTIES AND CONSTRUCTION CONSIDERATIONS

3.10.1 Engineering Properties

The engineering properties and foundation conditions for geologic units likely to be encountered during development of the proposed site are briefly considered on Table 3.2. As no detailed testing is available, the evaluations are qualitative and relative between the various units. The units evaluated include alluvium, residual soils, terrace deposits and Cretaceous sandstone. The landslide deposits are considered generally unsuitable for foundations and would require special treatment where encountered.

Flat areas for surface tanks or excavations for buried tanks will most likely have terrace deposits for foundations. These materials appear to have adequate compressive strength beneath the dark, 3- to 10-foot thick soil. However, they appear to be

Table 3.2

ENGINEERING PROPERTIES AND FOUNDATION CONDITIONS
OF THE RATTLESNAKE CANYON LNG SITE

	MATERIALS			
	Alluvium	Residual Soils	Terrace Deposits	Cretaceous Sandstone
Compressibility	High	Medium	Medium	Low
Strength	Low	Medium	Medium	High
Permeability	Low	Medium	Medium-High	Low
Shrink/Swell	Medium	Low	Low	Low
Bearing Capacity	Low	Medium	Medium	Very High
Pile Support Capacity	*	*	Medium	Very High
Settlement	High	Medium	Low-Medium	Low
Frost Heave	High	Medium	Medium	Low

*Too thin to be applicable

moderately expansive in place and pads should be undercut and refilled with properly compacted granular materials to avoid excessive differential motion across the tanks.

3.10.2 Construction Considerations

Construction considerations are summarized in Table 3.3. Construction of an LNG facility would involve only limited cuts and fills unless the landslides in the hills bordering the inland margin of the site were found to be unstable under present conditions or with respect to cuts. The landslides are more likely to be reactivated if excavations for buried tanks are made. Excavation of pits in which buried tanks might be built could be hazardous if landslide deposits are excavated in cut slopes. The large landslide near Pecho Creek appears to be related to the ancient sea cliff now supported by the terrace deposits. Removal of the terrace deposits during excavation could reactivate this landslide. One advantage of placement of tanks in excavated pits is that a smaller set-back from the sea cliff would be neccesary and a greater flexibility in tank location could result. In addition, expansive soils of the terrace deposits may require less special foundation preparation where they have been more deeply buried for long periods of geologic time.

The Cretaceous sandstone is the primary material likely to be encountered offshore. It is very hard, moderately well cemented and has steeply dipping beds. It will probably be necessary to drill or blast holes for piers. Drilling of pier holes may be difficult because the steeply dipping bedding may cause the drill bit to tend to follow the bedding orientation rather than the planned drilling direction. The erosion rate of the sandstone appears to be low; however, it may be significant for the trestle foundation. Accordingly, nearshore trestle foundations may require erosion protection as part of the trestle design.

Table 3.3

CONSTRUCTION CONSIDERATIONS
OF THE RATTLESNAKE CANYON LNG SITE

	MATERIALS			
	Alluvium	Residual Soils	Terrace Deposits	Cretaceous Sandstone
Difficulty of Excavation	Low	Low	Low	Medium-High
Stability of Temporary Excavations	Low	Low	Medium	High
Use as Engineered Fill	Fair-Good	Poor	Fair-Good	Fair
Subgrade for Haul Roads	Fair-Good	Poor	Fair-Good	Fair

Preliminary evaluation of under-sea tunneling conditions for placing the cryogenic pipeline is based on observations onshore; the Cretaceous sandstones can be excavated by blasting and probably by tunnel boring machines. The rock mass appears to be strong, with joints widely spaced and tight where unweathered. Stability and support problems may be encountered due to the steeply dipping bedding attitudes, particularly where sheared shale interbeds occur and where faults and shear planes are present. Due to the probable relatively shallow depth of such a tunnel and the infinite source of water overhead, problems of water inflows along permeable discontinuities at faults or along bedding could be severe. Offshore borings and ground-water testing are required to evaluate the extent of potential ground-water inflows. With such short tunnel lengths involved and the potential problems of stability and severe water inflows, convential mining techniques may prove more feasible than a tunnel boring machine, unless additional data shows otherwise. It may be even more feasible to excavate an offshore trench to achieve the subsea alignment.

The Franciscan Formationmay crop out along some portion of the trestle or tunnel alignment. If present, this formation could significantly complicate construction of the trestle and especially the tunnel.

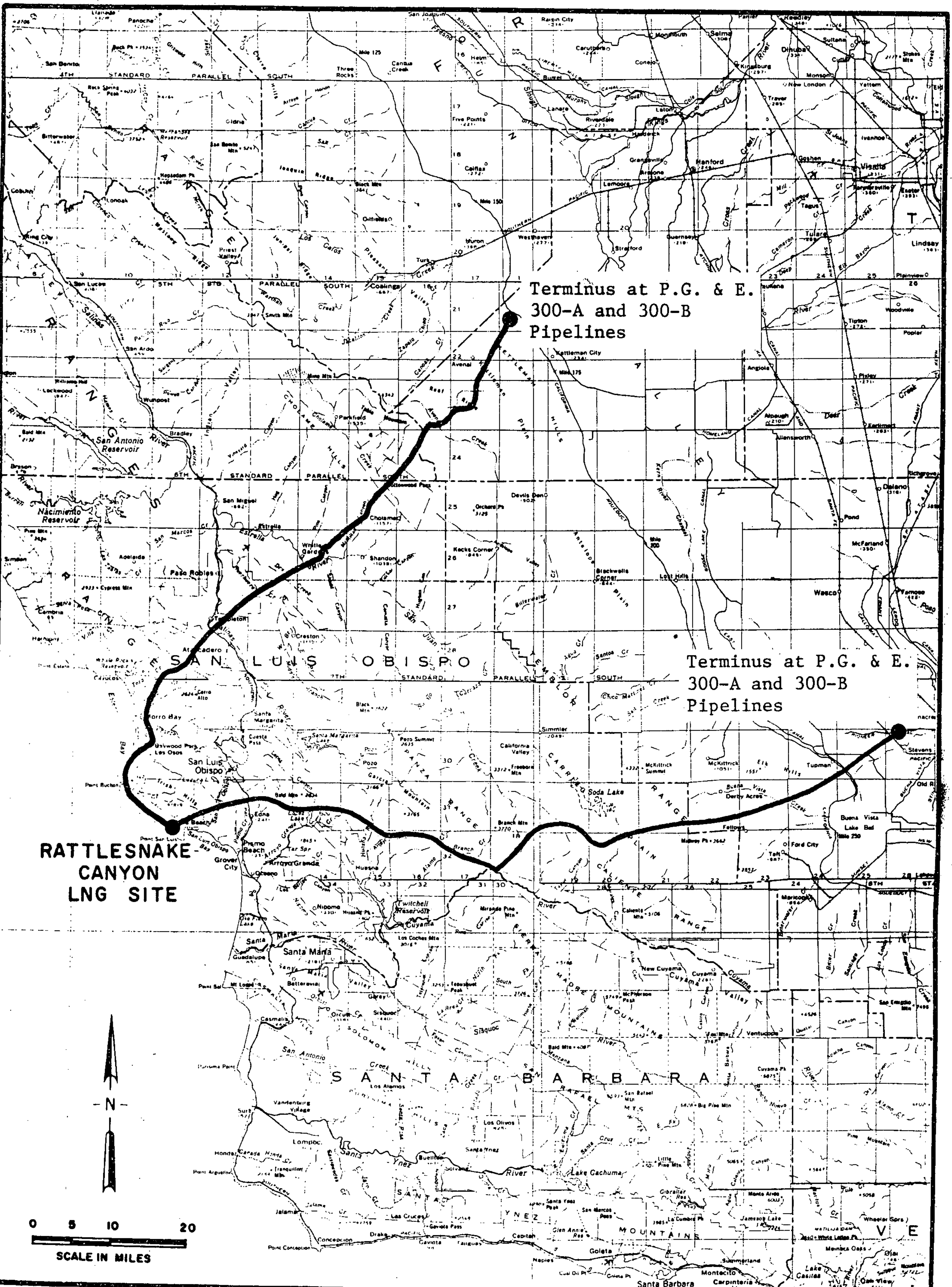
Material for use as concrete aggregate could probably be obtained from the same source used in the construction of the Diablo Canyon Nuclear Power Plant or from similar sources. The nature or location of these sources is not known at this time. Crushed, unweathered Cretaceous sandstone may be a potential candidate for aggregate; however, further evaluation is necessary. Borrow material for fill or road base may be obtained from local sources such as the terrace deposits, alluvium, or Cretaceous sandstone. The Cretaceous sandstone may require processing for use as foundation material.

3.11 EXIT PIPELINE ROUTES

Gas transmission lines from an LNG import terminal at Rattlesnake Canyon may traverse a 90-mile-long route to reach existing large diameter lines in the Central Valley near Kettleman City or alternatively a 100-mile-long route to Gosford near Bakersfield (Figure 3.7).

The alternative route with the fewest geotechnical problems would extend north along the coastal terrace and inland from Morro Bay to an existing pipeline corridor. This corridor begins at the PG&E power plant near Morro Rock and traverses through the steep, landslide-prone geologic terrain of the Franciscan Formation in the Coast Range. Near Paso Robles the terrain changes to more gentle topography developed on relatively stable, undeformed, nonmarine rock units. A few miles beyond Cholame Valley a short segment of landslide-prone Franciscan Formation and Knoxville Formation are encountered before large diameter trunk lines are reached near Kettleman City. Hydrocompaction is a common geologic hazard in the western Central Valley; the ground surface subsides due to compaction of the underlying sediments after wetting. This route crosses two youthful faults, the Rinconada fault and the San Andreas fault. The route avoids the terrain where excavation may be difficult and the long distances through unstable rocks of the Franciscan Formation that would be encountered by a more southerly route to the Central Valley.

Another alternative pipeline route would go directly east from the site to join the Gosford route proposed for the Cojo Bay site. The total distance to Gosford would be between 100 and 120 miles depending on final pipeline alignment. This route begins by crossing the landslide-prone San Luis Hills to the San Luis Valley which may be locally prone to liquefaction. From San Luis Valley the route crosses the rugged Santa Lucia Range. This range is underlain by extremely landslide-prone Cretaceous rocks over long intervals. More active faults would be crossed by this alignment because the area is characterized by major splay faults from the San Andreas fault and Rinconada fault. The splay faults may have a low risk of significant surface displacement because of their short length. Other hazards over the remainder of the route are described in Section 4.11. They include flood, surface displacement at active fault crossings and subsidence.



Project: LNG TERMINALS EVALUATION Project No: 41033I	EXIT PIPELINE ROUTES FOR THE RATTLESNAKE CANYON LNG SITE	Fig: 3.7

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4.0 COJO BAY (PT. CONCEPTION) LNG SITE

4.1 SUMMARY

The proposed Cojo Bay LNG site is located 3-1/2 miles east of Point Conception in western Santa Barbara County. It is situated on a gently sloping coastal terrace that is approximately 2,500 feet in width and 80 to 200 feet in elevation. The coastal terrace is underlain by competent sands, silts, and clays to an average depth of about 50 feet, with smaller areas of loose, compressible alluvium and hard shale and mudstone. Hard shale and mudstone form an irregular bedrock surface beneath the site below the alluvium and terrace deposits. Shale is exposed offshore where it has been eroded into a gently sloping surface without significant relief. Cojo Canyon flows through the site and contains a perennial stream of small discharge. Ground water is within the alluvium and bedrock at about sea level in the southern portion of the site, and near the surface in the northern portion underlain by bedrock and alluvium. The south branch of the Santa Ynez fault is 2-3/4 miles offshore and is interpreted as a potential source of earthquakes as large as magnitude 7-1/2. Other inland branches of the Santa Ynez fault are also interpreted to be potential sources of nearby earthquakes. The San Andreas fault, 62 miles to the northeast, may produce earthquakes as large as magnitude 8-1/2. Landslides have not been identified within the site.

Major geotechnical considerations include the foundation suitability of the terrace deposits and alluvium, the need for dewatering of excavations, erosion control, slope instability, the irregular bedrock surface of unknown origin and exposure to potentially damaging earthquakes. These considerations suggest Cojo Bay may be no more geotechnically favorable than other sites. Based on limited data, the terrace deposits below the loose surface soils are suitable for foundations. Alluvial deposits within the floodplain of Cojo and Cementerio Canyons may be unsuitable for foundations and they may need to be removed and replaced with engineered fill. Ground water is near the surface in areas where excavations are planned, and extensive dewatering may be required if alluvial deposits are removed. The ravines in the coastal bluff are highly active erosional features and may require stabilization by excavating to a smooth contour and filling with engineered fill. In addition, they should be protected from surface runoff. Coastal bluff recession of approximtely 6 inches per year should be considered for design. The irregular bedrock surface may conceal small faults of unknown activity. Seismic shaking from both nearby and distant earthquake sources is expected to be no more severe than for the other retained sites. The possibility of local, limited liquefaction is low within the terrace deposits, but needs further consideration where they are below the water table. The alluvial materials in Cojo Canyon are susceptible to liquefaction.

4.2 MAJOR GEOTECHNICAL CONSIDERATIONS

Geotechnical considerations include the foundation suitability of the terrace deposits and alluvium, the need for dewatering of excavations, erosion control, slope instability and seismic exposure.

4.2.1 Implications of Eastward Site Relocation

In April 1978, the proposed location of the Cojo Bay LNG site was moved 1,500 feet east by Western LNG Terminal Associates to avoid an archeological site near the former western site boundary. The relocated site overlaps the original site by about 50%. Movement of the site gives rise to new geotechnical considerations: landsliding in the terrace deposits and filling of a 40-foot-deep unnamed canyon that traverses the terrace.

One landslide has been identified by Slossen and Associates (1978) near the head of the unnamed canyon. This landslide appears to affect only the terrace deposits and may be controlled by the presence of ground water along the bedrock interface and a steepening of the bedrock surface. This landslide would need to be removed and repaired by placement of engineered fill. The potential for failure elsewhere along the bedrock-terrace deposit interface should be evaluated. The canyon drains water from the terrace and hill front, and may be important for maintenance of a low water table in the terrace deposits. Drainage structures for both surface and ground water should be provided if the canyon is filled. If it is not filled, surface water from the west should be diverted from the canyon to avoid headward erosion of the small side canyons.

A geotechnical advantage of the relocated site is that it is better centered between canyons that traverse the terrace; hence, the problem of compressible and liquefiable soils in Cojo Canyon may be avoided. The potential need for major dewatering during excavation of alluvium in Cojo Canyon may also be avoided.

4.2.2 Foundation Suitability

The foundation materials likely to be encountered at expected excavation depths include all of the major geologic materials found on the site. Of these, the suitability of the terrace deposits and alluvium need special consideration in design. The terrace deposits below the surficial soils are generally suitable for the structures anticipated. Based on limited data, the clayey soils of the terrace deposits are moderately expansive and hard, and the sandy and silty soils are generally dense. These materials are not expected to experience significant settlement but may have a susceptibility to liquefaction under seismic loads. The alluvial materials in Cojo Canyon are susceptible to liquefaction.

4.2.3 Dewatering of Excavations

Ground water is near the surface in areas where excavations are planned and minor dewatering subsequent to construction may be required for tanks sited on terrace deposits and bedrock. Proposed siting of one tank on alluvium may require either a special concrete mat foundation to reduce differential settlement or removal of the alluvial materials and replacement with engineered fill to a depth of approximately 40 feet. Existing boring data appear insufficient to determine the need for these procedures. If the alluvium is removed to bedrock, large-scale dewatering of the excavation may be required, as the water table is near the surface and the alluvial materials probably transmit large subsurface flows. It may be necessary to avoid the alluvium when final positions of the tanks are selected.

4.2.4 Erosion Control and Slope Stability

The ravines in the coastal bluffs are highly active erosional features that may erode many feet headward during years of heavy rain. The rate of headward erosion during the winter of 1978 is not known, but should be evaluated. One method of stabilizing the ravines would be to protect them from sheet wash derived from the terrace. All surface drainage on the terrace could be diverted to Cojo Canyon; this diversion of runoff should reduce erosion of the ravine. The residual erosion rate due to local runoff may still be significant. If so, the ravines should be excavated to an appropriate level and replaced with engineered fill.

4.2.5 Coastal Erosion

Cliff recession has been estimated to occur at a rate of 6 inches per year (Moore and Taber, 1974). The coastal terrace is broad enough to absorb this rate for many years without affecting LNG facilities if they are sufficiently set back from the sea cliff and if the trestle foundations are protected from erosion. Cliff recession over the life of the facility may affect the trestle foundation if piles are not set deeply enough within the bedrock near the beach. Shore protection such as riprap at the base of the sea cliff may reduce the rate of cliff recession.

4.2.6 Seismic Exposure

The irregular bedrock surface beneath the terrace deposits may conceal small faults of unknown activity. Relief on the bedrock surface beneath the Quaternary terrace deposits and alluvium is approximately 150 feet within the site. This relief appears to occur on an irregular surface, considering the outcrop pattern shown on the geologic map (Dames and Moore, 1977) and bedrock exposures observed during field reconnaissance. Bedrock is exposed at the confluence of Cojo and Cementerio Canyons in addition to areas shown on Figure 4.2. Similar irregularities in the bedrock surface are associated with active faults at other localities. The bedrock irregularities may be due to ancient erosion on the bedrock surface; however, the possibility of small-scale on-site faulting cannot be excluded with presently available data.

Seismic shaking due to both nearby and distant earthquake sources is expected to be severe, although no more so than for the other proposed LNG sites. The south branch of the Santa Ynez fault is 2-3/4 miles offshore. Other branches of the Santa Ynez fault are inland from the site at greater distances. Most of the branches, including the nearby south branch, are interpreted to be potential sources of earthquakes as large as magnitude 7-1/2. The San Andreas fault is 62 miles to the northeast, and may be a potential source of earthquakes as large as magnitude 8-1/2.

4.3 LOCATION

The proposed Cojo Bay LNG site is located in Santa Barbara County about 3-1/2 miles east of Point Conception. The area is reached by a private, paved road from Highway 101 at Gaviota. Access for construction equipment and materials may also be provided by the Southern Pacific Railroad that crosses the southern portion of the site at the top of the coastal bluffs.

The onshore portion of the proposed site considered for development is situated on a coastal terrace and is for the most part east of Cojo Canyon (Figure 4.1). Existing land use is for the railroad and grazing. There are a few private homes in the general vicinity to the east.

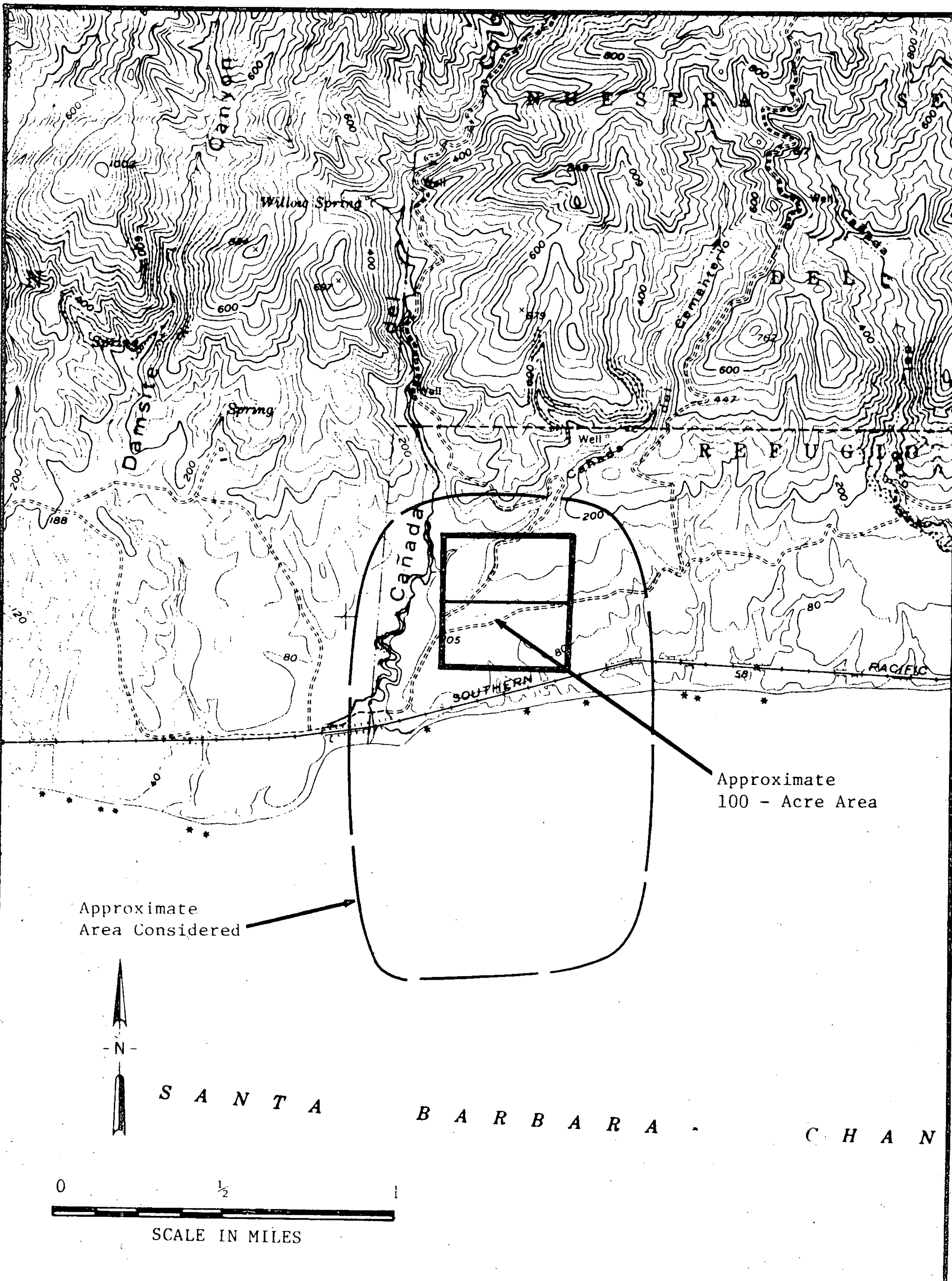
4.4 TOPOGRAPHY

The site is on a coastal terrace developed at the southern margin of the western Santa Ynez Mountains. The site is bounded by an 80-foot-high coastal bluff on the south and the foothills of the Santa Ynez Mountains on the north (Figure 4.1). The Santa Ynez Mountains west of Highway 101 reach an elevation of approximately 1,500 feet. The terrace has a 3% grade for 600 to 800 feet from the sea cliff and an approximate 6% grade over the remainder of the site. Canyons that traverse the terrace are incised into their adjacent flood plains an average of 25 feet. The flood plain of Cojo Canyon and Cementerio Canyon is about 1,000 feet wide and is bounded by bluffs approximately 25 feet in height. Three small, steep canyons traverse about 500 feet of the width of the flatter portion of the terrace.

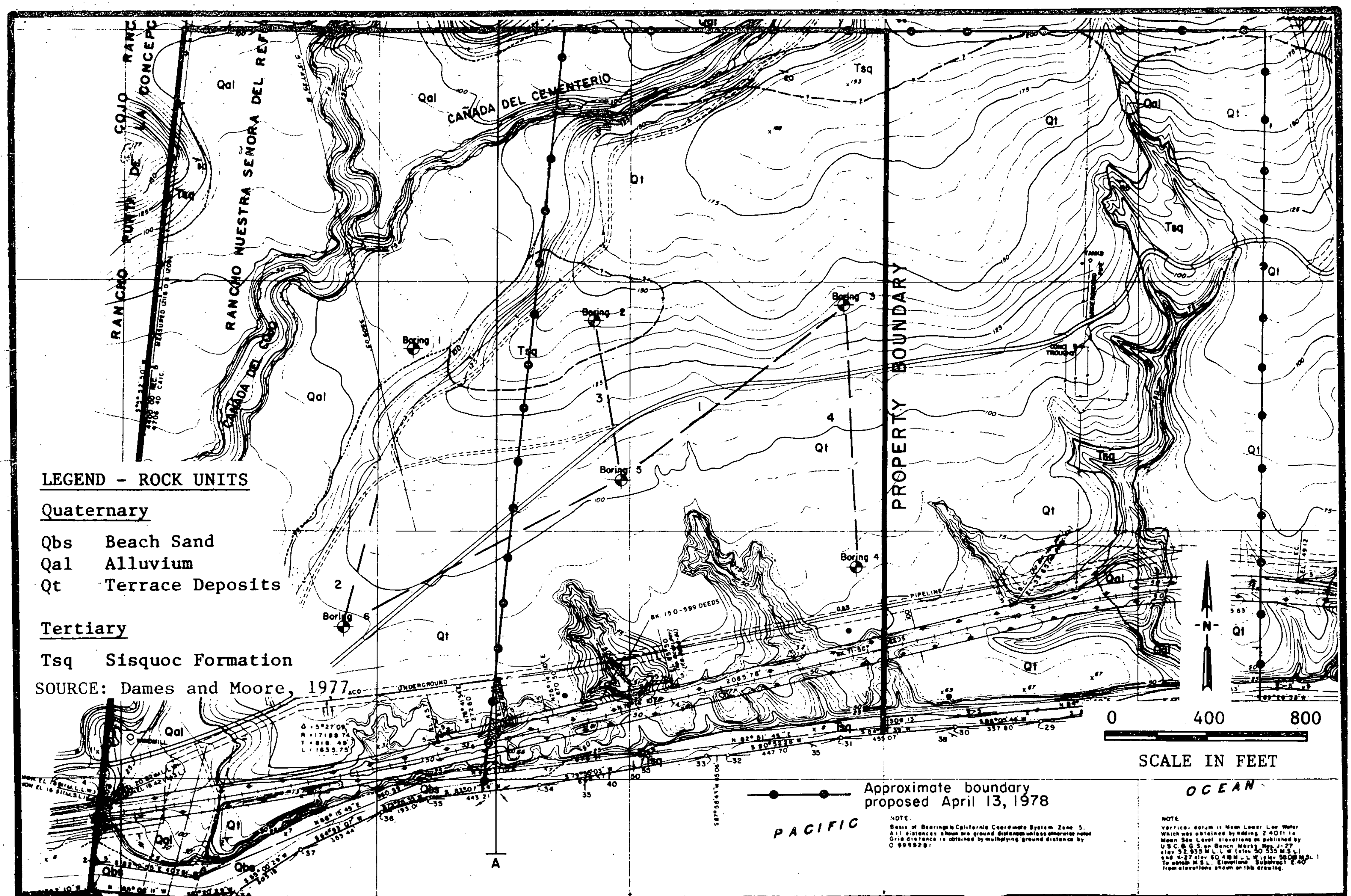
Sites for LNG storage tanks would be developed by excavation of moderate cuts in the steeper portions of the terrace and partial filling of the flood plain of Cojo Canyon.

4.5 GEOLOGIC UNITS

This discussion is based mainly on reports by Slossen and Associates (1978). Geologic units in the vicinity of Cojo Bay range in age from Tertiary to Holocene. Their distribution is shown on Figure 4.2 and 4.3. The oldest units are the Tertiary-age Monterey and Sisquoc Formations that form the bedrock exposed in the sea cliff and in the foothills north of the site. These bedrock formations are overlain by deposits of Quaternary age. The Quaternary deposits include the terrace deposits of both marine and nonmarine origin, recent alluvium, beach sand, and slope wash.



Project LNG TERMINALS EVALUATION Project No: 410331	LOCATION MAP OF THE COJO BAY (PT. CONCEPTION) LNG SITE	Fig: 4.1



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Project No. 41033I

GEOLOGIC MAP OF THE COJO BAY (PT. CONCEPTION) LNG SITE

Fig. 4.2

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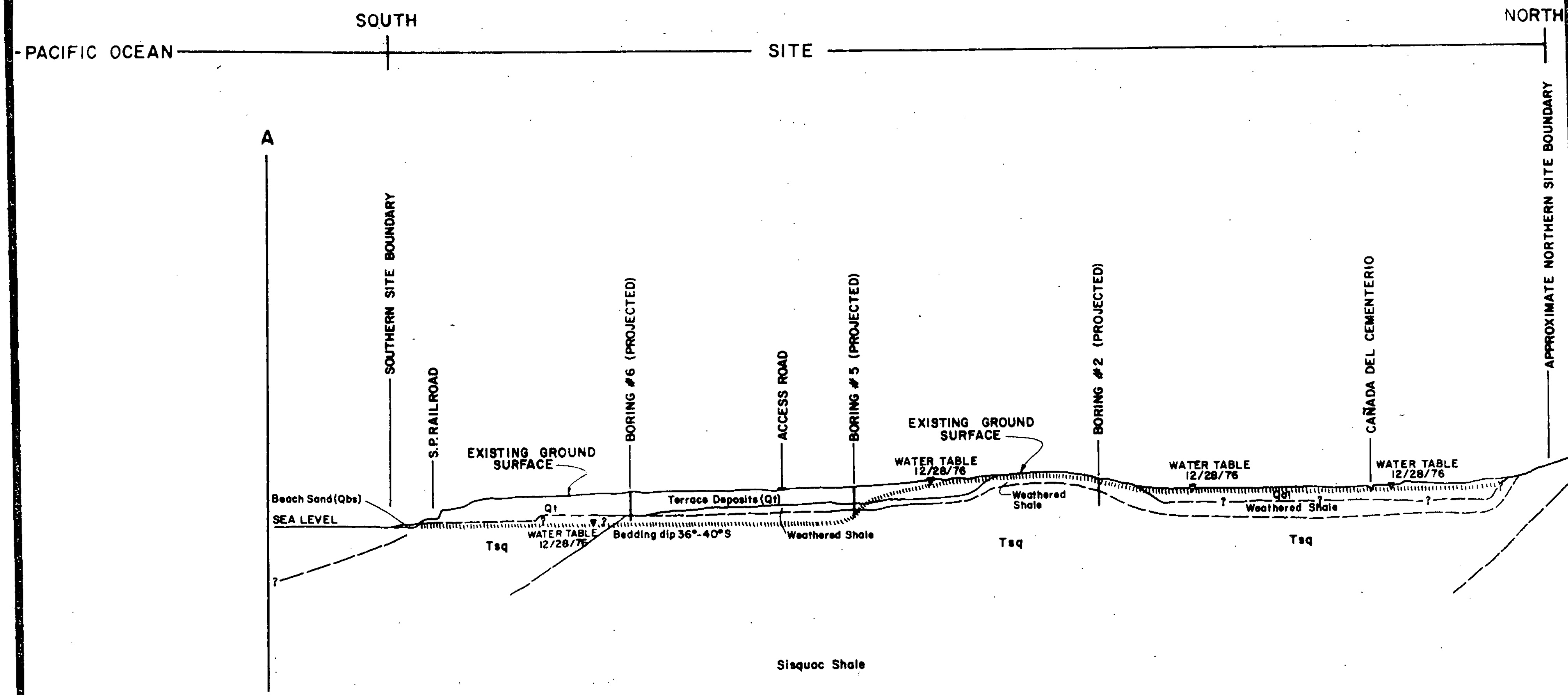

LEGEND - ROCK UNITS

Quaternary

Qbs Beach Sand
Qal Alluvium
Qt Terrace

Tertiary

Tsq Sisquoc Formation

SOURCE; Dames and Moore, 1977

0 400 800

SCALE IN FEET

Project: LNG TERMINALS EVALUATION Project No. 41033I	DIAGRAMMATIC CROSS-SECTION OF THE COJO BAY (PT. CONCEPTION) LNG SITE	Fig. 4.3

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The Monterey Formation is Miocene in age and crops out 1,500 feet north of the site. It is present at depths of approximately 2,000 feet beneath the site. This formation consists of hard shales.

The Sisquoc Formation is Pliocene and late Miocene in age and comprises the bedrock near the surface beneath the site. It consists of thinly bedded shale and mudstone. At the site it dips 40 to 50 degrees to the south.

The marine terrace deposits are about 30 feet thick at the sea cliff and rest directly on the bedrock. They are present in the southern one-half of the site and consist of silty and clayey, fine to medium sands. The liquefaction potential of these materials appears to require further consideration. Overlying the marine terrace deposits is a mixture of unconsolidated sandy silt, silty or clayey sand, and sandy or silty clay containing angular shale clasts and well rounded cobbles up to 4 inches in diameter (Dames and Moore, 1977). These nonmarine terrace deposits are very stiff to hard.

Quaternary alluvium underlies the flood plain of Cojo and Cementerio Canyons to depths as great as 40 feet. Near the confluence of the two canyons, the Sisquoc Formation lies just below the surface of the flood plain and is exposed in a cutbank. This outcrop suggests considerable variation in the thickness of alluvium at the site. The alluvium consists of unconsolidated clay, silt, sand and gravel; it may have to be removed and mixed with more granular materials for use as fill.

Beach sands occur along the coast beneath the sea cliff. They are generally less than 5 feet in thickness except perhaps near the mouth of Cojo Canyon (Dames and Moore, 1977).

Surface soils are reported to consist of clayey and sandy silts with some coarse sand and fine gravel. The subsurface soil conditions are variable depending on location, but consist predominantly of silty and sandy clays overlying shale. These materials are moderately expansive (Dames and Moore, 1977).

4.6 OFFSHORE GEOLOGY

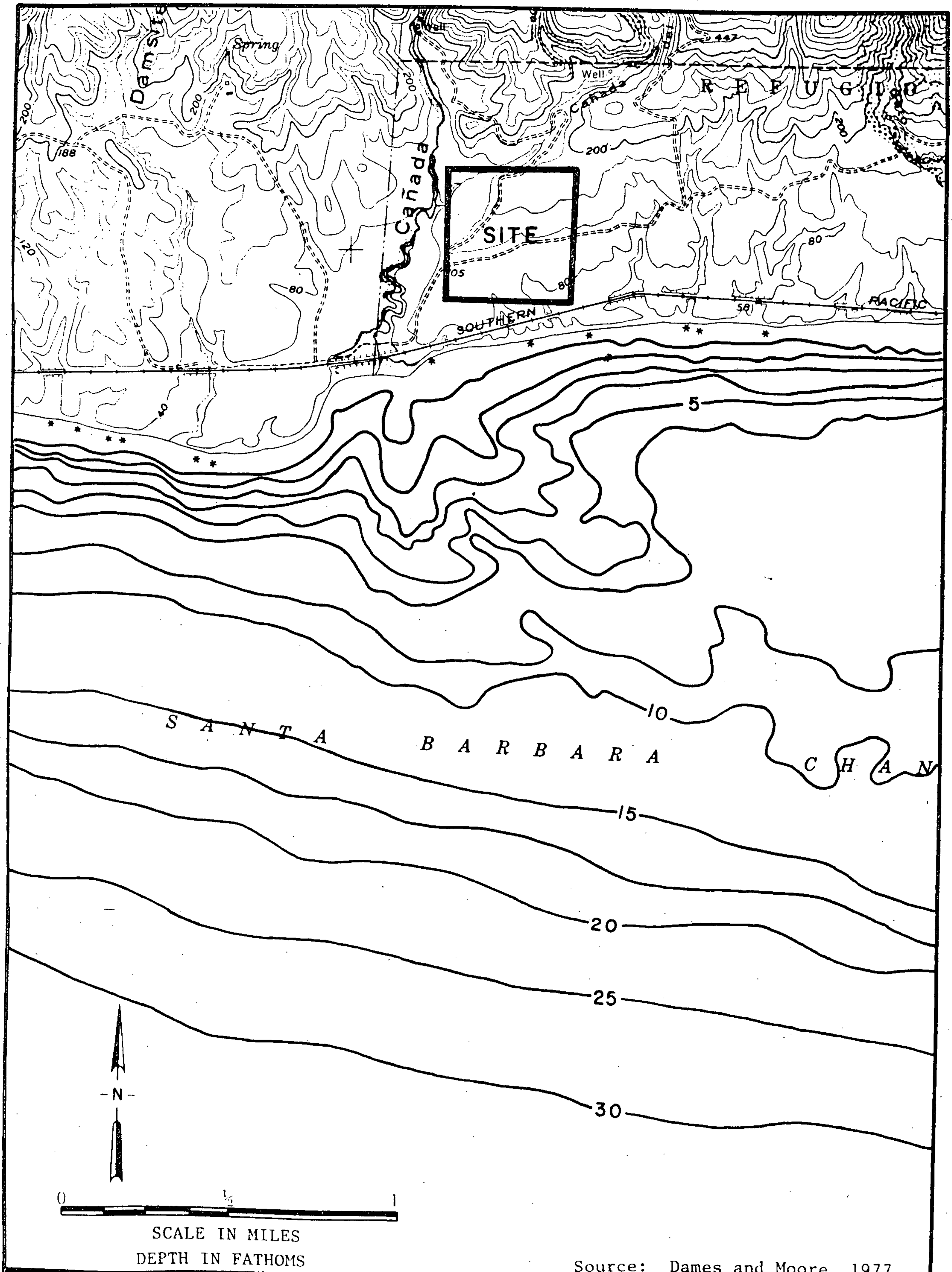
The offshore portion of the site has two low, broad ridges that extend southward and southeastward from the site (Figure 4.4). The valley between them is the seaward extension of Cojo Canyon. Beyond depths of 60 feet (10 fathoms), the bottom slopes relatively uniformly.

