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FINAL MARINE GEOPHYSICAL SURVEY

SAN FRANCISCO-OAKLAND BAY BRIDGE EAST SPAN SEISMIC SAFETY PROJECT

VOLUME 1 - MAIN TEXT & APPENDICES

Prepared for

CALIFORNIA DEPARTMENT OF TRANSPORTATION

March 2001

Earth Mechanics

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March 5, 2001
Project No. 98-42-0054

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Attention: Mr. Mark Willian
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Final Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

Dear Mr. Willian:

The geologic and geotechnical studies for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project are being conducted by Fugro-Earth Mechanics (a joint venture of Fugro West, Inc., and Earth Mechanics, Inc.) under California Department of Transportation (Caltrans) Contract 59A0053. The two-dimensional (2-D) and three-dimensional (3-D) marine geophysical surveys were conducted over the entire survey corridor specified by Caltrans as part of Task 1 (initial site characterization, geophysical survey phase) of the referenced contract. A supplemental 2-D geophysical survey was conducted in the area around Yerba Buena Island as a part of the Task 5 final site characterization studies. The marine exploration borings were conducted in 1998 as part of the Task 3 preliminary site exploration and testing (Phase 1) and Task 5 final site characterization studies (Phases 2) of the referenced contract. Additionally, cone penetration test (CPT) soundings, multi-beam bathymetric surveys, and a tidal flat bathymetric survey were conducted in 2000 as part of Task 5.

Previous geophysical reports and maps produced by Fugro-Earth Mechanics (Fugro-EM) include the preliminary report, supplementary report, and final report of the 1998 Phase 1 2-D marine geophysical survey and the draft final report for the 1998 Phase 1 3-D survey. The preliminary findings of the 2000 Phase 3 marine geophysical survey were reported in a memorandum.

This Final Marine Geophysical Survey report presents the results of the data acquisition, processing, and interpretation of the data from the three marine geophysical surveys. The interpretations integrate all of the geophysical, geotechnical, bathymetry, and geological data collected by Fugro-EM from 1998 to 2000 and pre-1998 geotechnical data provided by Caltrans. The report is a stand-alone submittal and the data and interpretations presented in this report supersede all those presented in the previous reports.

The report is physically bound in two volumes. Volume 1 contains the main text, plates, and appendices, and Volume 2 contains the maps. Data and supporting information are presented on 16 large-scale maps, 2 large-scale cross sections, 120 plates, 9 tables, and 5 appendices. The latter address the field operations for the surveys and data processing of the navigation, bathymetric, and seismic reflection data.

Earth Mechanics

Fugro - Earth Mechanics
A JOINT VENTURE

California Department of Transportation
March 5, 2001 (Fugro 98-42-0054)

On behalf of the project team, we appreciate the opportunity to contribute to Caltrans' design of the new bridge to replace the existing SFOBB East Span. Please call if we can answer any questions relative to the information presented in the enclosed report.

Sincerely,

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SAN FRANCISCO-OAKLAND BAY BRIDGE
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CONTENTS

VOLUME 1 - MAIN TEXT & APPENDICES

Page

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1-1
- 1.1 Background 1-1
  - 1.1.1 SFOBB East Span Seismic Safety Project 1-1
  - 1.1.2 Caltrans Contract for Geotechnical and Geophysical Investigations 1-2
  - 1.1.3 The N6 Alignment and Structures 1-3
- 1.2 Summary of the Marine Geophysical Surveys 1-4
  - 1.2.1 1998 Phase 1 2-D Survey 1-4
  - 1.2.2 1998 Phase 1 3-D Survey 1-5
  - 1.2.3 2000 Phase 3 2-D and Bay Cable Survey 1-6
- 1.3 Supplementary Data Sources Used in the Analyses of the Geophysical Data 1-6
  - 1.3.1 Geotechnical Borings 1-6
  - 1.3.2 Cone Penetration Test (CPT) Soundings 1-7
  - 1.3.3 Velocity Logs 1-7
  - 1.3.4 Multibeam and Tidal Flat Bathymetry Surveys 1-7
- 1.4 Summary of Geologic Units Mapped in the Survey Area 1-7
  - 1.4.1 Fill and Recent Shoal Sand Near Yerba Buena Island 1-8
  - 1.4.2 Young Bay Mud (YBM) 1-8
  - 1.4.3 Yerba Buena Island Local Sediments (YBIS) 1-8
  - 1.4.4 Merritt-Posey-San Antonio (MPSA) Formations 1-9
  - 1.4.5 Old Bay Mud/Upper Alameda Marine Sediments (OBM/UAM) 1-9
  - 1.4.6 Upper Alameda Marine Paleochannel Sand (PCst and PCsb, Top and Base) 1-9
  - 1.4.7 Lower Alameda Alluvial (LAA) Sediments 1-10
  - 1.4.8 Lower Alameda Alluvial Sand (LAAS) 1-10
  - 1.4.9 Franciscan Formation (FF) Bedrock 1-10
- 1.5 Previous Reports and Maps From the Marine Geophysical Surveys 1-11
- 1.6 Organization and Contents of the Final Marine Geophysical Survey Report 1-11

2.0 DATA PROCESSING, MAPPING, AND INTERPRETATION PROCEDURES 2-1
- 2.1 Project Datums 2-1
- 2.2 Bathymetry and Database Maps 2-2
  - 2.2.1 Multibeam Bathymetry and Geotechnical Database Map (Map 1) 2-2
  - 2.2.2 1998 Phase 1 2-D Survey Shiptrack and Cultural Features Map (Map 2) 2-2

VOLUME 1
CONTENTS -- CONTINUED

Page

2.2.3 1998 Phase 1 3-D Survey Database Map (Map 3) 2-3
2.2.4 2000 Phase 3 2-D and Bay Cable Database Map (Map 4) 2-3
2.3 Processing of Multichannel Seismic Data 2-4
2.4 Features Commonly Observed on the Seismic Records 2-4
2.4.1 Bay Floor Topography 2-4
2.4.2 Buried Utilities and Other Cultural Features 2-5
2.4.3 Seismic Data Artifacts 2-5
2.4.4 Shallow Gas in the Sediment Section 2-6
2.4.5 Paleochannels 2-7
2.4.6 Stratigraphic Relationships 2-8
2.4.7 Bedrock Topography 2-8
2.5 Seismic Images and Velocity Measurements From Geologic Units 2-9
2.5.1 Velocity Measurements in the Geotechnical Borings 2-9
2.5.2 Fill and Recent Shoal Sand Near Yerba Buena Island 2-9
2.5.3 Young Bay Mud (YBM) 2-9
2.5.4 Yerba Buena Island Local Sediments (YBIS) 2-10
2.5.5 Merritt-Posey-San Antonio (MPSA) Formations 2-10
2.5.6 Undifferentiated Old Bay Mud (OBM) and Upper Alameda Marine (UAM) Sediments 2-11
2.5.7 Upper Alameda Marine Paleochannel Sand (PCst and PCsb) 2-11
2.5.8 Lower Alameda Alluvial Sediments (LAA) and Sand (LAAS) 2-12
2.5.9 Franciscan Formation (FF) Bedrock 2-12
2.6 Data Integration and Mapping Procedures 2-13
2.6.1 The KINGDOM Suite 2d/3dPAK Seismic Data Interpretation Program 2-13
2.6.2 Integration of 2-D and 3-D Seismic Data Sets 2-15
2.6.3 Depth Conversions 2-15
2.6.4 Integration of Geotechnical and Seismic Data 2-17
2.6.5 Accuracy of Contours and Values Posted at Geotechnical Explorations 2-18

3.0 STRUCTURAL CONTOUR AND ISOPACH MAPS 3-1
3.1 Introduction to the Horizon and Isopach Maps 3-1
3.2 Structural Contours, Base of Young Bay Mud (Map 5) 3-2
3.3 Isopach of Young Bay Mud (Map 6) 3-3
3.4 Isopach of Merritt-Posey-San Antonio Formations (Map 7) 3-4
3.5 Structural Contours Near Top of Old Bay Mud (Map 8) 3-6
3.6 Maps of Upper Alameda Marine Paleochannel Sand (Maps 9a, 9b, and 9c) 3-8

VOLUME 1
CONTENTS -- CONTINUED

Page

3.7 Structural Contours, Top of Lower Alameda Alluvial Sediments (Map 10) 3-9
3.8 Structural Contours, Top of Lower Alameda Alluvial Sand (Map 11) 3-10
3.9 Isopach of Sediment Above Lower Alameda Alluvial Sand (Map 12) 3-11
3.10 Regional Structural Contours, Top of Franciscan Formation (Map 13) 3-11

4.0 SUMMARY OF ROCK AND SEDIMENT HORIZONS UNDERLYING THE N6 ALIGNMENT 4-1

4.1 Database and the N6 Alignment Cross Sections 4-1
4.1.1 Data Shown on Cross Sections 4-1
4.1.2 The N6 Alignment Cross Sections 4-2
4.2 Main Span, Yerba Buena Island to East Pier (Pier E2) 4-3
4.2.1 Geologic Setting 4-3
4.2.2 Bedrock Surfaces and Identification of Associated Reflectors 4-4
4.2.3 Pier E1 (Pylon) Footprint Area 4-6
4.2.4 Pier E2 (East Pier) Footprint Area 4-7
4.3 Skyway and Oakland Shore Approach, Pier E3 to Oakland Mole 4-8
4.3.1 Geologic Setting 4-8
4.3.2 The Western Part of the Skyway and Structure, Piers E2 to E8 4-9
4.3.3 The Eastern Part of the Skyway Structures, Piers E9 to E20 4-10

5.0 STRATIGRAPHY AND STRUCTURE OFFSHORE YERBA BUENA ISLAND ... 5-1

5.1 Purpose and Background of the Phase 3 Investigation 5-1
5.2 Possible Indications of Faulting at the Eastern End of the Island 5-2
5.2.1 Onshore Mapping 5-2
5.2.2 Onshore Geophysical Survey 5-2
5.2.3 Discontinuities in the Seismic Records From the Cove Area 5-3
5.3 Database for the Investigation 5-4
5.3.1 Historical Data 5-5
5.3.2 Previous Explorations for the N6 Alignment and SFOBB 5-5
5.3.3 Multibeam Bathymetry 5-6
5.3.4 Phase 3 Marine Geophysical Survey 5-6
5.3.5 Phase 3 CPT Soundings 5-6
5.4 Stratigraphic Units and Cross Sections Offshore Eastern Yerba Buena Island .. 5-7
5.4.1 Fill 5-7
5.4.2 Shoal Sand 5-8
5.4.3 Young Bay Mud (YBM) 5-9
5.4.4 Yerba Buena Island Sediment (YBIS) 5-9
5.4.5 Merritt-Oosey-San Antonio Formations (MPSA) 5-10

VOLUME 1
CONTENTS -- CONTINUED

Page

5.4.6 Old Bay Mud (OBM) 5-10
5.4.7 Upper Alameda Marine Sediments (UAM) 5-10
5.4.8 Franciscan Formation Bedrock 5-11
5.5 Analyses of Possible Faulting Offshore From the Eastern End of Yerba Buena Island 5-11
5.5.1 Velocity Analysis and Depth Conversion of Seismic Data 5-12
5.5.2 Structural Contour Map, Top of Franciscan Formation Offshore Yerba Buena Island 5-12
5.5.3 Sediment Unit Continuity Across the Cove Area 5-13
5.5.4 Sediment Unit Continuity Along the Southeast Side of the Island 5-13
5.6 Summary and Conclusions 5-14

6.0 REFERENCES 6-1

TABLES

Table

Summary of Geologic Units Mapped in Survey Area 1.1
New and Previous Maps From Geophysical Survey Data Interpretations 1.2
Cultural Features Shown on Map 2 and Plate 2.2 ..... 2.1
Summary of Borings in Area of Main Span-Pylon and Offshore Yerba Buena Island 2.2
Summary of Borings between Main Span-Pylon and Oakland Mole 2.3a,b
Summary of Phase 3 Cone Penetrometer Data, Main Span Area and Offshore Yerba Buena Island 2.4
Summary of Phase 3 Cone Penetrometer Data, Skyway Area, Pier E3 to Oakland Mole ... 2.5
Summary of Selected Geotechnical Data from Yerba Buena Island
Fugro-Earth Mechanics Borings 1998 to 2000 ..... 5.1a
Caltrans Explorations 1932 to 1996 ..... 5.1b

PLATES

Plate

Project Location Map 1.1
Bathymetry and N6 Alignment 1.2
Marine Exploration Map 1.3

VOLUME 1
CONTENTS -- CONTINUED

PLATES -- CONTINUED

Plate

Bathymetry and Marine Geotechnical Explorations 2.1
Shiptrack and Cultural Features Map, 1998 Phase 1 2-D Marine Geophysical Survey 2.2
Database Map, 1998 Phase 1 3-D Marine Geophysical Survey 2.3
Data Base Map, 2000 Phase 3 2-D Marine Geophysical Survey 2.4
Location Map for Seismic Data Illustrated in Sections 2.4 and 2.5 ..... 2.5
Bathymetric and Shallow Sediment Features, Data Example and Interpreted Schematic 2.6
Shallow Gas and Buried Channel Banks, Data Example and Interpreted Schematic 2.7
Paleochannel Sequences, Data Example and Interpreted Schematic 2.8
Hypothetical Schematic of Depositional Sequences in Paleochannels, Model 1 ..... 2.9
Hypothetical Schematic of Depositional Sequences in Paleochannels, Model 2 ..... 2.10
Local Topographic Feature at Top of Lower Alameda Alluvial Sediments, Data Example 2.11
Shallow Marine Sediments, Data Example and Interpreted Schematic 2.12
Top of Franciscan and Onlap of Lower Alameda Alluvial Sediments, Data Example 2.13
Velocity Logs From the 1998 Borings 2.14a-c
KINGDOM Suite Data Examples
- 3-D Survey Basemap with Location of Seismic Lines Illustrated in Section 2 ..... 2.15
- Seismic Line 306 with Boring 98-6 ..... 2.16
- Crossline 353 With Major Mapped Horizons 2.17
- Line 328 With Major Mapped Horizons 2.18
- Arbitrary Seismic Line With Interpreted Horizons 2.19
- Time Slice at 80 Milliseconds 2.20
- Colored Contour Map, Top of Franciscan Formation 2.21

Structural Contours, Base of Young Bay Mud 3.1
Isopach (Thickness) of Young Bay Mud 3.2
Isopach (Thickness) of Merritt-Posey-San Antonio Formations 3.3
Structural Contours, Near Top of Old Bay Mud 3.4
Structural Contours, Top of Upper Alameda Marine Paleochannel Sand 3.5
Structural Contours, Base of Upper Alameda Marine Paleochannel Sand 3.6
Isopach (Thickness) of Upper Alameda Marine Paleochannel Sand 3.7
Structural Contours, Top of Lower Alameda Alluvial Sediments 3.8
Structural Contours, Top of Lower Alameda Alluvial Sand 3.9
Isopach (Thickness) of Sediment Section Above Lower Alameda Alluvial Sand 3.10
Regional Structural Contours, Top of Franciscan Formation 3.11

Key to Cross Sections 4.1

Subsurface Cross Sections along N6 Alignment Yerba Buena Island to Oakland Mole,
Pier E1 to Pier E8 ..... 4.2a
Pier E9 to Pier E20 ..... 4.2b
Location Map for 3-D Seismic Data Illustrated in Section 4 ..... 4.3
Franciscan Weathering Surfaces, Main Span-Pylon Area,
Annotated 3-D Seismic Section Line 328 ..... 4.4
Annotated 3-D Seismic Section Crossline 824 ..... 4.5
Photographs of Representative Rock Samples from Main Span-Pylon Area 4.6
Structural Contours, Main Span-Pylon Area,
Top of Intensely Weathered Franciscan Formation 4.7
Top of Slightly Weathered/Fresh Franciscan Formation 4.8
Isopach (Thickness) of Weathered Franciscan Formation, Main Span-Pylon Area 4.9
Subsurface Cross Section Through Pier E2
With Undrained Shear Strength 4.10a
With P- and S-Wave Velocity 4.10b
Annotated Seismic Line, Arbitrary Line through East Pier Footprint 4.11
Geotechnical Cross Section Through Pier E3
With Undrained Shear Strength 4.12a
With P- and S-Wave Velocity 4.12b
Geotechnical Cross Section Through Pier E11
With Undrained Shear Strength 4.13a
With P- and S-Wave Velocity 4.13b
Subsurface Cross Section Along N6 Alignment Centerline, Borehole Lithology
With P- and S-Wave Velocity Data 4.14

Geological Map and Geotechnical Explorations at the Eastern End of Yerba Buena
Island 5.1
Onshore Seismic Reflection Profile R1 ..... 5.2a
Onshore Seismic Reflection Profile R3 ..... 5.2b
Location Map for 3-D Seismic Data Illustrated in Section 5 ..... 5.3
Interpreted 3-D Seismic Sections,
Line 265 Showing Top Franciscan Reflector Continuity across Ridge 5.3a
Line 300 Showing Possible Buried Landslide North of Yerba Buena Island 5.3b
Crossline 879 Showing Alternative Franciscan Formation Reflector in Cove Area ... 5.3c
Line 311 Showing Alternative Velocity Models 5.3d
Colored Contour Maps of Alternative Models for Top of Franciscan Formation
North of Yerba Buena Island 5.4

VOLUME 1
CONTENTS -- CONTINUED

PLATES -- CONTINUED

Plate

3-D Seismic Data Time Slices
At 70 Milliseconds with Top of Franciscan Formation Annotated 5.5a
At 100 Milliseconds with Top of Franciscan Formation Annotated 5.5b
Database Map 2000 Phase 3 Marine Geophysical Survey 5.6
1915 Bathymetric Data 5.7
Dredged Area (1936-1937) 5.8
Isopach (Thickness) of Fill (Mud) 5.9
Cross Section Locations Offshore Yerba Buena Island 5.10
Cross Sections A-A' to M-M' 5.11a-m
Depth Conversion Example in Area of Fill 5.12
Interpreted Seismic Sections, Southeastern Side of Yerba Buena Island
Multichannel Minisparker Record, Line 145 ..... 5.13a
High-Resolution Boomer Record Line 923 ..... 5.13b
Multichannel Minisparker Record Line 134 ..... 5.13c
Multichannel Minisparker Record Line 701 ..... 5.13d
Multichannel Minisparker Record Line 136 ..... 5.13e
Multichannel Minisparker Record Line 138 ..... 5.13f
Structural Contours, Top of Franciscan Formation Near Yerba Buena Island 5.14

APPENDICES

APPENDIX A: 1998 PHASE 1 2-D MARINE GEOPHYSICAL SURVEY OPERATIONS

Tables:

Summary of Field Operations, 1998 Phase 1 2-D Marine Geophysical Survey A.1
Detailed Specifications for 1998 Phase 1 2-D Multichannel Sleeve-Gun System A.2

Plates:

Project Location Map A.1
Instrumentation Layout A.2
Field Operations Photographs A.3a,b

VOLUME 1
CONTENTS -- CONTINUED

APPENDICES -- CONTINUED

APPENDIX B: 1998 PHASE 1 3-D MARINE GEOPHYSICAL SURVEY OPERATIONS

Tables:

1998 Phase 1 3-D Marine Geophysical Survey Operations Summary B.1
Detailed Specifications for 3-D Multichannel Sleeve-Gun System B.2

Plates:

Database Map B.1
Instrumentation Layout B.2
Field Operations Photographs B.3a-c

APPENDIX C: 2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY OPERATIONS

Tables:

Summary of Field Operations, 2000 Phase 3 2-D Marine Geophysical Survey C.1
Detailed Specifications for 2000 Phase 3 2-D Marine Geophysical Survey C.2

Plates:

Database Map, 2000 Phase 3, 2-D Marine Geophysical Survey C.1
Instrumentation Layout, Minisparker Survey C.2a-c
Field Operations Photographs C.3a,b

APPENDIX D: NAVIGATION, BATHYMETRIC, AND SEISMIC DATA PROCESSING

Tables:

Glossary of Terms Used in Discussion of Seismic Processing D.1

Plates:

2-D Processing Comparison D.1
3-D Coverage, Main Survey Area, 6.25-Meter Binning, All Offsets D.2
3-D Coverage, Cove Area, 6.25-Meter Binning, All Offsets D.3
3-D Survey, 3.125-Meter Bin Fold Count D.4
Comparison of 2-D and 3-D Processed Sleeve-Gun Records D.5
Processed Minisparker Record Example D.6
Processed Bay Cable Record Example D.7

APPENDIX E: 2000 PHASE 3 BATHYMETRIC SURVEY OPERATIONS AND DATA PROCESSING

Plates:

Project Location Map, Phase 3 Multibeam Bathymetry Survey E.1
Schematic Diagrams E.2
Project Location Map, 2000 Phase 3 Tidal Flat Bathymetry Survey E.3
3-D View of Multibeam Bathymetry From Yerba Buena Island E.4

VOLUME 2 - MAPS

	Map
Bathymetry and Geotechnical Data Base Map (1:5000)	1
1998 2-D Marine Geophysical Survey Shiptracks and Cultural Features Map (1:5000)	2
1998 3-D Marine Geophysical Survey Database Map (1:5000)	3
2000 Phase 3 2-D Marine Geophysical Survey Database Map (1:2000)	4
Structural Contours, Base of Young Bay Mud (1:5000)	5
Isopach (Thickness) of Young Bay Mud (1:5000)	6
Isopach (Thickness) of Merritt-Posey-San Antonio Formations (1:5000)	7
Structural Contours Near Top of Old Bay Mud (1:5000)	8
Structural Contours, Top of Upper Alameda Marine Paleochannel Sand (1:2000)	9a
Structural Contours, Base of Upper Alameda Marine Paleochannel Sand (1:2000)	9b
Isopach (Thickness) of Upper Alameda Marine Paleochannel Sand (1:2000)	9c
Structural Contours, Top of Lower Alameda Alluvial Sediments (1:5000)	10
Structural Contours, Top of Lower Alameda Alluvial Sand (1:5000)	11
Isopach (Thickness) of Sediment Section Above Lower Alameda Alluvial Sand (1:5000).	12
Regional Structural Contours, Top of Franciscan Formation (1:5000)	13
Structural Contours, Top of Franciscan Formation Near Yerba Buena Island (1:2000)	14

EXECUTIVE SUMMARY

DESCRIPTION AND OBJECTIVES OF THE MARINE GEOPHYSICAL SURVEYS

The geological, geophysical, and geotechnical studies for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project were conducted by Fugro-Earth Mechanics (a joint venture of Fugro West, Inc., and Earth Mechanics, Inc.) under Caltrans Contract 59A0053. Marine geophysical surveys were authorized under Task Order Nos. 1 and 5. This Final Marine Geophysical Survey report summarizes the three marine geophysical surveys and associated bathymetric surveys, and presents the results of our interpretation of the subsurface geology along the N6 alignment.

Task Order No. 1, issued in January 1998, included three geophysical surveys (two marine surveys and one on Yerba Buena Island). The initial survey, designated as the 1998 Phase 1 2-D survey, was a two-dimensional (2-D), multi-system, high-resolution survey of the area between Yerba Buena Island and the Oakland Mole. The survey was conducted in late January 1998. A differential global positioning system (DGPS) was used for navigation. The geophysical instrumentation consisted of an echo sounder, digital side scan sonar, CHIRP subbottom profiler, and a 5-cubic-inch, 12-channel sleeve-gun system. The high-resolution data were collected on a nominal grid of survey lines spaced at 50 meters while the sleeve-gun data were collected on a 50-by-100-meter grid. The objectives of this initial survey were to map the Bay floor, locate and identify Bay floor or buried cultural features, and identify and map the key sediment horizons and bedrock. The 2-D survey data also were used for planning the 1998 Phase 1 marine geotechnical explorations (Task Order No. 3). Results of the 2-D survey were initially reported in Fugro-EM (1998a,b,c).

The 2-D survey was immediately followed by the 1998 Phase 1 three-dimensional (3-D) survey of the same area. The 3-D data were collected in February 1998 using a DGPS navigation system with additional instrumentation to track the seismic source and cables. The seismic energy source was two to four sleeve guns mounted on a sled. Seismic reflection data were recorded using two to four 16-channel cables. The objectives of the 3-D survey were to provide a denser coverage of the subsurface horizons than the 2-D survey, and to improve the image quality of the deeper horizons by using a higher energy source and additional data channels. The 3-D survey data were used in planning the 1998 Phase 2 marine geotechnical explorations. These data were integrated with the results of the 2-D survey and the geotechnical explorations, and reported in draft form in Fugro-EM (1999).

The land survey on the eastern end of Yerba Buena Island consisted of seismic reflection and refraction lines designed to provide data on the depth of sediment in the saddle area and seismic velocity profiles related to bedrock weathering. Results from this survey were included in Fugro-EM (1998d).

Task Order No. 5 included the 1998 Phase 2 borings, the 2000 Phase 3 marine geophysical survey, Phase 3 marine cone penetration test (CPT) soundings, a multibeam bathymetric survey of the N6 alignment, and a bathymetric survey of the tidal flat area north of the Oakland Mole. The marine geophysical survey was designed to provide high-resolution reflection data on the stratigraphy and structure around the eastern end of Yerba Buena Island including the area of the Main Span structure. Geophysical data were collected on a nominal 25-by-50-meter grid of lines. DGPS was used for navigation. The seismic energy source was a multi-tip minisparker and data were recorded with a 24-channel cable. Seismic reflection data were collected in the near-shore areas using a 48-channel Bay floor cable and a single-channel (analog) boomer. The CPT soundings provided information on the geotechnical properties of the sediments offshore Yerba Buena Island and along the Skyway and Oakland Shore Approach structure sections of the N6 alignment. The bathymetric surveys used the latest technology to map the Bay floor along and around the N6 alignment.

OVERVIEW OF THE REPORT AND MAPS

This Final Marine Geophysical Survey report presents the results of the data acquisition, processing, and interpretation of the data from the three marine geophysical surveys. It supersedes all previous reports and maps regarding these surveys. The interpretations integrate all of the geophysical, geotechnical, bathymetry, and geological data collected by Fugro-Earth Mechanics (Fugro-EM) in 1998 to 2000 and pre-1998 geotechnical data provided by Caltrans. The geophysical and geotechnical databases and interpretation of the subsurface geology beneath the N6 alignment are illustrated in detail on 16 large-scale maps and two large-scale cross sections. Discussion sections of this report describe: a) the database; b) data reduction, processing, and mapping methods; c) the structural contour and isopach maps; d) the subsurface geology along the N6 alignment; and e) the investigation of potential faulting offshore eastern Yerba Buena Island. Nine tables, 120 plates, and five appendices support the discussions.

Section 1.0 - Introduction, summarizes the field operations and the geotechnical databases integrated into the interpretations. Summaries also are provided on the sediment and bedrock horizons mapped in the investigation, previous reports, and maps. Field operations and instrumentation for the 1998 Phase 1 2-D, 1998 Phase 1 3-D, and 2000 Phase 3 2-D and bay cable marine geophysical surveys are described in Appendices A, B, and C, respectively. Processing procedures for the navigation, bathymetric, and multichannel seismic reflection data are described in Appendix D. Field operations and instrumentation for the 2000 Phase 3 multibeam and tidal flat bathymetric surveys are documented in Appendix E.

Section 2.0 describes the data processing, mapping, and interpretation procedures. Maps 1 through 4 show the bathymetric contours and geophysical and geotechnical databases from the three marine geophysical surveys. Geologic and cultural features commonly seen on the seismic reflection data are described and shown in examples from the 2-D survey records. The mapped sediment and bedrock horizons are discussed with regard to the unit velocities and their

characteristic appearances on the seismic records. The appearances of the sediment units and bedrock on the seismic data are shown on record examples from both the 2-D and 3-D surveys. The KINGDOM Suite 2d/3dPAK, a commercial computer program specifically designed as a seismic data interpretation platform, was used to interpret the seismic data and to integrate the geotechnical database into the interpretation. The program and examples of interpretive products produced by the program are described. The examples, included as plates, are taken from the SFOBB data set and also are used to support the maps and interpretive conclusions discussed in the report. Procedures for integrating the 3-D data volume with velocity data, 2-D seismic lines, and geotechnical exploration data are discussed and illustrated with plates. The last subsection of Section 2.0 addresses the precision and accuracy of both the seismic data and geotechnical explorations with respect to the contour maps contained in the report.

Section 3.0 presents the results of the mapping of the sediment units and bedrock. The following 12 large-scale geologic maps are included with the report at scales of 1:2000 or 1:5000:

- Structural Contours, Base of Young Bay Mud (Map 5, 1:5000)
- Isopach of Young Bay Mud (Map 6, 1:5000)
- Isopach of Merritt-Posey-San Antonio Formations (Map 7, 1:5000)
- Structural Contours, Near Top of Old Bay Mud (Map 8, 1:5000)
- Maps of Upper Alameda Marine Paleochannel Sand (Maps 9a, 9b, and 9c, 1:2000)
- Structural Contours, Top of Lower Alameda Alluvial Sediments (Map 10, 1:5000)
- Structural Contours, Top of Lower Alameda Alluvial Sand (Map 11, 1:5000)
- Isopach of Sediment Above Lower Alameda Alluvial Sand (Map 12, 1:5000)
- Regional Structural Contours, Top of Franciscan Formation Bedrock (Map 13, 1:5000)
- Structural Contours, Top of Franciscan Formation Near Yerba Buena Island (Map 14, 1:2000)

There are six structural contour maps that show the elevations of the top or base of the sediment units. Four isopach maps depict the thickness of selected sediment units. Two maps of the Franciscan Formation bedrock depict that surface on both a regional scale and in detail on and around Yerba Buena Island. Discussions regarding the individual maps include the unit geometry, lithology, conditions of deposition, and relation to overlying and underlying units.

Section 4.0 presents detailed descriptions and illustrations of the sediment and bedrock horizons along the N6 alignment. Subsurface cross sections beneath the westbound structures, N6 centerline, and eastbound structures are presented at a horizontal scale of 1:2000 and a

vertical exaggeration of 4. The cross sections represent the integrated interpretation of the geotechnical explorations, laboratory tests, and geophysical surveys. The cross sections show the bedrock and sediment unit boundaries, lithology in the borings, shear strength and tip resistance from CPT soundings, and internal reflectors within the units. The Main Span-Pylon (Pier E1) and East Pier (Pier E2) areas are discussed separately. Bedrock weathering surfaces are mapped in the area of the Pylon and correlated with photographs of rock cores from the geotechnical borings in that area.

Section 5.0 presents the results of the 2000 Phase 3 studies around the northeast end of Yerba Buena Island. The Phase 3 geophysical survey and geotechnical explorations were undertaken to provide additional data that would identify the lithology and geotechnical properties of the sediments and bedrock structure offshore Yerba Buena Island, and enable their correlation with units mapped on the island and farther to the east along the N6 alignment. Historical data are reviewed to document and quantify the effects of the construction of Treasure Island on the Bay floor and subsurface sediments on the north side of Yerba Buena Island. The Franciscan Formation bedrock is mapped on the island and offshore to the north, east, and south of the eastern end of the island. The sediment section in the cove between the islands is tied into the units mapped beneath the N6 alignment and SFOBB with a series of subsurface cross sections. Several high-quality seismic sections illustrate the bedrock and sediment horizons on the southeastern side of the island. All of the data sets are examined with respect to the possibility that shear zones in the bedrock at the eastern end on the island continue offshore as faults.

SUMMARY OF THE SUBSURFACE GEOLOGY ALONG THE N6 ALIGNMENT

The N6 alignment is divided into three structure sections, the Main Span area, the Skyway structure, and the Oakland Shore Approach structure. The Main Span area extends from the West Pier at the eastern end of Yerba Buena Island to between Piers E2 and E3. The Skyway structure extends from east of Pier E2 to between Piers E16 and E17. The Oakland Shore Approach structure is located in the shallow water area west of the Oakland Mole and extends onto the Mole. This third section of the N6 alignment was not included in the geophysical survey areas because of the shallow water and is discussed in a separate report.

Main Span Area

The Main Span area includes the West Pier on eastern Yerba Buena Island, Pier E1 (Pylon) and Pier E2 (East Pier). Pier E1 will be constructed approximately 60 to 85 meters offshore Yerba Buena Island in an area of relatively shallow, sloping bedrock. Pier E2 (East Pier) will be situated about 450 meters east of the island beyond the toe of the bedrock slope. East of Yerba Buena Island, the Bay floor slopes steeply from mean sea level (the project vertical datum) down to elevation (El.) -23 meters and then more gently into the base of the scour hole at El. -25 to El. -26 meters beneath the N6 alignment between Piers E1 and E2. The

Bay floor then rises gently to El. -15 meters where it begins a very gentle eastward rise to the Oakland Mole. The northeastward Bay floor slope at the location of Pier E1 is about 13 degrees. The slope of the eastern side of the scour channel is about 6 degrees and the slope at the Pier E2 site is less than ½ degree.

Along the eastward slope into the scour channel, the bedrock is covered with a thin veneer of fill (mud). This material is most likely dredge spoil from the construction of Treasure Island. However, the material on the floor of the scour channel appears from the seismic data to be native Young Bay Mud. The Young Bay Mud thickens to the east as the bathymetry rises and is about 15 meters thick at Pier E2. The Franciscan Formation bedrock slope is about 17 degrees from outcrops on Yerba Buena Island to the toe of the slope at El. -90 to El. -95 meters, approximately 325 meters east of the island.

The sediment section at Pier E1 (Pylon) consists of a few (0 to 3) meters of fill (mud) overlying Franciscan Formation bedrock. The top of the intensely weathered bedrock slopes 13 degrees to the northeast beneath the Pier E1 footprint. Seismic, geotechnical, and rock core data were integrated to map the bedrock weathering surfaces in the area of Pier E1. The weathered zone, between rock fragments and intensely weathered material at the top and slightly weathered to fresh rock at the base, is 8 to 10 meters thick at the location of Pier E1.

The sediment section thickens rapidly eastward from the western bank of the scour channel. This rapid increase reflects both the rise in Bay floor elevation and the relatively steep northeast dip of the bedrock. The sediment section at Pier E1 consists of a few meters of fill (mud) whereas the section at Pier E2 is about 85 meters thick. All of the major sediment units are represented in the cross section at Pier E2. However, the medium- to coarse-grained sand horizon of the Lower Alameda Alluvial sediments is very thin or absent at this location. The sediment section at Pier E2 consists of the following units (the ranges represent variations between the sections beneath the westbound and eastbound lanes):

- Young Bay Mud (YBM), 15 to 16 meters of very soft to firm clay
- Merritt-Posey-San Antonio (MPSA) Formations, 6 to 8 meters of stiff to very stiff clay
- Old Bay Mud (OBM), 15 to 18 meters of very stiff to hard clay
- Upper Alameda Marine (UAM) sediments, 19 to 21 meters of very stiff to hard clay with thin layers of sand and silt above
- Upper Alameda Marine Paleochannel Sand (UAMPC [PCst and PCsb, top and base]), 15 meters of dense to very dense sand with hard clay layers
- Lower Alameda Alluvial (LAA) sediments, 5 to 10 meters of hard clay over 2 to 5 meters of very dense sand (LAAS)
- Weathered bedrock at about El. -97 meters

Considerations of Holocene Faulting in the Main Span Area

One of the primary objectives of the 2000 Phase 3 geotechnical and geophysical investigations was to determine if shear zones mapped in the bedrock at the eastern end of Yerba Buena Island continued offshore as Holocene faults. Detailed analyses of the integrated data sets presented in Section 5.0 of the report concluded that the available data appear to preclude the possibility that the onshore shear zones are representative of offshore Holocene faults. No evidence of offshore faulting in the area of the Main Span-Pylon was identified in our investigations.

Skyway Structure

The Skyway structure is about 2.1 kilometers long and includes Piers E3 to Piers E16. The Bay floor rises gently to the east from El. -12 meters at the western end of the structure to El. -2 meters between Piers E16 and E17. The Franciscan Formation bedrock dips gently to the east at about a 1-degree slope from El. -100 meters to El. -135 meters near the Oakland Mole. The thickness of the individual sediment units varies both along and across the structure. This occurs because the Skyway structure runs, at a slight angle, along the southern flank of the main branch of the ancient Temescal Creek paleochannel. The paleochannel was eroded into the top of the Old Bay Mud during the last sea level low stand and is now filled with Young Bay Mud and possibly sediments belonging to the Merritt-Posey-San Antonio Formations at the base. Several tributary channels run north to south across the N6 alignment between Piers E2 and E3, at Pier E7, and at Pier E16. The first two tributaries cut into the Old Bay Mud and contain relatively thicker sections of both the Young Bay Mud and the Merritt-Posey-San Antonio sediments. The tributary channel at Pier E16 was eroded into the Merritt Sand and did not affect the Old Bay Mud. The erosion into the Old Bay Mud and Merritt-Posey-San Antonio Formations between Piers E2 and E3 may also have been caused by a southward meander of the east-west-trending Temescal Creek paleochannel.

The medium- to coarse-grained sand of the Lower Alameda Alluvial-Sand is found beneath the entire length of the Skyway Structure generally at about El. -92 meters at Pier E16 to about El. -96 meters at Pier E3. It is a dense to very dense sand with hard clay layers. It is apparently 8 meters or more in thickness and between Piers E3 and E10 extends down to bedrock at elevations as deep as El. -115 meters. East of Pier E10 only a few borings penetrated the sand and it may be less than 10 meters thick east of Pier E16. It is planned that the support piles for Piers E3 to E5 will bottom in the bedrock and piles for Piers E6 to E16 in the medium- to coarse-grained sand of the Lower Alameda Alluvial sediments.

SECTION 1.0
INTRODUCTION

1.0 INTRODUCTION

This report is being provided to assist the California Department of Transportation (Caltrans) and its design team during the final design of the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project. This Final Marine Geophysical Survey Report summarizes the three marine geophysical surveys and associated bathymetric surveys, and presents the results of the interpretation of the subsurface geology.

The descriptions, maps, and cross sections of the subsurface soils and bedrock horizons along the marine part of the N6 alignment represent the integrated interpretation of the geological, geophysical, and geotechnical data collected by Fugro-Earth Mechanics (a joint venture between Fugro West, Inc., and Earth Mechanics, Inc.) between 1998 and 2000. Geotechnical data provided by Caltrans from pre-1998 explorations are also integrated into the database. The major text sections of the report address the following topics:

- The database.
- Data processing, mapping and interpretation procedures.
- Structural contour and isopach maps of the primary sediment horizons and the bedrock between Yerba Buena Island and the Oakland Mole.
- Subsurface sediment and rock horizons beneath the N6 alignment and at the Main Span Pylon and East Pier.
- Sediment stratigraphy, bedrock structure, and analyses of potential Holocene faulting offshore the eastern end of Yerba Buena Island.

Data and supporting information are presented on 16 large-scale maps, 2 large-scale cross sections, 120 plates, 9 tables, and 5 appendices. The appendices address the field operations for the surveys and data processing of the navigation, bathymetric, and seismic reflection data.

This report is physically bound into two volumes. Volume 1 contains the main text, plates, and appendices, and Volume 2 contains the maps.

1.1 BACKGROUND

1.1.1 SFOBB East Span Seismic Safety Project

The SFOBB carries 10 lanes of Interstate 80 traffic, 5 eastbound and 5 westbound, across San Francisco Bay. The bridge is bisected longitudinally by Yerba Buena Island, with the West Span(s) extending from San Francisco to Yerba Buena Island and the East Span(s) extending from Yerba Buena Island to Oakland. The existing bridge is a double-decked structure that was constructed in the 1930s.

During the 1989 Loma Prieta earthquake, the East Span(s) of the bridge suffered considerable damage, including the collapse of one span. Recognizing the vulnerability of the structure to future earthquake shaking, the California Department of Transportation (Caltrans) embarked on a seismic retrofit program to upgrade the bridge. In the summer of 1995, Caltrans presented their retrofit strategy for the SFOBB East Span to the Seismic Advisory Board, who raised the issue relative to replacement in lieu of retrofit.

Subsequently, Caltrans developed a 30-percent design of a continuous viaduct replacement structure. In 1996, that 30-percent design was presented to the Bay Bridge Design Task Force, who had been appointed by the Metropolitan Transportation Commission (MTC) to select a bridge type for the East Span replacement structure. The MTC and their task force then formed the Engineering and Design Advisory Panel (EDAP), who advised against the replacement bridge type proposed by Caltrans.

Following that recommendation, Caltrans contracted with a joint venture between TY Lin International and Moffatt & Nichol Engineers (TY Lin/M&N) to develop 30-percent designs for two alternative bridge types. The two bridge-type alternatives included a cable-supported Main Span offshore from Yerba Buena Island and a Skyway structure farther to the east, as well as the associated Yerba Buena Island transition structure(s) and Oakland Shore Approach structure(s). The alternative cable-supported main structures included either single-tower or dual-tower, cable-stayed or self-anchored suspension bridge structures.

In January 1998, Caltrans contracted with Fugro-Earth Mechanics (Fugro-EM) to undertake geological, geophysical, and geotechnical engineering investigations for the foundation design for the proposed replacement structures.

The timing for the design project required that Caltrans and TY Lin/M&N submit 30-percent design-level schedule and cost estimates to EDAP and MTC by May 29, 1998. In June 1998, EDAP and MTC selected the single-tower, self-anchored suspension bridge structures and concrete Skyway structures for final design. Final design of the chosen structure types and alignment was begun by the TY Lin/M&N team in late Fall 1998.

1.1.2 Caltrans Contract for Geotechnical and Geophysical Investigations

The geologic and geotechnical studies for the SFOBB East Span Seismic Safety Project were conducted by Fugro-EM under Caltrans Contract 59A0053.

To date, six task orders have been issued under contract 59A0053. The six task orders include:

- Task Order No. 1 - Initial Site Characterization-Geophysical Surveys Phase with a Notice to Proceed issued January 6, 1998.

- Task Order No. 2 - Project Management and Coordination with a Notice to Proceed issued January 26, 1998.
- Task Order No. 3 - Preliminary Site Exploration and Testing with a Notice to Proceed issued January 26, 1998.
- Task Order No. 4 - Probabilistic Seismic Hazard Analysis Update and Preliminary Site Response Analysis with a Notice to Proceed issued May 19, 1998.
- Task Order No. 5 - Phase 2 and 3 Site Exploration and Characterization with a Notice to Proceed issued July 23, 1998.
- Task Order No. 6 - Pile Installation Demonstration Project Engineering/Monitoring with a Notice to Proceed issued December 23, 1998.

Geophysical surveys were included in Task Order No. 1 and Task Order No. 5. Task Order No. 1 included three phases of geophysical exploration: a two-dimensional (2-D) marine geophysical survey, a three-dimensional (3-D) marine geophysical survey, and a land survey on the east end of Yerba Buena Island. Plate 1.1 shows the approximate boundaries of the original Caltrans survey corridor and the areas covered by the 1998 Phase 1 2-D and 3-D marine geophysical surveys. Task Order No. 5 authorized a high-resolution marine geophysical survey offshore the eastern end of Yerba Buena Island. The survey area is shown on Plate 1.1. Task Order No. 5 also included a multibeam (swath) bathymetric survey along the N6 alignment and around the eastern end of Yerba Buena Island and a tidal-flat bathymetric survey in the area north of the Oakland Mole. These survey areas also are outlined on Plate 1.1. Refer to Fugro-EM (2001a) for more information about specific investigations undertaken in the task orders.

1.1.3 The N6 Alignment and Structures

The N6 alignment as received from TY Lin/M&N (2001) is shown on Plate 1.2, all of the maps, and many of the other plates in this report. The N6 alignment is described in detail in Fugro-EM (2001a).

The N6 alignment structure is understood to include the following features:

- Twin bridge structures carrying separate eastbound and westbound traffic.
- A total width of the corridor for the new structures of about 70 meters. The design of the N6 alignment structure provides for five lanes of traffic in both directions, and a bike path along the eastbound structure.
- An approximately 410-meter-long transition structure extending from the Yerba Buena Island Tunnel to the eastern tip of Yerba Buena Island.

- An approximately 565-meter-long, single-tower, self-anchored suspension cable, Main Span signature structure extending offshore from the tip of Yerba Buena Island.
- An approximately 2.1-kilometer-long, four-frame Skyway structure extending from the signature structure eastward to the Oakland Shore Approach.
- An Oakland Shore Approach structure extending about 700 meters from the Skyway structure to the north side of the Oakland Mole.
- An earthen fill transition from the Oakland Shore Approach structure to the roadways leading to and from the existing bridge.

The Main Span signature structure will be an asymmetrical, self-anchored suspension cable structure. The signature structure will be supported on three piers, with the main pier and tower located west-of-center along the bridge alignment. The three piers are designated as follows: 1) West Pier on Yerba Buena Island, 2) a Pylon (Pier E1) located about 65 meters northeast of Yerba Buena Island, and 3) the East Pier (Pier E2) located about 450 meters northeast of the island. These piers are labeled on the maps and many of the reduced-scale maps that are presented as plates in this report.

The Skyway structure is approximately 2.1-kilometers long and will extend from the Main Span-East Pier to just west of the Oakland Mole. The Skyway structure will include separate, parallel, eastbound and westbound structures. As the Skyway approaches the Oakland Mole, pier height progressively decreases with water depth. Skyway piers will be supported on 2.5-meter-diameter, driven steel pipe piles. It is planned that Skyway Piers E3 through E14 will be supported on six piles each while Piers E15 and E16 will be supported on four piles each.

The marine area of the Oakland Shore Approach structures extends about 300 meters from about Pier E17 through Pier E22. This is an area of very shallow water and is partially onshore. No marine geophysical data were collected in the area of the Oakland Shore Approach structure. All subsurface information from this area is based on geotechnical explorations.

1.2 SUMMARY OF THE MARINE GEOPHYSICAL SURVEYS

1.2.1 1998 Phase 1 2-D Survey

The initial marine geophysical survey was conducted in January 1998. This survey area was designed to provide coverage of the various potential bridge alignments under consideration at the time Task Order 1 was issued. The survey area was extended beyond the Caltrans survey corridor to be able to image sediment units and bedrock on the north and south sides of a mud-filled paleochannel (Plate 1.1). The survey area is approximately 3.75 kilometers wide in an east-west direction, including the western extension into the cove north of Yerba Buena Island. The north-south dimensions of the survey area range from about 400 meters in the cove at the

western end to over 1,700 meters in the central part of the survey area. The area extends up to 500 meters south and 1,200 meters north of the existing SFOBB East Span.

Mobilization for the survey began on January 12 and data acquisition on January 16, 1998. The survey was completed on January 22, 1998, with a 1-day weather delay. Data were acquired from the following systems: a) Differential Global Positioning System (DGPS) for navigation, b) echo sounder, c) side scan sonar, d) CHIRP high-resolution seismic profiler, and e) a 5-cubic-inch sleeve (air) gun. Data from the first four systems were collected on a 50-by-100-meter grid of survey lines. Sleeve-gun data were collected on a 100-meter grid of lines and recorded with a 12-channel cable for post-survey processing.

Detailed information about the 2-D marine geophysical survey is provided in Appendix A, which describes the field operations, instrumentation, QA/QC program, and field data types and formats. Photographs of the operations and equipment are in that appendix.

1.2.2 1998 Phase 1 3-D Survey

The 3-D seismic data acquisition program mobilization began on January 24, 1998. Surveying began on January 31 and continued through February 28, 1998, with the exception of 10 days during which weather and sea state conditions prevented surveying, and 1 day in which equipment failures caused delays. Demobilization was completed on March 4, 1998. The area of the 3-D survey is outlined on Plate 1.1.

Equipment utilized for the 3-D survey consisted of a sophisticated vessel positioning system, an echo sounder and tide gauge, a seismic source array of four air guns, two to four 16-channel seismic hydrophone cables ("streamers"), and a digital recording system. The positioning and tracking equipment consisted of a DGPS supplemented by an inertial motion reference system, the Nautica multitasking navigation line control system, and a FanBeam™ laser tracking system. The system permitted continuous tracking of the position, orientation, velocity, and acceleration vectors of the ship at all times. Tracking buoys were placed on the seismic source and at the end of each streamer, and two magnetic compasses (birds) were placed on each streamer. Those data were integrated with the ship's positioning system data to determine the location of the seismic source and all geophone groups for each shot.

Seismic line spacing was a nominal 12.5 meters with a 6.25-meter interval between shots. This plan was adhered to over most of the survey area, the exceptions being the cove area north of Yerba Buena Island and under the existing bridge, where piers and other obstructions limited the turning radius for northwest-trending lines. In the area of the existing bridge, it was necessary to reduce the number of cables from four to two to minimize the effect of obstructions from the piers and allow more lines to be run between the piers. In the cove area and north of the existing bridge, additional lines were run in a nominal east-west direction to provide coverage in areas where geographic and cultural conditions limited access using northwest-trending lines. A

real-time field binning system was used to determine data coverage over a 6.25-by-6.25-meter grid.

A complete description of field operations, instrumentation, and quality assurance procedures are given in Appendix B. Photographs of the equipment of operations are included in that appendix.

1.2.3 2000 Phase 3 2-D and Bay Cable Survey

The 2000 Phase 3 2-D and bay cable survey was designed to provide detailed stratigraphic and bedrock data in the area around the eastern end of Yerba Buena Island. The area of the survey is shown on Plate 1.1. Data acquisition began on September 7, 2000, and continued through September 12, 2000, without any delays. The primary part of the survey consisted of 74 kilometers (km) of minisparker data collected on a nominal grid of 25 by 50 meters. Data were collected from the following systems: DGPS navigation, echo sounder, and a high-resolution, 24-channel minisparker seismic reflection system. Three bay cables were laid on the Bay floor in the nearshore area to collect bedrock reflections in areas not accessible with a towed cable. Approximately 8 km of data were collected in the nearshore and shoal areas using an analog boomer system with a short cable.

A complete description of field operations, instrumentation, and quality assurance procedures are given in Appendix C. Photographs of the equipment of operations are included in that appendix.

1.3 SUPPLEMENTARY DATA SOURCES USED IN THE ANALYSES OF THE GEOPHYSICAL DATA

1.3.1 Geotechnical Borings

During the 1998 Phase 1 and Phase 2 operations, Fugro-EM drilled and sampled 44 marine borings. The borings were logged in the field by geotechnical engineers and sampled for later laboratory testing and classification. CPT soundings were run in a majority of the borings and velocity data were measured using a suspension logging system. Boring locations are shown on Plate 1.3. There is a concentration of borings in the Main Span-Pylon area and between the Pylon (Pier E1) and the East Pier (Pier E2). One or more borings were completed in the vicinity of each of the remaining N6 piers from Pier E3 through Pier E17.

The marine boring operations are described in Fugro-EM (2001a) and the boring logs and laboratory test data are in the appendices of that report. Data from the borings are summarized in tables in Section 2.0 of this report.

Fugro-EM borings on Yerba Buena Island were drilled from 1998 to 2000. The field operations and boring logs are in Fugro-EM (2000a). Data from these borings are summarized in a table in Section 5.0 of this report.

Caltrans provided marine boring logs from pre-1998 explorations along the existing SFOBB East Span (Caltrans, 1997d) and on Yerba Buena Island (Caltrans, 1997c). These data are summarized in tables in Sections 2.0 and 5.0 of this report, respectively.

1.3.2 Cone Penetration Test (CPT) Soundings

Seventy-seven (77) CPT soundings were run in the Phase 3 investigation. Thirty-three (33) of the CPT soundings were in the area offshore Yerba Buena Island, including the cove north of the island, offshore the Coast Guard Station, and in the area of the temporary support towers for the Main Span construction. The remaining 44 CPT soundings are along the N6 alignment Skyway structure between N6 Pier E7 and the Oakland Mole.

The locations of the CPT soundings are shown on Plate 1.3. The CPT operations and data logs are in Fugro-EM (2001a). Data from the CPT soundings are summarized in tables in Section 2.0 of this report.

1.3.3 Velocity Logs

Compressional wave (P-wave) and shear wave (S-wave) velocity profiles were collected in a majority of the Fugro-EM marine borings. The data were collected by Geovision (1998 and 1999) using a suspension logging system. The velocity logs are in the Geovision reports and in Fugro-EM (1998d and 2001c). Velocity profiles from selected borings are shown on Plates 2.14a to 2.14c in this report.

1.3.4 Multibeam and Tidal Flat Bathymetry Surveys

Two bathymetric surveys were conducted as part of the 2000 Phase 3 investigations. A multibeam (swath) survey was completed along the N6 alignment and the eastern end of Yerba Buena Island. A tidal flat survey was conducted in the shallow water area north of the Oakland Mole. These data were integrated with data collected during the 1998 Phase 1 marine geophysical survey to produce the Bay floor elevation contours shown on Plates 1.1 and 1.2. The final bathymetric data are shown in greater detail on larger scale maps (Maps 1 and 4) in this report. The field operations, instrumentation, and data reduction procedures for the bathymetric surveys are described in Appendix E of this report.

1.4 SUMMARY OF GEOLOGIC UNITS MAPPED IN THE SURVEY AREA

The lithology and other properties of the primary geologic units (sediment horizons and bedrock) that underlie the survey area are summarized in Table 1.1. Lithologic descriptions are

summarized from the boring logs. P-wave and S-wave velocities are from measurements made with suspension logs in most of the marine borings. Shear strengths are from CPT soundings, and laboratory testing of samples are from the borings. The acronyms following the unit names in Table 1.1 are used on the seismic record illustrations accompanying this report.

Detailed descriptions of the sediment and rock units are located in Section 2.5 of this report as well as in Fugro-EM (2001a). Maps of the units are presented in Section 3.0 and are based on interpretations of the seismic reflection data integrated with data from 73 marine borings (Fugro-EM, 2001a; Caltrans, 1997d), and 77 marine cone penetration test (CPT) soundings (Fugro-EM, 2001a). Additional descriptions of the sediment and bedrock units and information on their regional distributions can be found in the literature including Caltrans (1997b), Rogers and Figures (1992), Goldman (1969), and Trask and Rolston (1951). The following paragraphs briefly describe their occurrence in the project area.

1.4.1 Fill and Recent Shoal Sand Near Yerba Buena Island

These sediments are found in the cove area between Yerba Buena Island and Treasure Island and on the southeast side of Yerba Buena Island offshore from the Coast Guard Station. Their presence was identified through a review of historical records and documented by Phase 3 CPT soundings. The shoal sand in the cove area was largely removed by dredging for the construction of Treasure Island. The fill material in the cove area is believed to be primarily Young Bay Mud dredge spoils from the construction of Treasure Island, but may contain dredge spoils from other areas and some natural deposits. The fill is up to 15 meters thick and extends onto the western slope of the present surge channel. The very slow and irregular velocity of the fill distorts the reflections from the lower horizons on the seismic records in the cove.

1.4.2 Young Bay Mud (YBM)

The YBM is fat, very soft to firm marine clay deposited since the end of the last sea level low stand (circa 11,000 years ago). It occurs as the surficial blanket of sediment that covers the majority of the Bay floor between Yerba Buena Island and the Oakland Mole. The YBM also fills a major east-west-trending paleochannel (ancient Temescal Creek) and its tributaries that were cut in the Bay floor during the last sea level low stand. The YBM is 5 to 10 meters thick south of the N6 alignment, but increases rapidly to over 25 meters in the thalweg of the paleochannel. Where the YBM is over 10 meters thick, biogenic gas in the sediment affects the seismic velocity thereby degrading the data and distorting the images of the underlying units. Structural contour and isopach maps of the YBM indicate the paleochannel turned north just east of Yerba Buena Island.

1.4.3 Yerba Buena Island Local Sediments (YBIS)

Sediments encountered in the borings and CPT soundings immediately adjacent to Yerba Buena Island include thin layers of stiff to very stiff silty clay, coarse sand, and gravel that may

have been derived from erosion of the island. The sediments range in thickness from less than 1 meter to over 8 meters, and are overlain by fill at some locations. They may be time equivalent to sediments of the Merritt-Posey-San Antonio (MPSA) Formations and grade laterally into the MPSA.

1.4.4 Merritt-Posey-San Antonio (MPSA) Formations

These sediment units underlie the Young Bay Mud and have been correlated with formations that crop out on the Oakland side of San Francisco Bay (Rogers and Figures, 1992; Rogers and Figures, 1991). The sediments include an upper section of dense to very dense sands (Merritt or Posey Formation) with layers of stiff to very stiff sandy clay, and a lower section of stiff to very stiff clay (San Antonio Formation). The upper sand was eroded, or not deposited, in many areas. The seismic reflection records indicate that individual layers are of limited lateral extent. The sequence generally is no more than 5 to 8 meters thick south of the SFOBB and up to 20 meters thick north of the N6 alignment. Along the N6 alignment, it fills a few channels eroded into the Old Bay Mud and was eroded and channeled prior to the deposition of the Young Bay Mud.

1.4.5 Old Bay Mud/Upper Alameda Marine Sediments (OBM/UAM)

The Old Bay Mud (OBM) and Upper Alameda Marine (UAM) sediments both consist primarily of very stiff to hard, fat clay. The lithology and geotechnical properties of the two units are similar and the boundary between the two was not mapped with the geophysical data. CPT soundings and shear strength data from the borings identified a crust (desiccated layer) between El. -50 to -54 meters that could be traced throughout the project area. This crust is designated as the OBM/UAM boundary on the cross sections contained in the report. Except where eroded by channeling, the top of the OBM is present at about El. -20 to -25 meters. Borings show that the combined nominal 60-meter thickness of the two formations typically includes multiple crust layers with locally higher strength. Geophysical reflectors within the sequence are generally flat lying, frequently discontinuous, and often show evidence of channeling (particularly in the western part of the area off Yerba Buena Island). Although composed primarily of clay, the western part of the UAM sediment sequence includes some sand layers that are more prevalent below about El. -65 meters. Structural contours on the top of the OBM are similar in form to those at the base of the Young Bay Mud.

1.4.6 Upper Alameda Marine Paleochannel Sand (PCst and PCsb, Top and Base)

In the western part of the survey area, the top of a fine to medium very dense sand horizon is found at elevations from El. -70 to El. -76 meters within the Upper Alameda Marine sediments. This horizon was mapped because of its possible impact on pile design and placement for the N6 alignment at Piers E2 (East Pier) to E6. The sand was mapped using Phase 2 borings and 3-D geophysical survey data. The sand appears to have filled a north-south-

trending paleochannel. It is up to 15 meters thick in the center of the paleochannel, 10 meters thick at the East Pier, and thins to the east where it grades into clay.

1.4.7 Lower Alameda Alluvial (LAA) Sediments

The deepest sediments in the survey area are primarily granular and interpreted to correspond to the LAA sediments (Caltrans, 1997a; Rogers and Figures, 1992). They are largely continental in origin compared to the marine origin for the shallower sediment units. The top of the LAA sediments is mapped at elevations ranging from El. -70 meters near the Oakland Mole to El. -85 to El. -90 meters where it onlaps the bedrock slope offshore Yerba Buena Island. The geophysical reflector mapped as the top of LAA sediments is a strong, generally continuous, flat-lying reflector. It correlates with a layer of hard, lean clay in the borings and to a distinct increase in primary and shear wave velocities. Beneath the N6 alignment, the top of LAA sediments slopes gently to the west from El. -75 meters in the east to El. -87 meters west of the Main Span-Pylon. The base of the Lower Alameda Alluvial sediments rests directly on the Franciscan Formation bedrock.

1.4.8 Lower Alameda Alluvial Sand (LAAS)

The top of a medium- to coarse-grained sand layer is found at nominal elevations ranging from El. -92 meters at the Oakland Mole to El. -98 meters beneath N6 alignment Pier E3. The top of this sand and the thickness of the total sediment section above the sand were mapped because of their possible considerations in length and bearing of support piles for the eastern piers of the N6 alignment.

The top of the medium- to coarse-grained sand is 5 to 12 meters below the LAA-clay cap and the sequence is 7 to 20 meters thick. The sequence is overlain by either clays and/or fine-grained sand layers. Lower portions of the sand unit include thin layers of hard clay and silty sand. In the eastern part of the N6 alignment, the sand unit overlies silt and sandy clay. In the western two-thirds of the Skyway structure, the base of the sand rests directly on the weathered top of the Franciscan Formation bedrock.

1.4.9 Franciscan Formation (FF) Bedrock

In the survey area, the Franciscan Formation bedrock consists of sandstone (graywacke) with interbedded siltstone and claystone. It is exposed on Yerba Buena Island and forms a north-trending and plunging buried ridge just east of the island. The bedrock dips steeply to the east (approximately 17 degrees) offshore Yerba Buena Island, reaching depths of El. -90 meters approximately 300 meters east of the island. It then slopes gently to the east to El. -135 meters at the Oakland Mole. On the island and buried ridge, the Franciscan Formation rocks are tightly folded and fractured. Outcrops and core samples range from soft to moderately hard and intensely weathered to fresh.

In the area of the proposed Main Span-Pylon (Pier E1), cores were taken into the bedrock and four zones were recognized based on the degree of weathering present in the samples. Those zones, in descending order, include: 1) rock fragments, 2) intensely weathered bedrock, 3) moderately weathered bedrock, and 4) slightly weathered to fresh bedrock. Boundaries between the various degrees of weathering are generally gradational, but 3-D geophysical survey data were used to map the Top of Bedrock (rock fragments or intensely weathered), Top of Slightly Weathered or Fresh Bedrock, and the thickness of the weathered zone. The weathered bedrock zone is 5 to 10 meters thick at the location of Pier E1.

1.5 PREVIOUS REPORTS AND MAPS FROM THE MARINE GEOPHYSICAL SURVEYS

Previous geophysical reports and maps produced by Fugro-EM include the preliminary report, supplementary report, and final report of the 1998 Phase 1 2-D marine geophysical survey (Fugro-EM, 1998a,b,c) and the draft final report for the 1998 Phase 1 3-D survey (Fugro-EM, 1999). The preliminary findings of the 2000 Phase 3 marine geophysical survey were reported in a memorandum (Fugro-EM, 2000b).

This Final Marine Geophysical Survey report includes the compilation and integration of all the significant data and interpretations presented in the previous reports. The data and interpretations presented in this report supersede all those presented in the previous reports.

Table 1.2 lists all of the maps produced at various scales for the previous preliminary and draft 2-D and 3-D marine geophysical survey reports. Table 1.2 associates maps from the previous reports with the updated versions in this report. Maps that are no longer valid are shaded in the table.

1.6 ORGANIZATION AND CONTENTS OF THE FINAL MARINE GEOPHYSICAL SURVEY REPORT

In addition to the introduction, this report contains four text sections, references, and five appendices. The supporting material includes 120 plates, 8 tables, and 16 maps.

Field operations and instrumentation for the 1998 Phase 1 2-D, 1998 Phase 1 3-D, and 2000 Phase 3 2-D and bay cable marine geophysical surveys are described in Appendices A, B, and C, respectively. Processing procedures for the navigation, bathymetric, and multichannel seismic reflection data are described in Appendix D. Field operations and instrumentation for the 2000 Phase 3 multibeam and tidal flat bathymetric surveys are documented in Appendix E.

Section 2.0 describes the data processing, mapping, and interpretation procedures. Geologic and cultural features commonly seen on the seismic reflection data are described and shown in examples from the 2-D survey records. The mapped sediment and bedrock horizons are discussed with regard to the unit velocities and their characteristic appearances on the seismic

records. The appearances of the sediment units and bedrock on the seismic data are shown on record examples from both the 2-D and 3-D surveys. The KINGDOM Suite 2d/3dPAK, a commercial computer program specifically designed as a seismic data interpretation platform, was used to interpret the seismic data and to integrate the geotechnical database into the interpretation. The program and examples of interpretive products produced by the program are described. The examples, included as plates, are taken from the SFOBB data set and are also used to support the maps and interpretational conclusions discussed in the report. Procedures for integrating the 3-D data volume with velocity data, 2-D seismic lines, and geotechnical boring data are discussed and illustrated with plates. The last subsection of Section 2.0 addresses the precision and accuracy of both the seismic data and geotechnical explorations with respect to the contour maps contained in the report.

Section 3.0 presents the results of the mapping of the sediment units and bedrock. The following 12 large-scale geologic contour maps are included with the report at scales of 1:2000 or 1:5000:

- Structural Contours, Base of Young Bay Mud (Map 5 - 1:5000)
- Isopach of Young Bay Mud (Map 6 - 1:5000)
- Isopach of Merritt-Posey-San Antonio Formations (Map 7 - 1:5000)
- Structural Contours, Near Top of Old Bay Mud (Map 8 - 1:5000)
- Maps of Upper Alameda Marine Paleochannel Sand (Maps 9a, 9b, and 9c - 1:2000)
- Structural Contours, Top of Lower Alameda Alluvial Sediments (Map 10 - 1:5000)
- Structural Contours, Top of Lower Alameda Alluvial Sand (Map 11 - 1:5000)
- Isopach of Sediment Above Lower Alameda Alluvial Sand (Map 12 - 1:5000)
- Regional Structural Contours, Top of Franciscan Formation Bedrock (Map 13 - 1:5000)
- Structural Contours, Top of Franciscan Formation Near Yerba Buena Island (Map 14 - 1:2000)

There are eight structural contour maps (Maps 5, 8, 9a, 9b, 10, 11, 13, and 14) that show the elevations of the tops or bases of the sediment units. Four isopach maps (Maps 6, 7, 9c, and 12) depict the thickness of selected sediment units. Two maps of the Franciscan Formation bedrock depict that surface on both a regional scale and in detail on and around Yerba Buena Island. Discussions regarding the individual maps include the unit geometry, lithology, conditions of deposition, and relation to overlying and underlying units.

Section 4.0 presents detailed descriptions and illustrations of the sediment and bedrock horizons along the N6 alignment. Subsurface cross sections beneath the westbound structures, N6 centerline, and eastbound structures are presented at a scale of 1:2000. The cross sections represent the integrated interpretation of the geotechnical explorations, laboratory tests, and geophysical surveys. The cross sections show the bedrock and sediment unit boundaries, lithology in the borings, shear strength and tip resistance from CPT soundings, and internal

reflectors within the units. The Main Span-Pylon (Pier E1) and East Pier (Pier E2) areas are discussed separately. Bedrock weathering surfaces are mapped in the area of the Pylon and correlated with photographs of rock cores from the geotechnical borings in that area.

Section 5.0 presents the results of the 2000 Phase 3 studies around the northeast end of Yerba Buena Island. The geophysical survey and geotechnical explorations were undertaken to provide additional data that would identify the lithology and geotechnical properties of the sediments and bedrock structure offshore Yerba Buena Island, and enable their correlation with units mapped on the island and farther to the east along the N6 alignment. Historical data are reviewed to document and quantify the effects of the construction of Treasure Island on the Bay floor and subsurface sediments on the north side of Yerba Buena Island. The Franciscan Formation bedrock is mapped on the island and offshore to the north, east, and south of the eastern end of the island. The sediment section in the cove between the islands is tied into the units mapped beneath the N6 alignment and SFOBB with a series of subsurface cross sections. Several high-quality seismic sections illustrate the bedrock and sediment horizons on the southeastern side of the island. All of the data sets are examined with respect to the possibility that shear zones in the bedrock at the eastern end on the island represent Holocene faulting. It is concluded that the Phase 3 offshore data appear to preclude the possibility that the shear zones extend offshore as Holocene faults. No evidence of Holocene faulting in the area of the Main Span-Pylon was detected in the data.

Unit Description	Abbreviations Used on Illustrations	Typical Soil Lithology	Thickness Range (meters)	Vs Range (m/sec)	Vp Range (m/sec)	Typical Range of Undrained Shear Strength (kPa)
Water Column	H2O	Water	1.5 to 30	-	1490	-
Fill (Mud)	Fill	Young Bay Mud dredge spoils, very soft	0 to 16	Not measured	700+/-	1-15
Shoal Sand	Shoal	Recent sand in cove area north of Yerba Buena Island. Mostly removed by dredging.	0 to 3	Not measured	Not measured	-
Young Bay Mud	YBM	Fat clay, very soft to firm, olive gray, with silt and organic pockets, sand seams and partings, occasional gas blisters and shell fragments. Dissolved gas in interstitial waters.	0 to 30	125 to 200	800 to 1,400	4-50
Yerba Buena Island Local Sediments	YBIs	Coarse sand to silty fine sand to silty clay to clay, medium dense to very dense, stiff to very stiff, dark yellowish brown to dark gray, with some gravel.	0 to 8	Not Measured	Not Measured	80-200
Merritt-Posey-San Antonio Formations	MPSA	Merritt-Posey Formations (M-P) – Silty fine sand to fine sand, gray, dense with clay pockets, stiff clay layer.	0 to 20	125 to 500	1,200 to 1,800	-
		San Antonio Formation (Sac) - Lean to fat clay, stiff to very stiff, greenish gray.				60-175
Old Bay Mud/Upper Alameda Marine Sediments (Undifferentiated)	OBM/UAM	Fat clay, very stiff to hard, greenish gray, with interbedded clay and sand, many silt pockets, partings and seams.	0 to 60	200 to 250	1,400 to 1,600	120-250
Upper Alameda Marine Paleochannel Sand	PCst (top) PCsb (bottom)	Fine to medium sand, very dense, dark gray, subangular to subrounded, with clay layers and some gravel.	0 to 15	250 to 500	1,550 to 1,700	-
Lower Alameda Alluvial Sediments	LAA	Lean clay, hard, dark greenish-gray, with sandy silt pockets, partings, and seams.	0 to 65	300 to 500	1,600 to 1,800	Clay cap 225-300
Lower Alameda Alluvial Sands	LAAs	Medium to coarse sand, dense to very dense, olive gray to gray, with interbedded clay and silty fine sand.	0 to 30	375 to 600	1,750 to 2,000	Clay layers 250-400
Franciscan Formation	FF	Sandstone with interbedded siltstone and claystone, dark gray, extremely weathered to fresh, moderately soft to hard. Depth extent of weathering determined only in Main Span-Pylon area.	Not Determined	1,000 to 3,000	2,000 to over 5,500	-

TABLE 1.1

SUMMARY OF GEOLOGIC UNITS MAPPED IN SURVEY AREA

SFOBB East Span Seismic Safety Project

Map Topic	Scale	Report				
		Final Marine Geophysical Survey Report	Draft Final 3-D Marine Geophysical Survey Report (August 1999)	Final 2-D Marine Geophysical Survey Report (June 1998)	Preliminary Summary Report Supplement (June 1998)	Preliminary Marine Geophysical Survey Summary (March 1998)
		Map No.	Map No.	Map No.	Map No.	Map No.
Bathymetry and Geotechnical Data Base Map	1:5000	1	--	--	--	--
1998 2-D Marine Geophysical Survey Shiptrack Map and Cultural Features (with Bathymetry)	1:5000	2	--	**1**	**1 (No culture)**	**1 (1:2000 scale)**
1998 3-D Marine Geophysical Survey Database Map	1:5000	3	**1**	--	**--**	--
2000 Phase 3 2-D Marine Geophysical Survey Shiptrack Map	1:2000	4	--	--	**--**	--
Side Scan Sonar Mosaic	1:2000	--	--	--	--	**2**
Map of Shallow Buried Channels and Extent of Shallow Biogenic Gas Horizon	1:5000	--	--	--	--	**3**
Structural Contours, Base of Young Bay Mud (YBM)	1:5000	5	**2**	**11**	--	--
Isopach (Thickness) of Young Bay Mud	1:5000	6	**3**	**12**	--	--
Isopach (Thickness) of Merritt-Posey-San Antonio Formations (MPSA)	1:5000	7	**4**	**10**	--	--
Structural Contours, Near Top of Old Bay Mud	1:5000	8	**5**	**8**	**7**	--
Isopach (Thickness) of Sediments Above Old Bay Mud (YBM plus MPSA)	1:5000	--	**--**	**9**	**8**	--
Structural Contours, Top of Upper Alameda Paleochannel Sand	1:2000	9a	**6a**	--	--	--
Structural Contours, Base of Upper Alameda Paleochannel Sand	1:2000	9b	**6b**	--	--	--
Isopach (Thickness) of Upper Alameda Paleochannel Sand	1:2000	9c	**6c**	--	--	--
Isopach (Thickness) of Old Bay Mud and Upper Alameda Marine Sediments (Undifferentiated)	1:5000	--	--	**7**	--	--
Structural Contours, Top of Lower Alameda Alluvial Sediments	1:5000	10	**7**	4	4	--
Structural Contours, Top of Lower Alameda Alluvial Sand	1:5000	11	**8**	--	-	--
Isopach (Thickness) of Sediments Above Lower Alameda Alluvial Sediments	1:5000	--	--	**6**	**6**	--
Isopach (Thickness) of Sediment Above Lower Alameda Alluvial Sand	1:5000	12	**9**	--	--	--
Isopach (Thickness) of Lower Alameda Alluvial Sediments	1:5000	--	--	**5**	**5**	--
Regional Structural Contours, Top of Franciscan Formation	1:5000	13	**10**	**2**	**2**	--
Structural Contours, Top of Franciscan Formation, Offshore Eastern Yerba Buena Island	1:2000	14	**11**	**2a (1:1000 scale)**	**2a (1:1000 scale)**	**5 (1:1000 scale)**
Total Sediment Thickness (Isopach) Contours	1:5000	--	--	**3**	**3**	**--**
Total Sediment Isopach Offshore Yerba Buena Island	1:1000	--	--	**3a**	**3a**	**6**

Maps indicated with shading have been superseded or eliminated from further use based on data acquired after the report was issued.

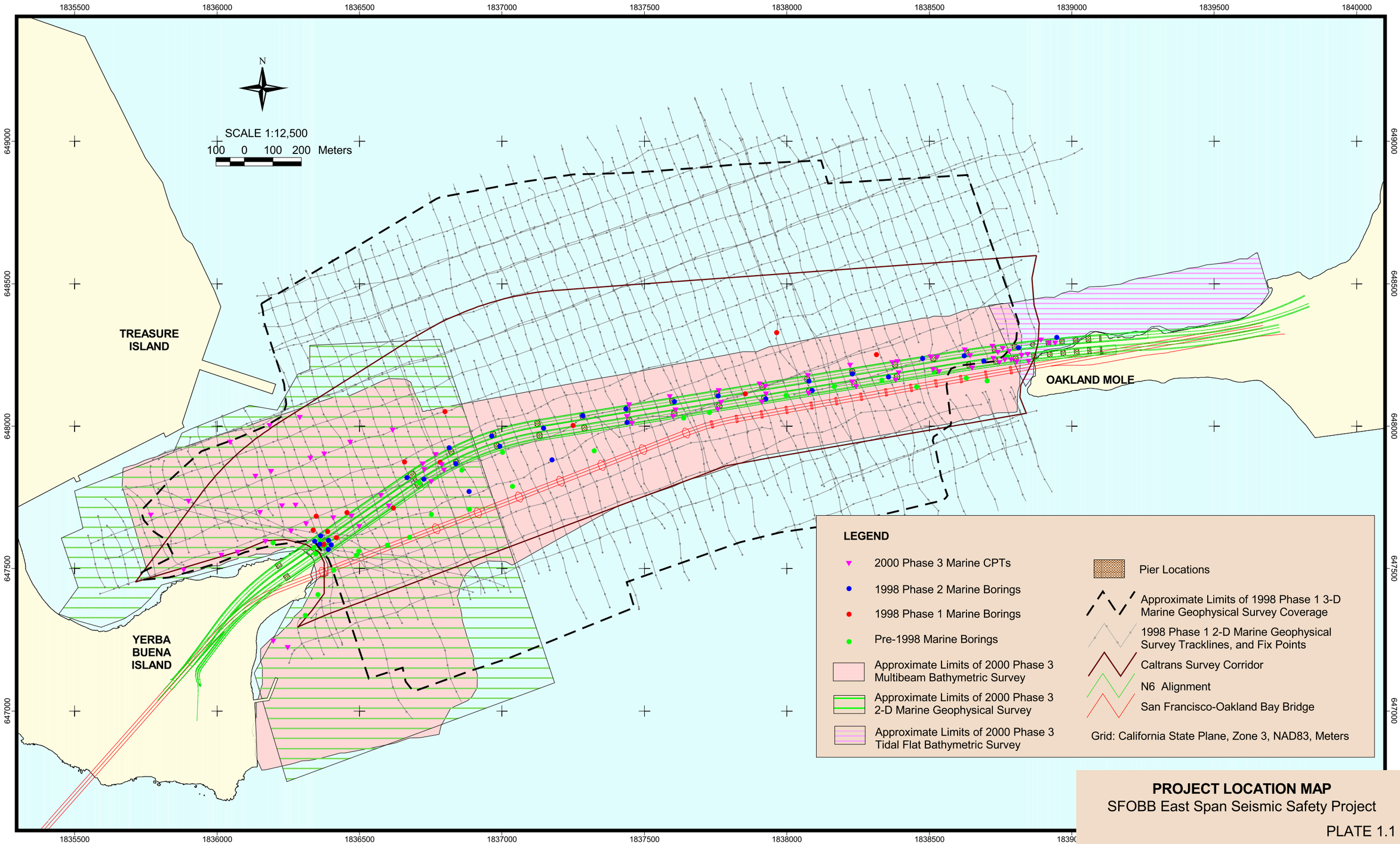
NEW AND PREVIOUS MAPS FROM GEOPHYSICAL SURVEY DATA INTERPRETATIONS

SFOBB East Span Seismic Safety Project

TABLE 1.2

Earth Mechanics

FUGRO



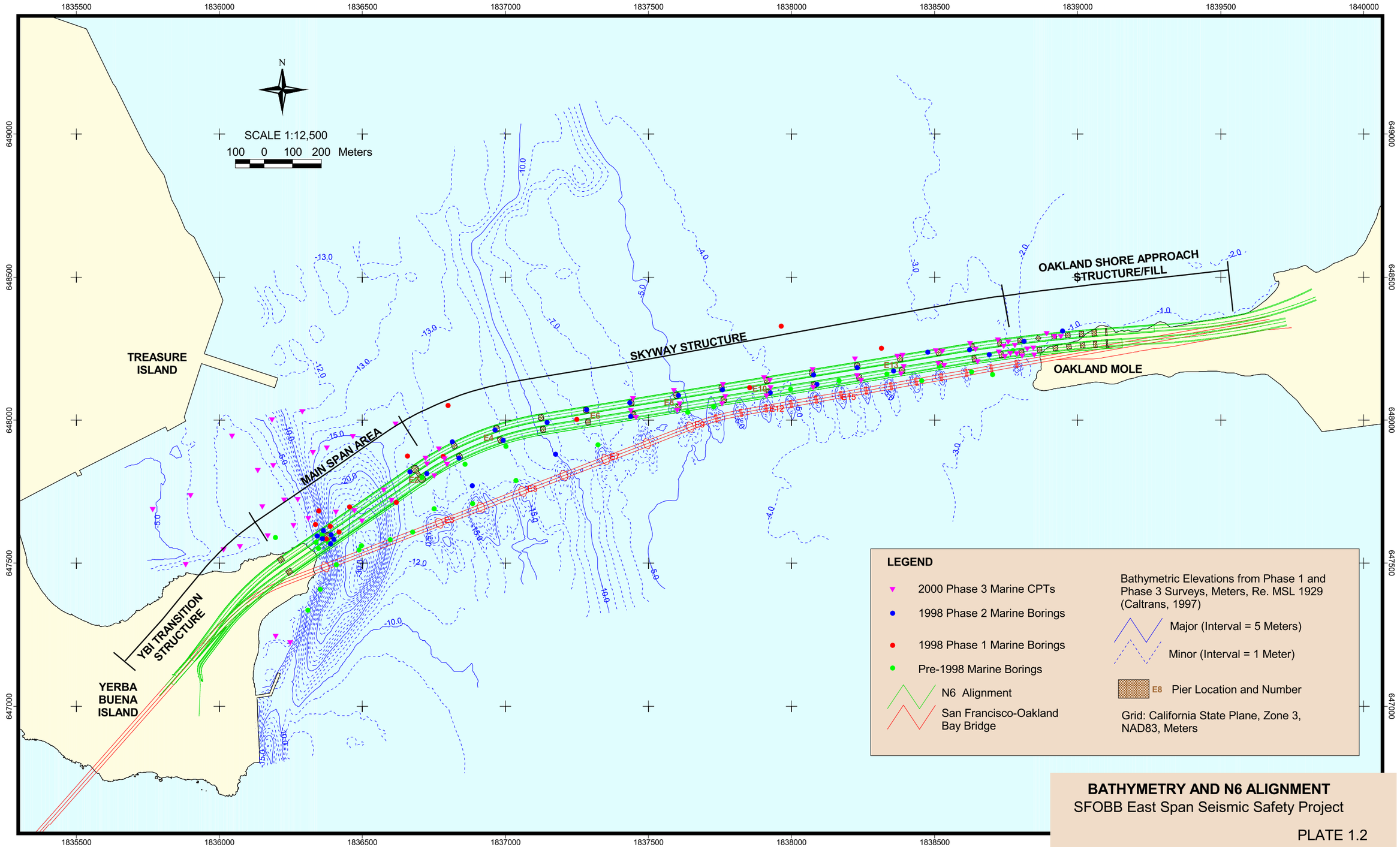
PROJECT LOCATION MAP
SFOBB East Span Seismic Safety Project

PLATE 1.1

j:\caltrans\reports\finalreports\marine_geophys_report_book1\section1\odb\plate1-1.odb, jschneider, 02/28/2001

Earth Mechanics

FUGRO



BATHYMETRY AND N6 ALIGNMENT
SFOBB East Span Seismic Safety Project

PLATE 1.2

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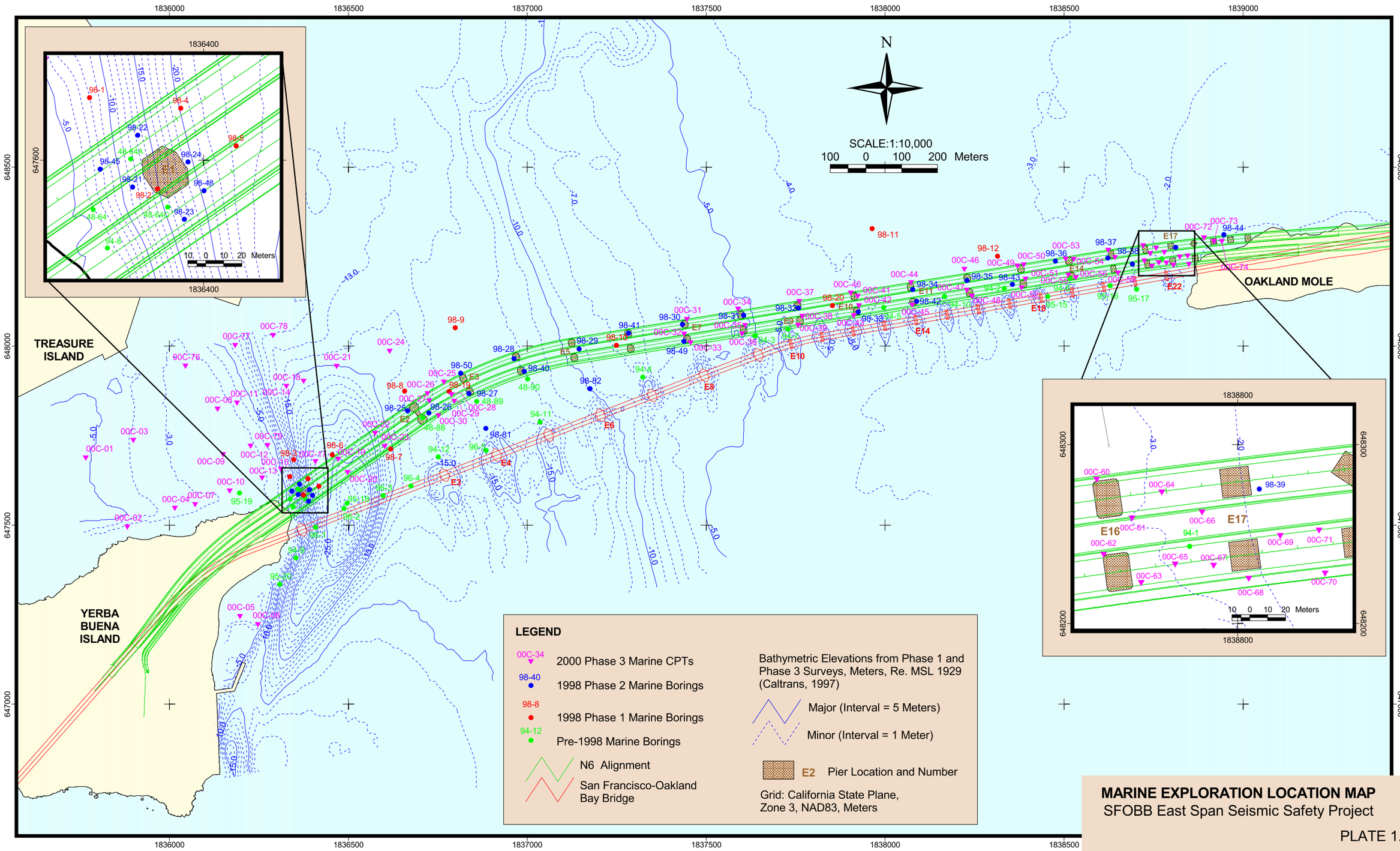
Earth Mechanics

FUGRO



MARINE EXPLORATION LOCATION MAP
SFOBB East Span Seismic Safety Project

PLATE 1.3

SECTION 2.0
DATA PROCESSING, MAPPING, AND INTERPRETATION PROCEDURES

2.0 DATA PROCESSING, MAPPING, AND INTERPRETATION PROCEDURES

2.1 PROJECT DATUMS

The following horizontal and vertical datums and map parameters were used to produce the base maps for the geophysical surveys. Metric units are used on the maps and throughout the report.

Parameters`	Horizontal Datum (Coordinates)	Vertical Datum (Elevations)
Ellipsoid	Geodetic Reference System of 1980 (GRS80)	--
Datum	North American Datum 1983 (NAD83)	MSL 1929 (Caltrans, 1997a); see below
Projection	Lambert California Zone 3	--
Latitude of Origin	36°30′00.00″ N	--
Longitude of Origin	120°30′00.00″ W	--

Note: MSL = mean sea level

The horizontal and vertical datums for the project were initially provided by Caltrans in a memorandum (Caltrans, 1997a). In that memorandum, it is stated that the vertical datum, MSL 1929, is 3.09 feet (0.942 meters) above Mean Lower Low Water (MLLW). This is the vertical datum used by Fugro-EM throughout the project. All water depth or Bay floor depth measurements for the marine work (both geotechnical and geophysical) were corrected for tides using tide gauges installed at Yerba Buena Island. The elevations of the tide gauges were determined by survey with respect to benchmark elevations referenced to MLLW. An adjustment of 0.942 meter was then made to reference the tide gauges to MSL 1929. Elevations of all previous Caltrans geotechnical explorations used in the project were converted from feet referenced to MLLW to meters referenced to MSL 1929 using the value of 0.942 meter as the difference between MLLW and MSL 1929.

An e-mail attachment to the memorandum (Caltrans, 1997a) states that the vertical datum is NGVD 29 (National Geodetic Vertical Datum of 1929). The memorandum implies that NGVD 29 and MSL 1929 are the same reference surface. However, the National Oceanic and Atmospheric Administration (NOAA) indicate on their web site that NGVD 29 is 2.87 feet (0.875 meter) above MLLW at Yerba Buena Island. Thus, there is a potential difference of 0.067 meter (0.942 minus 0.875) between vertical datums depending on which value was used to convert elevations referenced to MLLW to the project vertical datum. This difference is not critical when compared to the accuracy with which either geophysical surveys or geotechnical explorations can determine elevations of mapped geological horizons (see Section 2.6.5).

2.2 BATHYMETRY AND DATABASE MAPS

Four database maps have been prepared to indicate the areal distribution of the marine geophysical and geotechnical data used in this report. Map 1 shows the final bathymetric contours and all of the geotechnical explorations from Phases 1 to 3 as well as the pre-1997 Caltrans explorations. The other three maps show the survey coverage for the three geophysical surveys together with the geotechnical and bathymetric data available at the time the final report for that survey was submitted. Therefore, the bathymetry, geotechnical explorations, and shiptrack lines will vary between the three geophysical survey maps.

2.2.1 Multibeam Bathymetry and Geotechnical Database Map (Map 1)

The final bathymetric survey data and all of the marine geotechnical explorations are shown on Map 1 at a scale of 1:5000 and on Plate 2.1 at a scale of 1:10000. The bathymetric data are referenced to MSL 1929 and contoured at a 0.5-meter interval. The bathymetric data represent an integration of data from three surveys, the 2000 Phase 3 multibeam bathymetric survey (Appendix E), the 1998 Phase 1 2-D survey (Appendix A), and the 2000 Phase 3 tidal flat survey (Appendix E). Plate 1.1 shows the outlines of the three survey areas. The borders of the surveys are also indicated on Map 1 and Plate 2.1.

The marine geotechnical explorations shown on Map 1 include pre-1997 Caltrans borings, 1998 Phase 1 and Phase 2 Fugro-EM borings, and 2000 Phase 3 Fugro-EM CPT soundings.

2.2.2 1998 Phase 1 2-D Survey Shiptrack and Cultural Features Map (Map 2)

Map 2 (Plate 2.2) shows the geophysical survey lines for the 1998 Phase 1 marine geophysical survey conducted in January 1998, Bay floor and buried cultural features, and Bay floor elevations. Details of the survey operations and instrumentation are provided in Appendix A.

High-resolution data were collected using an echo sounder, side scan sonar, and CHIRP subbottom profiler on a nominal 50- by 100-meter grid of lines. Multichannel sleeve-gun data were collected on all of the east-west-trending lines and on the even-numbered, north-south-trending lines forming a 100-by-100-meter grid.

Navigation data were digitally recorded at a 1-second interval (about 1.5-meter interval at a vessel speed of 3 knots) during the field survey. A signal sent to the high-resolution system's analog recorders placed a fix mark on the records at a nominal 50-meter interval for correlation between the ship's position and the records. The positions of these 50-meter fix marks are indicated on Map 2.

The bathymetric elevations shown on Map 2 (Plate 2.2) are from this (2-D) survey and do not include any of the subsequent multibeam or tidal flat data.

The Bay floor and buried cultural features shown on Map 2 (Plate 2.2) are from a variety of sources. Data from several utility tracing surveys conducted by Fugro for Caltrans prior to 1998, as-built maps provided by the owners, and the side scan sonar data collected during this survey were used. The specific data sources are listed on Map 2, but not on Plate 2.2. Table 2.1 provides a summary of the cultural features shown on the map.

The cultural features shown on Map 2 are those that were present in 1998, and the map does not necessarily depict all present-day features. Other Caltrans consultants conducted a separate survey of the Bay floor for the purpose of detecting possible archaeological resources. The results of that survey are not included on Map 2.

2.2.3 1998 Phase 1 3-D Survey Database Map (Map 3)

The 1998 Phase 1 3-D marine geophysical survey was conducted in January and February. Multichannel sleeve-gun data were collected along a series of north-south-trending survey lines spaced at a nominal 12.5-meter interval. Additional lines were run in the east-west direction to increase the coverage along the alignment. 3-D data are processed as a data volume rather than individual lines, and data points are referenced to a bin grid (Appendix D). The bin grid interval was 3.125 meters. 3-D survey operations and instrumentation are described in Appendix B.

Map 3 (Plate 2.3) shows the 3-D survey bin grid, bathymetry of the survey area, and locations of the Caltrans and Fugro-EM Phase 1 and 2 borings. Some of the 3-D data also were processed as 2-D data lines to facilitate the integration with the previous 2-D data set (those shiptrack lines also are indicated on Map 3).

The bathymetry data shown on Map 3 are from the 2-D survey and are identical to that shown on Map 2. Bathymetric data were collected during the 3-D survey and used in the seismic processing, but a new bathymetry map was not produced from that data.

2.2.4 2000 Phase 3 2-D and Bay Cable Database Map (Map 4)

The 2000 Phase 3 marine geophysical survey was conducted offshore the eastern end of Yerba Buena Island. The survey shiptracks are shown on Map 4 (Plate 2.4). Data were collected on a nominal 25-by-50-meter grid using a high-resolution multichannel minisparker system. A few nearshore lines also were run using an analog boomer system. Three bay cable lines were laid out on the Bay floor as indicated by the red lines on the map. Reflection data were collected in the nearshore area by running source lines parallel to the bay cable. Survey operations and instrumentation are described in Appendix C.

The bathymetry shown on Map 4 is from the 2000 Phase 3 multibeam survey (Appendix E). The complete suite of geotechnical explorations (Phases 1 to 3) and Caltrans borings within the offshore area are shown on Map 4. Onshore geophysical and geotechnical exploration locations and the geology of the eastern end of Yerba Buena Island also are shown on Map 4, but the geology is not shown on the reduced-scale Plate 2.4.

2.3 PROCESSING OF MULTICHANNEL SEISMIC DATA

Transylvania Geophysical Corporation of Houston, Texas processed all three sets of multichannel seismic reflection data using the Vista software package. Transylvania is a small seismic processing contractor specializing in processing high-resolution data. All three data sets were different in terms of their data parameters and required slightly different processing routines. A description of the processing of the different data sets is provided in Appendix D, which also includes a glossary of terminology used to describe the various processing steps.

2.4 FEATURES COMMONLY OBSERVED ON THE SEISMIC RECORDS

Copies of both the high-resolution subbottom profile data and the processed 2-D and 3-D multichannel seismic reflection records are used in this report to illustrate the geological and cultural features observed in the data. Annotated records illustrating some of the more common features seen on the records are illustrated and discussed in this section. The illustrated data are from the 1998 Phase 1 2-D survey. The locations of the illustrated data are shown on Plate 2.5.

2.4.1 Bay Floor Topography

Although bathymetric data are usually illustrated as a contour map of bathymetric elevations, the Bay floor (or mudline or sea floor) are also present as reflectors on all seismic reflection records. Since the seismic energy sources are of a lower frequency content than the echo sounders, they will not have the same resolution as the echo sounders insofar as the accuracy to which the mudline reflector can be measured. However, the reflection systems penetrate the sediment units and provide information regarding the origin of the mudline shape and individual features. The high-resolution subbottom profile systems generally provide the best quality images for the analyses of the Bay floor features.

Plate 2.6 is a CHIRP profiler record from a line south of and parallel to SFOBB. It illustrates the scour channel east of Yerba Buena Island, the small-scale irregularities on the eastern side of the scour channel, and the broad plain leading toward the Oakland Mole. The small-scale features (1 to 2 meters high) between fix points 485 and 500 are attributed to slumping of the surficial sediments into the channel and are probably not of a permanent nature. They do not appear on the contour map as they lack the horizontal continuity to be mapped when the data are collected on 50-meter trackline spacing.

Plate 2.6 can be compared to Plate 2.13 that shows the processed multichannel sleeve-gun data along the same line. The vertical and horizontal scales are different on the two records, but the navigation fix points can be used to compare features at the same location. The general shape of the Bay floor is obvious on Plate 2.13, but little detail is apparent. Additional scour features are seen around the bridge piers, and are shown on the bathymetric maps (Plate 2.5) and on the high-resolution records on lines that passed close to the piers (Plate 2.7).

Other features annotated on Plate 2.6 are discussed in the following sections.

2.4.2 Buried Utilities and Other Cultural Features

The cultural features shown on Map 2 and listed in Table 2.1 were mapped from the 1998 Phase 1 side scan sonar data and previous surveys that were specifically designed to trace buried utility lines. Images of the buried features often appear on the high-resolution records. Plate 2.6 shows a reflection from the Oakland sewer outfall that runs parallel to the SFOBB. Plate 2.7 shows diffractions from the PG&E 10-inch gas pipeline at about fix point 727 and SFOBB Pier E15 next to the scour hole at fix point 719. The unlabeled diffraction near fix point 717 is likely from either the MCI or PacBell cables south of SFOBB.

Diffractions from surface or near-surface features are usually not present on the processed multichannel data because the source signal frequency is too low. Also, if they are present in the data, the diffractions should be removed by the processing.

2.4.3 Seismic Data Artifacts

Artifact refers to apparent reflection(s) on the seismic records that are not caused by a direct reflection from a subsurface soil or geologic unit boundary. Features commonly seen on the records from the 3-D survey include multiple reflections of the Bay floor and internal multiples from strong, shallow reflectors (peg legs). In discussions of some of the records in Sections 2.5 and 5.0, mention is made of the difficulty of mapping certain shallow horizons because of interference from the Bay floor multiple reflections.

Multiple reflections were common in the 3-D survey data because the higher energy source produced reverberations especially in the shallow water areas. Reprocessing of the sleeve-gun data using only the six near channels helped reduce, but could not totally eliminate, these effects. An example of multiple reduction from processing is shown in Appendix D.

Peg legs are similar to multiples, but they include an extra leg between two reflectors. Both multiples and peg legs are common on the processed sleeve-gun records, especially in the shallow water areas (Plates 2.8 and 2.13). The multiples and peg legs often approximately coincide with the reflectors from the base of Young Bay Mud and the base of Merritt-Posey-San Antonio Formations. Depending on the relative phases of the two components, they can either locally enhance or interfere with the primary reflectors that are being mapped.

2.4.4 Shallow Gas in the Sediment Section

The majority of the region surveyed for this project has shallow gas in the sediments. This gas is assumed to be biogenic in origin and is dissolved in the interstitial fluid in the sediment. On the 2-D survey data sets (CHIRP subbottom profiler, analog sleeve gun, and processed sleeve-gun records), the gas is shown as areas where bedding reflections become discontinuous, indistinct, or are absent. The gas appears to be primarily derived from within the Young Bay Mud channel-filling sediments, but there are a few places where it was also apparent in the Merritt-Posey-San Antonio sediments.

On the CHIRP data, the gas penetrates the middle of the inferred shallow channels and appears as dark (or "bright") reflections, often with uneven upper limits (Plates 2.6 and 2.7). The acoustic signal is scattered as it enters this section of the data, with the result being a very limited signal penetration. In the area east of Yerba Buena Island and Treasure Island (the western part of the survey area), depths to the top of the shallow gas range from 1.5 to 3.0 meters. Over the central and eastern area to the Oakland Mole, depths to the top of the shallow gas range from 3.0 to over 7.0 meters with the greatest depths coincident with the location of the north-south tributary paleochannel as mapped by Trask and Rolston (1951) southwest of the Oakland Mole.

In the west-central area of the survey, the shallow gas has a distinct signature with an irregular and chaotic appearance where the surface of the gas randomly occurs between 2.0 and 6.0 meters below the seafloor (Plate 2.7). The western extent of the irregular, chaotic zone corresponds to the location of somewhat steeper bathymetry between lines 33 and 37 on Map 2.

Reprocessing of the sleeve-gun records partially overcame the effects of the gas in the upper 20 to 30 meters of the sediments (Appendix D). In the central part of the channel, however, the absorption and scattering of the seismic energy by the gas still obscures or distorts the reflections from the deeper horizons. This is noted on maps of the Top of Lower Alameda Alluvial sediments (Map 10) and Top of Franciscan Formation (Map 13) and prevents mapping the tops of those units in several areas.

The effect of the gas on seismic velocities and associated depth and thickness estimates is discussed in Section 2.6. P-wave velocities in the range of 800 to 1,000 meters per second (m/sec) were noted in the upper 20 to 30 meters of sediment beneath the mudline from the suspension logs in Borings 98-8, 98-9, 98-11, 98-20 (Plate 2.14b) and on many of the records on Plate 2.14c. These velocities are significantly less than the velocity of sound in water (1,460 to 1,500 m/sec, [1,483 m/sec measured during the 2-D survey]). These relatively low velocities will increase reflection times to the deeper horizons making them appear deeper on the seismic records than those in the adjacent areas without the gas.

The P-wave velocity profiles indicate that the base of the low velocity zone lies at or near the base of the Young Bay Mud where it filled channels. The source of the gas may be at or near the base of the Young Bay Mud. The irregular top of the gas horizon (as seen on the CHIRP

records) suggests that it is migrating upward through the Young Bay Mud until it reaches an impermeable horizon. Since permeability of any layer may vary horizontally, the gas remains trapped beneath any given horizon only on a local basis.

2.4.5 Paleochannels

Buried paleochannels have been mapped by the geophysical survey and are illustrated on several plates and maps. They are present throughout the sediment section in the Young Bay Mud, Old Bay Mud, and Upper Alameda Marine sediments. The buried paleochannels include: a) the main channel cut into the top of the Old Bay Mud and filled with Merritt-Posey-San Antonio Formations and Young Bay Mud; b) the ancient Temescal Creek channel (Rogers and Figures, 1991; Goldman, 1969) and its tributaries shown on Maps 5 and 8; and c) numerous unmapped channels within the older formations.

Plates 2.8 and 2.12 show examples of the main Young Bay Mud-filled paleochannel. Plate 2.8 also shows reflections from paleochannel edges within the Old Bay Mud. Nested paleochannels within the Old Bay Mud are also illustrated on the cross sections in Section 4.0 and on plates showing seismic records in Section 5.0. The paleochannel thalwegs in the upper part of the Old Bay Mud often appear directly beneath the thalweg of the main channel filled with Young Bay Mud. Suggestions of minor channels are also seen in the Lower Alameda Alluvial sediments.

However, the lack of continuity and resolution of the individual reflectors at the depths of these units and the increased effect of the gas in the channels usually precludes mapping of individual channel horizons for more than a few hundred meters within these older sediments. One exception is a sand-filled paleochannel in the Upper Alameda Marine sediments that is mapped in the west-central part of the survey area (Section 3.6 and Maps 9a, 9b, and 9c).

Two models were developed for the deposition-channeling sequence in the upper sediment units based on appearances on the seismic records and analyses of geotechnical explorations of the Old Bay Mud, Merritt Sand, and Young Bay Mud. Model 1 (Plate 2.9) suggests that the Merritt Sand would be locally present and draping over the slopes and into the base of the channel. In this sequence, the Merritt Sand would subsequently be eroded, but some remnants should remain in a few slope areas and in the bottoms of the channels.

Model 2 (Plate 2.10) suggests that the Merritt Sand would be largely eroded from the sides of the paleochannel with a minor thickening sand near the edges of the paleochannel. In this model, the paleochannel edges at the top of the Old Bay Mud could lie outside (i.e., farther from the channel thalweg) than those at the base of the Young Bay Mud.

The seismic data suggest that both models are present with regard to the ancient Temescal Creek (the main Young Bay Mud-filled channel) and its tributaries. The seismic record shown on Plate 2.12 trends north to south across the main paleochannel axis. Either

paleochannel sequence model could be interpreted from the data. Since multiple channels are present within the Young Bay Mud, geotechnical data from the center and the flanks of the channel would be needed to confirm the sediment unit present in those areas.

Most of the cross sections developed in Sections 4.0 and 5.0 from the CPT soundings are similar to Model 1, at least on the southern flank of the Temescal Creek channel. Modifications and transitions between the two models are possible.

2.4.6 Stratigraphic Relationships

Plates 2.8, 2.11, 2.12, and 2.13 illustrate various types of stratigraphic relationships that are present in the seismic records. Plate 2.8 shows both shallow and deep paleochannel edges and the relatively horizontal layers of the sediments that filled the channels.

Plate 2.11 illustrates an apparent mound or hill of about 10 to 12 meters relative elevation in the top of the Lower Alameda Alluvial reflector. This mound is also observed on other tracklines in the southeastern part of the survey area. A 5- to 10-meter rise in the elevation of the Top of Lower Alameda Alluvial sediments occurs near the eastern end of the N6 alignment. Based on correlation with borings, the high amplitude reflector west of fix point 1365 at reflection time 0.102 second is the clay cap of the Lower Alameda Alluvial sediments that can be mapped west to the onlap with the Franciscan Formation bedrock (Plate 2.13).

The Top of Lower Alameda Alluvial reflector is flat where it onlaps the bedrock reflector, an indication that any tectonic uplift of the Franciscan Formation either occurred prior to the deposition of the Lower Alameda Alluvial sediments or to the west of the onlap area. Although the reflectors are not as continuous, the onlap of horizons from within the Old Bay Mud and Upper Alameda Marine sediments also is apparent. A minor amount of compaction after deposition of these sediments will lead to an apparent eastward slope in the onlap area.

Similar observations also are possible on the other east-west tracklines south of the existing bridge (Section 5.0). However, the quality of the reflection records from tracklines north of the existing bridge is reduced by gas in the sediment, and similar deductions are not possible from the seismic data in that area alone.

2.4.7 Bedrock Topography

The sloping surface of the Franciscan Formation bedrock is well imaged on the seismic records along the N6 alignment and to the south (Plate 2.13). Maps 13 and 14 are structural contour maps of this surface. Near-vertical steps in the top of the Franciscan Formation bedrock surface are noted on Trackline 103 (Plate 2.13, fix mark 502) as well as on other east-west-trending seismic lines illustrated in Section 5.0. These steps are in the vicinity of the intersection of these tracklines with north-south-trending Trackline 22. This may be an erosional feature

(similar to a wave cut terrace) or it may be an old basement fault. However, on the east-west-trending tracklines, the overlying Pleistocene and Holocene horizons do not appear to be offset.

2.5 SEISMIC IMAGES AND VELOCITY MEASUREMENTS FROM GEOLOGIC UNITS

2.5.1 Velocity Measurements in the Geotechnical Borings

Summary descriptions of the sediment and rock units are provided in Section 1.4 and Table 1.1. In Sections 2.5.2 to 2.5.9, the characteristic appearances of the units on the 2-D and 3-D sleeve-gun seismic survey data are described and illustrated with plates.

Seismic velocities were measured by the suspension log method in most of the 1998 Phase 1 and Phase 2 borings (Geovision, 1998 and 1999) as well as in a few Caltrans borings from 1994 and 1996 (Caltrans, 1997d). Velocities are summarized in Table 1.1 and velocity logs from many borings are annotated with horizon boundaries on Plates 2.14a to 2.14c. The use of the velocity data to identify specific horizons in the borings is discussed for the individual units below. The acronyms used to designate the tops of the sediment and rock units on the plates follow the subtitles. The map locations of the seismic record locations referenced in the following discussions are shown on Plate 2.5 (2-D seismic lines are shown on Plates 2.8 to 2.13) and Plate 2.15 (3-D seismic lines are shown on Plates 2.16 to 2.19).

2.5.2 Fill and Recent Shoal Sand Near Yerba Buena Island

These units occur in the cove area between Yerba Buena Island and Treasure Island. The majority of the shoal sand was apparently dredged for the construction of Treasure Island and the pit refilled with dredge spoils consisting of Young Bay Mud (Section 5.3). There are no borings with velocity measurements in this material. P-wave velocities estimated during the processing of the 2000 Phase 3 seismic reflection data were in the range of 700 to 800 m/sec, or only about one-half the normal value in water and shallow sediments. The fill is up to 15 meters thick and little or no penetration of seismic energy is achieved with the subbottom profilers. However, the multichannel systems are able to image bedrock reflectors through the fill.

2.5.3 Young Bay Mud (YBM)

The Young Bay Mud is a soft, unconsolidated clay deposited since the end of the last sea level low stand (circa 11,000 years ago). In the survey area, YBM fills channels incised into the older deposits and is a thin surficial blanket of sediment over most of the mapped area. In some areas, YBM was mapped using the high-resolution, subbottom profile data collected using the CHIRP system during the 2-D survey. On the CHIRP records (Plate 2.7), YBM appears almost transparent with local, very thin, darker horizontal and subhorizontal reflectors that represent interbeds with an increase in silt or sand content. Edges of paleochannels within the YBM are present; however, the base of the YBM is usually not imaged on the CHIRP records.

Evidence of gas within the Young Bay Mud is seen on both the CHIRP records and the sleeve (air) gun records. This gas has a significant impact on the appearance of the seismic records, signal penetration, and P-wave velocity in the YBM. Marine sediment velocities are usually at or near water velocity (1,483 m/sec for this area in January 1998). However, P-wave velocities in the YBM vary widely, and generally average less than 1,000 m/sec (Plates 2.14a to 2.14c). In areas of thick, gassy mud, penetration of the seismic signal is severely limited and sometimes totally blocked. The low velocity has a pushdown effect on the deeper reflecting horizons that causes apparent sags in otherwise planar reflectors.

The sleeve-gun signal was able to penetrate below the base of the Young Bay Mud in many areas underlain by the gas-saturated layer. It is the upper unit on most of the illustrated 2-D and 3-D sleeve-gun records illustrated in this section. The base of the unit is marked on the seismic records shown on Plates 2.8 and 2.12. On those records, the appearance is of thin horizontal to sub-horizontal layers filling paleochannels and a relatively thin (10- to 20-meter) blanket of horizontal layers on the flanks of the main paleochannel.

2.5.4 Yerba Buena Island Local Sediments (YBIS)

Offshore Yerba Buena Island, several of the borings encountered thin sediment deposits that could not be correlated directly with the sediment units east of the present day bathymetric channel. The sediments consist of clays, sands, and gravels, and are apparently older than the Young Bay Mud as they are locally covered by a thin mud layer. They may be age-equivalent to the Merritt-Posey-San Antonio Formations or younger, and may have been derived from erosion of the island. In Table 2.1, they are classified as Yerba Buena Island local sediments. No velocity measurements were made in these sediments.

2.5.5 Merritt-Posey-San Antonio (MPSA) Formations

Individual horizons from these units are usually not differentiated in the boring data or on the geophysical maps. The unit primarily consists of a thin layer (5 to 9 meters) of estuarine and alluvial sediments that occur between the Young Bay Mud and Old Bay Mud on the flanks of the most recent paleochannels. The upper part of the sediment sequence usually consists of dense to very dense sand (probably of the Merritt and Posey Formations) while the lower part is often the stiff clay of the San Antonio Formation. Outside the geologically Recent paleochannel, the base of the upper sand layer is a near-horizontal surface and is a fairly continuous reflector (Plates 2.8 and 2.12) south of the existing bridge. The top of the unit is less continuous as a reflector, and its appearance on the sleeve-gun records is of a 6- to 12-millisecond-wide negative pulse between two dark bands. The edge of the paleochannel where the upper sand layers have been eroded is quite irregular, but usually quite apparent on the seismic records. P-wave velocities in the Merritt-Posey-San Antonio Formations usually range between 1,200 and 1,800 m/sec, are occasionally irregular, and may be lowered by gas (Plates 2.14a to 2.14c).

2.5.6 Undifferentiated Old Bay Mud (OBM) and Upper Alameda Marine (UAM) Sediments

The Old Bay Mud (Yerba Buena Mud) and Upper Alameda Marine sediments are not differentiated in the seismic data. A crust (desiccated layer) that is quite extensive at El. -50 to El. -53 meters was identified in many of the CPT soundings and borings. In Section 4.0, this crust is attributed to the boundary between the two units. Occasionally the crust is associated with a small velocity increase at those elevations. This increase is observed in Borings 98-11, 98-12, and 98-34 to 98-43 (Plates 2.14b and 2.14c). No distinguishing characteristics of the boundary between the two units have been recognized in the seismic reflection data. Both units consist of a series of very stiff to hard marine clays, silts, and sandy clays. Sand layers are more prevalent toward the base of the Upper Alameda Marine sediments. Rogers and Figures (1992) indicate there was a period of erosion between the end of Alameda time and the beginning of deposition of the Old Bay Mud. This conclusion is based on onshore observations, but the extent of the depositional hiatus that occurred offshore has not been established. However, the existence of the crust would appear to confirm that hiatus.

On the seismic records, the Old Bay Mud and Upper Alameda Marine sediments appear as a series of horizontal layers that can be traced for up to several hundred meters. These layers can be seen in the reflection time range of 30 to 100 milliseconds (ms) (depth range of 20 to 80 meters) (Plates 2.11, 2.12, and 2.13). On the flanks of the paleochannel, the combined units are 50 to 65 meters thick, but thin where they Old Bay Mud has been eroded. The units onlap the Franciscan Formation bedrock (Plates 2.13, 2.16, and 2.19). The P-wave velocity (generally in the range of 1,400 to 1,600 m/sec) increases with depth within the unit (Plates 2.14a to 2.14c). Paleochannels evident in the elevation range of El. -40 to El. -60 meters also suggest a possible change in depositional environment from the Upper Alameda Marine into the Old Bay Mud. Neither the velocity anomaly nor the paleochannels are widely observed. The gas in the Young Bay Mud in the main paleochannel affects the quality of the seismic images of these deeper units north of the N6 alignment.

2.5.7 Upper Alameda Marine Paleochannel Sand (PCst and PCsb)

Both the top (PCst) and base (PCsb) of the sand were mapped from the 3-D data, and an isopach map was produced from the two horizons. The mapping was possible only because of relatively detailed boring control. The sand is not an especially significant reflector compared to others within the unit nor does it have a diagnostic velocity indication. However, on the 3-D seismic records, it is possible to trace a reflector between adjacent borings at the appropriate depths of the top of the sand as indicated in the borings. In the eastern part of the area where it occurs, the sand is thin (less than 4 meters) and appears as a single reflector package (Plate 2.18). In the west, where it onlaps the Franciscan Formation bedrock, the sand is 7 to 15 meters thick and separate reflectors of the top and base can be distinguished (Plate 2.19).

2.5.8 Lower Alameda Alluvial Sediments (LAA) and Sand (LAAS)

Seismic reflection records showing Lower Alameda Alluvial sediments are shown on Plates 2.13, 2.17, and 2.18. The continental deposits are primarily dense to very dense sand layers interbedded with thin, hard clay layers that were deposited directly on the Franciscan Formation bedrock. The Top of Lower Alameda Alluvial Sediments (as mapped by the geophysical data) is a prominent and relatively continuous reflector that slopes gently to the west (Plates 2.11 and 2.13) and onlaps onto the Franciscan Formation bedrock. This reflector correlates with a P-wave velocity increase to the range of 1,600 to 2,000 m/sec (Plates 2.14a to 2.14c), which in turn correlates with a hard, lean clay layer in the boring logs. Within the Lower Alameda Alluvial sediments, most reflectors are relatively thin and discontinuous.

Medium- to coarse-grained sand is observed at approximately El. -92 to El. -96 meters in many of the borings. This sand appears as a more prominent reflector on the 3-D records than on the 2-D records, was mapped over the eastern two-thirds of the survey area, and is shown on seismic sections in Plates 2.17 and 2.18. Neither the top of the Lower Alameda Alluvial Sediments nor the top of the sand could be mapped beneath the gassy sediments in the east-west Young Bay Mud-filled paleochannel.

2.5.9 Franciscan Formation (FF) Bedrock

The reflector at the top of the Franciscan Formation bedrock is shown on Plates 2.13, 2.16, 2.18, 2.19, and several plates in Section 5.0. The bedrock slopes steeply from Yerba Buena Island to an elevation of El. -95 meters, and then gently to El. -135 meters near the Oakland Mole. Outside of the geologically Recent paleochannel, which is filled with the gassy sediments of the Young Bay Mud, this reflector is generally continuous and mappable, although it becomes intermittent beneath the gas zone.

The top of the Franciscan Formation is not a smooth slope and shows indications of erosion or old faulting. These topographic irregularities are local and generally could not be traced any great distances. They are imaged primarily in the area south of SFOBB. Reflections from within the Franciscan Formation are also visible on the records. They are generally parallel or subparallel to the upper surface.

The top of the bedrock is marked by a rapid increase in both P-wave and S-wave velocities even when it is intensely weathered (Plates 2.14a to 2.14c). Where the upper part of the bedrock is fractured, the P-wave velocities are quite irregular, but are generally above 3,500 m/sec (Plate 2.3a). Further descriptions of the bedrock and its seismic characteristics are provided in Sections 4.2 and 5.5.

2.6 DATA INTEGRATION AND MAPPING PROCEDURES

2.6.1 The KINGDOM Suite 2d/3dPAK Seismic Data Interpretation Program

Maps that include survey lines, borehole locations, contours, isopachs, and cross sections were compiled for this report using The KINGDOM Suite 2d/3dPAK Interpretation Program. This versatile program, designed to run in a PC/WINDOWS NT-2000 Operating System, contains all the features necessary to do basic seismic interpretation including: a) horizon, fault, and well management; b) creation of contour maps; c) a map calculator and planimeter; and d) mis-tie analysis.

The KINGDOM Suite handles multiple seismic surveys. Any number of 2-D and 3-D data sets can be loaded and integrated into an interpretation. Arbitrary seismic lines can be constructed and faults, horizons, and grids can span across multiple surveys. Horizon information can be automatically tracked in the map view either along vertical seismic slices or within polygons. Faults can be interpreted along any vertical or time slice, and horizon and fault information can be used to generate contours. Both vertical and deviated well information can be projected into all map and vertical seismic windows, and can be used to compute interval and average velocity maps. This feature was utilized in creating the contour maps and isopachs from the seismic reflection records in time and converting them to isopach maps with thickness in meters and structure contour maps of horizons referenced to elevations.

Seismic, cultural, and well data are easily loaded from standard format files. The KINGDOM Suite is designed to look like a familiar menu-and-toolbar-driven, WINDOWS-like program. The main window supports three sub-windows, which can all be open simultaneously. These are:

- **The Project Tree -** The project tree is designed to look like the familiar WINDOWS Explorer display, and provides a visual and easily accessible listing of all data and interpretation objects that exist in the open KINGDOM Suite project.
- **The Basemap Window -** The basemap window provides a map view of the project data, and can be used to perform certain interpretation processes.
- **The Vertical Seismic Window -** The vertical seismic window allows the user to view and interpret data. It displays trace and projected well data in crossline or inline directions, or as arbitrary lines. Vertical windows are used to view and interpret seismic traces. Well information can be projected onto the vertical seismic slice, and there is no design limit on the number of vertical slices that can be simultaneously open.

Displays from The KINGDOM Suite program are used as illustrations in Sections 2.0, 4.0, and 5.0 of this report. Plates 2.15, 4.3, and 5.3 are examples of the basemap window display. The maps show selected cultural features including shorelines, the existing SFOBB, and

the N6 alignment. The locations of all the geotechnical borings are plotted and labeled. Project (X/Y) coordinates are shown, as are the binning grid lines for the 3-D lines and shiptrack lines for the 2-D surveys (see Appendix D for discussion of 3-D survey bins and other seismic terminology). Coordinate and bin grid intervals for display are selectable as are the scale and area of the basemap window. Active vertical seismic windows also are projected onto the basemap window. The latter feature has been used in Plates 2.15, 4.3, and 5.3 to plot the location seismic sections that are illustrated in the report.

Plates 2.16 through 2.19 are illustrations of vertical seismic windows containing parts of the seismic lines from the 3-D survey. The seismic data illustrated in Section 5.0 on Plates 5.3a to 5.3d and 5.13a to 5.13f are also seismic lines produced as illustrations directly from The KINGDOM Suite program. The appearance is that of a typical 2-D seismic line. The scales, location, length, and orientation of the seismic lines are user selectable as they are constructed from the 3-D data volume. Plates 2.16 to 2.18 are illustrations from 3-D survey lines and crosslines and Plate 2.19 is an arbitrary line constructed at an angle to bin grid as well as the original survey line pattern. Boring data are projected at user set distances onto the seismic sections. Horizons selected from the boring logs are labeled and converted by the program from depths to reflection times using a user-defined velocity model. Once horizons have been traced along seismic reflectors, they are projected onto the vertical seismic sections as shown on Plates 2.16 to 2.19.

Plate 2.20 is a time slice example. It is a map of the reflection amplitudes at a selected reflection time and is shown as an overlay to the active basemap window. Any active mapped horizons that occur at the chosen reflection time for the time slice are also projected onto the time slice. Time slices are used in various ways to map and identify subtle geologic features. (Refer to Sheriff and Geldhart [1995] for further discussion of time slices.) On Plate 2.20, the green line shows the outline of the intersection of the dipping Franciscan Formation bedrock reflector at a reflection time of 80 ms or approximately El. -60 meters. The outline of the buried bedrock structure and its relation to Yerba Buena Island are clearly visible. Assuming a constant velocity model, the green line would represent the El. -60-meter contour of the bedrock surface. Additional time slices are illustrated on Plates 5.5a and 5.5b and discussed in Section 5.2.3.

Plate 2.21 is an example of a colored contour map produced by mapping a horizon using The KINGDOM Suite program. The reflection times are projected onto the base map as they are traced on the vertical seismic sections, and the map is developed as the tracing progresses. On Plate 2.21, the rectangular limits of the map represent the arbitrary limits selected for mapping the top of the Franciscan Formation bedrock using the 3-D survey data. Plate 2.21 shows relative bedrock elevations that were converted from the reflection time map using the velocity model. (Note the elevation contours on the example were subsequently modified with an improved velocity model.) Contours also can be produced as standard contour lines on The KINGDOM Suite displays. However, for the large-scale contour maps based on the 3-D interpretation in this report, the digital bases produced by the interpretation program were

exported to a Geographic Information System (GIS) program (ArcView) and contoured with that program or by hand if additional control was available.

2.6.2 Integration of 2-D and 3-D Seismic Data Sets

The 1998 Phase 1 2-D and 3-D seismic records did not have the same zero time reference since the 2-D data were not corrected to MSL 1929 or processed for use on a seismic workstation. Thus, the 1998 Phase 1 3-D data and 2000 Phase 3 2-D data sets can be integrated through The KINGDOM Suite program, but the 1998 Phase 1 data would need to be reprocessed to be used on the program.

The 3-D data processed into a data volume have, for the same overall data quality, slightly less resolution in the upper horizons than the same lines processed as 2-D lines or lines from 2-D surveys using higher frequency energy sources. However, the 3-D data volume shows reflectors at greater depths and was more effective at penetrating the gas in the Young Bay Mud.

A number of the 3-D lines were also processed as 2-D lines to be able to utilize data where there were problems with the tail buoy tracking system as described in Appendix B. These were primarily the east-west lines shown on Map 3. Additional 3-D lines, primarily the north-south-trending lines on Map 3, were processed as 2-D lines at the same scale to facilitate the integration with the 1998 Phase 1 2-D seismic records. Where only minor revisions in contoured horizons were suggested by the 3-D data and Phase 2 and Phase 3 geotechnical explorations, the 1998 2-D survey lines are shown as the background. Where the horizon mapping was done primarily using the 3-D data volume, the bin grid is shown as the background. The map of Regional Structural Contours on Top of Franciscan Formation (Map 13, Section 3.10) utilized all three sets of seismic data and all three phases of geotechnical explorations.

2.6.3 Depth Conversions

The seismic reflection records show two-way reflection times on the vertical axis. To convert these times to depths, it is necessary to know the velocity of sound in the sediments. The true velocity varies in three dimensions throughout the survey area. It is particularly variable in the shallow sediments due to the presence of gas. The velocity field is not known in sufficient detail and it is necessary to simplify the conversion process based on the available information. The depth conversions are primarily based on the P-wave velocities measured in the pre-1998 Caltrans borings (Caltrans, 1997d) and in the Fugro-EM 1998 Phase 1 and 2 borings (Geovision, 1998 and 1999).

Velocity data from the 1998 borings are plotted on Plates 2.14a to 2.14c. The logs show plots of the S-wave and P-wave velocities for 20 of the offshore borings in which the measurements were made. The elevations at which the various horizons were identified in the borings are superimposed on the logs. Based on those data, average velocities were interpreted

for calculating the depths of the various horizons. The following velocity model was used for Maps 5 through 13:

- Water velocity as measured during the survey (1,483 m/sec)
- Average velocity in Young Bay Mud and Merritt Sand (1,525 m/sec)
- Average velocity to the top of Lower Alameda Alluvial sediments (1,525 m/sec)
- Average velocity to the top of Franciscan Formation:
  - 750 m/sec for fill section where it is present, then
  - if no Lower Alameda Alluvial sediment is present (1,525 m/sec)
  - if up to 15 meters of Lower Alameda Alluvial sediments are present (1,635 m/sec)
  - if >15 meters of Lower Alameda Alluvial sediments are present (1,670 m/sec)

Velocities in the Lower Alameda Alluvial sediments (and in some areas the lower part of the Upper Alameda Marine sediments) range between 1,600 and 1,800 m/sec. The variable velocity model was developed to tie the boring data to the Franciscan Formation reflector in the eastern part of the survey area.

The presence of gas in the sediment lowers the velocity. Velocities in the range of 700 to 1,000 m/sec were noted in the upper 20 to 30 meters of sediments beneath the mudline in Borings 98-8, 98-9, 98-11, and 98-12. This abnormally slow velocity causes a "push-down" effect on the underlying reflectors, thereby causing the reflection time to a given reflector to be greater than it would be if the gas were not present. If the lower velocity is not accounted for (or is underestimated), the increased travel times will result in calculated depths greater than the true depths for horizons below the gas layer.

Horizons were identified and traced on seismic sections (1998 Phase 1 2-D survey) or on vertical seismic windows (1998 Phase 1 3-D survey and 2000 Phase 3 2-D survey). Reflection times were converted to depths from zero time on the seismic record by use of a velocity model that was generally a multiple layer 2-D velocity model. However, spatial velocity variations in the near-surface sediments were included in depth determinations for the Top of Franciscan Formation. The conversion from depths to elevations referenced to the project vertical datum (MSL 1929 [Caltrans, 1997a]) required an additional correction for the value of tides at the time the survey lines were run. This correction was made manually for the Phase 1 2-D survey data and during the data processing for the other two surveys.

The 3-D data were tide corrected during the processing so that the zero time on the vertical seismic windows represented the MSL 1929 datum. Since the water column is part of the recorded time as the horizon is being traced, its effects must be included in the velocity model. By matching reflectors with horizon elevations observed in the borings, it was determined that a single velocity of 1,500 m/sec sufficed for depth and elevation conversions for the 3-D seismic data at or above the top of Lower Alameda Alluvial sediments. Although a more

complex conversion model can be accommodated by the program, it was determined that there was insufficient velocity control to justify its use. For that reason, there may be a mismatch of a few milliseconds between the horizons as drawn through a reflector on the section and the horizon as posted at the boring on the same section.

The particular velocity model used for depth conversions depended on the primary data set (2-D or 3-D) used for the initial mapping of the horizon. Notes on the maps describe the velocity values used for each map.

2.6.4 Integration of Geotechnical and Seismic Data

The process of integration of geotechnical data and the 2-D or 3-D geophysical data is relatively straightforward through use of The KINGDOM Suite program. Boring logs and velocity logs were reviewed with geologists and geotechnical engineers to estimate elevations where unit boundaries occurred in the borings. In many cases, boundaries could be accurately determined based on lithologic descriptions, geotechnical tests, and/or velocity data. Boundaries such as the base of the Young Bay Mud and top of Franciscan Formation are usually easily identified within the sampling interval. However, other boundaries like the top of Lower Alameda Alluvial sediments or between the San Antonio clays and Old Bay Mud are not always so easily recognized, or may be transitional.

The estimated elevations of the boundaries of all the units in a boring or CPT sounding were posted on the logs in The KINGDOM Suite program. A network of arbitrarily oriented seismic vertical windows (seismic sections) was developed that connected three or more borings on each line. By observing specific horizons in borings that did not fall on a reflector common to the horizon in the majority of the other borings, it was possible to recognize mis-ties between geophysical and geotechnical data. Where the mis-ties exceeded what might be expected from variations in seismic velocities, boring logs, and other data, the mis-ties were reviewed to determine their cause. In most cases, this procedure was sufficient to resolve the mis-tie. However, there were some areas in the shallow section, primarily at the boundary between the base of Young Bay Mud and the top of the Merritt-Posey sands, where the resolution of the 3-D seismic data was not adequate or where there was interference from water bottom multiples that masked any reflector that was associated with that unit boundary. Plates 2.16 to 2.19 illustrate the process of identifying reflectors in association with borings and tracing reflectors between borings. Note that the paleochannel slopes at the base of the Young Bay Mud/top of the Merritt-Posey-San Antonio are very subtle reflectors and would require additional, higher resolution data to map. This additional data came from the borings, 2-D seismic data, high-resolution CHIRP records, 3-D lines processed as 2-D lines, and 2000 Phase 3 CPT soundings.

Elevations of the sediment unit boundaries and bedrock elevations were determined from boring lithology, laboratory tests, seismic velocity logs, and CPT soundings. These values are summarized on the following tables:

- Summary of Borings in Main Span-Pylon Area and Offshore Yerba Buena Island - Table 2.2
- Summary of Borings Between Main Span-Pylon and Oakland Mole - Tables 2.3a and 2.3b
- Summary of Phase 3 Cone Penetrometer Data, Main Span Area and Offshore Yerba Buena Island - Table 2.4
- Summary of Phase 3 Cone Penetrometer Data, Skyway Area, Pier E3 to Oakland Mole - Table 2.5
- Summary of Selected Geotechnical Data from Yerba Buena Island - Tables 5.1a and 5.1b

2.6.5 Accuracy of Contours and Values Posted at Geotechnical Explorations

Measured horizon elevations and unit thickness values are posted at the locations of geotechnical explorations on the contour maps and some of the plates that accompany this report. In contrast, the structure contours are based on depth conversions of seismic reflectors that are mapped in reflection time, not depth. The isopach contours are based on the difference between two structural contour maps. The contours and posted values usually agree within the contour interval, but at times differ by several meters. These differences exist because of the limitations in precision and accuracy in identifying unit boundaries in the two different data sets (seismic reflection and geotechnical explorations). It should also be stated that the geotechnical criteria used to establish a sediment unit boundary will not always result in a seismic energy reflection and that strong reflections may arise from property changes that are not significant in the geotechnical classification of the sediments. Those reflections most easily recognized on the seismic records usually arise from a relatively large velocity change across the boundary and reflect changes in the orientation of internal layers between the two units.

The elevations of the tops of sediment units and bedrock in the geotechnical explorations are stated to the nearest 0.1 meter in the tables in this report and are rounded off to the nearest 1 meter when posted on the maps. If these elevations are determined from CPT soundings (a large number of the borings also have CPT data), this value of 0.1 meter represents the relative precision with which a depth point on the sounding curve can be determined. However, the accuracy of the elevation for that horizon at that specific location in San Francisco Bay depends on a number of other factors and measurements including:

- The accuracy of the horizontal location of the exploration
- The accuracy with which the mudline was measured
- The accuracy of the tide correction

- The accuracy of the association of "zero depth" on the measurement device with the mudline
- The correct association of the lithologic or geotechnical property criteria changes with a specific sediment unit

Under normal sea state conditions, the first four items listed above can all be determined within a meter or better. However, their combined effect may be greater than a meter. A comparison was made between reported mudline elevations for the 1948 to 1999 geotechnical borings and the elevations at the boring locations determined in the 2000 Phase 3 multibeam Bay floor survey. The mudline elevations reported for the borings agreed to within 0.5 meter with those from the multibeam survey for the majority of the borings. However, variations of 2 to 5 meters between the two data sets occurred at six mostly pre-1998 borings. It could not be determined if these differences resulted from post-boring mudline changes, errors in establishing the mudline at the time of the boring, or errors in mapping the bathymetry. However, almost all of those borings were located offshore Yerba Buena Island where significant changes in bathymetry occur over relatively short distances.

The precision with which the time of seismic reflectors from multichannel systems can be determined is less than that of the CPT systems. For the seismic systems, it depends in part on the frequency content of the seismic energy source and that of the resulting reflections. For the 2-D surveys, reflector times can be measured using The KINGDOM Suite to within ±1 ms; for the 3-D data that had a lower frequency energy source, that precision is reduced to ±1.5 ms. These times translate to ±0.75 meter and ±1.1 meters, respectively, when converted to depths using a velocity of 1,500 m/sec. If the data quality is marginal and the reflection peak or trough not sharp, then the values stated above may double.

The accuracy of a depth estimate at a given point on a seismic record is also subject to the same five factors listed above for the geotechnical borings. Therefore, while the relative accuracy of the contours based on seismic reflection data may be within ±2 meters, the absolute accuracy may vary across a given map. There is also an effect on the accuracy resulting from any smoothing during the contouring process whether the data being contoured are based on explorations or seismic data.

Based on the above discussions, the absolute accuracy of a contour map should be assumed to be no better than one-half the contour interval, although the relative accuracy of the surface may be somewhat better. If there is a discrepancy between a posted value at a geotechnical exploration and the adjacent contour line, the geotechnical exploration should be accepted as the more accurate value.

Feature	Approximate Location on Map 2[1]	Comment
Linear side scan sonar target	L103 between L33-35	Source unknown
Coarse bay floor sediment	L103 at L22	Source unknown
Sewer diffuser	L102-103 between L30-35	Linear side scan sonar target
Sewer outfall pipe	L102-103 between L35-68	Buried
Pacific Bell cable	L101-102 between L18-68	Buried
Submerged pier ruins	L101-103 between L37-43	
Platforms	L101-102 between L44- L45	
Pacific Bell and MCI cables	L101 between L18-68	Buried
Linear side scan sonar targets	L101 at L18	Possible cable trenches or berms
Dolphins – Yerba Buena Island Area	L101 west of L18	Near SFOBB Pier E2
Dolphins – Oakland Mole Area	L68 between L103-104	At southwest end of Mole
Small side scan sonar targets	L100B between L38-39	Source unknown
Navy cable	Between Treasure Island and Yerba Buena Island	Runs across cove
PG&E cables 3 and 6	From Treasure Island at L95 SE to Mole	Buried
Small side scan sonar targets	L100B between L38-46	Possible cable trenches or berms
Coarse bay floor sediment	L98 at L25	Source unknown
Scour holes along SFOBB at piers	Piers E2 to E19	See Map 1 for detailed bathymetry
Linear side scan sonar targets	L101-L102 between L26-L43	Possible cable trenches or berms
Linear side scan sonar target	L99 between L44-L48	Possible cable trench or berm
Navy power cable	L91 at L21 SE to Mole	Locally scoured
PG&E 10-Inch gas pipeline	L91 at L21 SE to Mole	Locally scoured
AT&T fiber optic cable	North of L91 SE to L71 at L100	
PG&E warning sign	L95 at L49	
Unknown utility	North of L91 SE to L75 at L96	Buried

[1] Location refers to seismic line designations on the map.

CULTURAL FEATURES SHOWN ON MAP 2 AND PLATE 2.2

SFOBB East Span Seismic Safety Project

Boring	Mudline Elevation	Isopach of Fill	Base of Fill	Young Bay Mud Isopach	Base of Young Bay Mud	Top of Yerba Buena Island Local Sediments	Yerba Buena Island Local Sediments Isopach	Top of Merritt-Posey-San Antonio Sediments	Merritt-Posey-San Antonio Sediments Isopach	Near Top of Old Bay Mud	Old Bay Mud/Upper Alameda Marine Sediments Isopach	Top of Intensely Weathered Franciscan Formation	Top of Slightly Weathered/ Fresh Franciscan Formation	Weathered Franciscan Formation Isopach	Completion Elevation
	Map 1	No Map	No Ma	Map 6	Map 5	No Map	Posted on Map 7	No Map	Map 7	Map 8	No Map	Plate 4.7	Plate 4.8	Plate 4.9	No Map
48-64	-8.6	NP	NP	NP	NP	-8.6	2.4	NP	NP	NP	NP	-11.0	-17.5	6.5	-17.8
48-64A	-16.8	0.8	-17.6	NP	NP	NP	NP	NP	NP	NP	NP	-17.6	NR	NR	-17.6
48-64C	-17.0	0.5	-17.5	NP	NP	NP	NP	NP	NP	NP	NP	-17.5	NR	NR	-17.5
94-8	-10.6	NP	NP	NP	NP	-10.6	2.1	NP	NP	NP	NP	-12.7	-20.8	13.2	-58.3
94-9	-12.0	NP	NP	NP	NP	-12.0	1.5	NP	NP	NP	NP	-13.5	-18.9	5.4	-57.1
95-19	-3.1	7.4	10.5	NP	NP	-10.5	6.1	NP	NP	NP	NP	-17.1	-28.0	10.9	-31.8
95-20	-6.5	7.3	-13.8	NP	NP	-13.8	1.5	NP	NP	NP	NP	-14.6	-20.7	6.1	-30.6
96-1	-15.0	3.5	-21.5	NP	NP	-21.5	4.0	NP	NP	-25.5	1.0	-26.5	-32.6	6.1	-38.0
98-1	-5.9	8.2	-14.2	NP	NP	-14.2	2.2	NP	NP	NP	NP	-16.4	-23.6	7.2	-51.6
98-2	-14.9	1.8	-16.7	NP	NP	NP	NP	NP	NP	NP	NP	-16.7	-25.0	8.3	-68.2
98-3	-11.9	3.5	-15.4	2.9	-18.3	-18.3	11.0	NP	NP	NP	NP	-29.3	-34.0	4.7	-61.3
98-4	-19.8	NP	NP	0.8	-20.6	-20.6	5.2	NP	NP	NP	NP	-25.8	-34.0	8.2	-89.3
98-5	-23.2	NP	NP	0.9	-24.1	NP	NP	-24.1	2.1	-26.2	10.7	-36.9	-44.0	7.1	-68.3
98-21	-10.3	4.4	-14.7	NP	NP	NP	NP	NP	NP	NP	NP	-14.7	-19.8	5.1	-51.9
98-22	-12.5	4.7	-17.2	NP	NP	NP	NP	NP	NP	NP	NP	-17.2	-26.5	9.3	-62.5
98-23	-16.8	0.9	-17.7	NP	NP	NP	NP	NP	NP	NP	NP	-17.7	-25.0	7.3	-62.5
98-24	-19.5	1.0	-20.5	NP	NP	NP	NP	NP	NP	NP	NP	-20.5	-32.5	12.0	-44.6
98-45	-6.9	5.5	-12.4	NP	NP	-12.4	3.8	NP	NP	NP	NP	-16.2	NR	NR	-17.0
98-48	-20.0	NP	NP	NP	NP	-20.0	0.9	NP	NP	NP	NP	-20.9	-29.1	8.2	-33.8

NOTES:
1) All values in meters; elevations are referenced to MSL 1929 (Caltrans, 1997a)
2) NP = Unit not present in boring; NR = Unit/Surface not reached in boring.
3) Horizon elevations based on analysis of boring lithology, geotechnical tests, velocity data, and seismic reflection records.