An offshore geophysical survey conducted by Dames and Moore (1977) suggests that the bottom is mainly exposed shale bedrock, and shale debris on a bedrock surface. The bottom is sandy southwestward from the mouth of Cojo Canyon. The general southward dip of the Sisquoc Formation onshore continues in the offshore area as far as a fault inferred to be the south branch of the Santa Ynez fault. Beyond this fault there is no apparent structure in the bedrock. The fault is approximately 2-3/4 miles offshore. Its connection with the onshore portion of the south branch of the Santa Ynez fault is based on the fact that the end of the mapped onshore and offshore fault segments project toward each other. The area of connection is near shore where good quality geophysical data are extremely difficult to obtain. No data have been obtained to define the presence or absence of the fault connection (Dibblee, 1978).

4.7 HYDROLOGY

4.7.1 Surface Water

Drainage across the site is by sheet wash on the terrace surface into the steep ravines at the seaward margin of the terrace, and through Cojo and Cementerio Canyons (Figure 4.5). These two main canyons drain an area of 3.2 square miles (Slossen and Associates, 1978). Their discharge is normally modest and perennial. Larger flows occur in the winter months and during storms. The canyons are sufficiently incised into their flood



Source: Dames and Moore, 1977

Project: LNG TERMINALS EVALUATION Project No: 41033I	BATHYMETRY OF COJO BAY (PT. CONCEPTION) LNG SITE	Fig: 4.4

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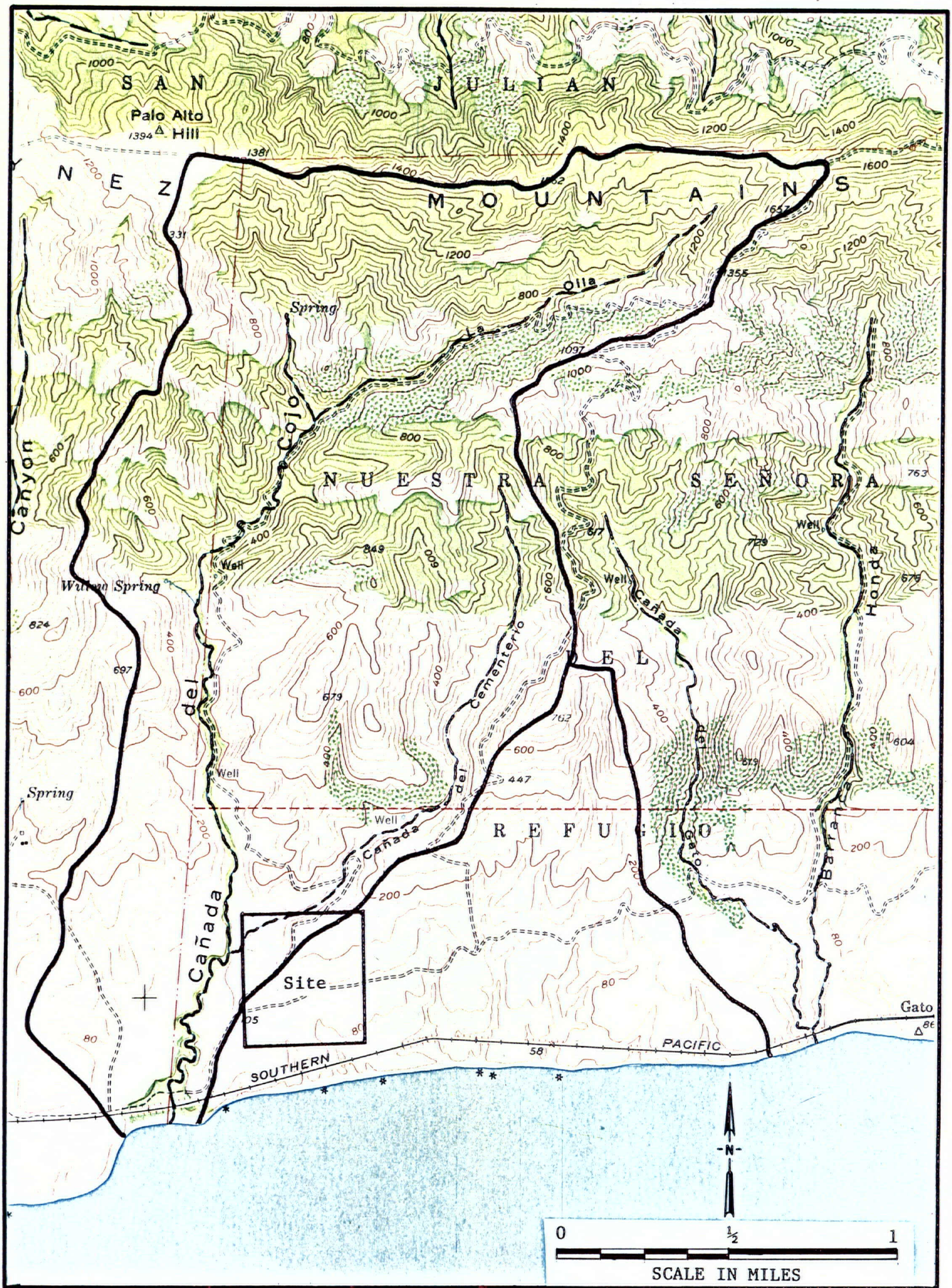


Project: LNG TERMINALS EVALUATION Project No: 41033I	DRAINAGE MAP OF THE COJO BAY (PT. CONCEPTION) LNG SITE	Fig: 4.5

WOODWARD-CLYDE CONSULTANTS

plain to contain large flow volumes. The potential for floods across the flood plain should be investigated further and necessary flood protection provided.

4.7.2 Stream Erosion

Erosion in Cojo Canyon does not appear to be a major consideration because the stream is incised. Floods across the flood plain appear to have been rare, as there are few gullies in the flood plain that drain to the incised canyon. The principal erosion consists of undercutting of the downstream cut bank of each entrenched meander. The impact of this erosion can be minimized by setting the facilities back from the stream channel.

The three large gullies in the seaward margin of the terrace are active erosional features that may propagate northward into the terrace at a high rate during large storms every 20 to 25 years (Slossen and Associates, 1978). These gullies may be stabilized with engineered fill and erosion protection.

4.7.3 Ground Water

Ground water is present in the alluvial materials, the terrace deposits, and to a lesser extent in fractures in the Sisquoc Formation. Ground water levels rise from near sea level at the coast and in the southern portion of the site, to within a few feet of the surface in the northern portion of the area. The water table is shown on Figure 4.3. During the winter of 1978, ground-water seeps were common along the bedrock-terrace contact at the base of the sea cliff.

Site development plans will need to consider the near-surface ground water in the northern portion of the site. It may be necessary to dewater that area prior to site development, and to provide special drainage and foundation designs for the proposed facilities. The water table was measured at the end of 1976 during a drought (Dames and Moore, 1977); the water table may be higher under normal conditions, especially in the terrace deposits in the southern portion of the site. The sea cliff appears to function as a free drainage face and should maintain a low water table near the bluff.

4.7.4 Fresh Water Supply

No data are available regarding the quality of surface and ground water in the area. There appear to be adequate quantities of water for construction and plant operation.

4.8 FAULTS AND SEISMICITY

4.8.1 Inactive Faults

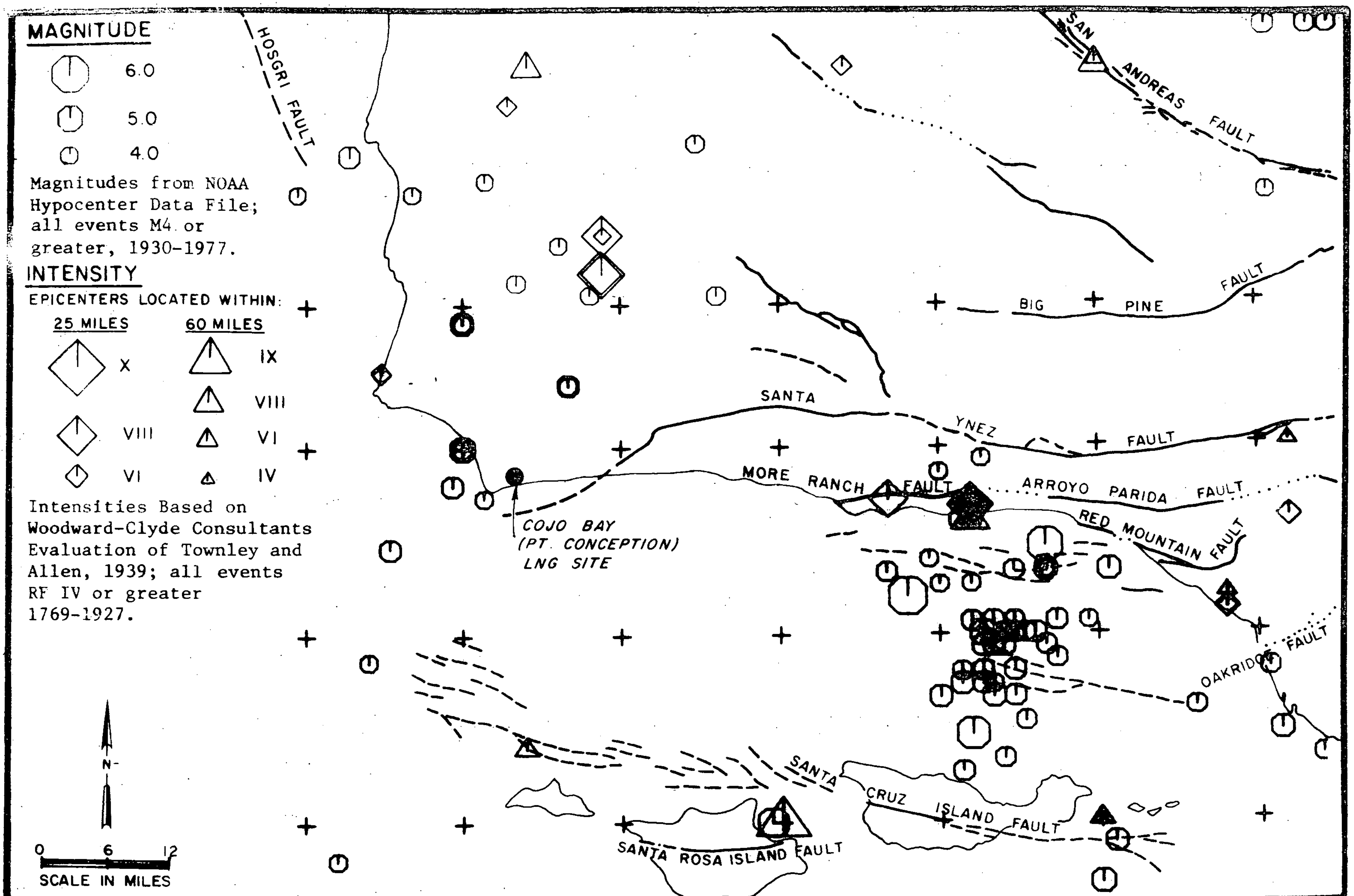
No on-site faults were identified by Dames and Moore (1977) or Slossen and Associates (1978).

4.8.2 Active Faults

No faults of Quaternary age are shown by Jennings (1975) within 5 miles of the site. However, recent investigation supervised by Dames and Moore (1977) suggests Quaternary but not Holocene activity along the south branch of the Santa Ynez fault near Alegria Creek, 8 miles east of the site. Dibblee (1978) assigns a late Pleistocene age to the most recent displacement based on several assumptions regarding the age of alluvial and terrace units, and displacement relationships. The displacement appears to decrease westward and may end in the offshore area (Dibblee, 1978). Slossen and Associates (1978) report the fault to be active or potentially active, because stream terrace deposits inferred to be younger than 50,000 years old are displaced. Further studies might be required if the Holocene rather than older ages of faulting were critical to an LNG import terminal.

4.8.3 Seismicity

This zone is dominated by large earthquakes that have occurred in the Santa Barbara Channel region, particularly those of 1812, 1925 and 1941. On the north-central part of Figure 4.6, seismic activity associated with the White Wolf fault and the 1952 Kern County earthquake is shown. The earthquake activity in the



Project LNG TERMINALS EVALUATION Project No. 41033I	REGIONAL FAULT AND SEISMICITY MAP OF THE COJO BAY (PT. CONCEPTION) LNG SITE	Fig. 4.6

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western part of the Santa Barbara Channel near the site has been much less than that in the central and eastern channel.

4.8.4 Sources of Significant Earthquakes

A magnitude 7-1/2 earthquake on the south branch of the Santa Ynez fault could produce strong ground motion in the Cojo Canyon area. Other branches of the Santa Ynez fault lie approximately 3 miles north of the site and may be a potential source of a magnitude 7-1/2 earthquake (Dibblee, 1978). Additional faults of Quaternary age are listed in Table 4.1. The nearest fault inferred to be Quaternary in age by Dames and Moore (1977) is the Santa Ynez River fault, at the southern margin of the Santa Maria Basin 12 miles from the site. However, Dibblee (1978) presents data to show that a major fault is not present along the Santa Ynez River. Bedrock accelerations from a magnitude 7-1/2 earthquake on that fault may be about 0.4g (Dames and Moore, 1977), but Dibblee (1978) suggests faults in the Santa Maria Basin may not be significant potential sources of earthquakes. The San Andreas fault is 62 miles to the northeast and is a potential source of earthquakes as large as magnitude 8-1/2.

4.8.5 Seismic Hazards

The potential for seismic hazards at the Cojo Bay LNG site include liquefaction, small landslides, and tsunami run-up on the beach. No faults are known on the site, although small faults of unknown activity may be concealed beneath the terrace deposits. The potential for liquefaction appears to be low in the terrace deposits because of the generally graded nature of the terrace materials and the low water table. Local zones of poorly graded deposits may exist. These zones, if saturated, may be susceptible to liquefaction; the alluvium in Cojo Canyon is susceptible to liquefaction. Blocks in the canyons and along the sea cliffs could slump. No upstream dams are known, and the beach is susceptible to tsunami run-up.

Table 4.1

FAULTS IN PROXIMITY TO THE COJO BAY (PT. CONCEPTION) LNG SITE[1]

Fault Name	Distance From Site (Miles)[1]	Fault Type[1]	Fault Length (Miles)[1]	Age Category[1]	Estimated 100-year Earthquake[2]	Estimated Maximum Credible Earthquake[3]
Santa Ynez including South Branch	3	Reverse w/ Strike-slip	104	Quaternary	5 1/2 to 6	7 1/2
Santa Ynez (other than the South Branch)	3	Reverse w/ Strike-slip	100	Quaternary	5 1/2 to 6	7 1/2
Santa Ynez River	12	Reverse w/ Strike-slip	80[6]	Holocene[7]	5 to 5 1/2	7 1/2[7]
Central Santa Maria Basin	23	Reverse w/ Strike-slip	80[6]	Quaternary[7]	5 to 5 1/2	7 1/2[7]
More Ranch - Arroyo Parida	23	Strike-slip	42	Quaternary	5 1/2 to 6	7 1/4[11]
Santa Maria River[7]	27	Reverse w/ Strike-slip	80[6]	Holocene[7]	5 to 5 1/2	7 1/2[7]
Hosgri	29	Normal w/ Strike-slip	80	Quaternary Historic	6 1/4 to 6 3/4	7 1/2[9]
Santa Cruz Island	31	Reverse w/ Strike-slip	44	Quaternary	6 to 6 1/2	7
Santa Rosa Island	35	Strike-slip	33	Quaternary	5 3/4 to 6 1/4	6 3/4
Big Pine	41	Strike-slip	50	Historic	5 3/4 to 6 1/4	7
San Andreas[5]	62	Strike-slip	>500	Historic	8 1/4	8 1/2

[1]Data from Jennings (1975) unless otherwise noted.

[2]Estimated earthquake activity is a judgement based upon knowledge of the historical seismicity of the region and local area, and upon the recent geological history of the faults considered. These estimates are considered to be conservative, especially in the upper ranges of magnitude.

[3]Based upon one-half the fault length rupturing to produce an earthquake of given magnitude, as shown by Patwardhan and others (1975), unless from another source. Estimates are to the nearest 1/4 magnitude value.

[4]Probable source of the Lockwood Valley earthquake of 1852.

[5]Source for the Fort Tejon earthquake in 1857.

[6]Implied by earthquake magnitudes estimated by Dames and Moore, 1977.

[7]From Dames and Moore (1977).

[8]From Gawthrop (1975).

[9]Verbal communication from Douglas H. Hamilton, Earth Science Associates, December 30, 1977.

[10]From Dibblee (1978).

[11]From Greensfelder, 1974.

4.9 SLOPE STABILITY

4.9.1 Landslides

No landslides have been identified at the site. A few small block slumps are at the sea cliff and in the steep-sided ravines, and several large mudflow and rotational landslides are located outside site boundaries to the north (Slossen and Associates, 1978). These are not expected to be major considerations for development of the site.

4.9.2 Cliff Recession

Sea cliff recession is controlled by the rate at which the Sisquoc Formation at the base of the cliffs is eroded. This formation has relatively low resistance to erosion. The Seismic Safety Element for Santa Barbara County (Moore and Taber, 1974) suggests that a long-term recession rate of 6 inches per year may be occurring in the Point Conception area. This long-term rate results from episodes of rapid erosion, such as during the winter of 1978. The foundation design for the near shore and beach portions of the trestle should consider erosion during the lifetime of the trestle. Ample room is available on the coastal terrace for setting the facilities back from the bluff.

4.10 ENGINEERING PROPERTIES AND CONSTRUCTION CONSIDERATIONS

4.10.1 Engineering Properties

The engineering properties and foundation considerations for geologic units likely to be encountered during development are summarized on Table 4.2. Both Dames and Moore (1977) and Slossen and Associates (1978) discuss the engineering properties of these materials. There is agreement that Sisquoc Formation, while landslide prone, is not likely to be a hazard to tanks sited on the surface because there are no steep or high cuts planned. Excavations for buried tanks may, however, be unstable. Alluvium may require special consideration as it might have to be removed down to bedrock, about 40 feet in depth, and replaced with engineered fill.

Table 4.2

ENGINEERING PROPERTIES AND FOUNDATION CONDITIONS
OF THE COJO BAY (PT. CONCEPTION) LNG SITE

	MATERIALS			
	Alluvium	Residual Soils	Terrace Deposits	Sisquoc Formation
Compressibility	High	Medium	Low	Low
Strength	Low	Medium	High	High
Permeability	Medium	Low	Medium	Low
Shrink/Swell	Medium	Low	Low	Low
Bearing Capacity	Low	Low	High	Very High
Pile Support Capacity	Low	Low	High	Very High
Settlement	Medium	Medium	Low	Low
Frost Heave	Medium	Medium	Medium	Medium

4.10.2 Construction Considerations

Construction of an LNG facility would require moderate cuts in the terrace deposits and Sisquoc Formation. Construction considerations are summarized on Table 4.3. Cuts planned for surface tanks are expected to be stable; however excavations in the landslide-prone bedrock for buried tank will require special design consideration. If an LNG tank is sited in the flood plain of Cojo Canyon, a major excavation may be required to remove and rework the alluvial materials down to bedrock. Sufficient quantities of adequate-quality borrow materials may not be available from planned cuts on site to fill the two large ravines in the southern portion of the site. A borrow source in the Quaternary terrace deposits or the flood plain alluvium of Cojo Canyon may be required. These sources are anticipated to produce suitable fill material. Fill from the Sisquoc Formation, although usable, would be less desirable because of increased difficulty in workability. Sufficient quantities of adequate borrow material for use as aggregate appear to be lacking within the site and may have to be imported.

A tunnel constructed for a cryogenic pipeline would encounter shale of the Sisquoc Formation over its length of about 4600 feet to reach a berthing area in 60-foot-deep water. The shale dips to the south and should be relatively easily excavated with tunnel boring equipment. However, problems associated with possible squeezing ground, fault crossings, shears, and high water inflows along permeable discontinuities may cause stability problems and significantly hamper machine tunneling.

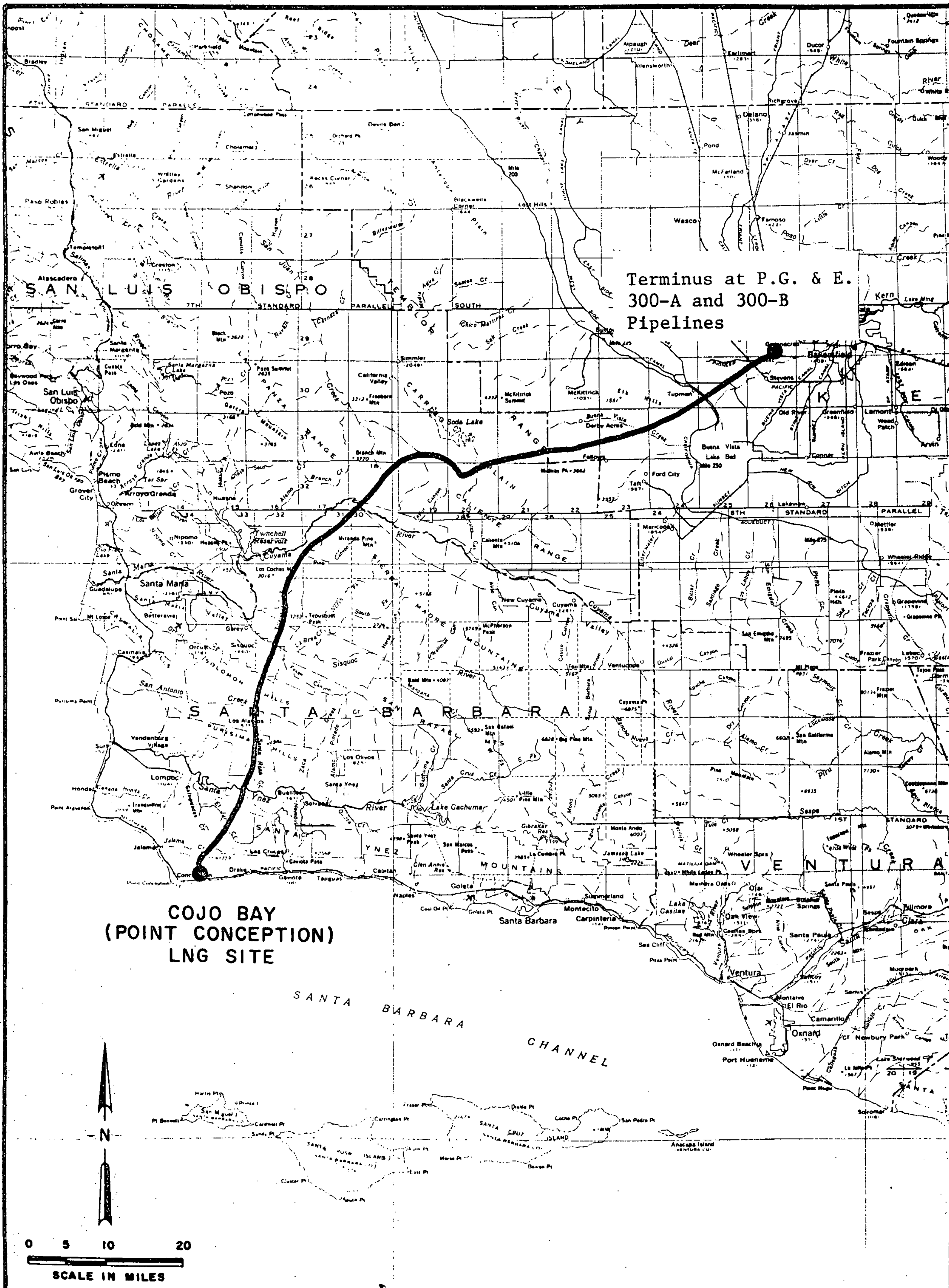
4.11 EXIT PIPELINE ROUTES

Gas transmission lines from an LNG terminal at Cojo Bay would traverse a 112-mile long route to reach existing large-diameter lines in the Central Valley at Gosford, west of Bakersfield (Figure 4.7).

Table 4.3

CONSTRUCTION CONSIDERATIONS
OF THE COJO BAY (PT. CONCEPTION) LNG SITE

	MATERIALS			
	Alluvium	Residual Soils	Terrace Deposits	Sisquoc Formation
Difficulty of Excavation	Low	Low	Low	Medium
Stability of Temporary Excavations	Low	Medium	Medium	High
Use as Engineered Fill	Fair	Poor	Fair-Good	Fair
Subgrade for Haul Roads	Fair	Poor	Fair-Good	Fair



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EXIT PIPELINE ROUTE FOR THE
COJO BAY (PT. CONCEPTION) LNG SITE

Fig: 4.7

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The route proposed by Western LNG Terminal Associates (1978) begins with a northeasterly trending segment across the Santa Ynez Mountains to the Santa Ynez River. The steep topography and many landslides in this segment would need to be considered in establishing the final alignment. Several active or potentially active splay faults of the Santa Ynez fault are crossed. The pipeline would continue across flood- and liquefaction-prone river beds and gently rolling, landslide-prone areas in the Santa Maria lowland to the San Rafael and Sierra Madre Mountains. These mountains have many landslide- and flood-prone areas, and 13 active faults with moderate potential for ground rupture would be crossed. Beyond these mountains the topography is generally less rugged with a few hundred feet of relief in landslide- and mudslide-prone formations, and with stream and river crossings subject to floods and liquefaction. The Carrizo Plain is generally flat but is subject to flood. Subsidence hazards due to hydrocompaction or fluid withdrawal are common. This segment of the pipeline will cross the San Andreas fault. The pipeline route through the Temblor Range is subject to landslide and flood hazards. From the Temblor Range the pipeline route is within the Great Valley to its terminus at Gosford. This segment is subject to subsidence from fluid and gas withdrawal, and hydrocompaction.

Construction of a pipeline along the proposed route will probably require some realignment and lengthening of the line to accommodate the many geologic hazards.

5.0 LAS VARAS LNG SITE

5.1 SUMMARY

The Las Varas LNG site is located on a broad coastal terrace 17 miles west of Santa Barbara. The coastal bluffs at the site are 40 to 60 feet high. The site is nearly flat with elevations ranging from 60 feet on the south to about 140 feet on the north. Expansive soils cover most of the site. The foundation materials consist of 30 to 40 feet of excavatable stiff soils overlying steeply dipping bedrock of shale. The bedrock units are prone to landsliding where they form steep slopes. Unconsolidated alluvium occurs in the stream drainages adjacent to the site and may be subject to liquefaction. Offshore the materials consist of a veneer of unconsolidated sediments over bedrock. Streams in the area are intermittent. Most of the water presently used is imported or from wells. Petroleum seeps occur in the area but no production was noted in the immediate vicinity of the site. A trench excavated on the site has revealed an apparently youthful fault that may extend across the site. The age of the apparent faulting is unknown, but is estimated to be within the past few tens of thousands of years. The historically active More Ranch fault appears to be as close as 2 miles south of the site and may be able to generate an earthquake of magnitude 7-1/2. Sea cliff retreat may be as much as 1 foot per year and may require setback of the site facilities from the top of the coastal bluff to minimize the impact of coastal erosion on the site. Construction of a tunnel to the offshore berthing area may be difficult due to the presence of shale. Exit pipeline alternatives include a route north across the rugged Santa Ynez and San Rafael Mountains to the Central Valley, or southeast along the coast to Ventura, then inland to Castaic Junction. Unstable slopes occur in the Santa Ynez and San Rafael Mountains along the northern route. The southeast route lies mostly on terrace deposits and alluvium.

5.2 MAJOR GEOTECHNICAL CONSIDERATIONS

5.2.1 Faulting on the Site

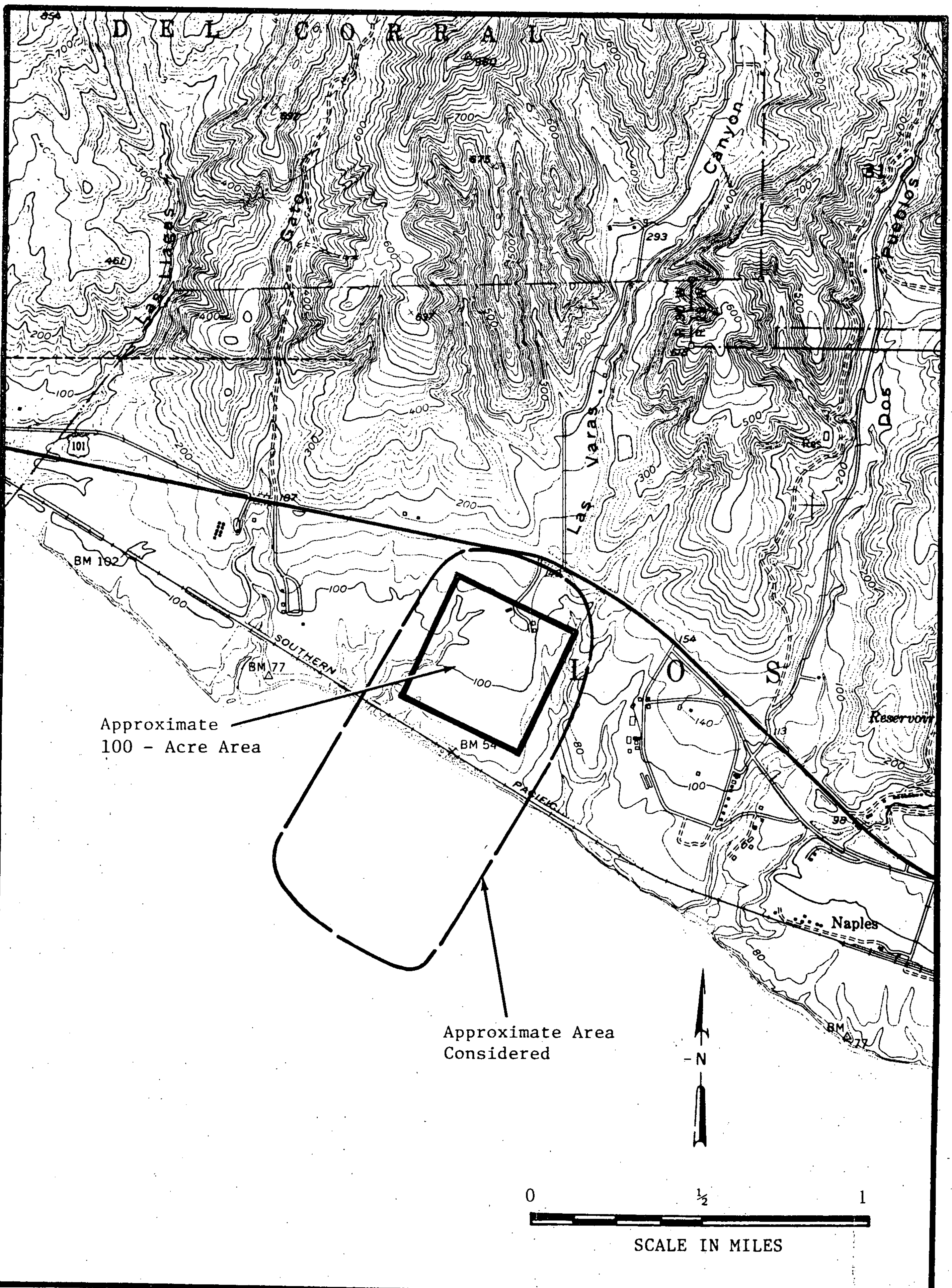
A trench at the Las Varas site has revealed a step at the base of the terrace deposits; this step may be interpreted as due to thrust faulting within the past few tens of thousands of years. The interpreted fault displacement appears to be approximately 3 feet. A broad topographic swale suggests that the apparent deformation extends westward across the site. Other similar features have not been observed at the site, although an intensive subsurface investigation to thoroughly map this feature and to explore for similar features will be required if this site is considered further. In addition, if the observed feature is considered to be an active fault for an LNG facility, shaking from a local earthquake generated by this fault will be a design consideration.

5.2.2 Coastal Erosion

Coastal erosion of the Santa Barbara area has been well documented (Norris, 1968) with rates ranging from negligible to 10 inches per year. The location of the site, nearly 300 feet inland, should minimize effects of coastal erosion during the lifetime of the proposed terminal, although special considerations may be required for the cryogenic pipeline between the berthing area offshore and the facilities onshore.

5.3 LOCATION

The Las Varas site is located on the Las Varas Ranch, about 17 miles west of Santa Barbara and about 3 miles east of El Capitan Beach State Park. The area is accessible by way of Las Varas Ranch Road, south of Highway 101. The site is bounded by Highway 101 on the north, the Southern Pacific Railroad on the south, Las Varas Canyon on the east and a small unnamed drainage on the west (Figure 5.1); the site is currently used for avocado groves and pasture land. Farm buildings and several residences are located in the northern part of the site. Unpaved farm roads and abandoned roads and trails cross the site on the east.



Project: LNG TERMINALS EVALUATION Project No: 41033I	LOCATION MAP OF THE LAS VARAS LNG SITE	Fig: 5.1

5.4 TOPOGRAPHY

The site lies on a broad coastal terrace that is about 3,000 feet wide, from the break in slope at the foot of the mountains on the north to the top of the coastal bluffs on the south. Elevations across the terrace range from about 60 feet at the southern edge of the site to about 120 feet on the northern edge of the site, with an average grade of less than 5% (Figure 5.1).

The coastline is characterized by steep, near-vertical coastal bluffs rising 40 to 60 feet above the beach. The top of the coastal bluffs has been dissected by sheet flow erosion off the terrace surface, but this appears to affect only the southern edge of the terrace.