Earth Mechanics

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TABLE 2.2

SUMMARY OF BORINGS IN AREA OF MAIN SPAN-PYLON AND OFFSHORE YERBA BUENA ISLAND

SFOBB East Span Seismic Safety Project

I:\WP2001\1998-0050\98-0054\GEOPHYSICAL SUMM\FINALIZEDWORDTBLS\4-TABLE 2_2.MAR.DOC

Boring	Mudline Elevation	Young Bay Mud Isopach	Base of Young Bay Mud	Top of Merritt-Posey-San Antonio Sediments	Merritt-Posey-San Antonio Sediments Isopach	Near Top of Old Bay Mud	Top of Upper Alameda Marine Sediments Paleochannel Sand	Bottom of Upper Alameda Marine Sediments Paleochannel Sand	Upper Alameda Marine Sediments Paleochannel Sand Isopach	Top of Lower Alameda Alluvial Sediments	Top of Medium to Coarse Sand in Lower Alameda Alluvial Sediments	Isopach of Sediments Above Medium to Coarse Sand in Lower Alameda Alluvial Sediments	Top of Franciscan Formation	Completion Elevation
	Map 1	Map 6	Map 5	No Map	Map 7	Map 8	Map 9a	Map 9b	Map 9c	Map 10	Map 11	Map 12	Map 13	No Map
48-88	-12.6	16.0	-28.6	-28.6	9.5	-38.1	-70.8	-81.6	10.80	-85.6	NP	NP	-97.0	-97.0
48-89	-12.6	6.4	-19.0	-19.0	8.8	-27.8	-70.5	-74.1	3.6	NR	NR	NR	NR	-76.7
48-90	-12.1	3.0	-15.1	-15.1	7.5	-22.6	-70.0	-75.1	5.1	NR	NR	NR	NR	-78.0
94-1	-2.2	12.0	-14.2	-14.2	8.0	-22.2	NP	NP	NP	-76.6	-91.9	89.3	-135.1	-169.0
94-2	-3.5	13.0	-16.5	-16.5	5.0	-21.5	NP	NP	NP	-80.3	-91.9	88.4	-127.0	-165.0
94-3	-5.5	11.6	-17.1	-17.1	3.0	-20.1	NP	NP	NP	-82.9	-94.2	88.7	-110.6	-147.0
94-4	-8.7	5.5	-14.2	-14.2	7.3	--21.5	NP	NP	NP	-84.3	-93.5	84.8	-109.6	-144.0
94-5	-4.7	11.8	-16.5	-16.5	8.0	-24.5	NP	NP	NP	-83.9	-92.5	87.8	-119.9	-134.5
94-6	-3.7	9.1	-12.8	-12.8	NR	NR	NR	NR	NR	NR	NR	NR	NR	-20.2
94-7	-6.5	12.2	-18.7	-18.7	7.3	-26.0	NP	NP	NP	-88.8	-93.0	86.5	NR	-109.8
94-10	-4.0	9.1	-13.1	-13.1	9.1	-22.2	NR	NR	NR	NR	NR	NR	NR	-54.4
94-11	-13.5	2.7	-16.2	-16.2	5.8	-22.0	-70.6	-75.9	5.3	-87.3	-95.2	81.7	-104.5	-142.2
94-12	-12.9	8.8	-21.7	-21.7	6.7	-28.4	-68.0	-78.5	10.5	-87.9	-92.4	79.5	-94.0	-112.0
95-15	-5.6	6.0	-11.6	-11.6	4.7	-16.3	NR	NR	NR	NR	NR	NR	NR	-18.7
95-16	-4.3	3.0	-7.3	-7.3	NR	NR	NR	NR	NR	NR	NR	NR	NR	-18.4
95-17	-4.7	5.0	-9.7	-9.7	5.7	-15.4	NR	NR	NR	NR	NR	NR	NR	-18.4
95-18	-28.0	5.0	-33.0	-33.0	3.2	-36.2	NP	NP	NP	NP	NP	NP	-58.3	-68.0
96-2	-26.5	NP	NP	-26.5	6.4	-32.9	NP	NP	NP	NP	NP	NP	-53.0	-67.5
96-3	-17.5	5.5	-23.0	-23.0	6.5	-29.5	-73.4	-79.7	6.3	NP	NP	NP	-79.7	-92.5
96-4	-13.4	8.8	-22.2	-22.2	7.3	-29.5	-72.7	-86.1	13.4	-86.3	-87.9	74.5	-97.9	-112.5
96-5	-16.0	3.4	-19.4	-19.4	9.1	-28.5	-70.2	-77.6	7.4	-89.8	-95.0	79.0	-102.4	-117.0
98-6	-24.4	1.8	-26.2	-26.2	2.2	-28.4	NP	NP	NP	NP	NP	NP	-59.3	0.0
98-7	-15.5	10.1	-25.6	-25.6	5.9	-31.5	-70.4	-85.6	15.2	-85.6	-90.5	75.0	-95.4	-119.7
98-8	-13.4	20.0	-33.4	-33.4	6.5	-39.9	-71.9	-84.4	12.5	-86.6	NP	NP	-97.5	-126.8
98-9	-12.8	24.7	-37.5	-37.5	7.9	-45.4	-69.4	-73.9	4.5	-90.8	-95.7	82.9	-103.0	-119.8
98-10	-7.6	13.4	-21.0	-21.0	11.1	-32.1	-69.6	-72.1	2.5	-85.6	-91.4	83.8	-109.4	-132.6
98-11	-3.6	26.4	-30.0	-30.0	9.0	-39.0	NP	NP	NP	-83.2	-91.5	87.9	-124.3	-142.4

NOTES:
1) All values in meters; elevations are referenced to NGVD 29 (MSL).
2) NP = Unit not present in boring; NR = Unit/Surface not reached in boring.
3) Horizon elevations based on analysis of boring lithology, geotechnical tests, velocity data, and seismic reflection records

TABLE 2.3a

SUMMARY OF BORINGS BETWEEN MAIN SPAN-PYLON AND OAKLAND MOLE

SFOBB East Span Seismic Safety Project

Earth Mechanics

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I:\WG2001\1998-005098-005AGEO\PHYSICAL SUMM\FINALIZED\WORD\TBLS\4-TABLE 2_3A.MAR.DOC

Boring	Mudline Elevation	Young Bay Mud Isopach	Base of Young Bay Mud	Top of Merritt-Posey-San Antonio Sediments	Merritt-Posey-San Antonio Sediments Isopach	Near Top of Old Bay Mud	Top of Upper Alameda Marine Sediments Paleochannel Sand	Bottom of Upper Alameda Marine Sediments Paleochannel Sand	Upper Alameda Marine Sediments Paleochannel Sand Isopach	Top of Lower Alameda Alluvial Sediments	Top of Medium to Coarse Sand in Lower Alameda Alluvial Sediments	Isopach of Sediments above Medium to Coarse Sand in Lower Alameda Alluvial Sediments	Top of Franciscan Formation	Completion Elevation
	Map 1	Map 6	Map 5	No Map	Map 7	Map 8	Map 9a	Map 9b	Map 9c	Map 10	Map 11	Map 12	Map 13	No Map
98-12	-3.7	16.8	-20.5	NP	NP	-20.5	NP	NP	NP	-79.2	-91.8	88.1	-128.4	-145.1
98-19	-12.8	15.2	-28.0	-28.0	9.8	-37.8	NR	NR	NR	NR	NR	NR	NR	-50.3
98-20	-4.0	15.0	-19.0	-19.0	4.0	-23.0	NP	NP	NP	-83.9	-92.4	88.4	NR	-94.8
98-25	-12.7	14.6	-27.3	-27.3	8.7	-36.0	-71.5	-86.3	14.8	-86.3	NP	NP	-95.9	-96.7
98-26	-12.7	16.5	-29.2	-29.2	7.0	-36.2	-71.7	-84.1	12.4	-87.7	NP	NP	-95.0	-95.5
98-27	-12.6	10.2	-22.8	-22.8	10.4	-33.2	-72.6	-75.4	2.8	-87.9	-96.0	83.4	-103.4	-103.6
98-28	-12.2	10.1	-22.3	-22.3	5.1	-27.4	NP	NP	NP	-86.3	-94.2	82.0	NR	-99.9
98-29	-9.8	14.0	-23.8	-23.8	2.5	-26.3	-69.5	-74.8	5.3	-87.5	-94.2	84.4	NR	-104.7
98-30	-6.0	29.0	-35.0	-35.0	7.3	-42.3	NP	NP	NP	-85.2	-90.6	84.6	NR	-105.6
98-31	-5.3	19	-24.3	-24.3	7.0	-31.3	NP	NP	NP	-85.2	-91.9	86.6	NR	-104.5
98-32	-4.0	15.0	-19.0	-19.0	7.5	-26.5	NP	NP	NP	-85.4	-93.0	89.0	NR	-99.8
98-33	-3.8	12.5	-16.3	-16.3	5.3	-21.6	NP	NP	NP	-83.8	-93.2	89.4	NR	-104.1
98-34	-3.8	11.9	-15.7	-15.7	6.1	-21.8	NP	NP	NP	-82.6	-93.4	89.6	NR	-103.0
98-35	-3.6	9.8	-13.4	-13.4	10.0	-23.4	NP	NP	NP	-80.5	-92.9	89.3	NR	-107.9
98-36	-3.0	12.0	-15.0	-15.0	9.6	-24.6	NP	NP	NP	-76.5	-91.2	88.2	NR	-106.9
98-37	-3.4	10.2	-13.6	-13.6	7.4	-21.0	NP	NP	NP	-76.4	-94.9	92.0	NR	-102.6
98-38	-3.4	11.9	-15.3	-15.3	4.1	-19.4	NP	NP	NP	-74.9	-90.7	87.3	NR	-107.6
98-39	-2.0	8.8	-10.8	-10.8	10.1	-20.9	NP	NP	NP	-78.5	-91.0	89.0	NR	-106.2
98-40	-12.0	5.5	-17.5	-17.5	5.8	-23.3	-65.9	-71.9	6.0	-85.8	-94.0	82.0	NR	-103.0
98-41	-7.6	20.1	-27.7	-27.7	7.0	-34.7	-68.3	-78.3	10.0	-85.3	-91.7	84.1	NR	-105.3
98-42	-3.9	10.8	-14.7	-14.7	9.8	-24.5	NP	NP	NP	-82.8	-90.8	86.9	NR	-103.1
98-43	-3.4	13.7	-17.1	-17.1	3.2	-20.3	NP	NP	NP	-78.1	-91.4	88.0	NR	-98.3
98-44	-0.9	10.1	-11.0	-11.0	10.0	-21.0	NP	NP	NP	-77.1	-92.3	91.4	NR	-100.9
98-49	-6.2	25.3	-31.5	-31.5	16.6	-48.1	NP	NP	NP	-84.7	-92.8	86.6	NR	-101.7
98-50	-12.3	16.3	-28.6	-28.6	6.0	-34.6	-70.2	-77.2	7.0	-86.8	-97.9	85.6	NR	-101.9
98-81	-12.3	7.3	-19.6	-19.6	7.0	-26.6	-67.2	-73.7	6.5	-90.3	-95.5	83.2	-101.3	-102.1
98-82	-9.8	5.0	-14.8	-14.8	7.8	-22.6	-67.7	-74.3	6.6	-86.0	-95.6	85.8	NR	-106.0

NOTES:
1) All values in meters; elevations are referenced to NGVD 29 (MSL).
2) NP = Unit not present in boring; NR = Unit/Surface not reached in boring.
3) Horizon elevations based on analysis of boring lithology, geotechnical tests, velocity data, and seismic reflection records

TABLE 2.3b

SUMMARY OF BORINGS BETWEEN MAIN SPAN-PYLON AND OAKLAND MOLE

SFOBB East Span Seismic Safety Project

Earth Mechanics

FUGRO

I:\WP2001\1998-0050\98-0054\GEOPHYSICAL SUMM\FINALIZEDWORDTBLS\4-TABLE 2_3B.MAR.DOC

CPT Sounding	Mudline Elevation	Top of Fill	Fill Isopach	Base of Fill	Top of Shoal Sand	Shoal Sand Isopach	Base of Shoal Sand	Top of Young Bay Mud	Young Bay Mud Isopach	Base of Young Bay Mud	Top of Yerba Buena Island Sediments	Yerba Buena Island Sediments Isopach	Base of Yerba Buena Island Sediment	Top of Merritt-Posey-San Antonio Sediments	Merritt-Posey-San Antonio Sediments Isopach	Base of Merritt-Posey-San Antonio Sediments	Near Top of Old Bay Mud	Base of Old Bay Mud	Top of Upper Alameda Marine Sediments	Top Franciscan Formation	Completion Elevation
	Map 1	No Map	Plate 5.9	No Map	No Map	No Map	No Map	No Map	Map 6	Map 5	No Map	Map 7	No Map	No Map	Map 7	No Map	Map 8	No Map	No Map	Map 14	No Map
00C-01	-5.2	-5.2	12.5	-17.7	NP	NP	NP	NP	NP	NP	-17.7	6.5	-24.0	NP	NP	NP	-24.0	NR	NR	NR	-48.3
00C-02	-2.6	-2.6	2.7	-5.3	NP	NP	NP	NP	NP	NP	-5.3	2.0	-7.3	NP	NP	NP	NP	NP	NP	-7.3	-7.5
00C-03	-3.9	-3.9	12.2	-16.1	-16.1	1.0	-17.1	NP	NP	NP	-17.1	11.9	-29.0	NP	NP	NP	-29.0	NR	NR	NR	-36.8
00C-04	-4.0	-4.0	12.3	-16.3	NP	NP	NP	NP	NP	NP	-16.3	9.0	-26.2	NP	NP	NP	NP	NP	NP	-26.0	-26.2
00C-05	-2.1	-2.1	6.5	-8.6	NP	NP	NP	NP	NP	NP	-8.6	NR	NR	NP	NP	NP	NP	NP	NP	NR	-13.4
00C-06	-2.9	-2.9	8.1	-11.0	NP	NP	NP	NP	NP	NP	-11.0	NR	NR	NP	NP	NP	NP	NP	NP	NR	-16.4
00C-07	-3.5	-3.5	12.7	-16.2	NP	NP	NP	NP	NP	NP	-16.2	5.0	-21.2	NP	NP	NP	NP	NP	NP	-20.5	-21.2
00C-08	-2.5	-2.5	14.5	-17.0	-17.0	3.5	-20.5	-20.5	7.7	-28.2	NP	NP	NP	-28.2	NR	NR	NR	NR	NR	NR	-33.9
00C-09	-2.2	-2.2	14.5	-16.7	NP	NP	NP	NP	NP	NP	-16.7	8.8	-25.5	NP	NP	NP	-25.5	NR	NR	NR	-40.6
00C-10	-2.8	-2.8	13.5	-16.3	NP	NP	NP	NP	NP	NP	-16.3	3.7	-20.0	NP	NP	NP	NP	NP	NP	-19.5	-19.9
00C-11	-3.4	-3.4	13.3	-16.7	-16.7	4.7	-21.4	-21.4	15.1	-36.5	NP	NP	NP	-36.5	NR	NR	NR	NR	NR	NR	-42.1
00C-12	-2.7	-2.7	14.8	-17.5	NP	NP	NP	NP	NP	NP	-17.5	7.1	-24.6	NP	NP	NP	-24.6	NR	NR	NR	-40.7
00C-13	-2.7	-2.7	9.7	-12.4	NP	NP	NP	NP	NP	NP	-12.4	8.6	-21.0	NP	NP	NP	NP	NP	NP	-24.5	-24.5
00C-14	-14.4	-14.4	3.6	-18.0	-18.0	1.3	-19.3	-19.3	18.2	-37.5	NP	NP	NP	-37.5	15.0	-52.5	NP	NP	-52.5	NR	-62.3
00C-15	-5.6	-5.6	8.5	-14.1	NP	NP	NP	NP	NP	NP	-14.1	7.9	-22.0	NP	NP	NP	NP	NP	NP	NR	-22.2
00C-17	-22.9	NP	NP	NP	NP	NP	NP	-22.9	0.8	-23.7	NP	NP	NP	-23.7	2.8	-26.5	-26.5	NP	NP	NR	-34.6
00C-18	-15.6	NP	NP	NP	NP	NP	NP	-15.6	18.4	-34.0	NP	NP	NP	-34.0	19.0	-52.5	-52.5	-53.0	-53.0	NR	-54.3
00C-19	-25.1	NP	NP	NP	NP	NP	NP	-25.1	0.5	-25.6	NP	NP	NP	-25.6	2.9	-28.5	-28.5	NR	NR	NR	-47.0
00C-20	-26.1	NP	NP	NP	NP	NP	NP	-26.1	1.4	-27.5	NP	NP	NP	-27.5	2.2	-29.7	-29.7	-52.5	-52.5	NR	-52.5
00C-21	-15.1	NP	NP	NP	NP	NP	NP	-15.1	11.4	-26.5	NP	NP	NP	-26.5	11.5	-38.0	-38.0	NR	NR	NR	-40.2
00C-22	-18.6	NP	NP	NP	NP	NP	NP	-18.6	6.4	-25.0	NP	NP	NP	-25.0	5.0	-30.0	-30.0	-53.5	-53.5	NR	-54.8
00C-23	-16.4	NP	NP	NP	NP	NP	NP	-16.4	8.1	-24.5	NP	NP	NP	-24.5	4.7	-29.2	-29.2	NR	NR	NR	-49.5
00C-24	-14.5	NP	NP	NP	NP	NP	NP	-14.5	22.1	-36.6	NP	NP	NP	-36.6	10.0	-46.6	-46.6	-52.6	-52.6	NR	-66.0
00C-25	-12.6	NP	NP	NP	NP	NP	NP	-12.6	18.2	-30.8	NP	NP	NP	-30.8	12.2	-43.0	-43.0	-52.0	-52.0	NR	-70.6
00C-26	-13.2	NP	NP	NP	NP	NP	NP	-13.2	18.6	-31.8	NP	NP	NP	-31.8	8.2	-40.0	-40.0	-52.0	-52.0	NR	-65.8
00C-27	-13.0	NP	NP	NP	NP	NP	NP	-13.0	18.0	-31.0	NP	NP	NP	-31.0	8.0	-39.0	-39.0	-52.0	-52.0	NR	-69.2
00C-28	-12.3	NP	NP	NP	NP	NP	NP	-12.3	14.9	-27.2	NP	NP	NP	-27.2	10.1	-37.3	-37.3	-51.5	-51.5	NR	-57.5
00C-29	-12.2	NP	NP	NP	NP	NP	NP	-12.2	13.8	-26.0	NP	NP	NP	-26.0	8.0	-34.0	-34.0	-53.0	-53.0	NR	-72.0
00C-30	-12.4	NP	NP	NP	NP	NP	NP	-12.4	13.6	-26.0	NP	NP	NP	-26.0	4.5	-30.5	-30.5	-52.4	-52.4	NR	-70.2
00C-76	-2.7	-2.7	12.8	-15.5	-15.5	5.1	-20.6	-20.6	12.6	-33.2	NP	NP	NP	-33.2	12.8	-46.0	-46.0	-51.0	-51.0	NR	-52.6
00C-77	-6.5	-6.5	9.1	-15.6	-15.6	1.5	-17.1	-17.1	18.9	-36.0	NP	NP	NP	-36.0	12.5	-48.5	-48.5	-51.0	-51.0	NR	-60.3
00C-78	-12.0	-12.0	2.0	-14.0	NP	NP	NP	-14.0	14.5	-28.5	NP	NP	NP	-28.5	20.5	-49.0	-49.0	-52.0	-52.0	NR	-62.0
00C-79	-4.2	-4.2	10.3	-14.5	NP	NP	NP	NP	NP	NP	-14.5	11.5	-26.0	NP	NP	NP	-26.0	NR	NR	NR	-34.8

NOTES: All values in meters. Vertical datum is MSL 1929 (Caltrans, 1997)
NP = Unit not present at the CPT location, NR = CPT sounding did nor reach horizon elevation or did not pass completely through the unit.
Horizon elevations based on analyses of CPT soundings and correlation's with boring lithology, geotechnical tests, velocity data and seismic reflection records.
Contacts between YBIs and MPSA or MPSA and OBM are not always definitive and are locally gradational. The YBIs includes a clay cap, sand and clay interlayers and a basal clay with low shear strength of approximately 100 kPa.
The Merritt-Posey-San Antonio sediments include the Merritt Sand (at the top when present) and interlayered sand, silt, and clay both as horizontal layers and in a series of nested paleochannels. The YBIs may be time equivalent or slightly later than the MPSA and is similar lithologically.

SUMMARY OF PHASE 3 CONE PENETROMETER DATA, MAIN SPAN AREA AND OFFSHORE YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

TABLE 2.4

CPT Sounding	Mudline and Top of Young Bay Mud Elevation	Young Bay Mud Isopach	Base of Young Bay Mud and Top MPSA	Merritt-Posey-San Antonio Sediments Isopach	Near Top of Old Bay Mud	Top of Upper Alameda Marine Sediments	Completion Elevation
	Map 1	Map 6	Map 5	Map 7	Map 8	No Map	No Map
00C-31	-6.0	29.0	-35.0	7.0	-42.0	NR	-42.2
00C-32	-6.1	27.9	-34.0	NR	NR	NR	-38.0
00C-33	-6.0	24.0	-30.0	NR	NR	NR	-32.1
00C-34	-5.0	22.0	-27.0	3.0	-30.0	NR	-31.0
00C-35	-5.0	17.0	-22.0	1.0	-23.0	NR	-44.0
00C-36	-5.0	17.5	-22.5	0.5	-23.0	NR	-29.2
00C-37	-4.3	19.4	-23.7	5.0	-28.7	NR	-31.8
00C-38	-4.2	12.6	-16.8	6.2	-23.0	-53.2	-54.2
00C-39	-4.3	12.2	-16.5	8.0	-24.5	NR	-28.7
00C-40	-4.1	18.3	-22.4	3.6	-26.0	NR	-27.1
00C-41	-3.9	16.0	-19.9	5.1	-25.0	NR	-47.6
00C-42	-3.9	13.1	-17.0	5.5	-22.5	NR	-32.3
00C-43	-4.7	11.8	-16.5	4.5	-21.0	NR	-38.2
00C-44	-3.8	12.7	-16.5	5.0	-21.5	NR	-30.8
00C-45	-4.1	8.9	-13.0	8.7	-21.7	NR	-28.8
00C-46	-3.8	9.9	-13.7	7.8	-21.5	NR	-28.0
00C-47	-3.8	9.8	-13.6	7.4	-21.0	NR	-39.0
00C-48	-3.8	8.6	-12.4	8.3	-20.7	NR	-25.9
00C-49	-3.5	12.2	-15.7	6.0	-21.7	NR	-26.2
00C-50	-3.3	10.2	-13.5	8.2	-21.7	NR	-38.0
00C-51	-3.4	8.8	-12.2	9.0	-21.2	NR	-33.1
00C-52	-3.4	12.1	-15.5	5.2	-20.7	NR	-32.2
00C-53	-3.3	10.9	-14.2	7.1	-21.3	NR	-32.2
00C-54	-3.3	10.5	-13.8	7.7	-21.5	NR	-28.0
00C-55	-3.5	9.5	-13.0	9.0	-22.0	NR	-29.5
00C-56	-3.5	9.5	-13.0	8.5	-21.5	NR	-43.5
00C-57	-3.5	12.0	-15.5	5.7	-21.2	NR	-30.0
00C-58	-3.4	10.1	-13.5	7.7	-21.2	NR	-30.0
00C-59	-3.6	8.9	-12.5	8.3	-20.8	NR	-38.7
00C-60	-3.5	17.0	-20.5	1.5	-22.0	NR	-30.5
00C-61	-3.0	14.0	-17.0	4.0	-21.0	NR	-29.2
00C-62	-3.5	12.9	-16.4	4.1	-20.5	NR	-40.7
00C-63	-3.3	8.5	-11.8	9.5	-21.3	-52.0	-54.8
00C-64	-2.9	13.6	-16.5	4.3	-20.8	-52.0	-53.0
00C-65	-2.9	13.1	-16.0	5.2	-21.2	NR	-32.8
00C-66	-2.6	9.5	-12.1	9.2	-21.3	NR	-27.6
00C-67	-2.6	9.0	-11.6	9.7	-21.3	NR	-42.6
00C-68	-2.4	8.6	-11.0	10.3	-21.3	NR	-44.6
00C-69	-0.9	8.6	-9.5	10.5	-20.0	NR	-40.9
00C-70	-1.6	8.8	-10.4	NR	NR	NR	-13.5
00C-71	-1.6	9.3	-10.9	NR	NR	NR	-12.8
00C-72	-1.4	10.0	-11.4	9.6	-21.0	-52.7	-52.7
00C-73	-1.1	10.5	-11.6	NR	NR	NR	-19.0
00C-74	-0.9	10.6	-11.5	NR	NR	NR	-13.5

NOTES: All values in meters. Vertical datum is MSL 1929 (Caltrans, 1997)

NP = Unit not present at the CPT location.

NR = CPT sounding did not reached the horizon elevation or did not pass completely through the unit by the CPT sounding.

Horizon elevations based on analyses of CTP soundings and correlations with boring lithology, geotechnical tests, velocity data and seismic reflection records.

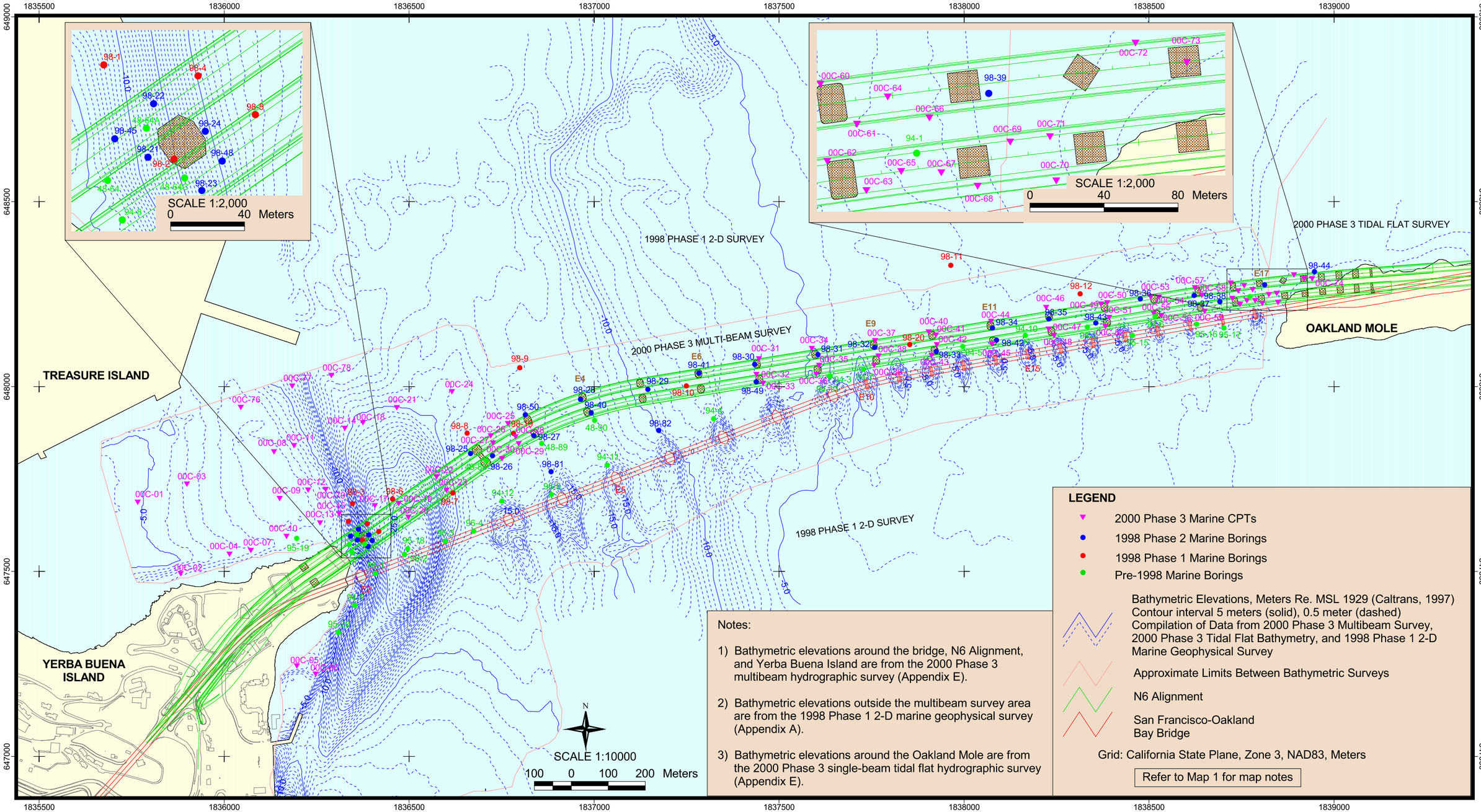
SUMMARY OF PHASE 3 CONE PENETROMETER DATA, SKYWAY AREA PIER E3 TO OAKLAND MOLE

SFOBB East Span Seismic Safety Project

TABLE 2.5

Earth Mechanics

FUGRO



Notes:

1) Bathymetric elevations around the bridge, N6 Alignment, and Yerba Buena Island are from the 2000 Phase 3 multibeam hydrographic survey (Appendix E).

2) Bathymetric elevations outside the multibeam survey area are from the 1998 Phase 1 2-D marine geophysical survey (Appendix A).

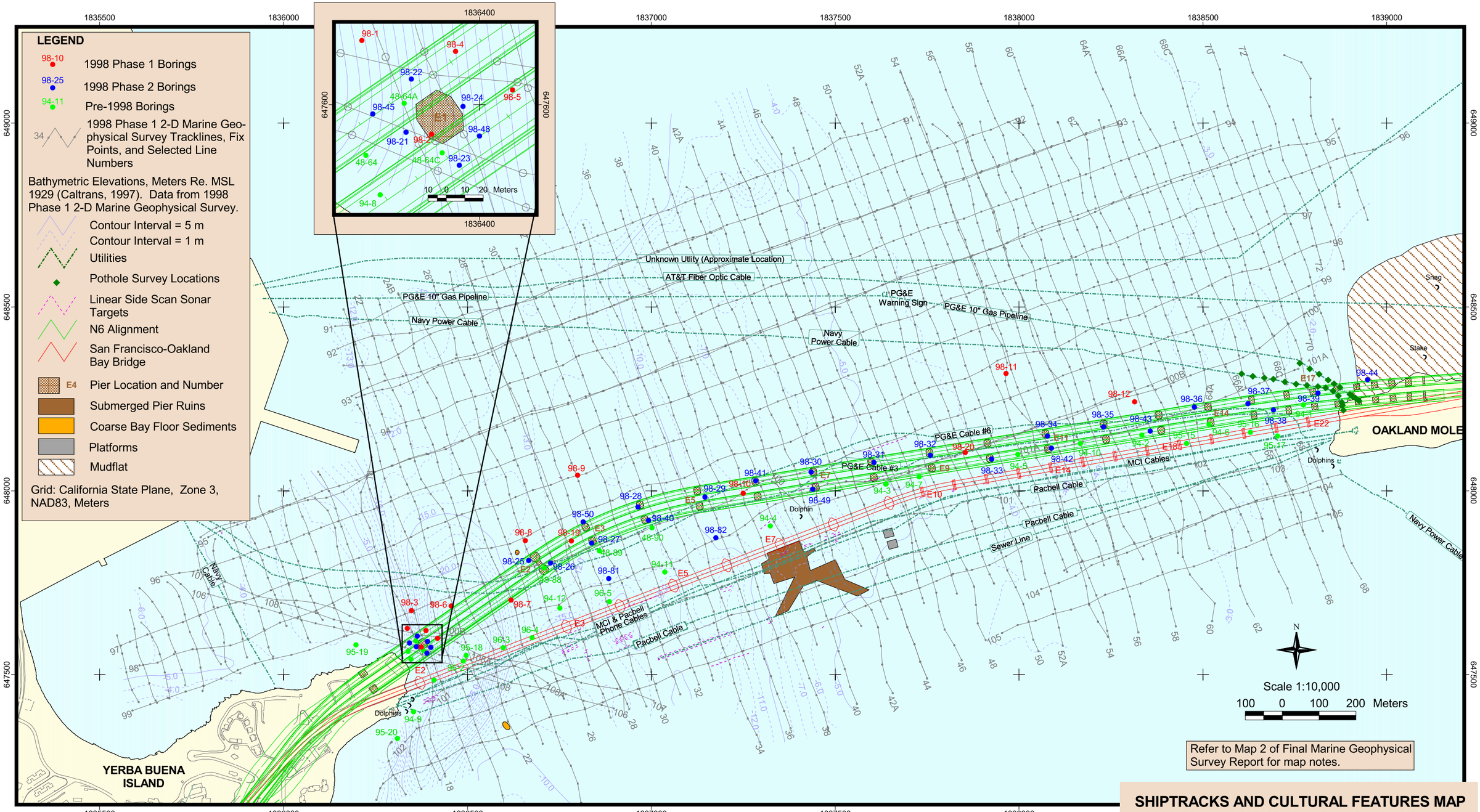
3) Bathymetric elevations around the Oakland Mole are from the 2000 Phase 3 single-beam tidal flat hydrographic survey (Appendix E).

BATHYMETRY AND MARINE GEOTECHNICAL EXPLORATIONS
SFOBB East Span Seismic Safety Project

PLATE 2.1

Earth Mechanics

FUGRO

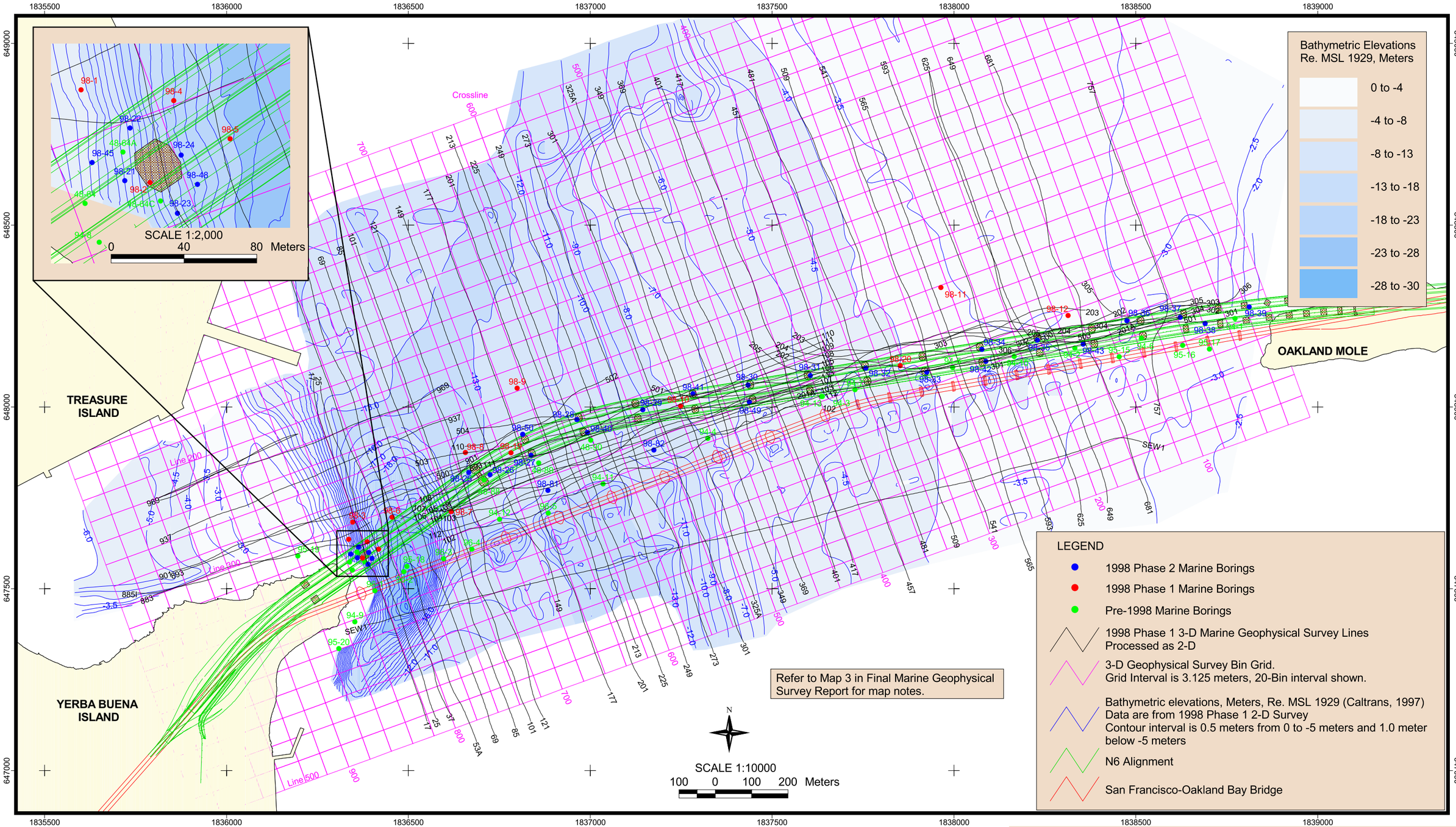


SHIPTRACKS AND CULTURAL FEATURES MAP
1998 Phase 1 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

PLATE 2.2

Earth Mechanics

FUGRO



DATABASE MAP

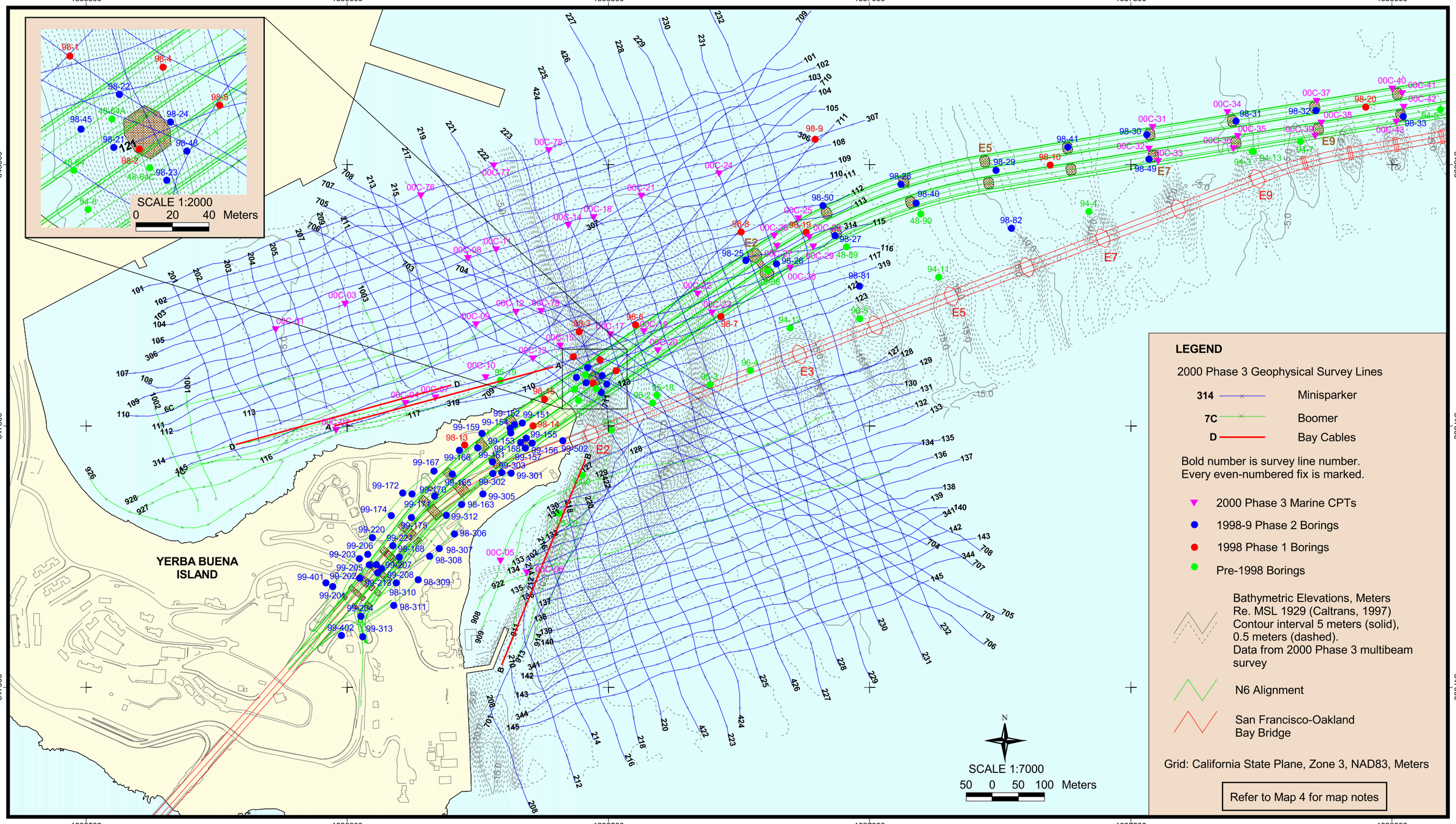
1998 Phase 1 3-D Marine Geophysical Survey

SFOBB East Span Seismic Safety Project

PLATE 2.3

Earth Mechanics

FUGRO

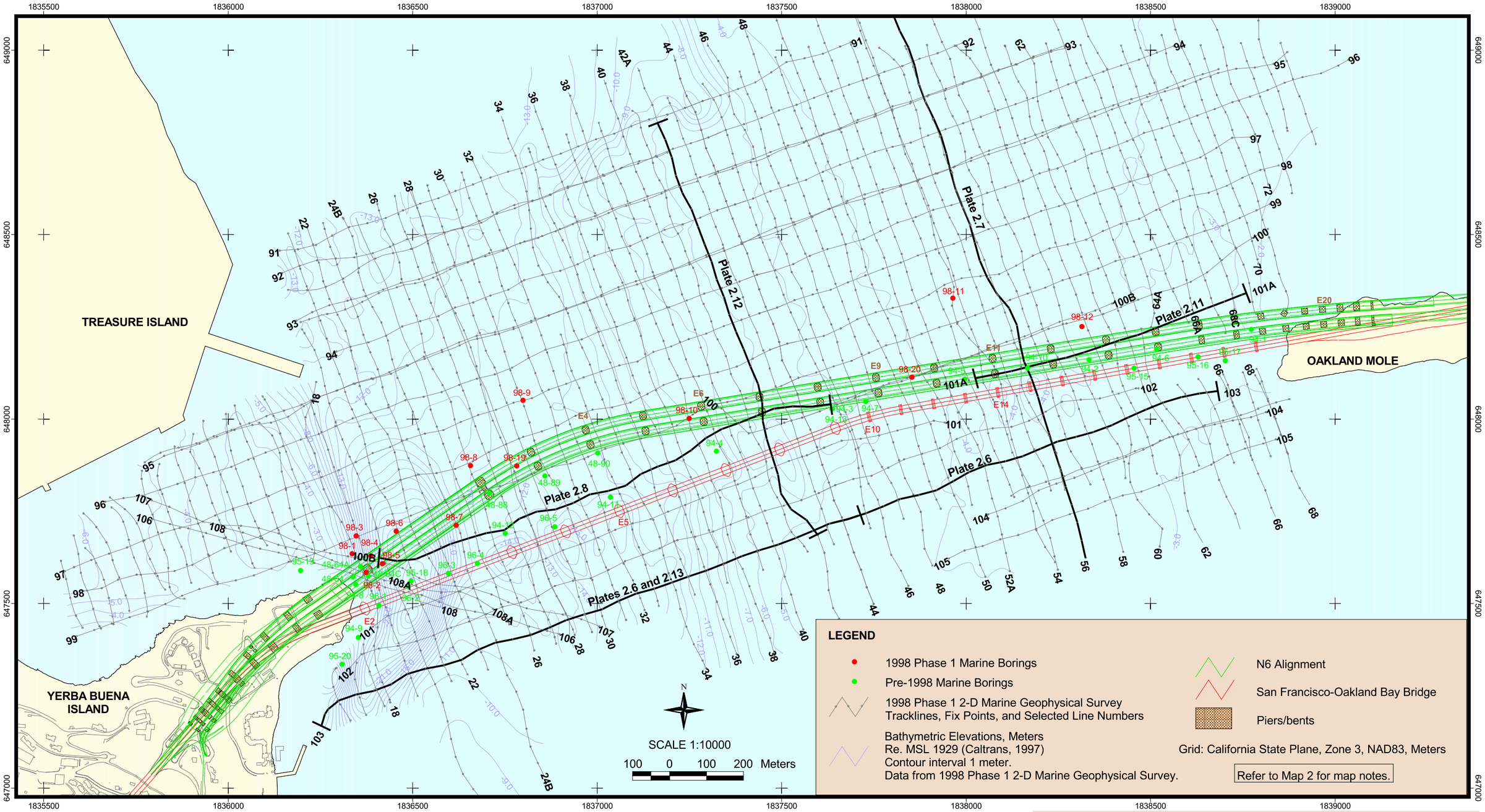


DATABASE MAP, 2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

PLATE 2.4

Earth Mechanics

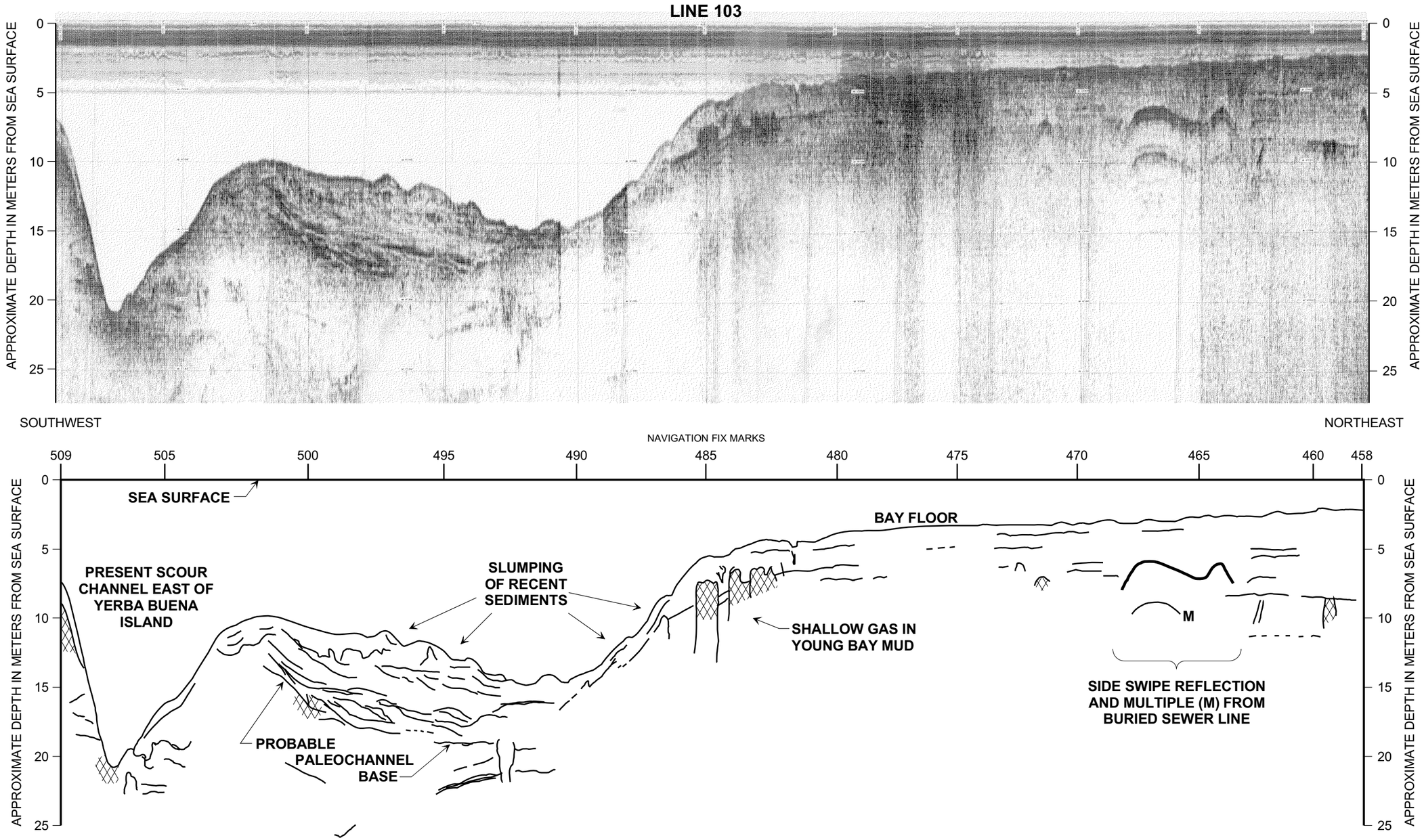
FUGRO



LOCATION MAP FOR SEISMIC DATA ILLUSTRATED IN SECTIONS 2.4 AND 2.5

SFOBB East Span Seismic Safety Project

PLATE 2.5



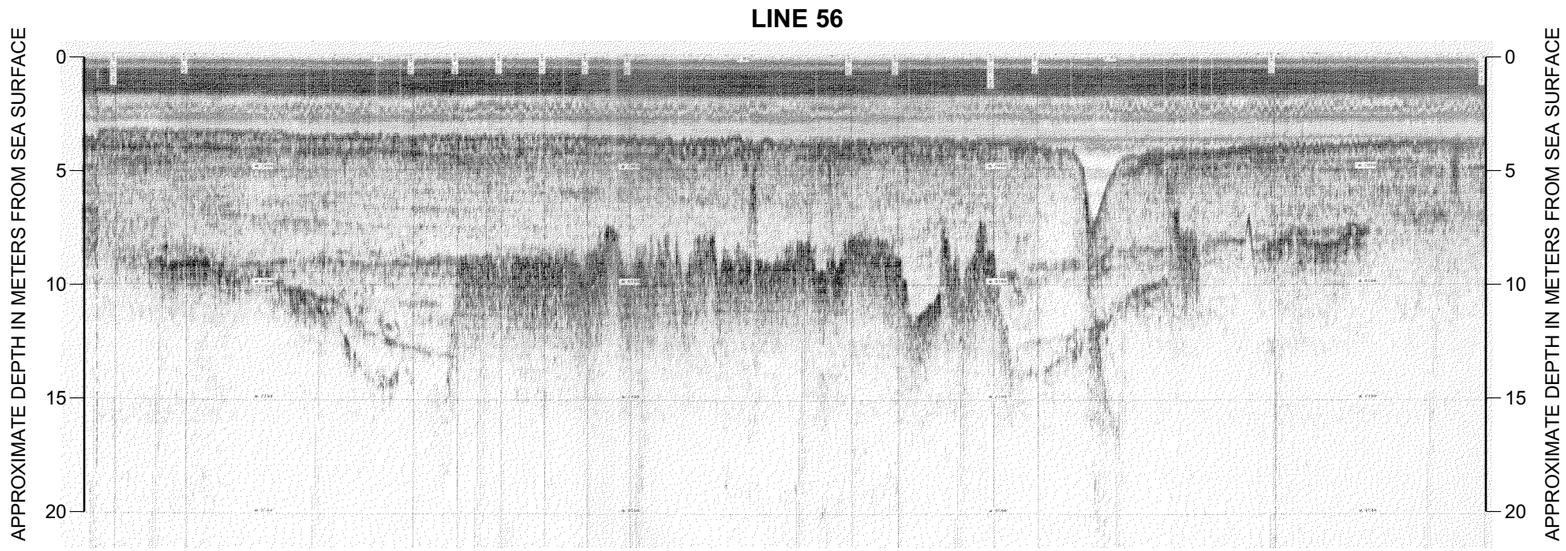
1) High-resolution CHIRP record, Line 103.

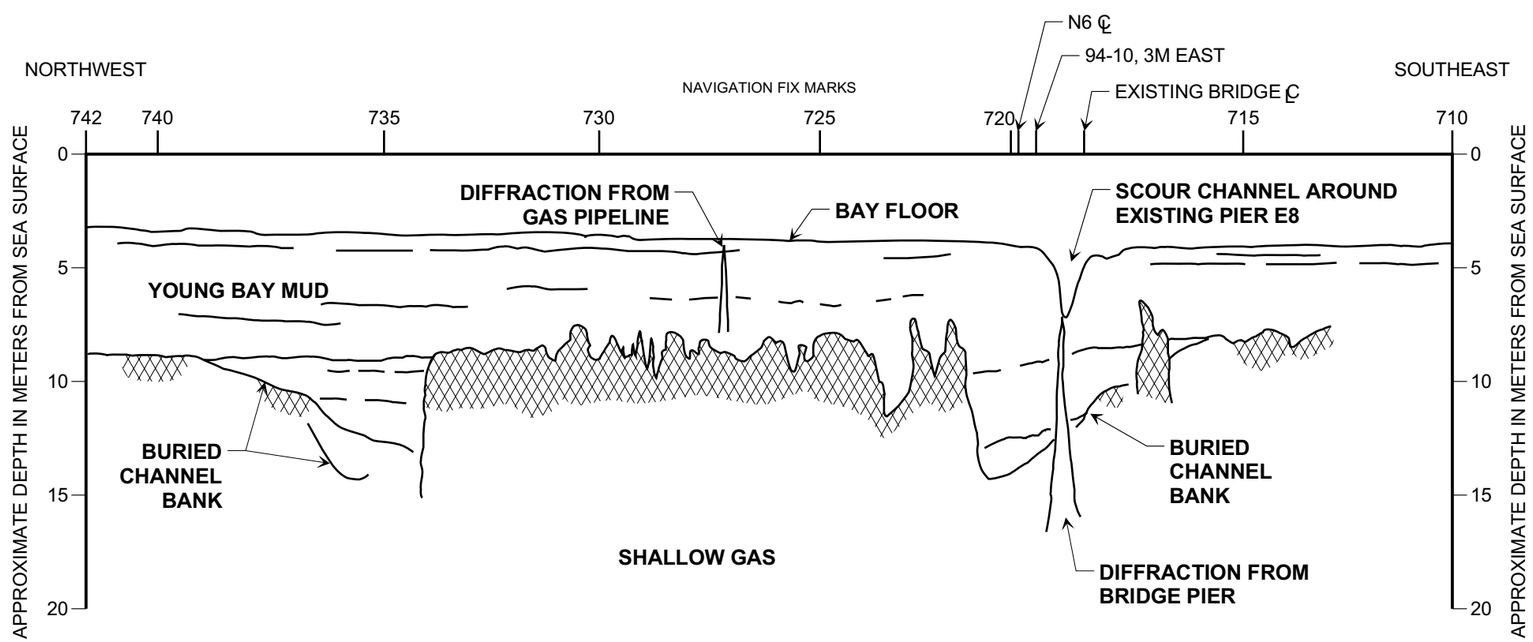
2) Fix mark interval = 50 meters, every fifth mark indicated.

3) Vertical exaggeration ≅ 25x.

BATHYMETRIC AND SHALLOW SEDIMENT FEATURES
Data Example and Interpreted Schematic
SFOBB East Span Seismic Safety Project

PLATE 2.6





1) High-resolution CHIRP record Line 56.

2) Fix mark interval = 50 meters, every fifth mark indicated.

3) Vertical Exaggeration ≅ 25x.

SHALLOW GAS AND BURIED CHANNEL BANKS
Data Example and Interpreted Schematic
SFOBB East Span Seismic Safety Project

9842\0054\56.ds\(1.2)

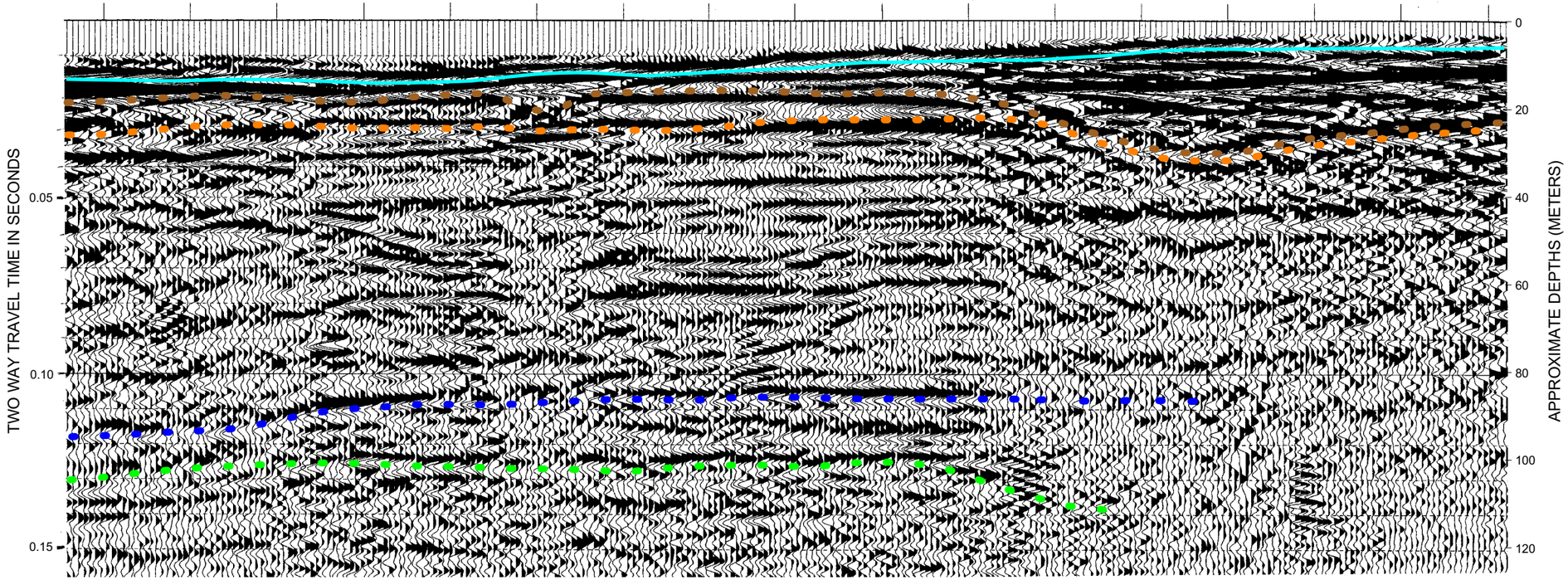
Earth Mechanics FUGRO

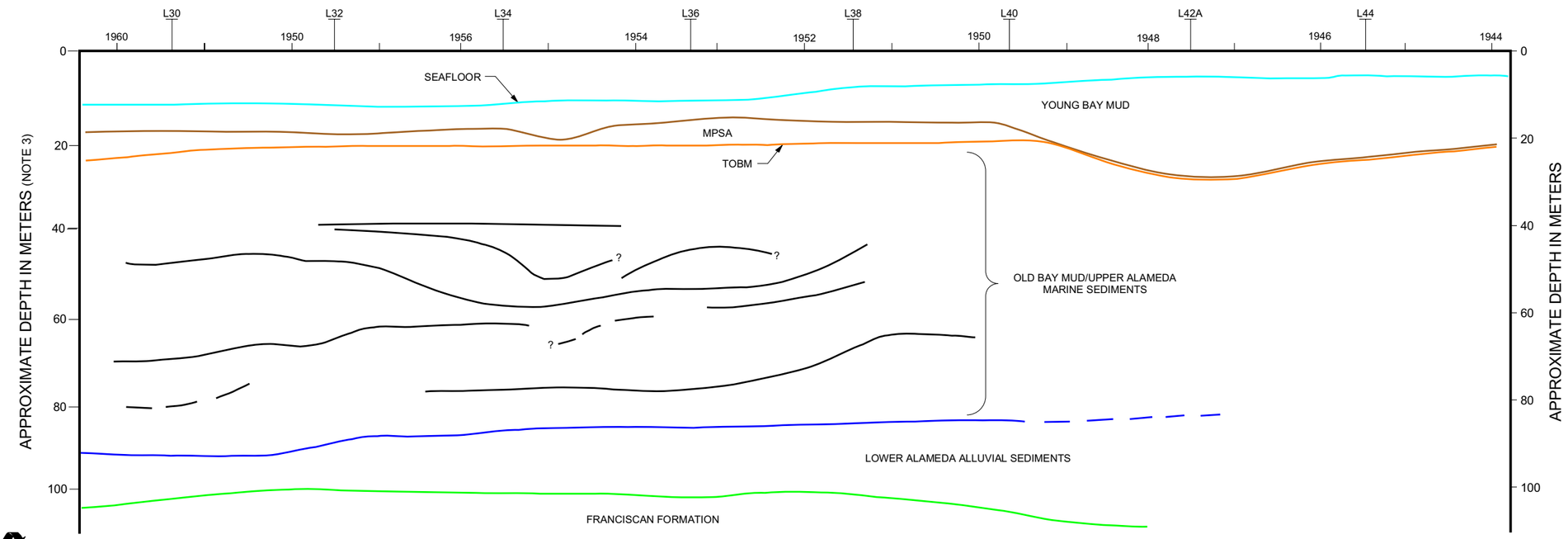
LINE 100B

NAVIGATION FIX MARKS

WEST — EAST

1960 1959 1958 1957 1956 1955 1954 1953 1952 1951 1950 1949 1948 1947 1946 1945 1944





LEGEND

1955 — Fix Mark on 2-D Geophysical Trackline Along Profile

L32 — 2-D Geophysical Survey Trackline Intersection with Line 100B

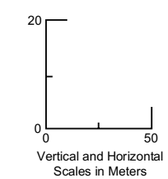
- Bay Floor
- Young Bay Mud (YBM)
- Base (BYBM)
- Merritt-Posey-San Antonio (MPSA)
- Top Old Bay Mud (TOBM)
- Old Bay Mud/ Upper Alameda Marine (OBM/UAM)
- Top Lower Alameda Alluvial (LAA)
- Top Franciscan Formation (FF)

NOTES:

1) Refer to Plate 2.5 for location of seismic line.

2) Zero time on reflection records not corrected for tides.

3) Depths calculated from two-way travel time using the multivelocity function described in the report.



PALEOCHANNEL SEQUENCES
Data Example and Interpreted Schematic
SFOBB East Span Seismic Safety Project

PLATE 2.8

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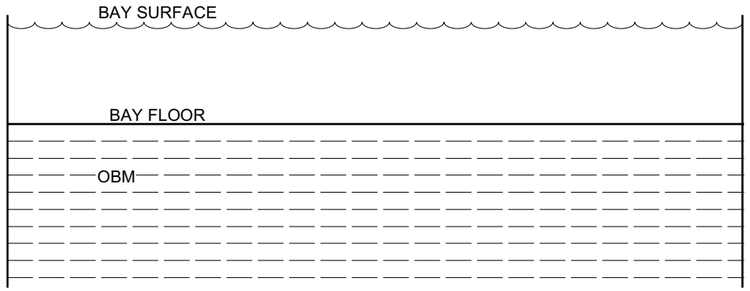
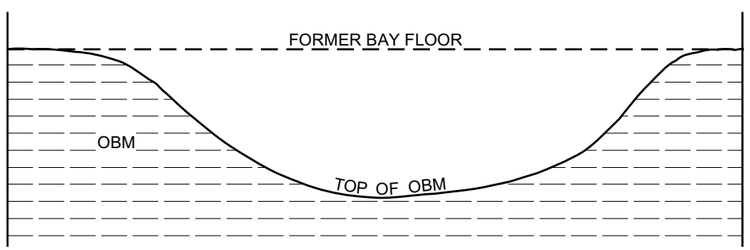
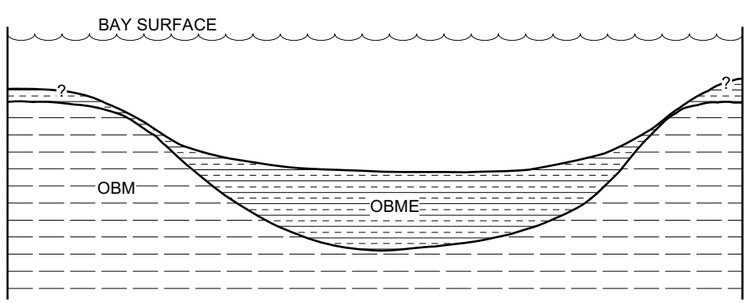


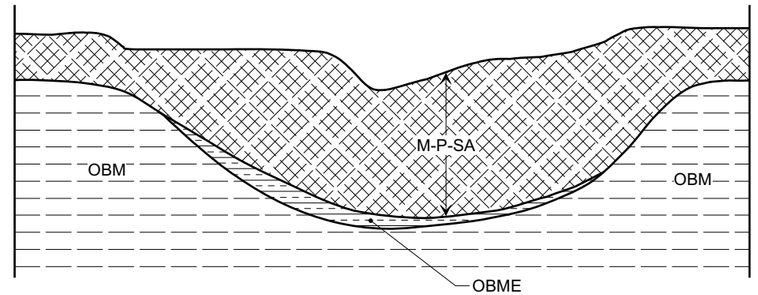
Stage 1: Following deposition of Old Bay Mud (OBM).



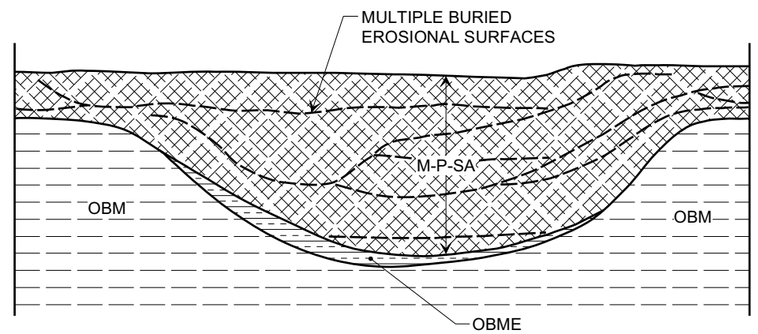
Stage 2: Channeling/erosion of Old Bay Mud.



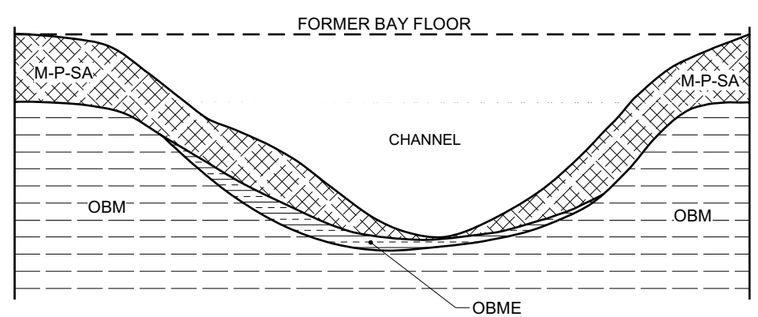
Stage 3: Initial filling of channel with sediments of similar lithology of OBM (OBME). May correlate to oldest of Merritt-Posey-San Antonio Formation sediment.



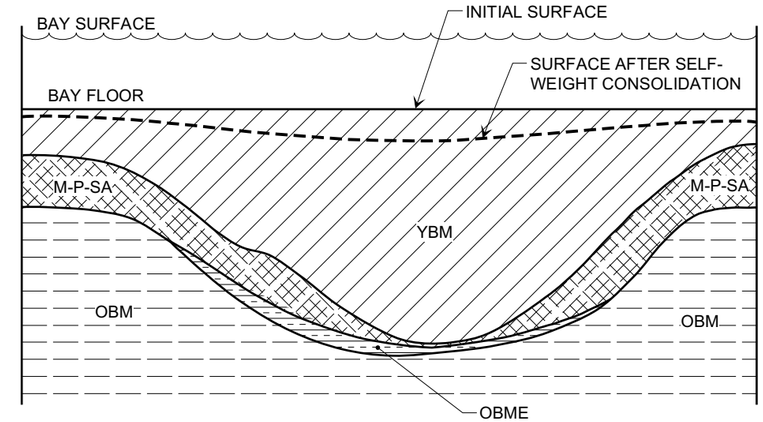
Stage 4: Rechanneling/erosion of OBME & channel and initial deposition of Merritt-Posey-San Antonio Formations (M-P-SA).



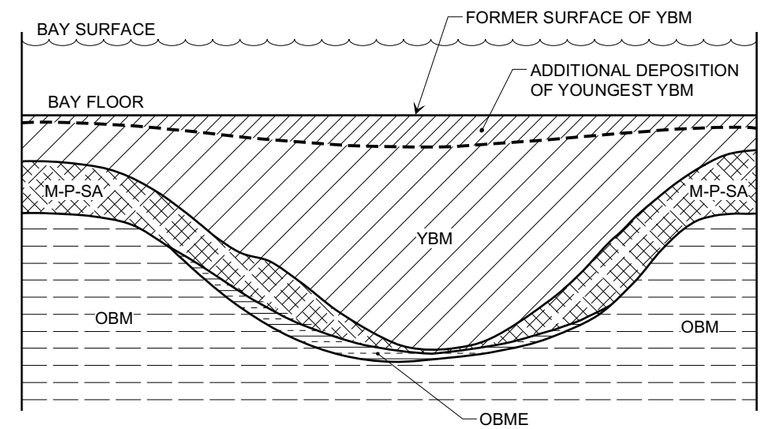
Stage 5: Multiple episodes of channeling and deposition in M-P-SA sequence.



Stage 6: Post M-P-SA channeling.



Stage 7: Deposition of initial Young Bay Mud (YBM).

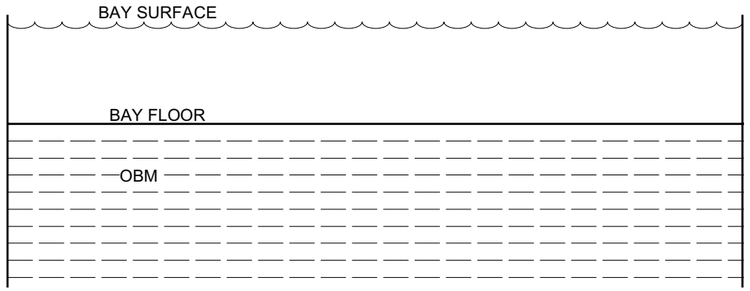


Stage 8: Deposition of most recent YBM.

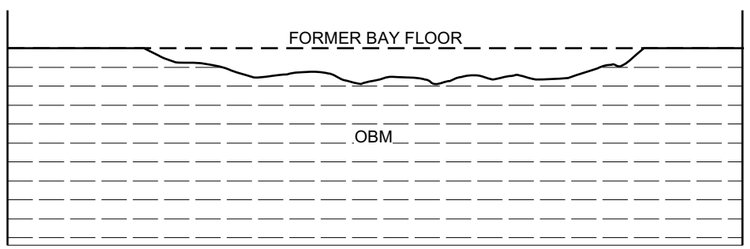
LEGEND

YBM	=	Young Bay Mud
M-P-SA	=	Merritt-Posey-San Antonio Formations (also may be referred to as Merritt Sand)
OBM	=	Old Bay Mud

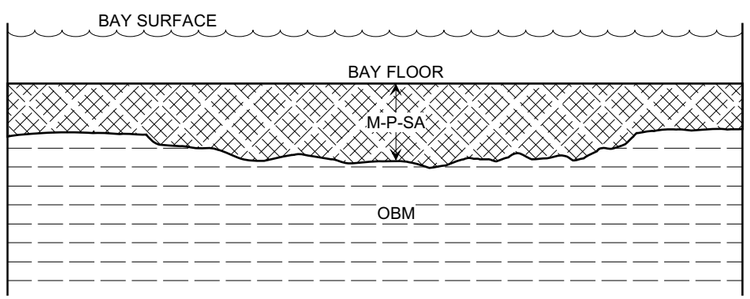
HYPOTHETICAL SCHEMATIC OF DEPOSITIONAL SEQUENCES IN PALEOCHANNELS
Model 1
SFOBB East Span Seismic Safety Project



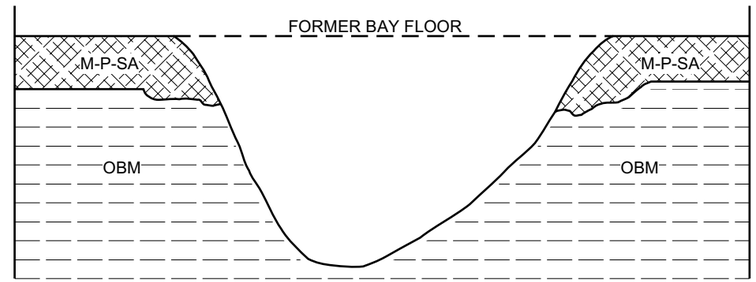
Stage 1: Following deposition of Old Bay Mud (OBM).



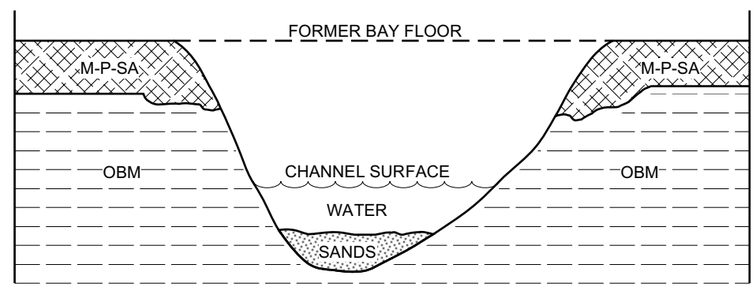
Stage 2: Channeling/erosion of Old Bay Mud.



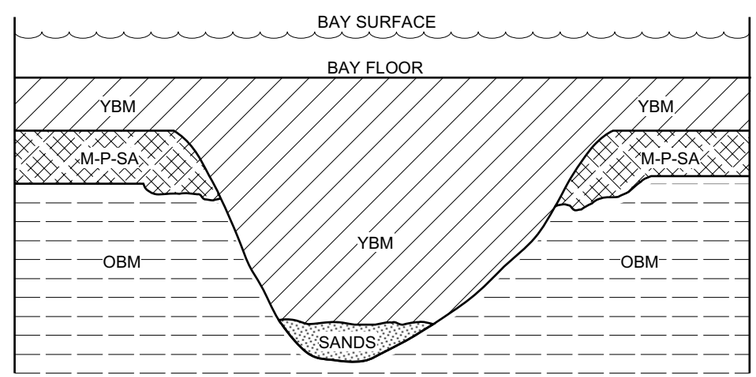
Stage 3: Initial filling of channel with sediments of Merritt-Posey-San Antonio Formations (M-P-SA).



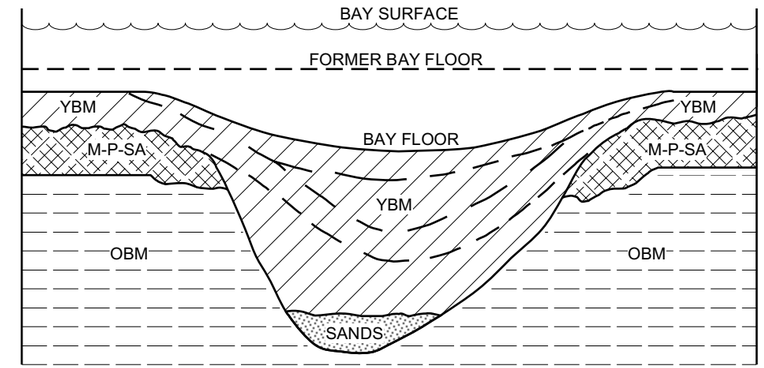
Stage 4: Erosion of deep channel through M-P-SA and into OBM.



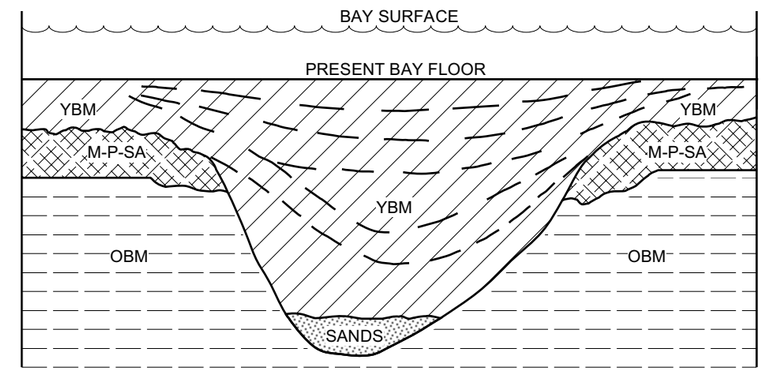
Stage 5: Initial deposition of sands into base of channel.



Stage 6: Completion of channel filling with Young Bay Mud (YBM).



Stage 7: Continued channeling and infilling in the YBM channel.



Stage 8: Deposition of most recent YBM. Upper dashed line is channel edge seen on CHIRP records.

LEGEND

YBM	=	Young Bay Mud
M-P-SA	=	Merritt-Posey-San Antonio Formations (also may be referred to as Merritt Sand)
OBM	=	Old Bay Mud

HYPOTHETICAL SCHEMATIC OF DEPOSITIONAL SEQUENCES IN PALEOCHANNELS
Model 2
SFOBB East Span Seismic Safety Project

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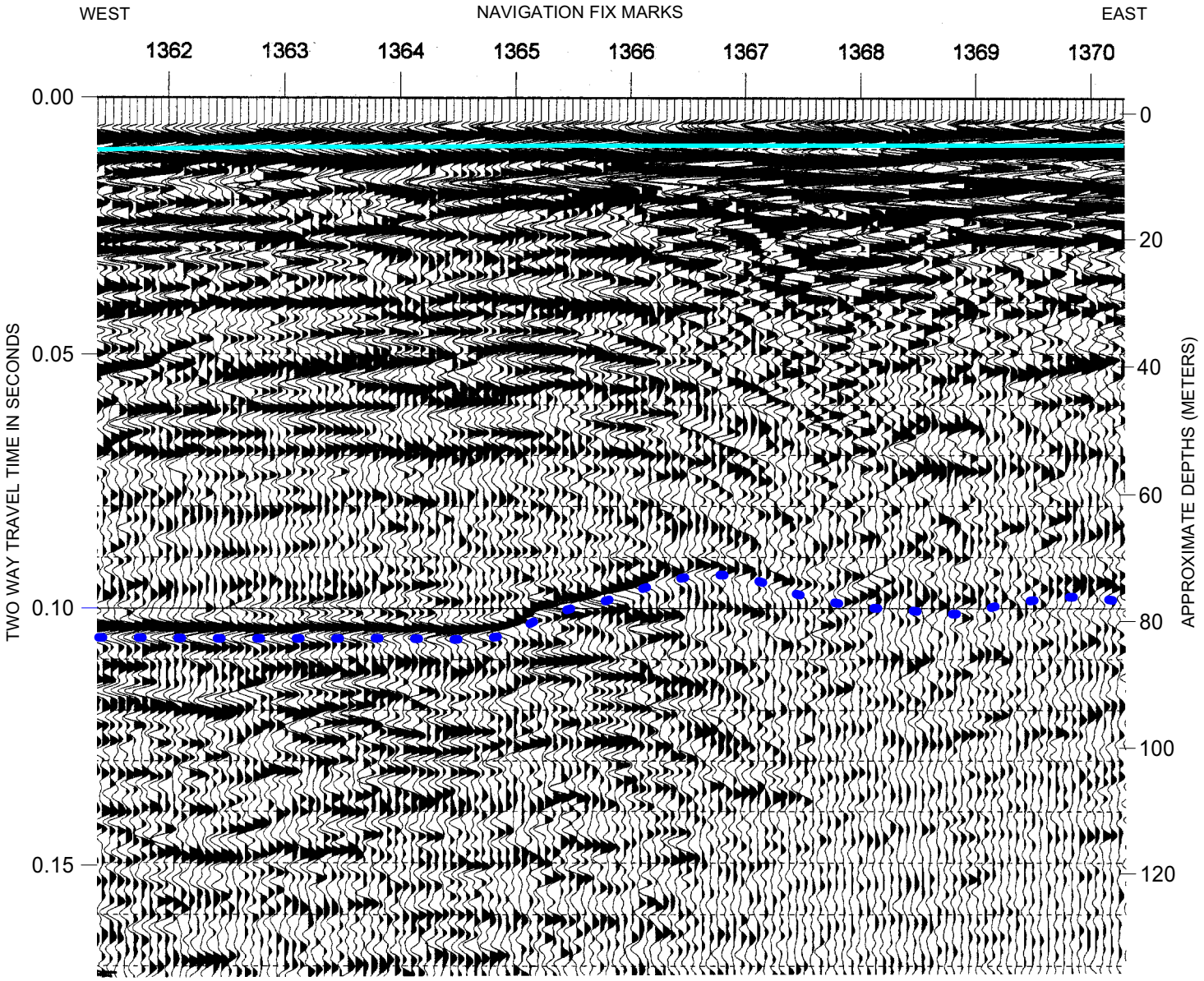
LINE 101A



NOTES:

1) Refer to Plate 2.5 for location of seismic line.

2) Zero depth on reflection record corrected for tides.

3) Depths calculated from the two-way travel time using the multivelocity function described in the report.