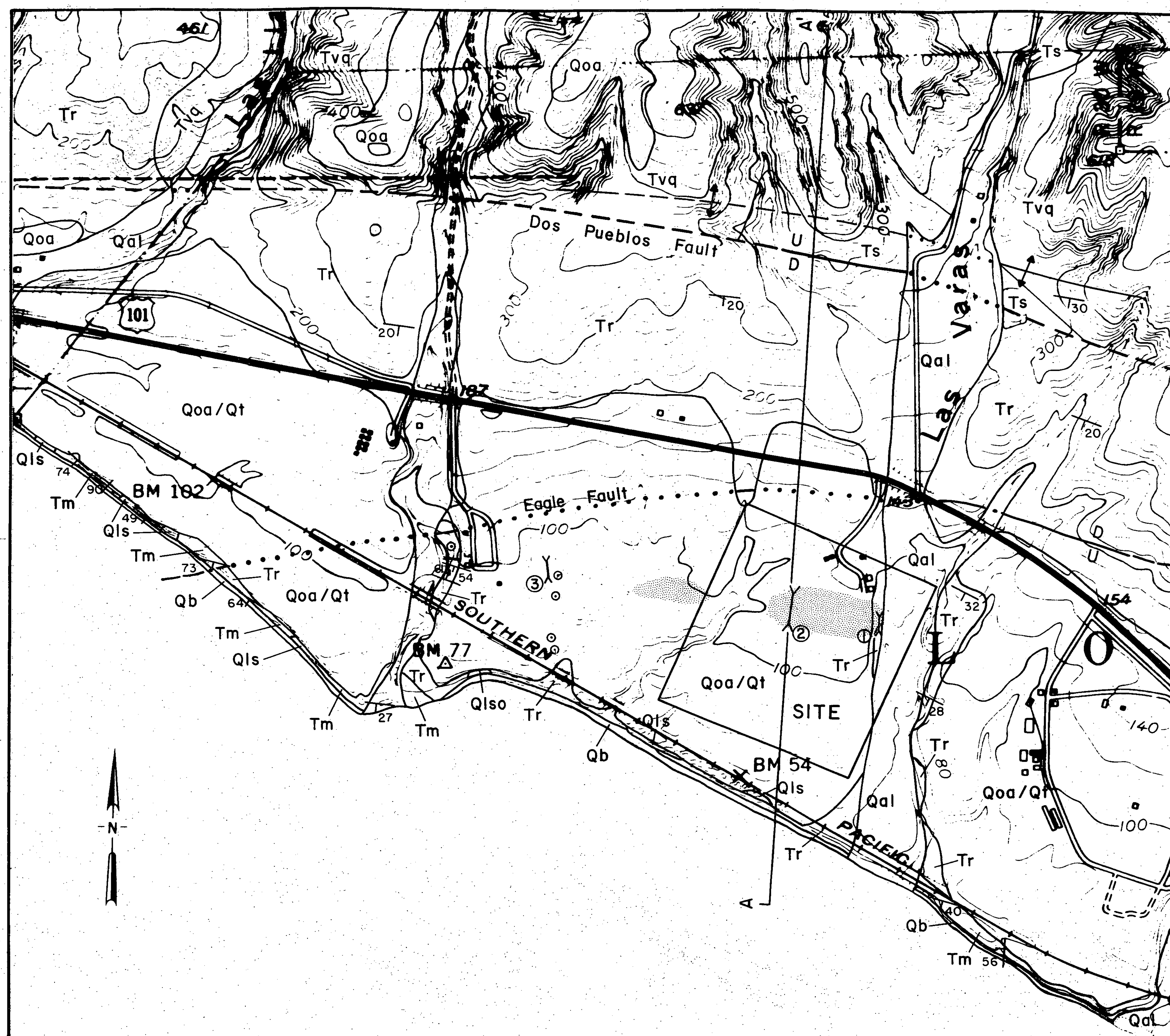
Las Varas Canyon forms the eastern boundary of the site, and a small unnamed drainage forms the western boundary. The walls of these drainages are not steep and they do not appear to be experiencing rapid erosion.

5.5 GEOLOGIC UNITS

The geologic units that are located in the vicinity of the proposed site include the Sespe Formation, Vaqueros Sandstone, Rincon Shale, Monterey Shale, Quaternary terrace deposits, stream alluvium, beach deposits, and residual soils (Figure 5.2).

The Sespe Formation consisting of sandstone and conglomerate, is a thick-bedded resistant, reddish-maroon, unit exposed in the area on the north side of the Dos Pueblos fault. Sandy and silty shales are interbedded locally. Cobbles and boulders of Sespe Formation are found in the Quaternary and Recent alluvium, but no outcrops of Sespe Formation have been identified at the site.

The Vaqueros Sandstone conformably overlies the Sespe Formation, and consists of fine to coarse sandstone and local conglomerate lenses, typically thick bedded to massive. The Vaqueros is more resistant to erosion than either the Sespe or the Rincon



EXPLANATION.

Quaternary	Qb	Beach deposits, medium to fine sand and cobble to boulder deposits
	Qls	Landslide deposits
	Qlso	Older landslide deposits, vegetation covered
	Qal	Stream deposited alluvium, consists of unconsolidated silt to boulder-size, locally water saturated sediments
	Qoa/Qt	Older alluvial fan deposits consisting of boulder conglomerate in red-brown silty sand matrix; terrace deposits of dense silt, sand and clay
Miocene	Tm	Monterey shale, thin bedded silty to siliceous shale locally petroliferous
	Tr	Rincon shale, thick to thin bedded silty shale and mudstone, locally siliceous shale
	Tvq	Vaqueros sandstone, resistant thick bedded fine to coarse sandstone and conglomerate lenses
Oligocene ?	Ts	Sespe Formation, resistant reddish coarse sandstone and conglomerate, sandy and silty shales locally

32 Strike and dip of bedding

61 Strike and dip of shear planes, possibly fault related

D U Fault, dashed where approximately located, dotted where covered

Lithologic contact

Anticline

Tar seep

Topographic swale

Trench location: (1) see figure 5.8; (2) see figure 5.9; (3) see figure 5.10

500 0 500 1000 FT.
SCALE IN FEET

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GEOLOGIC MAP OF THE LAS VARAS LNG SITE
(Modified after Dibblee, 1966)

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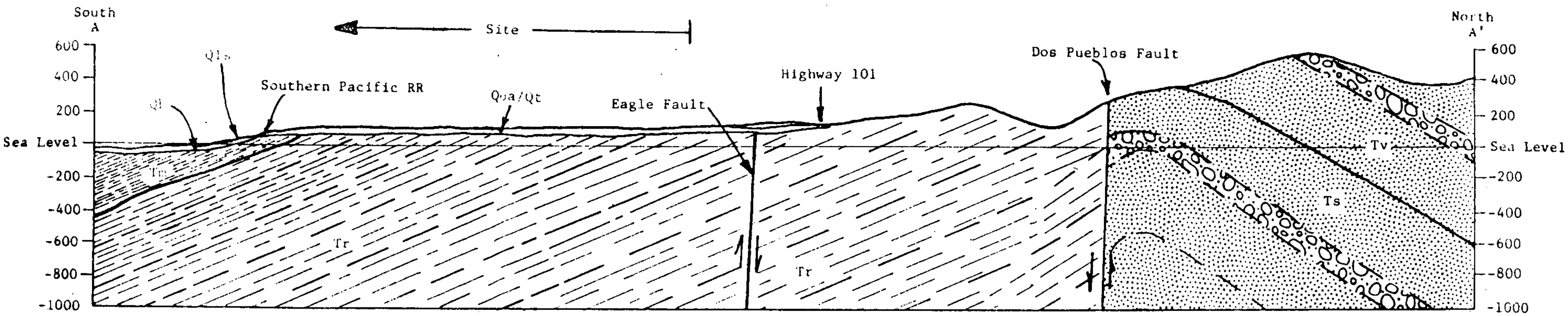
LNG TERMINALS EVALUATION

Figure: 5.2



500 0 500 1000

Scale in Feet

EXPLANATION

Quaternary	Qb	Beach deposits, medium to fine sand and cobble to boulder deposits
	Qls	Landslide deposits
	Qoa/Qt	Older alluvium consisting of boulder conglomerate in red-brown silty sand matrix. Terrace deposits of dense silt, sand and clay.
Tertiary	Tm	Monterey shale, thin bedded silty to siliceous shale locally petroliferous
	Tr	Rincon shale, thick to thin bedded silty shale and mudstone, locally siliceous shale
	Tvq	Vaqueros sandsone, resistant thick bedded, fine to coarse sandstone and conglomerate lenses
	Ts	Sespe Formation, resistant reddish coarse sandstone and conglomerate, sandy and silty shales locally

Project: LNG TERMINALS EVALUATION

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DIAGRAMMATIC CROSS-SECTION OF THE LAS VARAS LNG SITE

Fig. 5.3

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formations, and forms a prominent brush-covered ridge near the southern edge of the Santa Ynez Mountains. North of the site, the Dos Pueblos fault forms the southern contact of the Vaqueros Sandstone. No outcrops of this formation were observed in the immediate area of the site, although boulders of apparent Vaqueros origin are common in the Quaternary and Recent alluvium.

The bedrock at the site consists primarily of Miocene-age Rincon Shale, which is described by Dibblee (1966) as 1450 to 1750 feet thick. Where it is well exposed, as in the coastal bluffs, the Rincon is dense silty mudstone and shale, with locally coarser sandy interbeds. Some thin-bedded siliceous shale similar to the overlying Monterey Shale also occurs in the Rincon Shale. The moderately to steeply southward dipping bedrock has been planed off to form a wave-cut bench. The upper part of this wave-cut bench has been weathered to clay, and bedding is preserved only where sandy interbeds occur. This weathering profile has locally abundant stringers of caliche in the vicinity. Petroleum seeps have been identified in the Rincon Shale; some may be controlled by faults, although not all appear to be associated with known geologic structures.

Where the Rincon underlies moderate to steep slopes, it is prone to landsliding. This does not appear to affect the site except along the steep coastal bluffs. The formation is moderately to easily eroded, and appears to be easily excavatable in general, with the hardest material likely to be the siliceous shale portions. The formation does not appear compressible or susceptible to liquefaction. Economic deposits of hydrocarbons are not known to be present at the Las Varas site.

The coastal margin of the exposed bedrock locally consists of Miocene-age Monterey Shale, conformably overlying the Rincon Shale. These two formations are similar in age and lithology, with the Monterey being thinner-bedded and more siliceous. The Monterey Shale consists of thickly-bedded (6 to 8 inches) silty shales and thinly-bedded (less than 1/16 inch) hard, siliceous, locally cherty shales. The formation is typically fractured with petroleum residues common in many of the fractures.

As with the Rincon Shale, the Monterey is dense and not compressible or susceptible to liquefaction, but is landslide prone on moderate to steep slopes. Small landslides occur along unsupported bedding planes along the coastal bluffs. The Monterey shale is harder than the Rincon, and slightly less erodible. It should be easily excavated, due to the pervasive fracturing and thin-bedded nature of the formation. Petroleum deposits in the Monterey Formation are extensively developed southeast of the Las Varas site, but no current petroleum development is known at the site.

The Quaternary terrace deposits are best exposed at the top of the coastal bluffs and along the banks of small washes eroded into the southern edge of the terrace surface. Along the sea cliff, exposures near the site show the base of the terrace deposits consisting of locally iron-stained fine sand, which grades upward into red and buff mottled sand and silt. This is probably a marine or beach sand that was deposited over the wave-cut bench of Rincon and Monterey Shale. The upper part of the terrace deposits consists of dense reddish-brown silt, sand, and minor gravel lenses. These deposits are poorly bedded, 1/2 to 2 feet thick, and erode easily where they are not protected by vegetation.

In the vicinity of Gato Canyon, west of the site, the terrace deposits consist of coarse boulder alluvium, with boulders greater than 3 feet not uncommon. This unit thickens toward Gato Canyon and appears to represent an alluvial fan developed on the wave-cut bench of Rincon and Monterey bedrock. Nearly all of the terrace deposits at Gato Canyon have a distinct reddish color, suggesting they are nonmarine in origin.

The base of the terrace deposits is locally mottled gray and yellow, with numerous water seeps at the bedrock-terrace contact. This suggests that the base of the terrace material is not well drained, perhaps due to perched ground water at the contact with the fine-grained, weathered bedrock formations beneath.

The stream drainages that are located east and west of the Las Varas site contain unconsolidated cobble and boulder alluvium in a matrix of silt, sand, and clay. The boulders appear to be eroded from the Vaqueros and Sespe formations in the adjacent mountains and were apparently transported during flash floods. The streams that were flowing during the field investigation were much too small to transport these large clasts except during peak floods.

The unconsolidated and locally water-saturated material in the drainages may be subject to liquefaction during seismic shaking. This material may be somewhat compressible. The alluvium appears to erode easily, is easily excavatable, and except for the boulder-size material, could be useful as borrow for small amounts of fill.

A thin mantle of sand and cobble-to boulder-size gravel covers much of the beach area. Extensive areas of outcropping bedrock suggest that this mantle is probably not more than 5 feet thick. The sandy or silty beach deposits may be subject to liquefaction. Seasonal erosion and deposition of sand may change the configuration of the beach from what was observed during this field investigation.

The soil developed on the terrace surface at the Las Varas site, described by the Soil Conservation Service as Milpitas-Positas fine sandy loam (Shipman, 1977), consists of a topsoil about 1 foot thick, a silty loam about 2-1/2 to 3 feet thick, and a zone of weathered terrace deposits that grades to apparently unweathered material about 6 feet beneath the ground surface.

The topsoil is an organic silty sand with moderately plastic clay. The thickness of this unit varies, but generally is between 1 and 2 feet. It is a dark reddish brown to dark gray and contains abundant roots in the upper 6-10 inches. Beneath this topsoil is a dense silty clay loam with fine sand throughout. It is moderate to dark brown and has roots throughout the section, though they are more abundant nearer the surface. Below this silty loam are mottled buff and red to unmottled red terrace deposits of sand, silt and minor clay, that are apparently unweathered below about 5 or 6 feet. The upper topsoil appears to be highly expansive due to the high clay content. The silty loam and terrace deposits appear to be only slightly expansive and should make good foundation material.

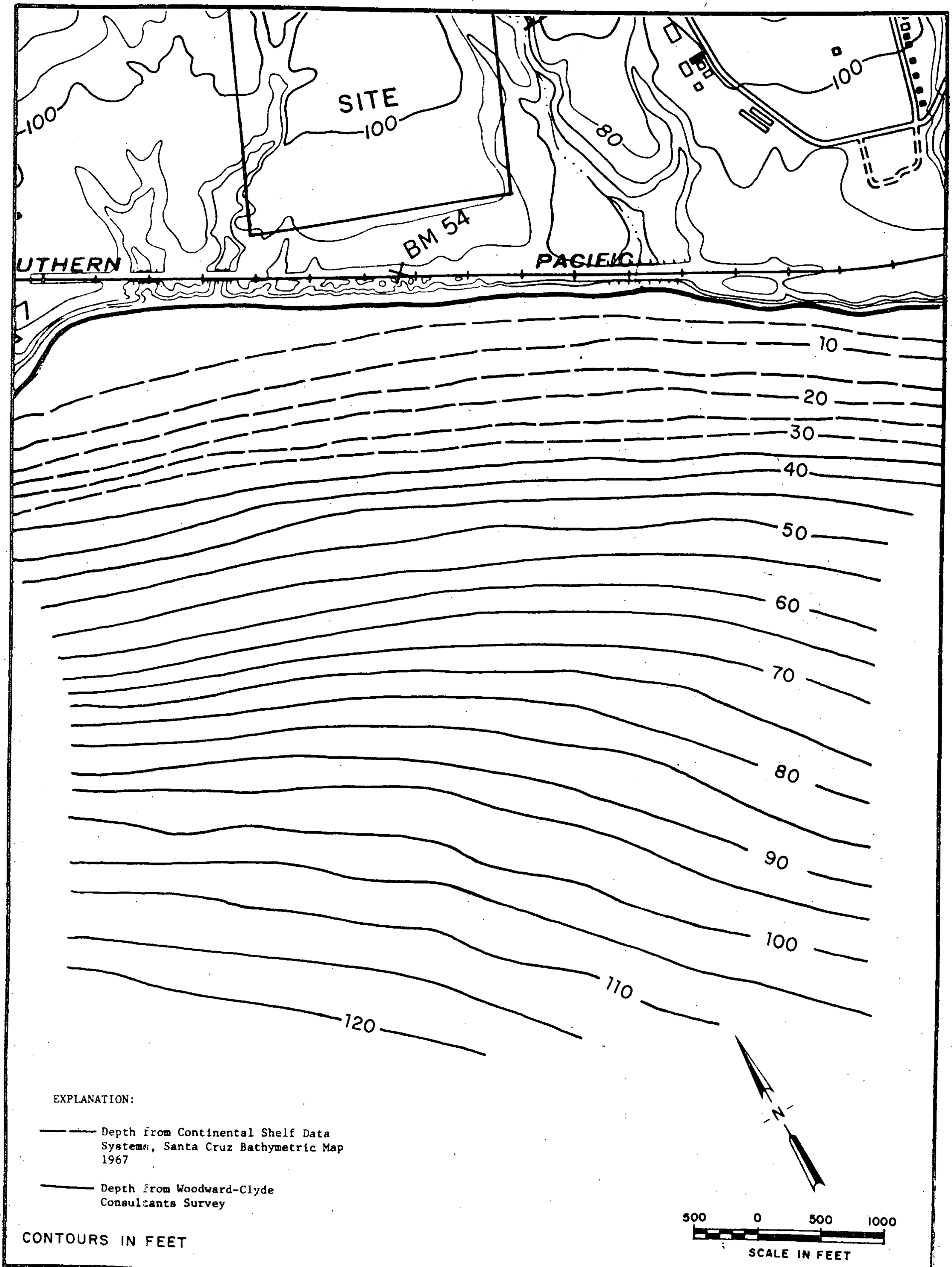
5.6 OFFSHORE GEOLOGY

In the offshore area slopes are gently to the south (Figure 5.4), with seafloor contours trending parallel to the coastline. Bottom conditions in the area consist of a mantle of unconsolidated sediments as thick as 50 feet over bedrock of Monterey and Rincon shales (Figure 5.5). No bedrock exposures were noted in the offshore area. The sediment mantle is expected to consist of a coarse fraction of cobbles and boulders, as exposed on the beaches, grading to fine sand offshore. Large rocks may occur locally on the sea floor. The possible projection of the More Ranch fault is 2-miles offshore but shows no evidence of displacement of the unconsolidated sediments and no clear trace on seismic profiles.

5.7 HYDROLOGY

5.7.1 Surface Water

The drainage basins in the vicinity of the Las Varas site are outlined on Figure 5.6. All streams in the area are intermittent. A small pond has been constructed on the eastern part of the site in Las Varas Canyon, apparently for irrigation supply. No information was available on the capacity of this pond.



Project: LNG TERMINALS EVALUATION

Project No: 41033I

BATHYMETRY OF THE LAS VARAS LNG SITE

Fig: 5.4

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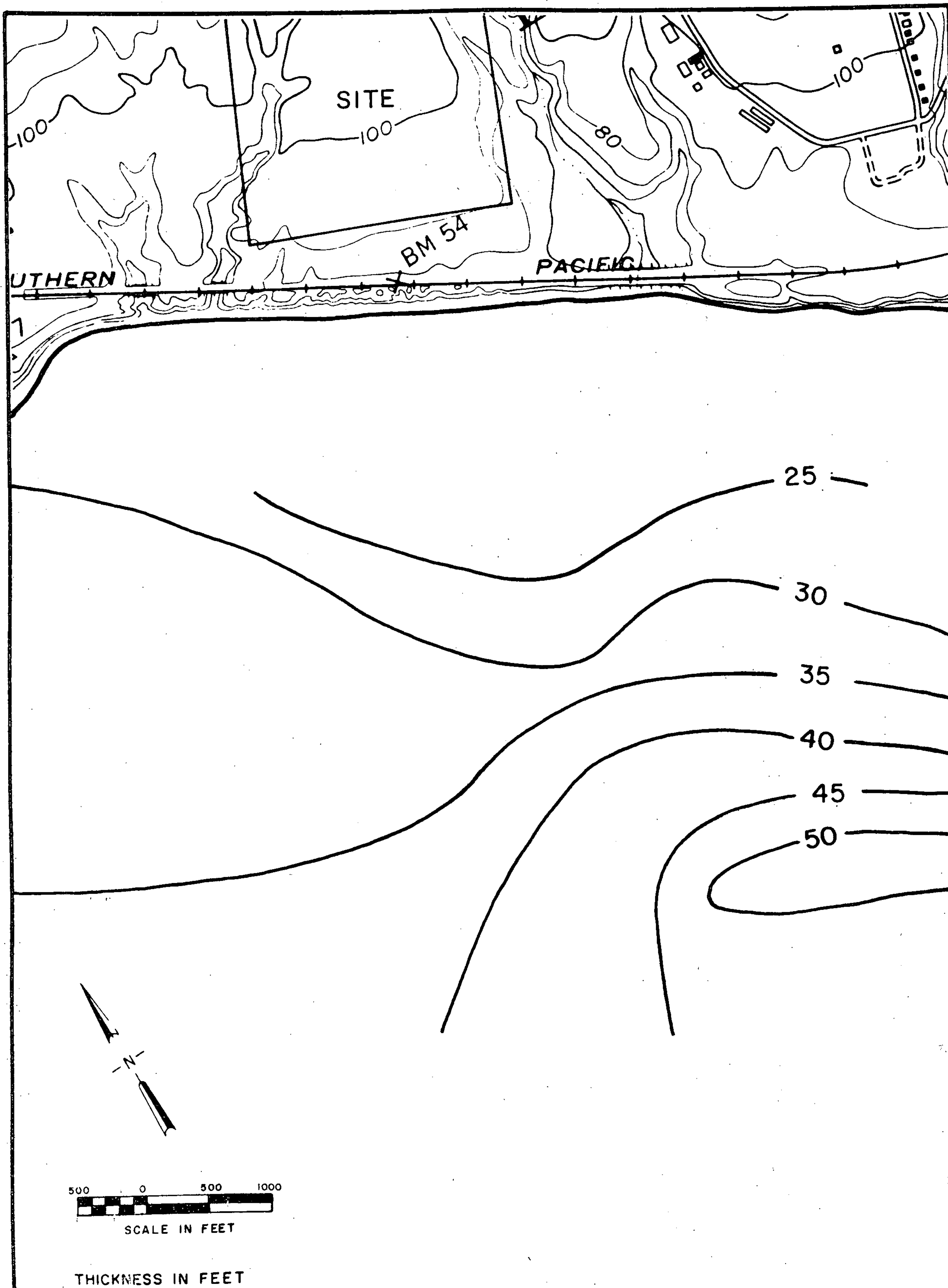
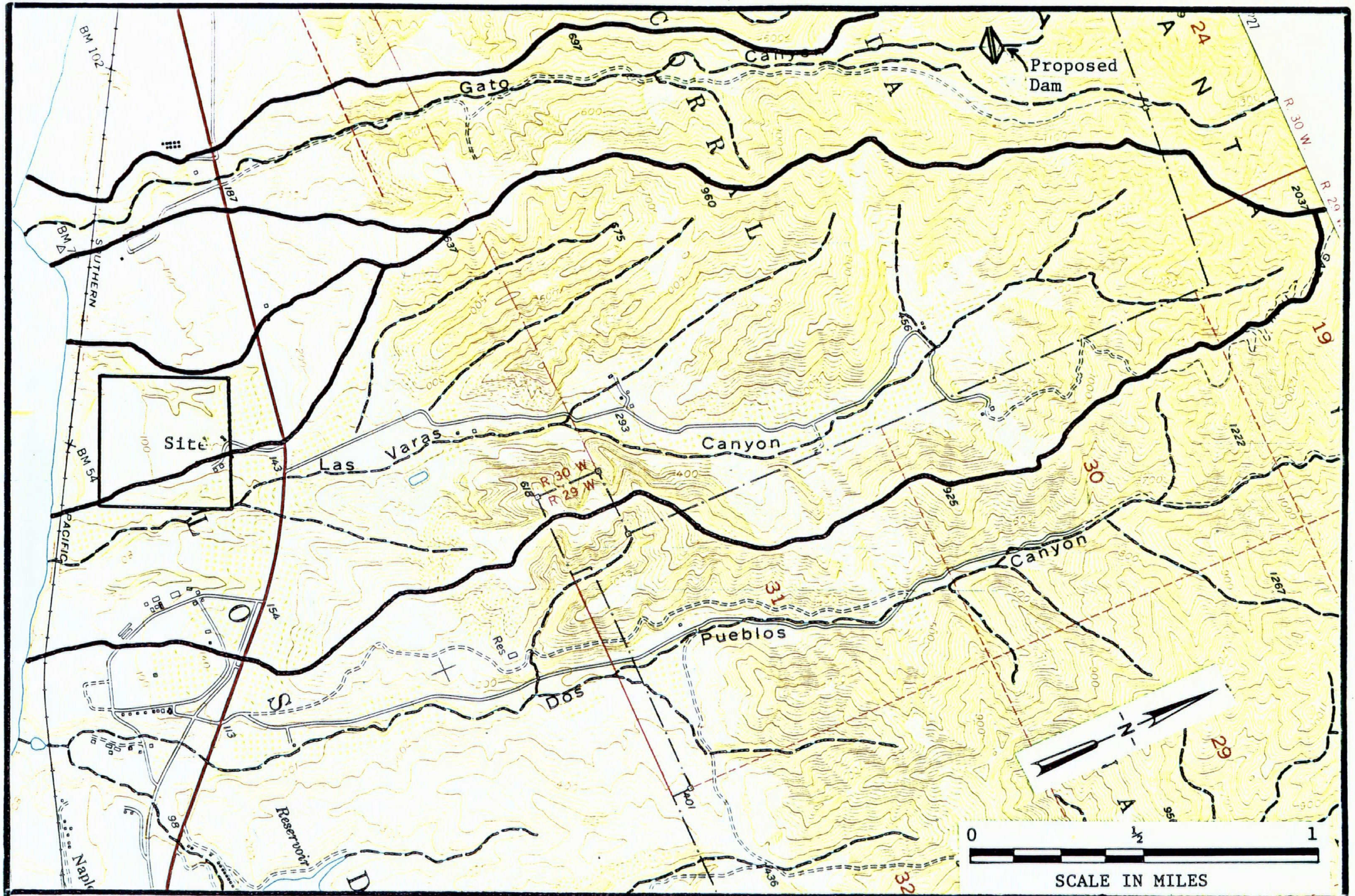


Project: LNG TERMINALS EVALUATION Project No: 41033I	THICKNESS OF UNCONSOLIDATED OFFSHORE SEDIMENTS AT THE LAS VARAS SITE	Fig: 5.5

WOODWARD-CLYDE CONSULTANTS



Project: LNG TERMINALS EVALUATION
Project No. 41033I

DRAINAGE MAP OF THE LAS VARAS LNG SITE

Fig. 5.6

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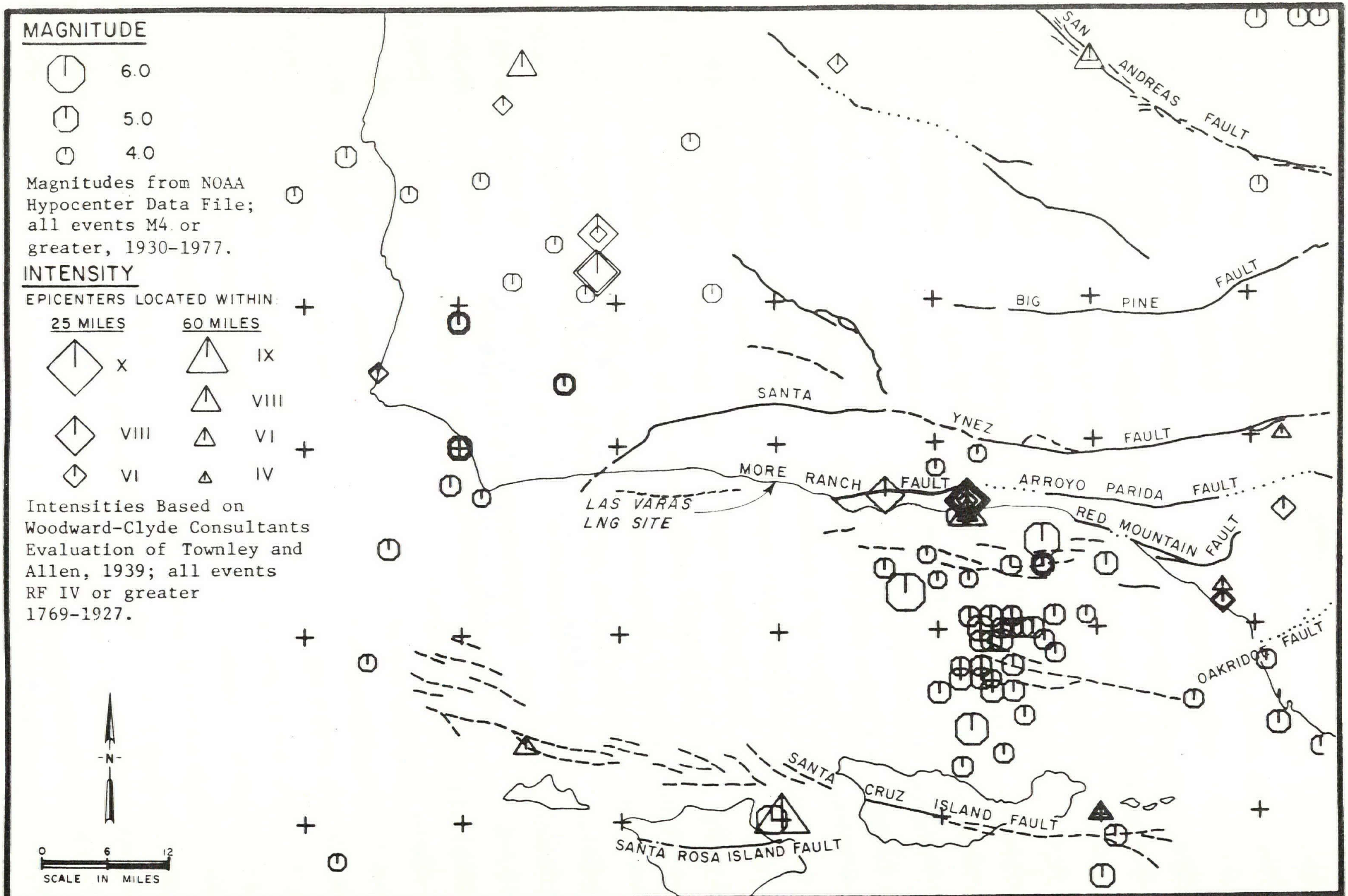

Project LNG TERMINALS EVALUATION Project No. 41033I	REGIONAL FAULT AND SEISMICITY MAP OF THE LAS VARAS LNG SITE	Fig. 5.7

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5.7.2 Stream Erosion

Las Varas Canyon borders the site on the east, and an unnamed drainage borders the site on the west. The floodplain for Las Varas Canyon is incised approximately 40 feet, with the active creek bed incised as much as 15 feet into the floodplain. Accordingly, stream erosion from Las Varas Creek is unlikely to affect the terrace margin upon which the site is located. The drainage west of the site includes a small drainage basin, with local scour and fill occurring during peak stream runoff. Eucalyptus trees along this drainage have stabilized some of the stream banks, so stream erosion is not expected to be a major consideration along that drainage either.

5.7.3 Fresh Water Supply

A small reservoir, with a surface area of approximately 20 acres is present in Dos Pueblos Canyon 1.5 miles east of the site. Another dam is planned to impound a reservoir with capacity of approximately 600 acre feet on a tributary in Gato Canyon west of the site (Figure 5.6). This reservoir is planned to be used for irrigation and recreation for the Las Varas Ranch. The distance between the mouth of Gato Canyon and the site virtually precludes significant hazard from failure of this dam. Most of the water used for irrigation in the area is imported from Cachuma Reservoir in the Santa Ynez River valley. Shortages have occurred during years of low rainfall (Shipman, 1977), and restricted use has been imposed.

5.7.4 Ground Water

Although no information is readily available on the level of the water table in the area, it is probably deep. Localized, perched water occurs near the base of the Quaternary terrace deposits. Water wells near the site are not producing, according to ranchers in the area, and were probably drilled in the fine-grained Rincon or Monterey bedrock. One well, to the north of Highway 101, was drilled into the Vaqueros Formation, but is producing very little water, according to the ranch manager.

Farmers have used the Dos Pueblos fault as a means for locating water wells on the north side of the fault. A ground-water barrier is apparently located along the fault, but ground-water supplies in the area are generally unreliable over the long term (Shipman, 1977).

5.8 SEISMICITY AND FAULTING

Faults of significance to the site include the apparent fault on the site, the Eagle, Dos Pueblos, More Ranch, Santa Ynez, Santa Cruz Island, offshore Oak Ridge, Big Pine, and San Andreas, faults (Figure 5.7). Pertinent characteristics of faults off the site are summarized in Table 5.1.

5.8.1 Active and Potentially Active Faults

Trenching at the Las Varas site has revealed a step in the wave-cut platform at the base of the terrace deposits that may be interpreted as a thrust fault with approximately 3 feet of displacement (Figure 5.8). The apparent fault relationships were observed at only one point, but if the feature is continuous, it may cross the site along an approximately east-west trend. The length of this feature is unknown, and the relationship of this feature to the Eagle fault is unknown. If it is a fault, it may be a minor fault unrelated to the Eagle fault, or it may be a branch of the Eagle fault.

A broad topographic swale across the site trends roughly east-west (Figure 5.2), and appears to be coincident with a projection of the apparent thrust fault relationships observed in the trench. This suggests that the surface of the terrace at the site is also deformed. No faulting was observed in a trench through the terrace deposits at the topographic swale (Figure 5.9), although several distinct horizons observed appear to be parallel to the topographic surface, suggesting that folding or gentle warping rather than faulting may have deformed the upper portion of terrace deposits exposed in the trench. A trench located west of a tar seep (Figure 5.10) revealed no evidence of deformation.

Table 5.1

FAULTS IN PROXIMITY TO THE LAS VARAS LNG SITE[1]

Fault Name	Distance From Site[1] (Miles)	Fault Type[1]	Fault Length[1] (Miles)	Age Category[1]	Estimated 100-year Earthquake[2]	Estimated Maximum Credible Earthquake[3]
More Ranch	2	Reverse w/ Strike-slip	42	Quaternary Historic?	5 to 5-1/2	7-1/4
Santa Ynez	7	Reverse w/ Strike-slip	104	Quaternary	5-1/2 to 6	7-1/2
Big Pine[4]	22	Strike-Slip?	50	Historic	5-1/4 to 5-3/4	7
Offshore Oak Ridge	24	Normal?	30	Quaternary Historic?	5 to 5-1/2	6-1/2
Santa Cruz Island	24	Reverse w/ Strike-slip	44	Quaternary	5-1/2 to 6	7
San Andreas[5]	48	Strike-slip	>500	Historic	7-1/2 to 8-1/4	8-1/2

[1]Data from Jennings (1975) unless otherwise noted.