LEGEND

1362 — Fix Mark on 2-D Geophysical Trackline along Profile

Lower Alameda Alluvial Sediment "Reflector" Interpreted from 2-D Seismic Geophysical Records

Bay Floor

LOCAL TOPOGRAPHIC FEATURE AT TOP OF LOWER ALAMEDA ALLUVIAL SEDIMENTS

Data Example

SFOBB East Span Seismic Safety Project

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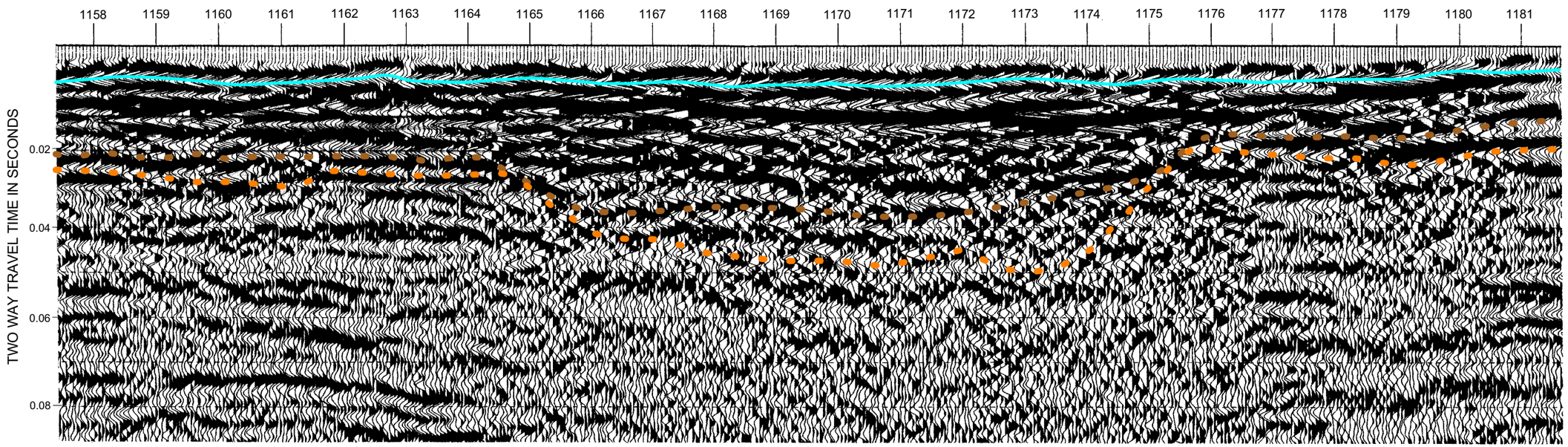
Earth Mechanics FUGRO

LINE 42A

NAVIGATION FIX MARKS

NORTH SOUTH

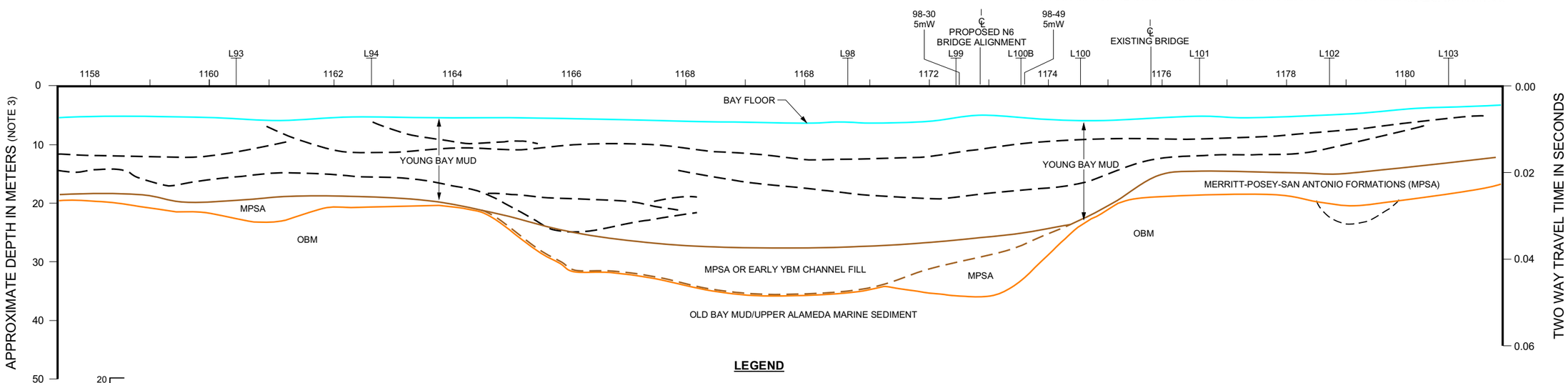


NOTES:

1) Refer to Plate 2.5 for location of seismic line

2) Zero time on reflection records not corrected for tides.

3) Depths calculated from two-way travel time using the velocity function described in the report.



LEGEND

- 1168 — Fix Mark on 2-D Geophysical Trackline Along Profile
- L99 — 2-D Geophysical Survey Trackline Intersection with Line 42A
- Intermediate Reflectors
- ℄ — Existing Bridge Centerline or Proposed N6 Alignment Centerline
- Bay Floor
- Young Bay Mud (YBM)
- Base (BYBM)
- Merritt-Posey-San Antonio (MPSA)
- Top Old Bay Mud (OBM)
- Old Bay Mud/ Upper Alameda Marine (OBM/UAM)
- Top Lower Alameda Alluvial (LAA)
- Top Franciscan Formation (FF)

20 0 0 100
Vertical and Horizontal Scales in Meters

SHALLOW MARINE SEDIMENTS
Data Example and Interpreted Schematic
SFOBB East Span Seismic Safety Project

PLATE 2.12

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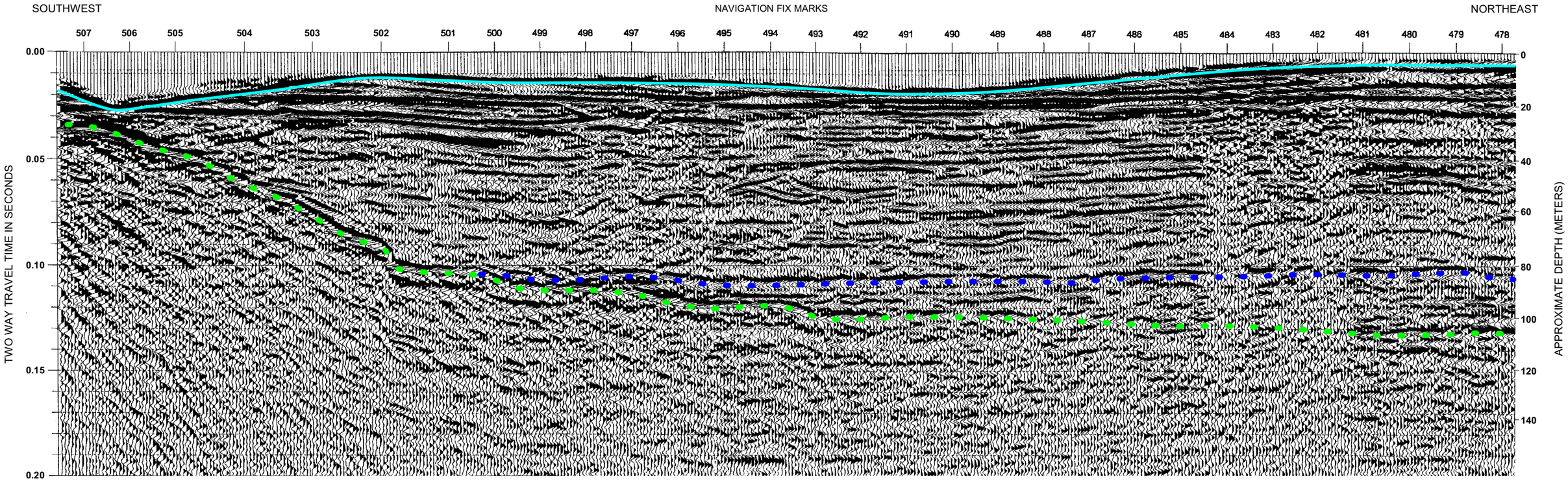
Earth Mechanics

FUGRO

LINE 103



NOTES:

1) Refer to Plate 2.5 for location of seismic line.
2) Zero depth on reflection record corrected for tides.
3) Depths calculated from the two-way travel time using the velocity function described in the report.
4) Vertical Exaggeration ≅ 3x.

LEGEND

502 — Fix Mark on 2-D Geophysical Trackline along Profile

Near Top Lower Alameda Alluvial Sediment "Reflector"

Near Top Franciscan Formation "Reflector"

Bay Floor

TOP OF FRANCISCAN FORMATION AND ONLAP OF LOWER ALAMEDA ALLUVIAL SEDIMENT
Data Example
SFOBB East Span Seismic Safety Project

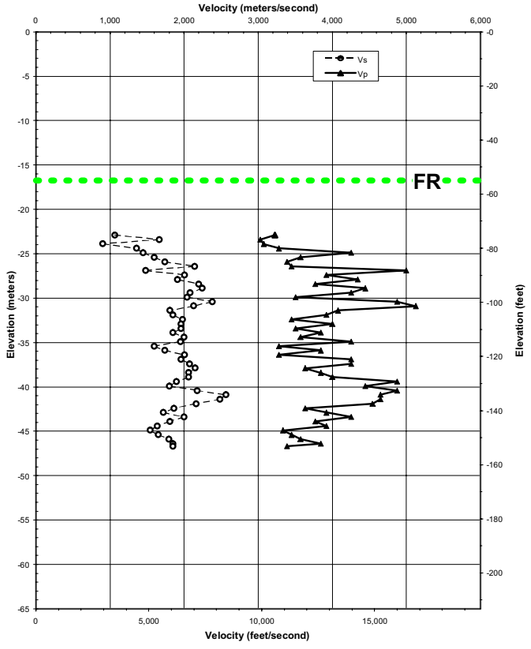
PLATE 2.13

9420054top.dsf(1,2)

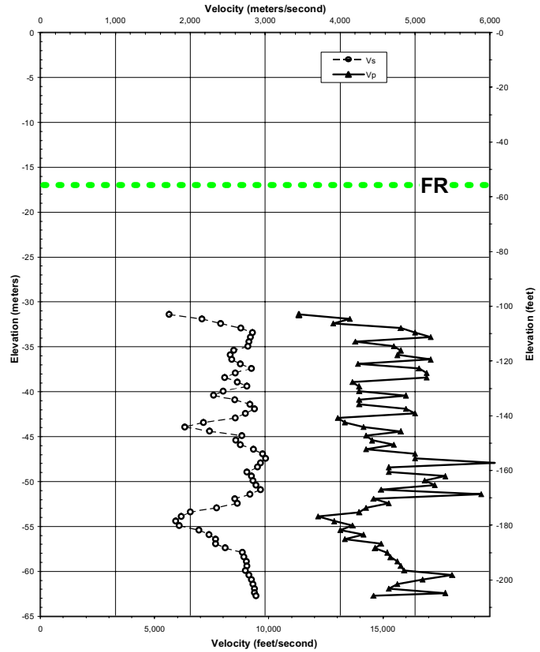
Earth Mechanics

FUGRO

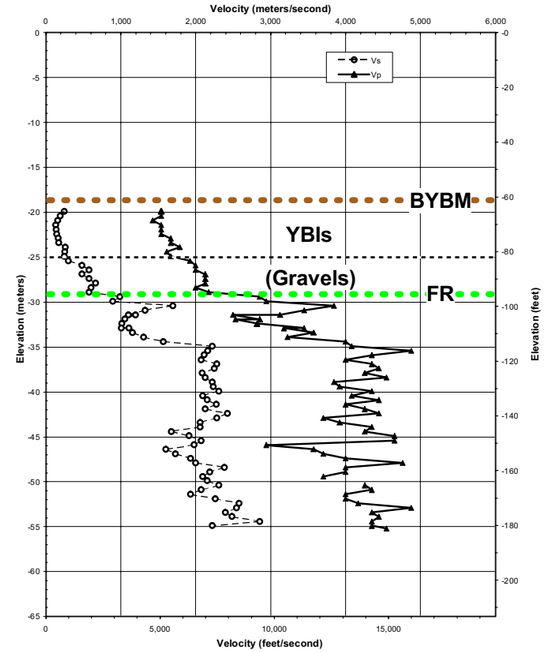
BORING 98-1
Mudline Elevation: -5.9m (MSL)



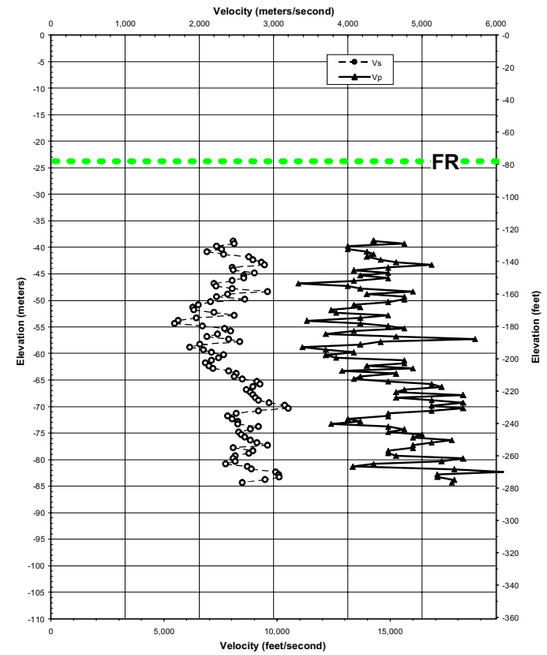
BORING 98-2
Mudline Elevation: -14.9m (MSL)



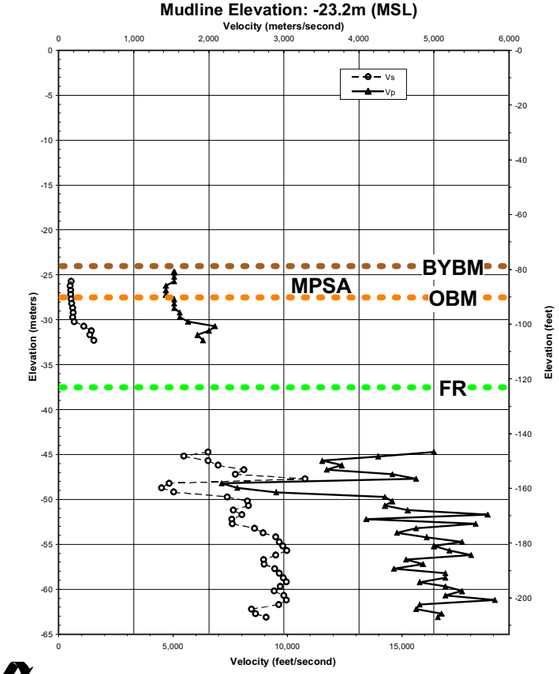
BORING 98-3
Mudline Elevation: -11.9m (MSL)



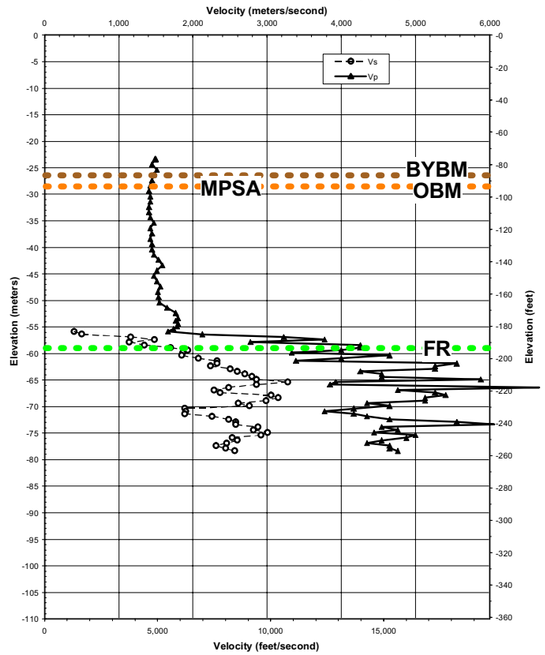
BORING 98-4
Mudline Elevation: -19.8m (MSL)



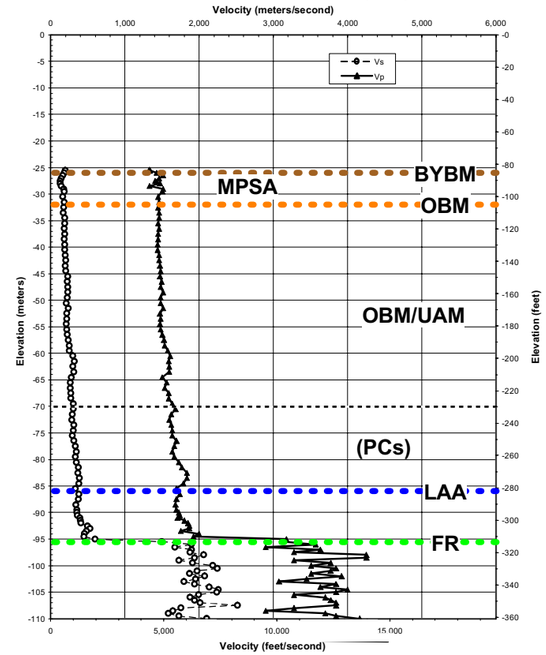
BORING 98-5
Mudline Elevation: -23.2m (MSL)



BORING 98-6
Mudline Elevation: -24.4m (MSL)



BORING 98-7
Mudline Elevation: -15.5m (MSL)



LEGEND

- Bay Floor
- Young Bay Mud (YBM)
- Base (BYBM)
- Merritt-Posey-San Antonio (MPSA) (or Yerba Buena Island Sediments (YBIs))
- Top Old Bay Mud (OBM)
- Old Bay Mud/ Upper Alameda Marine (OBM/UAM)
- Paleochannel Sand (PCs)
- Top Lower Alameda Alluvial (LAA)
- Lower Alameda Alluvial Sediments (LAA)
- Sand (LAAs)
- Top Franciscan Formation (FR)

VELOCITY LOGS FROM THE 1998 BORINGS

SFOBB East Span Seismic Safety Project

PLATE 2.14a

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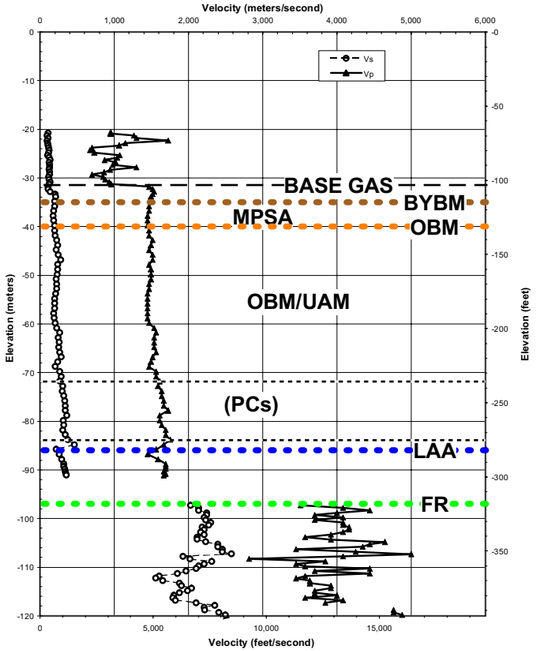
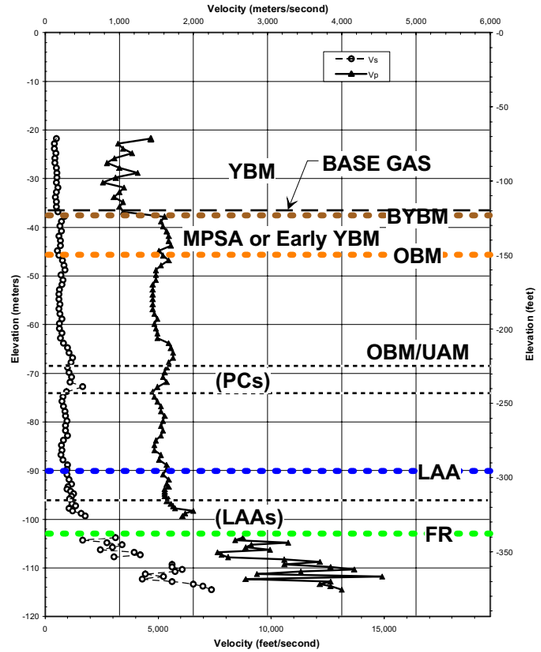
Earth Mechanics FUGRO

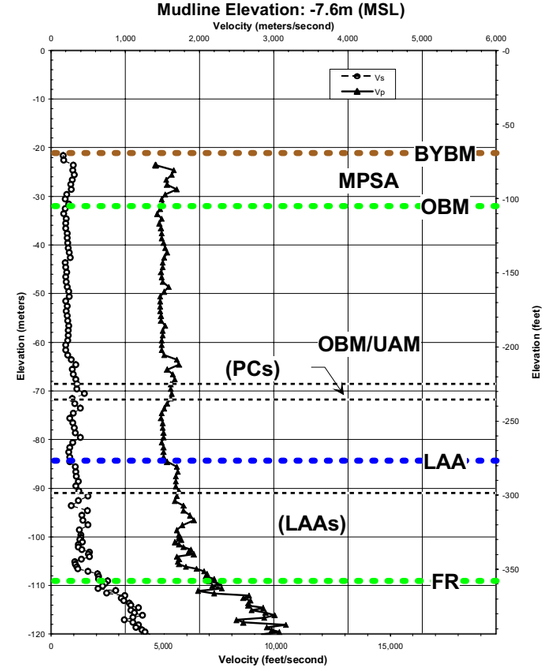
BORING 98-8
Mudline Elevation: -13.4m (MSL)



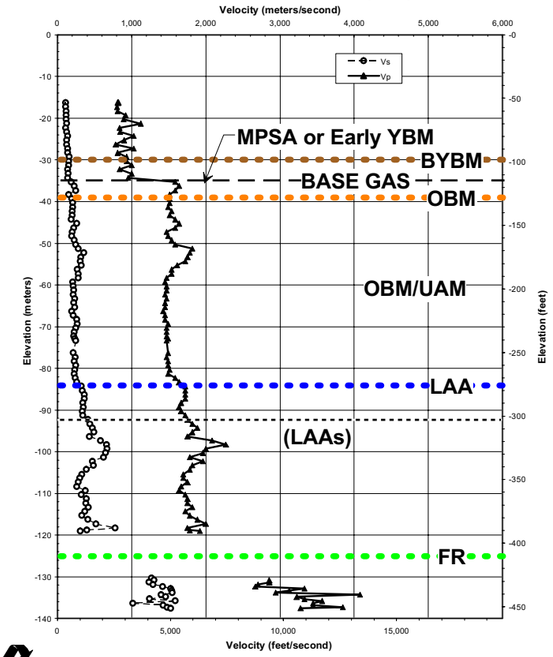
BORING 98-9
Mudline Elevation: -12.8m (MSL)



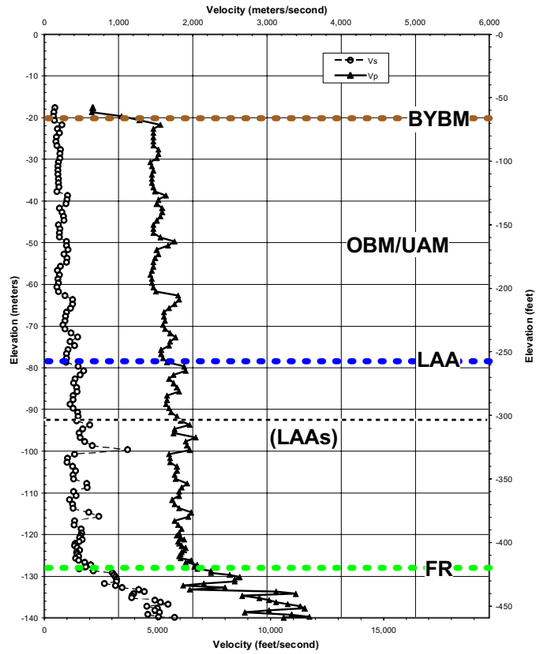
BORING 98-10
Mudline Elevation: -7.6m (MSL)



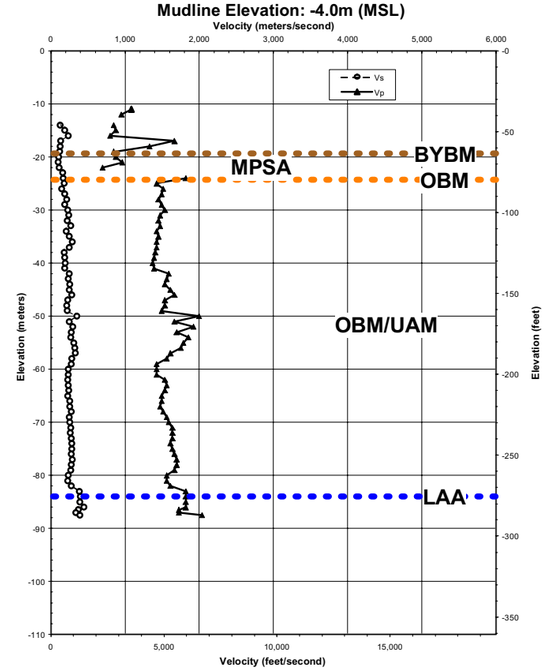
BORING 98-11
Mudline Elevation: -4.3m (MSL)



BORING 98-12
Mudline Elevation: -3.7m (MSL)



BORING 98-20
Mudline Elevation: -4.0m (MSL)



LEGEND

- Bay Floor
- Young Bay Mud (YBM)
- Base (BYBM)
- Merritt-Posey-San Antonio (MPSA)
- Top Old Bay Mud (OBM)
- Old Bay Mud/ Upper Alameda Marine (OBM/UAM)
- Paleochannel Sand (PCs)
- Top Lower Alameda Alluvial (LAA)
- Lower Alameda Alluvial Sediments (LAA)
- Sand (LAAs)
- Top Franciscan Formation (FR)

VELOCITY LOGS FROM THE 1998 BORINGS
SFOBB East Span Seismic Safety Project

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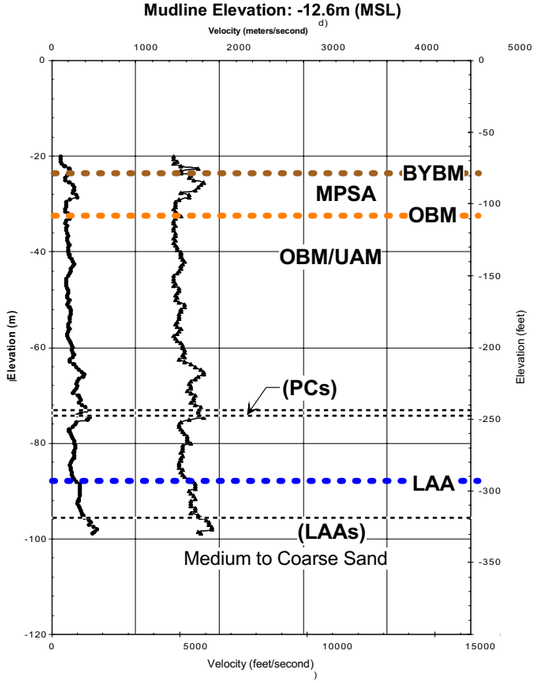
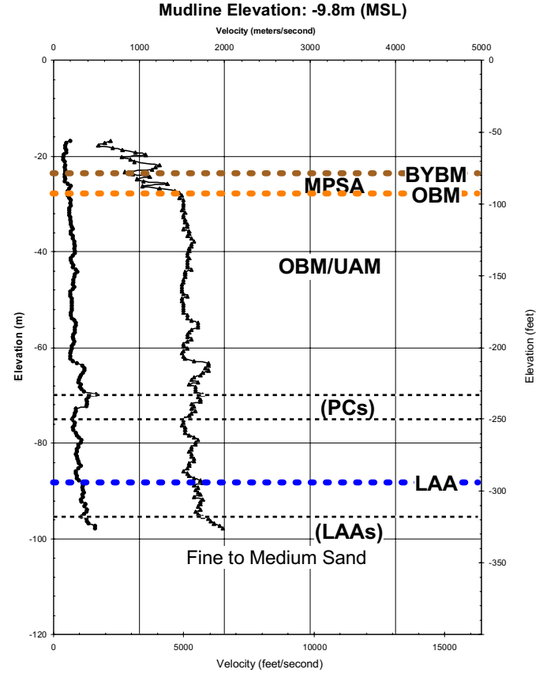
Earth Mechanics FUGRO

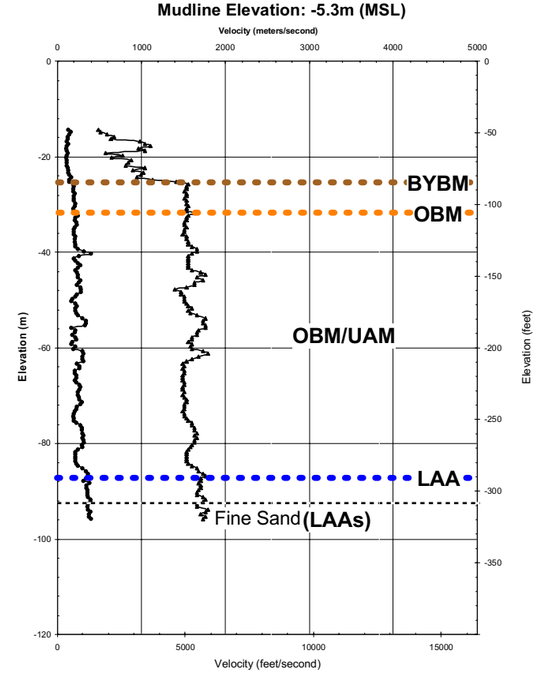
BORING 98-27
Mudline Elevation: -12.6m (MSL)



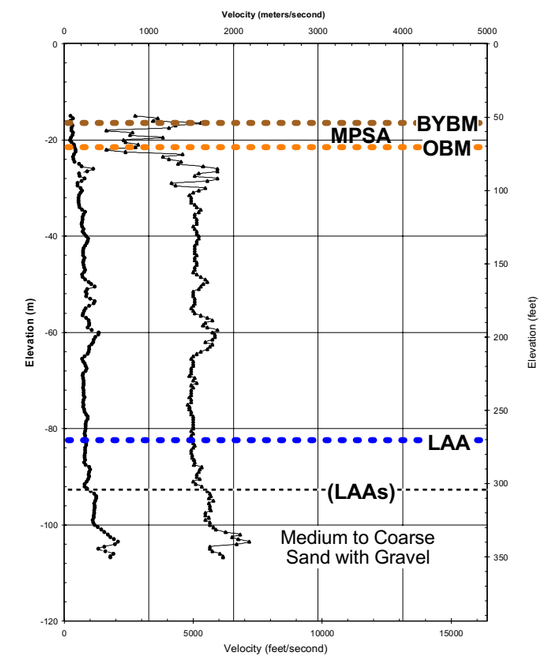
BORING 98-29
Mudline Elevation: -9.8m (MSL)



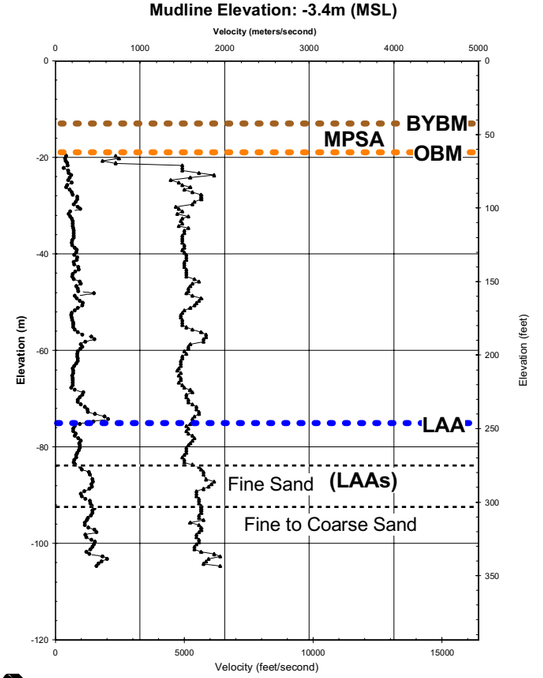
BORING 98-31
Mudline Elevation: -5.3m (MSL)



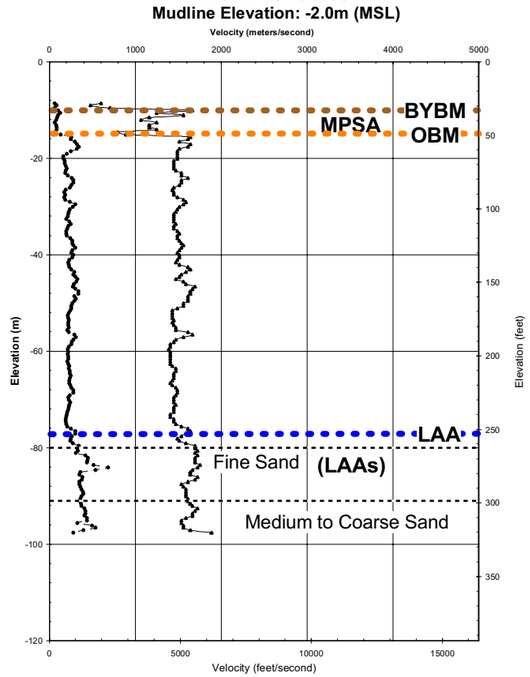
BORING 98-34
Mudline Elevation: -3.8m (MSL)



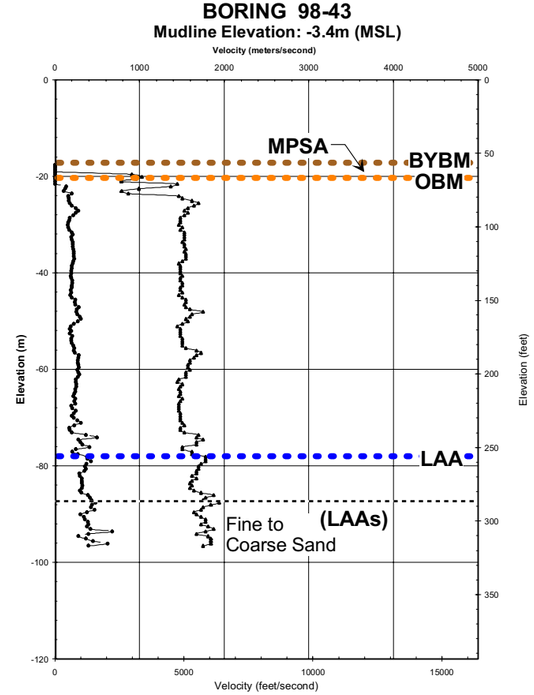
BORING 98-37
Mudline Elevation: -3.4m (MSL)



BORING 98-39
Mudline Elevation: -2.0m (MSL)



BORING 98-43
Mudline Elevation: -3.4m (MSL)



LEGEND

- Bay Floor
- Young Bay Mud (YBM)
- Base (BYBM)
- Merritt-Posey-San Antonio (MPSA)
- Top Old Bay Mud (OBM)
- Old Bay Mud/ Upper Alameda Marine (OBM/UAM)
- Paleochannel Sand (PCs)
- Top Lower Alameda Alluvial (LAA)
- Lower Alameda Alluvial Sediments (LAA)
- Sand (LAAs)
- Top Franciscan Formation (FR)

VELOCITY LOGS FROM THE 1998 BORINGS

SFOBB East Span Seismic Safety Project

PLATE 2.14c

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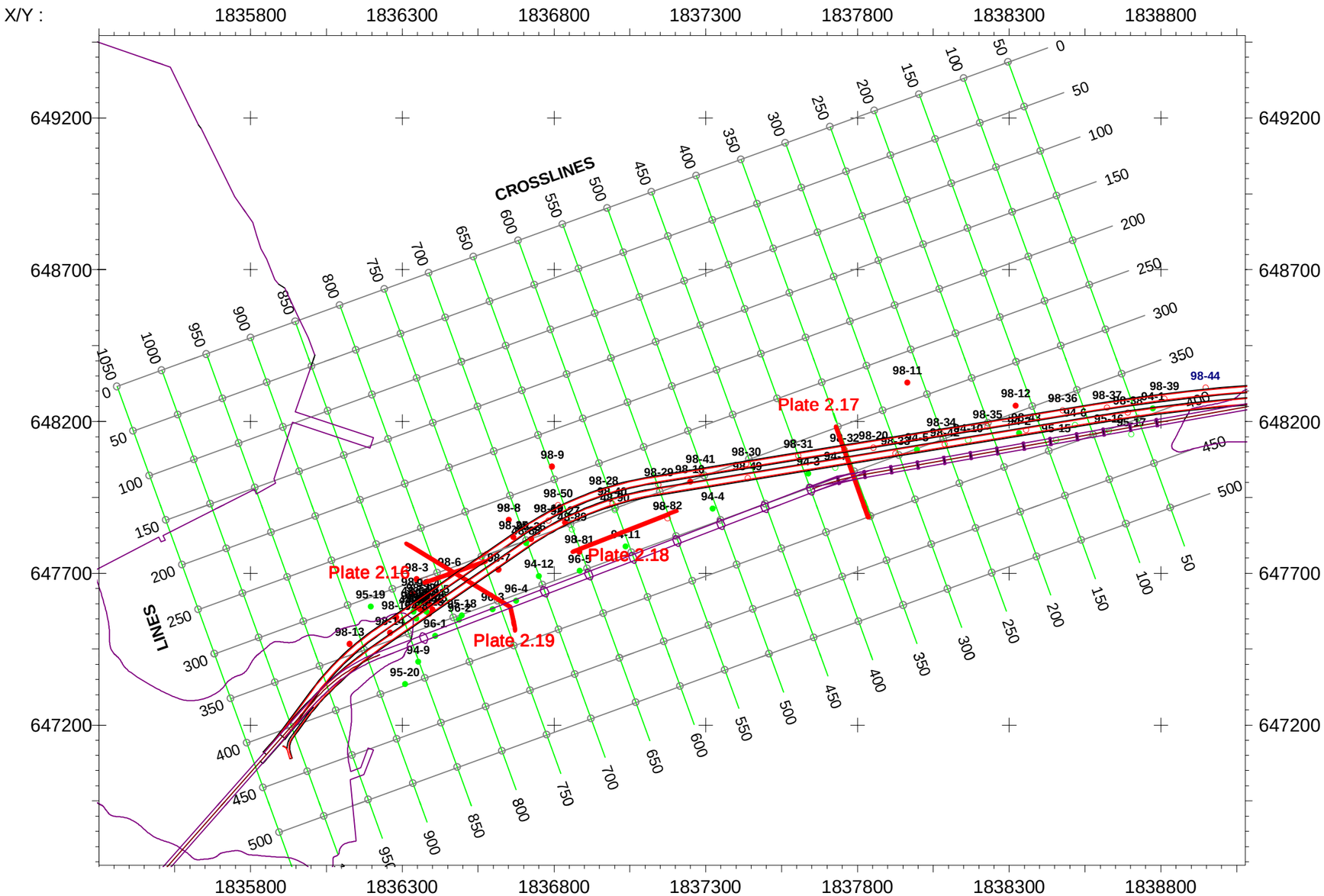


NOTES:

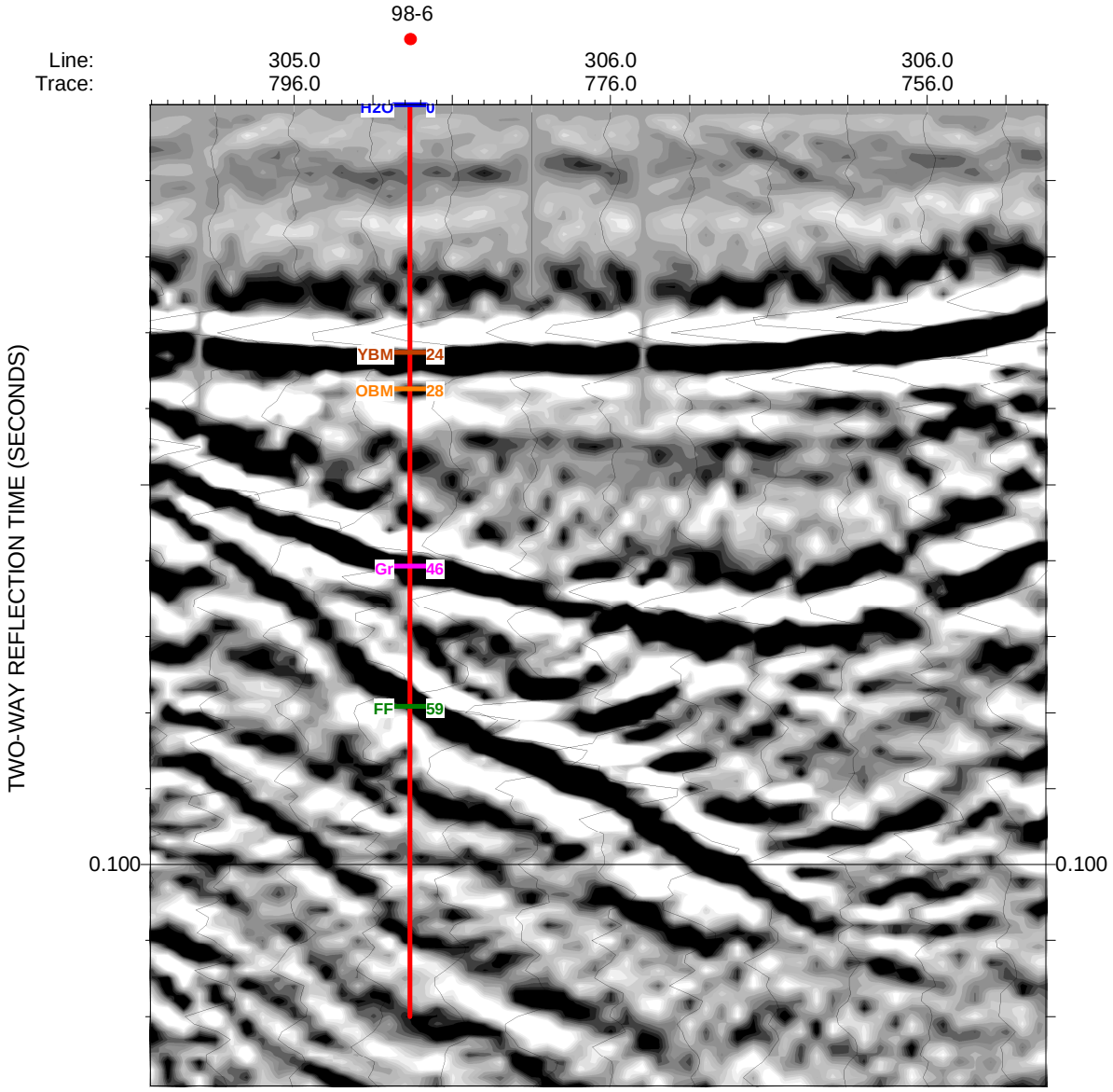
1.) Standard Basemap features include geographic coordinate system and 3-D survey bin grid. Optional features such as shorelines, SFOBB, and N6 alignment, can be turned "on or off" by interpreter.

2.) Basemap scale and colors can be changed. Bin-line spacing and labeling are also adjustable.

3.) When a seismic line is "activated" (brought up to screen for viewing) it is highlighted on basemap.

4.) Locations of seismic lines illustrated in Section 2.6 are shown.

3-D SURVEY BASEMAP WITH LOCATIONS OF SEISMIC LINES ILLUSTRATED IN SECTION 2
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project



NOTES:

Approximate Scales
Horizontal 1:1250
Vertical 1:625

1.) Boring Designations: YBM = Bay Floor/Top of Young Bay Mud
OBM = Top Old Bay Mud
Gr = Thin Sandy Clay with Gravel Layer (3 m)
FF = Top Franciscan Formation

2.) Horizontal depths picked in borings are converted to reflection times by Kingdom Suite using project velocity model. Borings are projected onto seismic lines to allow correlation of horizons with reflectors. Projection distance can be set in the program.

3.) See Plate 2.15 for location of Line.

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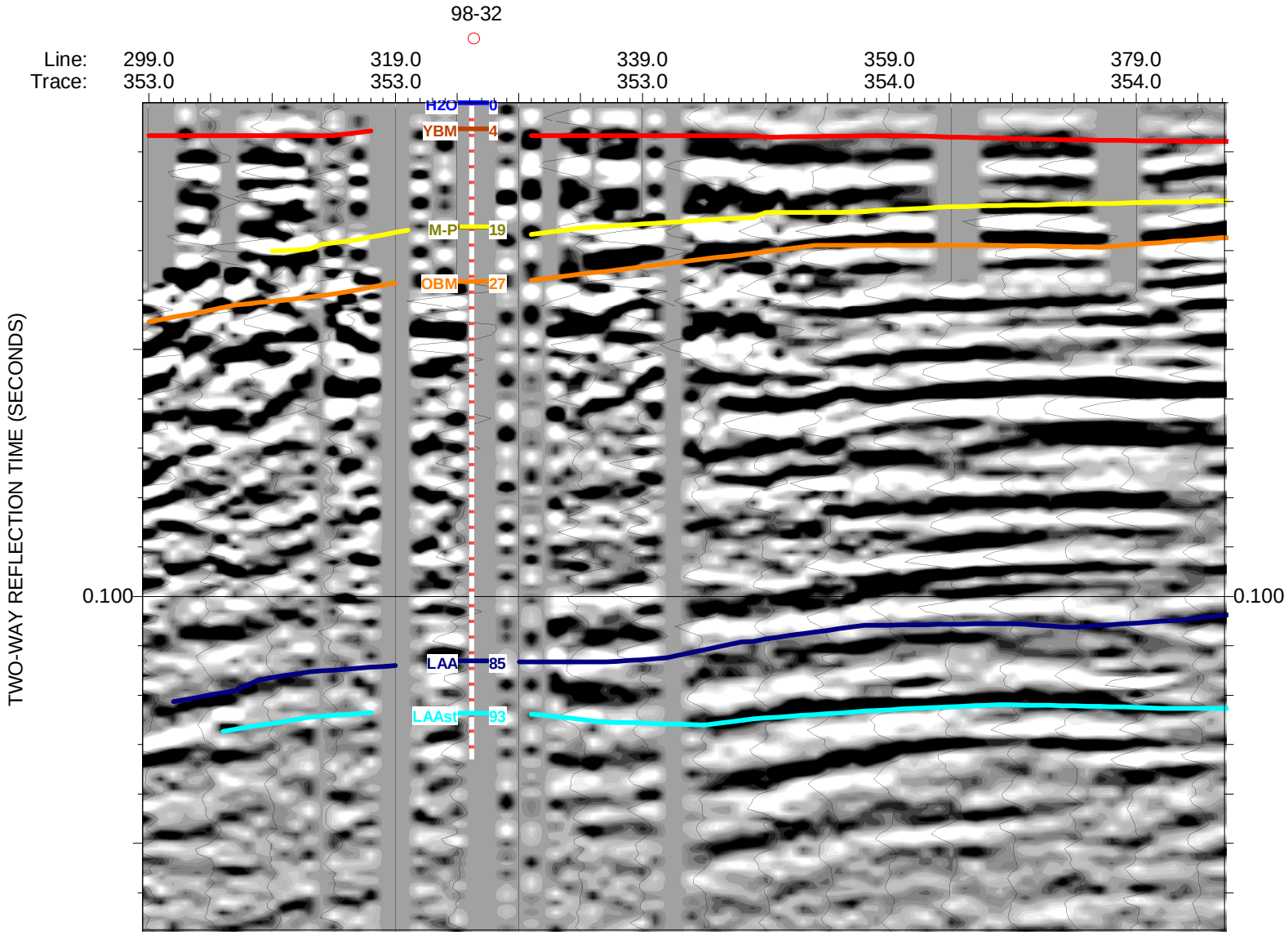
SEISMIC LINE 306 WITH BORING 98-6
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project



Approximate Scales
Horizontal 1:2000
Vertical 1:1000

NOTES:

1.) Refer to Plate 2.15 for location of line.

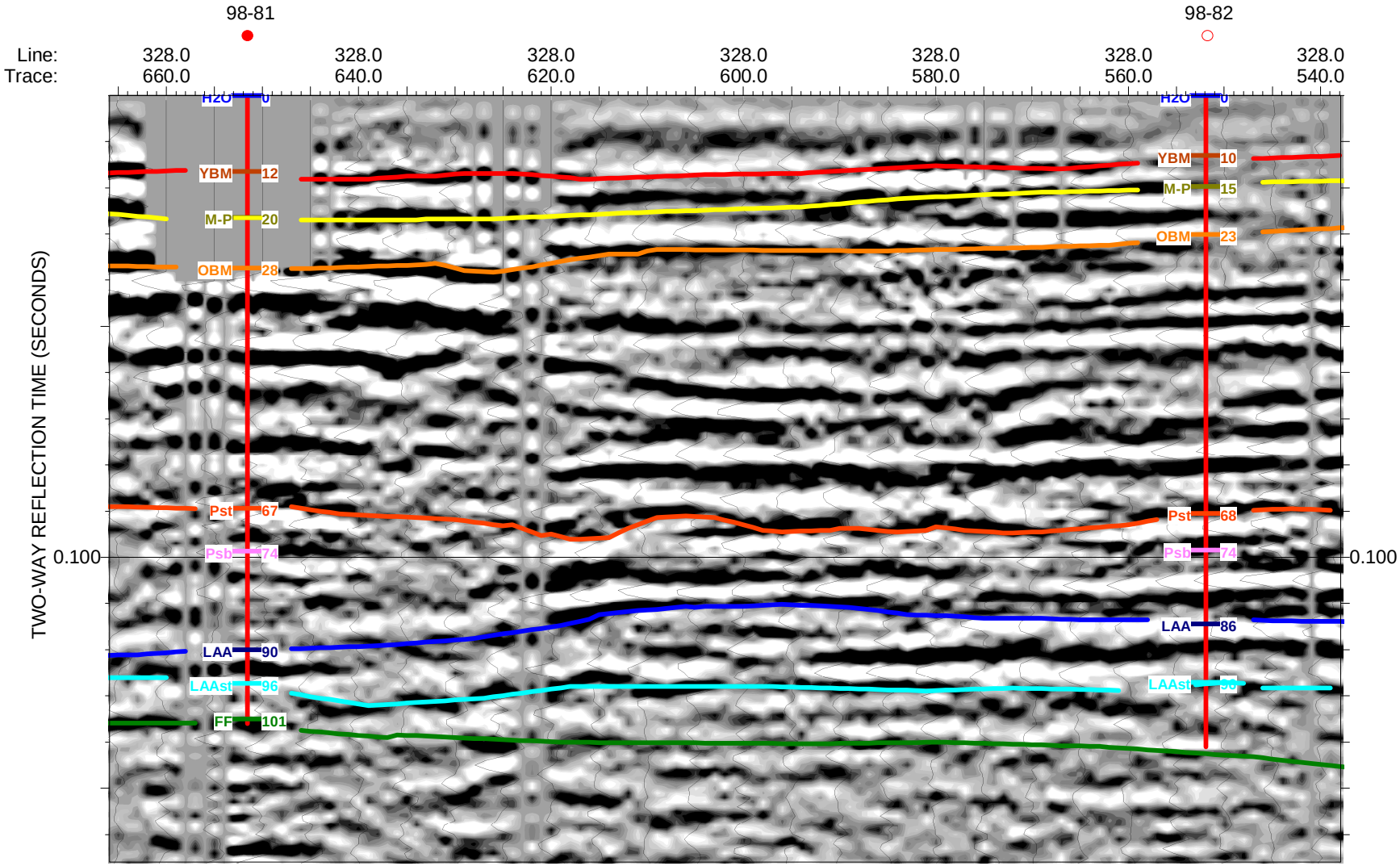
2.) Boring Notations:
YBM (Red) = Bay Floor and Top Young Bay Mud
M-P (Yellow) = Top Merritt-Posey Sands
OBM (Orange) = Top Old Bay Mud
LAA (Dark Blue) = Top Lower Alameda Alluvial Sediments
LAAst (Cyan) = Top LAA Sand

CROSSLINE 353 WITH MAPPED HORIZONS
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project

SFOBB Task Order No. 5
Project No. 98-42-0054

Earth Mechanics

FUGRO



NOTES:

1.) Refer to Plate 2.15 for location of Line.

2.) Boring Notations:
YBM (Red) = Bay Floor and Top Young Bay Mud
M-P (Yellow) = Top Merritt-Posey Sands
OBM (Orange) = Top Old Bay Mud
Pst, Psb (Salmon) = Upper Alameda Marine Paleochannel Sand Top (t) and Base (b)
LAA (Dark Blue) = Top Lower Alameda Alluvial Sediments
LAAst (Cyan) = Top LAA Sand
FF (Green) = Top Franciscan Formation

Approximate Scales
Horizontal 1:2000
Vertical 1:1000

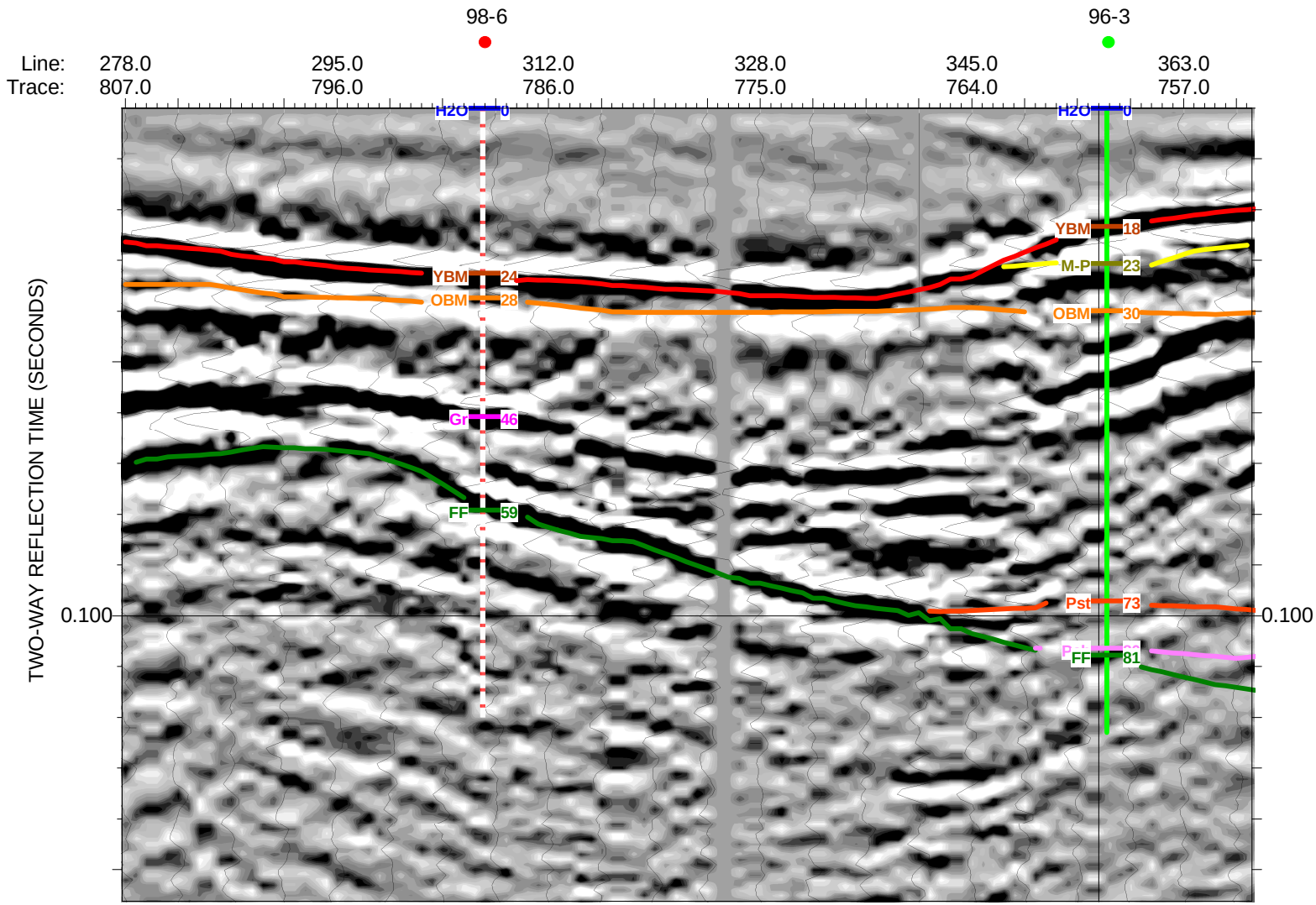
LINE 328 WITH MAJOR MAPPED HORIZONS
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project

PLATE 2.18

SFOBB Task Order No. 5
Project No. 98-42-0054

Earth Mechanics

FUGRO



NOTES:

1.) Kingdom Suite constructs arbitrary seismic lines as drawn by interpreter on the base maps. Line and trace (crossline) designations define path of line which can include bends. See Plate 2.15 for location of line.

2.) Boring (well) horizons, depth, are converted by Kingdom Suite program to reflection times using project velocity model.

3.) Horizons to be mapped are traced on the seismic line in chosen colors using a mouse. Strong, continuous reflectors can be traced automatically by the program.

Approximate Scales
Horizontal 1:2000
Vertical 1:1000

BORING AND HORIZON DESIGNATIONS:

YBM (Red) = Bay Floor
M-P (Yellow) = Top Merritt-Posey Sands
OBM (Orange) = Top Old Bay Mud
Gr (Magenta) = Thin Sandy Clay with Gravel Layer
Pst (Salmon) = Top of Paleochannel Sand
Psb (Pink) = Base of Paleochannel Sand
FF (Green) = Top Franciscan Formation

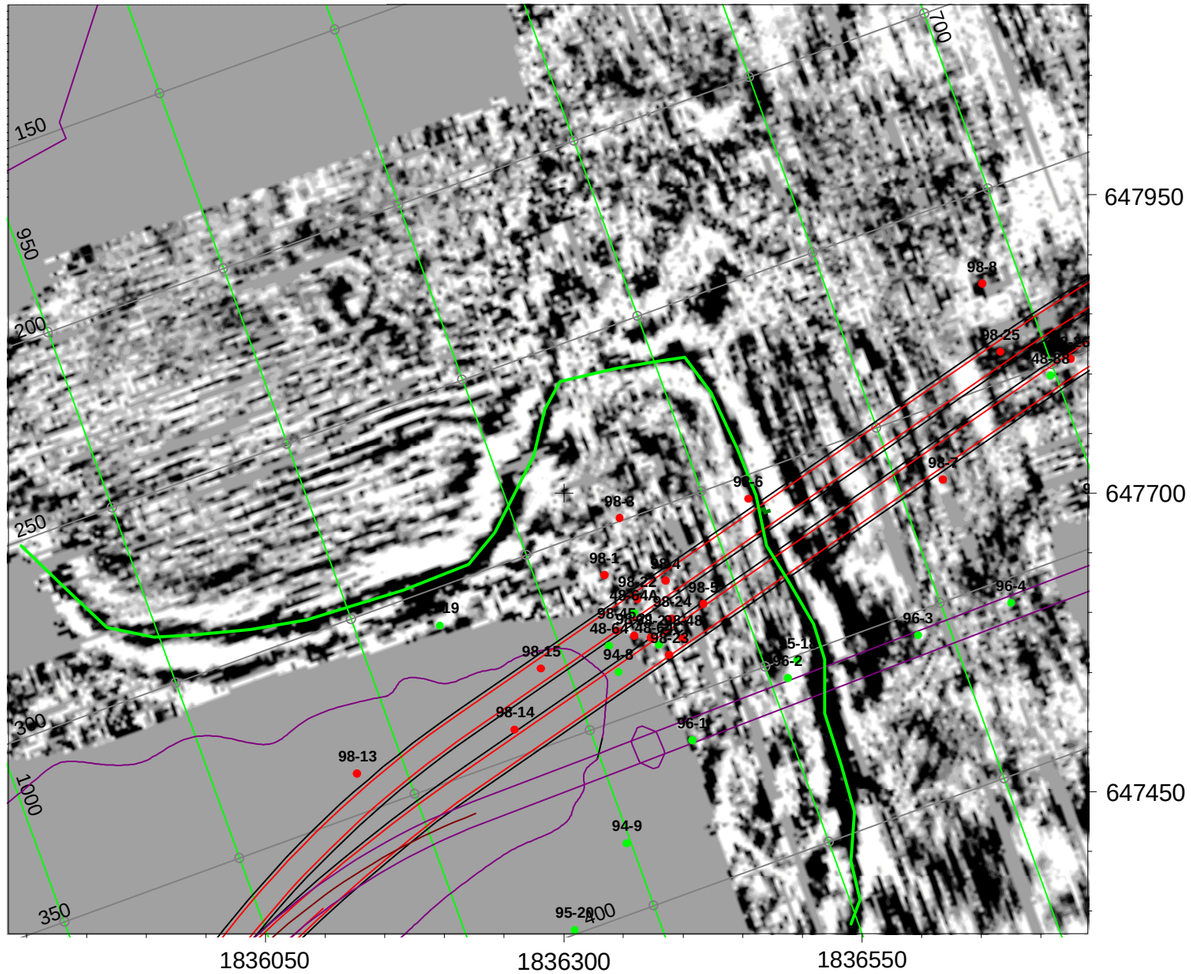
ARBITRARY SEISMIC LINE WITH INTERPRETED HORIZONS
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project

SFOBB Task Order No. 5
Project No. 98-42-0054

Earth Mechanics

FUGRO

X/Y :



Scale 1:5000

NOTES:

1.) Time slices show reflection amplitudes at a chosen two-way reflection time.

2.) Due to geologic structure and variations in seismic velocities the slice does not necessarily represent reflection amplitudes within the same geologic unit.

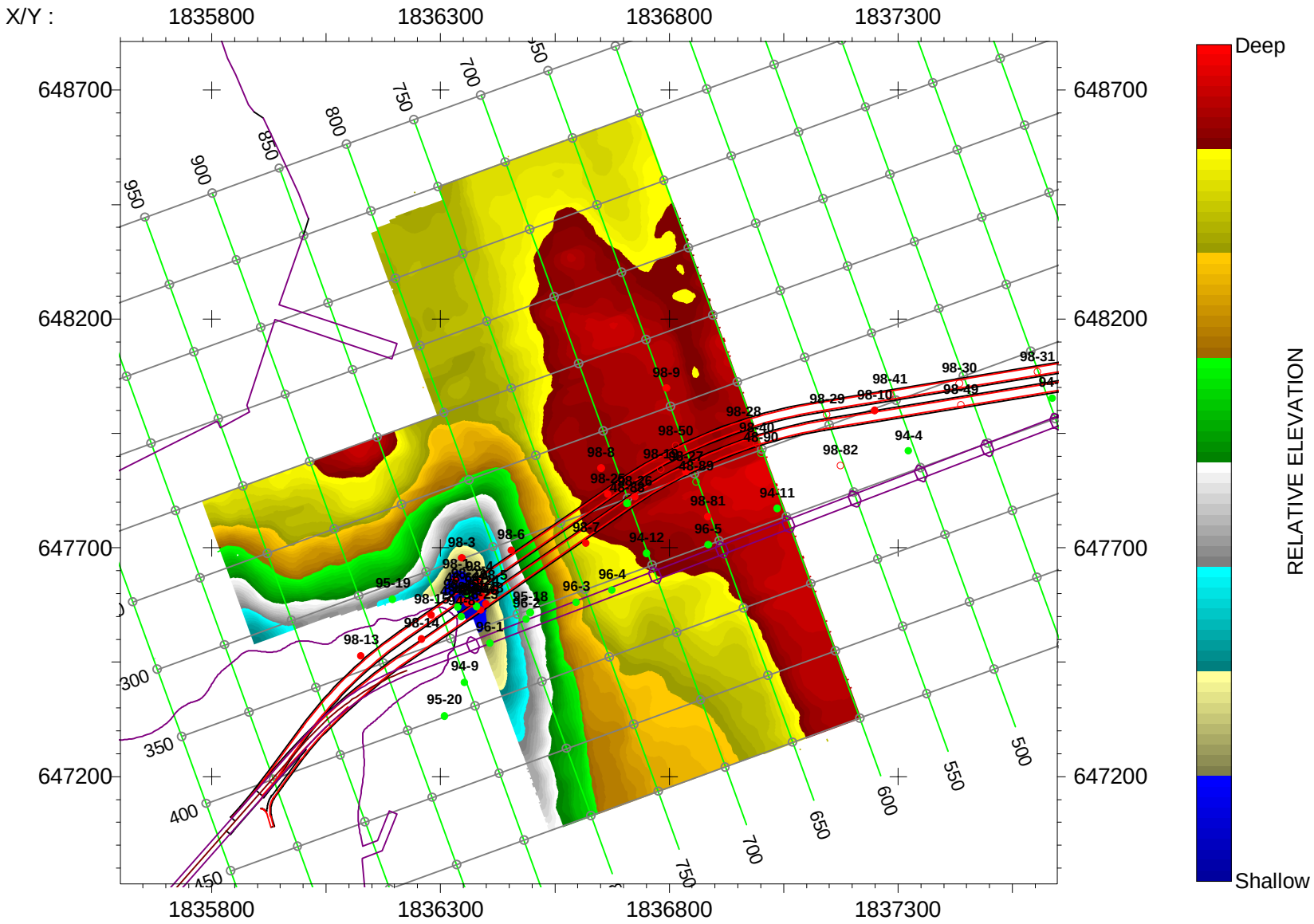
3.) Geologic horizons that have been mapped and are "active" in the program will show as colored lines where intersected by the time slice.

4.) On this figure the green line traces the Top of the Franciscan Formation where it has been mapped at a two-way reflection time of 80 milliseconds (approximate elevation of -60 meters). Compare trace with -60m contour on Map 11 which shows bedrock nose dipping to the northeast from Yerba Buena Island.

5.) Additional time slices are shown on plates 5.5a and 5.5b from Section 5.

TIME SLICE AT 80 MILLISECONDS
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project

9842\0054kn1_5_p3.doc



NOTES:

1.) Basemap shows project coordinates, 3-D survey bin grid (50-bin interval), boring locations, and cultural features (islands, bridge, N-6 Alignment).

2.) Color shading (80 shades) shows elevation of Top of Franciscan Formation at a 1.25m contour interval. Color bar selections are arbitrary.

3.) Map is constructed from Top of Franciscan Formation horizons as drawn by interpreter on the individual seismic lines and crosslines.

4.) Reflection times are converted to elevations using velocity model developed for survey area.

5.) Data from this map are exported to a graphic information system (GIS) program for final contouring.

Scale 1:12,000

COLORED CONTOUR MAP
TOP OF FRANCISCAN FORMATION
Kingdom Suite Data Example
SFOBB East Span Seismic Safety Project

PLATE 2.21

SFOBB Task Order No. 5
Project No. 98-42-0054

Earth Mechanics

FUGRO

SECTION 3.0
STRUCTURAL CONTOUR AND ISOPACH MAPS

3.0 STRUCTURAL CONTOUR AND ISOPACH MAPS

3.1 INTRODUCTION TO THE HORIZON AND ISOPACH MAPS

Twelve large-scale maps showing elevations of geologic unit horizons or isopachs (thickness) of sediment layers are included with this report. Ten of the maps are associated with the sediment units and one depicts the Franciscan Formation bedrock surface. Those eleven maps are discussed in the following parts of this section. The top of the Franciscan Formation bedrock in the area around the northeast point of Yerba Buena Island is also presented on a detailed map that is discussed in Section 5.0. All structural contour and isopach maps also are included in this report at smaller scales as 11x17-inch plates (Plates 3.1 through 3.11, and 5.14).

The procedures for constructing the maps and discussions of their relative accuracy compared to the geotechnical data are discussed in Section 2.6 of this report. All of the maps have been updated from the previous reports (Fugro-EM, 1998c and 1999) to reflect the additional geophysical and geotechnical data collected during the 2000 Phase 3 investigations. The following maps are included with this report and are described in this section.

- Structural Contours, Base of Young Bay Mud (Map 5, Plate 3.1, Section 3.2)
- Isopach (Thickness) of Young Bay Mud (Map 6, Plate 3.2, Section 3.3)
- Isopach (Thickness) of Merritt-Posey-San Antonio Formations (Map 7, Plate 3.3, Section 3.4)
- Structural Contours, Near Top of Old Bay Mud (Map 8, Plate 3.4, Section 3.5)
- Structural Contours, Top of Upper Alameda Marine Paleochannel Sand (Map 9a, Plate 3.5, Section 3.6)
- Structural Contours, Base of Upper Alameda Marine Paleochannel Sand (Map 9b, Plate 3.6, Section 3.6)
- Isopach (Thickness) of Upper Alameda Marine Paleochannel Sand (Map 9c, Plate 3.7, Section 3.6)
- Structural Contours, Top of Lower Alameda Alluvial Sediments (Map 10, Plate 3.8, Section 3.7)
- Structural Contours, Top of Lower Alameda Alluvial Sand (Map 11, Plate 3.9, Section 3.8)
- Isopach (Thickness) of Sediment Section Above Lower Alameda Alluvial Sand (Map 12, Plate 3.10, Section 3.9)
- Regional Structural Contours, Top of Franciscan Formation (Map 13, Plate 3.11, Section 3.10). A larger scale map of the Top of Franciscan Formation near Yerba Buena Island is discussed in Section 5 (Map 14, Plate 5.14, Section 5.5).

Most of the maps are at a scale of 1:5000 and the plates at a scale of 1:10000. However, Maps 9a to 9c (Upper Alameda Marine Paleochannel Sand) and Map 14 (Franciscan Formation near Yerba Buena Island) are at a scale of 1:2000, with the respective paleochannel sand plates (Plates 3.5 through 3.7) scaled at 1:4000 and 1:5000 for the bedrock (Plate 5.14). All structural contour maps are referenced to MSL 1929 (Caltrans, 1997a).

3.2 STRUCTURAL CONTOURS, BASE OF YOUNG BAY MUD (MAP 5)

This map depicts the shape and elevation of the Base of Young Bay Mud as a series of structural contours. The Young Bay Mud has filled a major paleochannel and its tributaries that formed during the last sea level low stand. The base of the Young Bay Mud reflects the topography as it existed at the end of the low stand. The Young Bay Mud lies on top of either the Merritt-Posey-San Antonio Formations or, where the latter have been eroded, directly on the Old Bay Mud.

Distinguishing characteristics of the Young Bay Mud and its basal reflector on the seismic reflection records include its surficial stratigraphic position, the unconformity with the underlying sediments, and the previously discussed gas content. The latter results in P-wave velocities that are consistently below 1,000 m/sec while P-wave velocities ascribed to the underlying units are around 1,500 m/sec. The velocity contrast gives rise to a high-amplitude basal reflector that is easily mapped except where the unit is greater than about 20 meters thick (and the seismic reflection is obscured by the gas in the sediments).

South of the existing SFOBB, the base of the Young Bay Mud contours are mapped directly from the seismic reflection data. Between the SFOBB and the N6 alignment, the seismic data are correlated with geotechnical explorations. However, as the base of the Young Bay Mud enters the main east-west-trending paleochannel, identification of the reflector as a continuous surface becomes less certain as the velocity variations associated with varying gas contents affect data quality and distort the seismic image, and there are only a few geotechnical explorations available for correlation. The result is that the shape of the basal surface is defined, but the relative accuracy of the contour lines decreases north of the N6 alignment. Examples of various types of seismic records showing the base of the Young Bay Mud reflector are included as plates in Sections 2.0, 4.0, and 5.0.

The structural contours of the base of the Young Bay Mud show that it has filled a southwest-trending valley that has been designated in the literature as the ancient channel of the Wisconsin Age Temescal Creek (Rogers and Figures, 1991). In the mapped area, seven tributary channels enter the main channel from the southeast, south, and north. The base of the main channel lies between El. -35 and El. -40 meters as indicated by both geotechnical borings and CPT soundings.

At the western end of the mapped area and to the northeast of Yerba Buena Island, the main channel turns northwest and heads toward the eastern side of Treasure Island. From there,

it apparently trended to the north along the eastern edge of what is now Treasure Island before turning west toward the Golden Gate (Lee and Praszker, 1969; Case History 2, Figure 1). Both Rogers and Figures (1991) and Goldman (1969; Plate 3) show the channel turning to the south around Yerba Buena Island. However, CPT soundings offshore the eastern end of the island show that the clay infill in the apparent northeast-southwest-oriented channel is very stiff and obviously older than the Young Bay Mud (see Subsurface Cross Sections, Plates 4.2a and 4.14). Mapping of the Fugro-EM geophysical data, integrated with shear strength data from CPT soundings, supports the northwesterly turn in the channel thalweg rather than the southern route.

Beneath the N6 alignment, the base of the Young Bay Mud dips relatively steeply along the channel edges and the slope gradually decreases into the broad channel base. Along the slope and within the channel bottom, the Young Bay Mud rests directly on either the Merritt-Posey-San Antonio Formations or, where they have been eroded, the Near Top of Old Bay Mud (Map 8). There is insufficient geotechnical data north of the N6 alignment to completely identify the geotechnical properties of the underlying sediment. (See discussion of paleochannel models, Section 2 and Plates 2.9 and 2.10.)

At the western end of the mapped area, the base of the Young Bay Mud onlaps either the Merritt-Posey-San Antonio Formations or the Yerba Buena Island sediments. In this area, recent sand deposits (designated as the shoal sand in Section 5.0) and artificial fill (mud) from the construction of Treasure Island overlie the Young Bay Mud.

The N6 alignment lies along the southern boundary of the paleochannel. The Base of the Young Bay Mud is quite irregular both along and across the alignment. Elevations of the base range from El. -11 meters near the Oakland Mole to El.-35 meters in a tributary channel at the location of N6 Pier E7. At the western end of the N6 alignment (east of Pier E1), the base of the Young Bay Mud ranges from El. -18 to El. -24 meters. In the latter area, the present scoured surge channel has modified or limited the deposition of the mud. In north-south sections across the N6 alignment, the base of the Young Bay Mud may be relatively flat (N6 Piers E14 to E17) or show relief of up to 8 meters (N6 Piers E4 to E6 and E8 to E10).

South of the N6 alignment, outside of the channels, the base of the Young Bay Mud is relatively flat and slopes gently to the west. It is between El. -11 to El. -14 meters at the east end of the survey area and reaches El. -33 between SFOBB Piers E2 and E3. In this area, the Young Bay Mud rests directly on the Merritt-Posey-San Antonio Formations.

3.3 ISOPACH OF YOUNG BAY MUD (MAP 6)

The isopach of the Young Bay Mud (Map 6, Plate 3.2) was constructed by subtracting the Base of Young Bay Mud (Map 5, Plate 3.1) from the Bathymetry (Map 2, Plate 2.2). The Bay floor elevations used as the upper surface of the Young Bay Mud are those from the 1998 Phase 1 survey, not the 2000 Phase 3 multibeam survey. The latter survey was completed after construction of Map 6 and only covered a limited area around the N6 alignment and the eastern

end of Yerba Buena Island. The only areas of difference in Bay floor elevations between the two surveys are in the vicinity of the local scour holes around the SFOBB piers. Elsewhere, the two surveys are generally within a few tenths of a meter.

The thickness of the Young Bay Mud ranges from less than 5 meters to over 25 meters. It is thinnest south of SFOBB and thickest along the thalweg of the main paleochannel and in the tributary channel at N6 alignment Pier E7. In many areas, there are approximately 5 meters of coarse sediments at the base of the main channel. Those sands represent early, basal channel-fill deposits. These basal channel-fill sediments are lithologically similar to the sediments of the Merritt-Posey Formations and are probably age-equivalent to the period between erosion of the Merritt-Posey-San Antonio Formations and deposition of the Young Bay Mud clay. They may also be age-equivalent to the Yerba Buena Island sediments described in Sections 1.4 and 2.5. The basal channel-fill deposits are evident in Borings 98-9 and 98-11 and are not included in the isopach contours.

Along the N6 alignment, the thickness of the Young Bay Mud ranges from approximately 10 meters at the Oakland Mole to over 25 meters in the tributary channel at N6 Pier E7. West of N6 Pier E7, the Young Bay Mud thins to less than 10 meters at Pier E4, and then thickens to about 16 meters at Pier E2. Farther to the west, the Young Bay Mud thins due to either non-deposition or erosion in the present scour channel off Yerba Buena Island. This is shown on Map 6 and Plate 3.2 in the insert area around the proposed Main Span-Pylon site. The thickness of Young Bay Mud at the base and western side of the scour channel is between 0 and 3 meters.

At the western end of the map area, the Young Bay Mud is overlain by a combination of shoal sand and artificial fill. The latter are likely dredge spoils of Young Bay Mud from the construction of Treasure Island and are usually separated from the natural Young Bay Mud by a thin remnant of shoal sand. The fill material is not included in the isopach of Young Bay Mud (Map 6, Plate 3.2). Further discussion of this area is presented in Section 5.3 and an isopach of the fill is shown on Plate 5.9.

South of the paleochannel and the N6 alignment, the Young Bay Mud is generally 5 to 12 meters thick except where it has filled tributary channels. It is 10 to 12 meters thick at the Oakland Mole and thins westward to 3 to 9 meters west of SFOBB Pier E6. Much of this thinning occurs between 2-D survey lines 40 and 34 (Map 6), where the apparent western front of the most recent lobe of surficial sediment ends. The western front appears as a 2-percent, west-facing, bathymetric slope between the El. -8 and El. -12 meter contours on Map 1 and Plate 2.1. It can be seen on the seismic section shown on Plate 2.13 between fix points 489 and 483.

3.4 ISOPACH OF MERRITT-POSEY-SAN ANTONIO FORMATIONS (MAP 7)

The identification of sediments belonging to the Merritt-Posey-San Antonio Formations includes stratigraphic, lithologic, and geotechnical considerations (Sections 1.4 and 2.5, Table 1.1). On the seismic records, the base of the overlying Young Bay Mud can usually be easily

recognized. However, the distinction between the base of the San Antonio Formation clay and the top of the Old Bay Mud is based on geotechnical characteristics that may be gradual and not result in a seismic reflector with significant amplitude or continuity to be mapped. In addition, mapping of individual horizons within Merritt-Posey-San Antonio Formations is difficult since they generally do not continue for great distances, are often channeled, and are intermixed with multiple reflections, peg-leg reflections, and other problems associated with seismic reflection data recorded in shallow water. Due to alternating reinforcement and interference from the unwanted signals, the apparent signal phase from these shallow geologic reflectors can alternate along strike, giving the appearance of lateral lithologic changes, false channel edges, or other geologic features.

An isopach map of the sediments from the Merritt-Posey-San Antonio Formations (Map 7, Plate 3.3) was constructed using both geotechnical and geophysical data. In the area of the N6 alignment, CPT soundings were the primary tool used to identify the top and base of this sediment sequence. South of the N6 alignment, the mapping is based on a combination of seismic reflection data and correlation with lithology and shear strength measurements from boring samples. Isopach values in this area were calculated by subtracting the Near Top of Old Bay Mud (Map 8, Plate 3.4) from the Base of the Young Bay Mud (Map 5, Plate 3.1). The contours were derived from two mapped surfaces rather than from direct measurements of thickness on the seismic records. Although neither of the top or bottom surfaces are tightly constrained by the seismic data or borings, the resulting isopach map appears to be quite uniform in this area.

North of the N6 alignment, there is generally insufficient geotechnical data to identify the contact between the base of the San Antonio Clay and the top of the Old Bay Mud. Possible basal channel-fill deposits along the Young Bay Mud-filled paleochannel (Borings 98-9 and 98-11) are grouped with the Merritt-Posey-San Antonio Formations as are the sediments encountered in the CPT soundings to the northeast of Yerba Buena Island. The significant component of sand in these deposits (indicated by a yellow highlight on the maps), their stratigraphic position beneath the Young Bay Mud, and the shear strength values of the interlayered clay result in their identification as sediments from the Merritt-Posey-San Antonio Formations rather than the Old Bay Mud.

Along the southern flank of the main paleochannel axis (Plates 3.1 and 3.2), the Merritt Posey-San Antonio Formations appear to have been at least partially eroded. Examination of seismic reflection records in some areas along the flanks of the channel show that the flat-lying sediment horizon immediately above the Near Top of Old Bay Mud has been eroded or thinned significantly on both the north and south flanks of the channel (Plates 2.8 and 2.12). This explanation agrees with a Rogers and Figures (1992) interpretation that the Merritt Sands were eroded in very-late Wisconsin time by a rejuvenated stream system, the Temescal Creek.

Along the N6 alignment, the Merritt-Posey-San Antonio Formations are 2 meters to 12 meters thick. Northward-flowing tributary channels of the ancient Temescal Creek have cut through the sediment section in the vicinity of N6 Piers E8 and E13. Except for those tributary channels, the Merritt-Posey-San Antonio Formations are 5 to 10 meters thick along the N6 alignment and generally contain 3 meters or more of sand.

At the northwest side of the mapped area, the Merritt-Posey-San Antonio isopach shows the sediments filling a channel in much the same area as the Young Bay Mud-filled paleochannel. Around the northeastern end of Yerba Buena Island, the Merritt-Posey-San Antonio sediments appear to interfinger with the Yerba Buena Island sediments. This interfingering is illustrated on the cross sections on Plates 5.11a to 5.11m.

In the area south of the N6 alignment, the top of the Old Bay Mud can be recognized as a local unconformity on the seismic reflection records (Plates 2.8, 2.12, 5.13b and 5.13c). The Merritt-Posey-San Antonio Formations are generally 3 to 9 meters thick in this area.

3.5 STRUCTURAL CONTOURS NEAR TOP OF OLD BAY MUD (MAP 8)

Map 8 and Plate 3.4 show elevation contours on a reflector interpreted to be at or near the Top of the Old Bay (Yerba Buena) Mud. The interpreted surface elevations range from El. -15 meters in the eastern part of the survey area to El. -49 meters in the paleochannel north of Yerba Buena Island.

Although in some locations the top of the Old Bay Mud is an unconformity, there are uncertainties in the recognition of a single horizon or seismic reflector as the Top of Old Bay Mud in both the borings and on the geophysical records. Of all the horizons for which structural contour maps were produced, this horizon is the least constrained by the seismic data and the reason the surface is named "Near Top of Old Bay Mud".

Identification of a specific reflector was originally based on ties with borings. However, at some locations, the lithologic and geotechnical properties of the overlying San Antonio Formation clay are similar to those of the upper part of the Old Bay Mud, and the property changes are gradational. As the interpretation developed, mis-ties between recent CPT soundings, adjacent borings, and continuous seismic reflectors connecting the borings required re-analysis of many of the boring picks, particularly those that were not supported by available laboratory analysis. In the final interpretation presented on Map 8 and Plate 3.4, the Top of Old Bay Mud was selected as the upper crust (desiccated layer) that appears beneath an extensive interlayered sand and clay horizon in the area west of the Oakland Mole. The crust is noted on the shear strength data in both the CPT soundings and borings and is most obvious in the cross sections (Plates 4.2a and 4.2b). Between the Oakland Mole and N6 Pier E8, the Near Top of Old Bay Mud is generally between El. -20 and El. -25 meters.

Annotated seismic record examples showing the reflector utilized to map the Top of Old Bay Mud are contained in Sections 2.0, 4.0, and 5.0. Examples from the seismic records are shown on:

- 1998 Phase 1 2-D Survey - Plates 2.8 and 2.12;
- 1998 Phase 1 3-D Survey - Plates 2.17, 2.18, 2.19, and 4.11; and
- 2000 Phase 3 2-D Survey - Plates 5.13b, 5.13c, 5.13d, 5.13e, and 5.13f.

On the seismic records from the 2000 Phase 3 survey near Yerba Buena Island, the reflector is continuous and easily identifiable in some areas as an unconformity. In other areas, the reflector is subject to interpretation as it merges into the series of nested, buried channels north of the existing bridge. The complex, nested channels both above and within the Old Bay Mud dominate the central part of the survey area and contain gas within the sediments that interferes with mapping of deeper seismic reflectors. The predominant east-west-trending channel base mapped as the Near Top of Old Bay Mud was one that could be satisfactorily correlated (loop tied) between east-west and north-south-oriented seismic lines.

In the borings and the CPT soundings, the identification of the Old Bay Mud in comparison to the overlying San Antonio Clay is based in part on the undrained shear strengths and the previously mentioned crust. The two different approaches to mapping the Top of Old Bay Mud (i.e., seismic signature correlation and shear strength) do not always precisely agree. Agreement within the relative accuracy of the various methods exists for the mapped Near Top of Old Bay Mud for most of the CPT soundings and 1998 Phase 1 and Phase 2 borings. However, sufficient shear strength data are not always present to make similar determinations from pre-1998 borings.

The Old Bay Mud is overlain by both the Merritt-Posey-San Antonio Formations and the Young Bay Mud (see key schematic on Map 8). In some areas, the Merritt-Posey-San Antonio sequence has been eroded (or was never deposited) and the Near Top of Old Bay Mud is the same as the Base of Young Bay Mud (Section 3.3). However, everywhere beneath the N6 alignment there appears to be at least a thin layer of Merritt-Posey-San Antonio sediments between the Young Bay Mud and Old Bay Mud (see cross sections, Plates 4.2a and 4.2b).

Several tributary channels that eroded into the Near Top of Old Bay Mud are mapped entering the main channel from both the north and south. The contours shown on Map 8 depict the main channel of the ancient Temescal Creek (prior to deposition of the San Antonio Formation clay) turning north around Yerba Buena Island rather than south as indicated by Rogers and Figures (1991). The structure contour map (Map 8) and nested paleochannels in the Old Bay Mud beneath the present scour channel suggest that there were channels in that area during the later stages of deposition of the Old Bay Mud.

Along the N6 alignment, the elevation of the Top of Old Bay Mud ranges from El. -20 meters at the Oakland Mole to El. -25 meters between N6 Piers E7 and E8. At the tributary channel crossing through N6 Pier E7, the surface drops to El. -48 meters. The surface then rises to El. -23 meters at N6 Pier E4 before sloping westward to reach another local low of El. -39 meters just east of Pier E3.

3.6 MAPS OF UPPER ALAMEDA MARINE PALEOCHANNEL SAND (MAPS 9A, 9B, AND 9C)

Maps 9a, 9b, and 9c (Plates 3.5, 3.6 and 3.7) show the top, base, and isopach of a sand layer within the Upper Alameda Marine sediments. The sand was mapped because of its potential impact on pile design and emplacement for the N6 alignment Main Span-East Pier (Pier E2) and Skyway Piers E3 to E6.

The contours shown on the maps are based primarily on a reflector mapped from the 3-D geophysical survey data. This reflector was tied to many of the borings shown on the maps and plates. However, gradual vertical and lateral changes in relative sand content are noted in the geotechnical records and are not always associated with elevation changes in the mapped reflector. An additional uncertainty in the accuracy of both mapped surfaces results from minor variations in seismic velocities from the value used for depth conversions of the seismic reflectors. Generally, the contours and values posted at the geotechnical exploration sites agree within a few meters. While the contour maps provide the shape and general elevation of the paleochannel sand, data from the borings should be used to identify elevations of the paleochannel sand at individual piers.

The western boundary of the mapped sand is the onlap of the unit onto the Franciscan Formation bedrock ridge. The eastern boundary is where the sand apparently thins and grades into a silty sand and clay. The northern and southern boundaries are arbitrary limits imposed by data quality and limit of interest to the project.

The maps show that the sand occurs primarily in the western third of the survey area and was not identified east of bin crossline 500 or in borings east of the proposed location for Pier E6. The top of the sand (Map 9a, Plate 3.5) is generally flat with only minor undulations. It dips gently to the west from about El. -70 meters in the east (near Boring 98-10) to El. -77 meters in the west, where it onlaps the Franciscan Formation bedrock ridge.

The base of the sand also slopes to the west from El. -72 meters at Boring 98-10 to about El. -80 meters, where it also onlaps the Franciscan Formation bedrock ridge (Map 9b, Plate 3.6). Because the bedrock ridge slopes to the east, the onlap of the base of the sand occurs to the east of the onlap of the top. However, the base of the sand deepens to El. -88 meters between bin crosslines 720 to 730, filling what appears to be a north-south-trending paleochannel.

The isopach (Map 9c, Plate 3.7) was constructed by subtracting the base of the unit (Map 9b) from the top (Map 9a). The sand is relatively thin (2 to 3 meters) in the east, and thickens relatively rapidly west of N6 Pier E3 to over 15 meters in the paleochannel near Boring 98-7. The sand is 14 to 15 meters thick at the proposed location for the Main Span-East Pier (Pier E2). It is only 3 to 7 meters thick at N6 Pier E3 and thins to less than 5 meters at Piers E4 to E6. One exception may be the north side of Pier E6, where the sand is 10 meters thick in Boring 98-41. This appears to be a local feature and may include a separate, slightly deeper sand that does not extend into the rest of the mapped area.

The general appearance of the sand top, base, and isopach is that of a channel-filling sand that filled a north-south-trending paleochannel and overflowed the channel banks on the east to form a thin layer. The west bank of the channel was apparently the Franciscan Formation bedrock ridge.

3.7 STRUCTURAL CONTOURS, TOP OF LOWER ALAMEDA ALLUVIAL SEDIMENTS (MAP 10)

The Top of Lower Alameda Alluvial Sediments was identified as a relatively flat, continuous reflector that dips gently to the west. The reflector onlaps the Franciscan Formation just to the east of 2-D survey line 22 (Map 10, Plate 3.8). The appearance of the mapped reflector on the 2-D seismic records is shown on Plates 2.11, 2.13 and on the 3-D sections on Plates 2.17 and 2.18. The reflector is generally associated with a lean clay layer (clay cap on Map 10 key) identified in the borings. That clay layer has geotechnical properties that are distinctly different from those of the overlying Upper Alameda Marine sediments. The reflector is occasionally associated with a crust and a velocity increase (Plates 2.14a, 2.14b, and 2.14c).

Elevations to the top of the reflector were calculated by adding the sediment thickness (determined from two-way reflection time using an average velocity of 1,600 m/sec) to the water depth determined along the seismic lines in the 1998 2-D Phase 1 survey. Since the reflector is relatively flat, mis-ties at line intersections are generally within the stated accuracy (±3 meters) of the method of determination.

The Top of Lower Alameda Alluvial Sediments is difficult to recognize beneath the shallow gas in the central channel. It is not as strong a reflector as the Franciscan Formation bedrock. Even though it lies above the bedrock, there are areas where intermittent bedrock reflectors can be recognized, but there is no evidence of a Top of Lower Alameda Alluvial Sediment reflector above them. This occurs in a broad area north of 2-D survey line 100 and east of line 40 (Map 10) where the Top of Lower Alameda Alluvial Sediment surface cannot be extended. However, the Top of Lower Alameda Alluvial Sediments reflector is recognized on parts of lines 100B, 101, and 101A, which lie beneath the proposed N6 Alignment as it approaches the Oakland Mole.

Elevations of the mapped surface at the onlap to the Franciscan Formation bedrock are about El. -86 meters. The mapped surface dips a couple of meters beneath N6 Piers E2 and E3 and then gradually rises to elevations around El. -80 meters in the vicinity of N6 Pier E12. It continues to rise to El. -77 meters at the Oakland Mole. The only topographic feature of note on this surface is at the southeastern limit of the survey area, where the top of the unit slopes upward from El. -80 to El. -70 meters. This is interpreted as an area of a buried topographic feature (Plate 2.11).

3.8 STRUCTURAL CONTOURS, TOP OF LOWER ALAMEDA ALLUVIAL SAND (MAP 11)

A medium- to coarse-grained sand occurs at El. -92 to El. -98 meters in many borings (Map 11, Plate 3.9). The sand was mapped because of its potential impact on pile design and emplacement of the N6 alignment from Piers E3 east to the Oakland Mole. The top of the sand was mapped using the 3-D geophysical survey data and ties with the 1998 Phase 1 and Phase 2 borings. It was also noted in most of the pre-1998 borings east of bin crossline 670.

The mapping boundaries in Map 11 are a combination of data limitations, arbitrary limits, and extent of the sand unit. The mapped horizon is shown on the seismic sections on Plates 2.17 and 2.18. The data extent and fold of the 3-D survey (Appendix B) limit the southern boundary of the mapped area. The mapped horizon is usually very prominent on seismic sections south of the existing bridge (Plate 2.17), but 3-D survey coverage is very sparse in that area, especially in the eastern third of the survey area. The same is true for the eastern boundary. North of the N6 alignment, the amplitude of the top of sand reflector diminishes. This amplitude change may be due to a change in grain size to a finer-grained or silty consistency (less contrast with overlying sediments) and/or the effects of the gas content in the surficial Young Bay Mud. The western boundary appears to be a limit to the sand deposition. The sand is not found in Borings 48-88, 98-8, 98-25, or 98-26. South of the N6 alignment, it may extend farther west but the sand noted in Borings 94-12, 96-4, and 98-7 is finer grained and at a slightly higher elevation. Therefore, the sand in the later borings is not considered to be part of the horizon mapped over the eastern two-thirds of the area.

Although the top of the sand slopes gently westward, it is flatter than the horizon mapped as the Top of Lower Alameda Alluvial Sediment. The top of the sand ranges from El. -92 to El. -94 meters near the Oakland Mole, to El. -94 to El. -98 meters at its apparent western end. Near the Oakland Mole, the top of the sand is 15 to 17 meters beneath the clay layer mapped as the Top of Lower Alameda Alluvial Sediments (Map 10, Section 3.7). Occasionally fine-grained sand occurs above the medium- to coarse-grained sand. This fine-grained sand is noted between N6 Piers E2 and E15 and at Pier E4. It is not included as part of the mapped Lower Alameda Alluvial Sand.

In the west, between N6 Alignment Piers E4 to E7, the sand is only 5 to 6 meters beneath the clay cap layer. At the borings that extend to the bedrock between N6 Piers E2 and E11, the medium- to coarse-grained sand extends down to within a few meters of the Lower Alameda Alluvial sediment contact with the Franciscan Formation bedrock. East of N6 Pier E11, the depth extent of the sand is unknown.

3.9 ISOPACH OF SEDIMENT ABOVE LOWER ALAMEDA ALLUVIAL SAND (MAP 12)

Map 12 (Plate 3.10) shows the combined thickness of the Young Bay Mud, Merritt-Posey-San Antonio Formations, undifferentiated Old Bay Mud/Upper Alameda Marine sediments, and that part of the Lower Alameda Alluvial sediments above the medium- to coarse-grained sand. The purpose of the isopach map is to indicate the thickness of sediment above the sand horizon as a general indicator for pile design and installation. Although the combined sediment section continues to exist outside of the area where the sand was mapped, the isopach map is limited to the area of the Lower Alameda Alluvial Sand (LAA-sand) map.

The isopach was constructed by subtracting the elevation of the Top of Lower Alameda Alluvial Sand (Map 11) from the bathymetry as mapped from the 3-D survey seismic line grid using The KINGDOM Suite program. This bathymetry is not shown as a separate map. Since the top of the sand was mapped using the 3-D data set, it was necessary to use the 3-D survey bay floor as the reference surface. Map 12 reflects both undulations in the Top of Lower Alameda Alluvial Sand (Map 11) and the Bay floor in the area where the sand was mapped. Minor bathymetric features (e.g., the scour holes adjacent to some of the existing bridge piers shown on the Phase 3 multibeam survey) are generally not reflected in this map. The 3-D survey did not get as close to the existing piers as the multibeam survey nor are the Bay floor reflections as accurately imaged on the multichannel seismic reflection data as they are with a multibeam system.

Sediment thickness above the Lower Alameda Alluvial sand horizon varies between 83 and 90 meters. It is slightly thicker in the east, which reflects the rise in Bay floor elevation at a slightly more rapid rate than the westward slope of the Lower Alameda Alluvial sand layer.

3.10 REGIONAL STRUCTURAL CONTOURS, TOP OF FRANCISCAN FORMATION (MAP 13)

Map 13 (Plate 3.11) shows the elevation contours on the top of the Franciscan Formation bedrock. The contours are based on integrated mapping using the following Caltrans and Fugro-EM marine and onshore data sets.

- 1998 Phase 1 2-D Marine Geophysical Survey (Fugro-EM)
- 1998 Phase 1 3-D Marine Geophysical Survey (Fugro-EM)
- 2000 Phase 3 2-D Marine Geophysical survey (Fugro-EM)

- Pre-1998 Marine Geotechnical Borings (Caltrans)
- 1998-1999 Phase 1 and Phase 2 Marine Geotechnical Borings (Fugro-EM)
- 2000 Phase 3 Marine CPT Soundings (Fugro-EM)
- Pre-1997 Land Borings (Caltrans)
- 1998-2000 Phase 1 and Phase 2 Land Borings (Fugro-EM)
- 1998 Land Seismic Profiles (NORCAL for Fugro-EM)
- 1998-2000 Geological Mapping (Fugro-EM)

The compilation of the marine data and the regional map are described in this section. Further details on the mapping and contours around the eastern end of Yerba Buena Island are discussed in Section 5.0 and presented in the 1:2000 scale Map 14 (Plate 5.14).

The 1998 Phase 1 2-D multichannel sleeve-gun data provided good quality images of the seismic reflector associated with the Franciscan Formation bedrock in the area between Yerba Buena Island and the Oakland Mole and south of the N6 alignment (Plate 2.13). North of the N6 alignment, gas in the shallow sediments degraded the images, but the reflector could still be identified over much of the survey area. The 3-D survey with a higher energy source and close line spacing added additional detail of the bedrock slope around the eastern end of Yerba Buena Island and into the cove between Yerba Buena Island and Treasure Island. Finally the 2000 Phase 3 multichannel minisparker and bay cable surveys provided additional detail in the nearshore area around northeastern Yerba Buena Island and in the cove.

Elevations to the top of bedrock were calculated by measuring the reflection time between the Bay floor and top bedrock reflector on the seismic records. The reflection time through the sediment section was converted to depths beneath the Bay floor using the previously described velocity data. In areas of thick Young Bay Mud with gas and in the cove where there is fill (dredge spoil), the velocity model was modified to account for the lower velocity in the gas-saturated sediments and fill. At navigation fix points, the calculated depths to the bedrock were added to the Bay floor elevations to produce elevations to the top of the bedrock. The horizon tracing and depth conversions were done using The KINGDOM Suite program (Section 2.6). The final contouring and integration with the marine geotechnical data were completed using the ArcView GIS program.

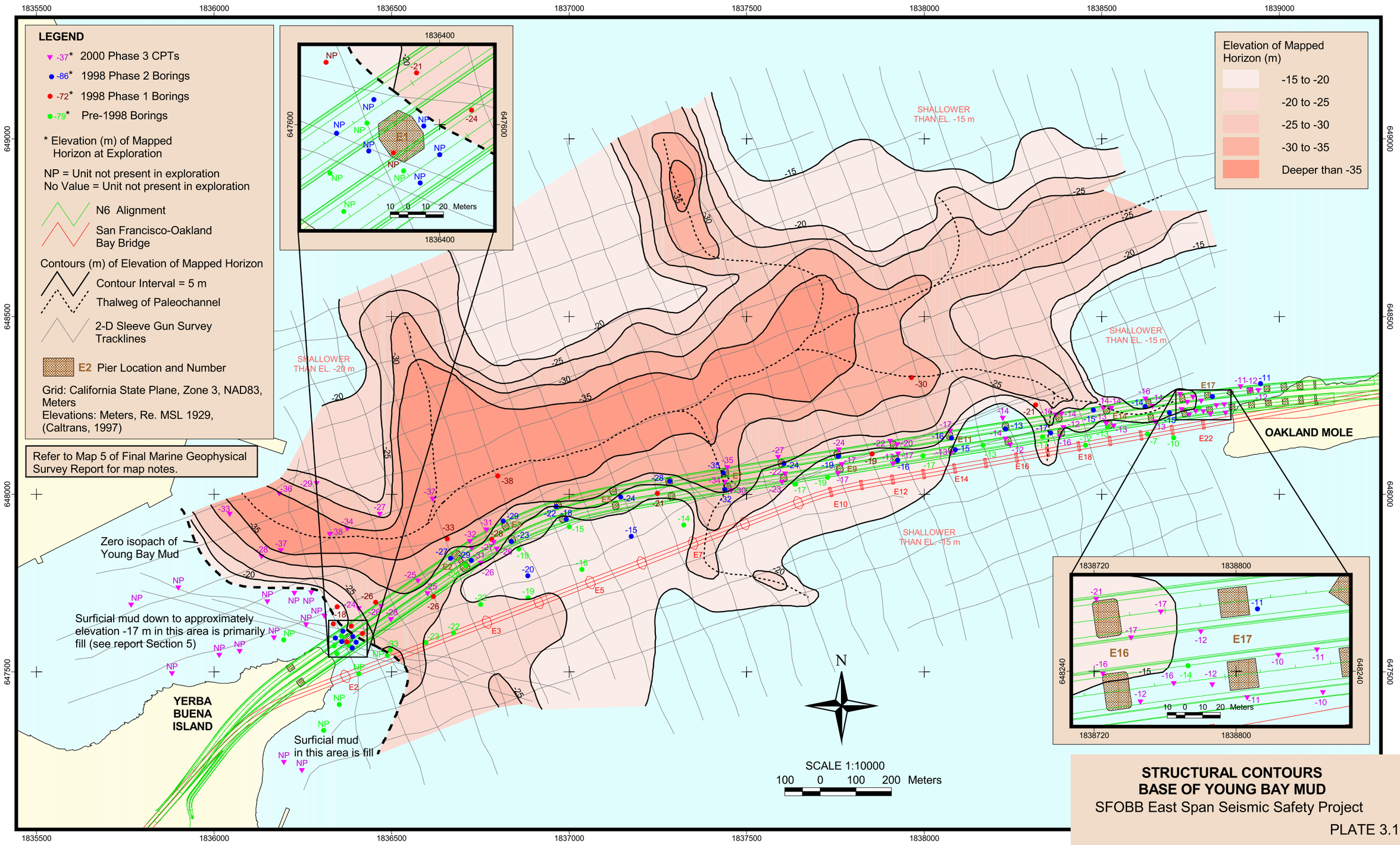
The top of Franciscan Formation bedrock forms an angular unconformity with the overlying sediments. This is evident from the illustrated seismic sections (Plates 2.13, 2.16, 2.19, 5.3a, 5.3b, 5.12, and 5.13a to 5.13f). The unconformity is also evident from the structural contour maps showing onlap of several of the sediment horizons including Near Top of Old Bay Mud (Map 8), Top and Base of the Upper Alameda Marine Paleochannel Sand (Maps 9a and 9b), and Top of Lower Alameda Alluvial Sediments (Map 10). As the age of the unit increases and its elevation deepens, the western edge (onlap point) of the mapped upper surface moves farther to the east along the bedrock slope.

In the area of the Main Span-Pylon (N6 Pier E1), the surface mapped as the Top of Franciscan Formation generally corresponds to the top of intensely weathered bedrock including weathered in-place rock fragments. Additional mapping of the bedrock weathering surfaces was done in this area using both borings and seismic reflection data (Section 4.2). East of N6 Pier E1, there are fewer borings that reach bedrock and the depth of weathering was not always available in the detail necessary to provide correlation with the seismic data. Also, as the sediment section thickens, velocity variations add an additional uncertainty to the depth conversions. The surface mapped as the Top of Franciscan Formation from the seismic reflection data generally agrees within ±2 to 3 meters with posted bedrock elevations from the geotechnical data.

Map 13 shows that along the N6 alignment, the Franciscan Formation bedrock slopes 15 to 18 degrees from the shoreline at the eastern end of Yerba Buena Island down to between El. -90 and El. -100 meters. Eastward, the slope reduces to an average of approximately 1 degree and reaches El. -136 meters at Boring 94-1, just west of the Oakland Mole. Local topography observed along the geophysical survey lines is on the order of 2 to 5 meters. Depending on the geophysical survey line spacing, it is not always possible to correlate local bedrock topographic features between survey lines, and they may not be reflected in the 5-meter contour interval.

Contours beneath the gassy sediments in the center of the survey area are dashed on Map 13 to indicate there is less certainty about the depth of the reflector. As discussed in Sections 2.4 to 2.6, reflectors beneath the gas zone are intermittent and often difficult to correlate across the zone. Also the reflectors may be "pushed down" on the seismic records as a result of the slower velocities in the gas zone sediments. The thickness of the gas zone has not been mapped. Suspension log data (Borings 98-8, 98-9, 98-11, and 98-20 [Plate 2.14b]) indicate the gas zone locally may be up to 30 meters thick. The base of the gas zone usually corresponds to the base of the Young Bay Mud, but in a few borings (98-11 and 98-20 [Plate 2.14b]) appears to extend a small distance into the coarser Merritt-Posey sediments below the base of the Young Bay Mud.

Based on the velocities given in Section 2.4, the "push down" effect could increase the apparent sediment thickness by 2 to 6 meters, depending on the relative thickness of the gassy sediments compared to the total sediment section. This would also result in the estimated depth of the Franciscan Formation from the seismic data being slightly deeper than the elevation observed in the same location in a boring. That may be the case at the borings in the vicinity of the N6 Pier E2 (Borings 98-8, 48-88, 98-25, 98-26), just west of the El. -100 meter contour on Map 13, where the map contours are 3 to 5 meters deeper than the borings. However, to the east of N6 Pier E2, there is good agreement between elevations interpreted from the seismic data and those encountered in the borings.



STRUCTURAL CONTOURS
BASE OF YOUNG BAY MUD
SFOBB East Span Seismic Safety Project

PLATE 3.1

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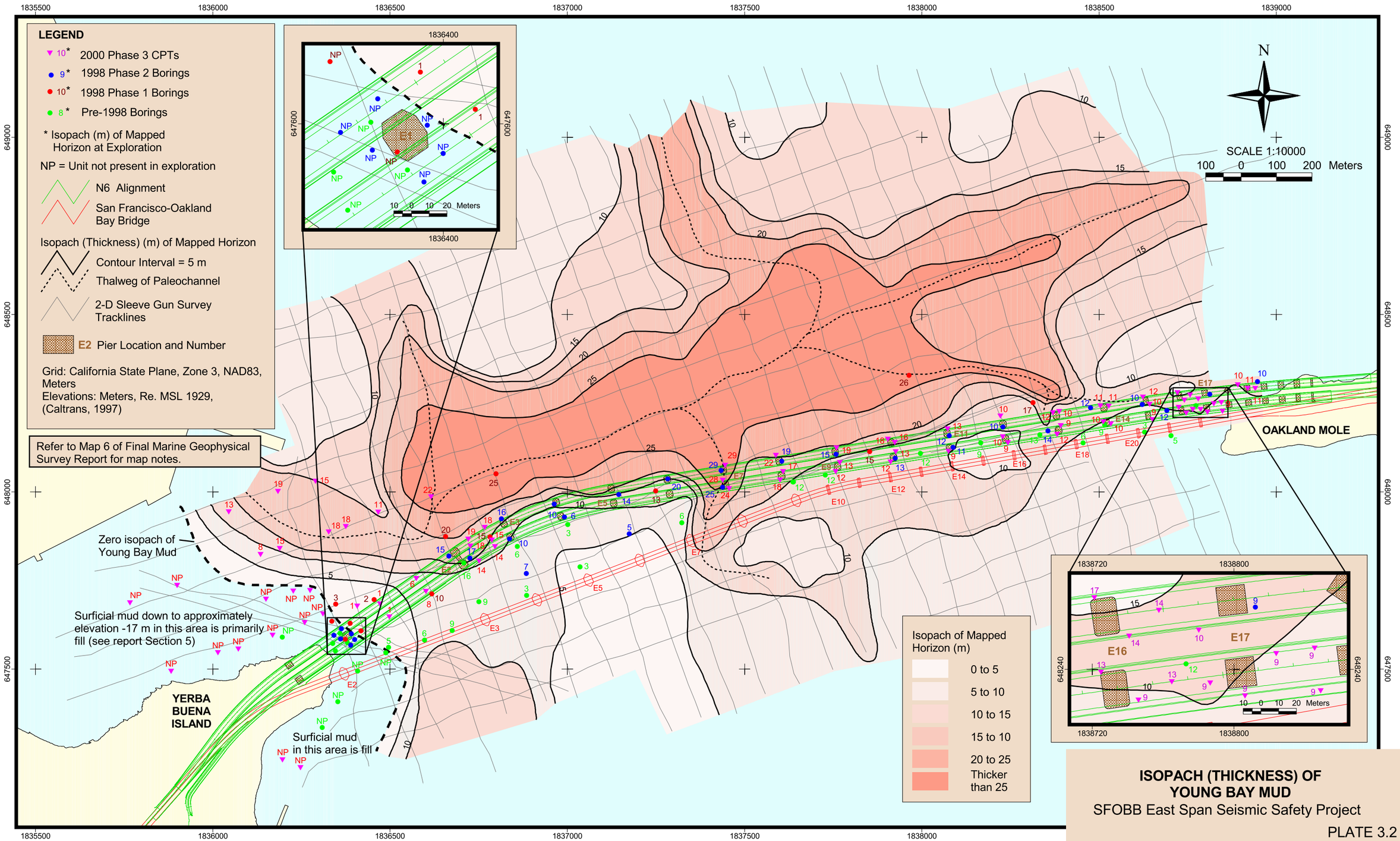


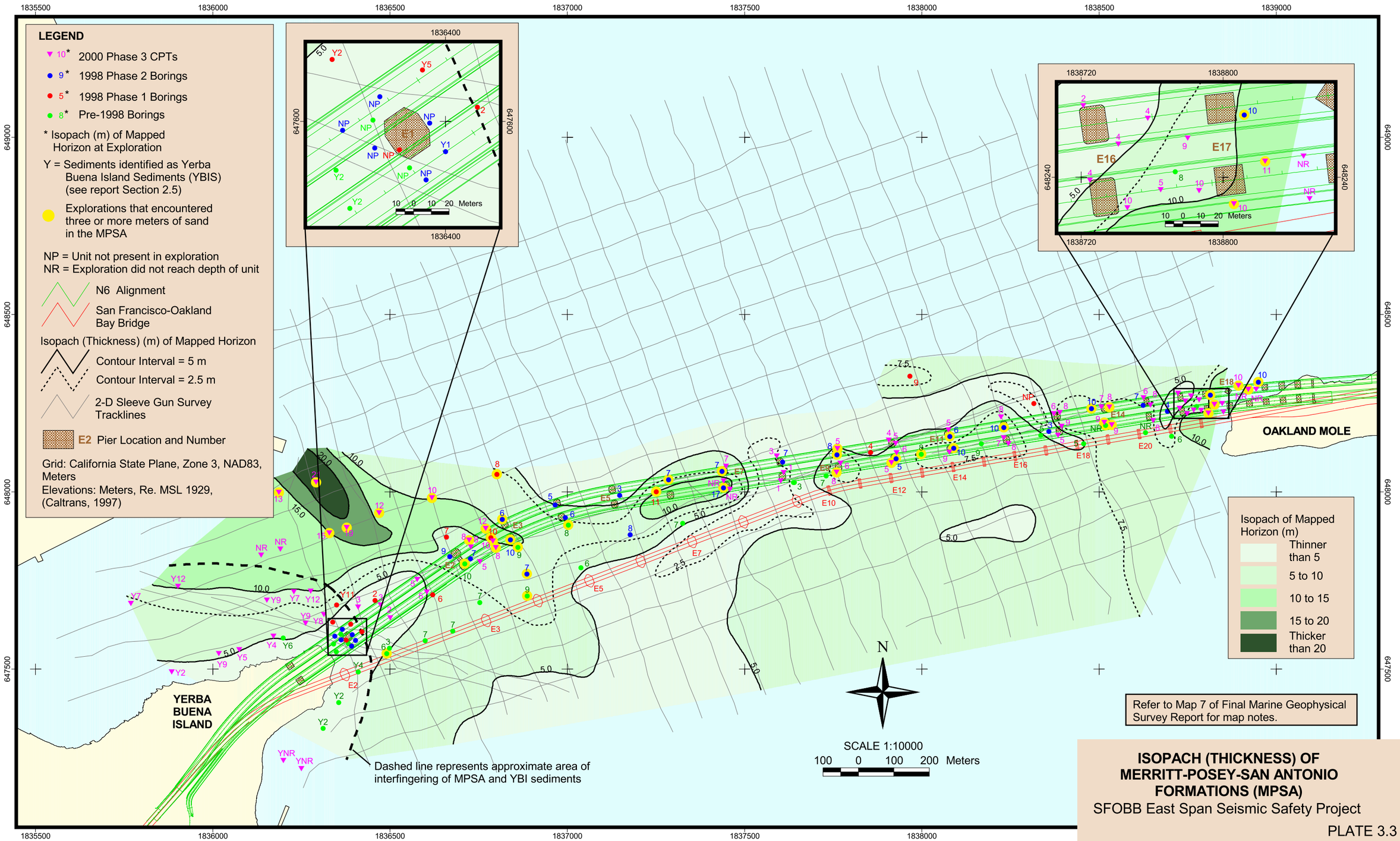
ISOPACH (THICKNESS) OF YOUNG BAY MUD

SFOBB East Span Seismic Safety Project

PLATE 3.2

Earth Mechanics

FUGRO



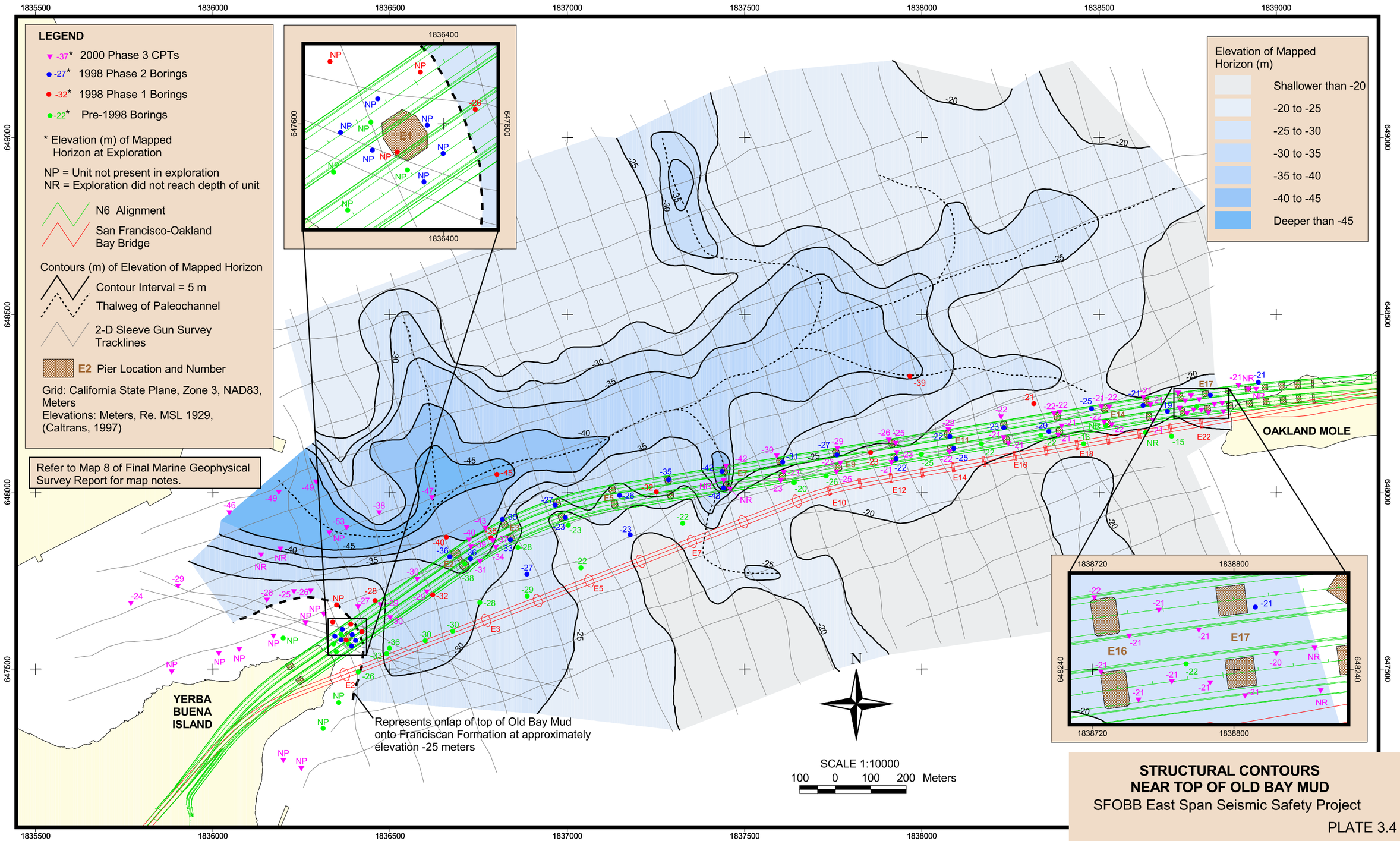
ISOPACH (THICKNESS) OF MERRITT-POSEY-SAN ANTONIO FORMATIONS (MPSA)

SFOBB East Span Seismic Safety Project

PLATE 3.3

Earth Mechanics

FUGRO



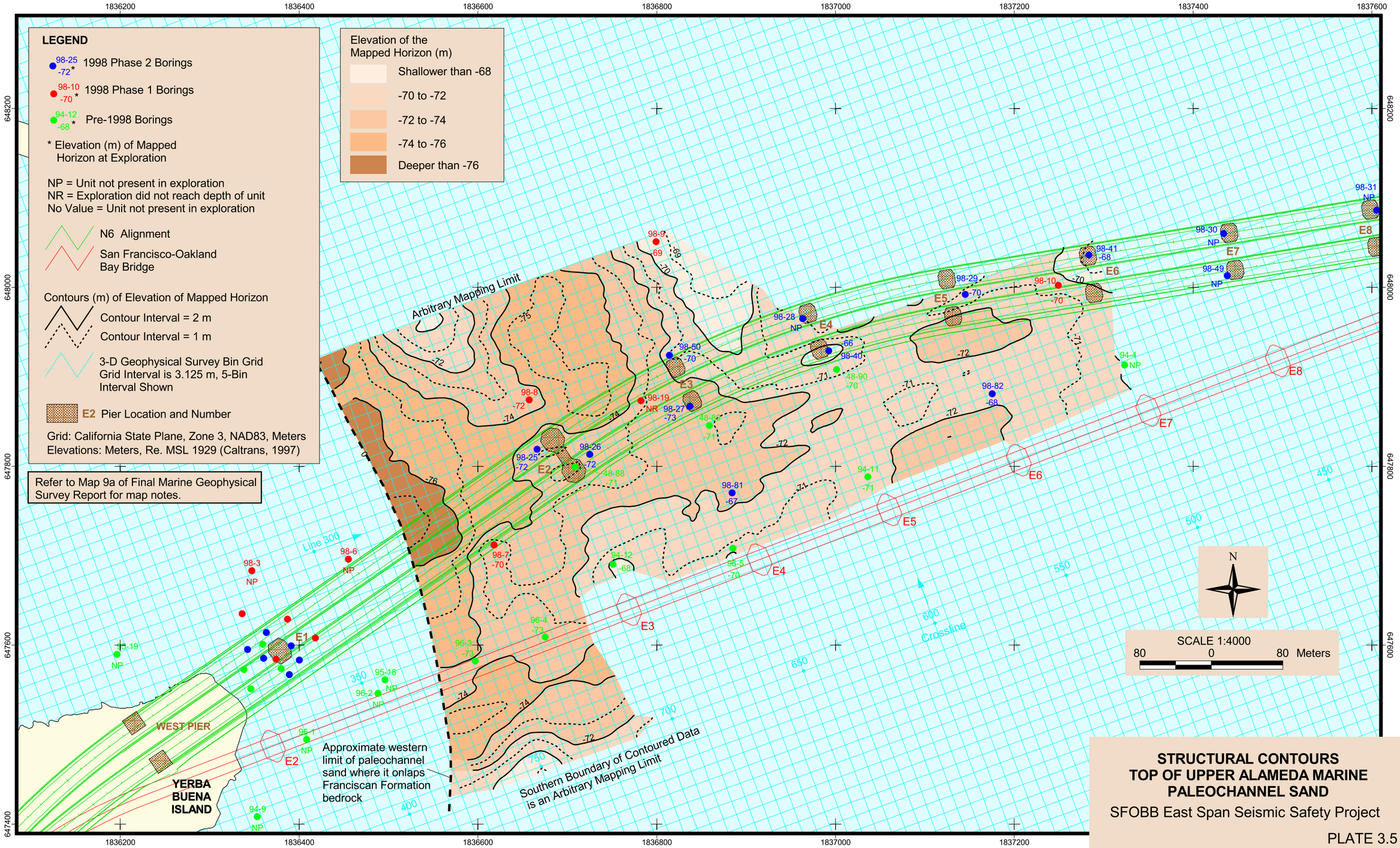
STRUCTURAL CONTOURS NEAR TOP OF OLD BAY MUD

SFOBB East Span Seismic Safety Project

PLATE 3.4

Earth Mechanics

FUGRO



STRUCTURAL CONTOURS
TOP OF UPPER ALAMEDA MARINE PALEOCHANNEL SAND

SFOBB East Span Seismic Safety Project

PLATE 3.5

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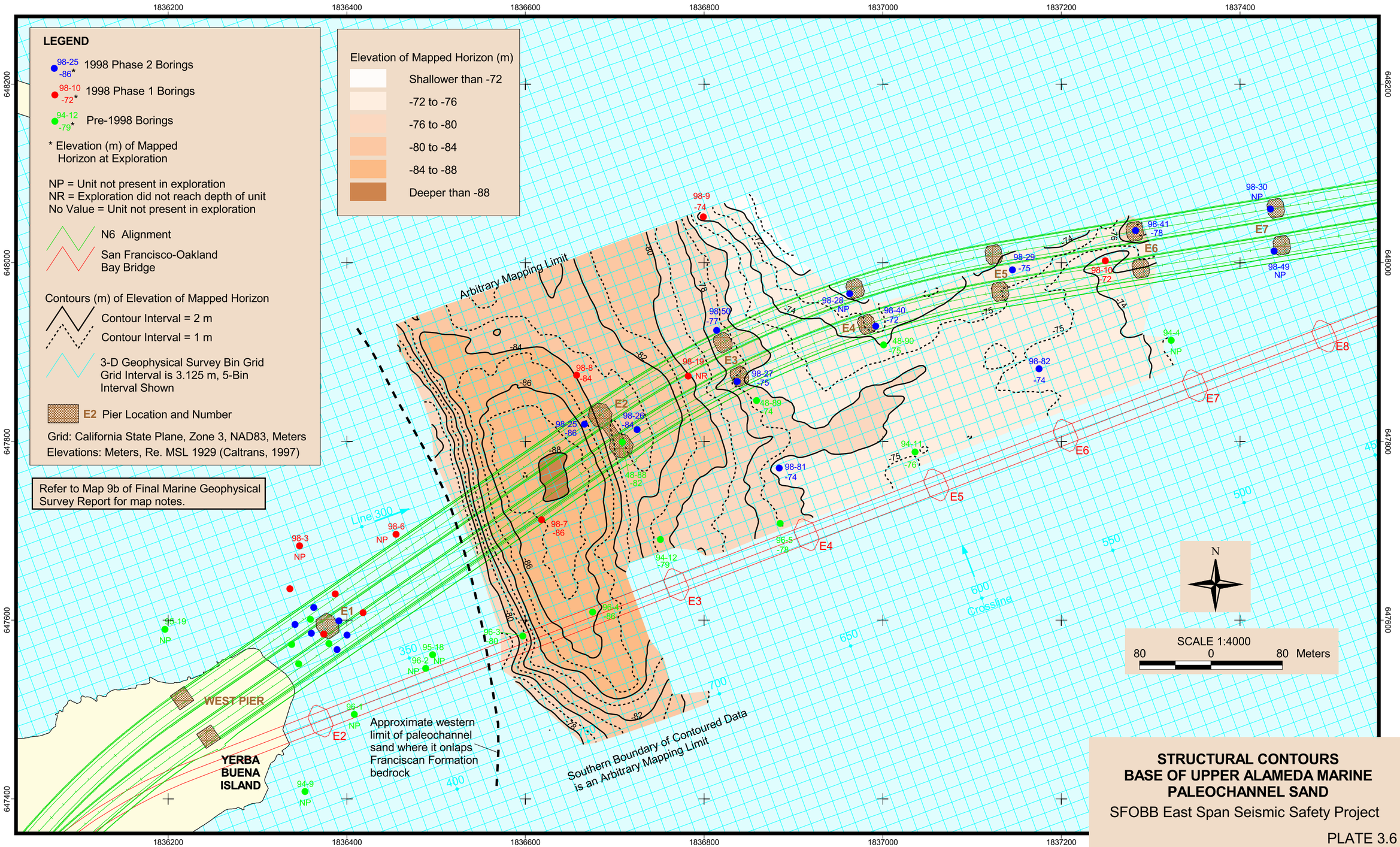
Earth Mechanics

FUGRO



STRUCTURAL CONTOURS
BASE OF UPPER ALAMEDA MARINE PALEOCHANNEL SAND

SFOBB East Span Seismic Safety Project

PLATE 3.6

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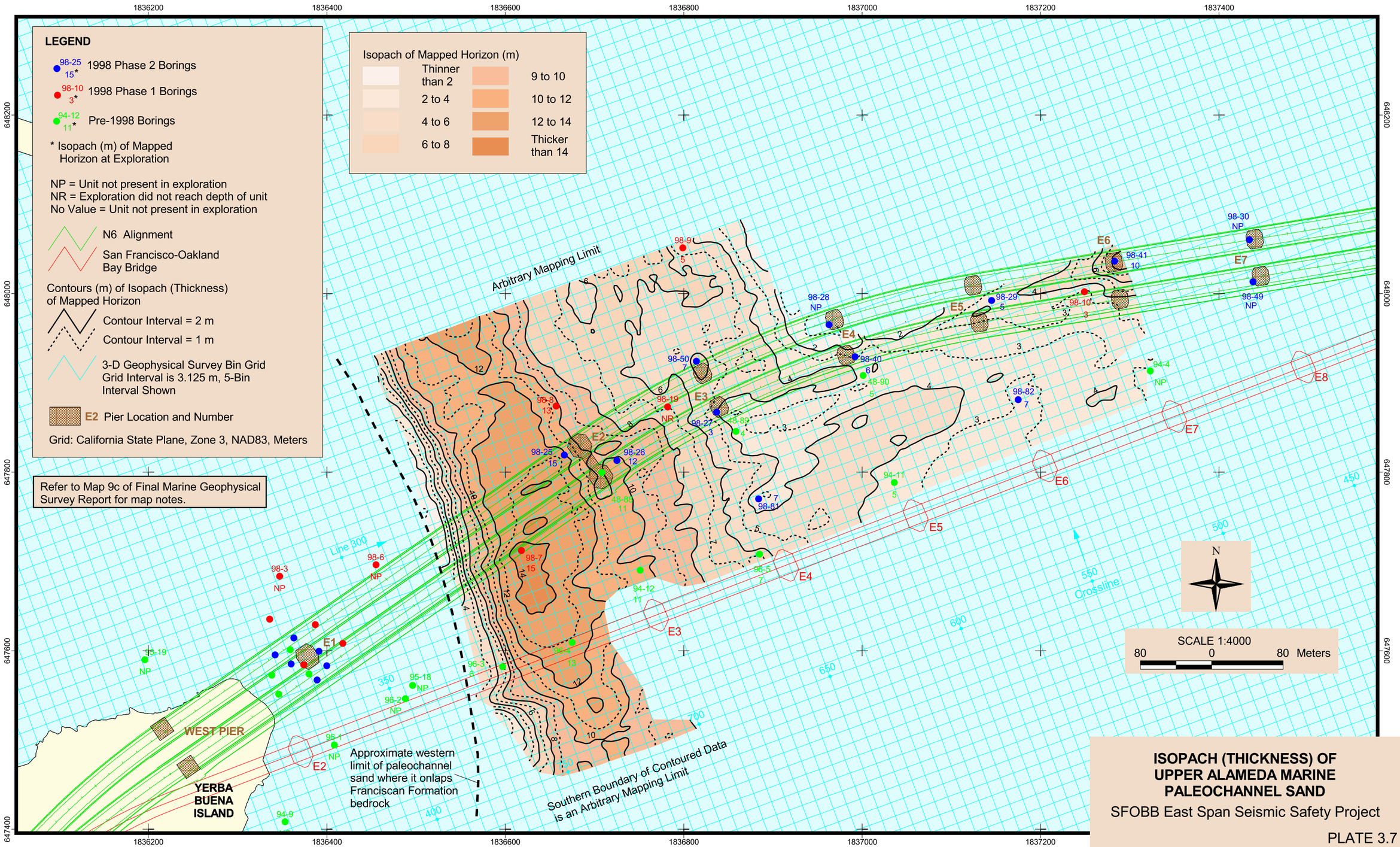
Earth Mechanics

FUGRO



ISOPACH (THICKNESS) OF UPPER ALAMEDA MARINE PALEOCHANNEL SAND

SFOBB East Span Seismic Safety Project

PLATE 3.7

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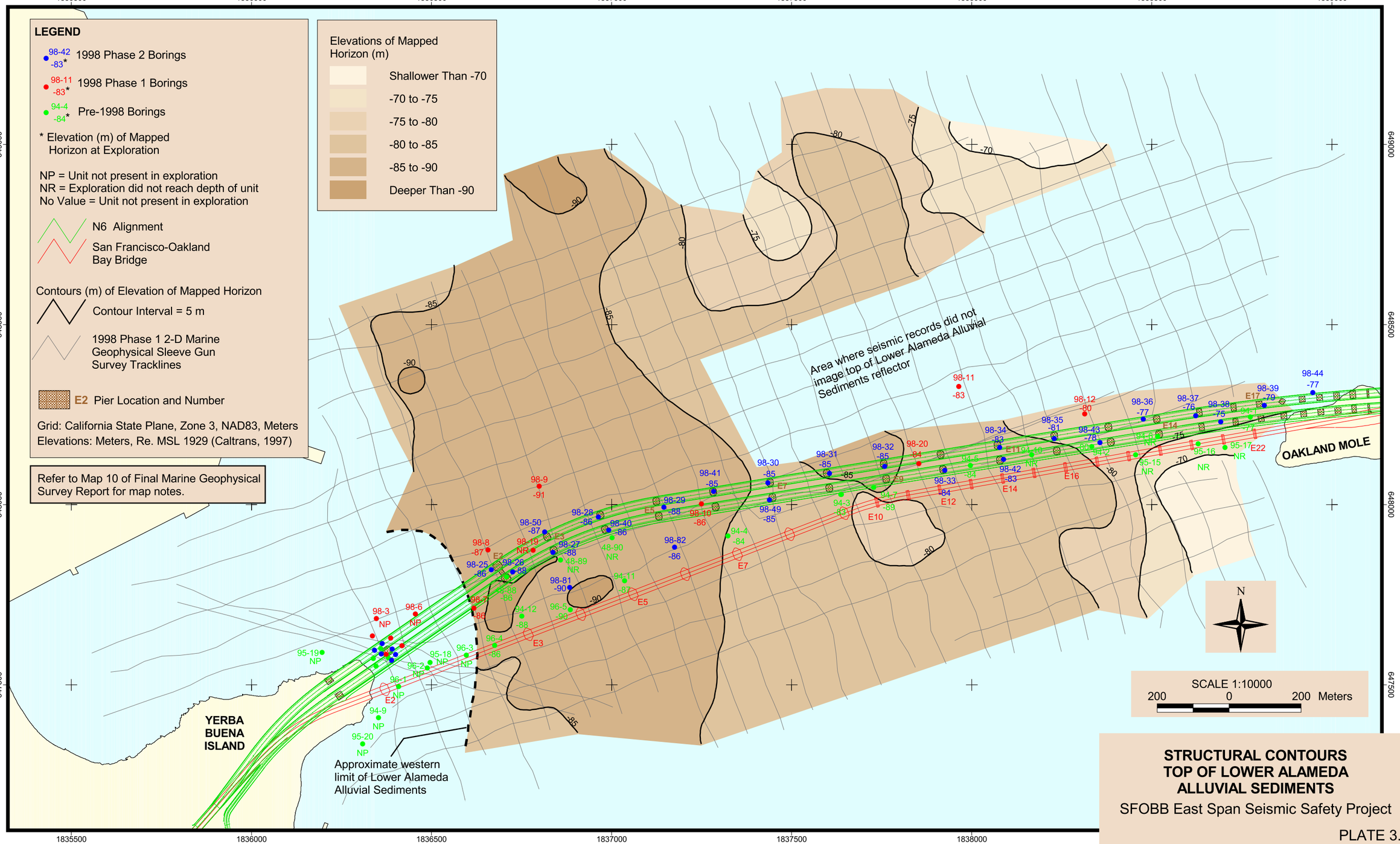
Earth Mechanics

FUGRO



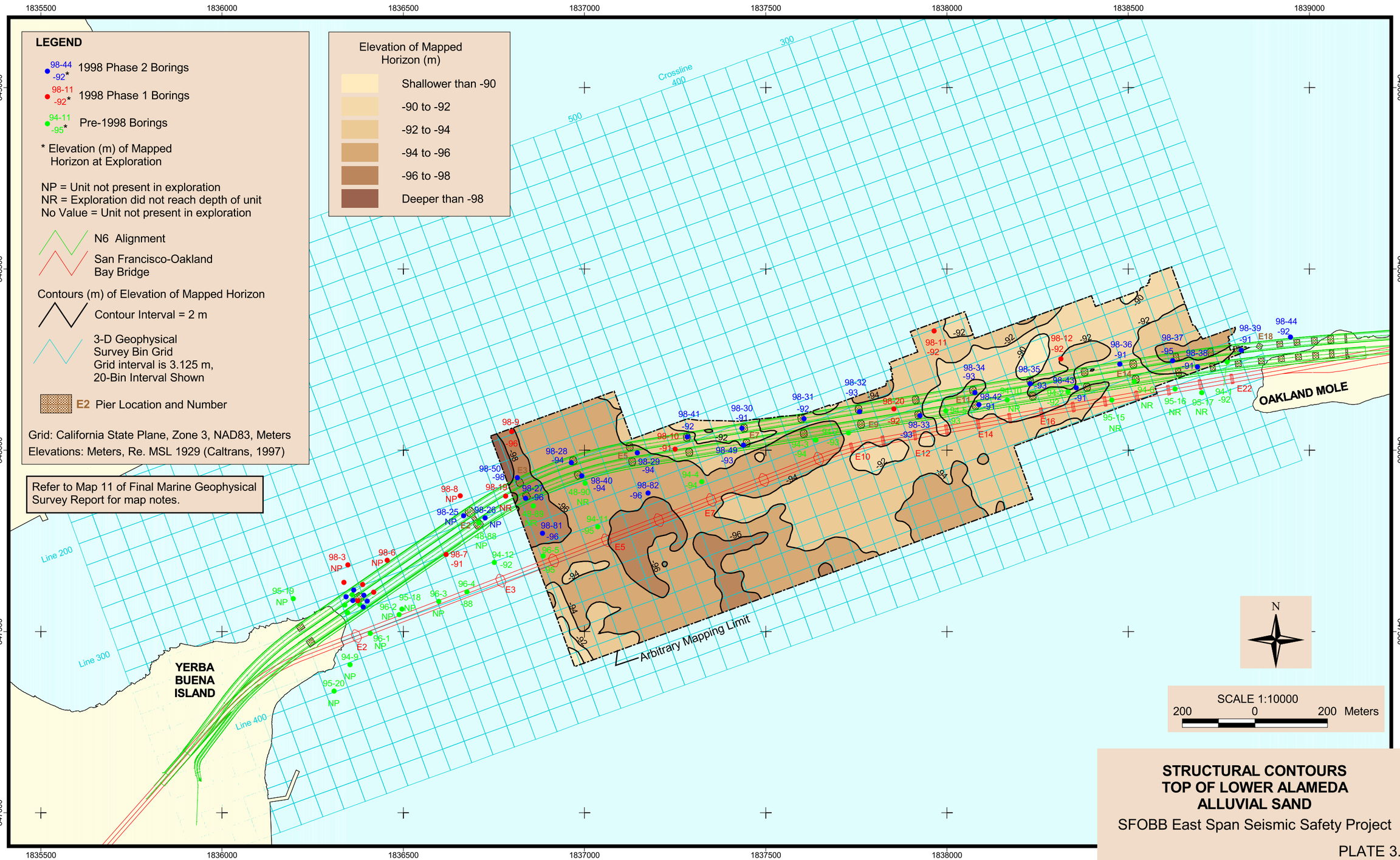
STRUCTURAL CONTOURS
TOP OF LOWER ALAMEDA
ALLUVIAL SEDIMENTS

SFOBB East Span Seismic Safety Project

PLATE 3.8

Earth Mechanics

FUGRO



STRUCTURAL CONTOURS
TOP OF LOWER ALAMEDA
ALLUVIAL SAND

SFOBB East Span Seismic Safety Project

PLATE 3.9

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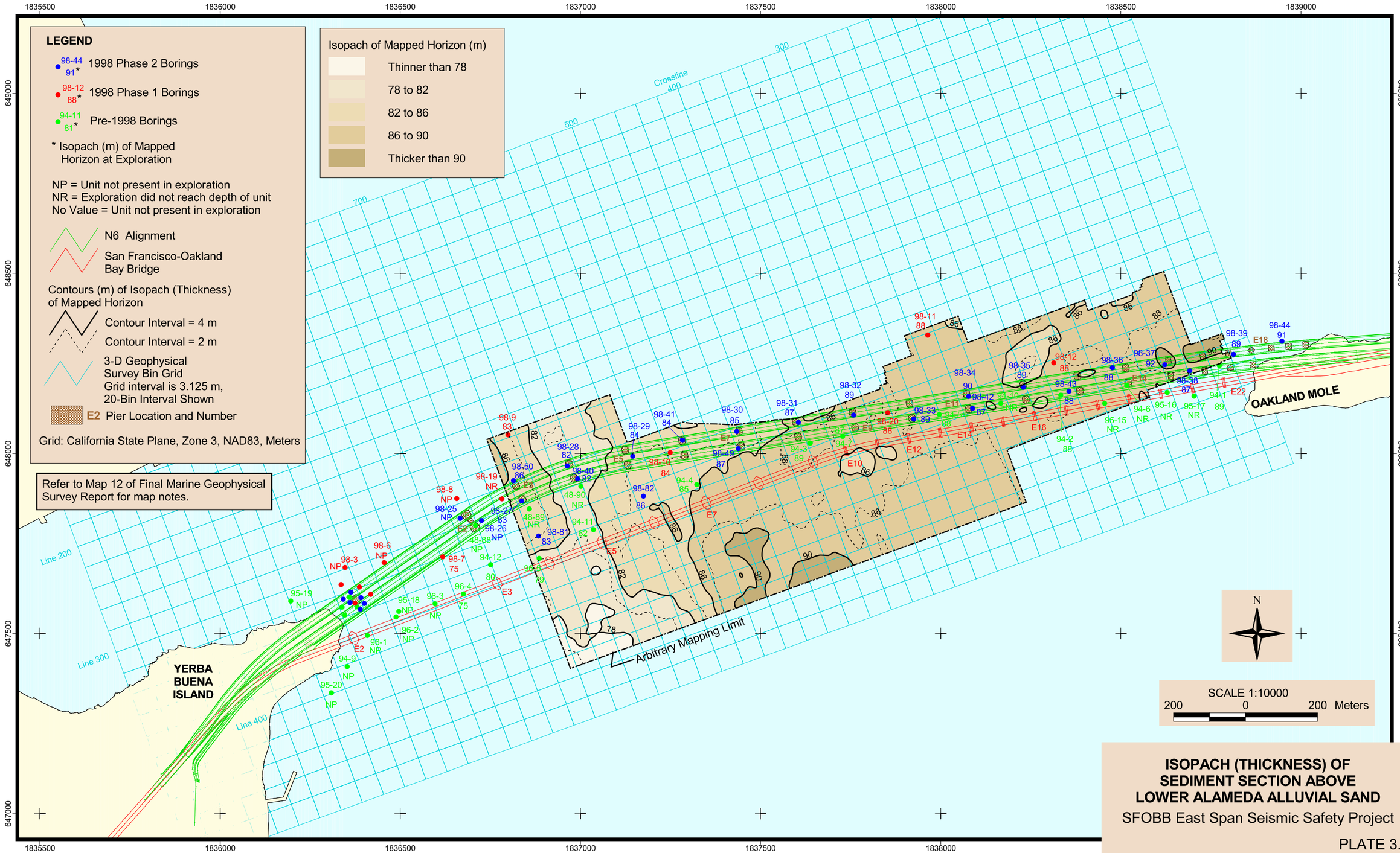
Earth Mechanics

FUGRO



ISOPACH (THICKNESS) OF SEDIMENT SECTION ABOVE LOWER ALAMEDA ALLUVIAL SAND

SFOBB East Span Seismic Safety Project

PLATE 3.10

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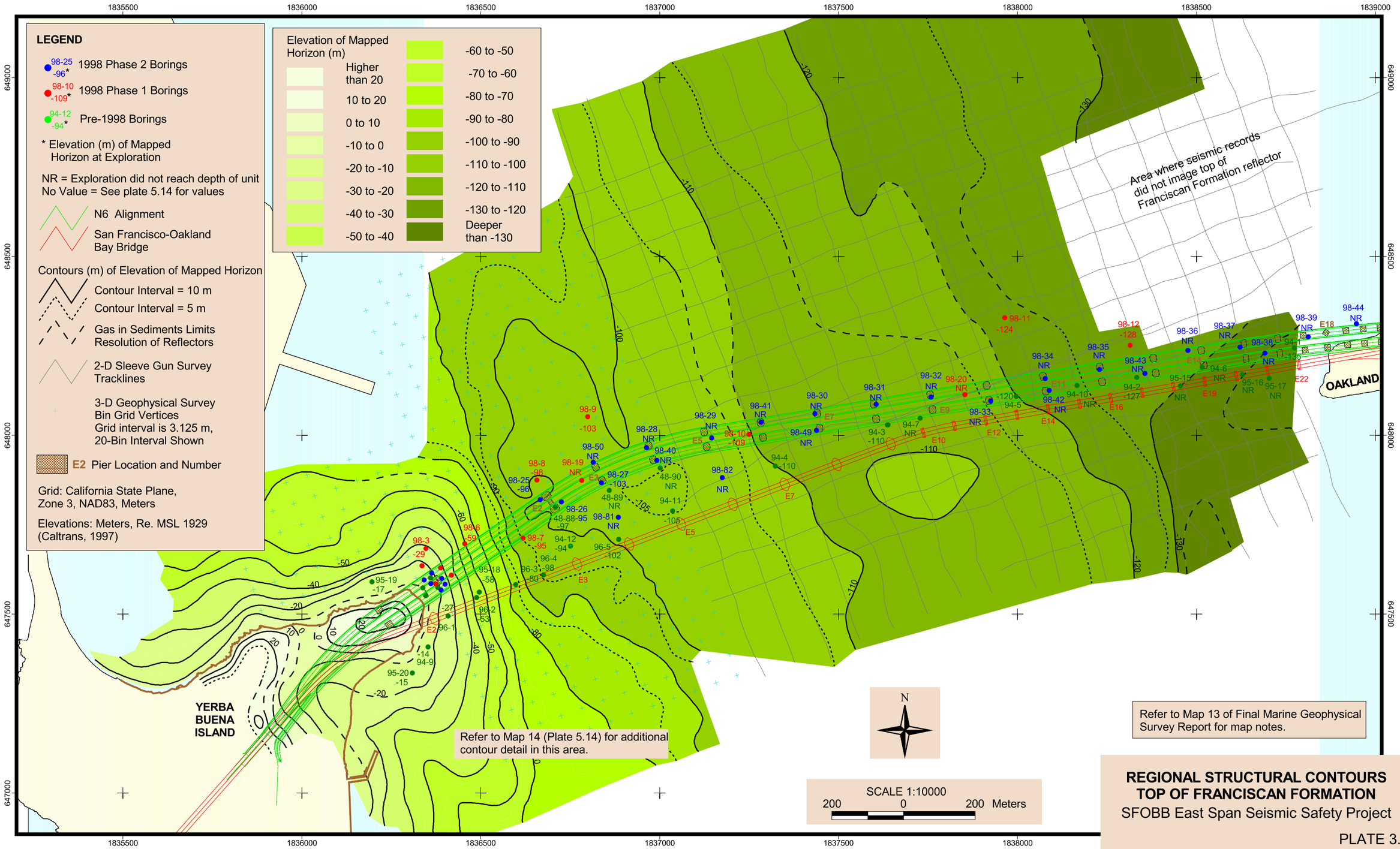


Refer to Map 13 of Final Marine Geophysical Survey Report for map notes.

REGIONAL STRUCTURAL CONTOURS
TOP OF FRANCISCAN FORMATION
SFOBB East Span Seismic Safety Project

PLATE 3.11

SECTION 4.0
SUMMARY OF ROCK AND SEDIMENT HORIZONS UNDERLYING THE N6 ALIGNMENT

4.0 SUMMARY OF ROCK AND SEDIMENT HORIZONS UNDERLYING THE N6 ALIGNMENT

4.1 DATABASE AND THE N6 ALIGNMENT CROSS SECTIONS

The geological setting of the East Span Seismic Safety Project was presented in Section 3.0 as a series of structural contour and isopach maps that depicted the shape, elevation, and thickness of the major sediment units and the shape and elevation of the Franciscan Formation bedrock. Section 4.0 presents the integrated geological and geotechnical information specific to the N6 alignment and its major offshore structures. These site-specific data are presented as large-scale maps and cross sections.

4.1.1 Data Shown on Cross Sections

The cross sections illustrate one or more of the following basic data items:

- Borehole locations with respect to the cross section line,
- Soil and rock lithology in the geotechnical borings,
- Undrained shear strength measurements (kPa) on samples from the borings,
- Symbols indicating the laboratory technique or instrument used to measure the shear strengths,
- Tip resistance (megapascals [MPa]) and shear strength estimates (kPa) from downhole CPT soundings in the borings,
- P-wave and S-wave velocity measurements (m/sec) from suspension logging in the boreholes,
- CPT sounding locations with respect to the cross section line,
- Tip resistance and shear strength estimates from CPT soundings,
- Soil lithology estimated from CPT tip resistance and friction ratio measurements based on the Robertson and Campanella (1988) correlation chart,
- Sediment and bedrock unit boundaries as derived from an integrated interpretation of geotechnical explorations and seismic reflection data, and
- Minor (internal to the units) strata continuity and geometry based on seismic reflection data, borehole lithology, and shear strength measurements.

Plate 4.1 provides the Key to Cross Sections that summarizes the symbols and scales used to depict the above items. Large-scale plots of the geotechnical data are available in Fugro-EM (2001a,b).

4.1.2 The N6 Alignment Cross Sections

Composite cross sections along the N6 Alignment are presented as Plates 4.2a and 4.2b. Plate 4.2a covers the western part of the alignment from Yerba Buena Island to between Piers E8 and E9. Plate 4.2b adjoins Plate 4.2a and covers the eastern part of the alignment from between Piers E8 and E9 to the Oakland Mole. Each plate shows three sections, one along the centerline of the westbound (northerly) structures, one along the centerline of the N6 alignment, and one along the centerline of the eastbound (southerly) structures. The horizontal scale of the cross sections is 1:2000 and the vertical scale is 1:500 resulting in a vertical exaggeration of 4:1.

The vertical scale of the two outside sections along the westbound and eastbound centerlines goes down to El. -80 meters, which includes the paleochannel sand unit of the Upper Alameda Marine Sediments. The centerline section goes down to Franciscan Formation Bedrock, El. -120 meters on Plate 4.2a and El. -140 meters on Plate 4.2b. The deeper units are shown only on the centerline section since they are relatively flat in the north-south direction at the alignment. Minor elevation variations in these deeper units across individual pier structures can be estimated from the structural contour maps of the Top of Lower Alameda Alluvial Sediments (Map 10), Top of Lower Alameda Alluvial Sand (Map 11), and Top Franciscan Formation (Map 13). Cross sections across many of the pier structures are presented in Fugro-EM (2001a).

The cross sections on Plates 4.2a and 4.2b represent integrated interpretations of the geotechnical explorations (borings and CPT soundings) and the seismic reflection data. They show the major sediment units and bedrock, the soil lithology and geotechnical classifications within the sediment units, CPT sounding tip resistances, and the shear strengths measured from boring samples and calculated from the CPT soundings.