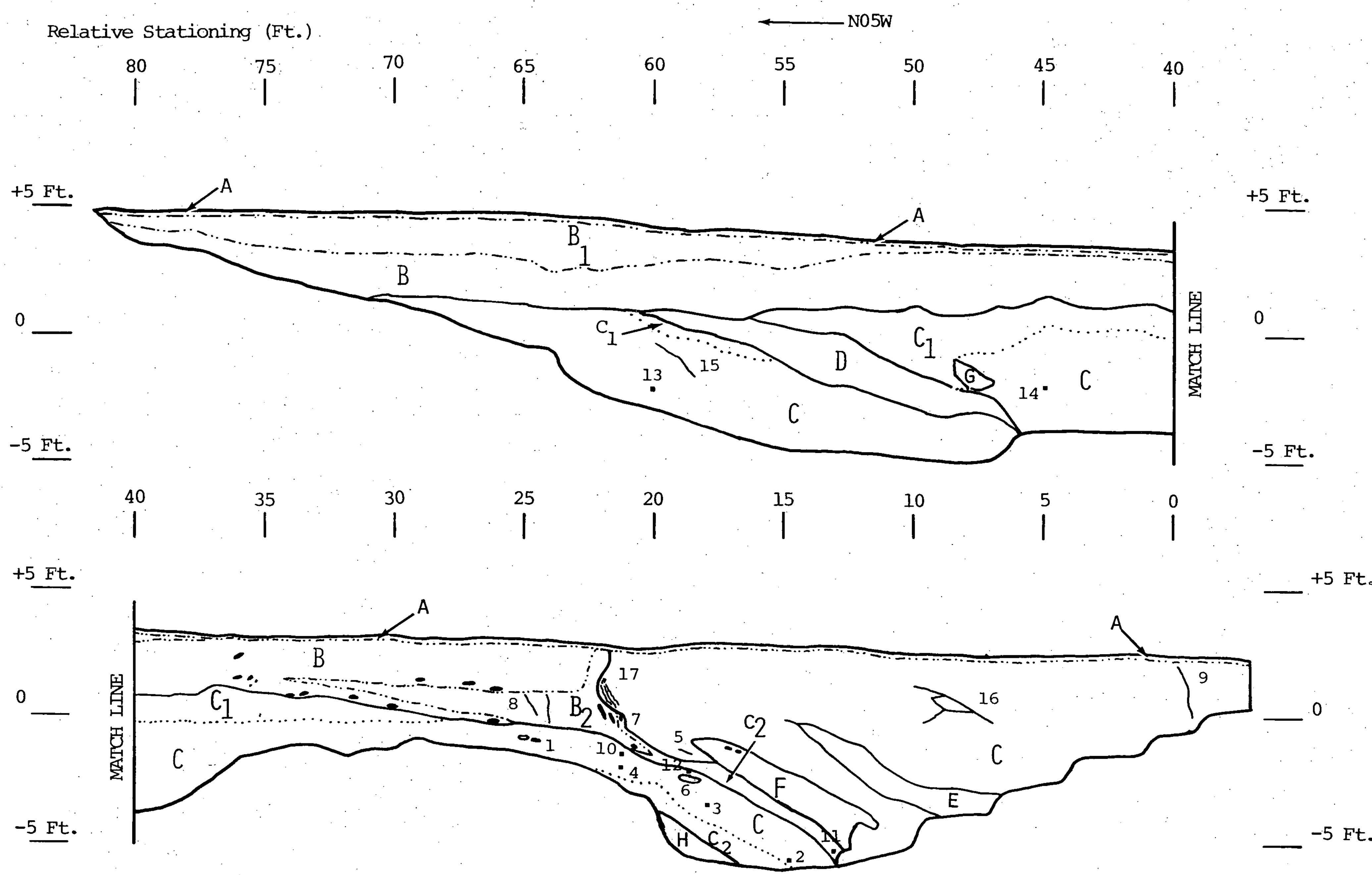
[2]Estimated earthquake activity is a judgment based upon knowledge of the historical seismicity of the region and local area, and upon the recent geological history of the faults considered. These estimates are considered to be conservative, especially in the upper ranges of magnitude.

[3]Based upon one-half the fault length rupturing to produce an earthquake of given magnitude, as shown by Patwardhan and others (1975). Estimates are to the nearest 1/4 magnitude value.

[4]Probable source of the Lockwood Valley earthquake of 1952.

[5]Source for the Fort Tejon earthquake of 1857.

[6]Greensfelder (1974)



LITHOLOGIC DESCRIPTIONS

A SANDY SILT, moderate brown, very fine grained

B SILTY SAND, moderate brown, large boulders with medium grained matrix, hard, dry to moist

B_1 SILTY SAND, moderate brown, medium grained with few boulders, dry

C SHALE (Rincon Formation), light olive gray with moderate brown mottles, totally weathered to SILTY CLAY, trace sand, slightly moist, some manganese staining, partings approximately 2 inches apart

C_1 SHALE (Rincon Formation) as above, carbonate stringers and nodules, partings approximately 1/4 inch apart

C_2 CLAY, highly sheared, probably totally weathered shale, light gray to light orange brown, microfolds, slickensides

C_3 SILTY CLAY, (Rincon Formation), light olive gray, manganese staining

D SANDY SILT (Rincon Formation), dark yellowish orange with yellowish brown streaks and mottles, blocky partings, highly weathered, moist

E SANDY CLAY (Rincon Formation), dark yellowish orange, mottled, blocky partings, slightly Plastic, moist

F SILTY CLAY, trace sand (Rincon Formation), light brown, carbonate stringers, plastic, moist

G SILT with CLAY (Rincon Formation), greenish gray, with moderately weathered, highly fractured red siliceous shale boulders

H SANDY CLAY (Rincon Formation), orangish black, partings approximately 2 inches apart

EXPLANATION

-·-·-·· Soil Contact

——····· Lithologic Contact, dotted where gradational

NOTES

Trench Orientation: N05W, Viewer Facing East Wall
Logged By: RS and DDP

1. Siliceous fragments, angular
2. Joints, several parallel, N 10W, 66E
3. Bedding (?) orientation, N 65W, 34 SW
   Joint, N 15W, 65NE
   (WEST WALL)
4. Fractures, several parallel, N 80E, 90
5. Root
6. Sandstone boulder, surrounded by reddish brown rim
7. Root
8. Rootlets
9. Vertical dark brownish black sandy silt feature
10. Slickensides, N 52E, 38S
11. Slickensides, N 60W, 38S
12. Slickensides, N 80W, 20S
13. Partings, N 83E, 04S
14. Joint, N 15E, 81S
15. Clay stringer
16. Carbonate stringer
17. Carbonate stringers

0 5 10 15
SCALE IN FEET

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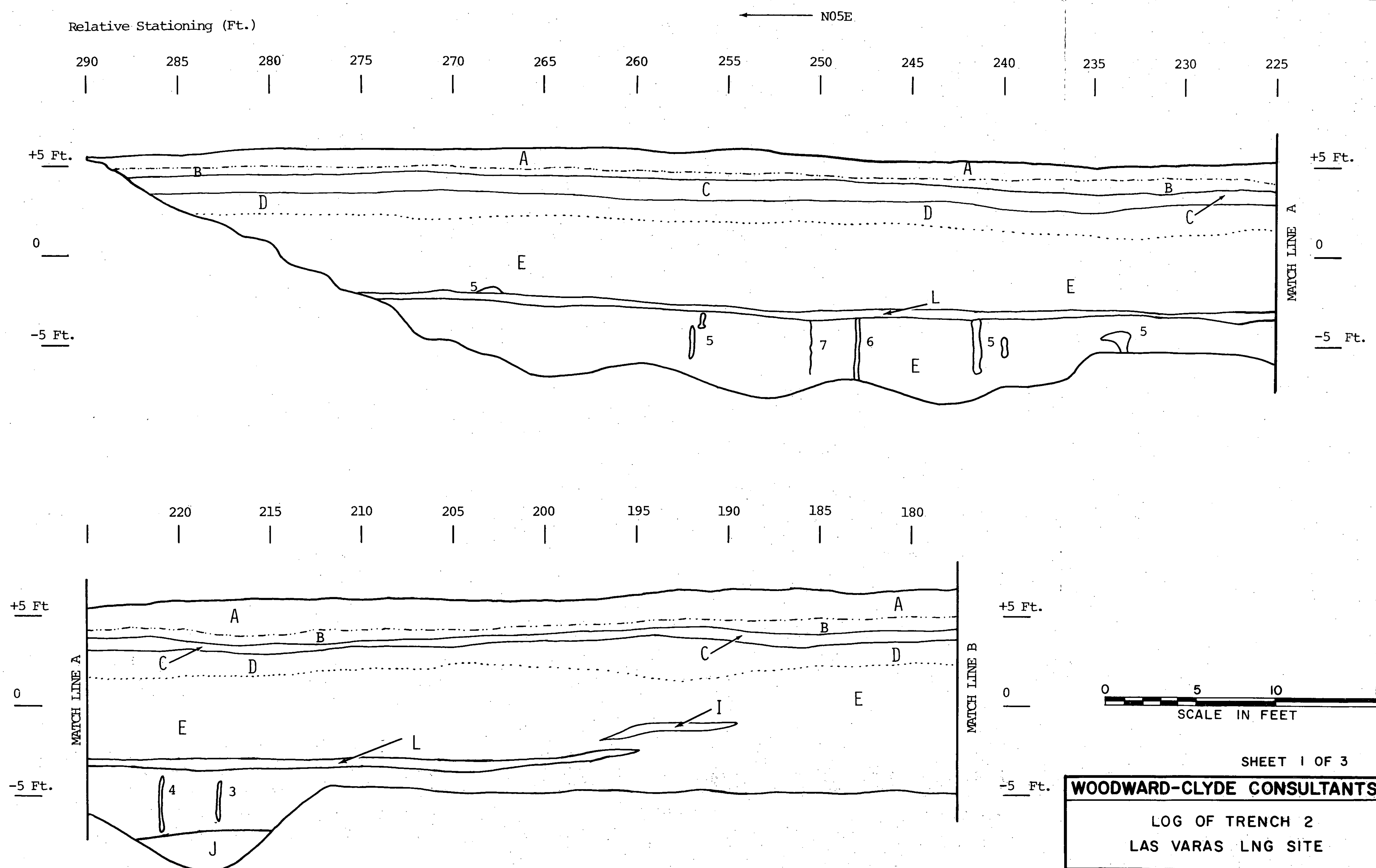
LOG OF TRENCH 1
LAS VARAS LNG SITE

Project No. 41033I

LNG TERMINALS EVALUATION

Figure: 5.8



SHEET 1 OF 3

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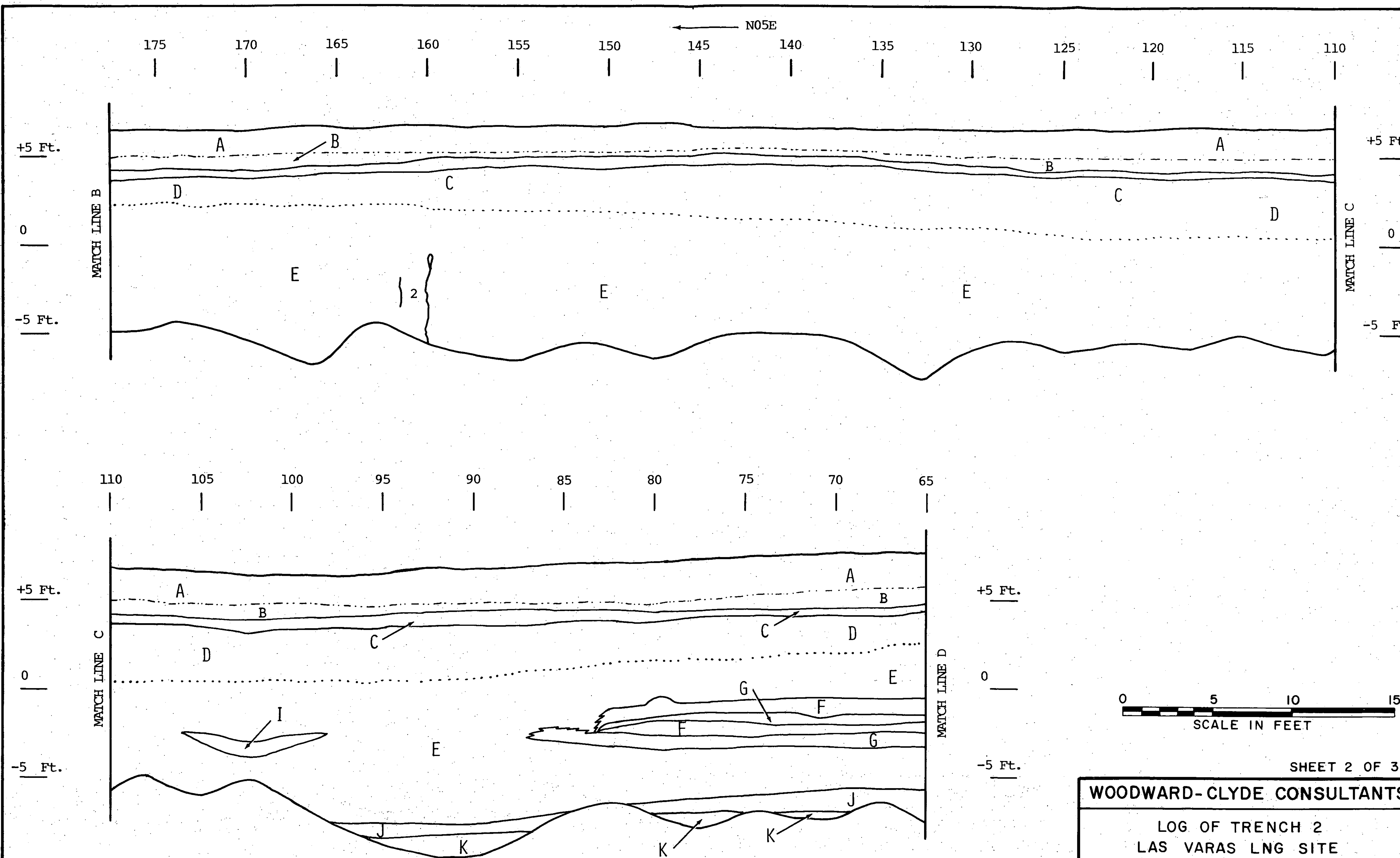
LOG OF TRENCH 2

LAS VARAS LNG SITE

Project No. 41O33I
LNG TERMINALS EVALUATION

Figure: 5.9

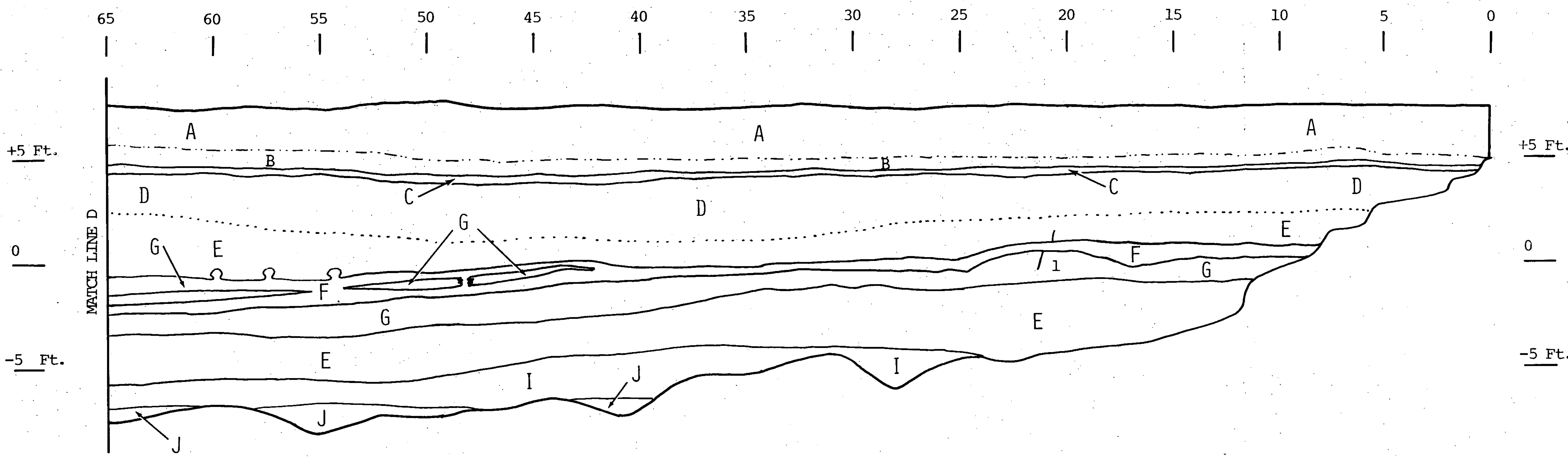


SHEET 2 OF 3

WOODWARD-CLYDE CONSULTANTS

LOG OF TRENCH 2
LAS VARAS LNG SITE

Project No. 41033I	Figure:
LNG TERMINALS EVALUATION	5.9



LITHOLOGIC DESCRIPTIONS

A SILTY SAND, blackish brown, rootlets extend 1 ft. into unit, 0.5 ft. saturated zone at base
B SILTY CLAY, moderate gray brown, soft, moist to wet
C CLAY, some silt, gray to reddish brown, soft, moist
D SANDY CLAY, brown to reddish brown, hard, dry
E CLAYEY SAND, brown to brownish red, dense, friable, dry
F SAND, buff to light gray, fine to medium grained, friable, dry
G SANDY CLAY, reddish brown, hard, dry
H SAND, yellowish orange to moderate brown, coarse grained with pebbles, some clay pods, thin beds of silty sand
I SILTY SAND, reddish brown, coarse grained, small pebbles in lower 1 ft.
J SILTY SAND, light reddish brown, medium to fine grained
K SANDY CLAY, trace silt, brick red to reddish brown, very thin rootlets

NOTES

Trench Orientation: N05E, Viewer Facing East Wall
Logged By: RS and DDP

1. Clay stringer, brown to black
2 Buff sand feature, with ¼ inch thick black sand at center. Reddish brown clay at top.
3. Thin vertical buff sand feature, fine grained, with thin black rootlets. Trends approximately N72W.
4. Thin vertical buff sand feature, fine grained, with thin black rootlets. Trends approximately N65W.
5. Buff sand, fine grained.
6. Thin vertical buff sand feature, fine grained, with thin black rootlets.
7. Thin zone of black colored sandy clay, probably rootlet.

EXPLANATION

—··—··— Soil Contact

———····· Lithologic Contact, dashed where gradational

Scale: 1 inch = 5 feet

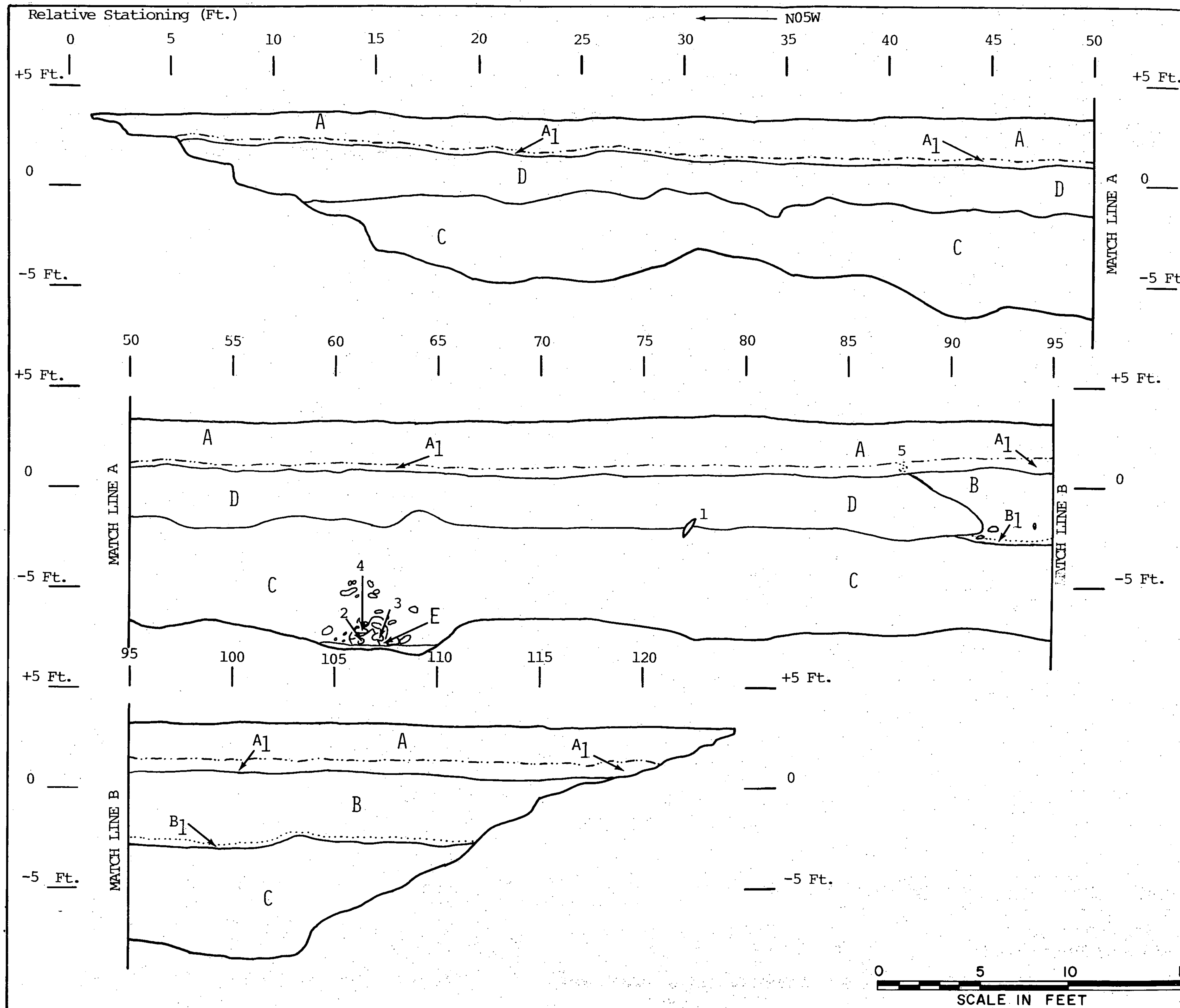
SHEET 3 OF 3

WOODWARD-CLYDE CONSULTANTS

LOG OF TRENCH 2
LAS VARAS LNG SITE

Project No. 41033I
LNG TERMINALS EVALUATION

Figure: 5.9



LITHOLOGIC DESCRIPTIONS

- A SILT, trace sand, dark yellow brown, slightly moist to moist, stiff, roots extend 1 ft. into unit
- A_1 SANDY SILT, trace clay, moderate yellow brown, some pebbles, moist, seepage occurring from 0 to 95 ft.
- B CLAYEY SILT, trace sand, moderate yellow brown
- B_1 SANDY SILT with clay, moderate yellow brown, small pebbles common, hard
- C COBBLES with SANDY SILT and SILTY SAND Sandstone cobbles, 0.5 to 1.0 ft. in length
  Matrix- Sandy silt and silty sand, trace clay, pebbles common, soft, friable
- D SILTY SAND, moderate brown, hard, small well rounded pebbles common, poorly sorted, rootlet holes, randomly oriented clay pods
- E SAND, trace clay, black, medium grained, impregnated with tar, small rounded pebbles with tar coating common

NOTES

Orientation: N05W, Veiwer Facing East Wall
Logged By: RS and DDP

1. Fine to medium grained yellow sand, probably weathered sandstone boulder
2. Fine to medium grained greenish gray sand, well indurated
3. Yellowish brown sandstone fragment, very hard
4. Light brown weathered sandstone fragment
5. Seepage zone ends at 95 ft.

EXPLANATION

—··—··— Soil Contact

————······ Lithologic Contact, dahsed where gradational

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LOG OF TRENCH 3
LAS VARAS LNG SITE

Project No. 41033 I LNG TERMINALS EVALUATION	Figure: 5.10

The age of the apparent deformation is not known at this time. K. Lajoie (personal communication, 1978) has indicated that a terrace at Santa Barbara Point is approximately 85,000 years old, and that the terrace at Isla Vista is approximately 40,000 years old. It is not known if either of these terraces may be the same terrace as at the Las Varas LNG site. If the Las Varas terrace is deformed by faulting or folding, the deformation must be younger than the deformed materials or surface. Accordingly, the deformation may have occurred within the past few tens of thousands of years.

The nearest off site fault is the Eagle fault (Figure 5.2), located adjacent to and north of the site. The Eagle fault was mapped by Dibblee (1966) as being buried by Quaternary terrace deposits, and indicated that no faulting had occurred since their deposition. Dibblee (1978, personal communication) indicated the pre-Quaternary age was based upon apparent lack of deformation of the terrace surface. A railroad cut across the trend of the Eagle fault reveals a truncated conglomerate; the truncation may be due to either faulting or normal depositional processes. No fracturing was observed at the truncation, suggesting that normal depositional processes appear to control the truncation of the conglomerate.

The nearest major off site fault is the Dos Pueblos fault (Figure 5.2), located about 3/4 mile north of the site along the base of the Santa Ynez Mountains. It is classified as pre-Quaternary in age by Jennings (1975); however, it is aligned with the Erburu fault of a Quaternary age, located about 4 miles west of the site, and is mapped as approximately located in Quaternary terrace deposits by Dibblee (1950). No evidence of Quaternary activity along the Dos Pueblos fault was observed during the field reconnaissance.

5.8.2 <u>Sources of Significant Earthquakes</u>

The More Ranch fault, 4 to 5 miles east of the area onshore and possibly as close as 2 miles offshore, shows evidence of active creep (Jennings, 1975). Along the coastal bluffs at the western end of the onshore segment of the More Ranch fault, the base of the Quaternary terrace deposits is displaced 20 to 30 feet, up to the south, and the Quaternary terrace surface has a north-facing break in slope along the trace of the fault. The More Ranch fault is part of the larger More Ranch-Mesa-Arroyo Parida fault zone; the length of this zone depends upon the number of faults that may be connected. Based on the estimated 42-mile length of the More Ranch fault, and evidence of Quaternary activity, the More Ranch fault may be able to generate earthquakes as large as magnitude 7-1/4 (Greensfelder, 1974)

The offshore Oak Ridge fault is mapped as Quaternary in age by Jennings (1975) and seismic records for the Santa Barbara Channel area (Figure 5.7) indicate historical activity in the area. The fault appears to be very steep and the nearest mapped trace lies about 24 miles southeast of the site. Profiles across the structure indicate that Holocene deposits are folded rather than faulted. Based on a 30-mile length of the fault, it may be able to generate an earthquake of magnitude 6-1/2.

The Santa Ynez fault, Big Pine fault, Santa Cruz Island fault and San Andreas fault are all youthful, and may generage earthquakes that could affect the Las Varas site. Earthquake-related characteristics of these faults are summarized on Table 5.1.

5.8.3 Seismic Hazards

The potential for fault rupture across the Las Varas site requires detailed evaluation if this site is considered further as a potential LNG import terminal site. The apparent fault identified in the trench at the base of the terrace deposits (Figure 5.8) must be fully evaluated to identify its origin, location, length, and possible relationships to the Eagle fault and other nearby faults. In addition, further exploration of the base of the terrace deposits may be warranted, in order to identify whether or not other similar features are located elsewhere beneath the site.

Other earthquake-related hazards to be evaluated include liquefaction, settlement, landslides, floods and tsunamis. Liquefaction may be possible in beach and near-shore deposits and in unconsolidated, water-saturated alluvium. The dense nature of the Quaternary terrace deposits and Tertiary bedrock minimizes the potential for significant liquefaction. Although landslides are common along the coastal bluffs, they are relatively small.

Dams and reservoirs east and west of the site appear to pose no threat due to their distance from the site and because they are in drainage basins that are remote from the site.

The height of the terrace precludes tsunami run-up on the terrace surface. Tsunami run-up is possible where the pipeline would cross the shore at the base of the coastal bluffs.

5.9 SLOPE STABILITY

Slope stability hazards at the site primarily result from retreat of the sea cliff. Numerous small landslides occur along the coastal bluffs, but do not affect a large area. The nearly horizontal terrace surface minimizes significant soil creep. Norris (1968) has described sea cliff retreat in the Santa Barbara area to the east and has determined rates of erosion ranging from negligible to 10 inches per year. Silicified Monterey Formation appears to contribute to the negligible cliff retreat in some places. Other, less resistant cliff-face materials are eroded at rates of 2 to 10 inches per year. The site, as outlined on Figures 5.1 and 5.2, is set back approximately 300 feet from the edge of the sea cliffs and does not appear likely to be affected by the erosion during the design life of the terminal.

5.10 ENGINEERING PROPERTIES AND CONSTRUCTION CONSIDERATIONS

The engineering properties and foundation conditions for the geologic units likely to be encountered during development of the Las Varas site are briefly evaluated in Table 5.2. The units evaluated at this site include residual soils, alluvium, terrace deposits, and Rincon and Monterey Shale. A rating system of high, medium, and low has been used to assess both the properties and foundation conditions. These terms are qualitative and are useful only for a relative comparison between the materials identified at the site.

5.10.1 Engineering Properties

The Rincon and Monterey shales, which make up the bedrock at the site, have characteristics of good foundation materials, for example very low compressibility, medium to high strength, very high pile support capacity and very low settlement. The terrace deposits may also be foundation materials and, although not as good as the bedrock, they have low compressibility, medium strength, medium pile support capacity and low settlement potential. The stream alluvium and residual soils are less attractive for foundations but underlie only a small portion of the site or are thin enough to allow for their removal.

5.10.2 Construction Considerations

From the preliminary estimates of the engineering characteristics, the behavior that might be expected during and after construction can be ascertained. Those conditions which are considered of importance for construction are briefly evaluated in Table 5.3.

The construction considerations of most consequence may be the medium to high difficulty of excavation in the bedrock shales. This could affect the options for excavation of buried tanks. The stability of excavations within the bedrock shales may be affected by the southward dipping bedding which could be prone to landslides where the bedding is unsupported. Perched ground

Table 5.2

ENGINEERING PROPERTIES AND FOUNDATION CONDITIONS
OF THE LAS VARAS LNG SITE

	MATERIALS			
	Alluvium	Residual Soils	Terrace Deposits	Rincon Shale & Monterey Shale
Compressibility	Medium	Medium	Low	Very Low
Strength	Low	Medium	Medium	Medium-High
Permeability	Medium-High	Low	Medium	Low
Shrink/Swell	Low	High	Low	Medium
Bearing Capacity	Low	Low-Medium	Medium	High
Pile Support Capacity	*	*	Medium	Very High
Settlement	Medium	Medium	Low	Very Low
Frost Heave	Medium	Medium	Medium	Medium

*Too thin to be applicable.

Table 5.3

CONSTRUCTION CONSIDERATIONS
OF THE LAS VARAS LNG SITE

	MATERIALS			
	Stream Alluvium	Residual Soils	Terrace Deposits	Rincon Shale & Monterey Shale
Difficulty of Excavation	Low	Low	Low	Medium-High
Stability of Temporary Excavations	Low	Medium	Medium	Medium
Use as Engineered Fill	Fair	Poor	Good	Fair
Subgrade for Haul Roads	Fair	Poor	Fair-Good	Fair

water may be encountered near the base of the terrace deposits. Other than pad grading and removal of the expansive topsoil, the relatively flat terrace surface should not require significant cut and fill to develop the site.

Sources of aggregate may be found in the nearby stream channels where gravels formed of competent sandstones could be crushed to the proper sizes. The material excavated from the Monterey or Rincon Formation will probably not be suitable for aggregate.

Ground subsidence due to subsurface fluid withdrawal is not expected to affect the site, as no water or oil wells are currently in production in the immediate vicinity of the site.

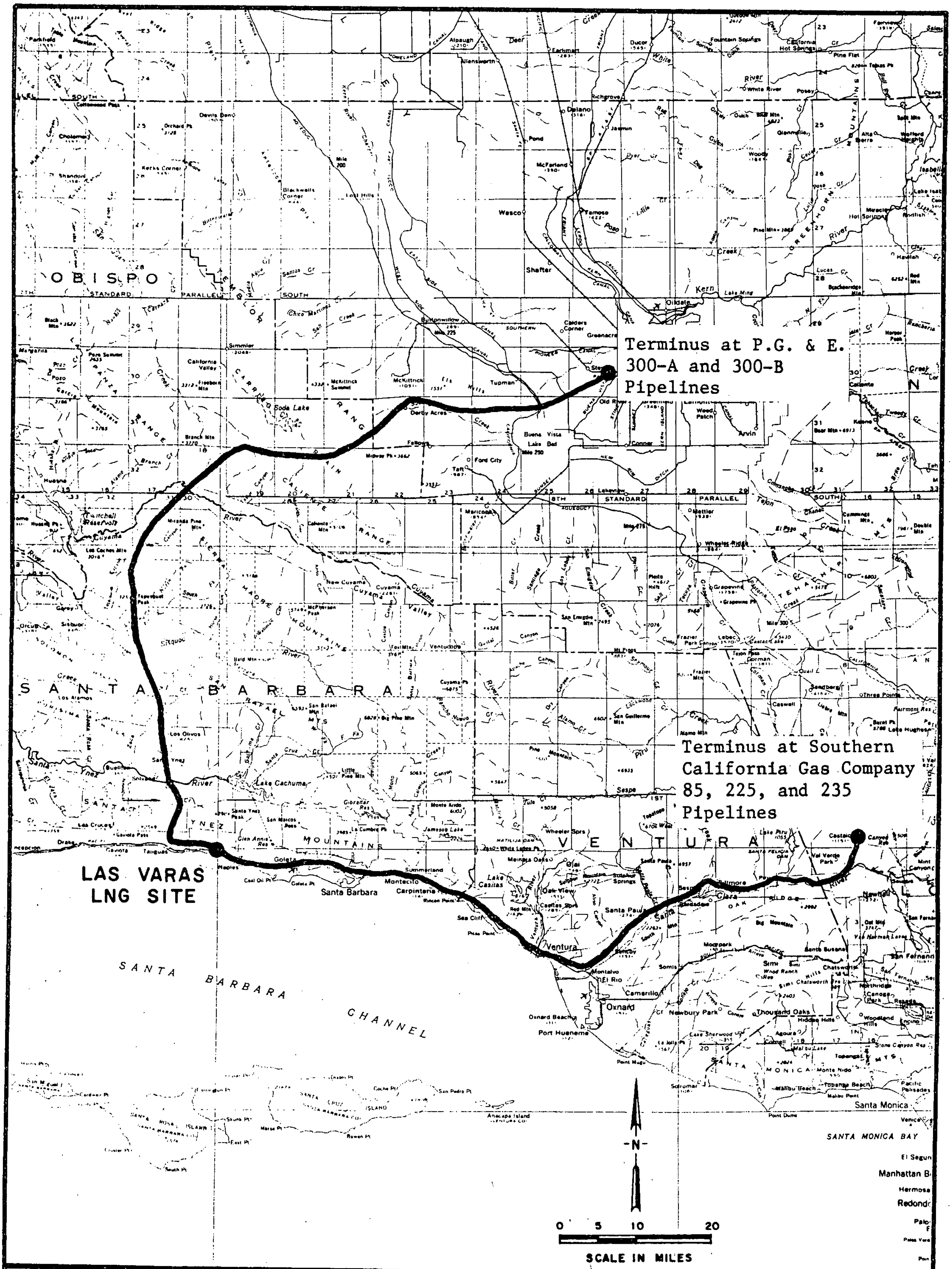
Exposed bedrock in the surf zone and the apparently thin beach deposits at the site suggest that the Trestle containing the cryogenic pipeline from the berthing area to shore could be founded on the bedrock. Special protection of the bluff from erosion may be required to maintain a stable foundation for the trestle.

An offshore tunnel of about 1/2-mile length for the cryogenic pipeline would have to be of sufficient depth below the soft unconsolidated bottom sediments to encounter the shales and mudstones of the Rincon or Monterey Formation and provide sufficient rock cover. Although probably easily excavated with a machine, problems associated with squeezing and possibly swelling ground may be encountered and may rule out machine usage. The probable occurrence of bedrock faults, and weak and steeply dipping beds could also result in tunneling difficulties and the need for heavy support. The problems of possible water inflows into the tunnel through permeable discontinuities and the potential presence of gas and oil would require further evaluation. The short length of this tunnel may make the use of conventional tunneling techniques desirable.

5.11 EXIT PIPELINE ROUTES

Two alternative exit pipeline routes fom the Las Varas site are shown on Figure 5.11. The northern route to the Central Valley area near Bakersfield, proposed by Western LNG Terminal Associates, would cross the Santa Ynez Mountains. This route, about 120- to 130-miles long, through sparsely populated areas, would cross very rugged terrain, and several major faults, including the San Andreas fault and Santa Ynez fault. Unstable, landslide prone formations, such as the Rincon and Monterey shales, occur on both the northern and southern slopes of the Santa Ynez Mountains, and unstable Cretaceous sandstone occurs in the San Rafael Mountains. Near the northern end, the route would skirt the southern edge of Elk Hills.

An alternative would be to construct the pipeline parallel to the coast and easterly, through the Ventura area to Castaic Junction, a distance of about 100 miles. Fewer faults and less rugged topography would be encountered along this route. This route would cross the More Ranch-Arroyo Parida fault zone and parallel the Oak Ridge fault from Ventura to near Piru. The materials encountered would consist primarily of Monterey Formation to Ventura and alluvium from there to Castaic Junction. Existing pipeline routes could be followed for almost the entire distance.



Project: LNG TERMINALS EVALUATION	EXIT PIPELINE ROUTES FOR THE LAS VARAS LNG SITE	Fig:
Project No: 41033I		5.11

6.0 DEER CREEK AND CANYON LNG SITE

6.1 SUMMARY

The proposed Deer Creek and Canyon LNG site is located in Ventura County 11 miles northwest of Point Dume and 5 miles southeast of Point Mugu. It is situated in a deeply incised, steep-sided canyon in the western Santa Monica Mountains. The canyon is approximately one mile wide between the bounding ridges and contains an intermittent creek with many small tributaries. The Topanga Formation, consisting of sandstones and conglomerates with some interbedded shales, and Tertiary intrusive rock are the principal geologic materials underlying the site. Limited evidence suggests that regional ground water is at or near sea level, and that perched ground water is present at higher elevations in fractures. The Malibu Coast fault is interpreted to be approximately 2-1/2 miles from the site and may be a potential source of earthquakes as large as magnitude 6-3/4. The San Andreas fault, 52 miles to the northeast, may produce earthquakes as large as magnitude 8-1/2. Potentially active landslides are common along the coast at Deer Canyon and apparently inactive landslides occur to a lesser extent inland.

Major geotechnical considerations include slope stability, the limited area available and steep slopes in the canyon, the difficulty of excavation, and seismic exposure. Landslides along the coastal bluff demonstrate the instability of the Topanga Formation on steep slopes roughly parallel to bedding. This instability must be considered for design of the cryogenic pipeline at the coast, in the canyon, and for each cut in the canyon. Landslides in the canyon appear to be inactive, but each landslide requires special evaluation. The landslide to the east of the site area should probably be removed and used as fill material if suitable, and the resulting cut should be evaluated for stability. The limited area available in the canyon will require development of flat areas by placement of thick fills or excavation of deep cuts. Alternatively, individual tanks could be placed in excavations within the bedrock. Excavation of the Topanga Formation and Tertiary intrusive rocks may require some blasting. Observations at the surface suggest blasting will not be extensive, but borings are needed to estimate excavation characteristics at depth. Seismic shaking due to both nearby and distant sources is expected to be more severe than at other sites.

6.2 MAJOR GEOTECHNICAL CONSIDERATIONS

Geotechnical considerations that should influence site selection include slope stability, the limited area available in the canyon, the difficulty of excavation, and seismic exposure.

6.2.1 Slope Stability

Slope stability is a critical geotechnical design consideration for Deer Creek and Canyon. Landslides along the coastal bluff and within the canyon demonstrate the instability of the Topanga Formation on steep slopes roughly parallel to bedding. This instability must be considered for design of the cryogenic pipeline at the coast, in the canyon, and for each cut slope.

The cryogenic pipeline will probably pass through the mouth of Deer Creek. Landslides are on both sides of the canyon mouth. The landslide on the east side is a very large block failure without internal disruption. It appears to be stable at the present time, but should be given detailed evaluation. The landslide on the west is a large, shallow failure on bedding within the Topanga Formation. It appears to have moved toward the coast at its nearest approach to the canyon mouth. The canyon mouth appears to be protected from this landslide by a ridge of undisturbed rock that forms the steep western bank at the mouth of Deer Creek. These interpretations suggest it may be possible to safely align the cryogenic pipeline through the canyon mouth, but detailed design studies would be required.

Landslides on the canyon sides appear to be inactive; however, their stability should be thoroughly investigated. The landslide on the east side of the canyon could be removed and used as fill material. The resulting cut slope would then need to be evaluated for stability. This landslide may presently be providing lateral support to adjacent, landslide-prone hillsides.

The regional bedding orientation is more favorable to development of a stable cut slope on the east side of the canyon than on the west; however, the east side of the canyon is steeper with about a 43 percent grade. Several joint orientations are well developed that could make cuts developed on these steep slopes unstable. The west side of the canyon has about a 33 percent grade, and rises to ridges that are approximately 100 feet lower than on the east. Cut slopes on the west could be inherently more stable, as they could be developed mostly within the Tertiary intrusive rocks, which are less prone to landsliding. The Topanga Formation within this possible cut area has been reoriented along its fault contact with the intrusive rock, so that the local bedding orientation may allow a stable cut slope to be developed.

Soil development is not extensive in the area and is restricted to a veneer on the ridges. Locally thick colluvium may be located in broad swales. This colluvium is subject to soil creep. Soil creep and rockslides may be a consideration on the steeper ridges and hillslopes.

6.2.2 Rugged Topography

The rugged topography of Deer Canyon will require extensive grading to provide sufficient flat area for project facilities. One-hundred acres of flat area could be provided by excavation of a deep cut in the canyon bottom at an elevation of 200 feet, as suggested by Western LNG. This alternative may result in severe problems of slope stability and would require off site disposal of large amounts of excavated material in the Oxnard area, in an adjacent canyon to the west, or elsewhere.

Another alternative with less severe slope stability problems and greater efficiency involves filling the canyon with material cut from the slopes of the canyon. This would involve filling the canyon to an elevation of 400 to 500 feet above sea level; if so, fill thicknesses could be as much as 300 feet. Grading operations of this size and larger have been undertaken for other large projects. Material to fill the canyon could be derived from either or both sides of the canyon.

6.2.3 Difficulty of Excavation

Borrow would primarily be derived from the Topanga Formation and the intrusive rocks. Both units are generally rippable but local blasting may be required in limited areas within the Topanga formation where massive sandstone or conglomerate may be present, or in the intrusive rocks where they are unweathered. Borings may be required to estimate rippability at depth. Based on surface observations, weathering is deep and excavation may not become more difficult within expected excavation depths.

6.2.4 Seismic Exposure

Seismic shaking due to both nearby and distant earthquake sources is expected to be more severe than at other sites. The Malibu Coast fault is a thrust fault located 2-1/2 miles offshore; it may be the source of earthquakes as large as magnitude 6-3/4. The San Andreas fault is 52 miles to the northeast, and may be a potential source of earthquakes as large as magnitude 8-1/2. Seismic activity along the Malibu Coast fault may induce small displacements along the inactive faults through the site, because the site is on the relatively upthrown block of the thrust. Landslides may be initiated or reactivated by ground motion from earthquakes.

6.3 LOCATION

The proposed Deer Creek and Canyon LNG site is located in Ventura County, approximately 2 miles west of the Los Angeles County line. Point Dume, eleven miles southeast, and Point Mugu, five miles northwest, are the nearest prominent coastal landmarks. The nearest town is Oxnard, fifteen miles northwest. The site can be reached from Highway 1 by way of Deer Creek Road. Vehicle access is restricted by barriers. The area is owned by the Mansdorf Trust and has been nominated as a LNG site by the owners.

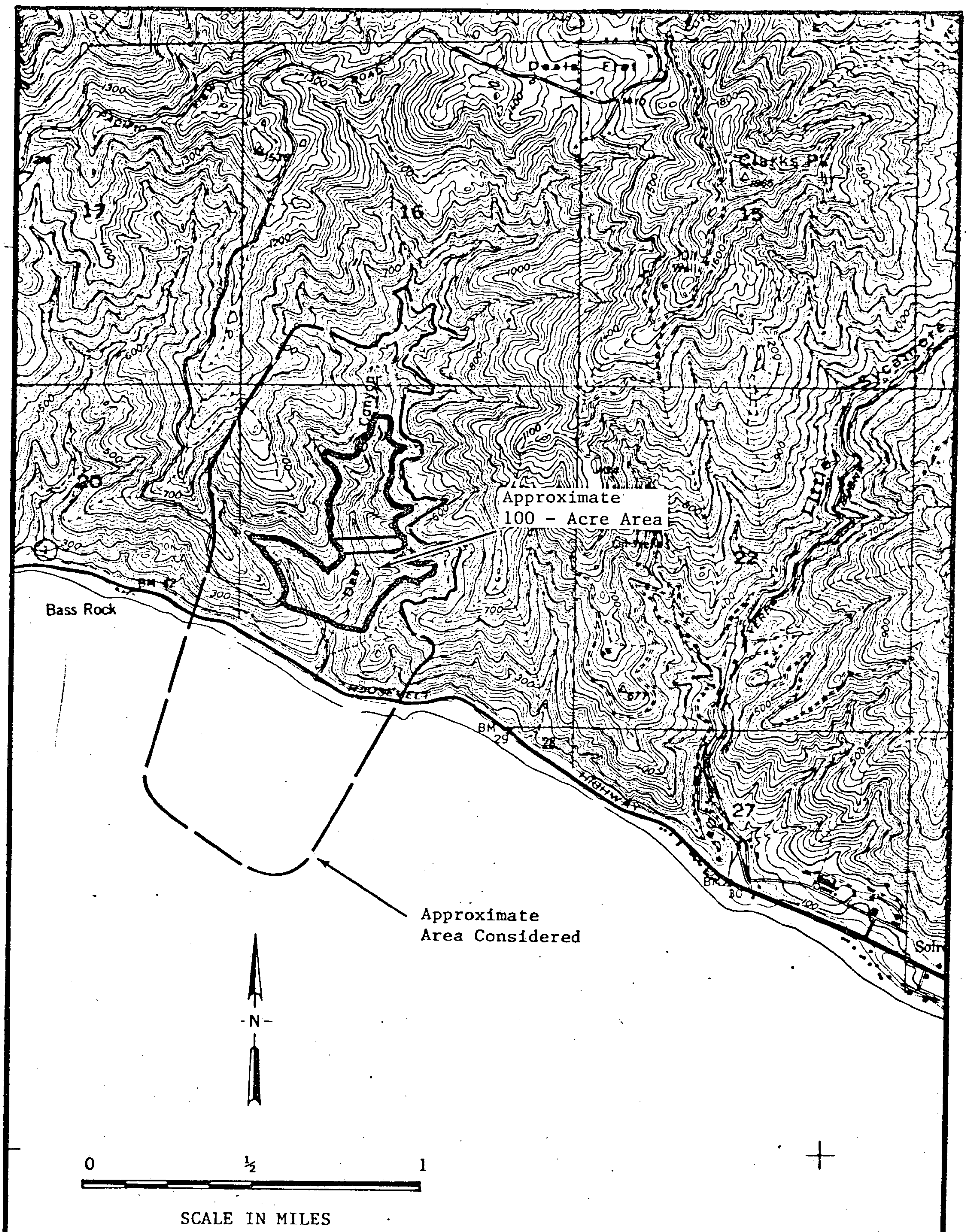
The site is presently unimproved except for Highway 1 and Deer Creek Road, which leads to private residences and orchards north of the site along the ridge at the head of the canyon and northeast of the canyon at Deal's Flat. Land use southeast of Deer Creek is for residences and recreational camps. Point Mugu State Park is northwest of the site.

The onshore portion of the site considered for development extends approximately one mile up the canyon from the coast and approximately 3/8 mile up and down the coast from the outlet of Deer Creek (Figure 6.1).

6.4 TOPOGRAPHY

The site is located within Deer Canyon, a deeply incised, steep-sided canyon in the western Santa Monica Mountains. Deer Creek, an intermittent stream, flows south and extends two-miles inland from the coast. The canyon is approximately one-mile wide between the bounding ridges. Many tributaries with steep-sided canyons flow into Deer Creek which empties directly into the Pacific Ocean through a narrow opening in the coastal bluffs.

Total relief in the vicinity of the site is in excess of 1,500 feet. Elevations within the site range from sea level to as high as 1,000 feet in areas considered for sources of fill material (Figure 6.1). The coastal bluffs rise nearly continuously to 700 feet in elevation. Three gently sloping areas on ridge tops are higher than 700 feet in elevation west of Deer Creek within the site. These gently sloping areas manifest the 33 percent average slope west of Deer Creek compared to the 43 percent average slope



Project: LNG TERMINALS EVALUATION Project No: 41033I	LOCATION MAP OF THE DEER CREEK AND CANYON LNG SITE	Fig: 6.1

east of Deer Creek. Steeper slopes are present locally within the area.

Remnants of a marine terrace with limited areal extent occur along the coast between elevations of 100 and 200 feet. The terrace remnants have been extensively modified by past wave action, stream erosion and the construction of Highway 1, so that no topographic benches are present. There are two other recognizable marine terraces that have geomorphic expression, but no terrace deposits at elevations higher than 700 feet. The terraces form some of the gentle ridge tops.

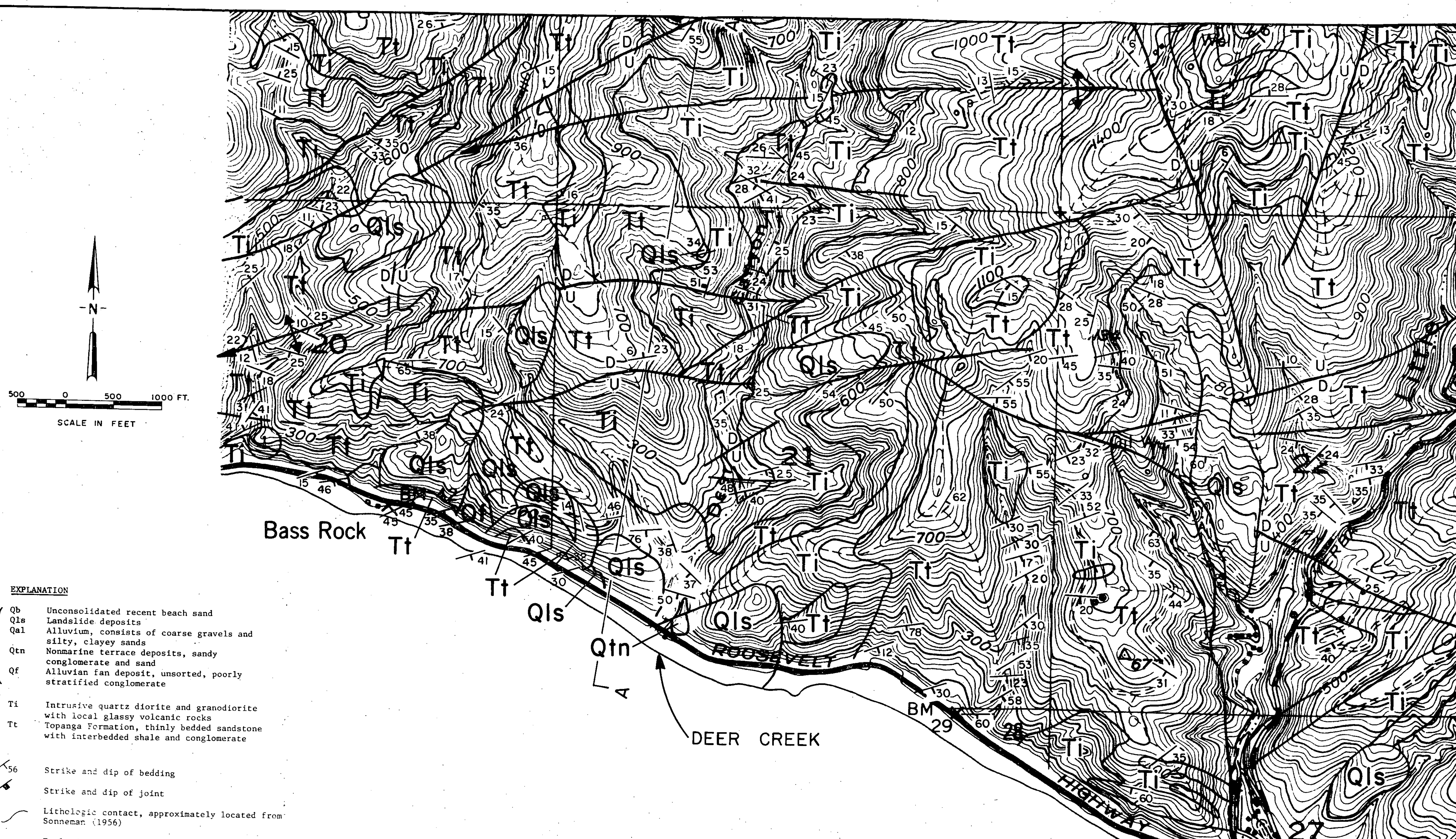
Bluffs extend in both directions from the site along Highway 1. These bluffs reach an elevation of 700 feet where Topanga Formation and Tertiary intrusive rocks crop out. The steep slope of the sea cliffs combined with the significant out-of-slope dips of strata result in slope instability.

Underlying bedrock units affect the topography to some extent, but this control appears to be based more on degree of weathering than upon geological structures. Inactive faults are common throughout the bedrock and generally trend in northeast-southwest or east-west directions. These faults are not well expressed geomorphically and exert only indirect control on the topography of the area by controlling the distribution of bedrock units.

The thick chaparral on the hills and in the valleys surrounding Deer Creek and Canyon poses a fire hazard, especially during the dry summer months. A small fire scar on the west side of the canyon reportedly resulted from a fire in 1976. Very large, uncontrolled brush fires have previously occurred in the Santa Monica Mountains.

6.5. GEOLOGIC UNITS

Geologic units in the vicinity of Deer Creek vary in age from late Tertiary to Holocene. The rock units are highly variable in



EXPLANATION

Quaternary
- Qb — Unconsolidated recent beach sand
- Qls — Landslide deposits
- Qal — Alluvium, consists of coarse gravels and silty, clayey sands
- Qtn — Nonmarine terrace deposits, sandy conglomerate and sand
- Qf — Alluvial fan deposit, unsorted, poorly stratified conglomerate

Tertiary
- Ti — Intrusive quartz diorite and granodiorite with local glassy volcanic rocks
- Tt — Topanga Formation, thinly bedded sandstone with interbedded shale and conglomerate

56 — Strike and dip of bedding

Strike and dip of joint

Lithologic contact, approximately located from Sonneman (1956)

Fault from Sonneman (1956)

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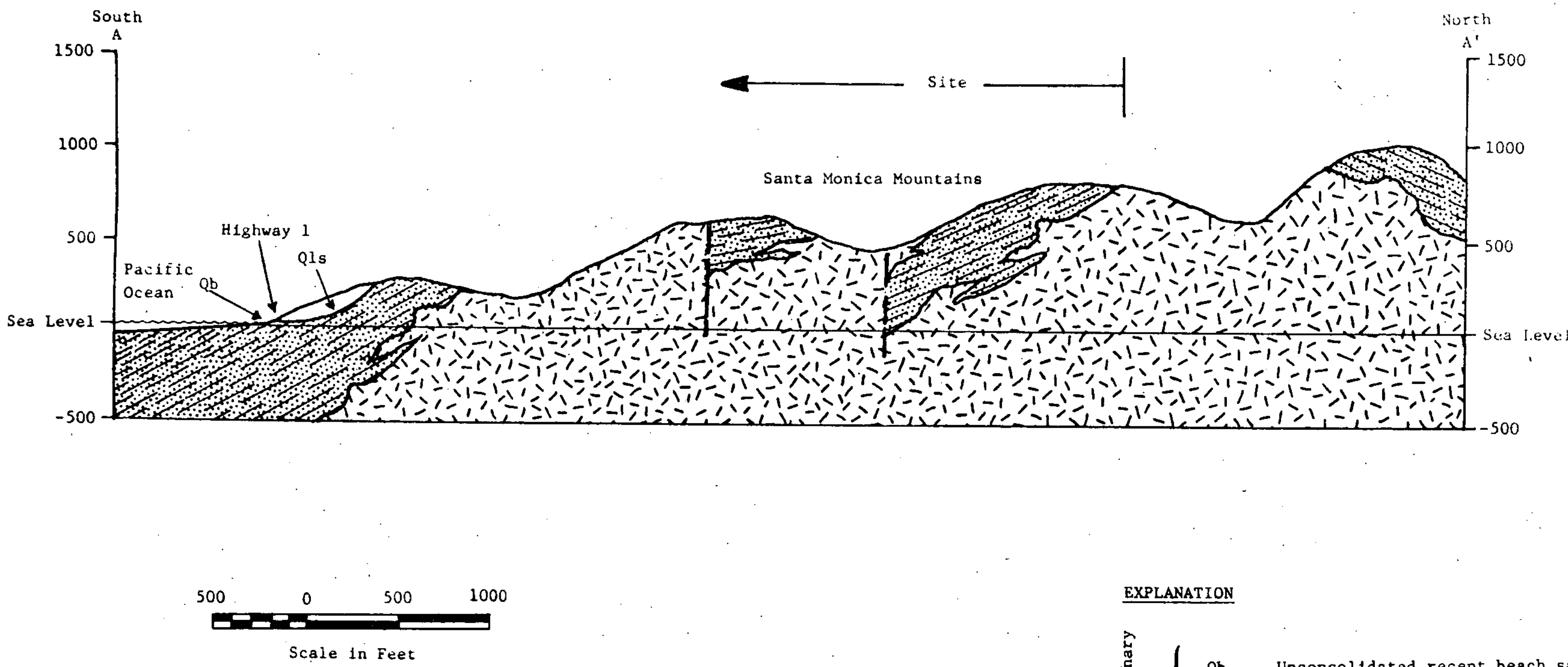
GEOLOGIC MAP OF THE DEER CREEK AND CANYON LNG SITE (modified from Sonneman, 1956)

Project No. 41033I

LNG TERMINALS EVALUATION

Figure: 6.2



EXPLANATION

Quaternary
- Qb Unconsolidated recent beach sand
- Qls Landslide deposits

Tertiary
- Ti Intrusive quartz diorite and granodiorite with local glassy volcanic rocks
- Tt Topanga Formation, thinly bedded sandstone with interbedded shale and conglomerate

Project: LNG TERMINALS EVALUATION

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DIAGRAMMATIC CROSS-SECTION OF THE DEER CREEK AND CANYON LNG SITE

Fig. 6.3

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their physical characteristics including degree of weathering, hardness, grain size, fracturing characteristics, and distribution of rock types. Two Tertiary geologic formations are present in the vicinity of Deer Creek (Figure 6.2). The Topanga Formation consists of sandstone and conglomerate with some interbedded shale. Locally, Tertiary intrusive rocks form dikes, sills and irregular bodies within the Topanga Formation, and make up a considerable percentage of it. Elsewhere, the Tertiary intrusive rocks occur in larger bodies emplaced roughly parallel to bedding in the Topanga Formation and form the second major mappable formation (Figure 6.3). Isolated erosional remnants of non-marine terrace materials and alluvial fans deposited on a relatively flat marine terrace occur at the mouth of Deer Creek and along the coastal bluffs. The relatively flat marine terrace has been destroyed by erosion. Minor deposits of Quaternary alluvium are present in the canyon bottom; beach sand is present along the coast. The most extensive Quaternary materials are landslides, which are derived mainly from the Topanga Formation and colluvial rubble.

The Topanga Formation consists of thinly-bedded, well consolidated, moderately graded sandstone, with interbeds of massive sandstone and conglomerate. Shale is present in minor amounts through most of the section, and is locally common at Deer Canyon. It is thinly-bedded and fractures into small blocks and flat chips. The shale becomes predominant to the west of the Santa Monica Mountains where it is named the Rincon Formation. The Topanga Formation is lower Miocene in age, based on stratigraphic position, and underlies most of the Deer Creek and Canyon area.

The Tertiary intrusive rocks in the area are quartz dioritic to granodioritic in composition. The texture varies from the moderately coarse-grained intrusive textures to glassy volcanic textures. The glassy volcanic textures are more common where the Tertiary intrusive rock forms tabular bodies, termed dikes and sills in the Topanga Formation. The intrusive rocks were intruded into the Topanga Formation along faults and between layers of bedding. They may have a common source with the Conejo Volcanics that crop out to the north. Topographic expression for the intrusive rocks ranges from steep, rugged terrain, with resistant layers forming linear ridges or steep slopes, to rounded, gentle slopes and broad valleys when highly weathered.

The distribution of Topanga Formation and the Tertiary intrusive rocks is controlled by the regional northeasterly strike and southeasterly dip of stratigraphic units and by east-west to northeast-trending late Tertiary faults. The distribution of these materials is shown on Figure 6.2. This geologic map has been modified from Sonneman (1956) to emphasize structural information and Quaternary materials.

Non-marine terrace materials and alluvial fans are found as isolated erosional remnants along the bluffs facing Highway 1. The non-marine terrace materials and alluvial fans were deposited on a relatively flat marine terrace with underlying marine terrace materials. The seaward and lower portions of this terrace have been eroded away by wave action leaving only the non-marine materials. Larger remnants of this ancient marine terrace are present at Sesquit Point and Point Dume. The non-marine terrace materials are light red-brown, and moderately sorted and stratified silty sands and gravels. The alluvial fan deposits are dark red-brown, very poorly sorted, and poorly stratified sands and gravels. The materials appear to be generally dense, moderately erodible, and slightly compressible.

Thin alluvial deposits are found in the canyon bottom. The character of the alluvium varies depending on the source area. The alluvium may be composed of angular rock fragments in a sandy matrix below canyons underlain by Tertiary intrusive rocks, or it may be well sorted with a large percentage of clay and silt below and within canyons underlain by Topanga Formation. These materials are of relatively low density and are compressible. The small quantities of alluvium should be removed during site preparation.

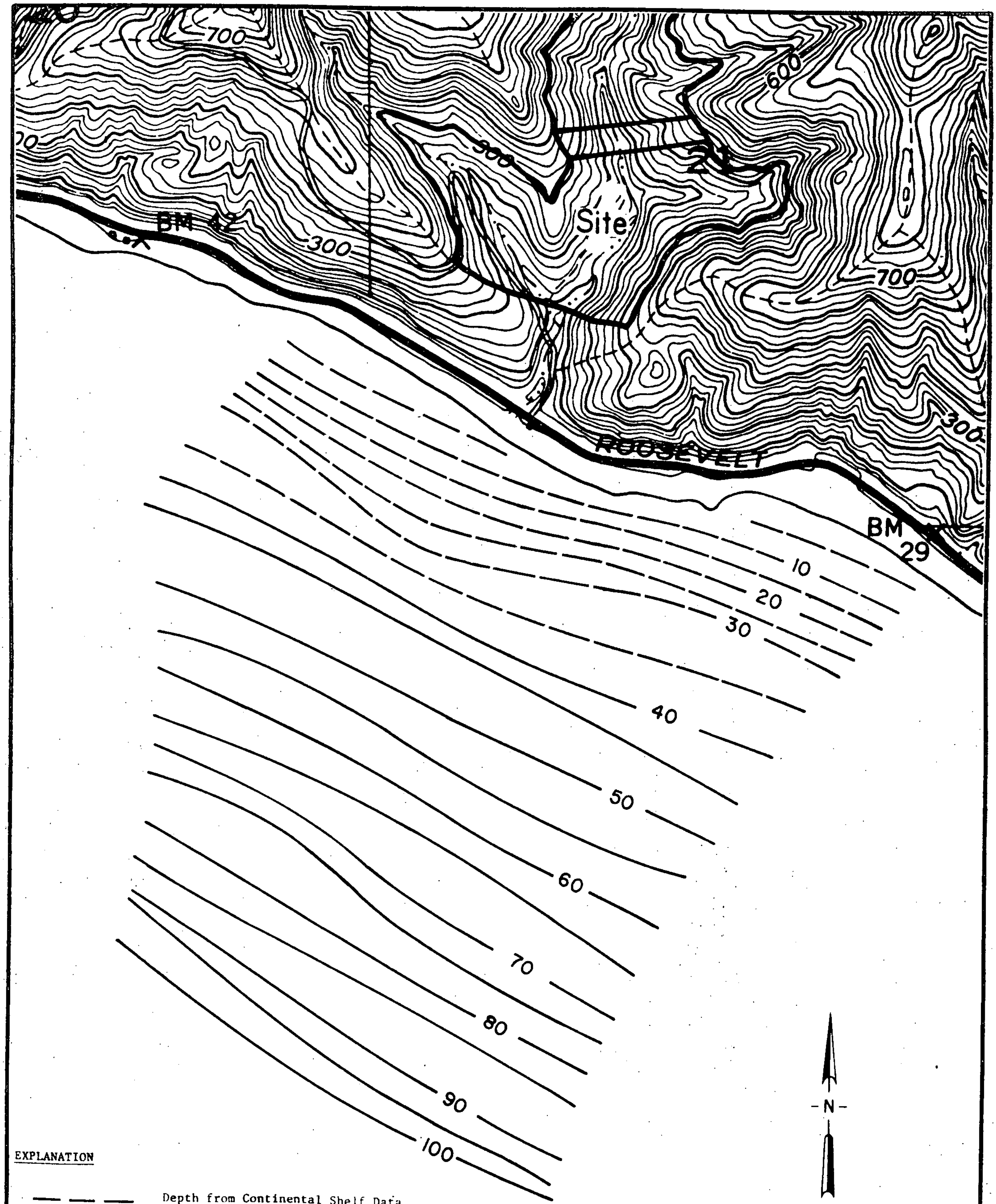
The Quaternary landslide materials are derived primarily from the Topanga Formation and colluvial rubble. They are unbedded and unsorted, internally structureless, and include blocks of Topanga Formation as long as several meters. The landslide block southeast of the mouth of Deer Creek is different in that it maintained its internal structure and consists of Tertiary intrusive rocks as well as Topanga Formation.

Beach sand is coarse and includes some gravel. It forms a mantle on the Tertiary bedrock that may be 10 feet thick in some places. The sand is moderately well sorted, medium to coarse-grained sand eroded from the coastal bluffs and transported along the coast from rivers and streams draining the Oxnard Plain to the northwest. The unconsolidated and water saturated nature of these deposits indicates a significant liquefaction potential. Approximately 5 feet of beach erosion due to winter storms was observed during field studies, based on comparison with remnants of the pre-existing summer beach.

Soils are very thin and poorly developed on the steep slopes. Soils on the more gentle ridge tops are generally a clayey sand. Thick colluvial deposits fill broad, steep swales in the canyon sides. No deposits of economic value were observed within or near the site.

6.6 OFFSHORE GEOLOGY

The offshore area slopes gently seaward with no significant relief (Figure 6.4). The nearshore portion of the site consists of an eroded bedrock bench of Topanga Formation and Tertiary intrusive rock with a thin sand cover (Weber and others, 1973). At about 1,000 to 1,500 feet offshore an unconsolidated sediment wedge begins thickening seaward and includes finer grained



EXPLANATION

— — — Depth from Continental Shelf Data Systems, Point Dume Bathymetric Map 1967

——— Depth from Woodward-Clyde Consultants Survey

Project: LNG TERMINALS EVALUATION Project No: 410331	BATHYMETRY OF THE DEER CREEK AND CANYON LNG SITE	Fig: 6.4

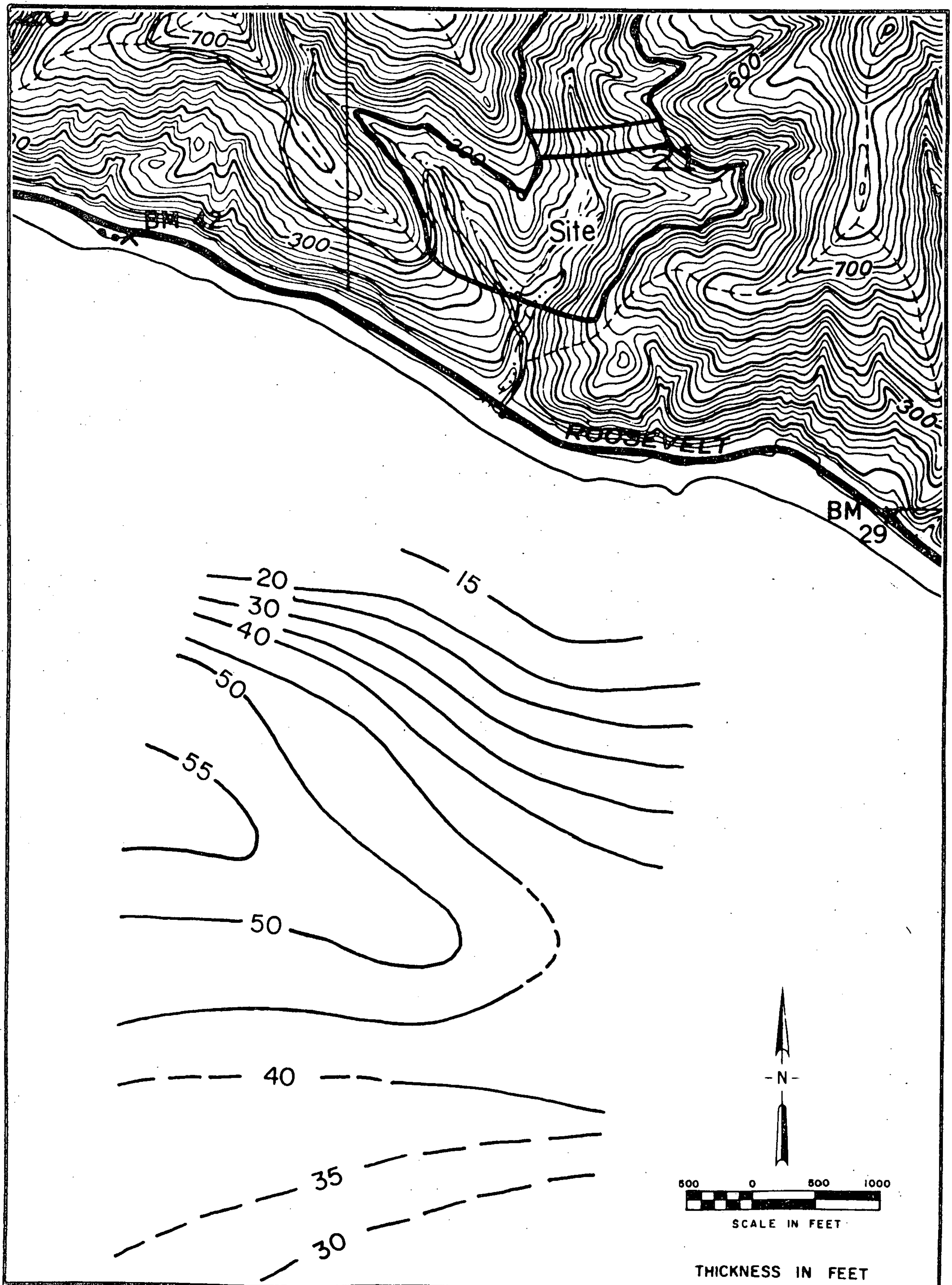
sediments (Figure 6.5). The sediment wedge thickens from about 10 to 20 feet at the 40-foot bathymetric contour to in excess of 40 feet at the 60-foot bathymetric contour. In water depths over 90 feet, about 4000 feet from shore, the wedge begins to thin seaward. At 10,000 feet offshore, the unconsolidated sediments have thinned to about 20 feet. In some places farther offshore the unconsolidated sediments are absent and the Tertiary sediments are exposed on the sea floor. Subbottom reflection profiles show that the Tertiary rocks are highly folded and possibly faulted similarly to the bedrock exposed onshore. Approximately 2-1/2 miles offshore severe deformation of the Tertiary strata, and some rock pinnacles may mark a fault; this may be the Malibu Coast fault.