The geotechnical explorations shown on each cross section are projected from their true locations. The majority of the projections are less than 20 meters. Explorations outside of the N6 structure envelope (shown by the green lines on the maps) are projected onto either the westbound structure cross section (if north of the N6 alignment) or eastbound structure cross section (if south of the N6 alignment). Explorations from within the N6 structure envelope are projected both onto the centerline cross section and either the westbound or eastbound structure centerline cross sections depending on their relative location. These projections result in a greater density of explorations shown on the N6 centerline cross section than on either the westbound or eastbound sections.

Horizon boundaries between the geotechnical explorations are based on correlation with the seismic reflection data. Intermediate horizons within the sediment units are based on seismic reflections and crusts (desiccated layers) identified by localized peaks in the shear strength values. Because the explorations are projected and the unit boundaries and intermediate horizons

are not flat, the stratigraphic contacts marked on the cross sections may not exactly correspond to the indications (lithology changes, shear strengths, etc.) in the boring logs and CPT soundings.

The centerline cross section is repeated at the same scale as Plate 4.14. On Plate 4.14, S-wave and P-wave velocity profiles have replaced the shear strength values. The velocity data are from suspension log measurements in the boreholes. Large-scale plots of the velocity data are available in Geovision (1998, 1999) and in Fugro-EM (1998d, 2001c).

Discussions of the sediment horizons and bedrock illustrated on the cross sections beneath the Main Span and Skyway follow in Sections 4.2 and 4.3.

4.2 MAIN SPAN, YERBA BUENA ISLAND TO EAST PIER (PIER E2)

4.2.1 Geologic Setting

The Main Span extends from the West Pier on Yerba Buena Island to between Piers E2 and E3. It includes two offshore structures: Pier E1 (Pylon), and Pier E2 (East Pier). Pier E1 will be constructed approximately 60 to 85 meters offshore Yerba Buena Island in an area of relatively shallow, sloping bedrock. Pier E2 (East Pier) will be situated about 450 meters east of the island beyond the toe of the bedrock slope (Plate 4.2a).

Maps 4 and 14, along with the cross sections in Plate 4.2a, illustrate the basic geologic setting of the Main Span section of the N6 alignment. The maps and cross sections are at the same horizontal scale 1:2000. Map 4 shows the topography and geology of eastern Yerba Buena Island, the Bay floor elevation contours from the multibeam survey, and the location of the Phase 3 marine geophysical survey lines. The geology on the island is from Fugro-EM (2000a). Also indicated on Map 4 are the locations of both onshore and offshore geotechnical explorations and the locations of the seismic survey lines on the island. Map 14 shows structure contours on the Franciscan Formation bedrock superimposed on the island geology and offshore seismic lines. Some of the details of the geological map shown on Map 4 are not shown on Map 14 in order to avoid interference with the bedrock contours. Bedrock elevations at geotechnical explorations both on the island and offshore are posted on Map 14.

East of Yerba Buena Island, the Bay floor slopes steeply from mean sea level (the project vertical datum) to El. -23 meters, and then more gently into the base of the scour hole at El. -25 to El. -26 meters beneath the N6 alignment. The Bay floor then rises gently to El. -15 meters where it begins a very gentle eastward rise to the Oakland Mole. The northeastward slope beneath the N6 alignment at the location of Pier E1 is about 13 degrees. The slope of the eastern side of the scour channel is about 6 degrees and the slope at the Pier E2 site is less than ½ degree (Map 4).

Along the eastward slope into the scour channel, the bedrock is covered with a thin (0 to 3 meters) veneer of fill (mud). This material is most likely dredge spoil from the construction of

Treasure Island (see Section 5.3, Plate 5.9). However, the material on the floor of the scour channel appears from the seismic data to be native Young Bay Mud. The Young Bay Mud thickens to the east as the bathymetry rises and is about 15 meters thick at Pier E2 (Plate 4.2a).

The sediment section thickens rapidly eastward from the western bank of the scour channel. This rapid increase reflects both the rise in Bay floor elevation and the relatively steep northeast dip of the bedrock. The sediment section at Pier E1 consists of a few meters of fill (mud) whereas the section at Pier E2 is between 84 and 85 meters thick. All of the major sediment units are represented in the cross section at Pier E2. However, the medium- to-coarse-grained sand horizon of the Lower Alameda Alluvial sediments is very thin or absent at this location (Plate 4.2a).

The main features of the bedrock surface beneath the N6 alignment east of Yerba Buena Island (Map 14) are:

- Northward-plunging ridge extending from the east end of the island,
- Relatively steep eastern flank of the ridge where the average bedrock slope down to El. -90 meters is 17 degrees and there are local slopes in excess of 25 degrees,
- Sudden decrease in slope in the range of El. -95 to El. -100 meters, and
- Minor topography in the south and east of El. -95 meters.

Locally, near the base of the slope east of the island, near-vertical steps on the order of 8 to 10 meters are seen on several of the east-west-oriented seismic lines. An example is shown in Plate 2.13 east of fix point 502. The steps may be old basement faults or wave cut terraces developed during a low sea level stand. The overlying Pleistocene and Holocene horizons do not appear to be offset on the seismic sections, so they are not ascribed to active faulting. These local topographic slopes are not noted along the N6 alignment centerline. The bedrock slope beneath the Pier E2 footprint is only 1 to 2 meters (Section 4.2.4).

4.2.2 Bedrock Surfaces and Identification of Associated Reflectors

Analysis of cores from borings in the area of the Main Span-Pylon identified several zones of weathering between the elevation identified as the top of bedrock and the elevation identified as fresh rock. Seismic reflection data from the 3-D survey was correlated with geotechnical borings and used to map two of the weathering surfaces in the area of Pier E1 (Pylon). Plate 4.3 shows the location of two seismic sections (Plates 4.4 and 4.5) that illustrate the correlation between the seismic reflectors and the weathering zones as interpreted in the borings. Plate 4.6 shows five photographs of cores containing representative rock samples from the weathering zones.

These zones, in order of descending elevation within the bedrock, are designated and described as follows:

- **Rock Fragment Zone.** In some, but not all borings, a zone of rock fragments with sand and clay was encountered below the soft surface clay and above weathered rock. The maximum interpreted thickness of the rock fragment zone was 3 to 4 meters in Borings 98-22, 98-45, and 98-48. Standard drilling techniques and thick-wall drive tube samples were collected from the rock fragment zone. Sample recovery ranged from about 10 to 30 mm for 30 to 50 downhole hammer blows. Samples consisted of subangular to angular, 10- to 25-millimeter (-mm) pieces of light gray to light brown, intensely to moderately weathered sandstone with minor amounts of sand, silt, and clay. The origin of the rock fragment zone is uncertain, and it could represent intensely weathered to decomposed bedrock.
- **Intensely Weathered Rock.** Intensely weathered rock was encountered in some but not all borings. Locally, the 2- to 6-meter-thick zone of intensely weathered rock was encountered below the rock fragment zone, and the contact between the two rock zones is transitional. Elsewhere, the intensely weathered rock was encountered directly below the surface sediments. The intensely weathered rock is differentiated from the rock fragments by the inability to advance the borehole without rock coring in the intensely weathered zone. In addition, the quantity and size of the individual pieces of rock recovered were greater and larger (25 to 50 mm) in the intensely weathered zone than in the rock fragment zone. Rock core samples from this zone consist of light gray to light brown, intensely weathered and fractured, moderately hard sandstone. The core recovery in the intensely weathered zone was typically about 30 to 60 percent, while the Rock Quality Designation (RQD) was 0.
- **Moderately Weathered Rock.** The moderately weathered bedrock is characterized by a 3- to 5-meter-thick zone of light yellowish brown to light brown, moderately hard sandstone (graywacke) that is intensely to very intensely fractured. Core recovery within the moderately weathered zone typically was about 50 to 80 percent. The rock, however, was generally intensely fractured (by natural processes) into pieces ranging from about 25 to 125 mm long. The RQD of the moderately weathered zone generally is less than about 25.
- **Slightly Weathered Rock.** A relatively thin (1.5- to 3-meter-thick) layer of slightly weathered rock forms a transitional boundary between the light brown moderately weathered rock and the underlying dark gray, fresh rock. The slightly weathered rock is characterized by a zone with up to 25 mm of light brown moderately weathered rock on each side of the fractures and joints. The slightly weathered bedrock strata grades from moderately weathered to fresh over the length of this zone. The RQD in the slightly weathered zone is typically about 30 to 50.

- **Fresh Rock.** The fresh rock is characterized by hard, well indurated, thickly bedded to massive sandstone with thinly interbedded siltstone and claystone layers. The sandstone is typically moderately to slightly fractured with zones of intensely fractured sandstone up to about 1.5 to 1.8 meters thick in several borings. The siltstone and claystone interlayers are typically dark gray to black, thinly bedded to laminate, moderately hard, and normally intensely to very intensely fractured into pieces generally less than about 100 mm (4 inches) long. The siltstone/claystone beds typically range from about 0.1 to 0.3 meter (several inches to about 1 foot) thick, although several zones of fine-grained rock were up to 3 meters thick. The RQD of the fresh sandstone is typically greater than 50, and values greater than 70 are representative of intact, unfractured zones. RQD values of less than 50 are generally representative of the interbedded siltstone and claystone.

Plates 4.4 and 4.5 are annotated seismic records from the 3-D survey that pass close to a series of borings in the Pier E1 (Pylon) footprint area. Line 328 (Plate 4.4) runs from west to east and crossline 824 (Plate 4.5) runs from north to south. Two surfaces, top of intensely weathered rock (including rock fragments) and top of slightly weathered to fresh rock, are associated with seismic reflectors that can be mapped throughout the Pier E1 (Pylon) footprint area. In general, the primary seismic reflector mapped as the Top of Franciscan Formation generally corresponds to the intensely weathered bedrock surface, including the rock fragment zone, where it is present. The results of the detailed mapping of the weathering surfaces in the area of the Main Span-Pylon are discussed in the following section.

4.2.3 Pier E1 (Pylon) Footprint Area

The Main Span-Pylon is located on the eastern flank of the Franciscan Formation bedrock ridge that plunges north from the eastern tip of Yerba Buena Island. The bay floor footprint is approximately 28 meters in a northwest-southeast direction across the alignment and 22 meters parallel to the alignment. Water depths in the general area range from El. -5 to El. -20 meters increasing along the alignment and are between El. -9 and El. -12 meters across the footprint (Map 1, Plate 2.1).

The site is covered by a veneer of fill (mud) that ranges from 4 meters thick at the western edge of the footprint to 1 meter at the eastern edge (Borings 98-21 and 98-24, Table 2.2). Beneath the fill (mud) is the top of the intensely weathered Franciscan Formation bedrock. The elevation of the intensely weathered bedrock surface ranges from El. -16 to El. -21 meters from west to east. Elevations and estimates of the thickness of the geologic units in the borings from the Main Span-Pylon area and eastern Yerba Buena Island are given in Table 2.2.

Plates 4.7, 4.8, and 4.9 present the results of mapping the bedrock weathering surface in the area surrounding Pier E1 (Pylon) using the geophysical and geotechnical exploration data. The contours are based on the geophysical mapping and depth conversions using a velocity of

1500 m/sec. Postings adjacent to the borings are elevation estimates of the weathering surfaces from descriptions in the boring logs. Plate 4.7 shows the top of intensely weathered rock. Agreement between the mapped surface and the borings appears to be generally within ±1 to 2 meters, which is the limit of accuracy of the two methods in identifying an irregular surface. Plate 4.8 is the top of slightly weathered or fresh rock as mapped from the geophysical data. Agreement with borings is within the stated accuracy of the two methods. An isopach (thickness) map of the weathered rock was obtained from the difference in elevations of the two mapped surfaces. The isopach is shown in Plate 4.9. Both the borings and mapping from the reflection data indicate that 5 to 10 meters of weathered bedrock should be expected above the fresh bedrock surface in the Pier E1 (Pylon) footprint area.

4.2.4 Pier E2 (East Pier) Footprint Area

The Main Span-Pier E2 (East Pier) of the N6 alignment is approximately 450 meters east of the northeastern end of Yerba Buena Island. The pier is oriented in a northwest-southeast direction and the footprint is about 68 meters by 22 meters. Plates 4.10a and 4.10b are cross sections through the long axis of the pier footprint (perpendicular to N6 alignment). They are similar except that Plate 4.10a shows the shear strengths determined from the borings and CPT soundings, and Plate 4.10b shows seismic velocity profiles in the borings. The P-wave velocities in the upper sections of Borings 98-8, 98-25, and 98-26 are generally less than the velocity of sound in water, indicating that the Young Bay Mud contains biogenic gas. As the mud section thickens, the gas affects the quality of the seismic data and distorts ("pushes down") the reflectors. Plate 4.11 is an annotated seismic line through the borings with the designated horizon depths based on an average velocity of 1,500 m/sec. The velocity variations from the gas in the mud affect the apparent correlation between the borings and reflectors and diminish the amplitudes of the lower reflectors.

The Pier E2 footprint sits astride the edge of the main east-west-trending paleochannel that cuts through the Merritt-Posey-San Antonio Formations and into the top of Old Bay Mud. The thickness of the Young Bay Mud beneath the footprint is a nominal 15 to 16 meters, but increases to the north toward Boring 98-8. The underlying Merritt-Posey-San Antonio Formations sediments increase from about 5 meters beneath the eastbound lanes to about 8 meters beneath the westbound lanes.

At approximately El. -72 meters, the top of Upper Alameda Marine Paleochannel Sand is encountered. That sand is very dense with hard clay layers. It is 10 to 14 meters thick at this location (Plate 4.10a). The Lower Alameda Alluvial sediments are encountered at about El. -85 meters, but the medium- to coarse-grained sand mapped to the east appears to be absent (Map 11, Plate 3.9).

Franciscan Formation bedrock is mapped at El. -100 meters based on the seismic reflector (Map 13, Plate 3.11), but appears slightly shallower (El. -95 to El. -97 meters) in nearby

borings. The 2-meter to 3-meter difference may be due to a minor velocity variation (-20 m/sec) from the 1,500-m/sec value used in the depth conversion or it may be the effect of weathering surfaces. Neither Boring 98-25 nor 98-26 penetrated a sufficient distance into the bedrock to establish a rock weathering profile. Boring 48-88 lies within the Pier E2 footprint area and apparently encountered the top of unweathered rock at El. -97 meters (-314 feet, MLLW) (Caltrans, 1997d). The boring log contains no indication of weathered bedrock.

4.3 SKYWAY AND OAKLAND SHORE APPROACH, PIER E3 TO OAKLAND MOLE

4.3.1 Geologic Setting

The N6 alignment Skyway structure extends east from Pier E2 to between Piers E16 and E17. The Oakland Shore Approach structure includes offshore Piers E17 to E20 and associated onshore structures (Plate 1.2). Only the offshore pier locations in the Oakland Shore Approach are discussed in this report. The entire Oakland Shore Approach structure/fill area is addressed in a separate report (Fugro-EM, 2001b).

The sediment and bedrock units underlying the N6 alignment Skyway structure and offshore part of the Oakland Shore Approach structure are documented on Maps 5 through 13 (Plates 3.1 to 3.11) and in longitudinal cross sections on Plates 4.2a, 4.2b, and 4.14. In addition, cross sections across the N6 alignment are provided at Pier E3 (Plates 4.12a and 4.12b) and Pier E11 (Plates 4.13a and 4.13b).

The geologic stratigraphic section and structure underlying the N6 alignment east of the Main Span structure includes the following general features.

- The Franciscan Formation bedrock surface slopes gently from about El. -96 meters at Pier E2 (East Pier) to about El. -135 meters at the west end of the Oakland Mole. The surface is an erosional unconformity with minor topographic relief and an average slope of 1 degree to the east. The bedrock surface is nearly horizontal in the north-south direction beneath this part of the alignment.
- Holocene- and Pleistocene-age marine and alluvial sediments unconformably overlay the Franciscan Formation bedrock. In general, the marine sediments (deposited during sea level high stands) are primarily clays and silts. In contrast, the alluvial sediments (deposited during sea level low stands) are more commonly sands.
- Except where eroded and replaced by channeling, the inclination of the bedding of the marine and alluvial sediments is slight and, for practical purposes, the bedding can be considered to be near horizontal. The Holocene- and Pleistocene-age marine and alluvial sediments, however, are frequently interfingered and interlayered. Thus, although the stratigraphic sequence generally can be extrapolated between borings using geophysical data, the lithologic and geotechnical properties of the soils can vary

significantly over limited horizontal distances. This is evident from the lithology in the boring logs on Plates 4.2a and 4.2b and the limited distances over which intermediate horizons can be correlated.

- The Holocene- and Pleistocene-age sequence has been eroded (and complicated) by various episodes of channeling. A Recent east-west-trending paleochannel is present to the north of and subparallel to the N6 alignment (Maps 5, 6, 7, and 8). Several tributary channels from the south cross the N6 alignment to reach the main channel. These tributary channels cross the N6 alignment in the vicinity of N6 Piers E7, E13, and E16.
- The N6 alignment is curved and not parallel to the axis of the paleochannel. As a result, the elevation and thickness of the upper sediment units vary along the N6 alignment in response to changes in the relative positions of the alignment and paleochannel axis. At some piers, this non-parallelism results in significant variations in subsurface soil profiles between the locations of structures supporting the westbound lanes and those supporting the eastbound lanes. Plates 4.12a and 4.13a show south-to-north variations at Piers E3 and E11. Similar variations between the westbound and eastbound structures are also evident on Plates 4.2a and 4.2b at Piers E6, E7, and E16.
- In general, the marine clays are thicker and the alluvial sands are thinner (or absent) within the buried paleochannels. However, a few explorations in the center of the main paleochannel encountered coarser grained material in the basal few meters of the channel.
- It is not unusual to find that the alignment of near-surface channels overlie the alignment of deeper and older channels. The geophysical survey records suggest that such sets of nested paleochannels are present in the Old Bay Mud beneath the bathymetric channel east of Yerba Buena Island and in several of the tributary paleochannels that enter into the main paleochannel from the south.

4.3.2 The Western Part of the Skyway and Structure, Piers E2 to E8

The division of the Skyway structure into western and eastern parts is partially arbitrary in the sense that it represents the break in the cross sections between Plates 4.2a and 4.2b. However, the division also represents a transition in the relative variability of the sediment unit geometries both along and across the N6 alignment.

The subsurface geometries of the sediment units under the western part of the Skyway (between Piers E2 and E8) vary significantly in both the north-south and east-west directions. This variation results from two sources. First, the N6 alignment is curved in this part of the alignment and the distance and orientation (with respect to the main paleochannel axis) varies. Second, two possible tributary paleochannels, one at N6 Pier E7 and another between N6 Piers

E2 and E3, cross this part of the alignment. The possible tributary between Piers E2 and E3 may be a bend in the flank of the main paleochannel.

The paleochannel tributary at N6 Pier E7 is obvious in the contours of the Base of Young Bay Mud (Map 5) and the Top of Old Bay Mud (Map 8). It is also reflected in the Isopach of the Merritt-Posey-San Antonio Formations (Map 7) and in the top of the Upper Alameda Marine sediments (Plate 4.2a). This paleochannel results in significant difference in the soil profiles at Pier E7 when compared to those at N6 Piers E6 and E8. Lower shear strengths in the Old Bay Mud clays are found at greater depths at N6 Pier E7 than the adjacent piers. It also affects the thickness of the Merritt-Posey-San Antonio Formations sediments in a north-south direction across the axis of the adjacent N6 Piers E6 and E8.

The second paleochannel tributary, between Piers E2 and E3, is evident in both the cross sections and the Isopach of Merritt-Posey-San Antonio sediments. This tributary paleochannel trends northwest between N6 Piers E2 and E3. This paleochannel results in north-south variations in the thickness of the Merritt Sand at N6 Piers E3 and E4. An alternative interpretation of the variations in Young Bay Mud thickness between Piers E2 and E3 is that this is an area where the axis of ancient Temescal Creek meandered to the south, and the southern flank of the channel is located a little further south than along the remainder of the N6 alignment.

4.3.3 The Eastern Part of the Skyway Structure, Piers E9 to E20

In general, the subsurface geometries of the sediment units underlying the eastern two-thirds of the Skyway section of the N6 alignment (between N6 Piers E9 and E20) show less variation than in the western part. This is because the eastern part of the Skyway structure is farther south from the axis of the primary paleochannel than the western part of the alignment. This section of the N6 alignment is still on the southern flanks of the paleochannel, but in the area of less slope and shallower tributary channels than the western part.

There is a broad Young Bay Mud-filled tributary channel along the axis of the N6 alignment from N6 Pier E13 east to Pier E17. The effects of this channel are most obvious at N6 Pier E16 where the Young Bay Mud is 4 to 6 meters thicker than at the adjacent piers along the westbound structures.

Another shallow Young Bay Mud-filled paleochannel crosses the N6 alignment just west of N6 Pier E13, but does not result in any significant change in the thickness of the Young Bay Mud between the eastbound and westbound piers.

In general, the Young Bay Mud increases in thickness in both northerly and westerly directions beneath this part of the N6 alignment. In a similar manner, the isopach of the Merritt-Posey-San Antonio sediments decreases in the same directions. Except at the previously mentioned paleochannel tributaries, the changes in the thickness of the two upper sediment units are quite gradual.

The deeper sediment units are quite flat beneath this section of the N6 alignment. The top of the medium- to coarse-grained Lower Alameda Alluvial Sand is at El. -92 to El. -94 meters. At N6 Piers E12, E13, E15, and possibly E14, there is a fine-grained sand at or near the top of the Lower Alameda Alluvial sediments that is separated from the underlying medium- to coarse-grained sand by a hard clay layer (Plate 4.2b).

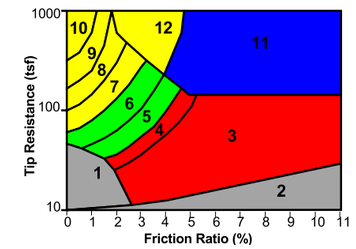
Earth Mechanics

FUGRO

KEY TO SOIL LITHOLOGY:

- Well graded GRAVEL (GW)
- Poorly graded GRAVEL (GP)
- GRAVEL with sand (GP or GW)
- GRAVEL with clay (GP or GW)
- Clayey GRAVEL (GC)
- GRAVEL with silt (GP or GW)
- Silty GRAVEL (GM)
- Well graded SAND (SW)
- Poorly graded SAND (SP)
- SAND with gravel (SP or SW)
- SAND with clay (SP-SC)
- Clayey SAND (SC)
- Silty SAND (SM)
- SAND with silt (SP-SM)
- Fat CLAY(CH)
- Sandy fat CLAY (CH)
- Lean CLAY (CL)
- Sandy lean CLAY (CL)
- Silty CLAY (CL-ML)
- Elastic SILT (MH)
- SILT (ML)
- Sandy SILT (ML)
- Clayey SILT (ML/CL)
- Highly plastic ORGANICS (OH)
- Low plasticity ORGANICS (OL)
- SANDSTONE (Rx)
- SILTSTONE (Rx)
- CLAYSTONE (Rx)
- Interbedded Rock Strata (Rx)
- CONGLOMERATE (Rx)
- PAVEMENT
- Rock Fragments (Rf)

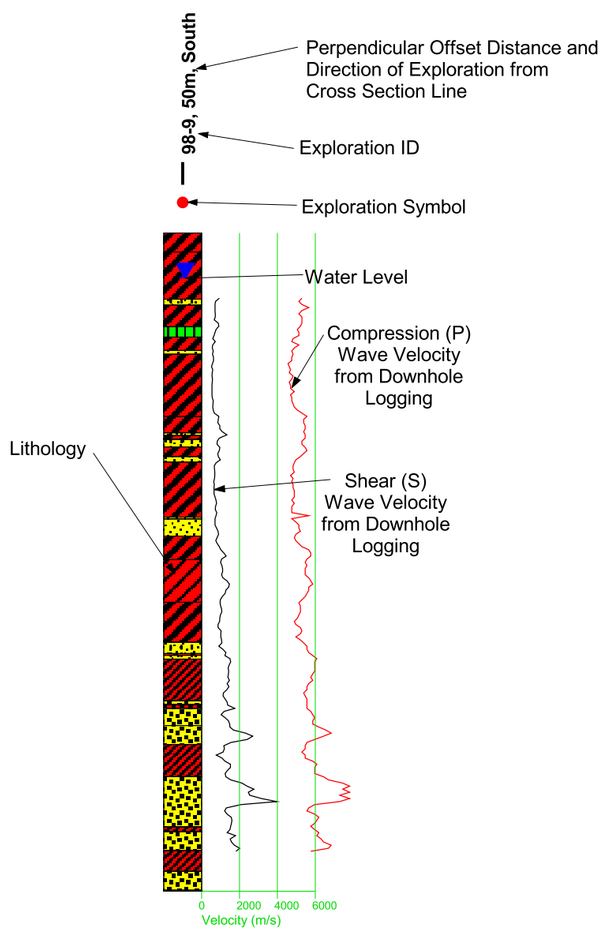
CPT CORRELATION CHART (Robertson and Campanella, 1988)



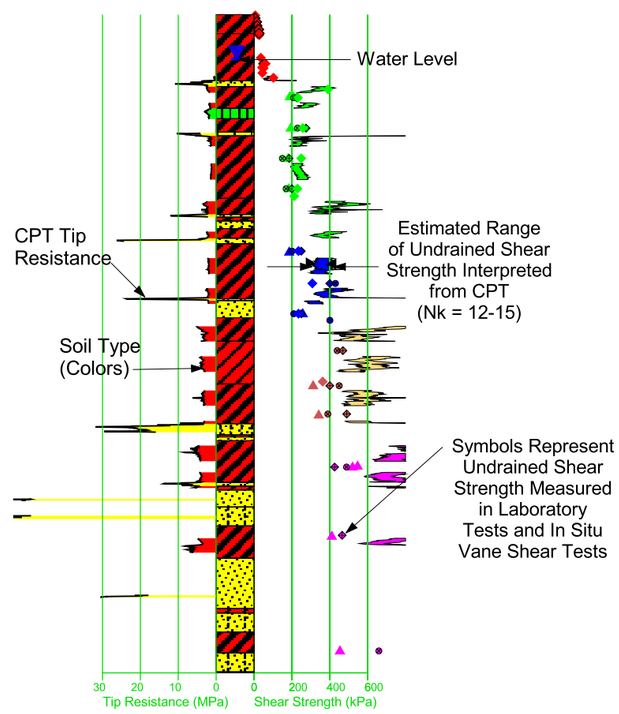
Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-OH
3	Clay	CH
4	Silty Clay to Clay	CL-CH
5	Clayey Silt to Silty Clay	MH-CL
6	Sandy Silt to Clayey Silt	ML-MH
7	Silty Sand to Sandy Silt	SM-ML
8	Sand to Silty Sand	SM-SP
9	Sand	SW-SP
10	Gravelly Sand to Sand	SW-GW
11	Very Stiff Fine-grained *	CH-CL
12	Sand to Clayey Sand *	SC-SM

*overconsolidated or cemented

SOIL AND ROCK BORING LITHOLOGY WITH P- AND S-WAVE VELOCITY



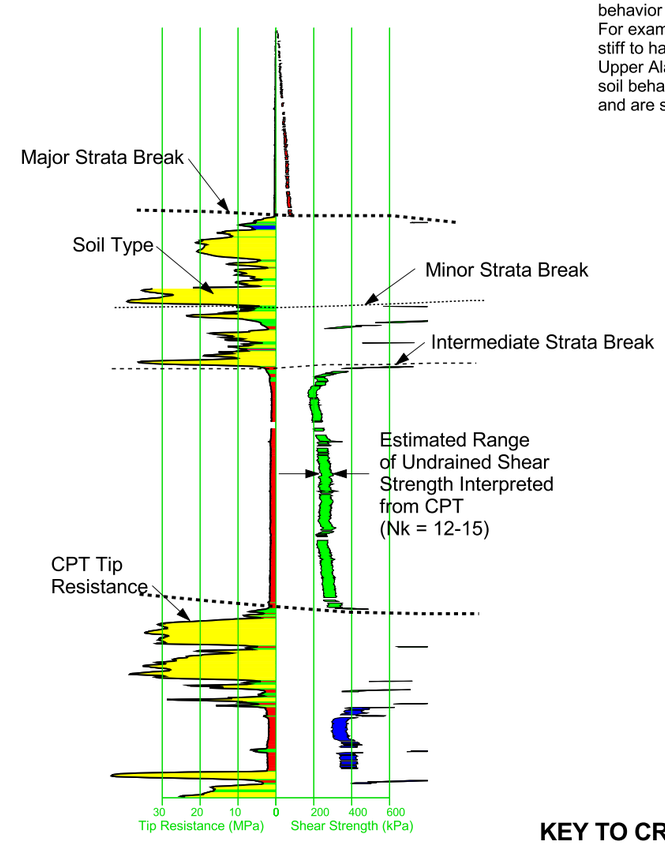
SOIL BORING LITHOLOGY WITH UNDRAINED SHEAR STRENGTH AND CPT



SHEAR STRENGTH SYMBOLS

- ▲ Unconsolidated Undrained (UU)
- □ Unconfined Compression (UC)
- ⊗ Pocket Penetrometer (PP)
- ⊕ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

CPT SOUNDING WITH UNDRAINED SHEAR STRENGTH AND INTERPRETED LITHOLOGY

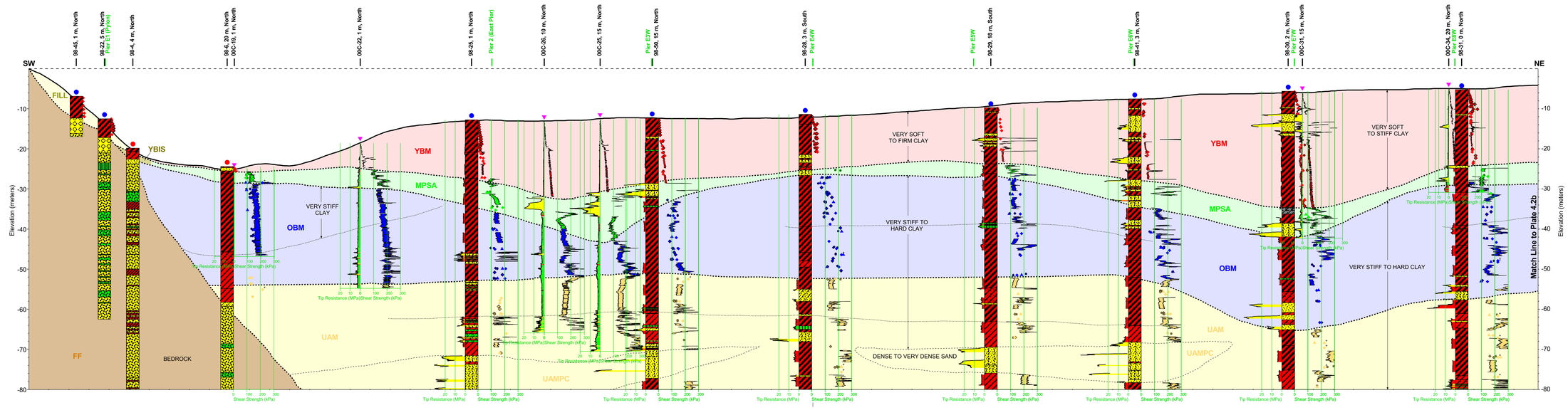


Note:
Soil lithologic classifications based on the Robertson and Campanella (1988) soil behavior chart are sometimes inaccurate. For example, CPT data from many of the stiff to hard clay layers of the Old Bay Mud/ Upper Alameda Marine Formations plot in soil behavior zones that corresponds to silts and are shown in green on the cross sections.

KEY TO CROSS SECTIONS

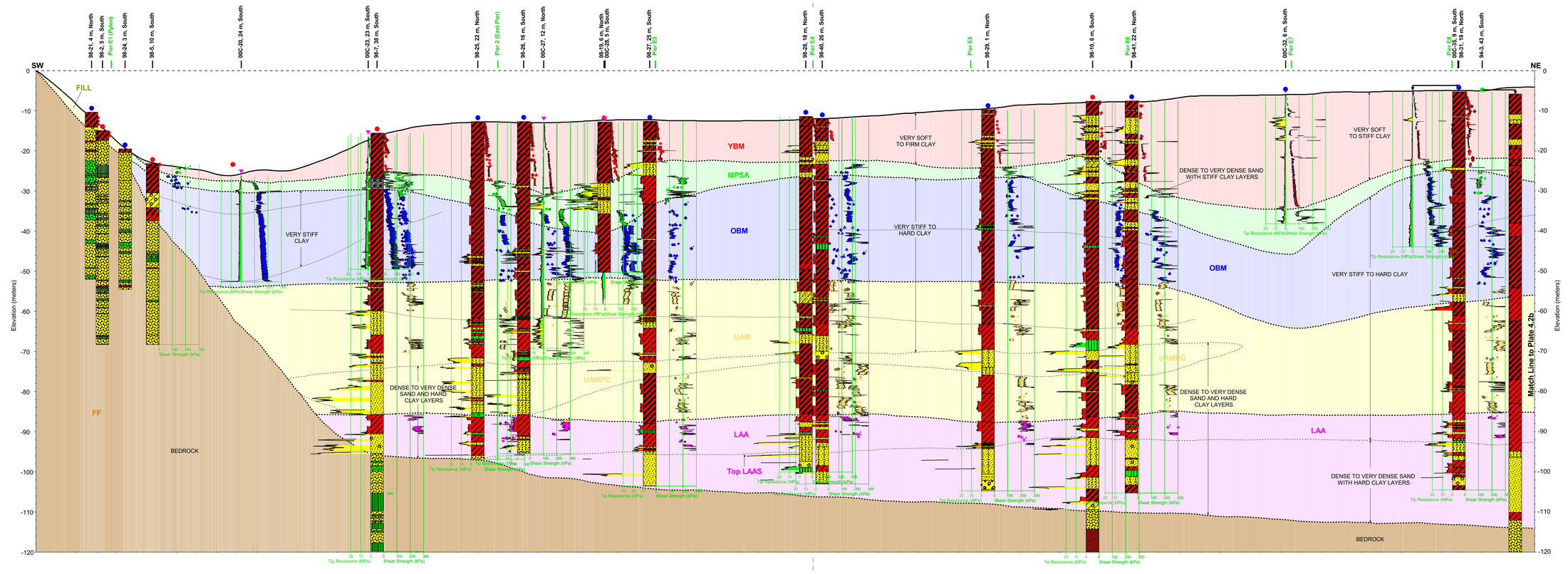
SFOBB East Span Seismic Safety Project

CENTERLINE OF WESTBOUND STRUCTURES



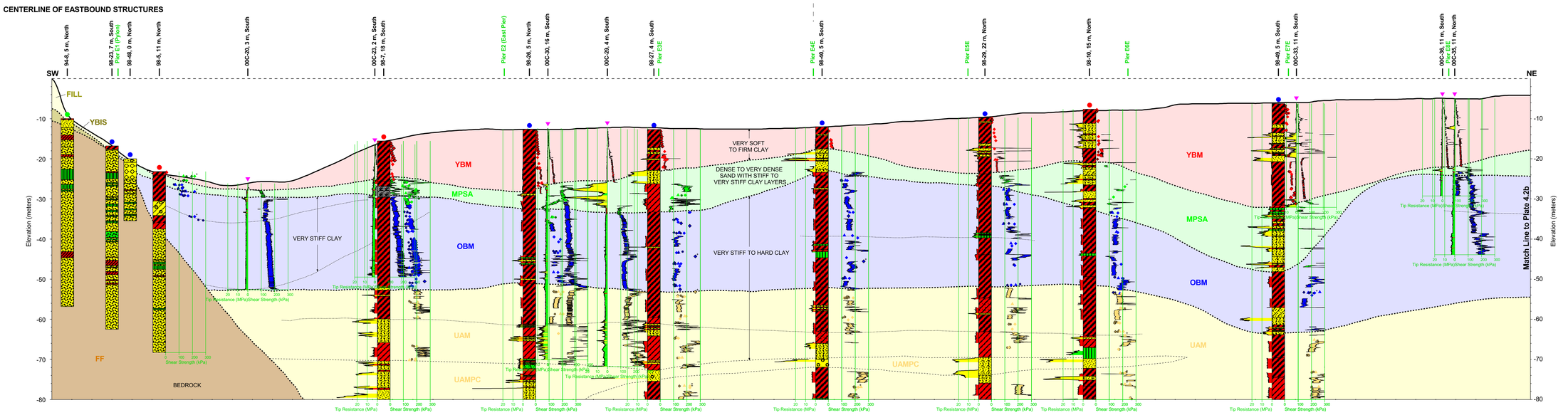
Horizontal Alignment of Sections is on Pier E4 Centerline

CENTERLINE OF N6 ALIGNMENT



Horizontal Alignment of Sections is on Pier E4 Centerline

CENTERLINE OF EASTBOUND STRUCTURES



10m
40m

KEY TO GEOLOGIC UNITS

FILL	Fill	UAM	Upper Alameda Marine
YBM	Young Bay Mud	UAMPC	Upper Alameda Marine Paleochannel Sand
MPSA	Merritt-Posey-San Antonio Formations	LAA	Lower Alameda Alluvial
YBIS	YBI Sediments	LAAS	Lower Alameda Sand
OBM	Old Bay Mud	FF	Franciscan Formation

SHEAR STRENGTH SYMBOLS

- ▲ Unconsolidated Undrained (UU)
- □ Unconfined Compression (UC)
- ⊗ Pocket Penetrometer (PP)
- ◇ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- * Strength Exceeds Capacity of Measuring Device

Notes:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Boring and CPT sounding logs are projected onto the lines of the cross sections. Therefore stratigraphic contacts may not exactly correspond to the contact indications (lithology, shear strength, etc.) in the logs.

3) Shear strengths are calculated from CPT tip resistances and measurements made on samples from borings.

4) Horizon geometry between borings based on correlations with seismic reflection data.

5) Lithology from pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

6) Horizontal datum is California Coordinate System Zone 3, NAD83, in meters. Vertical datum is MSL 1929, in meters (0.942 meters above MLLW; Caltrans, 1997).

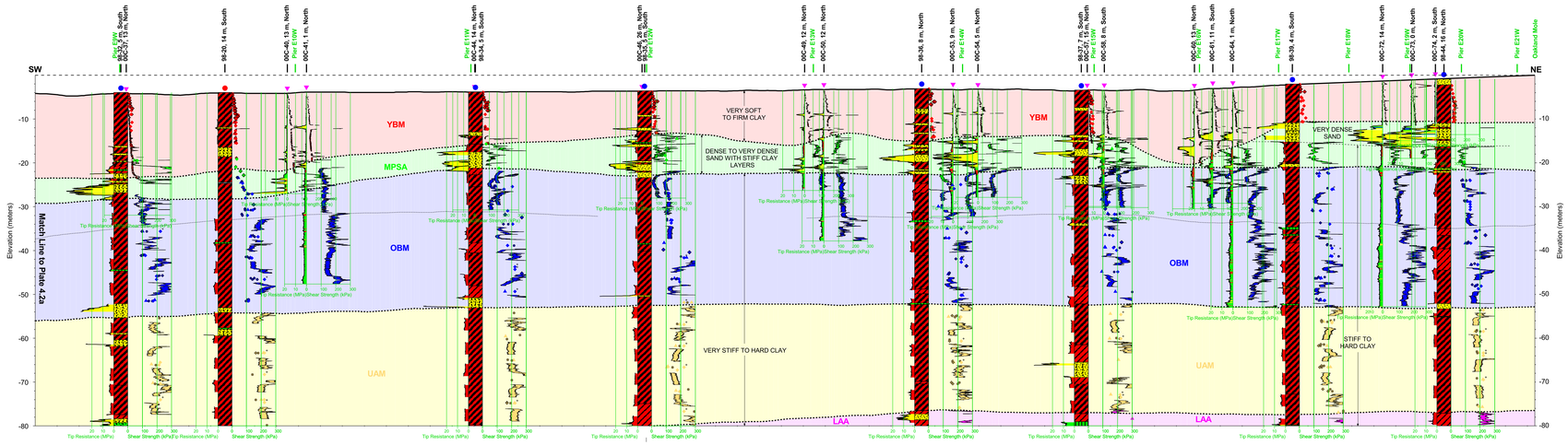
7) Refer to Plate 4.2b for Cross Section Location Map and Key to Data Shown on Borings and CPT Soundings.

SUBSURFACE CROSS SECTIONS ALONG N6 ALIGNMENT
YERBA BUENA ISLAND TO OAKLAND MOLE
PIER E1 TO PIER E8

SFOBB East Span Seismic Safety Project

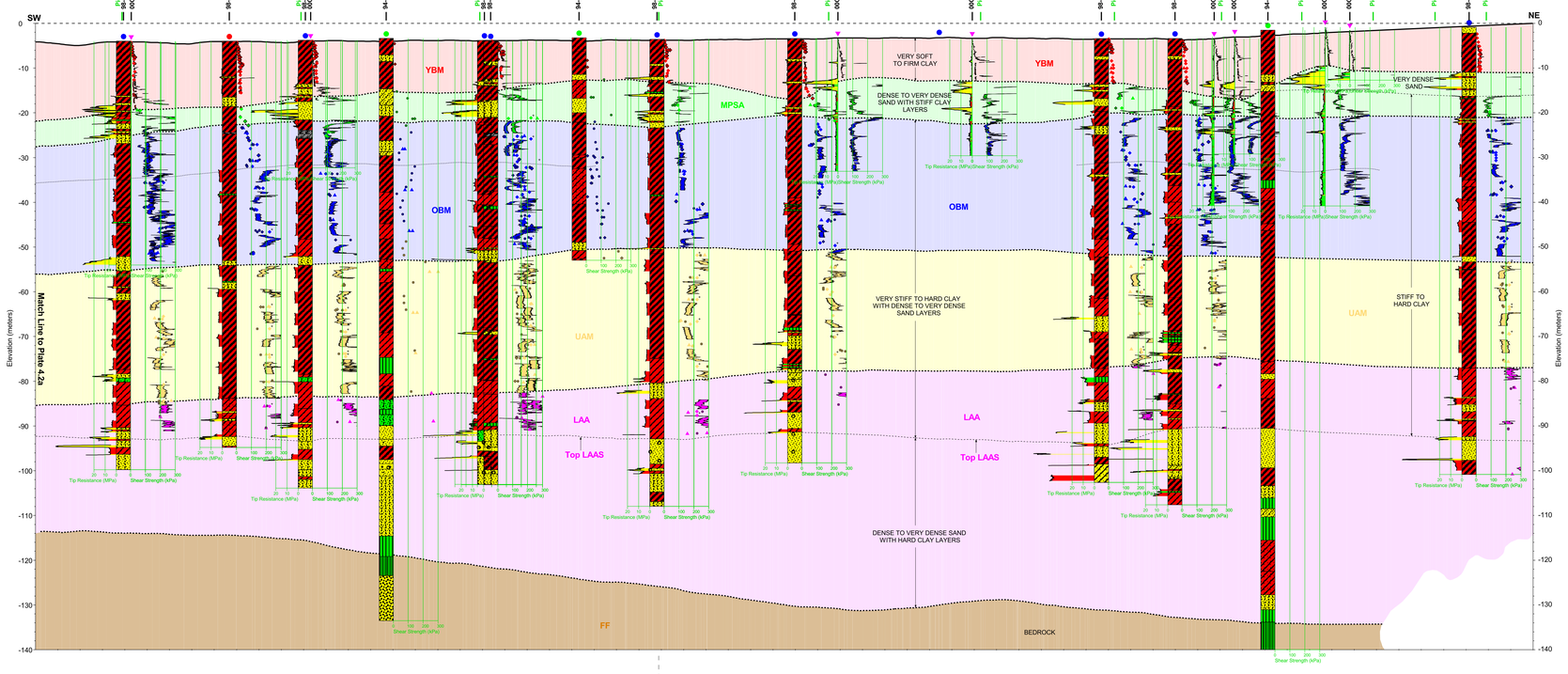
PLATE 4.2a

CENTERLINE OF WESTBOUND STRUCTURES



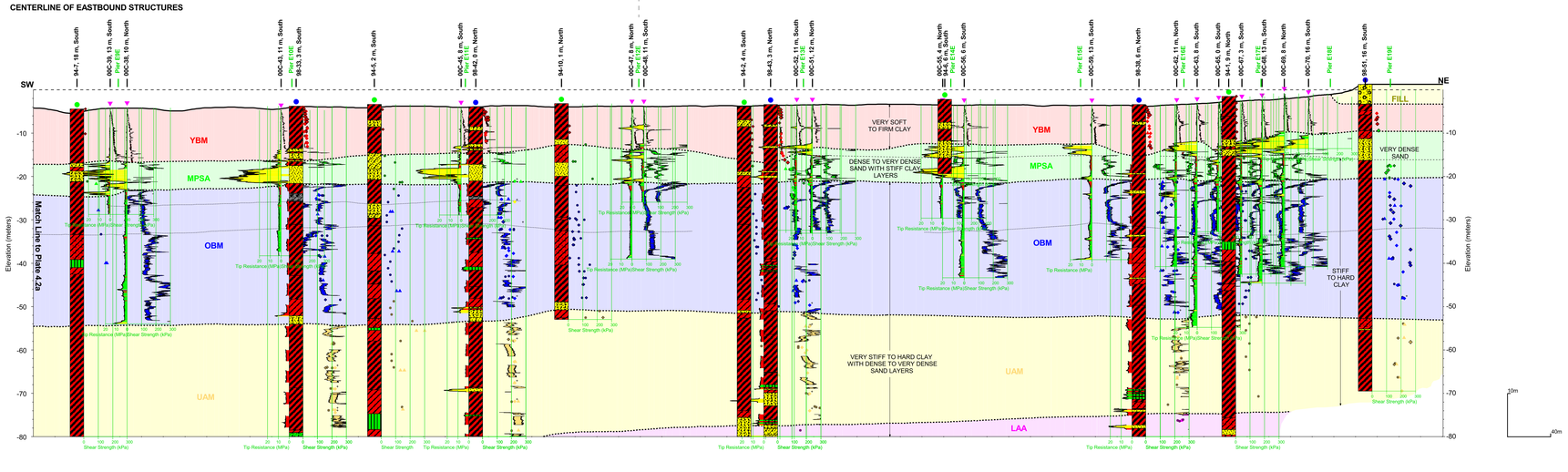
Horizontal Alignment of Sections is on Pier E12 Centerline

CENTERLINE OF N6 ALIGNMENT

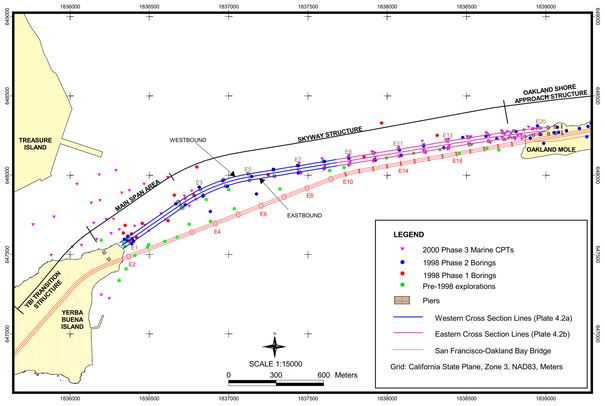


Horizontal Alignment of Sections is on Pier E12 Centerline

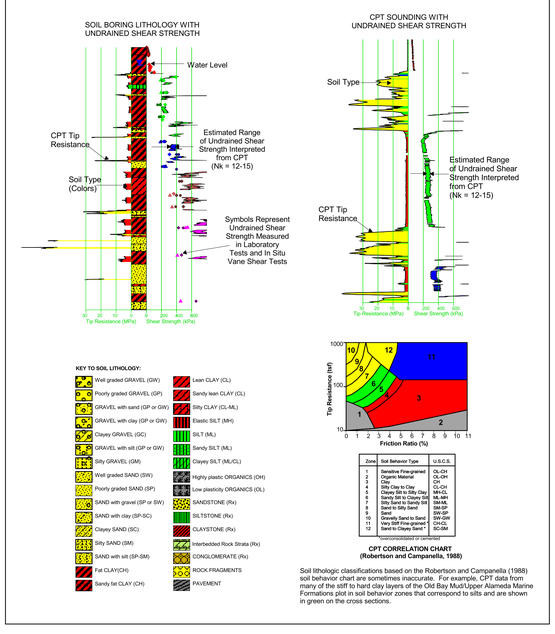
CENTERLINE OF EASTBOUND STRUCTURES



CROSS SECTION LOCATION MAP



KEY TO BORING LOGS AND CPT SOUNDINGS ON CROSS SECTIONS



Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-CH
3	Clay	CL-CH
4	Silty Clay to Clay	ML-CH
5	Clayey Silt to Silty Clay	ML-MH
6	Sandy Silt to Clayey Silt	SM-ML
7	Silty Sand to Sandy Silt	SW-ML
8	Sand to Silty Sand	SW-SP
9	Gravelly Sand to Sand	SW-GW
11	Very Stiff Fine-grained*	SV-CL
12	Sand to Clayey Sand *	SC-SM

*Overconsolidated or cemented

KEY TO GEOLOGIC UNITS

- FILL — Fill
- YBM — Young Bay Mud
- MPSA — Merritt-Posey-San Antonio Formations
- OBM — Old Bay Mud
- UAM — Upper Alameda Marine
- LAA — Lower Alameda Alluvial
- LAAS — Lower Alameda Sand
- FF — Franciscan Formation

SHEAR STRENGTH SYMBOLS

- Unconsolidated Undrained (UU)
- Unconfined Compression (UC)
- Pocket Penetrometer (PP)
- Torvane (TV)
- Miniature Vane (MV)
- Remote Vane (RV)
- * Strength Exceeds Capacity of Measuring Device

Notes:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Boring and CPT sounding logs are projected onto the lines of the cross sections. Therefore stratigraphic contacts may not exactly correspond to the contact indications (lithology, shear strength, etc.) in the logs.

3) Shear strengths are calculated from CPT tip resistances and measurements made on samples from borings.

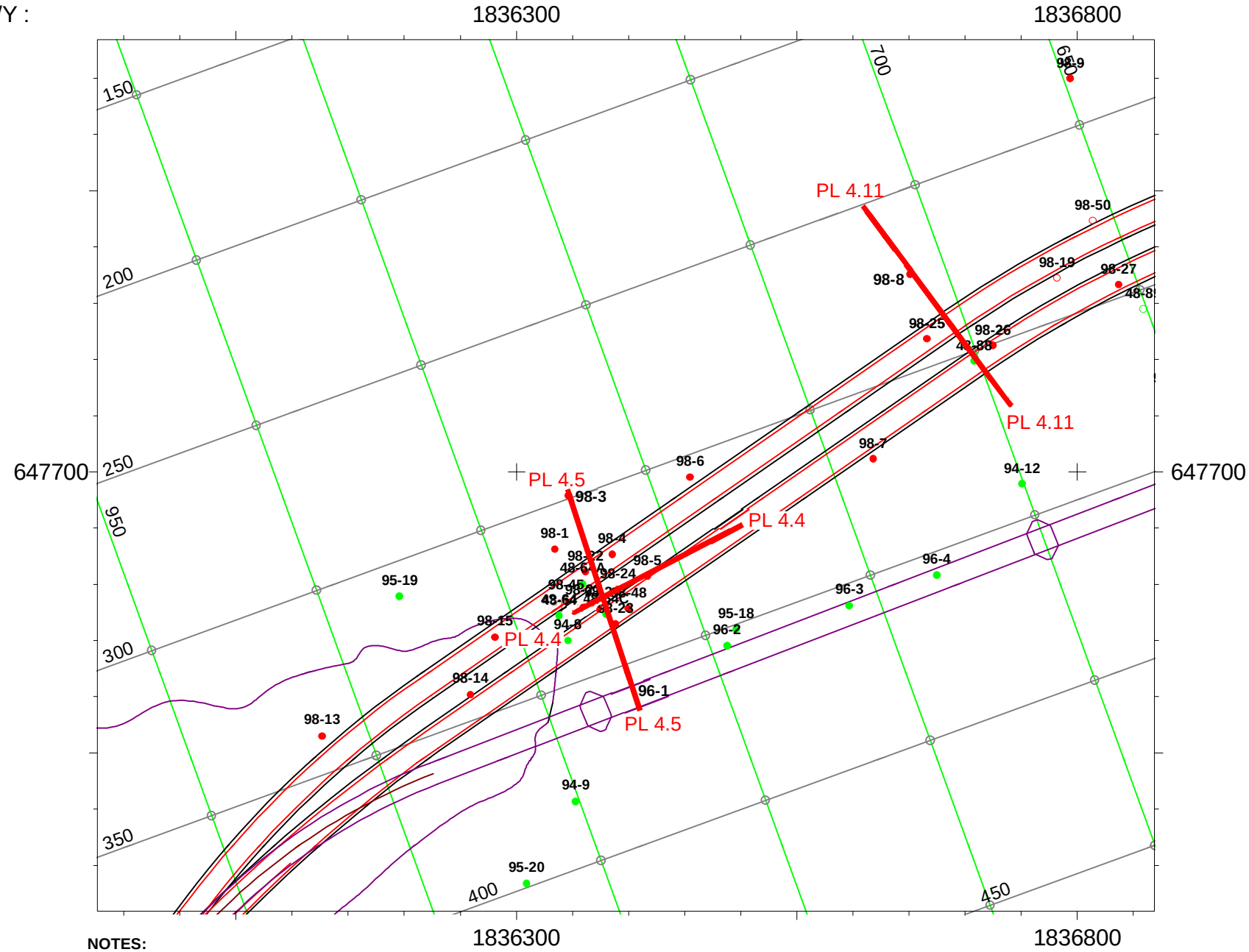
4) Horizon geometry between borings based on correlations with seismic reflection data.

5) Lithology from pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

6) Horizontal datum is California Coordinate System Zone 3, NAD83, in meters. Vertical datum is MSL 1929, in meters (0.942 meters above MLLW; Caltrans, 1997).

SUBSURFACE CROSS SECTIONS ALONG N6 ALIGNMENT
YERBA BUENA ISLAND TO OAKLAND MOLE
PIER E9 TO PIER E20

SFOBB East Span Seismic Safety Project



NOTES:

1) See notes on Plate 2.15.

Scale 1:5000

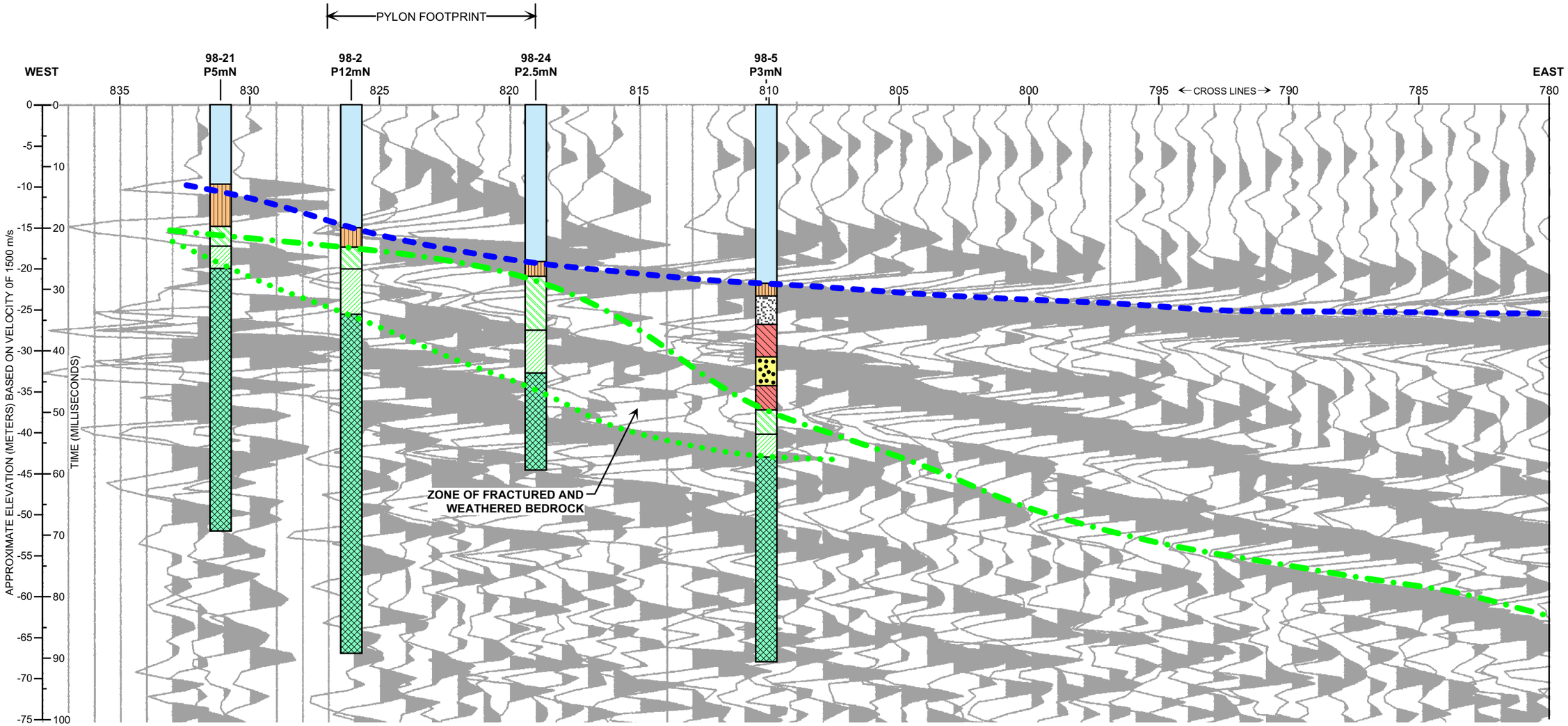
LOCATION MAP FOR 3-D SEISMIC DATA ILLUSTRATED IN SECTION 4

SFOBB East Span Seismic Safety Project

SFOBB Task Order No. 5
Project No. 98-42-0054

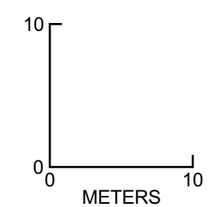
Earth Mechanics

FUGRO



LEGEND

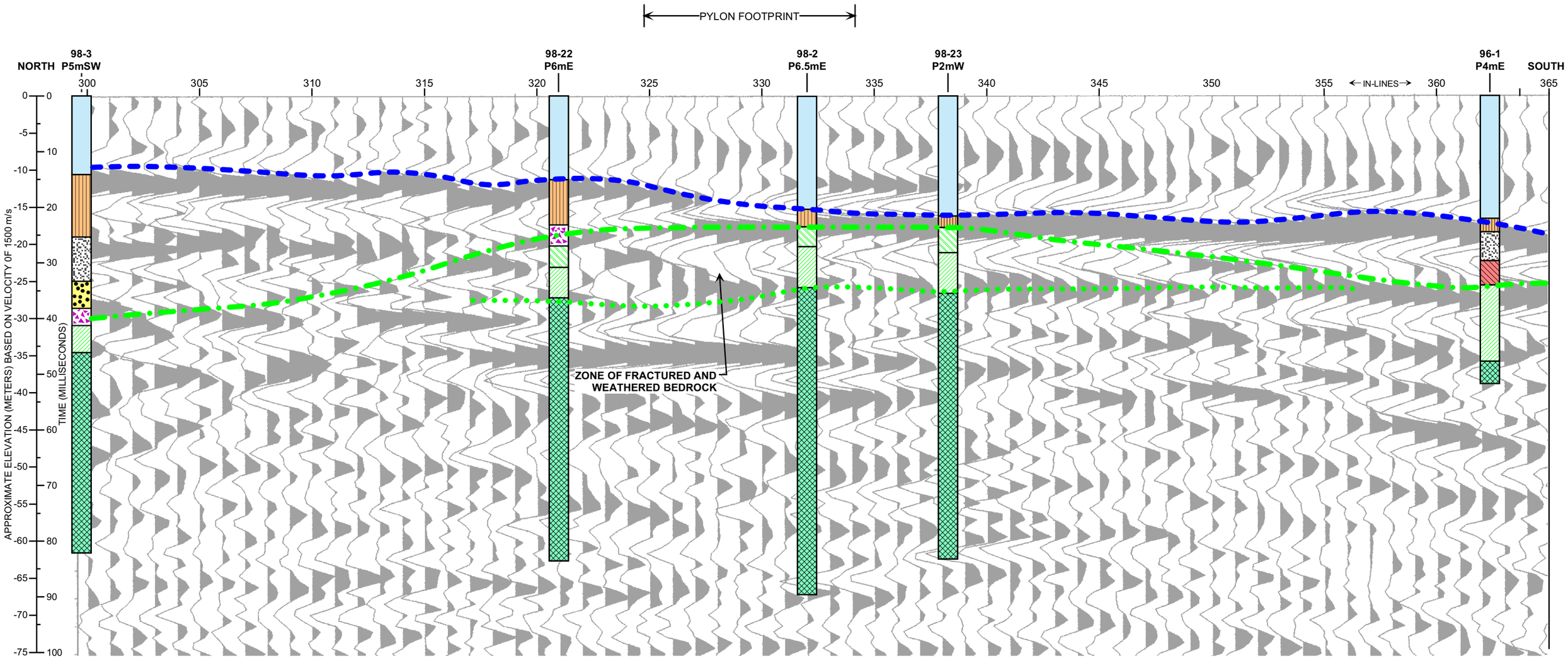
- Water
- Young Bay Mud or Fill
- Stiff Clay with Sand
- Gravel
- Old Bay Mud
- Rock Fragments
- Intensely Weathered Bedrock
- Moderately Weathered Bedrock
- Slightly Weathered to Fresh Bedrock
- Mudline
- Top of Franciscan Formation Bedrock as Shown on Maps 13 and 15
- Top of Slightly Weathered to Fresh Bedrock



(Vertical Scale Applies to Sediment Section)

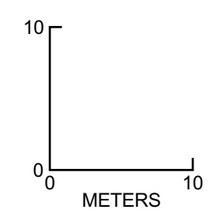
FRANCISCAN FORMATION WEATHERING SURFACES MAIN SPAN-PYLON AREA
Annotated 3-D Seismic Line 328
SFOBB East Span Seismic Safety Project

98420054rec1.dsf(1.3).p2



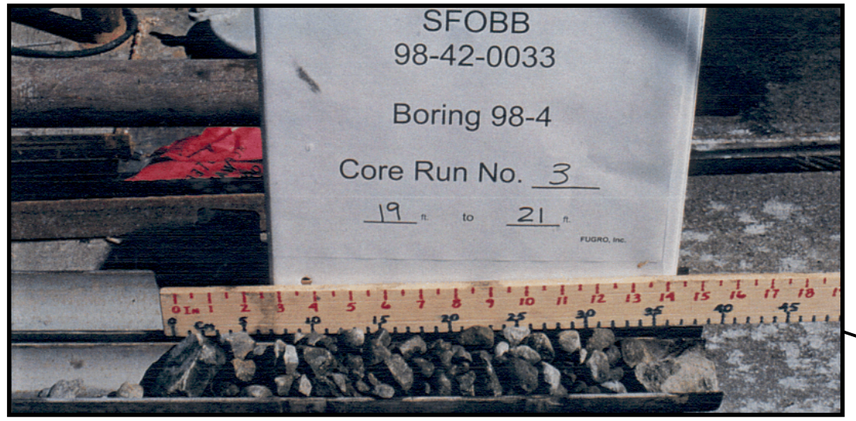
LEGEND

- Water
- Young Bay Mud or Fill
- Stiff Clay with Sand
- Gravel
- Old Bay Mud
- Rock Fragments
- Intensely Weathered Bedrock
- Moderately Weathered Bedrock
- Slightly Weathered to Fresh Bedrock
- Mudline
- Top of Franciscan Formation Bedrock as Shown on Maps 13 and 15
- Top of Slightly Weathered to Fresh Bedrock

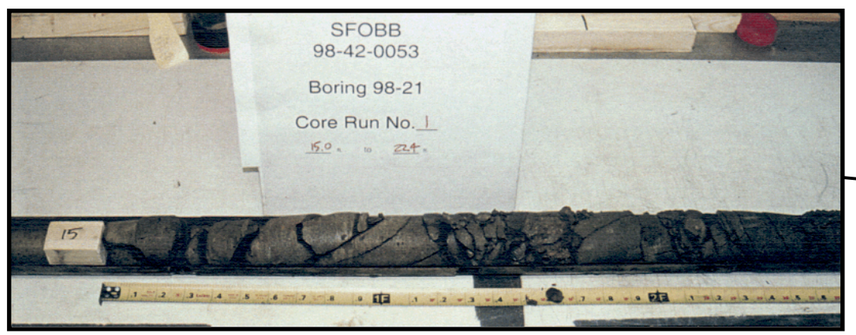


(Vertical Scale Applies to Sediment Section)

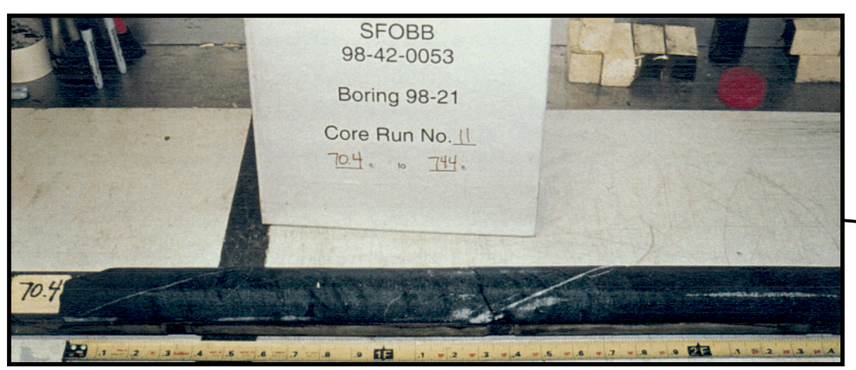
FRANCISCAN FORMATION
WEATHERING SURFACES
MAIN SPAN PYLON AREA
Annotated 3-D Crossline 824
SFOBB East Span Seismic Safety Project



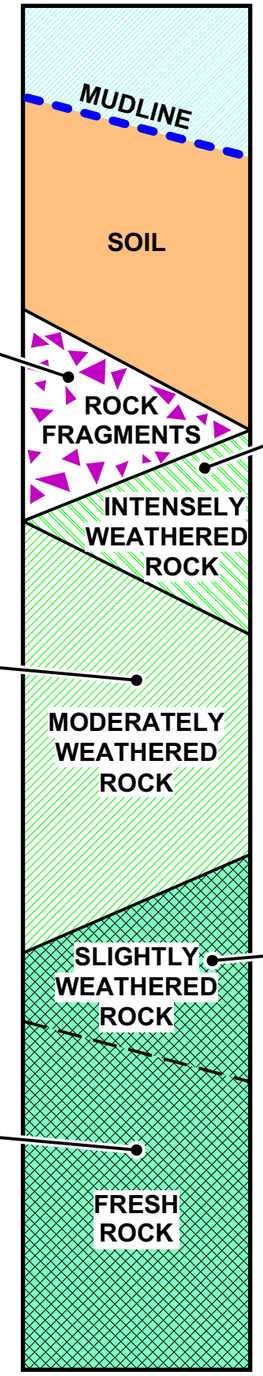
Rock Fragment Zone. Samples consisted of subangular to angular, 10- to 25-mm pieces of light gray to light brown, intensely weathered sandstone with variable amounts of sand, silt and clay. The origin of the rock fragment zone is uncertain, and it could represent intensely-weathered to decomposed bedrock.

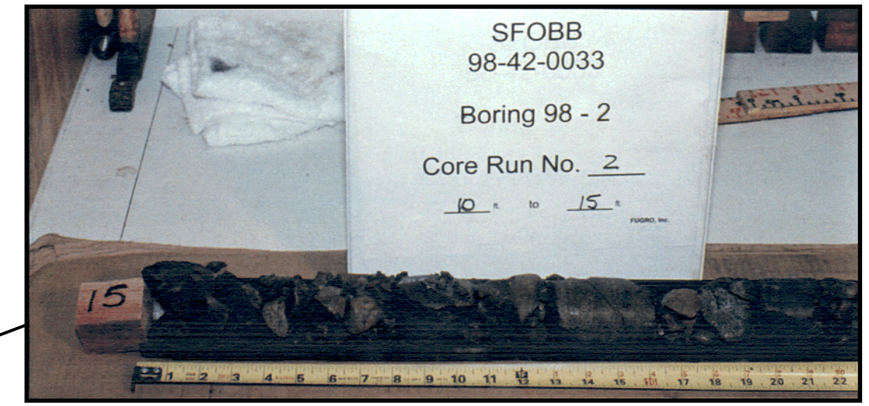


Moderately-weathered Rock. The moderately-weathered bedrock consists of a 3- to 5-meter thick zone of light yellowish brown to light brown, moderately hard sandstone (graywacke) that is intensely to very intensely fractured. Core recovery was typically 50 to 80 percent, but the rock was generally intensely fractured (by natural processes) into pieces ranging from about 25 to 125 mm long.

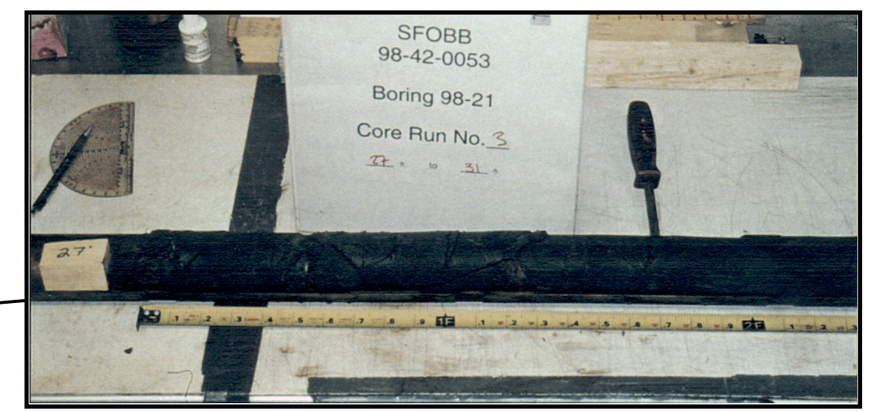


Fresh Rock. The fresh rock is characterized by hard, well indurated, thickly bedded to massive sandstone with thinly interbedded siltstone and claystone layers. The sandstone is typically moderately to slightly fractured with zones of intensely fractured sandstone up to about 1.5 to 1.8 meters thick. The siltstone and claystone interbeds are typically thinly bedded to laminated, dark gray to black, moderately hard, and normally intensely to very intensely fractured into pieces generally less than about 100 mm (4 inches) long. The siltstone/claystone beds typically range from about 0.1 to 0.3 meters thick, although several zones of fine-grained rock were up to 3 meters thick.





Intensely-weathered Rock. Rock core samples from this zone consist of light gray to light brown, intensely weathered and fractured, moderately hard, sandstone. The core recovery in the intensely weathered zone was typically about 30 to 60 percent, with an RQD of 0.



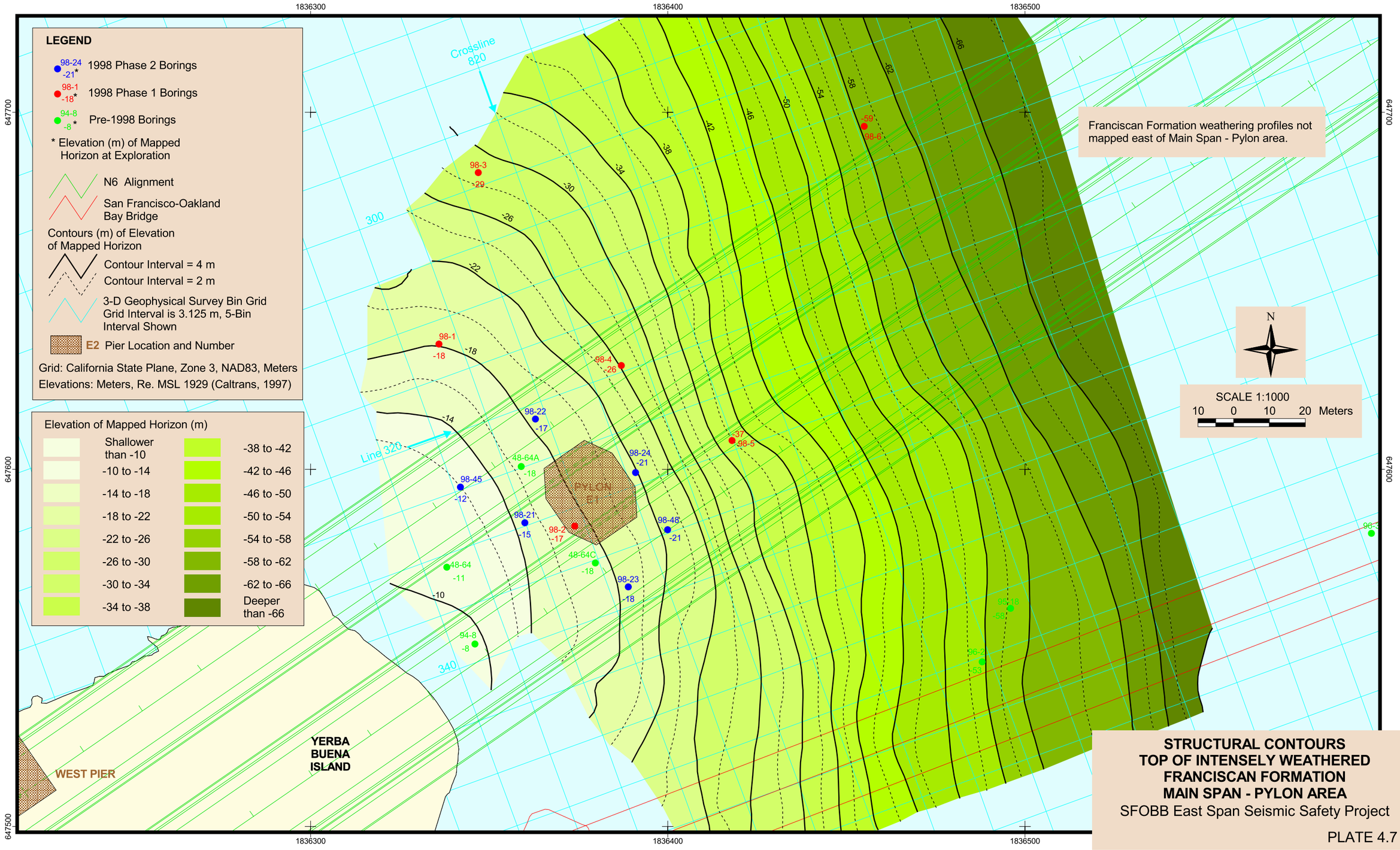
Slightly-weathered Rock. A relatively thin, 1.5 to 3 meter thick, layer of slightly weathered rock forms a transitional boundary between the light brown moderately-weathered rock and the underlying dark gray, fresh, unweathered rock. The slightly weathered rock is characterized by a zone with up to 25 mm of light brown moderately weathered rock on each side of the fractures and joints. The slightly weathered bedrock strata grade from moderately weathered to fresh over the length of this zone.