6.7 HYDROLOGY

6.7.1 Surface Water

The major drainage in this site is Deer Canyon, with a drainage basin of approximately 2 square miles (Figure 6.6). Deer Creek is an intermittent stream that flows during the winter months or during storms. Other intermittent streams occur in the deeply incised canyons tributary to Deer Creek. No perennial streams or standing bodies of water were found within or near the site, and no dams are presently located within the Deer Canyon.

Flooding of a pad developed in Deer Creek could occur, especially during periods of peak rainfall, if adequate provision for drainage through the site is not provided. Storm runoff should be limited to the stream channel areas. The principal hazard to the site would occur if culverts or diversion structures become partially blocked, and cause damming. Overtopping of the diversion structure, and erosion of the area around it could occur. A very large and well maintained culvert through the site could mitigate this potential flood hazard.



Project: LNG TERMINALS EVALUATION Project No: 41033I	THICKNESS OF UNCONSOLIDATED OFFSHORE SEDIMENTS AT THE DEER CREEK AND CANYON LNG SITE	Fig. 6.5

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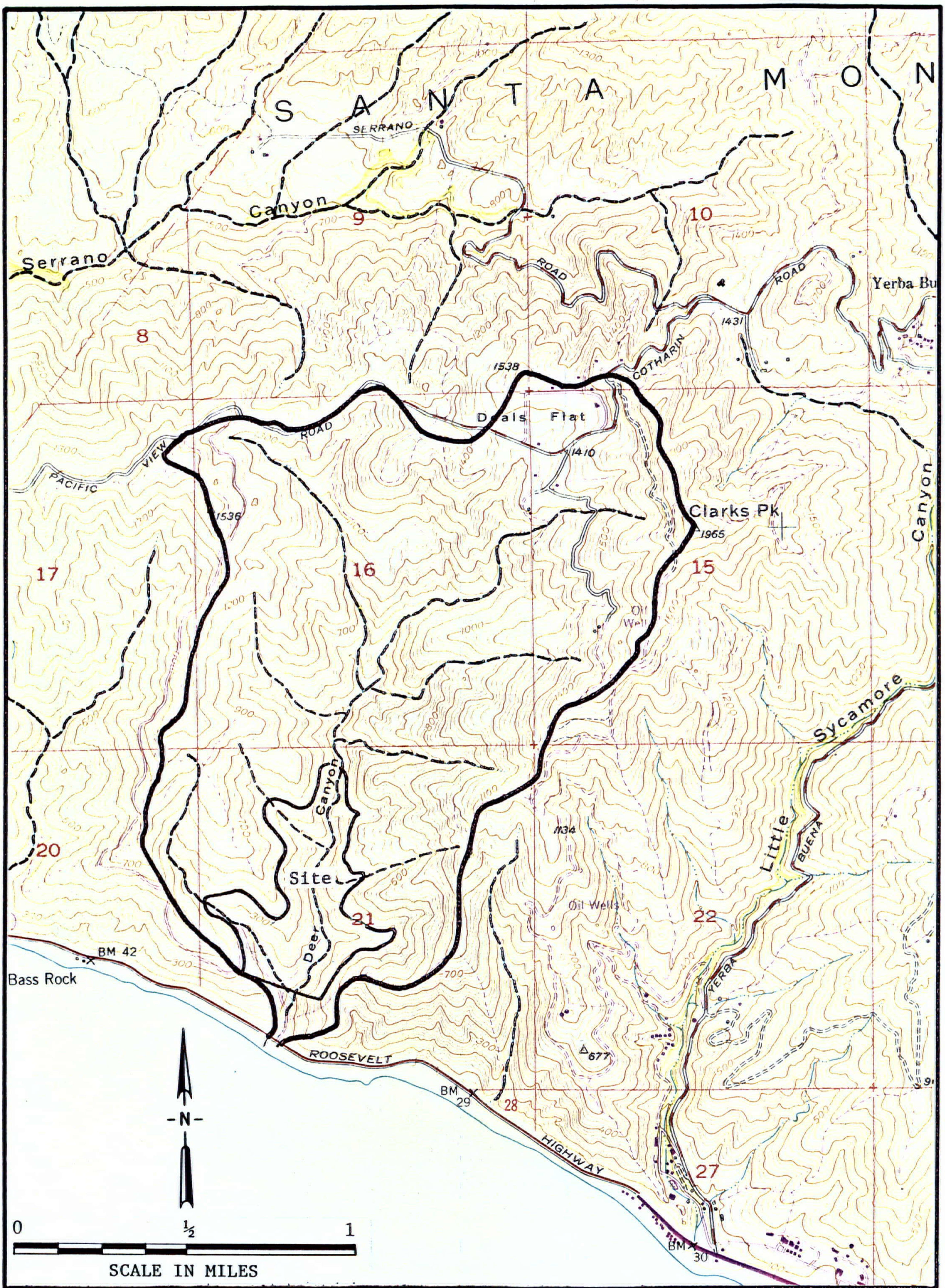

Project: LNG TERMINALS EVALUATION Project No: 41033I	DRAINAGE MAP OF THE DEER CREEK AND CANYON LNG SITE

Fig: 6.6

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6.7.2 Stream Erosion

Deer Canyon and its numerous tributary canyons form a fairly stable erosional environment with a low rate of erosion. The drainage pattern for the area is also stable and occurs along incised canyons and well defined channels through the coastal bluffs. Headward erosion and extensive downcutting of the drainage channel does not appear to be occurring at a high rate.

6.7.3 Ground Water

The regional water table in the bedrock is at unknown depth, but it may be near sea level. Minor amounts of perched water are present. No seeps or springs were found in the area during field reconnaissance, nor are any identified on published maps.

Wells are used for private water supply at residences north of Deer Canyon. The intrusive rocks are generally water bearing, with water located in fractures within the rock. Locally, the Topanga Formation may yield water, but it tends to be brackish at depth (Weber and others, 1973). Ground water may also be found in minor amounts in the alluvial deposits.

6.7.4 Fresh Water Supply

Fresh water supply in the study area is restricted to ground water. The water table appears to be low, perhaps near sea level. No springs or seeps were noted in the coastal bluffs or along the basal contacts of the terrace deposits with the bedrock. Present development of water supply in the area consists of wells for private residences. The ground water in the area may not be adequate to supply requirements for construction an LNG facility. Evaluation of potential water sources appears warranted if this site is considered further.

6.8 FAULTING AND SEISMICITY

6.8.1 Inactive Faults

Many inactive faults are within and across Deer Canyon; these faults divide the south flank of the underlying anticline into separate blocks. Regionally, these faults are classified as early Cenozoic in age by Ziony and others (1974). They displace early Miocene units and therefore may be late Miocene or Pliocene in age. No evidence of later activity was observed in field studies or is known from the literature. The faults have displaced the Tertiary formations on the order of a few thousand feet. These displacements have been sufficient to reorient bedding within the fault blocks by 20 to 25 degrees (Figure 6.2). The faults mapped within the site are based on offset geologic units, anomalous structural orientations, or gouge-filled and dike-filled zones. The fault planes are generally near vertical, with the northerly block down relative to the southerly block. These faults do not cut younger alluvial units, and their topographic expressions are minimal. They were probably formed during folding of the Tertiary formations. Their traces have been observed on aerial photographs to extend beyond the area mapped in Figure 6.2.

The Sycamore Canyon fault passes within three miles northwest of the site. It has a northeast trend and is a normal fault with approximately 5000 feet of stratigraphic separation (Sonneman, 1956). Weber and others (1973) show a left-lateral sense of displacement. A one-day reconnaissance of the Sycamore Canyon area where the fault parallels the canyon revealed no geomorphic evidence of youthful faulting; however, the Point Mugu earthquake of 1973 may have occurred on the offshore extension. The fault controls some of the morphology of the canyon by juxtaposing Tertiary intrusive rock against Topanga Formation. This is the apparent relationship at Wood Canyon where the fault leaves Big Sycamore Canyon; there is an apparent left-lateral offset of Wood Canyon. The offset appears to have resulted either from differential erosion of the Tertiary intrusive rocks relative to the Topanga Formation or down-cutting of Wood Creek from a left-lateral offset produced in early Quaternary or pre-Quaternary time.

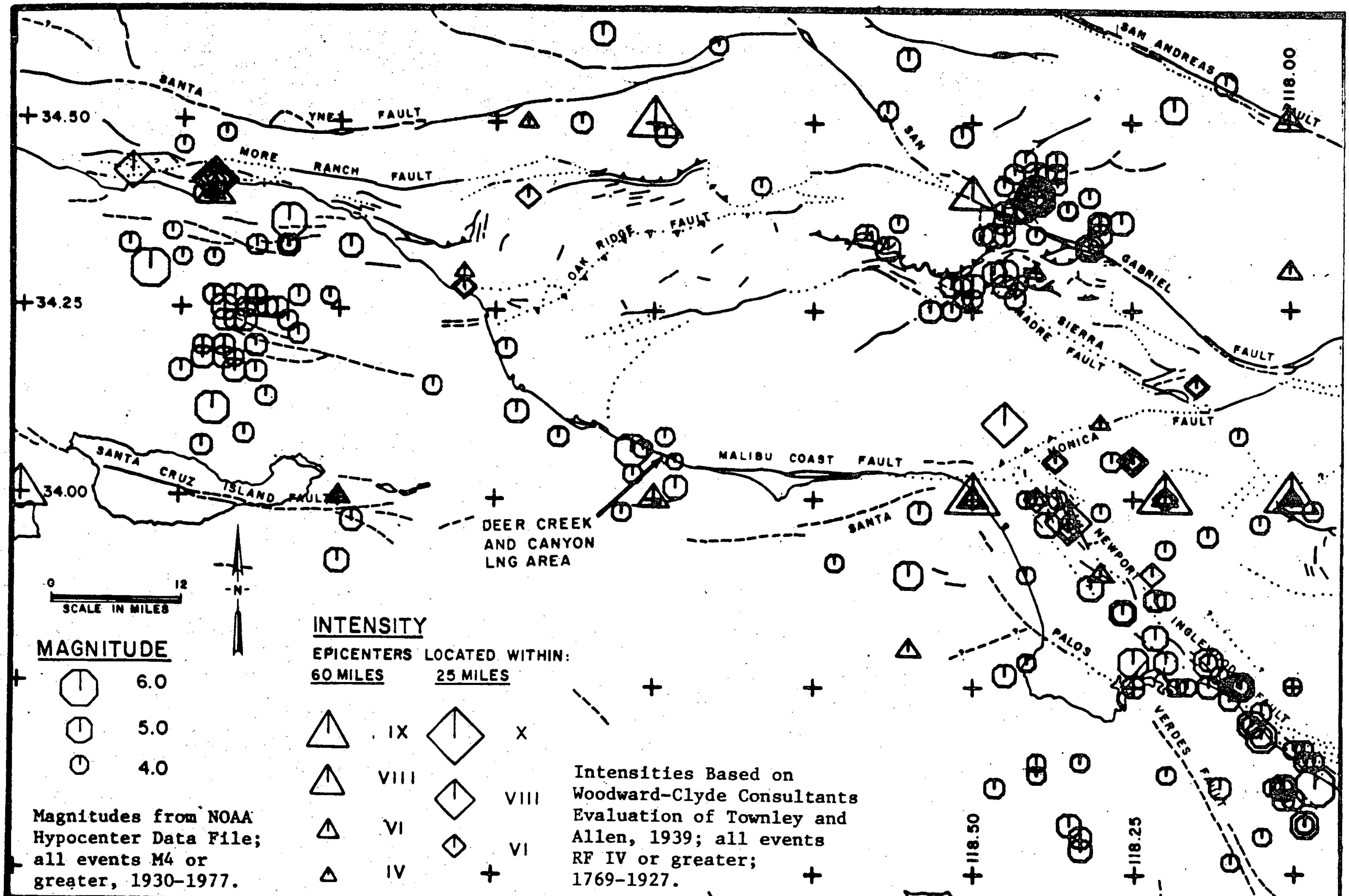
6.8.2 Active Faults

No active faults are known within the Deer Creek and Canyon site. The active fault nearest the site is the Malibu Coast fault located 2-1/2 miles offshore. This fault may generate the strongest seismic shaking at the site. Earthquakes expected from the Malibu Coast and other faults in the region (Figure 6.7) are shown on Table 6.1.

6.8.3 Seismicity

Approximately nine major damaging earthquakes have been noted in the region within approximately 50 miles of Deer Creek since 1925. On February 21, 1973, the latest of these events occurred near Deer Creek and Canyon. The epicenter has been located just off Point Mugu. It was assigned a magnitude of 5.9 and was followed by several aftershocks (Coffman and von Hake, 1975). Major damage occurred in Oxnard, which suffered economic losses of about one million dollars (Coffman and von Hake, 1975). No tectonic surface rupture was reported, although many ground cracks from lurching were found near Point Mugu (Coffman and von Hake, 1975). One of the most prominent natural features caused by the earthquake was evidence of liquefaction and compaction of saturated sediments in coastal areas (Coffman and von Hake, 1975). The fault plane solution is interpreted to be north-over-south reverse slip on an east-west fault; this geometry is compatible with that of the Malibu Coast fault, although the fault that generated the earthquake is unknown.

No seismicity has been noted on the Malibu Coast fault east of Deer Creek and Canyon. West of the site, two earthquakes of magnitude greater than 4 have occurred offshore from the Oxnard Plain beyond the active zone of the 1973 Point Mugu earthquake. More distant sources of seismicity shown on Figure 6.7 include the active zone in the Santa Barbara Channel, the area of the 1971 San Fernando earthquake, and the seismicity of the Newport-Inglewood fault zone. The larger earthquakes are associated with these zones of seismicity. The diffuse pattern of seismicity



Project: LNG TERMINALS EVALUATION Project No. 41033I	REGIONAL FAULT AND SEISMICITY MAP OF THE DEER CREEK AND CANYON LNG SITE	Fig. 6.7

Table 6.1

FAULTS IN PROXIMITY TO THE DEER CREEK AND CANYON LNG SITE[1]

Fault Name	Distance From Site[1] (Miles)	Fault Type[1]	Fault Length[1] (Miles)	Age Category[1]	Estimated 100-year Earthquake[2]	Estimated Maximum Credible Earthquake[3]
Malibu Coast	2-1/2	Reverse	27	Quaternary	5-3/4 to 6-1/4	6-3/4
Unnamed Offshore	4	Reverse	6	Quaternary	3-1/2 to 4	5
Santa Monica	8	Reverse Strike-slip	50	Quaternary	6 to 6-1/2	7
Simi	13	Reverse	30	Quaternary	5-1/2 to 6	6-3/4
Oak Ridge Onshore	17	Reverse Strike-slip	35	Quaternary	5-1/2 to 6	6-3/4
Oak Ridge Offshore	35	Normal Strike-slip	30	Quaternary	5-1/2 to 6	6-1/2
Santa Cruz Island	21	Reverse Strike-slip	44	Quaternary	6 to 6-1/2	7
Santa Susana	25	Reverse	26	Quaternary	5-1/2 to 6	6-1/2
San Cayetano	24	Reverse	25	Quaternary	5-1/2 to 6	6-1/2
More Ranch	26	Reverse	50	Quaternary	5-1/2 to 6	6-1/2
Santa Ynez	34	Reverse Strike-slip	50	Quaternary	6-6 to 1/2	7-1/4
San Gabriel	36	Strike-slip	64	Quaternary	5-1/2 to 6	7
Newport-Inglewood	30	Strike-slip	>120	Quaternary	5-3/4 to 6-1/4	7-1/4
Big Pine	48	Strike-slip	>500	Historic	5-3/4 to 6-1/4	7
San Andreas	52	Strike-slip	>500	Historic	7-1/2 to 8-1/4	8-1/2

[1] Data from Jennings (1975) unless otherwise noted.

[2] Estimated earthquake activity is a judgment based upon knowledge of the historical seismicity of the region and local area, and upon the recent geological history of the faults considered. These estimates are considered to be conservative, especially in the upper ranges of magnitude.

[3] Based upon one-half the fault length rupturing to produce an earthquake of given magnitude, as shown by Patwardhan and others (1975). Estimates are to the nearest 1/4 magnitude value.

over the remaining map area may be associated with active faults that are not known to have generated damaging earthquakes since 1925.

6.8.4 Sources of Significant Earthquakes

Most of the faults shown on Figure 6.7 are potential sources of earthquakes that may be as large as magnitude 6-1/2. With the exception of the San Andreas fault, none are expected to produce effects at Deer Creek and Canyon greater than the earthquakes estimated for the Malibu Coast fault. The Malibu Coast fault is Quaternary in age (Jennings, 1975) and is a potential source of nearby earthquakes. More distant potential earthquake sources that may affect the site include the onshore and offshore Santa Monica, Oak Ridge, Simi, and Santa Ynez faults (Figure 6.7). The San Andreas fault is located 52 miles to the northeast. Earthquakes of magnitude 8 to 8-1/2 are expected to recur on this fault at approximate intervals of 160 years (Sieh, 1977); the latest of these events occurred in 1857.

6.8.5 Seismic Hazards

Facilities placed on differentially thick fills may be subject to relatively complex and highly variable ground shaking. The complexities arise because the bedrock and fill transmit earthquake ground motions differently. These differential effects may or may not be significant.

The Malibu Coast fault may be located 2-1/2 miles offshore based on the offshore geophysical survey (Section 6.6). The location and linear extent of the Malibu Coast fault must be more definitively established for the design of offshore facilities. The 1973 Point Mugu earthquake occurred in the vicinity of the site and may be typical of earthquakes on the Malibu Coast fault, as suggested by geological evidence. The site is located on the upthrown block relative to expected earthquakes on the Malibu Coast fault; small differential movement along the inactive faults in the Deer Canyon area may occur in response to such an event.

6.9 SLOPE STABILITY

6.9.1 Landslides

Landslides are common along the coast at Deer Creek and Canyon, and occur to a lesser extent inland. Most of the landslides are controlled by shear failures along shale interbeds within the Topanga Formation. Although areally extensive, these landslides are not deep. There are small, active rotational failures within the older, large landslides apparently caused by cuts made for the highway. The landslide to the west of the mouth of Deer Creek is a large but shallow failure along bedding within the Topanga Formation. The landslide to the east of Deer Creek is a large, deep rotational block failure and includes Topanga Formation and Tertiary intrusive rocks. This landslide appears to be inactive but should be given detailed evaulation. The landslide to the east of the site can be removed and used for fill material. Any cuts made into the hillside would need to be evaluated for resulting slope stability; the landslide may presently be providing lateral support to adjacent landslide-prone slopes. Other, smaller landslides should be evaluated for present stability and treated if necessary.

6.9.2 Coastal Erosion

Coastal erosion appears to be controlled by mass wasting of the cliffs rather than from erosion by wave action. Cliff recession does not appear to be a significant consideration for the potential LNG facilities at Deer Canyon. Storm effects noted during January through March of 1978 included removal of a few feet of sand from the beach, and small slumps in the seaward shoulder of highway fill; no new landslides were noted at the mouth of Deer Canyon.

6.10 ENGINEERING PROPERTIES AND CONSTRUCTION CONSIDERATIONS

6.10.1 Engineering Properties

The engineering properties and foundation conditions for geologic units likely to be encountered during development of the proposed site are considered on Table 6.2. As no detailed testing is

Table 6.2

ENGINEERING PROPERTIES AND FOUNDATION CONDITIONS
OF THE DEER CREEK AND CANYON LNG SITE

	MATERIALS	
	Topanga Formation	Tertiary Intrusive
Compressibility	Low	Low
Strength	High	High
Permeability	Medium	Low
Shrink/Swell	Low-Medium	Low
Bearing Capacity	High	High
Pile Support Capacity	High	Very High
Settlement	Low	Low
Frost Heave	Low-Medium	Low

available, the evaluations are qualitative and relative between the various units. The units evaluated are the Topanga formation and Tertiary intrusive rocks.

Both the Topanga Formation and weathered Tertiary intrusive rocks should provide an excellent foundation in either cut or fill. Other Quaternary age materials, such as landslide deposits, alluvium and terrace materials could be mixed with these good materials.

6.10.2 Construction Considerations

Construction considerations are summarized on Table 6.3. The facility may be constructed almost entirely on fill, which can be obtained from the surrounding hills and valleys.

The sedimentary and igneous rocks in the area are rippable with localized areas that may require blasting. The outcrops most recently exposed by erosion in the bed of Deer Creek are very hard. Nevertheless, weathered material may be present in sufficient quantities on the canyon sides. Bedding orientation within the Topanga Formation will control cut orientations and slopes. The Topanga Formation on the site is not anticipated to be suitable as an aggregate source due to the high content of shale. There may be adequate unweathered Tertiary intrusive granodiorite found at shallow depths to provide a source for crushed aggregate; this requires further evaluation. Imported aggregate from the Ventura Basin may also be feasible. The existing highway would serve as a haul and access road.

If seismic response considerations require siting of facilities on cuts rather than fill, the spoil could be placed in the next canyon to the west. Slope instability could be severe, especially in areas where the bedding is nearly parallel or inclined less steeply than the slope. The Topanga Formation is highly fractured and may be unstable in moderately steep cut slopes of any orientation (Slossen and Associates, 1978).

Table 6.3

CONSTRUCTION CONSIDERATIONS
OF THE DEER CREEK AND CANYON LNG SITE

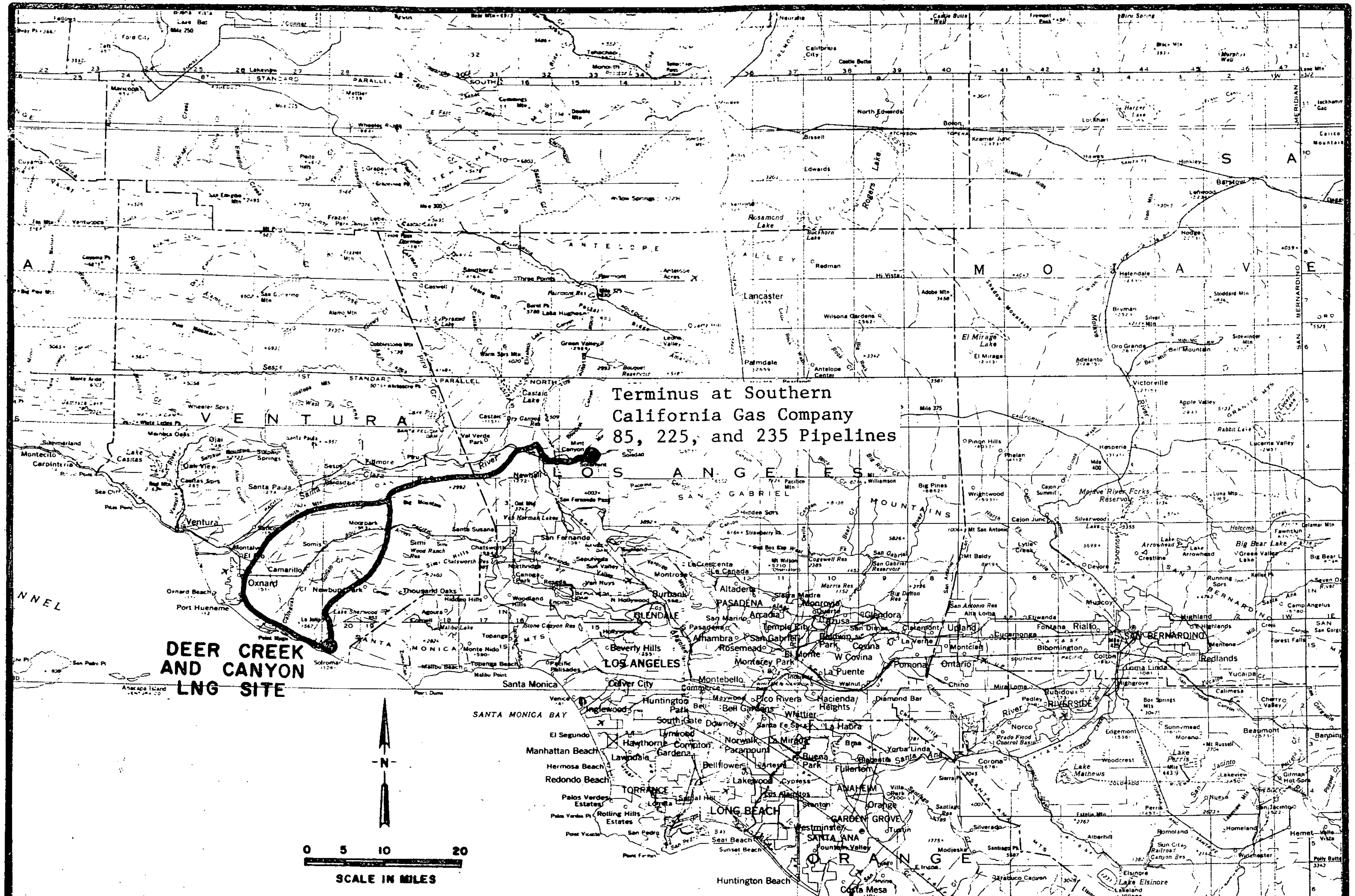
	MATERIALS	
	Topanga Formation	Tertiary Intrusive
Difficulty of Excavation	Medium	High
Stability of Temporary Excavations	Low-Medium*	Medium-High*
Use as Engineered Fill	Good	Good
Subgrade for Haul Roads	Fair-Good	Fair-Good

*Local landsliding depends on bedding attitude and excavation slope angle.

If a 1/2-mile long tunnel were considered as an alternative to a trestle from the berthing area to the onshore facilities, it would be excavated in Topanga Formation and Tertiary intrusive rock for a distance of three or four thousand feet. These formations are variable in their degree of fracturing and rock mass characteristics, and contain many inactive faults. Potentially permeable fault zones or open joints may allow sea water into the tunnel and may require grouting or other measures to control their flow. The gradually thickening wedge of unconsolidated sediments beginning about 1,000 to 1,500 feet offshore and extending seaward, may require a deep tunnel to keep the tunnel alignment in bedrock; this may also significantly affect the foundation of the trestle connecting the offshore berth. These variable conditions may make excavation of a tunnel at Deer Creek and Canyon difficult and conventional mining techniques may be more feasible than a tunnel boring machine. Detailed investigations would be needed to identify the best tunneling method and alignment.

6.11 EXIT PIPELINE ROUTES

Gas transmission lines from Deer Creek and Canyon may traverse the rugged topography over the Santa Monica Mountains to connect to large diameter lines north of the mountains near Moorpark (Figure 6.8). Such a route would continue up Deer Creek from the site, enter Serrano Canyon to the north and turn northwest to skirt the ridges between Serrano Canyon and Big Sycamore Canyon. Once in Sycamore Canyon, several routes could be followed to the north to reach the gentle topography in the vicinity of U.S. 101 at Thousand Oaks. The Simi fault is the only known active fault to be crossed by this route, and landslides could be avoided by careful selection of the final alignment. No special construction problems would be expected along this route other than those due to steep togography. The pipeline would pass through undeveloped portions of Point Mugu State Park in order to avoid the steepest topography where construction could be difficult.



Project: LNG TERMINALS EVALUATION Project No. 41033I	EXIT PIPELINE ROUTES FOR THE DEER CREEK AND CANYON LNG SITE

Fig. 6.8

An alternative to this route might intercept the same existing gas lines near Port Hueneme (Figure 6.8). This route could follow Highway 1 along the coast to the Oxnard Plain and Port Hueneme; it would require disruption of Highway 1 during construction and consideration of landslides and coastal erosion along the route. Several active faults are present in the Oxnard Plain, although those crossed by the pipeline are not known to have surface expressions. Portions of the Oxnard Plain may be subject to liquefaction during earthquakes.

7.0 CAMP PENDLETON LNG SITE

7.1 SUMMARY

The proposed Camp Pendleton LNG site is in northwestern San Diego County on a broad coastal terrace. The site is covered by expansive soil; the foundation materials are terrace deposits of stiff soil that are easily excavatable silty sand, clay, and gravel. The bedrock formations consist of sandstone, siltstone, shale and breccia. The offshore area has bedrock exposures covered by a thin discontinuous mantle of unconsolidated sands that are susceptible to liquefaction. No faults have been identified on the site. The nearest source of earthquakes is from the South Coast offshore zone of deformation, which is approximately 6 miles offshore and may generate earthquakes in the magnitude range of 5-3/4 to 6-1/4. Landslides are common along the coastal bluffs and affect the terrace surface as much as 400 to 450 feet inland from the coastline. A landslide was identified in the bedrock, but apparently has not moved in the last 130,000 years. Significant erosion has occurred along Dead Dog Canyon through the center of the site, which has eroded headward an average of 14 to 15 feet per year since 1932. Ground water at the site is apparently more than 80 feet deep. Exit pipeline alternatives include a 75- to 80-mile-long northerly route through San Juan Capistrano and Santa Ana to Riverside, and a 95- to 100-mile-long easterly and northerly route through Temecula to Riverside. Parts of both alternate routes parallel existing gas pipelines. The northerly route is underlain almost entirely by Quaternary terrace and alluvial deposits. The easterly route would require crossing the Santa Ana Mountains and would cross landslide-prone sediments, and granitic rocks as well as alluvium.

The unstable nature of the coastal bluffs will require significant mitigation measures, particularly where the cryogenic pipeline would cross the bluffs. A prudent setback distance of

perhaps 600 feet may be required for structures on the terrace surface. Erosion along Dead Dog Canyon must also be controlled. This may require filling the canyon with engineered fill and design of conveyence structures through the site.

7.2 MAJOR GEOTECHNICAL CONSIDERATIONS

Key geotechnical considerations at the Camp Pendleton LNG site are the unstable coastal bluffs, and erosion of Dead Dog Canyon through the site and Horno Canyon north of the site.

7.2.1 Slope Stability

Landslides are common along this section of the coast and have affected the terrace surface as much as 450 feet inland from the mean lower low water line. Landslides, dated as earlier than 130,000 years are found in the bedrock, and younger landslides that are currently active affect the bedrock and terrace deposits. A setback distance of perhaps 600 feet may be established for onshore facilities to mitigate this hazard, but the cryogenic pipeline must cross the coastline and may require special consideration. Setback distances should also be established along the near-vertical stream drainages of Dead Dog Canyon and Horno Canyon.

7.2.2 Erosion

Significant erosion has occurred along the channel of Dead Dog Canyon. Comparison of aerial photographs taken of the site in 1932 and 1970 document headward erosion of more than 560 feet, or about 14 to 15 feet per year. More than 100 feet of erosion has occurred in the last year. This demonstrates the episodic nature of coastal erosion. This canyon now extends into the center of the site, and is 60 to 80 feet deep and perhaps 100 feet wide.

Mitigation of this erosion could require filling the canyon and construction of structures to convey the flood waters through the site. The fill material may be obtained during excavation and grading of the site.

7.3 LOCATION

The proposed Camp Pendleton LNG site is located about 5 miles south of the San Onofre Nuclear Generating Station in northwestern San Diego County. The area considered extends from the coastal bluffs inland about 1/2 mile to the right-of-way for the Atchison, Topeka and Santa Fe rail line, and southeast about 3/4 mile from Horno Canyon (Figure 7.1). The land is part of the Camp Pendleton Marine Corps training base. Access to the site is through the Las Pulgas gate to Camp Pendleton and then by paved and unimproved roads on the base.

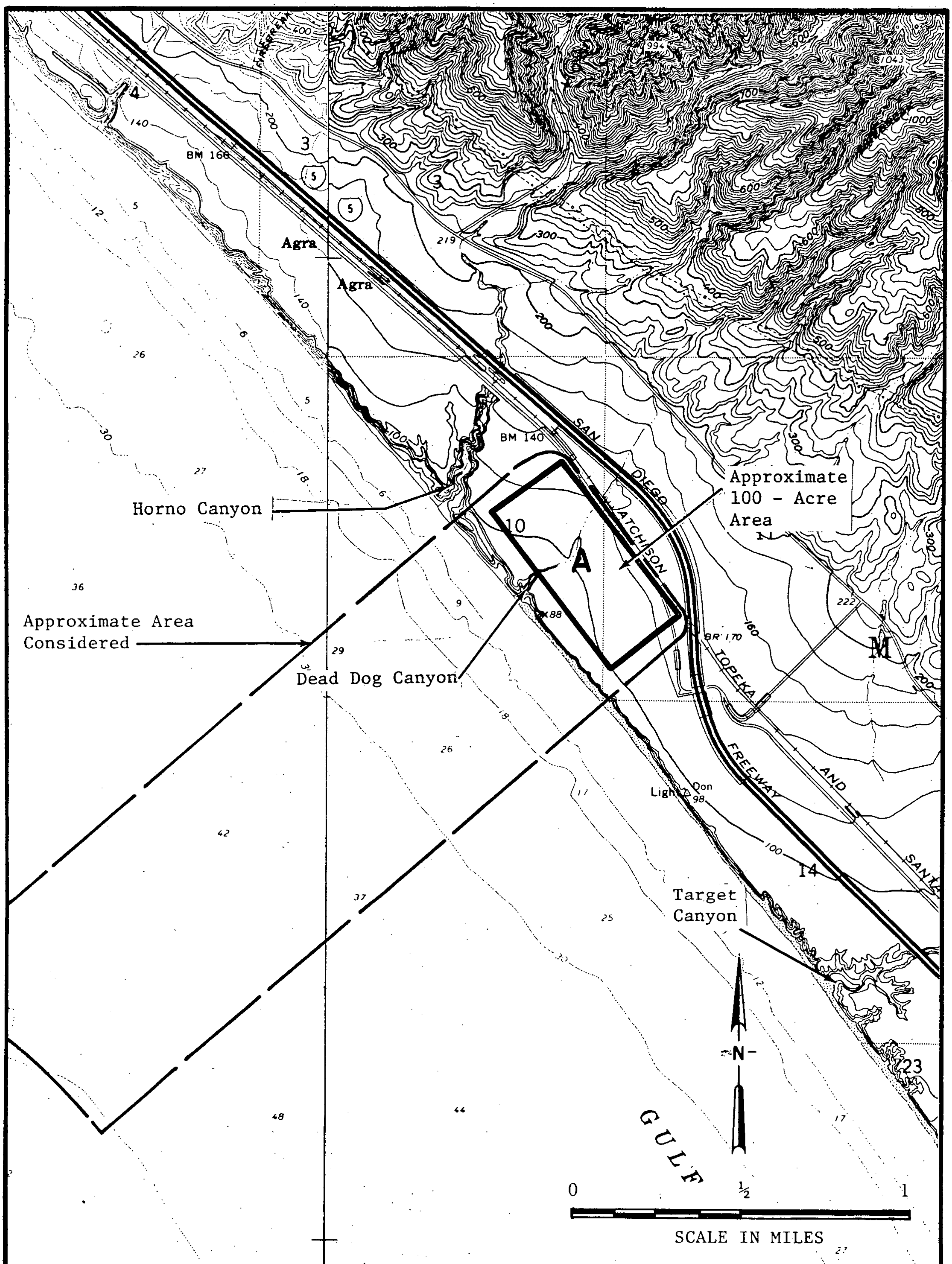
7.4 TOPOGRAPHY

The site is on a coastal terrace about 4,000 feet wide that slopes gently to the southwest at a grade of less than 5%. Elevations at the site range from about 88 feet at the top of the near-vertical coastal bluffs to about 130 feet at the inland edge of the site. Small alluvial fans are developed on the terrace surface at the canyon mouths where they discharge from the adjacent mountains. A narrow, steep-sided wash, Dead Dog Canyon, has been incised into the terrace surface from headward erosion of the coastal bluffs; this incision extends into the proposed site. A much larger wash, Horno Canyon, extends across nearly the full width of the terrace surface immediately northwest of the site.

The terrace surface is covered with a low growth of brush and grass. Large brush fires have occurred in the San Onofre Mountains to the northeast, but the fire hazard on the terrace appears to be relatively minor.

7.5 GEOLOGIC UNITS

The geologic units that are known in the vicinity of the proposed LNG site include the San Onofre Breccia, Monterey Formation, Quaternary terrace and alluvial fan deposits, stream deposits, beach sand and gravel, and soils (Figures 7.2 and 7.3).



Project: LNG TERMINALS EVALUATION Project No: 41033I	LOCATION MAP OF THE CAMP PENDLETON LNG SITE	Fig: 7.1

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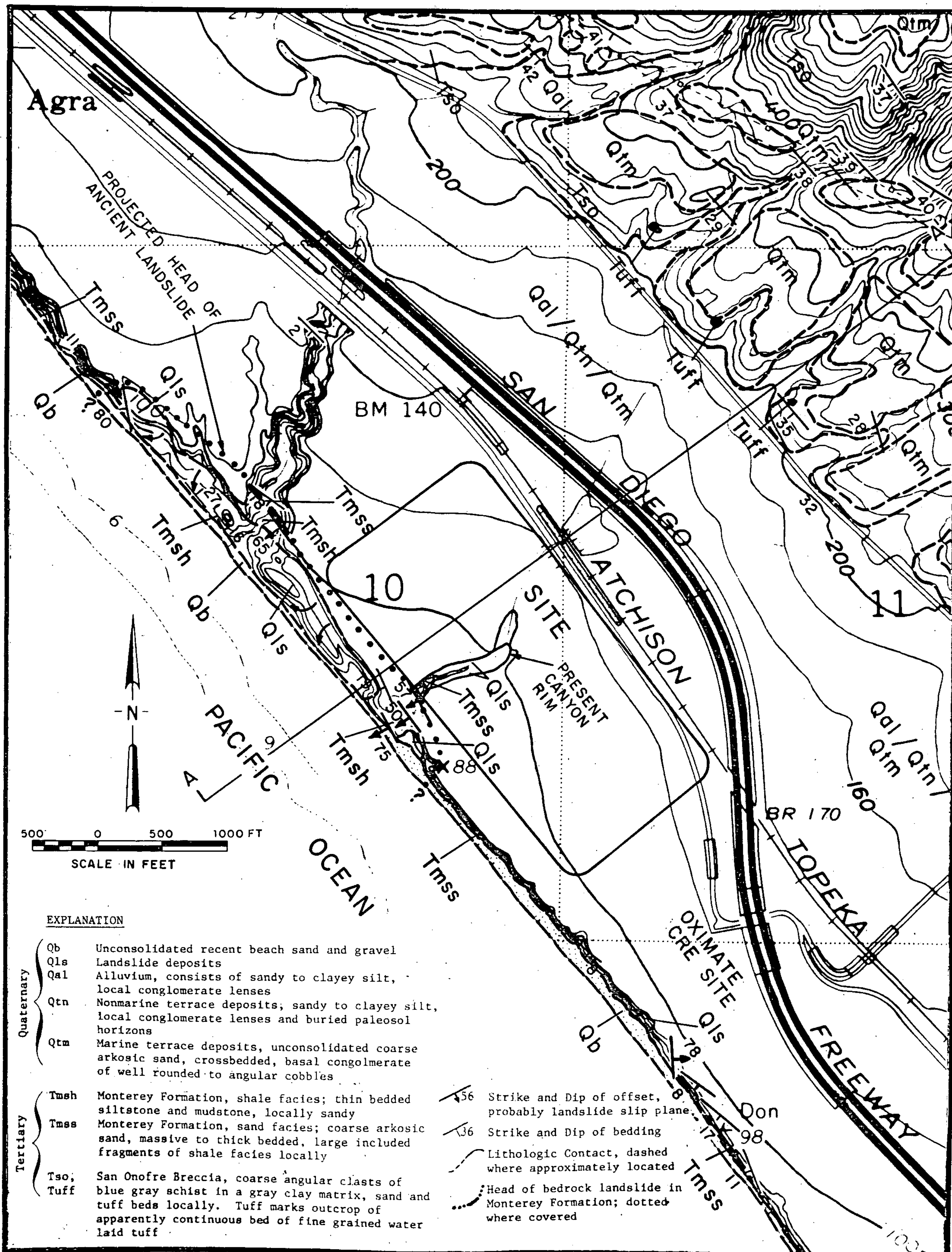

Project: LNG TERMINALS EVALUATION Project No: 41033I	GEOLOGIC MAP OF THE CAMP PENDLETON LNG SITE	Fig: 7.2

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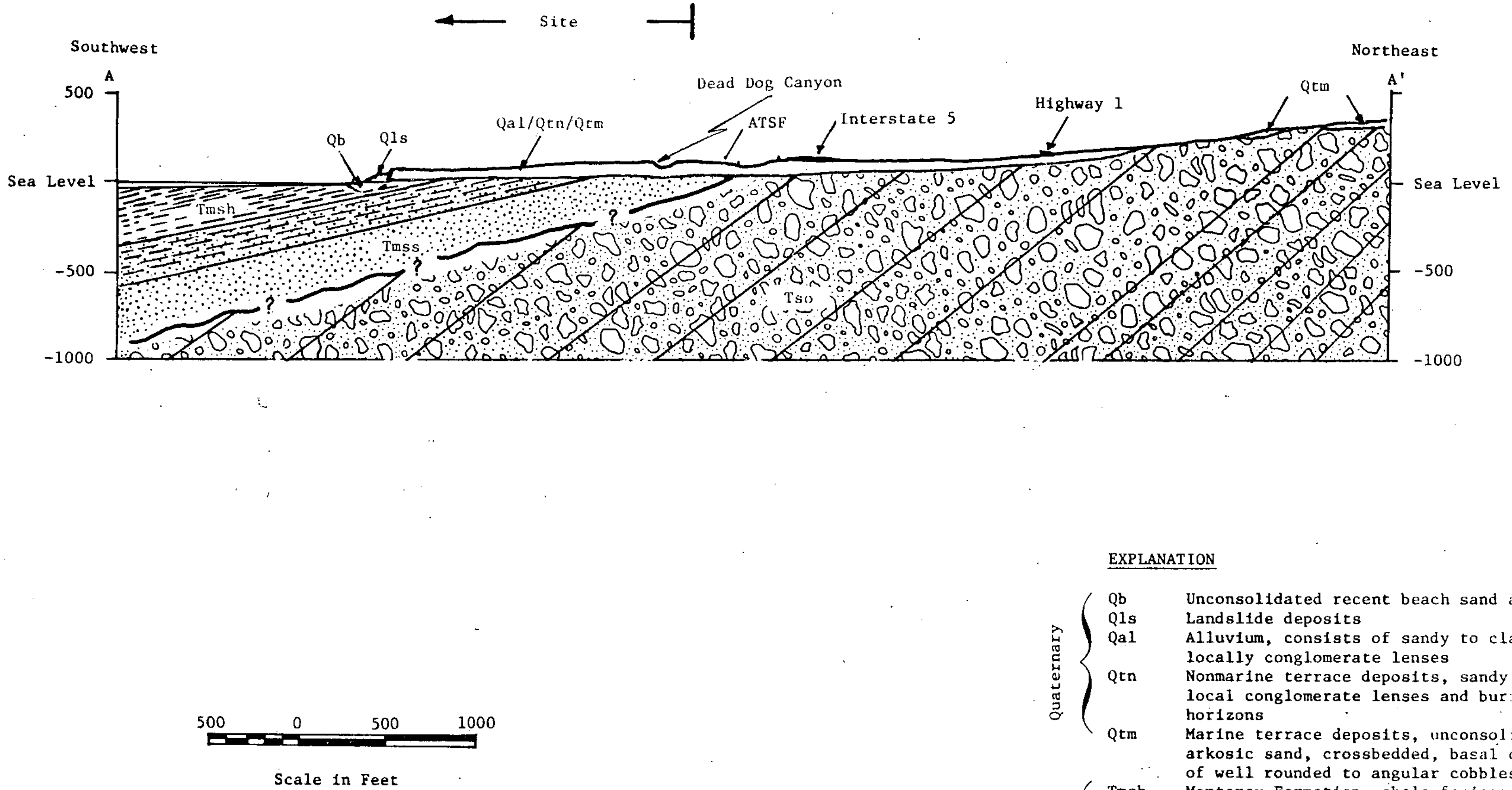


EXPLANATION

Quaternary

Qb	Unconsolidated recent beach sand and gravel
Qls	Landslide deposits
Qal	Alluvium, consists of sandy to clayey silt, locally conglomerate lenses
Qtn	Nonmarine terrace deposits, sandy to clayey silt, local conglomerate lenses and buried paleosol horizons
Qtm	Marine terrace deposits, unconsolidated coarse arkosic sand, crossbedded, basal conglomerate of well rounded to angular cobbles

Miocene

Tmsh	Monterey Formation, shale facies; thin bedded siltstone and mudstone, locally sandy
Tmss	Monterey Formation, sand facies; coarse arkosic sand, massive to thick bedded, large included fragments of shale facies locally
Tso	San Onofre Breccia, coarse angular clasts of blue gray schist in a gray clay matrix, sand and tuff beds locally

Project: LNG TERMINALS EVALUATION
Project No. 41033I

DIAGRAMMATIC CROSS-SECTION OF THE CAMP PENDLETON LNG SITE

Fig. 7.3

The San Onofre Breccia is the oldest unit exposed in the vicinity and crops out primarily in the San Onofre Mountains north of the proposed site. Several small outcrops have been identified in Target Canyon, about one mile to the southeast. The formation typically consists of a coarse angular breccia and conglomerate of cobble- and boulder-size blue-gray schist fragments and other metamorphic rocks. Locally, sand and tuff beds are found and give the best indication of bedding, which typically dips 30 to 60 degrees southwest. The formation is approximately 2,500 feet thick (Ehlig, 1977) and probably occurs at a depth of greater than 150 feet beneath the proposed site. The breccia is generally hard and resistant to erosion, but is locally clayey and may be prone to landsliding where it has been deeply weathered in the San Onofre Mountains.

The Monterey Formation unconformably overlies the San Onofre Breccia in the area of the site (Ehlig, 1977). Exposures are limited to the base of the coastal bluffs and the bottoms of canyons incised into the overlying terrace deposits. Microfossils from the area indicate an age of middle to upper Miocene (Ehlig, 1977).

The basal Monterey Formation consists of coarse sand to gravel-size, well-sorted, massive to poorly bedded, subangular quartz sandstone. These massive sandstones, with bedding on the order of 10-feet thick, grade upward into thin-bedded sandy siltstone, siltstone, and shale. The regional dip is about 15 degrees to the southwest. The Monterey Formation is generally very dense, resists erosion along sea cliffs and drainages, and is easily excavated. Where the silty and shaley sections are exposed, the formation is landslide-prone. Ground water percolating from the sandstone into the shales and the adverse dip of the bedding may contribute to the large landslides noted in the area.

Ehlig (1977) describes the Monterey Formation as being 800 feet thick in the vicinity of the San Onofre Nuclear Generating

Station. At the site it may be 150 to 250 feet thick; however, the base is not exposed and the actual thickness is unknown. The top has been eroded to form a wave-cut bench on which the Quaternary terrace materials have been deposited.

The top of the Tertiary section has been eroded to form a nearly planar wave-cut bench. The sequence of Quaternary sediments deposited unconformably on this bench include a basal conglomerate, marine deposits of beach sand, and nonmarine alluvial deposits of sand, silt, and conglomerate.

The basal conglomerate, which overlies the Tertiary deposits, is nearly continuous, making it an ideal feature to evaluate displacement of the overlying terrace deposits. An age of 70,000 to 130,000 years was obtained on a shell fragment from near the base of the Quaternary terrace deposits northwest of the site (Szabo and Vedder, 1971). Correlation of this terrace to the site allows a maximum age of approximately 130,000 years for the Quaternary terrace deposits.

The marine sediments at the base of the terrace deposits consist of cross-bedded, moderately sorted, very weakly cemented to uncemented coarse sand. The sands are yellow to buff with black laminae defining the cross-bedding. These sands are generally less than 15-feet thick and grade upward into reddish sands, silts and conglomerate lenses of the nonmarine deposits. The uncemented nature of the marine deposits makes them easily erodible, and undercutting of this sand has led to landsliding of the overlying, more competent nonmarine terrace deposits.

The upper 60 to 80 feet of the Quaternary terrace deposits consist of predominantly red-brown sandy to clayey silt, with local thick conglomerate lenses of angular slate and schist clasts eroded from the San Onofre Breccia. The materials are generally dense, moderately erodible and slightly compressible. Small voids, resulting from underground erosion of the coarse-grained gravel lenses, were noted along the coastal bluffs and in cliffs along the incised streams. These voids are probably concentrated near the edge of the bluff, and it is unlikely that they persist into the terrace more than a few feet.

The base of these nonmarine deposits is sandy but can be distinguished from the underlying marine sands by the red color and trough-and-fill cross-beds typical of braided streams. Several fossil soil profiles are evident within these deposits with prismatic clay horizons and calcified root zones.

The alluvial fans developed on the terrace surface consist of essentially the same materials as the nonmarine terrace deposits. They are dense, sandy to clayey silt with local gravel lenses.

Several levels of Holocene stream terraces have been identified along Horno Canyon. These terraces and the active stream bed alluvium consist of apparently thin deposits of unconsolidated silty sand and gravel. Several small terraces, 1 to 3 feet high, are present, and probably result from scour during severe storms.

Unconsolidated, recent beach sands and gravels to depths of perhaps 10 feet mantle the shoreline locally. The sand is a moderately well sorted, medium to coarse quartz sand, eroded from the coastal bluffs. The gravel clasts are typically blue-gray schist fragments eroded from the San Onofre Breccia and terrace deposits and fragments of siltstone eroded from the Monterey Formation.

The residual soil developed on the Quaternary terrace and alluvium is described by the Soil Conservation Service (Shipman, 1977) as Salinas clay loam and consists of a surface layer of pebbly black silty clay loam that is highly expansive. This layer is about 1-1/2 to 2 feet thick, has abundant roots, and was farmed for several years, although it now has a native brush and grass cover. Under this is a weakly prismatic brown clay horizon about 1- to 2-feet thick. This horizon is also highly expansive. Below this clay horizon, the weathered parent material of alluvium or terrace deposits consists of sandy to silty soil, locally pebbly, which grades downward into unweathered sediments. Below the clay-rich surface material, the soils are quite permeable, moderately well consolidated, have low shrink/swell, and stand in vertical cliffs.

7.6 OFFSHORE GEOLOGY

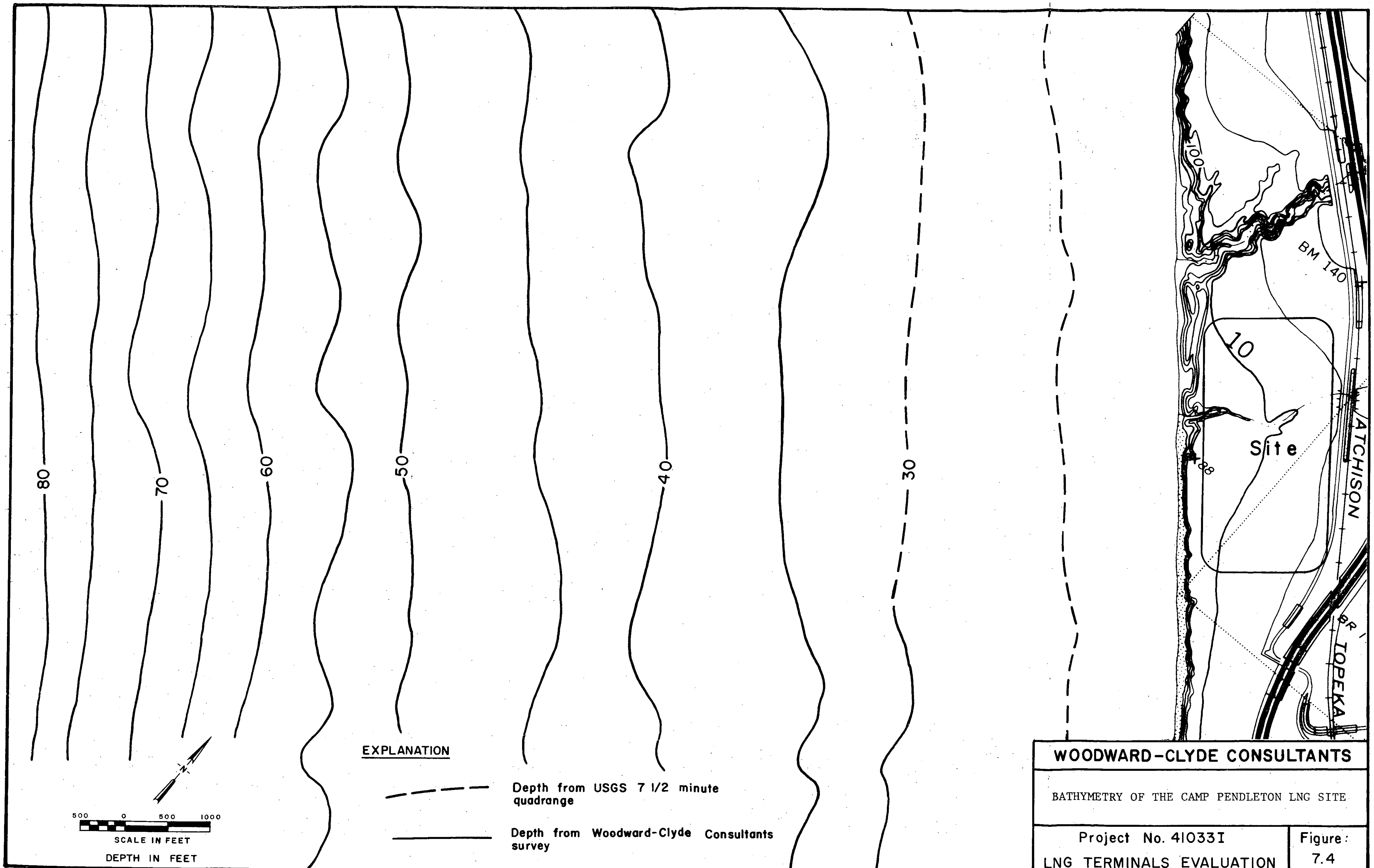
The bathymetry at the site slopes gently southwest with contours trending parallel to the shoreline (Figure 7.4). Sediments along the offshore region exhibit a zonation parallel to the shore (Henry, 1976). Medium to coarse sand mantles the shore from the base of the sea cliffs to approximately 9-foot depths, with bedrock exposed farther offshore. A fan-shaped shoal was noted off the mouth of Dead Dog Canyon and may represent a fan delta of sediments eroded from the canyon. Beyond the bedrock exposures, approximately 1-1/2 to 2 miles offshore (Figure 7.5), a wedge of unconsolidated Holocene sediment extends to the shelf margin, approximately 5 miles offshore (Henry, 1976). The nearest offshore fault lies 5 to 6 miles offshore and appears to be part of the South Coast offshore zone of deformation.

Seaward migration of the nearshore and beach sediments occurs during winter and spring storms, resulting in erosion of the beaches. During calmer summer and autumn periods, the sediment is transported shoreward, resulting in building of the beaches. Most of this seasonal sediment transport occurs at depths less than 30 feet (Henry, 1976). Longshore currents also transport sediment parallel to the shoreline, generally to the south, due to waves striking the shore at an angle from the northwest.

7.7 HYDROLOGY

7.7.1 Surface Water

Surface water in the study area is limited to intermittent streams in Horno and Dead Dog Canyons (Figure 7.6). Cattle



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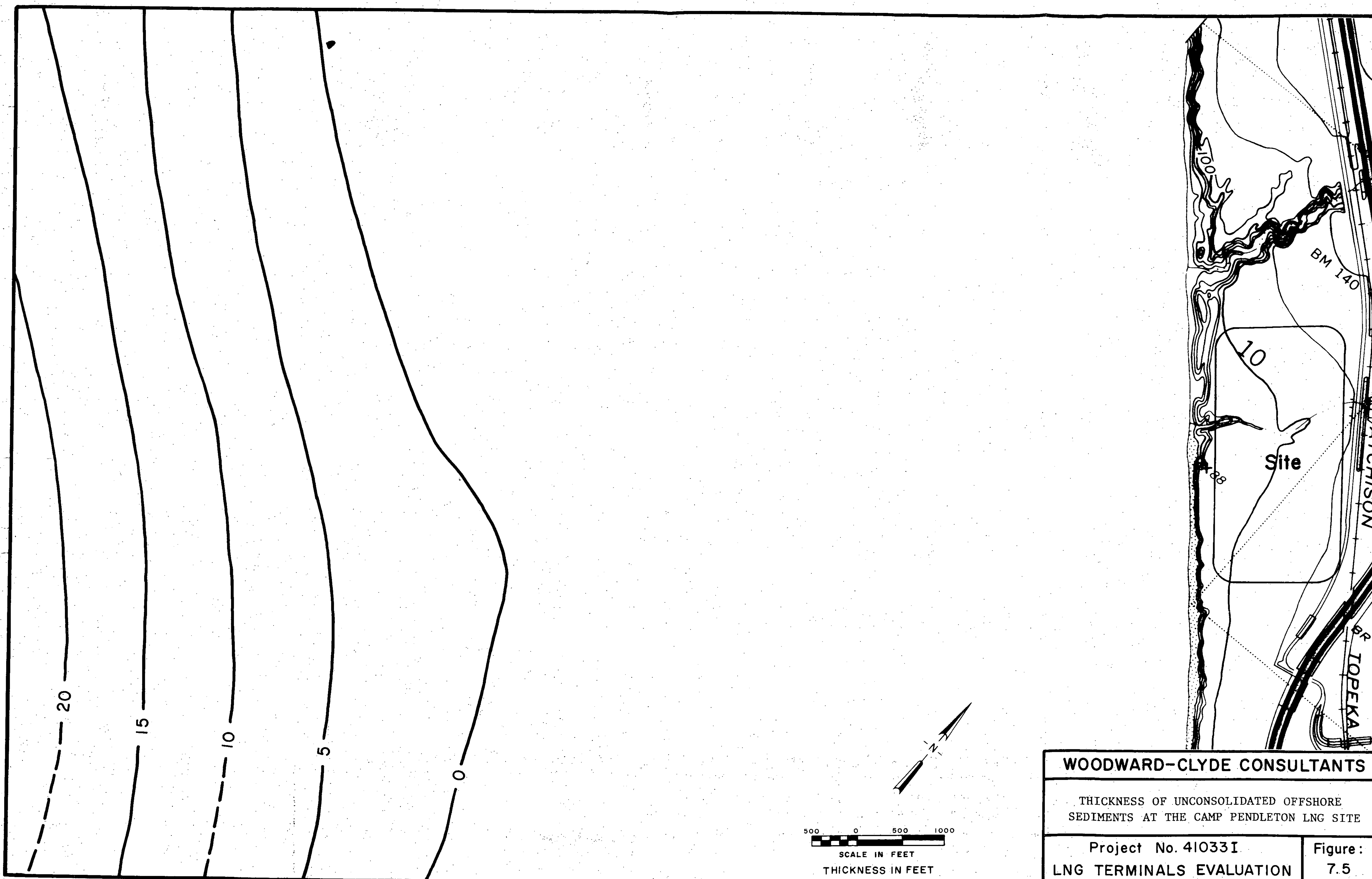
BATHYMETRY OF THE CAMP PENDLETON LNG SITE

Project No. 41033I	Figure:
LNG TERMINALS EVALUATION	7.4



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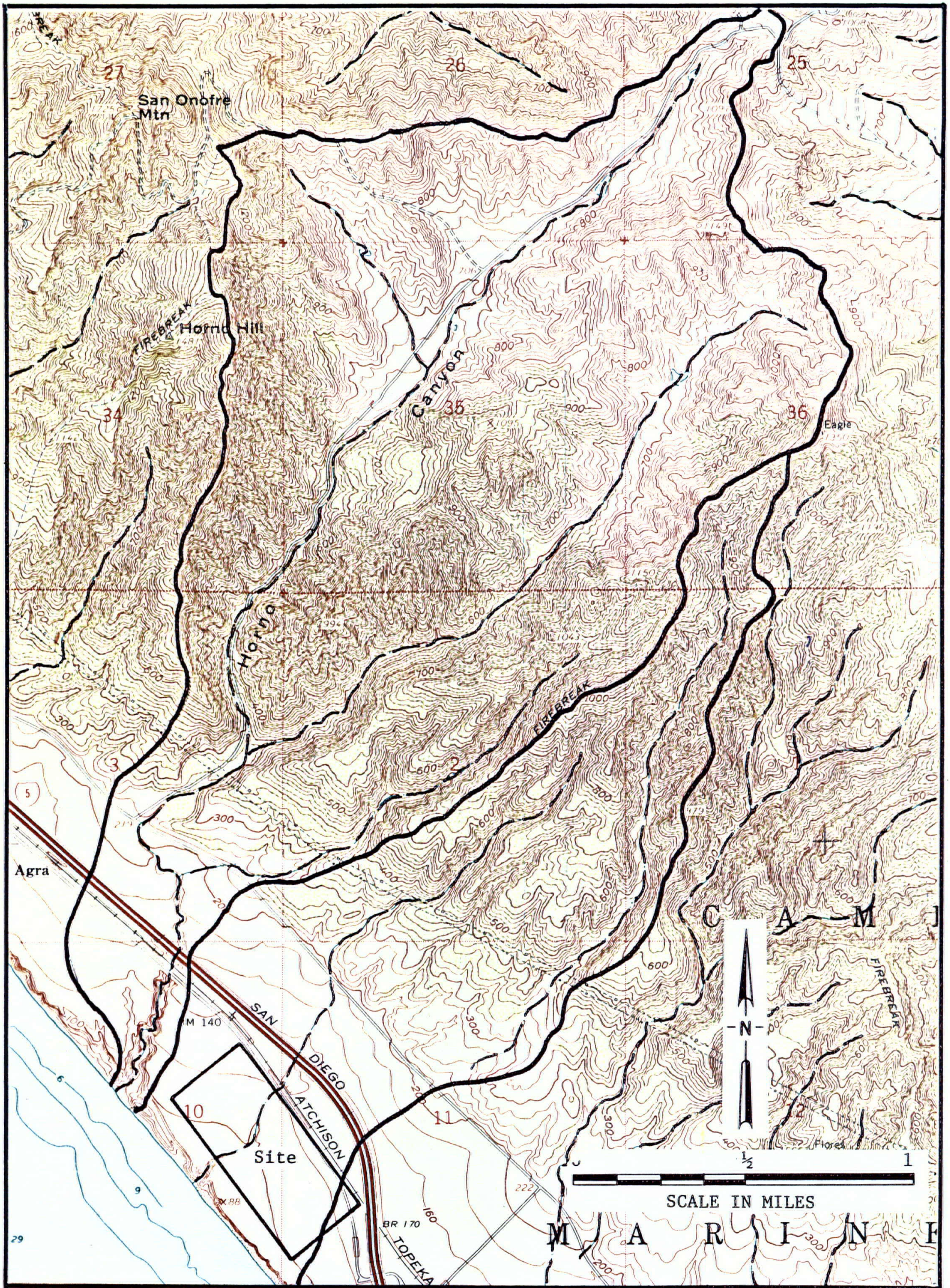
THICKNESS OF UNCONSOLIDATED OFFSHORE SEDIMENTS AT THE CAMP PENDLETON LNG SITE

Project No. 41033I
LNG TERMINALS EVALUATION

Figure: 7.5



Project: LNG TERMINALS EVALUATION Project No: 41033I	DRAINAGE MAP OF THE CAMP PENDLETON LNG SITE	Fig: 7.6

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watering basins have been constructed in the canyons upstream from the site, but these typically dry up during the summer months. Flooding of the site from the possible failure of these basins is unlikely, as the roadbed for Interstate 5 would act as a dam. During the heavy rains of early 1978, large volumes of run-off flowed through Horno and Dead Dog Canyons. Any development that would affect these drainages could be subject to flooding during periods of heavy rains. Conveyance structures must be large enough to accommodate the flow.

7.7.2 Stream Erosion

Dead Dog Canyon, which cuts into the center of the proposed site, has experienced significant headward erosion. Much of this erosion appears to be due to the concentration of several drainages flowing from the San Onofre Mountains into a few culverts under Interstate 5. During recent storms in January, February, and March 1978, some culverts were insufficient to convey the storm runoff and water was retained upslope from the highway and flowed over the roadway. Although the drainage basin for Dead Dog Canyon is only about 1.4 square miles, comparison of aerial photographs taken in 1932 and 1970 shows approximately 560 feet of headward erosion along Dead Dog Canyon. This amounts to about 14 to 15 feet of headward erosion per year. In addition, more than 100 feet of headward erosion occurred during the heavy rains which fell during the field investigation. This demonstrates the episodic nature of erosion. The eroded channel is about 60- to 80-feet deep and 60- to 100-feet wide.

Horno Canyon is a sinuous channel, apparently the result of a pre-existing meander pattern being incised during or subsequent to the elevation of the terraces. Only minor erosion has been identified along Horno Canyon between 1932 and 1970. Erosion during February and March, 1978, caused the collapse of the abandoned route of Highway 101 where it crosses Horno Canyon.

Lateral erosion (widening) of the canyons is mainly by slumping after undercutting of the near-vertical canyon walls. This widening is most pronounced where unconsolidated sand of the Quaternary marine deposits is exposed to fluvial scour. The silty and clayey nonmarine deposits stand well in near-vertical cliffs.

7.7.3 Ground Water

The ground-water resource in the area is only poorly known. No springs or seeps, not directly attributed to heavy rainfall, were observed in the sea cliffs or in drainages cut into the terrace. This suggests that the water table is low, perhaps near sea level. In bridge foundation borings drilled by the California Department of Transportation along Interstate 5, no ground water was encountered at 80-foot depths. Ground water may occur near the base of the terrace deposits or within the Monterey or San Onofre bedrock units.

7.7.4 Fresh Water Supply

No development of the ground water at or near the site is known. Fresh water for development of the site would probably have to be imported.

7.8 SEISMICITY AND FAULTING

7.8.1 Inactive Faults

No active faults have been identified within the Camp Pendleton area. The nearest fault is the Cristianitos fault, which has been mapped onshore about 3-miles north of the area and may extend offshore of the site. This fault does not displace Quaternary terrace deposits and is not considered a potential source of earthquakes.

Several faults in bedrock have been identified in the San Onofre Mountains to the northeast (Ehlig, 1977). They are primarily mapped between downfaulted portions of Monterey Formation and San Onofre Breccia, although some surfaces along which shearing has occurred were observed in bedrock exposures in Horno Canyon during this field investigation. These surfaces were generally near vertical with horizontal grooves, suggesting primarily strike-slip motion. These faults trend generally parallel to the Cristianitos fault and, like the Cristianitos, do not offset the base of the terrace deposits. They are thus not considered a potential source of earthquakes.

In Target Canyon, about 1-mile southeast of the site, a series of offsets were examined during the field investigation. The offsets are relatively abundant in the bedrock Monterey Formation, but some extend into the overlying Quaternary terrace deposits. Displacements up to 14 inches have been reported in the Quaternary materials (Fugro, 1977). There does not appear to be a single zone of failure, and the amount of displacement diminishes upward to zero rather than displacing the entire Quaternary terrace section. A bedrock high of San Onofre Breccia is exposed in Target Canyon. The offsets east of this bedrock high generally dip east, whereas those west of the bedrock high generally dip west. One interpretation (Fugro, 1977) suggests these offsets have resulted from settlement around the bedrock high. From observations made during this investigation, the offsets do not appear to be tectonic and may be the result of settlement, as suggested by Fugro (1977). The offsets are not known to extend north of the Target Canyon area, and their trends do not strike into the site.

7.8.2 Active Faults

Both the Rose Canyon and Newport-Inglewood zones are youthful faults that are considered potential sources of earthquakes. The Whittier-Elsinore fault, the San Jacinto fault and the San Andreas fault are more distant faults, located 22, 44 and 60 miles respectively from the site. These faults may also generate earthquakes that could affect the Camp Pendleton site. The historic record of earthquakes on the San Jacinto fault indicates that damaging earthquakes have been generated every few years to

Table 7.1

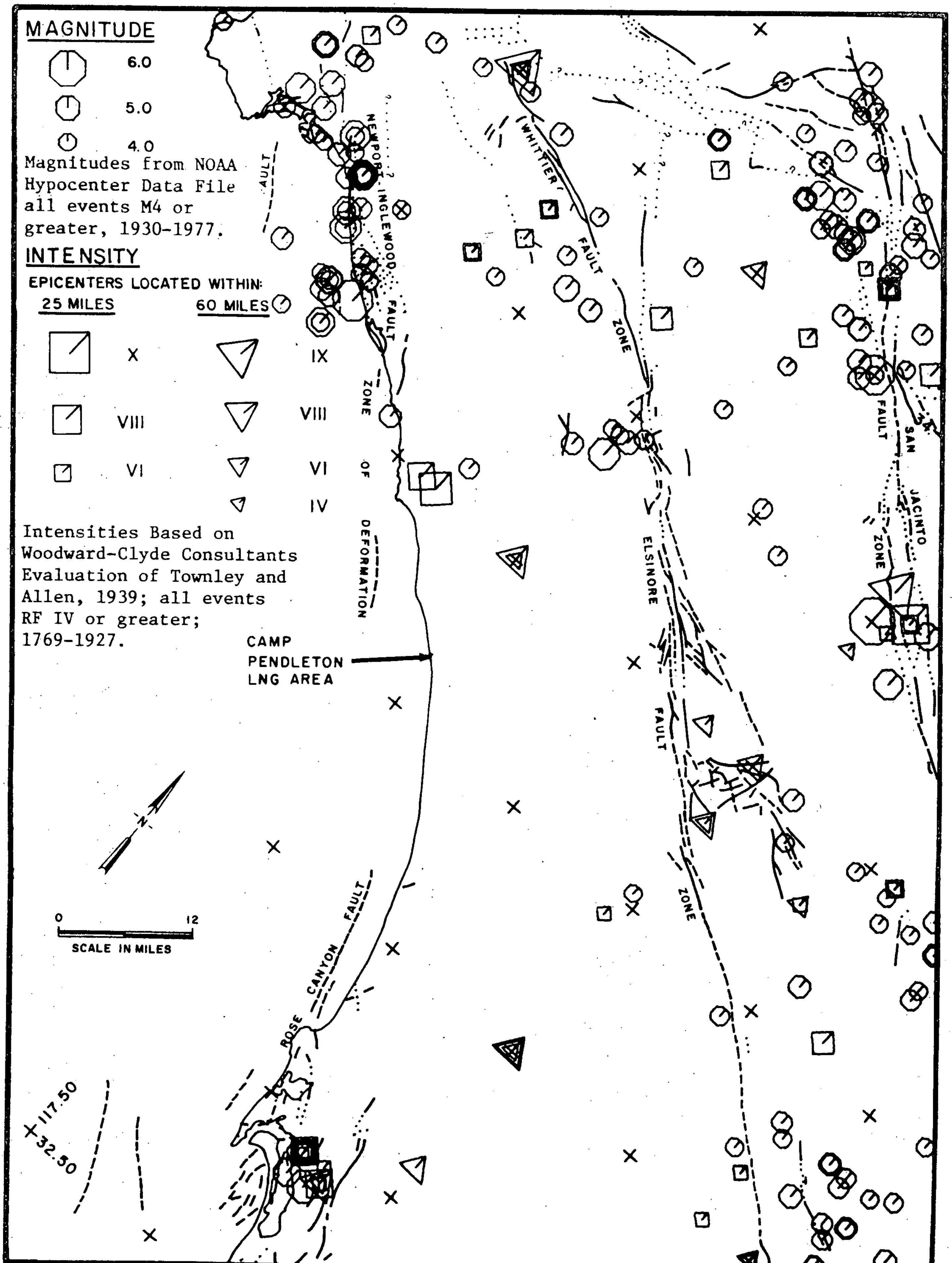
FAULTS IN PROXIMITY TO THE CAMP PENDLETON LNG SITE[1]

Fault Name	Distance From Site[1] (Miles)	Fault Type[1]	Fault Length[1] (Miles)	Age Category[1]	Estimated 100-year Earthquake[2]	Estimated Maximum Credible Earthquake[3]
South Coast Offshore Zone of Deformation	6	Strike-Slip	130	Quaternary	5-3/4 to 6-1/4	7-1/4
Whittier-Elsinore	22	Strike-Slip	145	Quaternary	5-1/2 to 6	7-1/2
San Jacinto	44	Strike-Slip	130	Historic	6-3/4 to 7-1/4	7-3/4
San Andreas	60	Strike-Slip	>500	Historic	7-1/2 to 8-1/4	8-1/2

[1]Data from Jennings (1975) unless otherwise noted.