PHOTOGRAPHS OF REPRESENTATIVE ROCK SAMPLES FROM MAIN SPAN-PYLON AREA
SFOBB East Span Seismic Safety Project

9842\0054samp.dsf(1,2)

Earth Mechanics

FUGRO



STRUCTURAL CONTOURS
TOP OF INTENSELY WEATHERED
FRANCISCAN FORMATION
MAIN SPAN - PYLON AREA
SFOBB East Span Seismic Safety Project

PLATE 4.7

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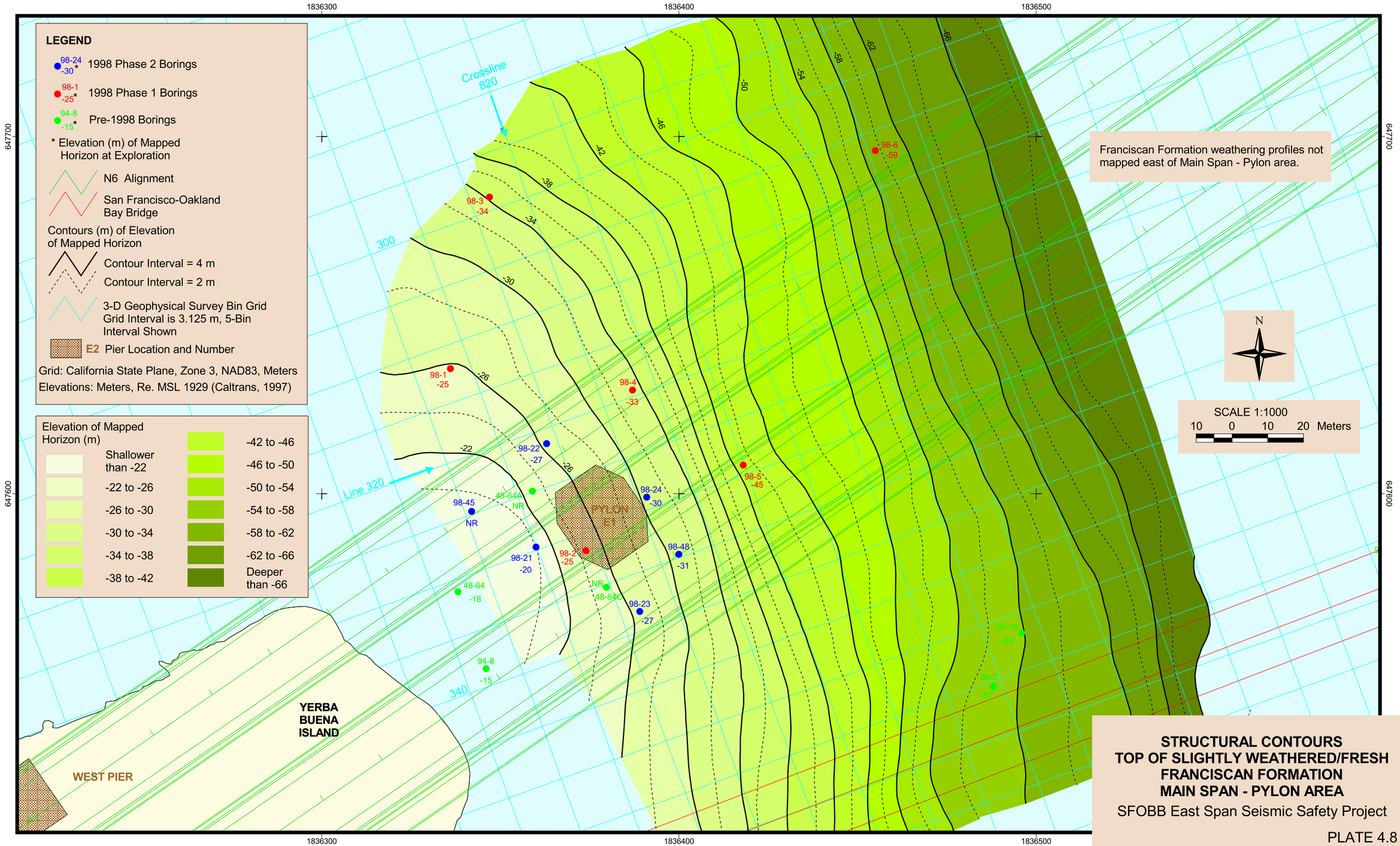

STRUCTURAL CONTOURS
TOP OF SLIGHTLY WEATHERED/FRESH FRANCISCAN FORMATION
MAIN SPAN - PYLON AREA

SFOBB East Span Seismic Safety Project

PLATE 4.8

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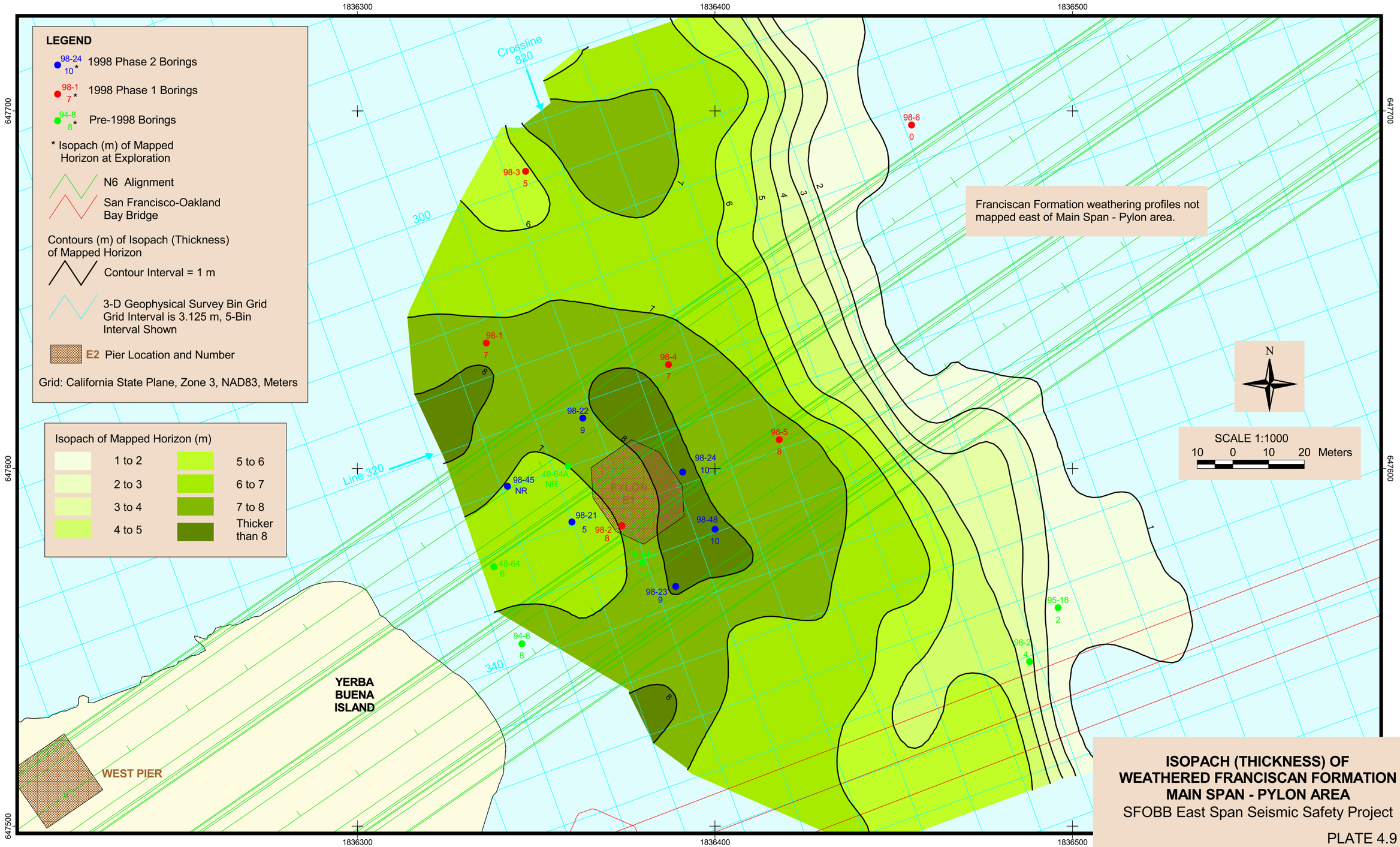
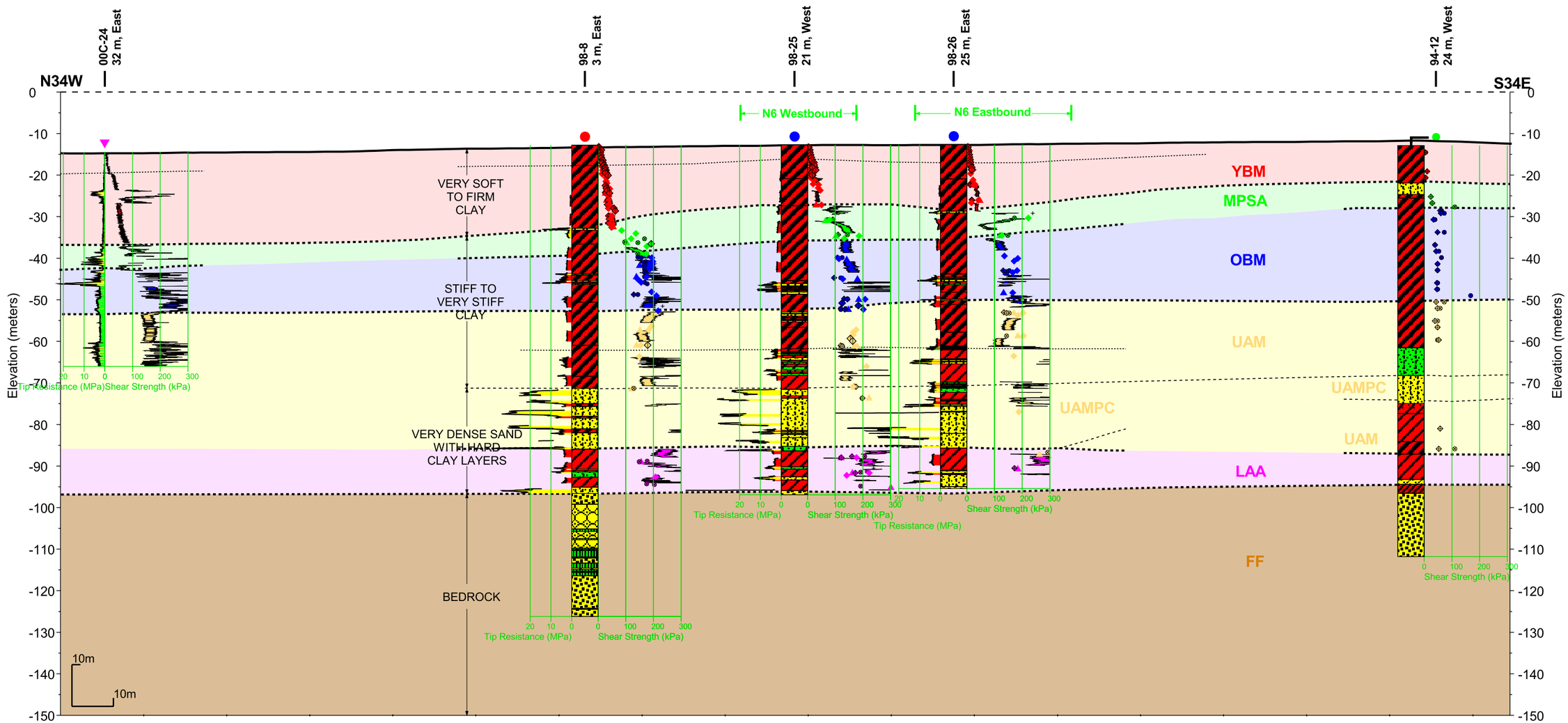


ISOPACH (THICKNESS) OF WEATHERED FRANCISCAN FORMATION MAIN SPAN - PYLON AREA

SFOBB East Span Seismic Safety Project

PLATE 4.9

j:\caltrans\reports\finalreports\marine_geophys_report_book1\section4\odb\plate4-9.odb, cdean, 03/01/2001



GENERAL NOTES:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Refer to Key to Cross Sections for descriptions of boring and CPT data shown above.

3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

SHEAR STRENGTH SYMBOLS

- ▲ Unconsolidated Undrained (UU)
- □ Unconfined Compression (UC)
- ⊗ Pocket Penetrometer (PP)
- ⊕ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

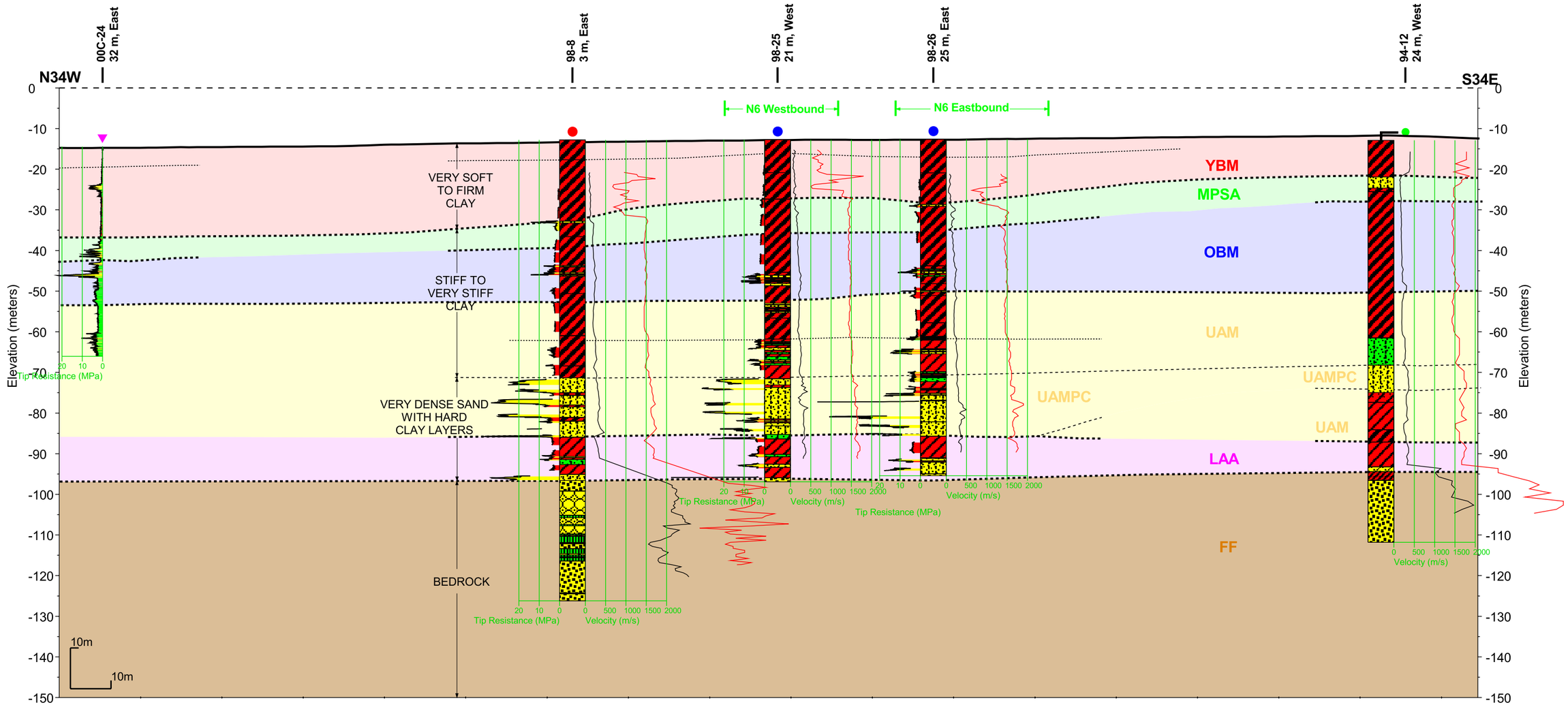
YBM	Young Bay Mud	LAA	Lower Alameda Alluvial
MPSA	Merritt-Posey-San Antonio Formations	FF	Franciscan Formation
OBM	Old Bay Mud		
UAM	Upper Alameda Marine		
UAMPC	Upper Alameda Marine Paleochannel Sand		

SUBSURFACE CROSS SECTION THROUGH PIER E2
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 4.10a

Earth Mechanics

FUGRO



GENERAL NOTES:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Refer to Key to Cross Sections for descriptions of boring and CPT data shown above.

3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

LEGEND

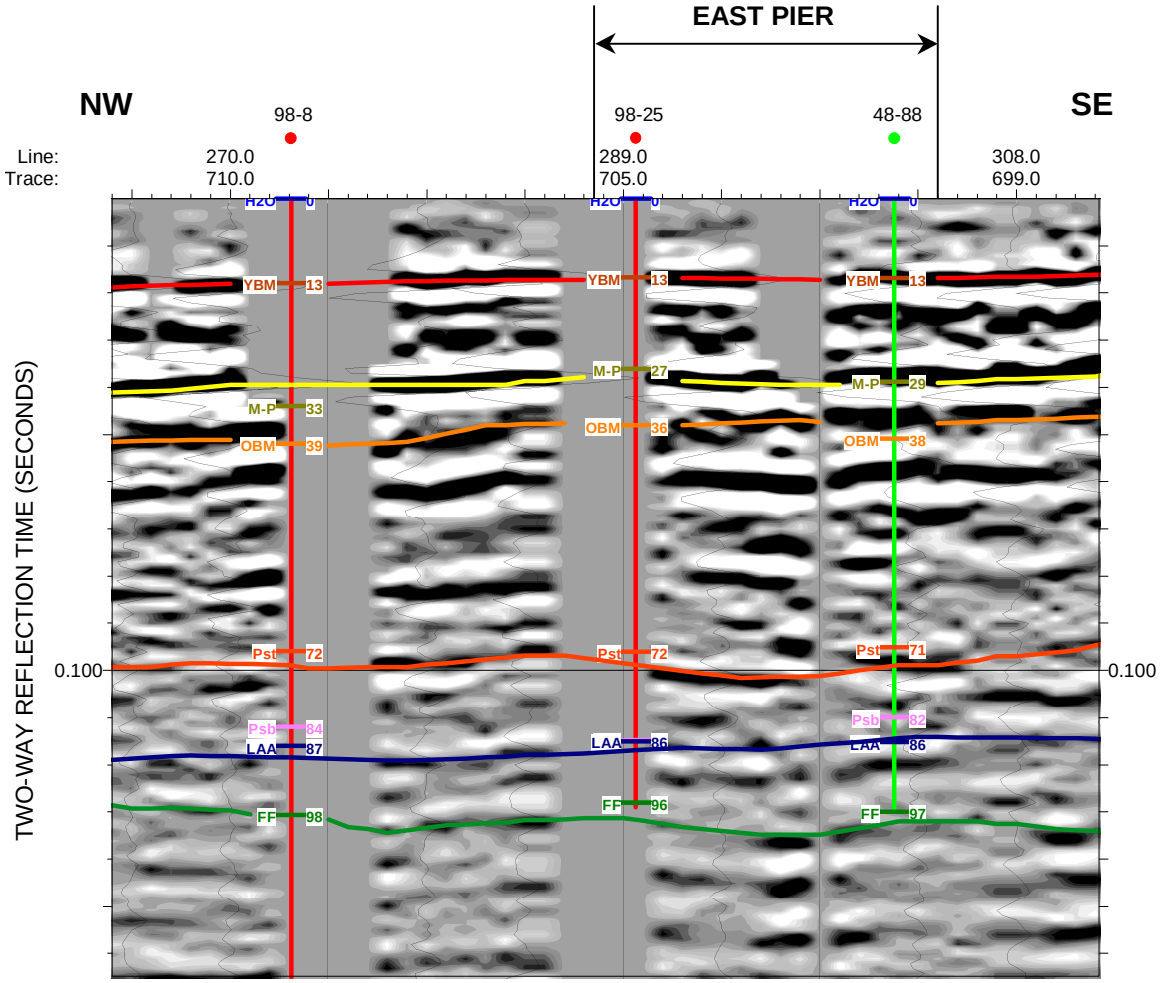
- P-Wave Velocity
- S-Wave Velocity

KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud	LAA	Lower Alameda Alluvial
MPSA	Merritt-Posey-San Antonio Formations	FF	Franciscan Formation
OBM	Old Bay Mud		
UAM	Upper Alameda Marine		
UAMPC	Upper Alameda Marine Paleochannel Sand		

SUBSURFACE CROSS SECTION THROUGH PIER E2
With P- and S-Wave Velocity
SFOBB East Span Seismic Safety Project

PLATE 4.10b



Approximate Scales
Horizontal 1:880
Vertical 1:940

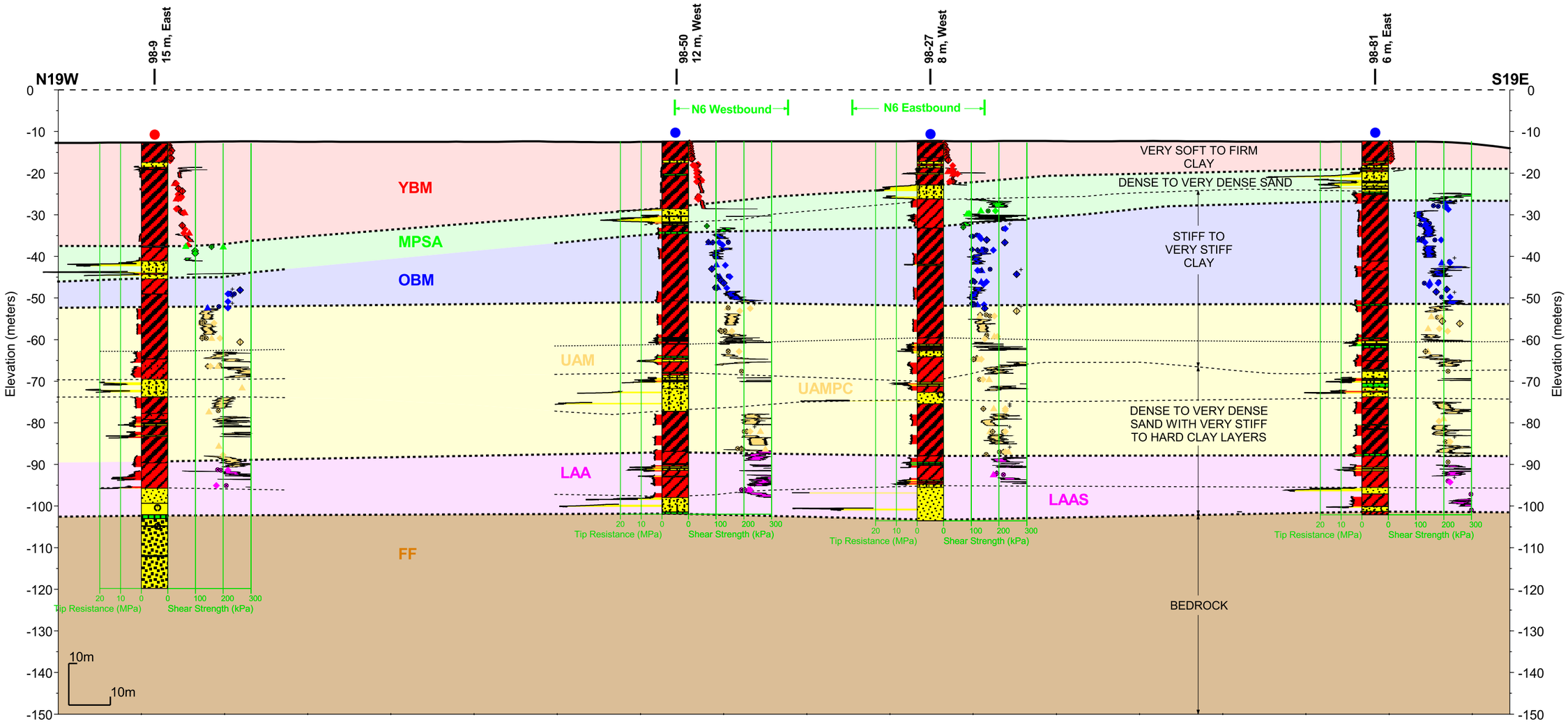
NOTES:

1.) Unit Designations: YBM = Bay Floor/Top Young Bay Mud
M-P = Top Merritt-Posey-San Antonio Formations (MPSA)
OBM = Top Old Bay Mud/Upper Alameda Marine Sediments
Pst, Psb = Paleochannel Sand Top and Base
LAA = Top Lower Alameda Alluvial Sediment
FF = Top Franciscan Formation

2.) See Plate 4.3 for location of Line.

ANNOTATED SEISMIC LINE
Arbitrary Line Through East Pier Footprint
SFOBB East Span Seismic Safety Project

PLATE 4.11



GENERAL NOTES:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Refer to Key to Cross Sections for descriptions of boring and CPT data shown above.

3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

SHEAR STRENGTH SYMBOLS

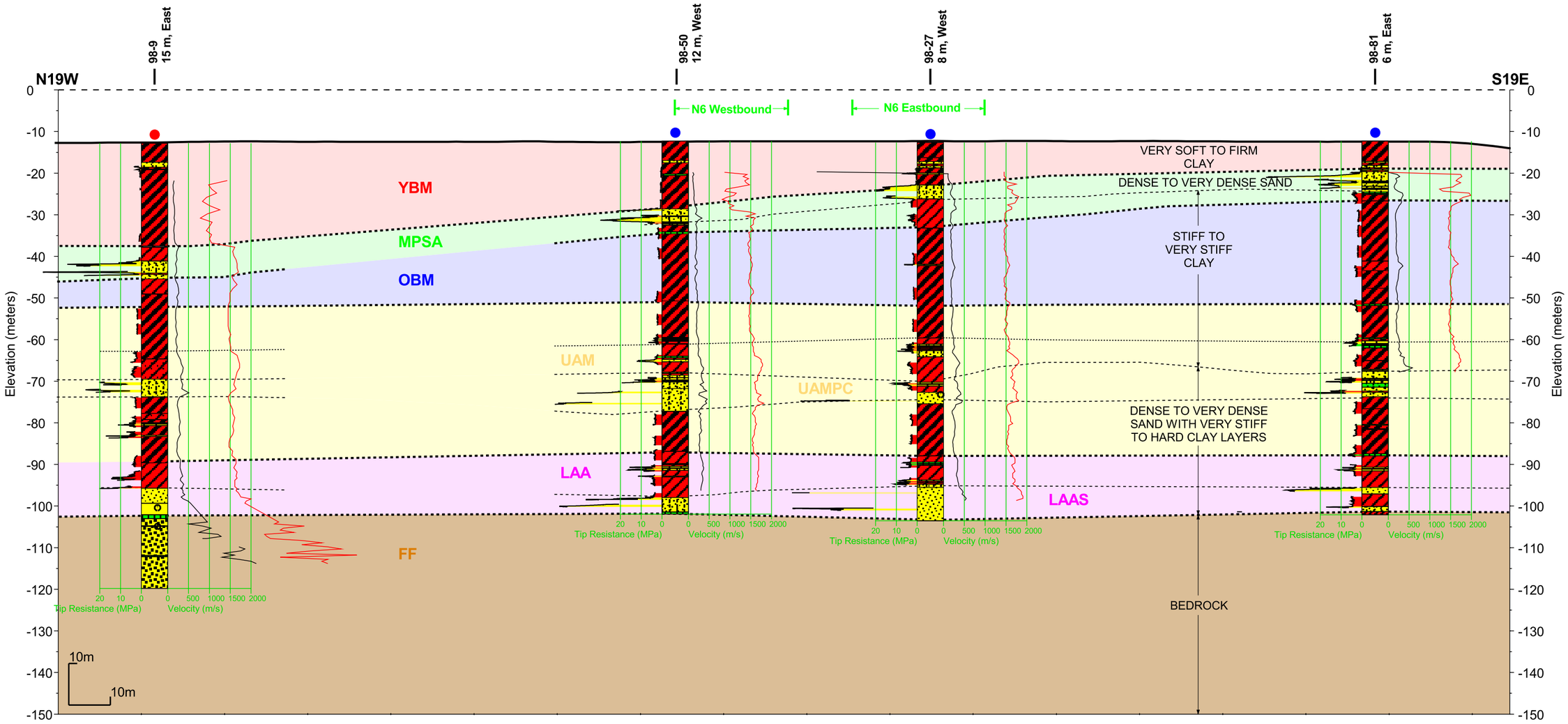
- ▲ Unconsolidated Undrained (UU)
- □ Unconfined Compression (UC)
- ⊗ Pocket Penetrometer (PP)
- Torvane (TV)
- ◆ Miniature Vane (MV)
- Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud	LAA	Lower Alameda Alluvial
MPSA	Merritt-Posey-San Antonio Formations	LAAS	Lower Alameda Sand
OBM	Old Bay Mud	FF	Franciscan Formation
UAM	Upper Alameda Marine		
UAMPC	Upper Alameda Marine Paleochannel Sand		

SUBSURFACE CROSS SECTION THROUGH PIER E3
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 4.12a



GENERAL NOTES:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Refer to Key to Cross Sections for descriptions of boring and CPT data shown above.

3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

LEGEND

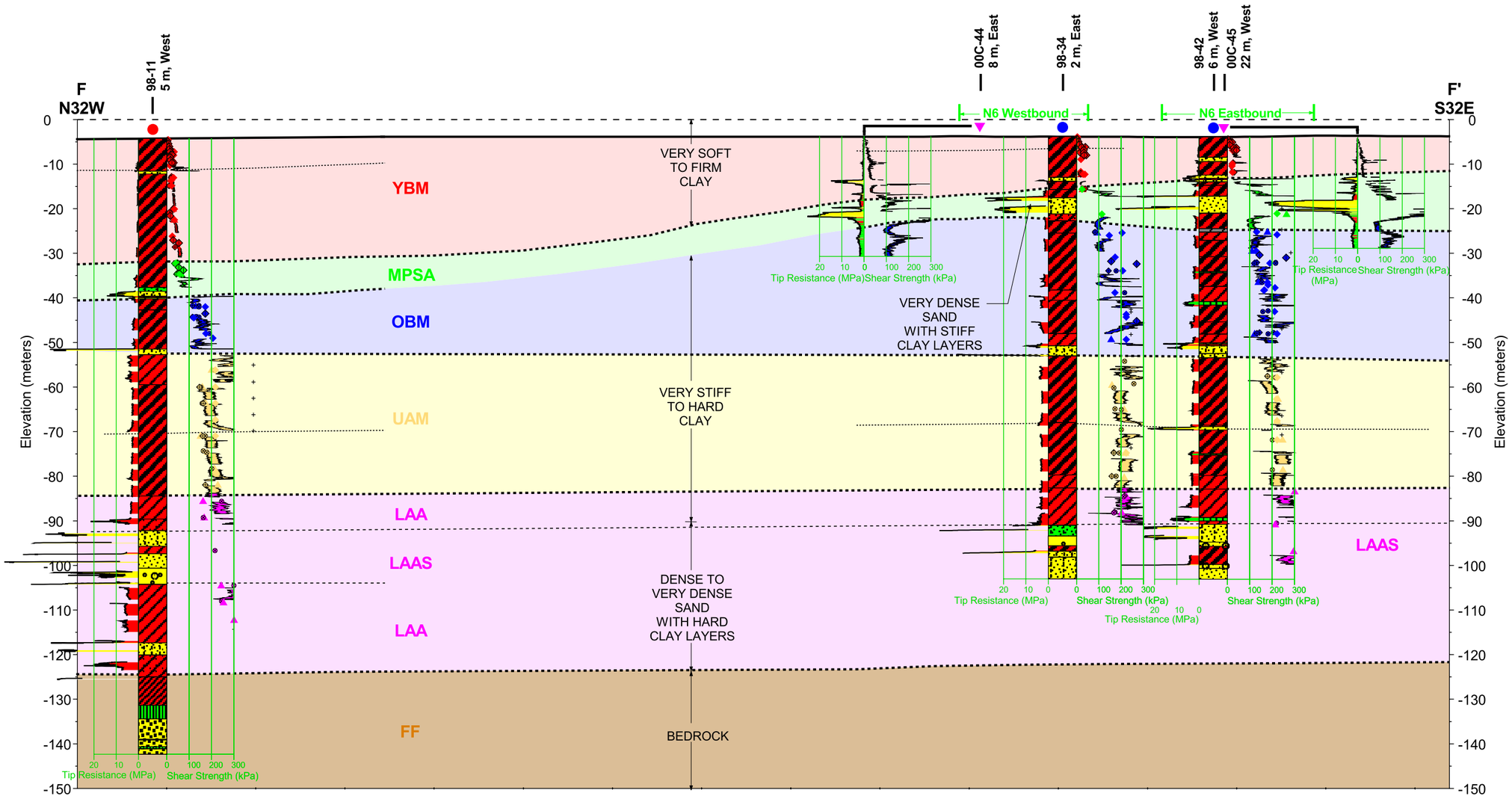
- P-Wave Velocity
- S-Wave Velocity

KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud	LAA	Lower Alameda Alluvial
MPSA	Merritt-Posey-San Antonio Formations	LAAS	Lower Alameda Sand
OBM	Old Bay Mud	FF	Franciscan Formation
UAM	Upper Alameda Marine		
UAMPC	Upper Alameda Marine Paleochannel Sand		

SUBSURFACE CROSS SECTION THROUGH PIER E3
With P- and S-Wave Velocity
SFOBB East Span Seismic Safety Project

PLATE 4.12b



10m
10m

GENERAL NOTES:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Refer to Key to Cross Sections for descriptions of boring and CPT data shown above.

3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

SHEAR STRENGTH SYMBOLS

- ▲ Unconsolidated Undrained (UU)
- □ Unconfined Compression (UC)
- ⊗ Pocket Penetrometer (PP)
- ⊕ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

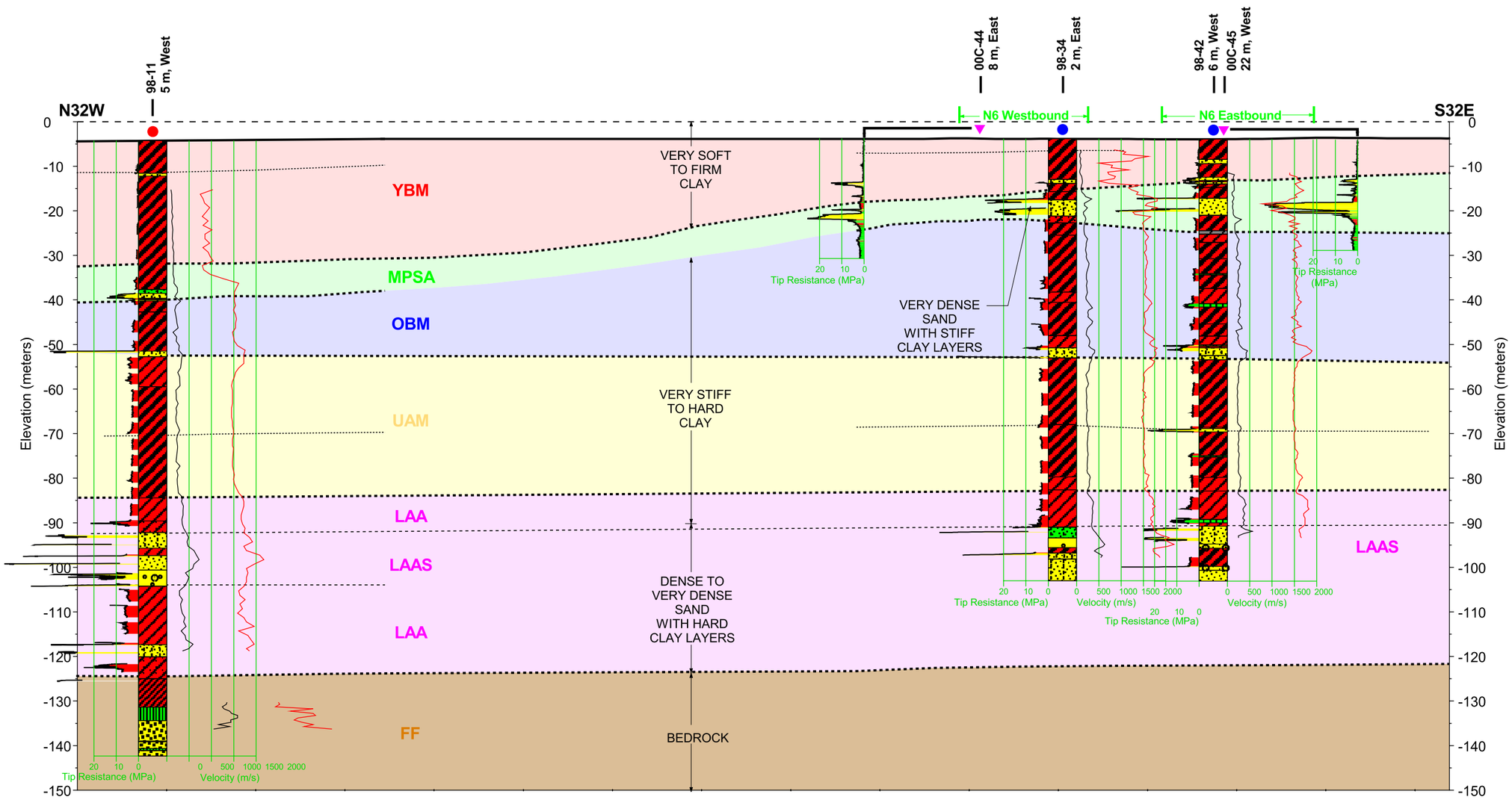
YBM	Young Bay Mud	LAA	Lower Alameda Alluvial
MPSA	Merritt-Posey-San Antonio Formations	LAAS	Lower Alameda Sand
OBM	Old Bay Mud	FF	Franciscan Formation
UAM	Upper Alameda Marine		
UAMPC	Upper Alameda Marine Paleochannel Sand		

SUBSURFACE CROSS SECTION THROUGH PIER E11
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 4.13a

Earth Mechanics

FUGRO



10m
10m

GENERAL NOTES:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Refer to Key to Cross Sections for descriptions of boring and CPT data shown above.

3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

LEGEND

- P-Wave Velocity
- S-Wave Velocity

KEY TO GEOLOGIC UNITS

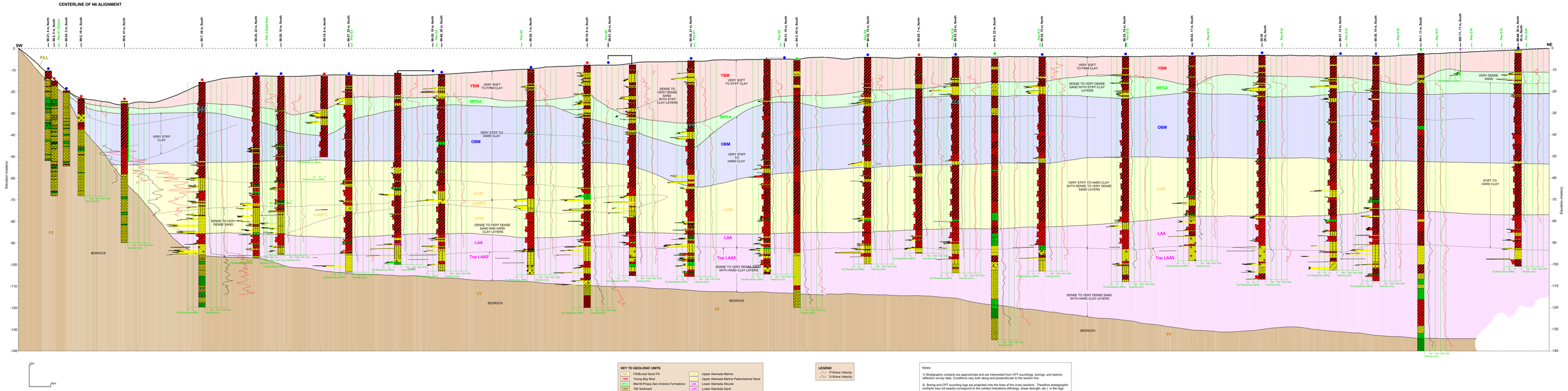
YBM	Young Bay Mud	LAA	Lower Alameda Alluvial
MPSA	Merritt-Posey-San Antonio Formations	LAAS	Lower Alameda Sand
OBM	Old Bay Mud	FF	Franciscan Formation
UAM	Upper Alameda Marine		
UAMPC	Upper Alameda Marine Paleochannel Sand		

SUBSURFACE CROSS SECTION THROUGH PIER E11
With P- and S-Wave Velocity
SFOBB East Span Seismic Safety Project

PLATE 4.13b

Earth Mechanics

Tetra Tech



20m
0m

KEY TO GEOLOGIC UNITS

FILL	Fill/Buried Sand Fill	UAM	Upper Alameda Marine
YBM	Young Bay Mud	UAMPC	Upper Alameda Marine Paleochannel Sand
MPSA	Merritt-Posey-San Antonio Formations	LAA	Lower Alameda Alluvial
VBS	VBI Sediment	LAAS	Lower Alameda Sand
OBM	Old Bay Mud	FF	Franciscan Formation

LEGEND

- P-Wave Velocity
- S-Wave Velocity

Notes:

1) Stratigraphic contacts are approximate and are interpreted from CPT soundings, borings, and seismic reflection survey data. Conditions vary both along and perpendicular to the section line.

2) Boring and CPT soundings logs are projected onto the lines of the cross sections. Therefore stratagraphic contacts may not exactly correspond to the contact indications (lithology, shear strength, etc.) in the logs.

3) P-wave and S-wave velocities measured with an OYO suspension logging system.

4) Horizon geometry between borings based on correlations with seismic reflection data.

5) Refer to Key to Cross Sections for description of boring and velocity data.

6) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

SUBSURFACE CROSS SECTION ALONG N6 CENTERLINE
Borehole Lithology with P- and S-Wave Velocity Data
SFOBB East Span Seismic Safety Project

PLATE 4.14

SECTION 5.0
STRATIGRAPHY AND STRUCTURE OFFSHORE YERBA BUENA ISLAND

5.0 STRATIGRAPHY AND STRUCTURE OFFSHORE YERBA BUENA ISLAND

5.1 PURPOSE AND BACKGROUND OF THE PHASE 3 INVESTIGATION

The Main Span-West Pier will be located on a Franciscan Formation bedrock outcrop on the northeastern end of Yerba Buena Island. The Main Span-Pylon (Pier E1) will be constructed on the eastern flank of the Franciscan Formation bedrock ridge that plunges north from the eastern tip of Yerba Buena Island (Maps 4 and 14). Marine geophysical survey data and geotechnical explorations indicate that the outcrop and plunging ridge are part of the same bedrock structure.

Geological mapping at the outcrop on the eastern end of the island identified shear zones in the Franciscan Formation bedrock (Map 4; Fugro-EM, 2000a). The bedrock is of Jurassic-Cretaceous age, and examination of the shear zones did not reveal any distinguishing characteristics that would establish the age or amount of the latest offset along any of the shear zones. Seismic refraction and reflection data collected on the outcrops and in the saddle area west of the bedrock outcrop identified features that could be associated with near-vertical offsets in the bedrock. In the cove area, between Yerba Buena Island and Treasure Island, the 3-D geophysical survey data could not be correlated with the limited amount of available geotechnical data from the area. The above observations suggested the possibility of fault offsets, but were not conclusive evidence nor did they place any limits on the time at which the possible bedrock offsets could have occurred.

The poor quality of seismic reflection data and the lack of borings around the northern and southern sides of eastern Yerba Buena Island limited previous (Phase 1 and Phase 2) mapping of the sediment units and bedrock in those areas. The Phase 3 exploration program was designed to provide additional data that would identify the lithology and geotechnical properties of the sediments and bedrock structure offshore Yerba Buena Island, and enable their correlation with units mapped on the island and farther to the east along the N6 alignment.

The Phase 3 exploration program included a 74-km, high-resolution multichannel marine geophysical survey and 33 CPT soundings. The survey area included:

- Cove between Yerba Buena Island and Treasure Island,
- Area offshore from the U.S. Coast Guard station on the southeastern side of the island, and
- Offshore area extending 550 meters beyond the eastern end of the island to the area of the proposed Main Span-East Pier (Pier E2) (Map 4, Plate 2.4).

The 2000 Phase 3 marine geophysical survey is described in Appendix C and the CPT soundings are provided in Fugro-EM (2001a). Other data that were collected as part of the 2000 Phase 3 field investigations included multibeam and tidal flat bathymetry surveys (Appendix E, Map 1), and an additional 44 CPT soundings. The additional 44 CPT soundings were collected along the proposed N6 alignment Skyway and Oakland Shore Approach structure locations. These data are incorporated into the plates and discussions in Section 4.0 of this report.

The preliminary analysis of the 2000 Phase 3 data, which was presented in a memorandum (Fugro-EM, 2000b), concluded that there was no evidence of Holocene faulting in the sediment section offshore Yerba Buena Island. The remainder of Section 5.0 describes the geologic features of concern and documents the conclusions regarding faulting. This report section supersedes the interpretations presented in Fugro-EM (2000b).

5.2 POSSIBLE INDICATIONS OF FAULTING AT THE EASTERN END OF THE ISLAND

5.2.1 Onshore Mapping

The geologic map of the eastern end of Yerba Buena Island is on Map 4 and, in a simplified form, on Plate 5.1. These data are from field investigations described in Fugro-EM (2000a). Shear planes are plotted on Map 4 along the north side of the two outcrop areas on the north side of the island and along the southern side of the outcrop at the northeast end of the island. Shear zones also were observed in Borings 99-151 (on the outcrop at the northeast point of the island) and 98-308 (in the Coast Guard Base area).

It is further noted in Fugro-EM (2000a, page 4-9) that, "The shear zones identified at the Northeast Point and Saddle area are not new features. They were already mapped by Berkeley's Professor Andrew C. Lawson in 1932 for a pre-construction study for the existing Bay Bridge. Those features represent minor faults presumably associated with the formation of the island."

5.2.2 Onshore Geophysical Survey

NORCAL Geophysical Consultants, Inc. conducted seismic reflection and refraction surveys at the eastern end of Yerba Buena Island. The objectives of the surveys were to measure bedrock shear-wave velocities, to determine weathering profiles in the bedrock, and to identify depth to bedrock in the saddle area of the island. The onshore seismic lines are shown on Maps 4 and 14. The reflection lines are labeled Profiles R1 to R2 and the refraction lines are labeled Profiles A to F.

On two of the reflection seismic lines, Profiles R1 and R3, NORCAL noted events that may have arisen from a fault. Their interpretation of these lines is shown on Plates 5.2a and 5.2b. The remainder of the seismic data and the report are in NORCAL (1998), which is included in Fugro-EM (1998d). On Profile R1 (Plate 5.2a), two diffractions are noted at depth,

but no vertical discontinuity is noted in the surface that NORCAL mapped as the "bedrock horizon". While diffractions can arise from a fault plane, there are many other possible causes, including sharp features (boulders, bedding terminations, etc.) within the bedrock and out-of-plane point sources such as buried utilities. On Profile R3 (Plate 5.2b), two "disturbed zones" are marked with vertical green lines. These "disturbed zones" do not appear to be involved in any offset of the surface identified as the "bedrock horizon". Those two zones also are not noted on the intersecting profiles, R2 and E, where the "bedrock horizons" are not disturbed. Therefore, the disturbed zones on Profile R2 are interpreted to be local effects on that line, possibly interference from multiple reflections or erratic near-surface velocity variations.

5.2.3 Discontinuities in the Seismic Records From the Cove Area

Discontinuities in the mapping of the 3-D seismic reflection data in the cove area between Yerba Buena Island and Treasure Island were previously noted (Fugro, 1999), but not resolved. Plate 5.3 shows the location of 3-D seismic reflection records that indicate the specific nature of the discontinuities.

Plate 5.3a shows 3-D survey line 265 where it crosses the nose of the plunging bedrock ridge offshore northeastern Yerba Buena Island. The ridge is contoured on Map 13 (Plate 3.11). The green line on Plate 5.3a is interpreted as the top of the Franciscan Formation bedrock. There is an apparent break, but no offset, in the reflector between traces 825 and 835. West of trace 820, there appears to be considerable disruption and lack of continuity in the seismic reflectors above the one marked in green and in the reflection time range of 0.030 to 0.090 second.

Plate 5.3b is a similar section, parallel to but south of the section shown on Plate 5.3a and closer to the island. On this record, the bedrock reflector is tied to Boring 98-3. However, there is some continuity to the reflectors on the western side of the record. The hummocky and tilted reflections above the green horizon between traces 835 and 900 (shaded green area) have greater continuity than the reflectors at the same location on line 265 (Plate 5.3b). The relative low frequency content of the reflector in the shaded green area is indicative of bedrock rather than sediments, and was initially interpreted as a possible buried bedrock landslide from the island. The hummocky reflector package was mapped as being about 200 meters across in both length and width. However, there was no geotechnical exploration to identify the nature of the soil or rock associated with the reflectors.

Plate 5.3c shows crossline 879 that intersects both of the seismic lines discussed above. Crossline 879 also intersects Boring 95-19, the only geotechnical exploration to reach bedrock in the cove that was available in 1999. The horizon interpreted as top of Franciscan Formation bedrock on Plates 5.3a and 5.3b and tied to Boring 98-3 is also marked in dark green on Plate 5.3c. This reflector does not appear to tie into Boring 95-19. A reflector marked in light green appeared to provide a better tie with the boring. Plate 5.3d is another seismic record through Borings 98-1 and 95-19. Horizon elevations in both borings are converted to reflection times

using a velocity of 1,500 m/sec for the combined water column and sediment section. Again, the high-amplitude reflector that appears to be an angular unconformity ties with Boring 98-1 but not with 95-19. (The depth-section for Boring "95-19 Slow" was developed as a result of the 2000 Phase 3 survey and is discussed in Section 5.5.1.)

Plate 5.4 shows two contour models that were initially developed for the top of bedrock in the cove area. Model A is the dark green horizon on the seismic sections shown on Plates 5.3a to 5.3d, and Model B is the horizon that ties with Boring 95-19. Both contour versions are based on a velocity of 1,500 m/sec for depth conversions. Model B suggests a near-vertical discontinuity along the western side of the ridge. This discontinuity can be seen as a break in the reflector patterns observed in the time slices on Plates 5.5a (70 ms) and 5.5b (100 ms). (See Section 2.6.1 for an explanation of a time slice.)

Alternate explanations, other than faulting, were recognized as possible reasons for the apparent disagreement between Boring 95-19 and the reflector that was mapped as the Top of Franciscan Formation. Those explanations were:

1. Boring 95-19 may have been drilled into an unrecognized landslide deposit.
2. The bedrock identified as Franciscan Formation in Boring 98-19 may belong to a Franciscan Formation unit or other bedrock formation that is younger than the erosional surface on the ridge to the east.
3. The shallow sediments above the bedrock in Boring 95-19 (and the rest of the cove area) were not correctly identified and did not have the same velocities as those used for the depth conversions.

An examination of the bedrock core sample from Boring 95-19 eliminated the second of those possible explanations and cast significant doubt on the plausibility of the first explanation. The 2000 Phase 3 investigation was undertaken, in part, to resolve the problems with mapping the bedrock in the cove area and to either eliminate or confirm the existence of faulting offshore Yerba Buena Island.

5.3 DATABASE FOR THE INVESTIGATION

Map 4 and Plate 5.6 illustrate the locations of much of the data used in the fault investigation. The data sources include:

- Historical maps and articles regarding construction activities at the northeast end of the island;
- Onshore explorations for SFOBB and the N6 alignment;
- Onshore geophysical survey data;
- Onshore geological mapping;

- Multibeam bathymetry data;
- The Phase 3 marine geophysical survey data; and
- Phase 3 CPT soundings.

5.3.1 Historical Data

Construction activities around the eastern end of Yerba Buena Island have altered the near-surface geologic profile both onshore and offshore. Historical records regarding the pre-Treasure Island Bay floor elevations, construction dredging, and fill activities were reviewed to quantify the changes to the natural environment. The following documents provided the basis for plates included in this report:

- **U.S. Coast and Geodetic Survey (USC&GS) (1915),** San Francisco Entrance, Chart 5532, scale 1:40000. This map is the basis for Plate 5.7 - 1915 Bathymetric Data. It shows that a sand shoal existed on the north side of Yerba Buena Island prior to the construction of Treasure Island, and that the Bay floor shape was significantly different in this area from the present Bay floor shown on Plate 5.6.
- **U.S. Army Corps of Engineers, San Francisco District (USACOE-SFD) (1937),** Yerba Buena Shoal Reclamation Project, San Francisco Bay, California, 33 pp. This unpublished report is the basis for Plate 5.8 - Dredged Area (1936-1937). The report and figure show that the sand shoal on Plate 5.7 was dredged to provide part of the material needed to construct Treasure Island.
- **Lee, C.H. (1969),** "Case History 2, Treasure Island Fill," in Lee, C.H., and Praskzer, M., "Bay Mud Developments and Related Structural Foundations," in Goldman, H. B., ed., *Geologic and Engineering Aspects of San Francisco Bay Fill*, California Division of Mines and Geology, Special Report 97, pp. 69-72. This article describes the dredging and the removal of mud from the area of Treasure Island and is, along with the CPT data, the basis for Plate 5.9 - Isopach (Thickness) of Fill (Mud).

5.3.2 Previous Explorations for the N6 Alignment and SFOBB

Previous explorations in the area of this investigation include both borings and geophysical surveys. Fugro-EM conducted onshore borings between 1998 and 2000 (Table 5.1a) and Caltrans borings on the island were drilled in 1932-1933 and 1994-1996 (Table 5.1b). Onshore boring locations are shown on Map 4 and Plate 5.6. Geological mapping was done on the island by Fugro-EM between 1998 and 2000 (the geologic map is shown on Map 4). NORCAL Geophysical Consultants (Section 5.2.2) conducted onshore geophysical surveys and their profile locations are shown on Map 4 and Plate 5.1. Both 2-D and 3-D multichannel marine seismic reflection surveys were conducted in 1998 by Fugro-EM. The surveys are shown on Maps 2 and 3 and documented in Appendices A and B. Caltrans conducted offshore borings

near Yerba Buena Island in 1948 and 1994 to 1996. Fugro-EM conducted offshore borings in 1998 and 1999. The offshore boring data are summarized in Table 2.2.

5.3.3 Multibeam Bathymetry

Bay floor elevations in the vicinity of Yerba Buena Island are shown on Maps 1 and 4 and Plate 5.6. The contour interval is 0.5 meter and the data are referenced to MSL 1929 (Caltrans, 1997a). The data were collected by Fugro-EM in May 2000 using a Reson Seabat 8101 multibeam sonar integrated with a TSS POS M/V motion/position/heading system, a DGPS navigation system, and HYPACK navigation software system. The survey encompassed the entire N6 alignment and included over 90 million soundings. These data represent the most accurate depiction available of the current bathymetry. The multibeam survey operations and instrumentation are described in Appendix E.

5.3.4 Phase 3 Marine Geophysical Survey

High-resolution marine seismic reflection data were collected in September 2000 using a multichannel minisparker system integrated with a DGPS navigation system and HYPACK navigation software system. The energy source and 24-channel recording cable were designed to provide higher resolution near-surface reflection data than was obtained with the sleeve-gun systems used for the previous 2-D and 3-D surveys. The survey lines shown on Map 4 and Plate 5.6 represent approximately 74 kilometers (40 nautical miles) of multichannel sparker data. In addition, 15 km (8.3 nautical miles) of survey data were collected with three bay cable lines laid along the north and south shorelines, and 6.1 km (3.3 nautical miles) of analog boomer data were collected in the nearshore areas. The 2000 Phase 3 marine geophysical survey operations and instrumentation are described in Appendix C.

5.3.5 Phase 3 CPT Soundings

Seventy-seven (77) CPT soundings were advanced during September and October 2000 using Fugro's 20-ton, wheel-drive tethered Seacalf system. The Seacalf system was operated from a barge positioned by a DGPS navigation system. Thirty-three (33) of the soundings are in the vicinity of Yerba Buena Island and are shown on Map 4 and Plate 5.6. Locations were selected using the recently acquired Phase 3 high-resolution seismic reflection data. The locations were chosen to test specific sediment features observed in the seismic records and at the locations of proposed permanent and temporary structures for the N6 alignment. CPT investigation depths ranged from 5 to 60 meters depending, in part, on the depth of bedrock and the nature of the foundation for the bridge structure to be placed at the site. Data from the CPT soundings are summarized in Table 2.4.

With the Seacalf system, four wheels grip the cone rod and push it into the soil at a controlled rate of 2 centimeters/second (cm/sec). As the cone penetrates the sub-seafloor sediment, variations in cone tip resistance, sleeve friction, and dynamic pore pressure are

recorded at 0.25-second intervals (approximately 5 mm). Post-measurement processing provides an estimation of sediment lithology (Plate 4.1, Key to Cross Sections) and undrained shear strength.

5.4 STRATIGRAPHIC UNITS AND CROSS SECTIONS OFFSHORE EASTERN YERBA BUENA ISLAND

The CPT sounding data were integrated with borings and seismic reflection data to construct a sequence of cross sections in the cove and the area east of the island. The locations of the cross sections are shown on Plate 5.10 and the cross sections are on Plates 5.11a to 5.11m (Cross Sections A-A' through M-M'). The cross sections show CPT soundings (cone tip resistance, lithology, and interpreted undrained shear strength), borings (lithology and undrained shear strengths), and continuity and shape of unit boundaries based in part on the seismic reflection records.

The integration of the historical data, Phase 1 and Phase 2 exploration data, and Phase 3 CPT soundings has resulted in: 1) the identification of several sediment units not described in previous Fugro-EM reports, and 2) the subdivision of some of the previously mapped units. A description of the units, their properties, and lateral extent in the vicinity of Yerba Buena Island is provided in the following paragraphs and is illustrated on the cross sections on Plates 5.11a to 5.11m. The sediment units are discussed in sequence beginning with the youngest. Basic descriptions and properties of the sediment and rock units are summarized in Table 1.1. The following discussions are specific to the area offshore Yerba Buena Island. In the following subheadings, the acronyms are those shown on the cross section.

5.4.1 Fill

A review of the historical bathymetric data indicates that the present cove area on the northeastern side of Yerba Buena Island was a sand shoal prior to the construction of Treasure Island (Plate 5.7). During construction of the Island in 1936 and 1937, over 6,300,000 cubic yards of "soft blue marine sand" were dredged from this area and placed as fill in the area that became Treasure Island (Plate 5.8). Calculations based on the reported area of dredging, volume of sand dredged, and original bathymetry suggest that dredging to approximately El. -16 to El. -17 meters (MSL 1929) would have been required to produce the reported volume of sand.

Since the current bathymetric elevations in the area (El. -2.5 to El. -8 meters, Map 4) are significantly shallower than the estimated dredge elevations, it appears that a large volume of fill (or dredge spoil) has been placed in the original dredge pits since 1936. The CPT soundings (Table 2.4) show that the soil down to El. -16 to El. -17 meters is similar to, but softer than, the Young Bay Mud (YBM). Therefore, the most likely source of this fill is the YBM that had to be removed from the fill area of Treasure Island. The cove area may also have been used for other dredge spoils and may also contain natural sedimentation. However, it would appear that the majority of the fill is hydraulically placed, YBM-type material.

Cross Sections A-A' through I-I' (Plates 5.11a through 5.11i) illustrate the CPT data from this area and clearly delineate the base of the fill. A schematic of the approximate isopach of the fill based on the CPT sounding data is shown on Plate 5.9. A comparison of the Bay floor elevations of 1915 and 2000 (Plates 5.7 and 5.6, respectively) suggests that the present Bay floor slope between El. -5 meters and El. -13 to -15 meters is the frontal lobe of this fill deposit.

The fill material appears to be composed of clay soils that are similar in appearance to the natural deposits of Young Bay Mud. However, slightly (but distinctly) lower CPT tip resistances and undrained shear strengths distinguish the fill materials.

The fill also has a large effect on the seismic data, severely limiting the penetration of the higher frequency components of the signals. The fill also has a lower seismic velocity than natural deposits of YBM. Analysis of stacking velocities in the fill indicates that the average velocity of sound is about 700 m/sec. This is less than half the velocity of sound in water and only about two-thirds the value measured in the YBM. This very low velocity severely distorts the reflection times on the seismic records from this area. An example of this distortion is illustrated on Plate 5.12, and its impact on previous interpretations is discussed in Section 5.5.1 of this report. It also is likely that the velocity of sound within the fill materials is less uniform than within the underlying naturally occurring deposits. This lack of uniformity can complicate the ability to convert from time to depth on the geophysical profiles and will therefore reduce the accuracy with which stratigraphic boundaries can be mapped in areas with thick fill.

5.4.2 Shoal Sand

Remains of the Shoal Sand below the dredging depth are seen in the CPT soundings in Cross Sections D-D' through G-G' (Plates 5.11d to 5.11g). The base of the sand ranges from El. -18 to El. -20 meters. The original lateral extent of the Shoal Sand is shown on Plate 5.7. In the eastern part of the dredged area, the sand overlies the Young Bay Mud and, in the western part, it overlies older sediments tentatively identified as either Yerba Buena Island sediments (YBIS) or Merritt-Posey-San Antonio (MPSA) sediments. Sand layers are also present within the YBM, YBIS, and the MPSA. The Shoal Sand can be distinguished from the other sand units by its relative stratigraphic position, differences in shear strengths of the interlayered clay, its position relative to the historical bathymetry (Plate 5.7), and dredging history. On average, the Shoal Sands are characterized by somewhat lower relative density than the older YBIS or MPSA sand. Similarly, clay layers within the Shoal Sand appear to be relatively normally consolidated and are typically soft to firm while clay layers within the MPSA and YBIS units are overconsolidated and very stiff to hard.

5.4.3 Young Bay Mud (YBM)

The Young Bay Mud (YBM) is soft, normally to slightly overconsolidated clay deposited since the end of the last sea level low stand (circa 11,000 years ago). The undrained shear strength is usually below 40 to 60 kPa. Where the deposit is very thick, the undrained shear

strength may reach 70 to 80 kPa at the base of the deposit. The YBM is the surficial sediment unit throughout the survey area except in the cove where it is covered with Shoal Sand and/or Fill. The YBM appears on most of the cross sections and has filled paleochannels. The northwestern flank of the ancient Temescal Creek channel is seen on Cross Section C-C' and D-D' (Plates 5.11c and 5.11d). In the southeastern part of the survey area, the YBM forms a relatively thin blanket of surficial sediment on the base and eastern flank of the present scour channel.

The CPT soundings from the Phase 3 investigation provide the first "hard" data on the geometry of the YBM deposit in the cove area to the north of Yerba Buena Island. In the western part of the cove, the YBM was originally overlain by the Shoal Sand (Plate 5.7) and now by the remnants of the Shoal Sand and Fill (Mud) (Plate 5.9). Where the Fill (Mud) overlies the YBM, either directly or separated by a thin layer of Shoal Sand, the two units are distinguished by small but distinct changes in undrained shear strength. In general, an approximately 20-kPa step is observed in the trend of increasing shear strength with depth near the interface between the fill and YBM (Plates 5.11d1 through 5.11f). Historical bathymetric data and dredging volume estimates also served as guides in determining the base of the fill.

5.4.4 Yerba Buena Island Sediment (YBIS)

Yerba Buena Island Sediment (YBIS) is an informal designation originally applied in Fugro-EM reports to thin sediment deposits found in several of the borings on the flanks of Yerba Buena Island. The sediments consist of interlayered stiff to hard clay, dense sand, and gravel that is apparently older than the YBM, but which cannot be correlated with sediment units in borings farther to the east along SFOBB and the N6 alignment. The YBIS may have originated from erosion of the island and are possibly age-equivalent to the MPSA sediments. The extent and relative stratigraphic position of the YBIS are shown in Cross Sections B-B' to D-D' and F-F' to H-H' (Plates 5.11b1, 5.11c, 5.11d1, 5.11f, 5.11g, 5.11h) and on Map 7.

The lithology of the YBIS as depicted in the CPT soundings appears quite similar to the lithology of the MPSA sediments. In general, the YBIS sequence consists of a thin surficial overconsolidated clay layer, a sand layer, and a lower clay layer. The shear strengths of the clay layers are greater than those of the overlying YBM and generally less than those in the underlying Old Bay Mud (OBM). The relatively high shear strength of the surficial clay identifies that the underlying sand unit belongs to the YBIS rather than the overlying Shoal Sand or a sand horizon in the YBM. The YBIS variously overlies Franciscan Formation bedrock, OBM, and the MPSA sediments. In general the YBIS is at a shallower elevation than the MPSA sequence (in this area), but the boundary between the two units is not distinct in the CPT data.

5.4.5 Merritt-Posey-San Antonio Formations (MPSA)

Merritt-Posey-San Antonio Formations (MPSA) sediments are identified as separate formations onshore in the eastern side of San Francisco Bay. Offshore, they consist of a

sequence of estuarine and alluvial sediment that is mapped from beneath the Oakland Mole to the eastern flank of Yerba Buena Island (Map 7). In some areas, the upper layers of Merritt and Posey sands are distinct and comprise the majority of the mapped unit (Plates 4.2a and 4.2b). The undrained shear strength of the San Antonio clay is generally in the range of 100 to 140 kPa, and is intermediate between the undrained shear strengths of the YBM and the OBM.

The CPT data provide a more comprehensive depiction of the MPSA sequence near Yerba Buena Island than is available from the boring data. In the eastern part of the Phase 3 survey area, a 5-meter- to 8-meter-thick section of Merritt Sand is present at the top of the sequence on Cross Sections B-B', D-D', L-L', and M-M' (Plates 5.11b2, 5.11d2, 5.11l, and 5.11m). At a lower elevation farther west, the sequence becomes a series of thin interlayers of clay, silt, and sand that filled a series of nested paleochannels (Plates 5.11d1, 5.11d2, and 5.11e). The series of thin interlayers and the undrained shear strength of the clay layers distinguish this sequence in the CPT soundings. The MPSA sequence is everywhere underlain by the OBM/UAM.

5.4.6 Old Bay Mud (OBM)

The Old Bay Mud (OBM) is a relatively thick sequence of very stiff to hard lean clay with only occasional silt or sandy clay interlayers. The top of the unit, except where it has been eroded, is interpreted to be a crust (desiccated layer) beneath which the undrained shear strength generally increases to 140 kPa or greater. The OBM has been mapped throughout the project area including an on-lap relationship with the Franciscan Formation bedrock at Yerba Buena Island (Map 8). However, the poor quality of seismic data and lack of borings previously limited mapping of the unit in the cove area west of the present bathymetric channel. The Phase 3 CPT data indicate that it is present in the cove area along Cross Sections C-C', D-D', F-F', and G-G' (Plates 5.11c, 5.11d1, 5.11f, and 5.11g).

A series of paleochannel clays occur offshore the eastern end of Yerba Buena Island beneath the present bathymetric channel and a thin layer of YBM and MPSA sediments. They are mapped as part of the OBM based on the CPT sounding lithology and shear strength data. The clay sequence is shown on Cross Sections A-A', M-M' (Plates 5.11a and 5.11m), and several of the north-south sections.

5.4.7 Upper Alameda Marine Sediments (UAM)

The OBM and the underlying Upper Alameda Marine Sediments (UAM) have not been distinguished on the maps produced for this project. However, many of the CPT soundings from both the Yerba Buena Island area and the Skyway structure area (Section 4.3) encountered a crust in the elevation range of El. -50 to El. -53 meters. When these data were correlated with shear strength measurements from the borings, the lateral extent of the crust across the entire N6 alignment became obvious (Plates 4.2a and 4.2b). This crust, for the purposes of this report, is taken as the boundary between the OBM and UAM.

The UAM crust and underlying clay layers are recognized in many of the CPT soundings offshore Yerba Buena Island. The UAM appears on all of the cross sections (Plates 5.11a to 5.11m) except for the western part of B-B' (Plate 5.11b1). The top of the UAM crust is generally between El. -51 and El. -53 meters. The significance of this layer is its areal extent and the fact that it apparently has not been deeply eroded or affected by Quaternary structural deformation. Thus, it is a useful marker in the analysis of possible offshore faulting.

5.4.8 Franciscan Formation Bedrock

The CPT soundings did not penetrate into bedrock, although several of those on Cross Section B-B' (Plate 5.11b1) apparently ended at the top of weathered bedrock or rock fragments. This cross section is in an area where the seismic images of the bedrock could be directly correlated with the base of the CPT soundings.

North of Cross Section B-B', the CPT soundings did not reach bedrock, but provided minimum elevations to use in the depth conversion analyses for the seismic reflection data. The bedrock elevations shown on the cross sections are taken from the seismic reflection mapping described in Section 5.5.

5.5 ANALYSES OF POSSIBLE FAULTING OFFSHORE FROM THE EASTERN END OF YERBA BUENA ISLAND

The analyses of possible faulting offshore eastern Yerba Buena Island included four components:

1. Mapping the Top of Franciscan Formation from the offshore areas where it is controlled by geotechnical explorations and good quality seismic images through the island and across the buried bedrock ridge into the cove area.
2. Identifying and tracing an undeformed Quaternary-age sediment horizon into the cove area.
3. Identifying and tracing undeformed Quaternary-age sediment horizon(s) along the southeast side of the island.
4. Reviewing regional seismicity data and other geophysical and geological data regarding tectonic activity and faulting in the San Francisco Bay Block.

5.5.1 Velocity Analysis and Depth Conversion of Seismic Data

Both the Phase 3 minisparker data and the previous 3-D sleeve-gun survey imaged the top bedrock reflector in the cove area. However, converting the reflection times to depths required knowledge of the seismic velocities in the overlying sediments. In the cove area, apparent bedrock surface discontinuities or mis-ties with geotechnical data resulted when standard velocities were used for depth conversions (Section 5.2.3).

The short phone spacing and rapid firing interval used in the Phase 3 geophysical survey allowed for an estimate of the sound velocity in the fill material. The velocity analysis during the processing sequence of the multichannel minisparker data identified very low velocities of approximately 700 to 800 m/sec. This velocity range is about one-half the normal velocity measured in salt water and shallow marine sediments.

The CPTs and historical data regarding dredging and bathymetry and an accurate map of the present bathymetry provided a quantitative model for depth-converting the seismic sections. Plate 5.12 is an example of depth conversions using the "normal sediment velocity" of 1,500 m/sec and a "slow velocity" for the fill. The use of the "slow velocity" virtually eliminates the apparent structural anomalies associated with the bedrock reflector.

Plate 5.3d provides another example of the velocity effect. The horizon depths in Boring 95-19 were converted to reflection times using the 1,500 m/s velocity for the entire sediment section. The horizon depths in Boring "95-19 Slow" were converted to reflection times using a velocity of 700 m/sec for the fill layer and 1,500 m/sec for the remaining water-sediment column. The slow velocity effectively increases calculated reflection times to provide better agreement with the reflection times of the top of bedrock unconformity on the seismic record.

5.5.2 Structural Contour Map, Top of Franciscan Formation Offshore Yerba Buena Island

A contour map was constructed of the Top of Franciscan Formation Bedrock Near Yerba Buena Island (Map 14, Plate 5.14). The map is based on an integrated interpretation of offshore and onshore geological, geotechnical, and geophysical data. Contours of the bedrock surface on the island are based on borings (Tables 5.1a and 5.1b), outcrop topography, geologic mapping, and onshore geophysical profiles. Offshore contours are based on seismic reflection data from the 2000 Phase 3 and the 1998 Phase 1 3-D surveys, and marine geotechnical explorations (Tables 2.2 and 2.4).

In the cove area, the slow-down effect of the fill was estimated using the isopach map on Plate 5.9 and a velocity of 700 m/sec. The calculated time was then applied as a correction in calculating depths from observed reflection times.

The main features of the contour map include:

- The north-trending and plunging bedrock nose extending from the northeast point of the island is somewhat broader and shallower than it appears when a higher velocity is used (Plate 5.4).
- The outcrop to the west of the saddle on the island extends north beneath the cove as a buried ridge.

- The saddle area on the island is apparently part of an older erosional feature that trended to the southeast.
- There are no near-vertical steps or other apparent offsets to the contour pattern that would suggest active faulting past the time when the bedrock was covered by the present sediments.