[2]Estimated earthquake activity is a judgment based upon knowledge of the historical seismicity of the region and local area, and upon the recent geological history of the faults considered. These estimates are considered to be conservative, especially in the upper ranges of magnitude.

[3]Based upon one-half the fault length rupturing to produce an earthquake of given magnitude, as shown by Patwardhan and others (1975). Estimates are to the nearest 1/4 magnitude value.



Project: LNG TERMINALS EVALUATION Project No: 41033I	REGIONAL FAULT AND SEISMICITY MAP OF THE CAMP PENDLETON LNG SITE	Fig: 7.7

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every few tens of years. The characteristics of faults that are pertinent to the area are summarized in Table 7.1; the locations of the faults are shown on Figure 7.7.

7.8.3 Sources of Significant Earthquakes

A broad zone of deformation offshore about 6 to 7 miles, termed the South Coast Offshore zone of deformation, is the nearest source of potentially damaging earthquakes. This zone has been interpreted by some investigators to connect with the Newport-Inglewood zone of deformation to the north, and the Rose Canyon fault to the south (S.C.E., 1977). This interpretation suggests a zone approximately 130-miles long, with an inferred potential for generating earthquakes as large as magnitude 7-1/4.

7.8.4 Seismic Hazards

The nature of the soils and subsurface materials at the Camp Pendleton site suggests there should be little or no unusual effects from earthquake shaking. No on-site faults have been identified. The terrace deposits appear to have low susceptibility to liquefaction, and are not highly compressible. The beach and near-shore deposits and the Holocene stream deposits are susceptible to liquefaction. Reactivation of landslides along the coastal bluff is possible, but is not expected to greatly affect more of the terrace surface than has already been displaced. The elevation of the terrace precludes tsunami run-up at the terrace surface, which is estimated to be 15 to 16 feet at the San Onofre Nuclear Generating Station (S.C.E., 1977); accordingly, tsunami run-up and draw-down would affect the beach and near-shore areas of the site.

7.9 SLOPE STABILITY

7.9.1 Landslides

Landslides are very common and well-developed along the coastal bluffs of the study area. Approximately 80% of the coastline from the Cristianitos fault on the north to the proposed site is involved in landslides. Some smaller landslides also occur along the walls of drainages incised into the terraces.

Landsliding in the area is evidenced by a variety of geomorphic features. Well developed scarps and down-dropped blocks mark the heads of many of the larger slides; for example, at the mouth of Horno Canyon, and 1 to 2 miles north of the proposed site. Bedding inclined to the east along the bases of many of the sea cliffs suggests that the toes of some of these slides are at the coastline or not far offshore. Preserved, undisturbed terrace surfaces that have been dropped several tens of feet indicate that the slide blocks moved as units, with a minimum of internal disruption.

In addition to the geomorphic evidence of landsliding, historic accounts of landslides document failures as large as 1,700 feet long and 350 feet wide along the bluffs about 1-1/2 miles north of the site. During June and July of 1941, a cultivated field subsided in a block 20 to 60 feet deep and 1,500 to 1,700 feet long (Harry Witman, personal communication, 1977). Examination of aerial photographs taken in 1932 of an area that failed in 1941 shows evidence of an incipient failure at least 9 years before the major relief developed on the landslide. This suggests that potentially unstable slopes may be identified years in advance of catastrophic failures.

Landslides along this section of coast have involved from a few feet to more than 400 feet of terrace surface inland from the beach. At the site, nearly 200 feet of terrace surface inland from the coast has been displaced by landslides. The materials involved in these slides include bedrock of Monterey Shale and the Quaternary terrace deposits. From evaluations of rates of coastal erosion discussed in this section and landslide activity along the coast, a setback of perhaps 600 feet from the coastline is recommended.

At least three episodes of landslides have been identified in the vicinity of the site. The base of a large landslide in the Monterey Formation is exposed in Horno and Dead Dog canyons. This old landslide does not displace the basal conglomerate of the Quaternary terrace deposits; thus, this landslide is older than 130,000 years, and appears to be stabilized.

The large landslides that displace the Quaternary terrace deposits along the sea cliffs are the second generation of landslides. They include the terrace deposits and are inferred to be younger than the age of these deposits, but they are not known to be historically active. The third generation of landslides includes the landslides that have been active historically. The historically active landslides appear to be similar geomorphically to the pre-historic landslides, suggesting that landsliding is a continuous process along this segment of the coast.

7.9.2 Coastal Erosion

Another form of slope instability at the site involves sea cliff erosion. This form of instability may be due to wave erosion along the base of the coastal bluffs, and rilling by sheet wash from heavy rainfall off the terrace surface, in addition to the landslides discussed previously. Wave erosion along the base of the coastal bluffs acts primarily during times of storms and high surf, eroding the base of the sea cliffs, oversteepening and locally undercutting the bluffs, which ultimately slump. Rilling of the face of the bluff, appears to account for only a minor amount of coastline retreat. Individual incisions are typically only a few feet to a few tens of feet deep.

Retreat of the shoreline at the proposed site has been estimated by comparison of aerial photographs taken in 1932 and 1970. Most of the coast experienced minor retreat on the order of 20 feet, or an average rate of about 1/2 foot per year. One location north of Horno Canyon has been extended seaward, apparently because a large landslide moved seaward during that time interval. Where the cryogenic pipeline crosses the coastal bluffs, erosion control and slope stability may be significant considerations.

7.10 ENGINEERING PROPERTIES AND CONSTRUCTION CONSIDERATIONS

7.10.1 Engineering Properties

The engineering properties and foundation conditions for the geologic units likely to be encountered during development of the proposed site are briefly summarized in Table 7.2. The units evaluated at this site include residual soils, alluvium, terrace deposits, and Monterey Formation. A rating system of high, medium, and low has been used to assess both the properties and foundation conditions. These terms are qualitative and are useful only for a relative comparison between the materials identified at the site.

The bedrock of Monterey Formation has characteristics of good foundation material; for example, very low compressibility, medium to high strength, very high pile support capacity, and very low settlement potential. The terrace deposits are also likely to be foundation materials and although they are not as attractive as the bedrock, they appear to have low compressibility, medium strength, medium pile support, and bearing capacity and low settlement potential. The residual soils are less attractive for foundation materials but are thin enough to allow their economic removal.

7.10.2 Construction Considerations

From the preliminary estimates of the engineering characteristics, the behavior that might be expected during and after construction can be ascertained. Those conditions which are considered of importance for construction are briefly evaluated in Table 7.3.

Table 7.2

ENGINEERING PROPERTIES AND FOUNDATION CONDITIONS
OF THE CAMP PENDLETON LNG SITE

	MATERIALS			
	Alluvium	Residual Soils	Terrace Deposits	Monterey Formation
Compressibility	Medium	Medium	Low	Very Low
Strength	Low	Medium	Medium	Medium-High
Permeability	Medium-High	Low	Medium	Low
Shrink/Swell	Low	High	Low	Medium
Bearing Capacity	Low	Low-Medium	Medium	High
Pile Support Capacity	*	*	Medium	Very High
Settlement	Medium	Medium	Low	Very Low
Frost Heave	Medium	Medium	Medium	Medium

*Too thin to be applicable.

Table 7.3

CONSTRUCTION CONSIDERATIONS
OF THE CAMP PENDLETON LNG SITE

	MATERIALS			
	Stream Alluvium	Residual Soils	Terrace Deposits	Monterey Formation
Difficulty of Excavation	Low	Low	Low	Medium
Stability of Temporary Excavations	Low	Medium	Medium	High
Use as Engineered Fill	Fair	Poor	Good	Fair-Good
Subgrade for Haul Roads	Fair	Poor	Fair-Good	Fair

Significant amounts of cut and fill are not required to develop a level pad at the site. Some filling of incised drainage channels may be required, which could necessitate over-excavation to generate the required amounts of fill. The sandy to clayey silt of the Quaternary terrace deposits appears to be the most suitable material available around the site for use as fill. The deposits at the site appear to lack suitable coarse material for use as aggregate. Borrow sources used for aggregate should probably be similar to those used at the San Onofre Generating Station. Importing such material will be facilitated by the close location of roads and the railroad.

The excavation for buried tanks appears to be a viable consideration at the Camp Pendleton site. The terrace deposits appear to be more than 80 feet thick and are easily excavated. The bedrock units of Monterey Formation and San Onofre Breccia would be more difficult to excavate, but should be rippable without requiring blasting. Perched ground water may be encountered near the base of the terrace deposits or within the bedrock units. The stability of temporary excavations in the terrace deposits should be adequate with the exception of the uncemented to weakly cemented marine sands at the base of the terrace deposits. Temporary excavations in the bedrock units are likely to be stable although the southward dipping Monterey Formation may be cause for concern if the bedrock is exposed in steep cuts.

The absence or relative thinness of the recent sediment mantle offshore suggests the trestle for the pipeline to shore could be founded on the Monterey Formation bedrock, at least for a portion of the alignment. Offshore 1-1/2 miles, a seaward-thickening wedge of unconsolidated sediments (Henry, 1976) may make the founding of trestle piles more difficult.

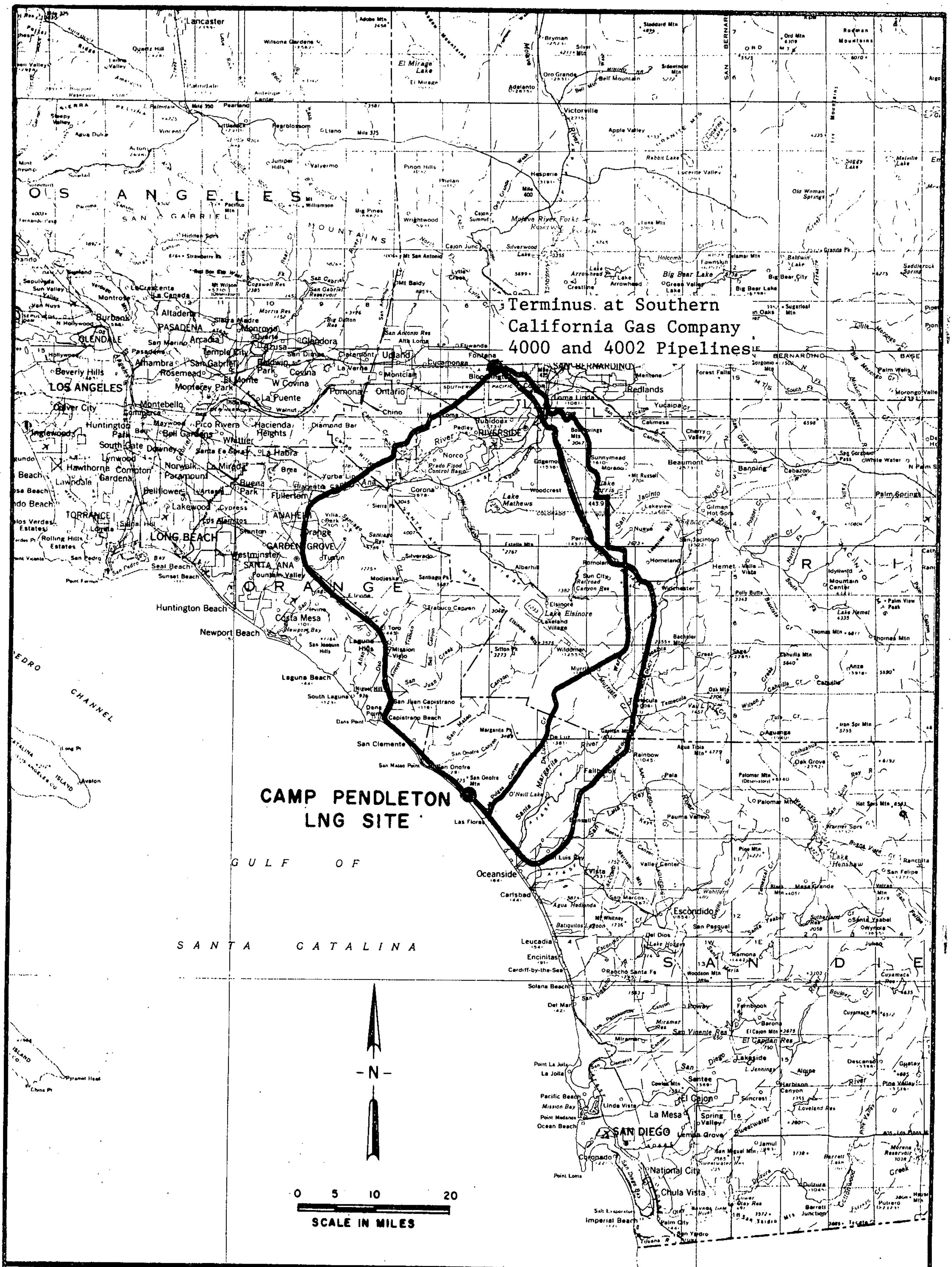
A tunnel 2-miles long from the site to the berthing facilities offshore would be initially excavated in Monterey shale. This formation should be relatively easy to excavate by tunnel boring machines, however it may produce stability problems due to squeezing and swelling ground, which could significantly hamper a machine operation. Additional support problems may be encountered due to weak, steeply dipping bedding planes and inactive faults. Although the formation is relatively impermeable, possible water inflows along permeable faults or other discontinuities must be addressed.

The foundation materials below the expansive soils do not appear susceptible to seismic settlement, and subsurface erosion of gravel lenses appears to affect only the margin of the terrace adjacent to steep slopes. No subsidence is expected, as no development of the ground water has been identified within the site, and no production of petroleum or geothermal deposits is known in the area.

7.11 EXIT PIPELINE ROUTES

Transmission pipelines from the Camp Pendleton LNG site may be located along three alternate routes. The shortest route of 75 to 80 miles would extend northward, parallel to the coastline. This route could parallel the existing Southern California Gas line to Dana Point, and from there it could parallel existing PG&E lines north into western Riverside County to Brea-Olinda, Upland, or Fontana. The Whittier-Elsinore fault would be crossed near the Orange-Riverside County line along this route. The geologic units encountered would be primarily Quaternary terrace and alluvial deposits. The existing gas lines along this entire route suggest that geotechnical hazards may be minimal; engineering properties of materials along the route have been acceptable for construction of other gas pipelines.

A second alternative which is 95 to 100 miles long could involve crossing the Santa Ana Mountains east of the Camp Pendleton site. The rugged topography and unstable slopes in rocks of the La Jolla group may pose slope instability and construction



Project: LNG TERMINALS EVALUATION Project No: 41033I	EXIT PIPELINE ROUTES FOR THE CAMP PENDLETON LNG SITE	Fig: 7.8

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considerations along problems for this route. Much of the route would be on granitic and metamorphic rocks which make up the core of the Santa Ana Mountains. A new alignment would be established from the site to the town of Rainbow, near the San Diego-Riverside County line. From Rainbow to Riverside and Fontana, the new line could parallel existing 16-inch and 24-inch Southern California Gas Company lines. The existing gas lines along this portion of the route suggest that geotechnical hazards encountered may be minimal; engineering properties of materials along the route have been acceptable for construction of other gas pipelines. This route would require crossing the Elsinore fault in the vicinity of Rainbow. The route suggested by Western LNG runs eastward, up the Las Pulgas and De Luz Canyons from the site, through Murrieta and across the Perris Plain to Fontana. It crosses much the same topography and geologic units as the route through Rainbow but does not follow existing gas lines. It may be 5 to 10 miles shorter than the route through Rainbow.

8.0 EARTHQUAKE SHAKING

A relative comparison of earthquake-shaking effects at each of the five potential LNG sites is based on an assessment of the earthquake exposure of each site. For purposes of uniformity of these comparisons, a conservative estimate of a 100-year earthquake was selected for analysis of an active fault within 10 miles of each site. Those faults will cause motions at the sites which may be characterized as having relatively large peak accelerations (1/3 to 1/2 the acceleration of gravity, or g) lasting for a relatively short time (a few tens of seconds). Also for purposes of uniformity of these comparisons, the maximum event on the San Andreas fault was considered. Because this event would be, at its closest point, at a relatively long distance from each site (40 to 60 miles), the motions may be characterized as having relatively small accelerations but relatively large displacements (4 to 10 inches), and lasting a relatively long time (a few minutes). Thus, a total of ten combinations of site and earthquake were used for this comparison. Because this comparison relies upon specific terminology for engineering, definitons of key terms are provided in the following section.

8.1 DEFINITION OF TERMS

For purposes of these comparisons, the terms which will be used to describe the earthquakes are:

<u>Amplitude:</u> the size or force of the earthquake motions, expressed here in terms of the maximum displacements (inches), and accelerations (percent of gravity, or g).

<u>Damping:</u> the dissipation of energy with time or distance.

<u>Duration:</u> the length of time during which strong shaking occurs, expressed in seconds or minutes.

Frequency: the rapidity at which the earthquake vibrations occur, expressed as the number of vibrations or cycles of shaking per second (cps or hertz).

Frequency of Occurrence: the expected average number of years between occurrences of a given earthquake on a given fault.

Period: the time required to complete one cycle of vibratory motion, expressed in seconds or fractions of seconds. The reciprocal of frequency.

Return Period: same as frequency of occurrence.

Response Spectrum: a graphical method of expressing the way in which simple structures will vibrate when shaken by a particular earthquake at a particular site.

8.2 INTRODUCTION

The important characteristics of earthquake-induced ground motions in terms of structural design are:

(1) the acceleration amplitude and frequency content of the motion;

(2) the displacement amplitude of long-period surface waves; and

(3) the short wavelength out-of-phase displacements caused by short-period surface waves.

Acceleration amplitude and frequency content are important to the design of individual structures and to assessment of possible interactions between adjacent structures. Displacement amplitudes of long-period waves have direct impact on the design of long-period structures, such as liquid-storage tanks. Displacements of short-period surface waves primarily affect the differential transient movement of structures with large base dimensions. The relative severity of the three types of motions at each of the five sites is discussed in the following sections, and summarized in Table 8.1.

8.3 ACCELERATION AMPLITUDE AND FREQUENCY CONTENT OF EARTHQUAKE MOTIONS

The faults and their 100-year earthquakes have been presented in Table 3.1 for Rattlesnake Canyon, Table 4.1 for Cojo Bay, Table 5.1 for Las Varas, Table 6.1 for Deer Creek and Canyon, and Table 7.1 for Camp Pendleton. The procedure used to evaluate the acceleration amplitude and frequency for each site involved the following steps:

1. Using the Richter Magnitude of the earthquake of interest and the distance to the causative fault for each site, estimate the maximum bedrock acceleration from empirically based attenuation curves by Schnabel and Seed (1973).

2. Based on the subsurface soil conditions at each site and their respective maximum bedrock acceleration from Step 1, estimate the maximum surface accelerations from empirically based site-response data suggested by Seed and others (1975).

3. Using the subsurface soil conditions and the maximum surface acceleration from Step 2, estimate the response spectrum for each site using the statistical mean spectral shapes suggested by Seed and others (1974).

Based on a review of the subsurface conditions for each site, the Camp Pendleton, Las Varas, Rattlesnake Canyon and Cojo Bay sites are classified as stiff soil sites, while the Deer Creek and Canyon site is classified as a rock site (or otherwise, if filled). The classifications were used in Step 2 of the evaluation to arrive at the estimated maximum ground-surface comparison accelerations presented below. These accelerations

TABLE 8.1

SUMMARY OF EARTHQUAKE SHAKING PARAMETERS

Site	Distance to San Andreas Fault, Miles	Nearby Fault	Estimated 100-year Earthquake Magnitude	Minimum Distance From Site, Miles	Estimated Maximum Ground-Surface Comparison Acceleration, g*	Estimated Maximum Horizontal Displacement, inches *
Rattlesnake Canyon	47	Hosgri	6-3/4 to 6-3/4	5	0.4	4 to 7
Cojo Bay (Pt. Conception)	62	Santa Ynez (South Branch)	5-1/2 to 6	3	0.4	7 to 10
Las Varas	48	More Ranch	5 to 5-1/2	2	0.4	7 to 10
Deer Creek and Canyon	52	Malibu Coast	5-3/4 to 6-1/4	2-1/2	0.5	4 to 7
Camp Pendleton	60	South Coast Offshore Zone of Deformation	5-3/4 to 6-1/4	6	0.4	6 to 9

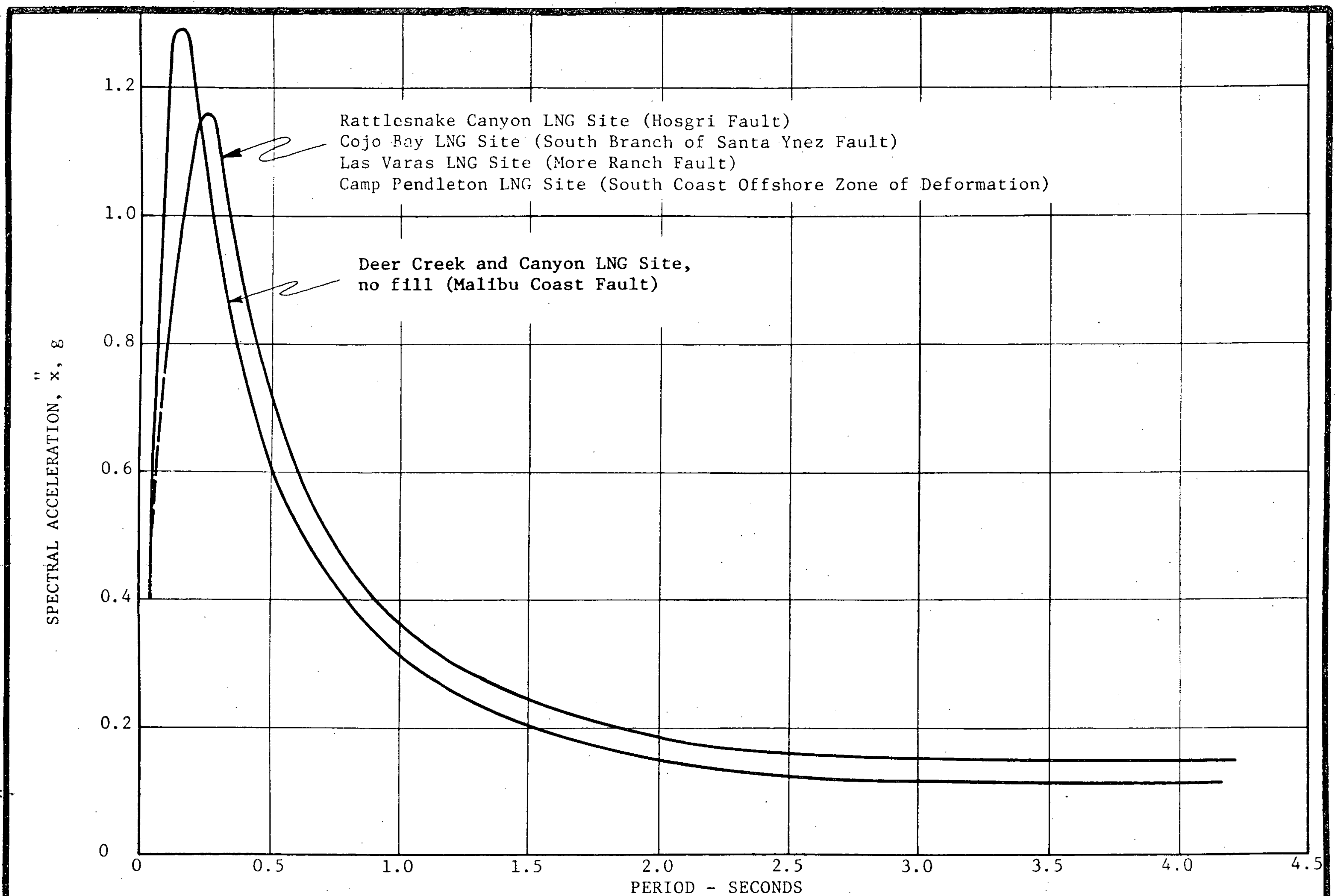
* Estimated maximum ground-surface comparison accelerations and estimated maximum horizontal displacement are presented for purposes of comparison between sites only, they are not design values.

are presented for relative comparison of the sites only, and are not intended for use in design.

Site	Estimated Maximum Ground-Surface Comparison Acceleration, g
Rattlesnake Canyon	0.4
Cojo Bay	0.4
Deer Creek and Canyon (no fill)	0.5
Las Varas	0.4
Camp Pendleton	0.4

These acceleration values have engineering meaning only when considered in the context of their frequency and the overall site responses they induce. Those responses are shown in the form of response spectra developed by the procedures described in Step 3 above, in Figure 8.1.

The response spectra of Figure 8.1 assume that little significant grading is done at any of the sites and the earthquake is associated with a fault within 10 miles of the site. While this may be a reasonable engineering assumption for four of the sites, it is probably not reasonable for Deer Creek and Canyon, which may require extensive grading. To help assess the comparative effects of such grading, we have prepared Figure 8.2 to show how the site responses might depend on the amount of fill. An additional consideration exists at Deer Creek and Canyon where a large difference in the vibratory properties (termed an impedance mismatch) could exist between the fill and the bedrock, and between the two slopes on the sides of the valley and the length of the valley. This condition could lead to an amplification or focusing of motions locally (Dezfulian and Seed, 1969). Therefore, the siting and design of structures at that site should be done carefully, taking into account effects of amplification or focusing of motion due to the underlying sloping

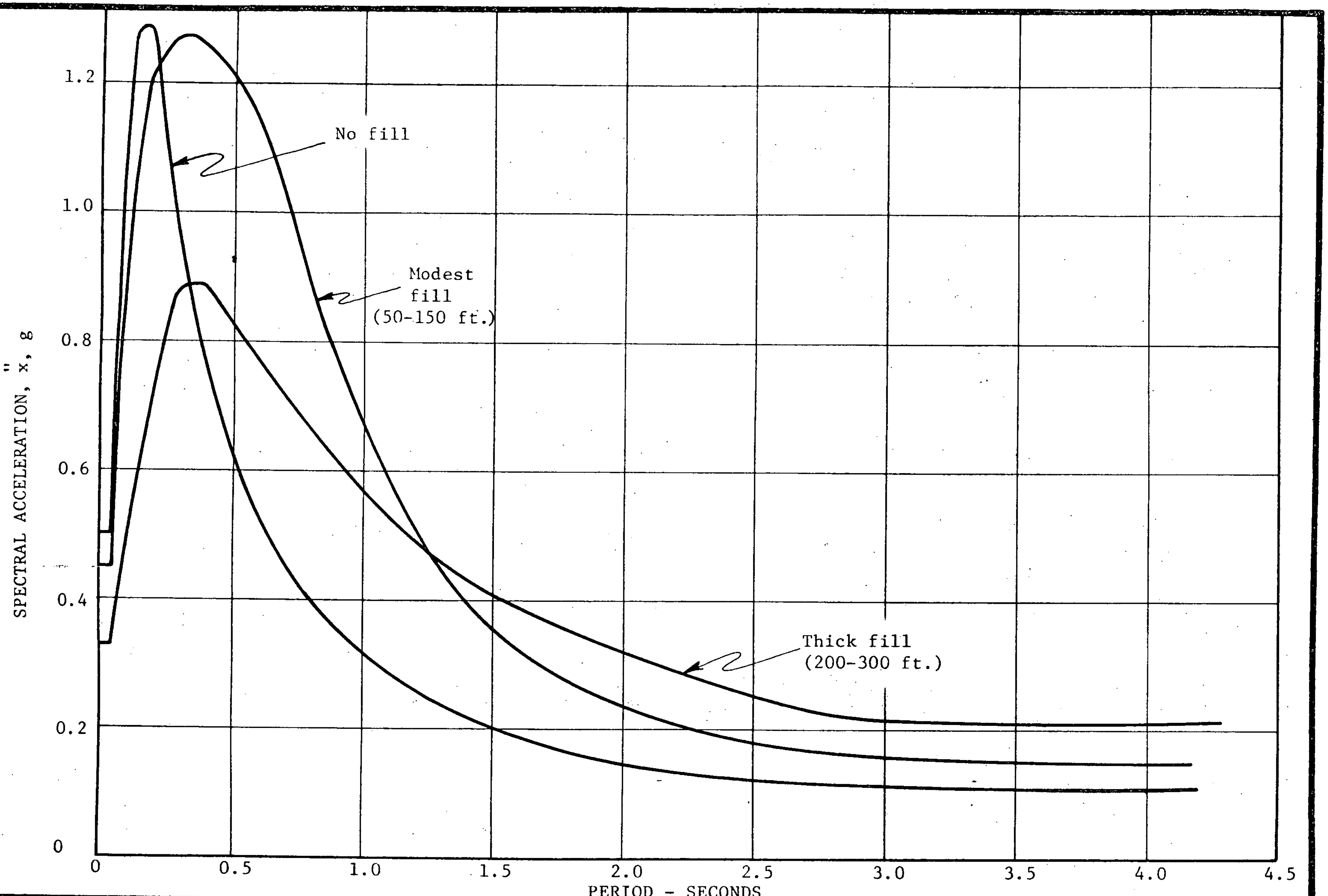


Project: LNG TERMINALS EVALUATION

Project No. 41033I

ESTIMATED SITE RESPONSE CHARACTERISTICS, 100 - YR EVENT
5% OF CRITICAL DAMPING

Fig. 8.1



Project: LNG TERMINALS EVALUATION

Project No. 410331

ESTIMATED SITE RESPONSE CHARACTERISTICS DEER CREEK AND CANYON, 100- YR EVENT (MALIBU COAST FAULT), 5% OF CRITICAL DAMPING

Fig. 8.2

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bedrock surface. For the comparison purpose of the present study, these effects could be at least partially accounted for by using the worst combination or envelope of the spectra presented on Figure 8.2 together with the effects of short-period surface waves described in Section 8.5 below.

The sites are all about the same distance from the San Andreas fault, and they all appear to have stiff-soil or bedrock characteristics. Therefore, as a practical matter for purposes of comparisons, all five sites may be considered to respond similarly to a major event on the San Andreas, except when considering the effects of long- and short-period surface waves as described in Sections 8.4 and 8.5 below. The estimated response spectra for the San Andreas fault were found to exhibit lower response accelerations than those for the nearby faults shown on Figure 8.1, and therefore are not presented.

8.4 LONG-PERIOD SURFACE-WAVE EARTHQUAKE MOTION

The displacements of long-period (2 to 10 second) surface waves are generally controlled by regional geology and seismicity, and are not strongly influenced by near-surface (a few hundred feet) soil conditions. Their wavelengths are long, commonly greater than a few thousand feet. Further, the response spectra presented in Figures 8.1 and 8.2 do not generally incorporate the effects of these long-period motions, but rather emphasize the acceleration amplitude of shorter-period motion. A revision of the long-period motions from historic nearby (within 10 miles) moderate earthquakes and distant (greater than 40 miles), great earthquakes shows that the maximum displacements and durations for 2- to 10-second surface waves were estimated as follows:

Earthquake	Horizontal Displacement Amplitude	Duration
Nearby Moderate Earthquake (M. 6 - 6-1/2 within 10 miles)	5-8 inches	10 to 20 seconds
Distant, Great Earthquake (M. 8+ at 40 to 60 miles)	5-8 inches	2 to 3 minutes

The relative values to be used for each site depend on the regional geology to depths of several thousands of feet: the and softer regions with thick young materials experience the largest displacements. This was evidenced during the 1971 San Fernando earthquake, where the displacements in the deep Hollywood Basin were 2 to 4 times greater than those of other, more shallow, sedimentary sites. By comparing the regional conditions of the five sites the following maximum displacement amplitude values were developed:

Site	Maximum Horizontal Displacement
Rattlesnake Canyon	4 to 7 inches
Cojo Bay (Point Conception)	7 to 10 inches
Las Varas	7 to 10 inches
Deer Creek	4 to 7 inches
Camp Pendleton	6 to 9 inches

The duration of motion could vary between 10 to 20 seconds and 2 or 3 minutes depending on the source of motion described above. The amplitude of vertical displacement can be assumed to be equal to 1/2 that of the above horizontal values for the purposes of the present evaluation.

8.5 SHORT-PERIOD SURFACE-WAVE EARTHQUAKE MOTION

Short-period (less than 2 second period) surface waves are created due to scattering and reflection of waves at sharp changes in local geologic structure for each site. The terrace deposits exposed at the Camp Pendleton, Las Varas, Rattlesnake Canyon and Cojo Bay sites and the sharp valley topography and construction of fill at the Deer Creek site could cause such scattering and reflection. The characteristic amplitude of these waves are expected to be less than the long-period waves, on the order of 1/2 inch or less. Wavelengths for such waves are expected to be on the order of 150 to 300 feet. Data on each of these sites are insufficient to estimate the differences in relative displacement amplitudes and wave lengths of motion for use in site comparisons. Therefore, for the purposes of the present study, we recommend that the effects of short-period surface waves on structures be considered the same for all five sites. The Las Varas site may be on the relatively upthrown block of an active reverse fault that crosses the site. The length of this fault is unknown, however, based upon an apparent displacement of 3 feet, it may be able to generate earthquakes as large as magnitude 5-1/2 to 6. Shaking due to such an earthquake would include high-amplitude, high-frequency motions that may be important for some structures. In addition, the ground motion could contain long-period lurches because of movement on the upthrown block. These ground motions, both high frequency and long period due to an earthquake on a nearby fault are called near-field effects. Their implications for design would require further evaluation.

9.0 ACKNOWLEDGMENTS

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TABLE A

THE GEOLOGIC TIME SCALE

Era	Period	Epoch	Approximate Length of Time before Present (Millions of Years)
Cenozoic	Quaternary	Holocene	.011
		Pleistocene	1.8-2
	Tertiary	Pliocene	5-7
		Miocene	24
		Oligocene	37
		Eocene	53-55
		Paleocene	65
Mesozoic	Cretaceous		136-145
	Jurassic		190-195
	Triassic		225
Paleozoic	Permian		280
	Pennsylvanian		325
	Mississippian		345
	Devonian		395
	Silurian		430
	Ordovician		500
	Cambrian		570
Precambrian			
Origin of Earth			4500