5.5.3 Sediment Unit Continuity Across the Cove Area

Evidence that indicates the onshore shear zones do not continue northward into the cove area as Holocene faults is present in the east-west-trending Cross Sections B-B' to E-E' (Plates 5.11b1, 5.11c, 5.11d1, and 5.11e). All four sections cross the area where the offshore extensions of the shear zones would lie, and all indicate horizons with no apparent vertical offset. The base of the fill and base of Shoal Sand are too young to use as Holocene markers, but the crust at the top of the OBM on Cross Section C-C' (Plates 5.11c) appears continuous, as does the crust at the Top of the UAM on Cross Section E-E' (Plate 5.11e). The latter can be traced throughout the survey area with little or no apparent distortion (Plates 4.2a and 4.2b).

5.5.4 Sediment Unit Continuity Along the Southeast Side of the Island

The quality of seismic reflection data on the southeast side of the island is much better than in the cove due to a lack of surficial fill or substantial thickness of YBM containing gas. Plates 5.13a to 5.13f are annotated examples from this area. The illustrated lines were selected to preclude any faulting crossing the area without crossing at least two of the seismic lines. The locations of the lines are best observed on the large-scale maps (Maps 4 or 14).

Plate 5.13a is line 145 across the southern boundary of the Phase 3 survey area. It shows the erosional channel as a saddle in the bedrock. The channel may have formed in an older shear zone, but the overlying sediment horizons (including an unconformity) show no evidence of offsets. Plates 5.13b and 5.13c are east-west-trending lines about 120 meters south of northeast point. Plate 5.13b is a boomer line and shows the detail of the sediment layers within the units and the minor unconformities between the units. Plate 5.13c is an adjacent minisparker line that images the top of bedrock reflector across the entire survey area. A step in the bedrock is noted at point 5620, but the overlying sediment horizons are not disturbed. Both lines show the same features including the shallow paleochannel at point 3928 on Plate 5.15b and at point 5400 on Plate 5.13c. The minisparker record shows a greater depth range and is presented with little or no vertical exaggeration. The boomer record vertical exaggeration is about 4.5 and emphasizes the sediment deposition and erosion features.

Plate 5.13d is of line 701, which runs parallel to the southeast coast of the island from south of the Coast Guard pier to the SFOBB. The shallow bedrock reflector shows the form of the erosional channel heading offshore from the saddle area and the horizontal nature of the sediment layers within the channel. There is no offset of the basement reflector that is also

reflected in the sediment horizons. An apparent break in the top of Old Bay Mud reflector appears to be caused by interference on the record and is not reflected in either the bedrock or the Bay floor. Lines 136 (Plate 5.13e) and 138 (Plate 5.13f) are illustrated because any fault extending south from the island that cut line 701 would also have to cross one or both of these lines in the vicinity of their intersections with line 216 (line intersections are annotated on the top of the records). On both lines, the top of Old Bay Mud reflector is continuous through that area.

5.6 SUMMARY AND CONCLUSIONS

The possibility of the shear zones mapped on the northeast end of Yerba Buena Island extending offshore as Holocene faults was investigated by integrating the Phase 3 marine geophysical and CPT data with previous onshore and offshore geophysical and geotechnical data. The top of the Franciscan Formation was mapped across the northeast end of the island and into the cove area south of Treasure Island. Apparent near-vertical offsets in the bedrock offshore from the northeast side of the island were resolved using a velocity conversion model that accounted for the slow velocity in the fill material that was placed in the cove during the construction of Treasure Island. The contour map does not show features that are indicative of recent offsets of the bedrock. Since the bedrock surface forms an angular unconformity with the overlying sediments, even strike-slip faulting would result in an apparent vertical offset of the bedrock.

CPT soundings were used to establish the correlation of older sediment horizons across the bedrock ridge and into the western part of the cove area. These horizons are flat and show no evidence of vertical offsets in areas where the shear zones would extend offshore. On the southeast side of Yerba Buena Island, high-resolution seismic reflection data indicate the continuity of pre-Holocene sediment units across areas where onshore shear zones may be projected.

Yerba Buena Island lies in the center of the San Francisco Bay Block. The Bay Block lies between the San Andreas and Hayward faults and is an area of only low-level diffuse seismic activity. Olson and Zoback (1998) published a review of the microseismicity of the Bay Block and its implications for seismic hazard. Their review of the microseismicity data, historical seismicity, U.S. Geological Survey seismic reflection and aeromagnetic data, and geologic literature did not indicate any evidence of active faulting on Yerba Buena Island or in the area between Yerba Buena Island and the Oakland Mole. Recently published maps of historical seismicity (Zoback et. al., 1995; Walter et. al., 1998) indicate a total absence of earthquake epicenters on or within about 3 km of Yerba Buena Island. The closest epicenters are 3 km west with a hypocenter depth of 15 km or more, and 6 km northeast with a hypocenter depth range of 7.5 to 9.9 km. The magnitude associated with the all the earthquakes referenced above is less than 3.0.

These data appear to preclude the possibility of the shear zones mapped on the northeast end of Yerba Buena Island extending offshore as Holocene faults or of Holocene faulting in the area of the Main Span-West Pier and Main Span-Pylon.

Boring ID	Northing (m)	Easting (m)	Surface Elevation (m)	Top Bedrock (m)	Boring Depth (m)	Completion Elevation (m)
98-13	647466.0	1836128.0	20.3	18.8	30.5	-10.2
98-14	647503.0	1836259.0	23.2	21.7	30.5	-7.3
98-15	647554.0	1836281.0	4.2	3.6	76.2	-72.0
98-163	647352.0	1836122.0	7.0	-11.9	30.8	-23.8
98-168	647251.0	1836003.0	8.3	-15.8	31.6	-23.3
98-306	647296.0	1836108.0	3.0	-21.1	27.9	-24.9
98-307	647268.0	1836079.0	2.8	-24.6	33.5	-30.7
98-308	647253.0	1836061.0	2.6	-22.7	28.4	-25.8
98-309	647208.0	1836039.0	2.5	-14.4	22.0	-19.5
98-310	647202.0	1835997.0	6.8	-3.9	17.1	-10.3
98-311	647159.0	1835992.0	6.5	4.2	11.0	-4.5
99-151	647508.0	1836238.0	20.1	19.9	73.2	-53.1
99-152	647505.0	1836223.0	19.7	15.6	79.9	-60.1
99-153	647489.0	1836216.0	20.0	20.0	62.3	-42.3
99-155	647479.0	1836246.0	20.8	20.8	60.4	-39.6
99-156	647470.0	1836257.0	21.0	20.8	66.9	-45.9
99-157	647460.0	1836244.0	20.6	20.4	60.1	-39.5
99-158	647471.0	1836235.0	20.4	20.4	66.9	-46.5
99-159	647488.0	1836161.0	19.1	19.1	39.0	-19.9
99-160	647461.0	1836153.0	19.2	19.2	42.4	-23.2
99-161	647434.0	1836181.0	18.6	17.7	55.3	-36.7
99-165	647410.0	1836104.0	10.0	9.7	45.7	-35.7
99-166	647456.0	1836118.0	18.1	18.1	30.0	-11.9
99-167	647416.0	1836069.0	9.4	7.1	30.3	-20.9
99-170	647368.0	1836070.0	10.9	-10.4	28.0	-17.1
99-171	647372.0	1836027.0	11.3	-5.5	24.4	-13.1
99-172	647374.0	1836009.0	11.5	-5.0	25.9	-14.4
99-174	647331.0	1835987.0	11.5	-2.3	35.1	-23.6
99-175	647327.0	1836026.0	11.0	-11.3	30.5	-19.5
99-201	647195.0	1835875.0	50.3	14.9	42.5	7.8
99-202	647211.0	1835927.0	45.8	6.2	43.6	2.2
99-203	647248.0	1835926.0	38.1	Not reached	9.6	28.5
99-204	647138.0	1835929.0	45.7	24.4	30.5	15.2
99-205	647237.0	1835945.0	40.3	Not reached	9.6	30.7
99-206	647257.0	1835942.0	32.5	Not reached	8.1	24.4
99-207	647237.0	1835959.0	37.4	Not reached	7.2	30.3
99-208	647229.0	1835969.0	27.7	Not reached	8.1	19.6
99-213	647221.0	1835961.0	33.2	Not reached	9.6	23.6
99-220	647289.0	1835951.0	20.8	-6.6	38.1	-17.3
99-221	647273.0	1835990.0	20.8	-11.2	40.9	-20.1
99-301	647412.0	1836217.0	4.6	4.6	30.5	-25.9
99-302	647413.0	1836199.0	5.0	4.9	30.5	-25.5
99-303	647412.0	1836182.0	5.4	3.5	30.5	-25.1
99-305	647372.0	1836163.0	3.3	-11.5	31.1	-27.8
99-312	647331.0	1836093.0	7.4	-17.1	37.9	-30.5
99-313	647099.0	1835933.0	48.7	Not reached	15.7	33.0
99-401	647202.0	1835862.0	54.8	Not reached	5.2	49.6
99-402	647101.0	1835892.0	52.6	Not reached	11.1	41.5
99-502	647474.0	1836316.0	3.0	2.1	29.6	-26.6
00-154	647498.0	1836215.0	19.7	19.7	90.6	-70.9

Bedrock elevation is the top of weathered Franciscan Formation in boring logs from Fugro-EM (2000a)
Horizontal Datum: California State Plane, Zone 3, NAD 83, meters
Vertical Datum: MSL 1929, meters, (Caltrans, 1997)

SUMMARY OF SELECTED GEOTECHNICAL DATA FROM YERBA BUENA ISLAND
Fugro-Earth Mechanics Borings 1998 to 2000
SFOBB East Span Seismic Safety Project

TABLE 5.1a

Boring ID	Northing (m)	Easting (m)	Surface Elevation (m)	Top Bedrock (m)	Boring Depth (m)	Completion Elevation (m)
94-1	647180.3	1835899.6	50.0	Not Reached	15.7	34.3
94-14	647488.9	1836312.4	2.9	-0.3	62.3	-61.2
95-1	647291.1	1836012.8	10.8	-13.7	44.2	-33.4
95-2	647400.5	1836146.1	6.8	2.1	29.9	-23.1
95-3	647341.8	1836064.6	10.6	-13.1	43.6	-33.0
95-4	647405.1	1836226.9	4.4	2.1	47.0	-42.6
95-5	647449.6	1836233.8	20.2	18.3	60.2	-40.1
95-6	647214.9	1835929.1	45.5	5.8	56.1	-10.6
95-1	647214.9	1835929.1	45.5	5.8	55.3	-9.8
C95-2	647175.9	1835898.6	50.5	Not Reached	18.8	31.7
C95-3	647190.1	1835910.8	48.3	Not Reached	18.8	29.6
C95-4	647181.9	1835904.4	49.6	Not Reached	13.5	36.1
C95-5	647170.3	1835894.0	51.2	Not Reached	10.5	40.7
C95-6	647161.6	1835886.8	51.4	Not Reached	12.5	38.9
C95-7	647213.8	1835931.8	45.4	Not Reached	27.5	18.0
C95-8	647209.9	1835927.9	45.7	Not Reached	25.9	19.8
C95-9	647206.3	1835924.6	46.1	Not Reached	27.5	18.6
C95-10	647185.8	1835907.8	49.0	Not Reached	10.6	38.4
96-1	647170.7	1835894.2	51.2	20.0	34.8	16.4
96-2	647163.1	1835885.6	51.4	18.9	39.9	11.5
96-3	647189.3	1835909.2	48.6	14.3	35.8	12.8
96-4	647123.9	1835880.2	51.2	31.4	21.6	29.6
96-5	647149.7	1835903.1	51.4	21.6	32.0	19.4
96-6	647162.7	1835914.6	51.4	19.8	33.5	17.9
96-7	647114.5	1835872.0	51.1	37.2	15.5	35.6
96-8	647137.6	1835892.4	51.3	28.0	24.1	27.2
96-9	647172.1	1835931.5	46.1	17.0	29.6	16.5
32-318	647350.0	1836099.0	8.1	-13.3	28.0	-20.1
32-337	647106.0	1835854.0	55.6	41.7	18.3	37.3
33-164	647067.0	1835818.0	69.9	57.6	14.8	55.1
33-YB1a	647235.0	1835951.0	38.8	-2.8	45.8	-7.0
33-YB1b	647211.0	1835964.0	28.2	0.4	32.1	-3.9
33-YB1c	647223.0	1835943.0	44.6	2.4	46.4	-1.8
33-YB1d	647206.0	1835956.0	31.0	4.5	33.5	-2.5
33-YB2a	647292.0	1836000.0	16.1	-11.8	33.2	-17.1
33-YB2b	647276.0	1836021.0	10.7	-18.6	32.9	-22.2
33-YB3a	647349.0	1836062.0	10.7	-11.6	24.1	-13.4
33-YB4a	647403.0	1836138.0	9.9	6.1	5.7	4.2
33-YB4b	647381.0	1836150.0	1.9	-4.8	8.7	-6.8

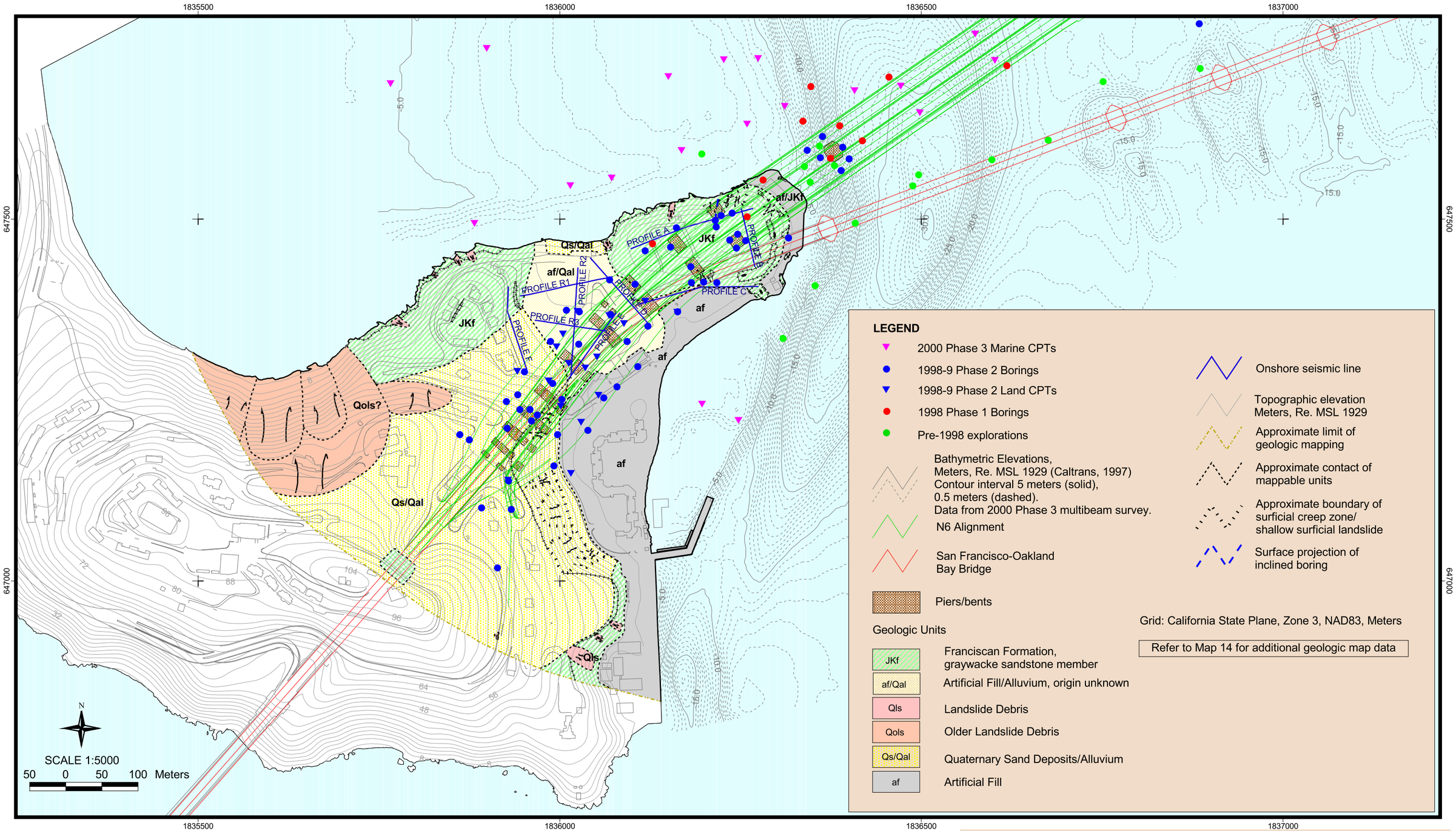
Bedrock elevation is the top of weathered Franciscan Formation in boring logs from Caltrans (1997c)
Horizontal Datum: California State Plane, Zone 3, NAD 83, meters
Coordinates of Pre-1994 borings estimated from stationing along SFOBB
Vertical Datum: MSL 1929, meters (Caltrans, 1997)

SUMMARY OF SELECTED GEOTECHNICAL DATA FROM YERBA BUENA ISLAND
Caltrans Explorations 1932 to 1996
SFOBB East Span Seismic Safety Project

TABLE 5.1b

Earth Mechanics

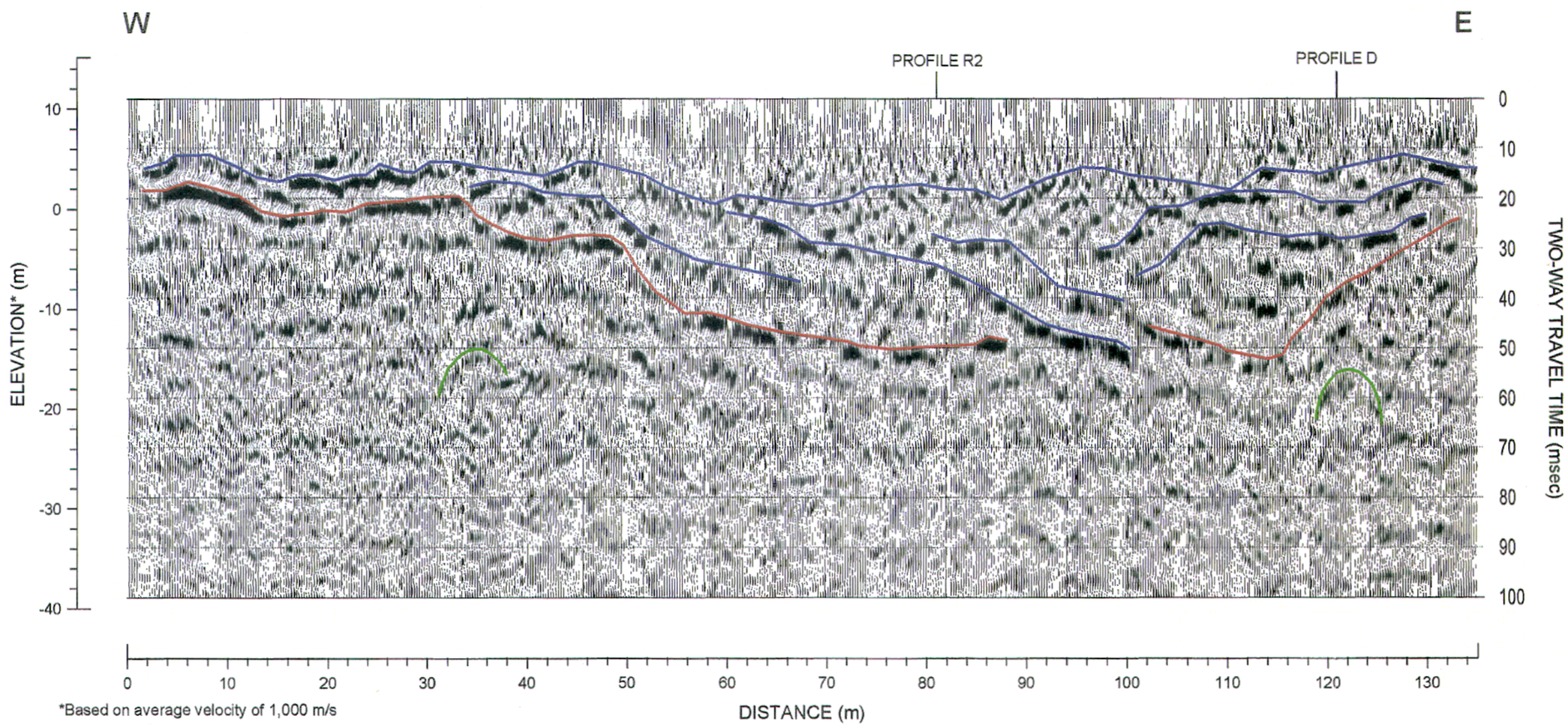
FUGRO



GEOLOGIC MAP AND GEOTECHNICAL EXPLORATIONS AT THE EASTERN END OF YERBA BUENA ISLAND

SFOBB East Span Seismic Safety Project

PLATE 5.1



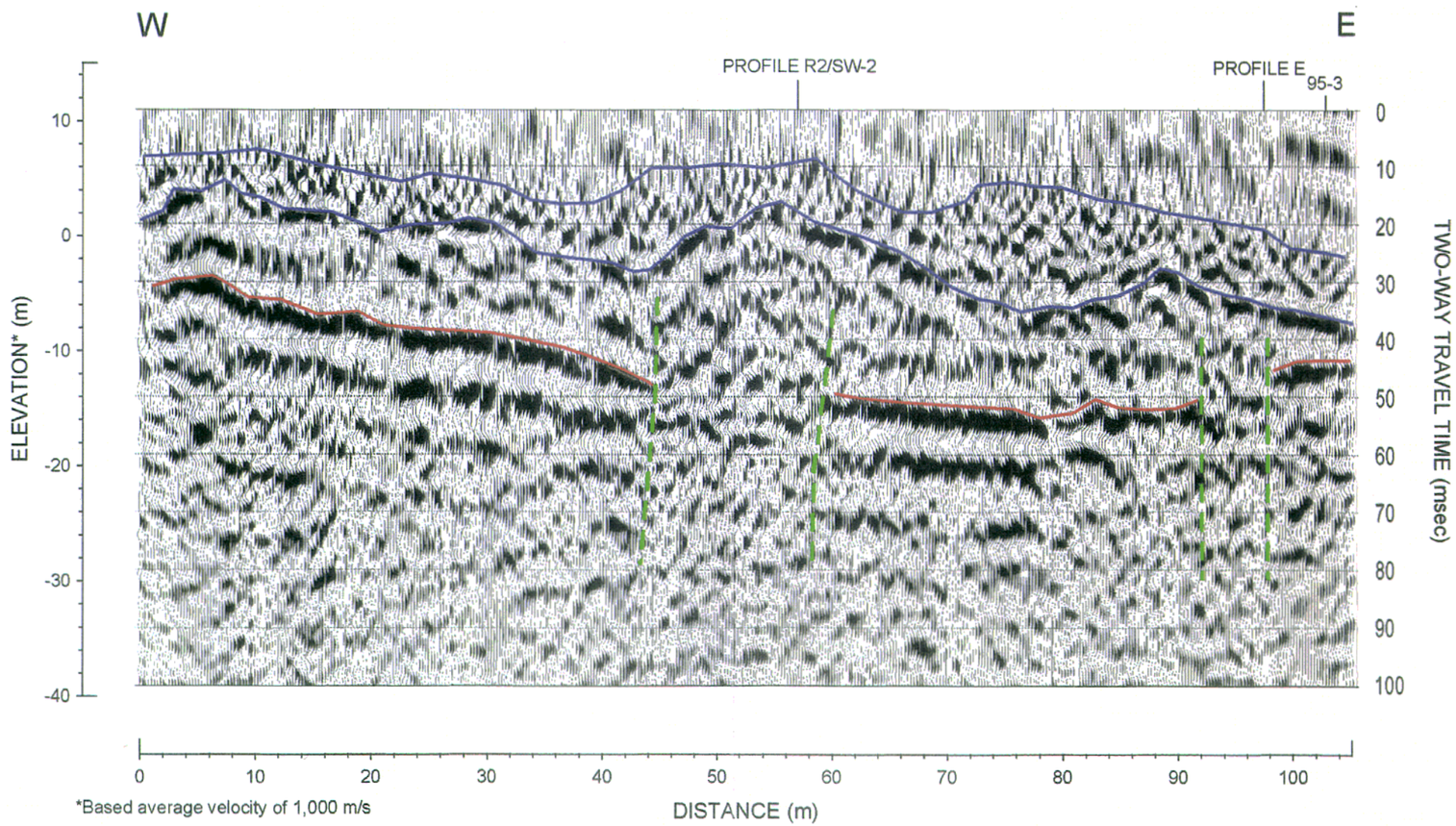
Data and interpretation by NORCAL Geophysical Consultants, Inc. (NORCAL, 1998).

INTERPRETATION
Bedrock Horizon
Alluvial Horizon
Boundary of disturbed zone

ONSHORE SEISMIC REFLECTION PROFILE R1
SFOBB East Span Seismic Safety Project

PLATE 5.2a

98420054onsh.dsf(1,2).p1



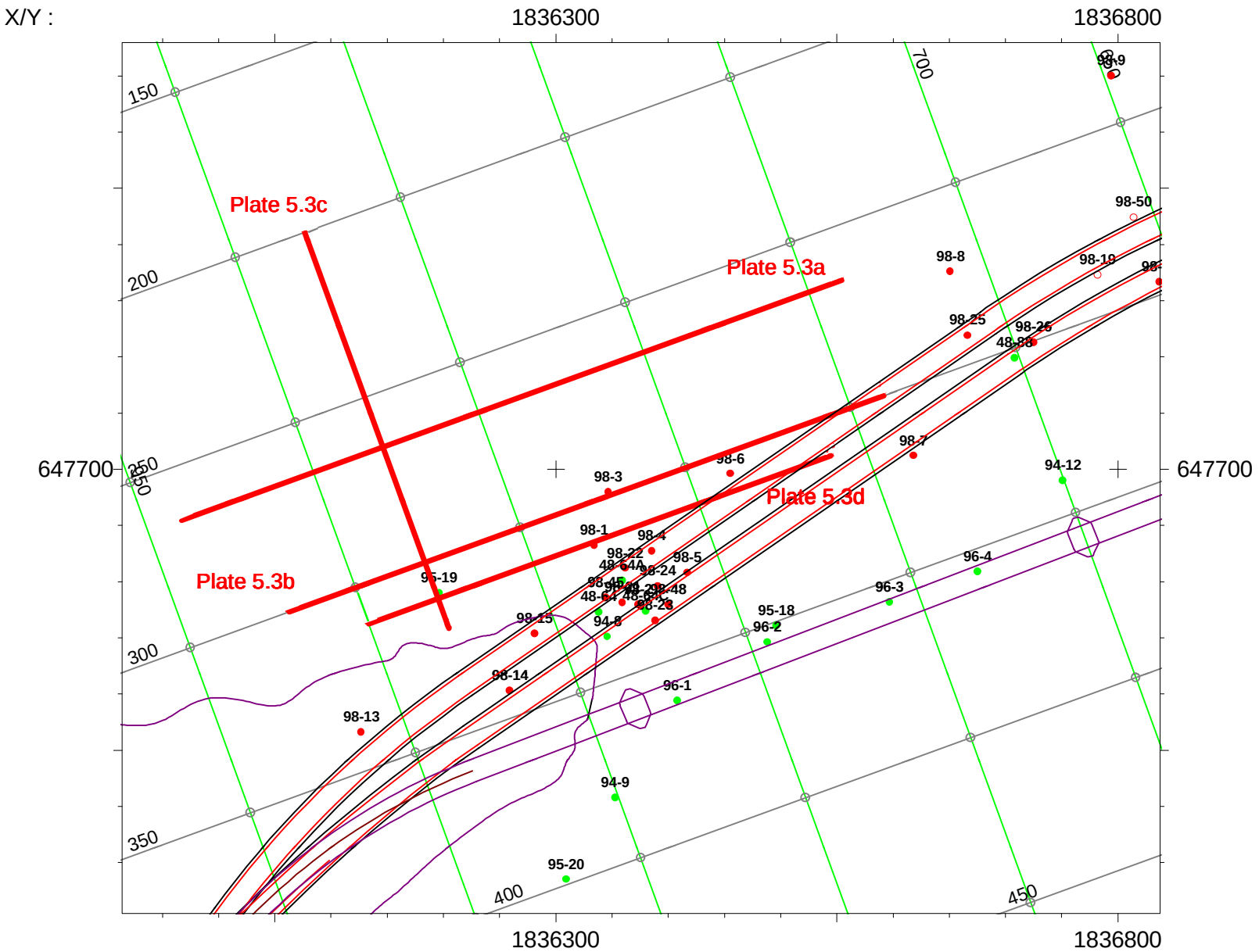
Data and interpretation by NORCAL Geophysical Consultants, Inc. (NORCAL, 1998).

INTERPRETATION
Bedrock Horizon
Alluvial Horizon
Boundary of disturbed zone

ONSHORE SEISMIC REFLECTION PROFILE R3
SFOBB East Span Seismic Safety Project

PLATE 5.2b

9842\0054onsh.dsf(1:2)p2



NOTES:

1.) See notes on Plate 2.15.

Scale 1:5000

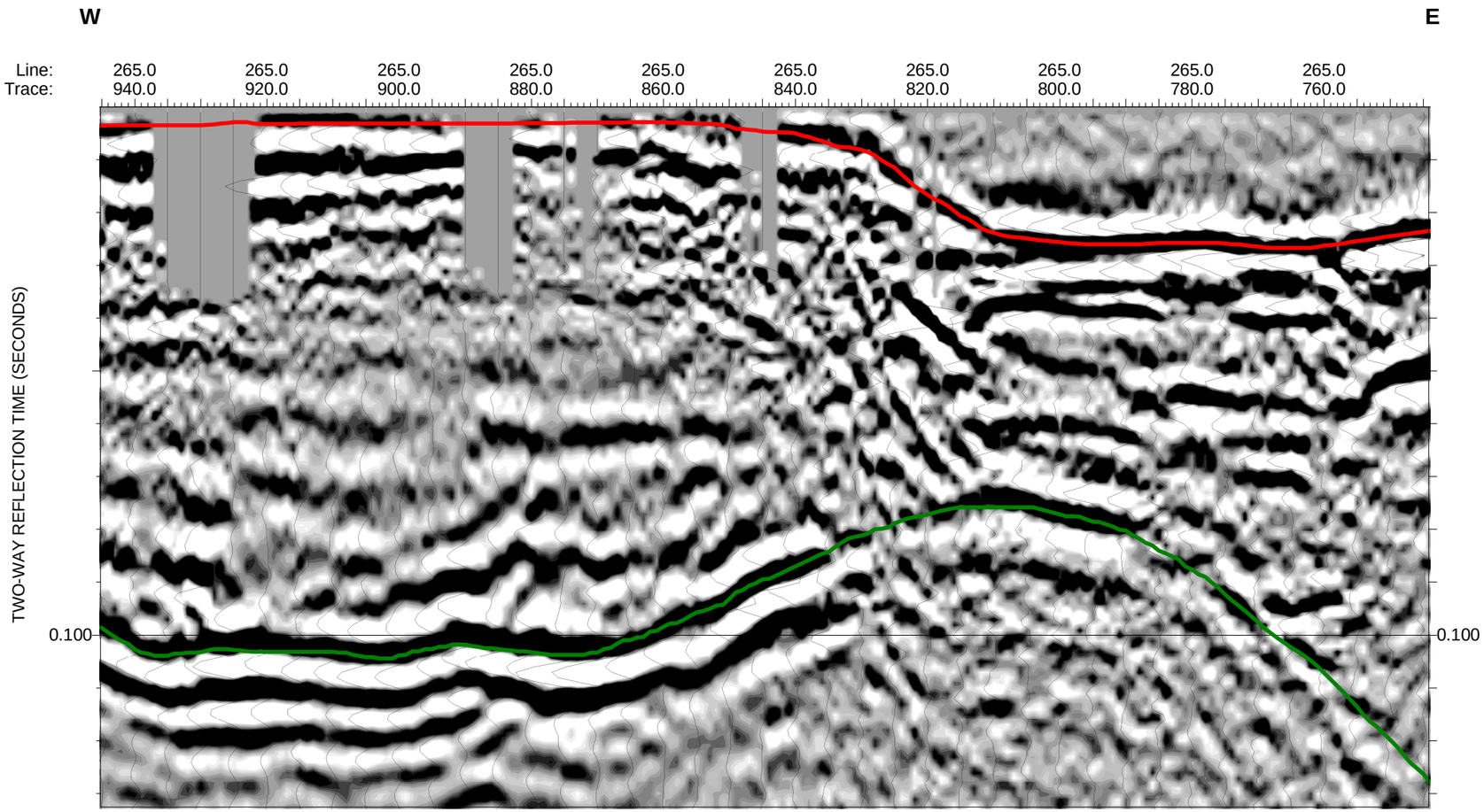
LOCATION MAP FOR 3-D SEISMIC DATA ILLUSTRATED IN SECTION 5

SFOBB East Span Seismic Safety Project

SFOBB Task Order No. 5
Project No. 98-42-0054

Earth Mechanics

FUGRO



Approximate Scales
Horizontal 1:2500
Vertical 1:750

NOTES:

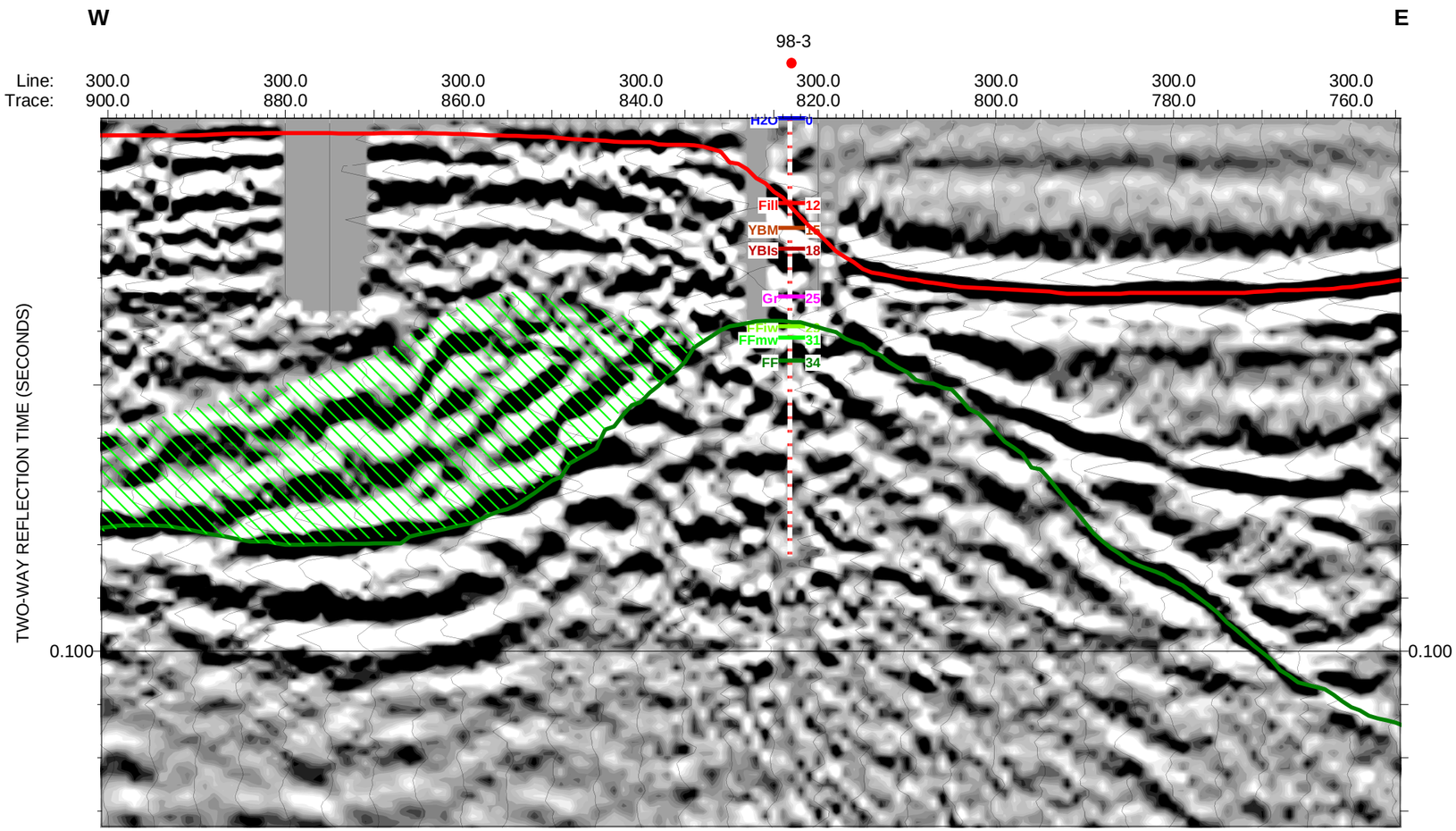
1.) See Plate 5.3 for location of line.

2.) Green line represents reflector interpreted to be the top of the Franciscan Formation. Red line is bay floor.

3-D SURVEY LINE 265 SHOWING TOP FRANCISCAN REFLECTOR CONTINUITY ACROSS RIDGE

SFOBB East Span Seismic Safety Project

PLATE 5.3a



Approximate Scales
Horizontal 1:2000
Vertical 1:750

NOTES:

1.) See Plate 5.3 for location of line.

2.) Red line is Bay Floor reflector.

3.) Green line is interpreted Franciscan Formation reflector.

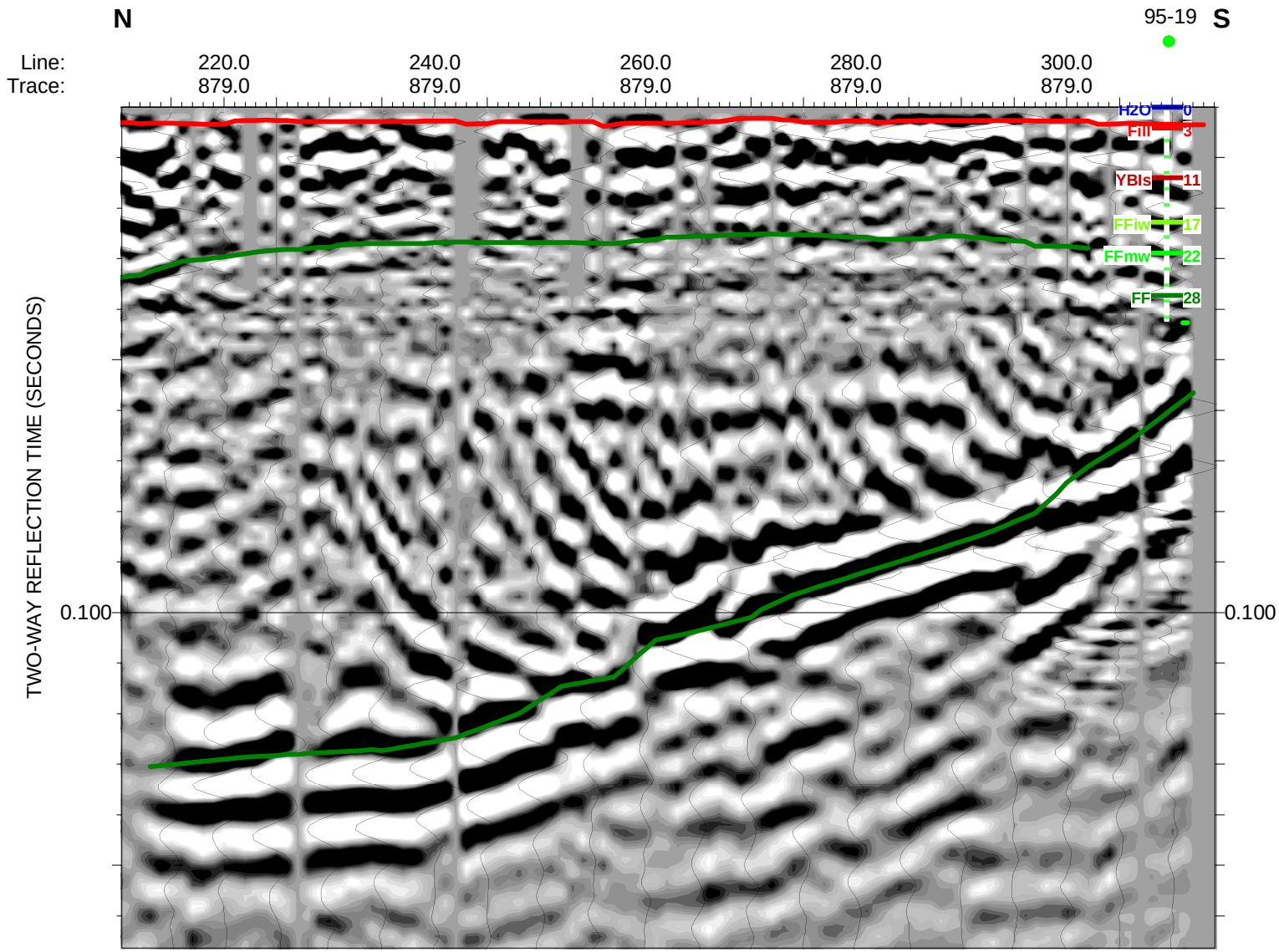
4.) Hummocky and tilted reflections above green line may represent a buried landslide of Franciscan Formation units.

BORING DESIGNATIONS:

Fill = Bay Floor west of Boring98-3
YBM = Top of Young Bay Mud (Bay Floor east of Boring 98-3)
YBls = Local Sediments offshore Yerba Buena Island
Gr = Gravel, possibly weathered in-place bedrock
FF = Franciscan Formation
FFiw = intensely weathered Franciscan Formation
FFmw = moderately weathered Franciscan Formation

3-D SURVEY LINE 300 SHOWING POSSIBLE BURIED LANDSLIDE NORTH OF YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.3b



Approximate Scales
Horizontal 1:2000
Vertical 1:1000

NOTES:

1.) See Plate 5.3 for location of Line.

2.) Refer to Plate 5.3b for boring designations.

3.) Green lines represent alternative interpretations of bedrock reflector. Upper line is based on apparent tie with Boring 95-19, lower line on correlation with reflector and borings to the east.

4.)Refer to Plate 5.3d for alternative horizon configurations of Boring 95-19.

CROSSLINE 879 SHOWING ALTERNATIVE FRANCISCAN FORMATION REFLECTORS IN COVE AREA

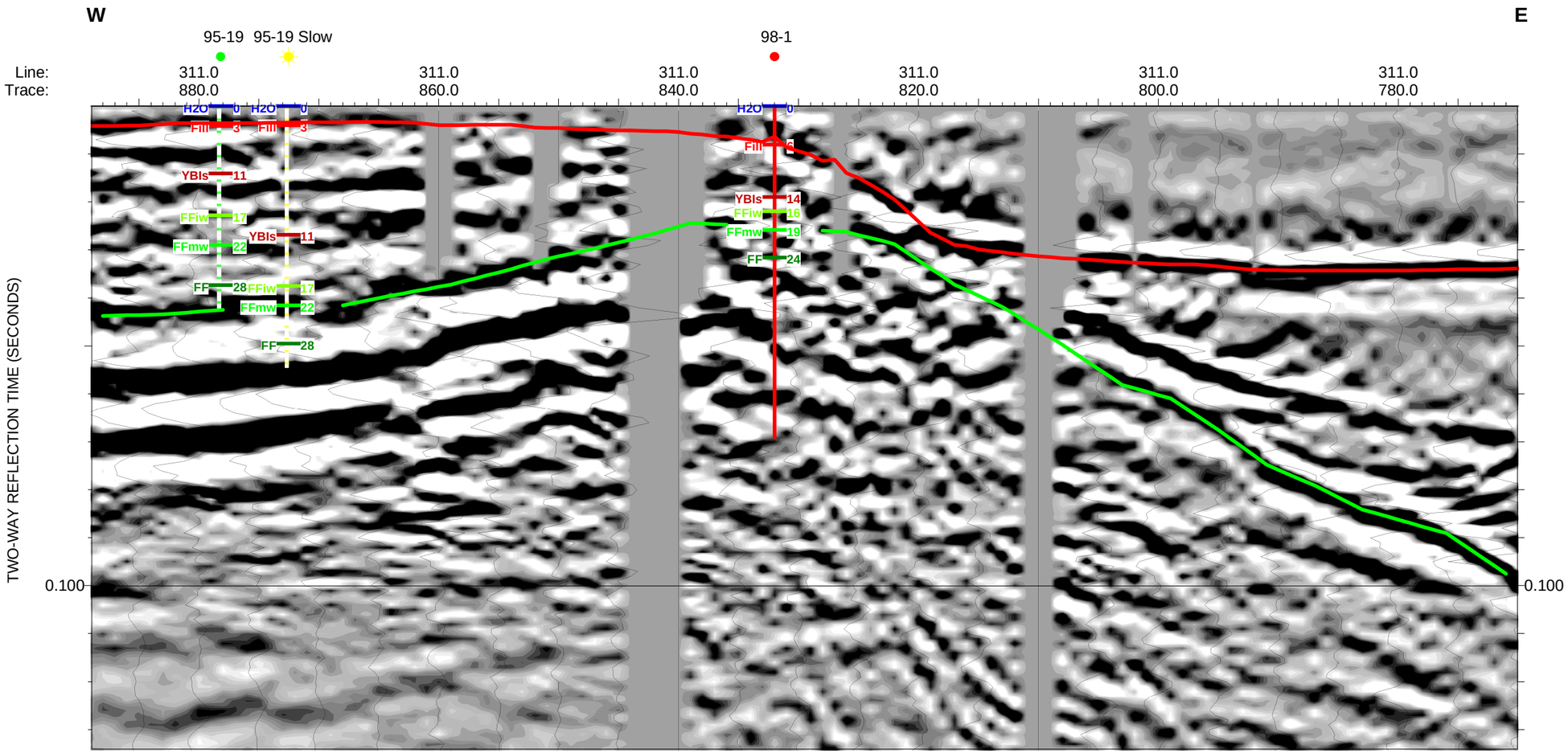
SFOBB East Span Seismic Safety Project

PLATE 5.3c

SFOBB Task Order No. 5
Project No. 98-42-0054

Earth Mechanics

FUGRO



Depth section for Boring 95-19 based on a velocity of 1500 m/s for Fill.
Depth sections for Boring 95-19 slow based on a velocity of 1100 m/s for Fill.
Green line represents reflector mapped as the top of Franciscan Formation.

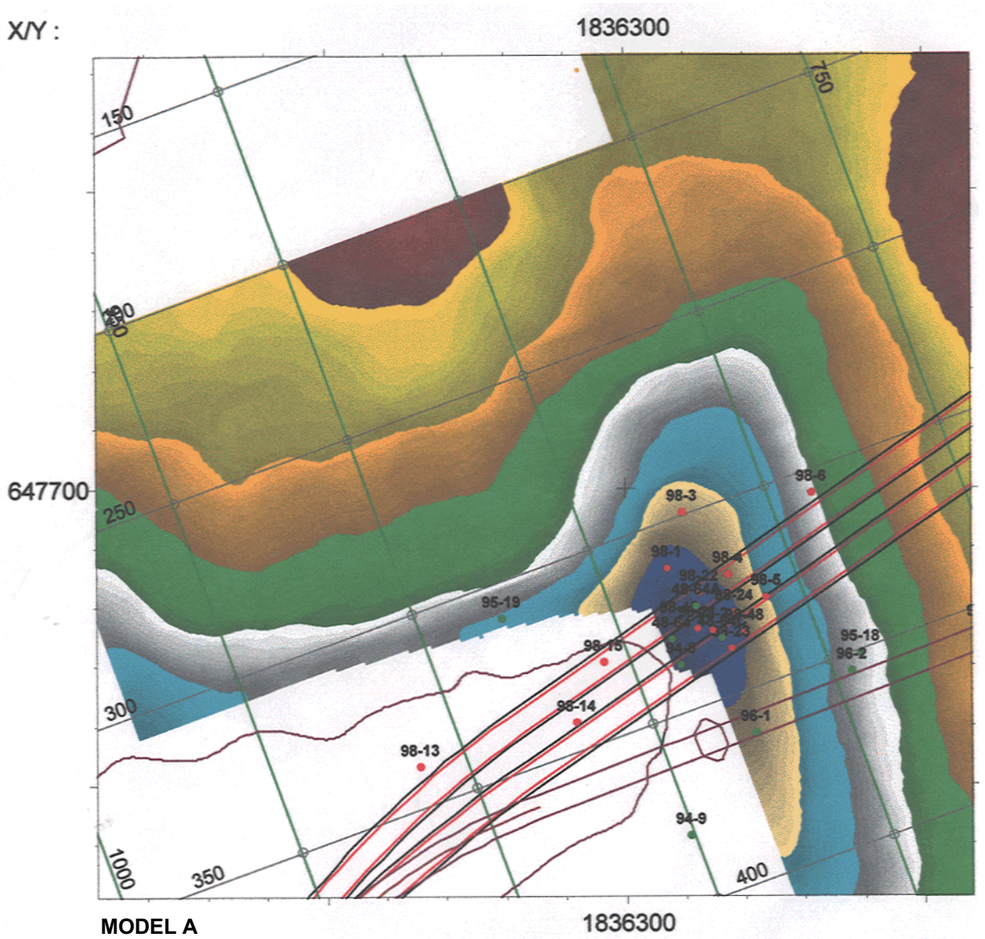
NOTES:

1.) See Plate 5.3 for location of line.

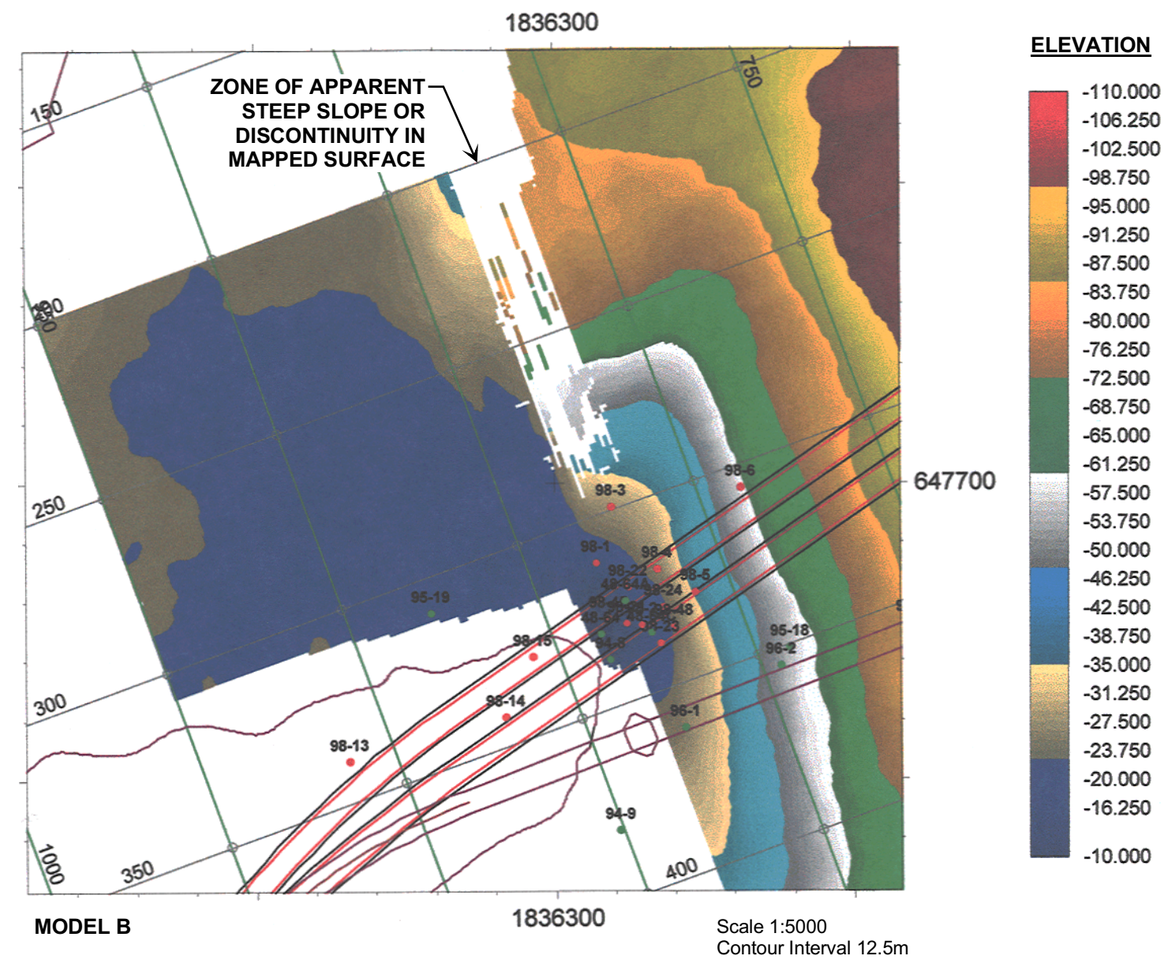
2.) Refer to Plate 5.3b for boring designations.

3-D SURVEY LINE 311 SHOWING ALTERNATIVE VELOCITY MODELS
SFOBB East Span Seismic Safety Project

PLATE 5.3d



MODEL A



MODEL B

Scale 1:5000
Contour Interval 12.5m

NOTES:

1) Map on left is referred to as Ridge Model and represents the dark green horizon shown in Plates 5.3a and 5.3b.

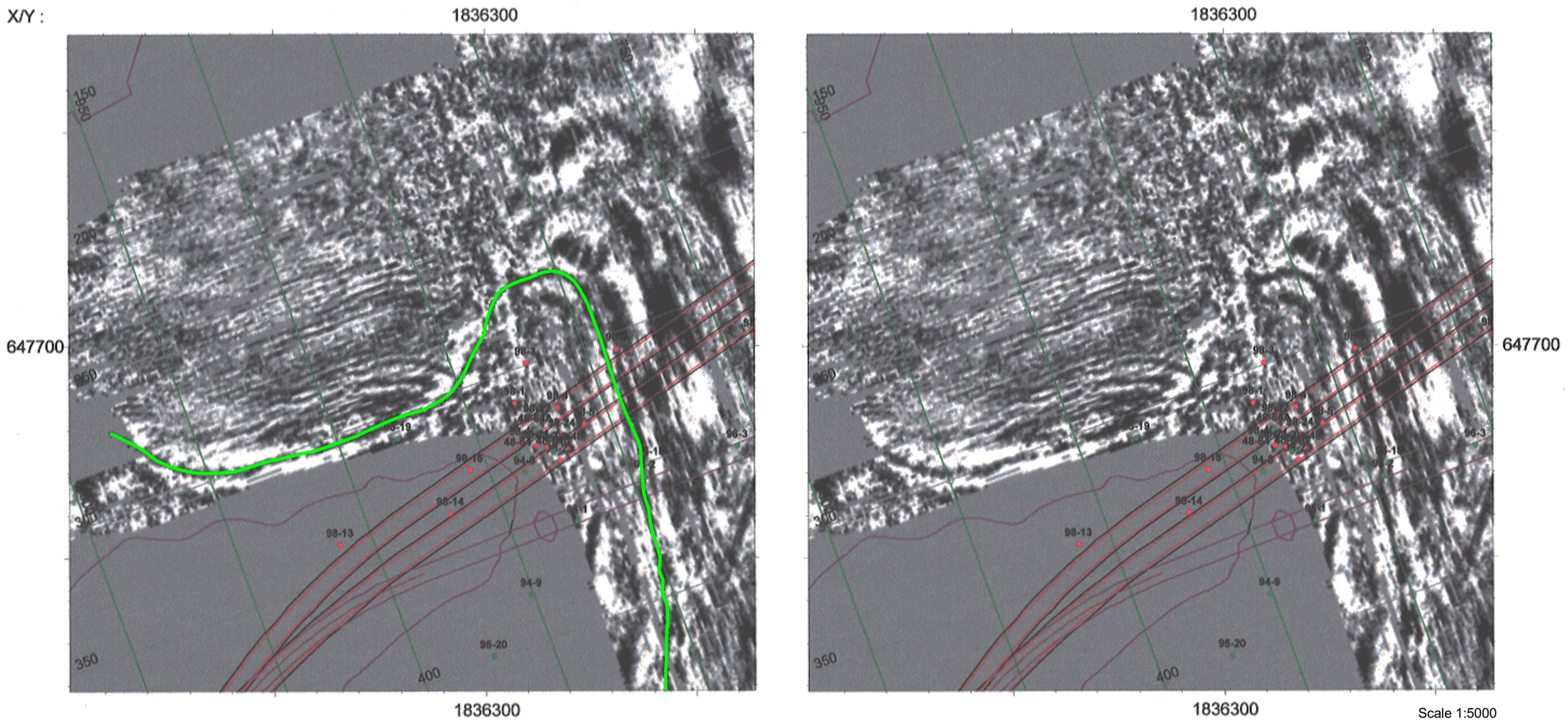
2) Map on right is referred to as the Alternative Cove Model and represents the upper (light) green horizon through Boring 95-19 in Plates 5.3c.

3) Elevation scale for both models assumes a constant sediment velocity of 1500 m/s for conversion of reflection times to depths. This velocity results in an incorrect boring correlation for Model B (see Plate 5.3d). The shape of Model A is correct but elevations are incorrect because they do not account for low seismic velocity of fill.

4) Refer to Map 14 (Plate 5.14) for revised elevations.

COLORED CONTOUR MAPS OF ALTERNATIVE MODELS FOR TOP OF FRANCISCAN FORMATION NORTH OF YERBA BUENA ISLAND

SFOBB East Span Seismic Safety Project



NOTES:

1.) Time slice on left shows intersection of Ridge Model Top Franciscan Formation Reflector as a green line.

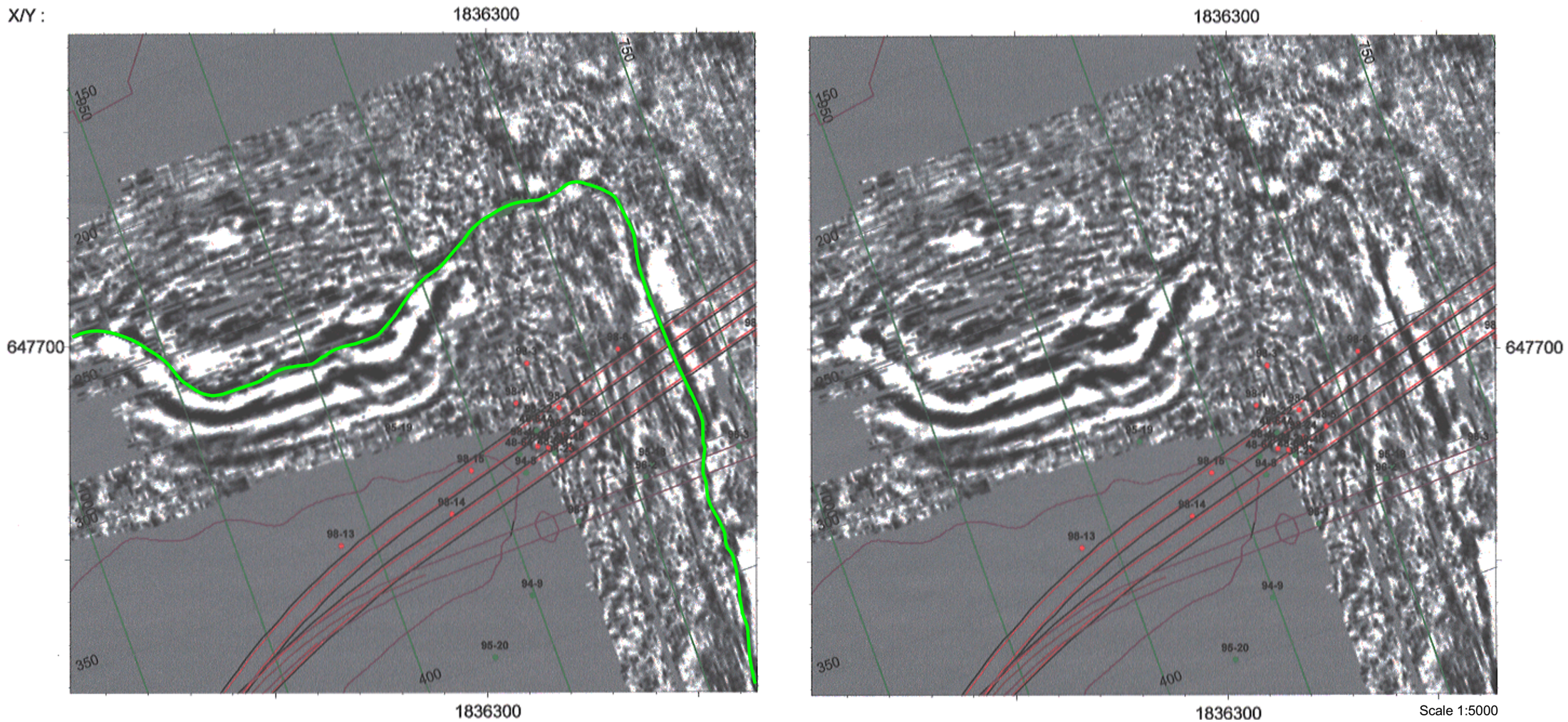
2.) Time slice on right is not annotated. Note break in apparent continuity of reflector running northwest from Boring 98-3.

3.) Approximate depth of time slice is -53m.

3-D SEISMIC DATA TIME SLICE
AT 70 MILLISECONDS
Top Franciscan Formation
Reflector Annotated
SFOBB East Span Seismic Safety Project

PLATE 5.5a

9842\0054kin5.dsf.p1



NOTES:

1.) Time slice on left shows intersection of Ridge Model Top Franciscan Formation Reflector as a green line.

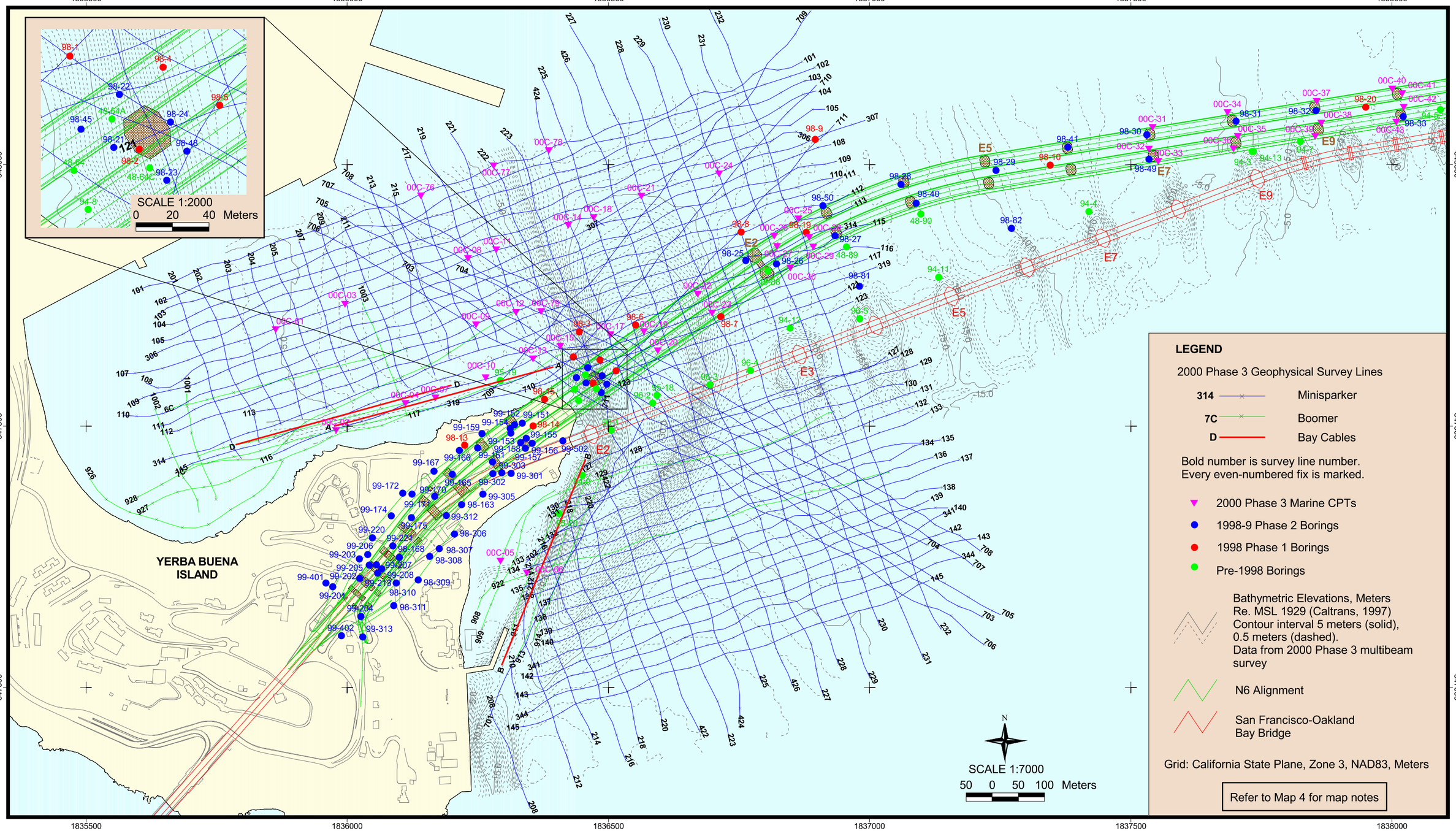
2.) Time slice on right is not annotated. Note break in apparent continuity of reflector running northwest from Boring 98-3.

3.) Approximate depth of time slice is -75m.

3-D SEISMIC DATA TIME SLICE
AT 100 MILLISECONDS
Top Franciscan Formation
Reflector Annotated
SFOBB East Span Seismic Safety Project

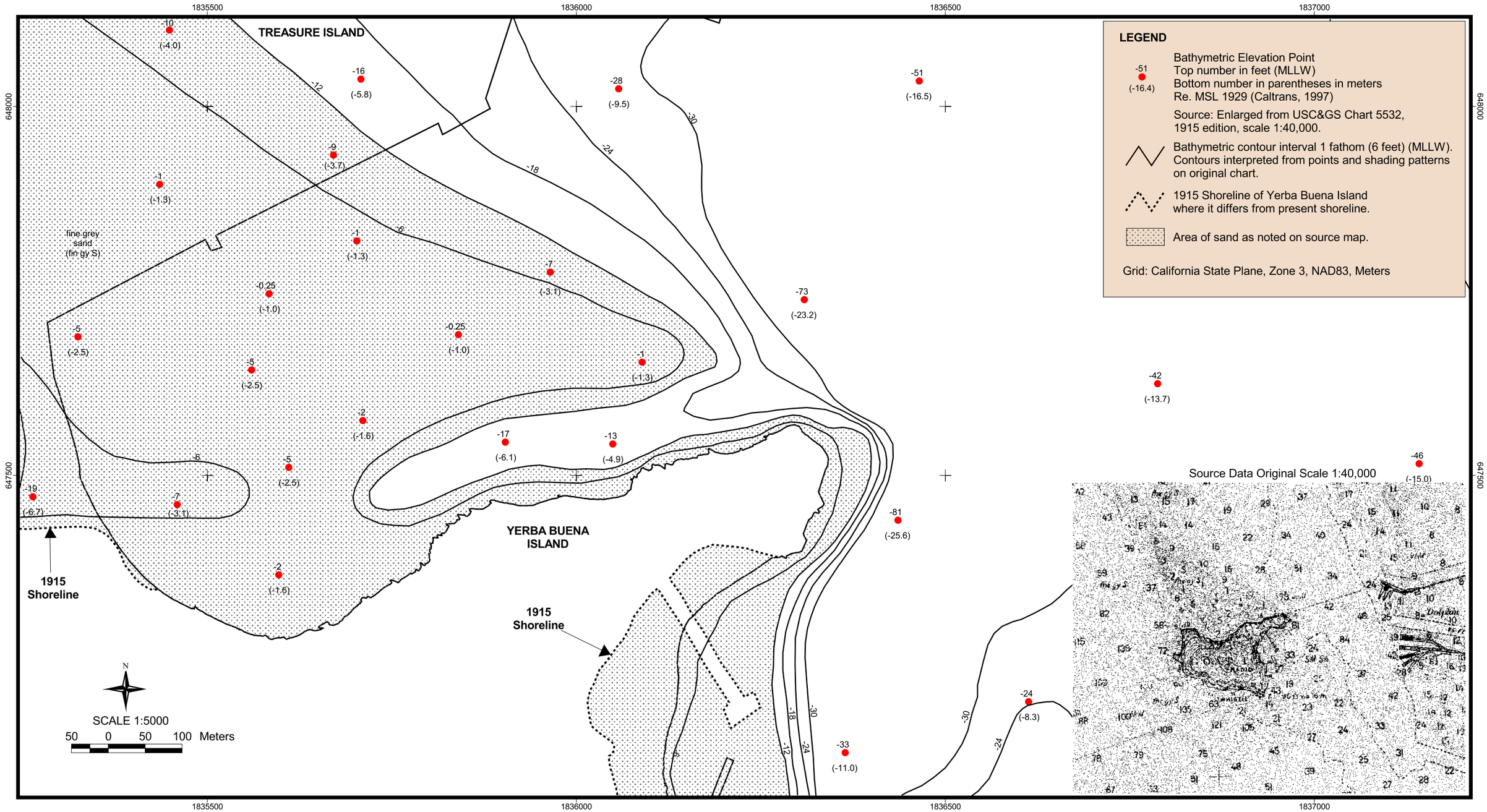
PLATE 5.5b

9842\0054kin6.dsf.p2



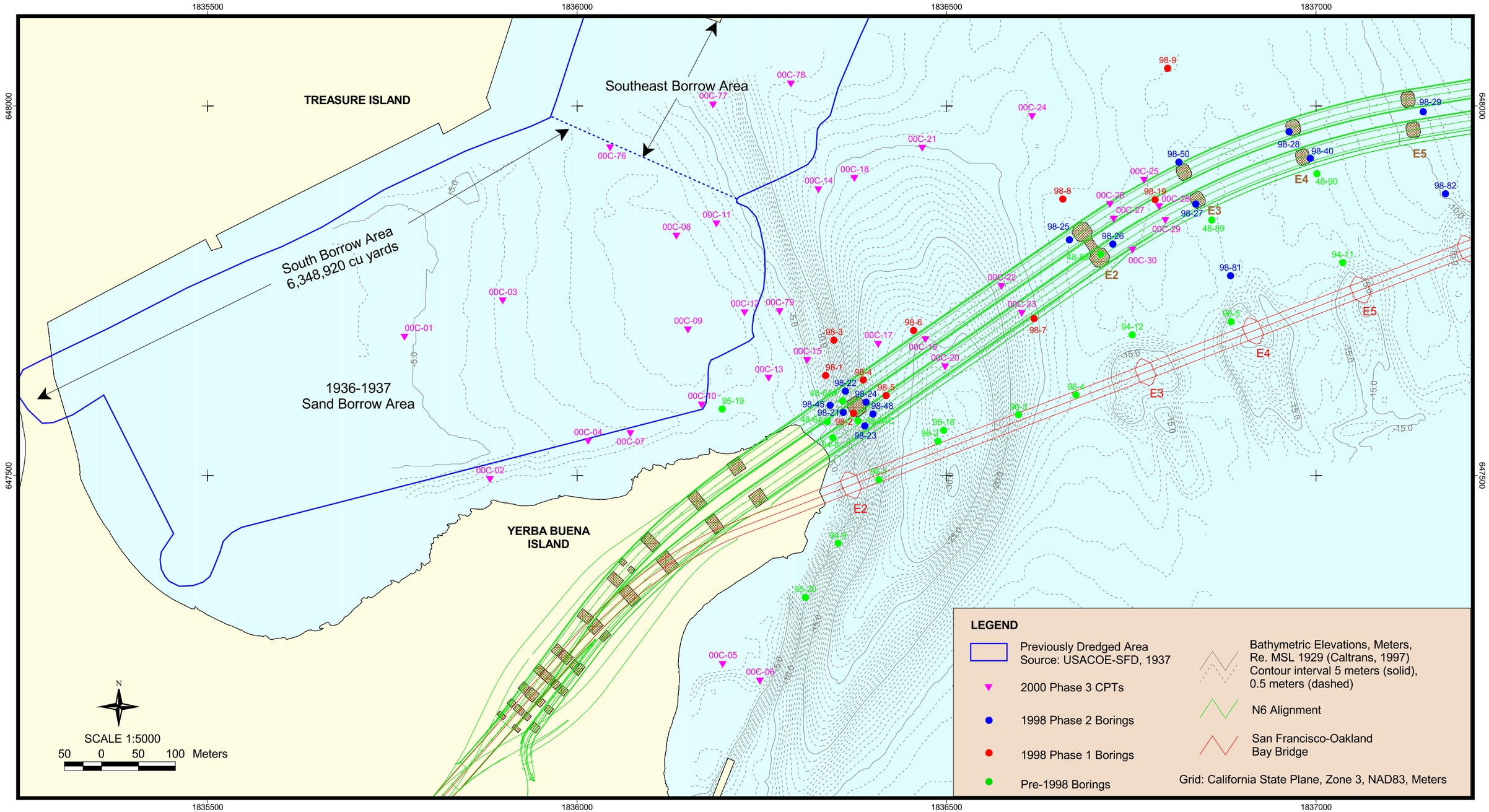
DATABASE MAP, 2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

PLATE 5.6



1915 BATHYMETRIC DATA
SFOBB East Span Seismic Safety Project

PLATE 5.7

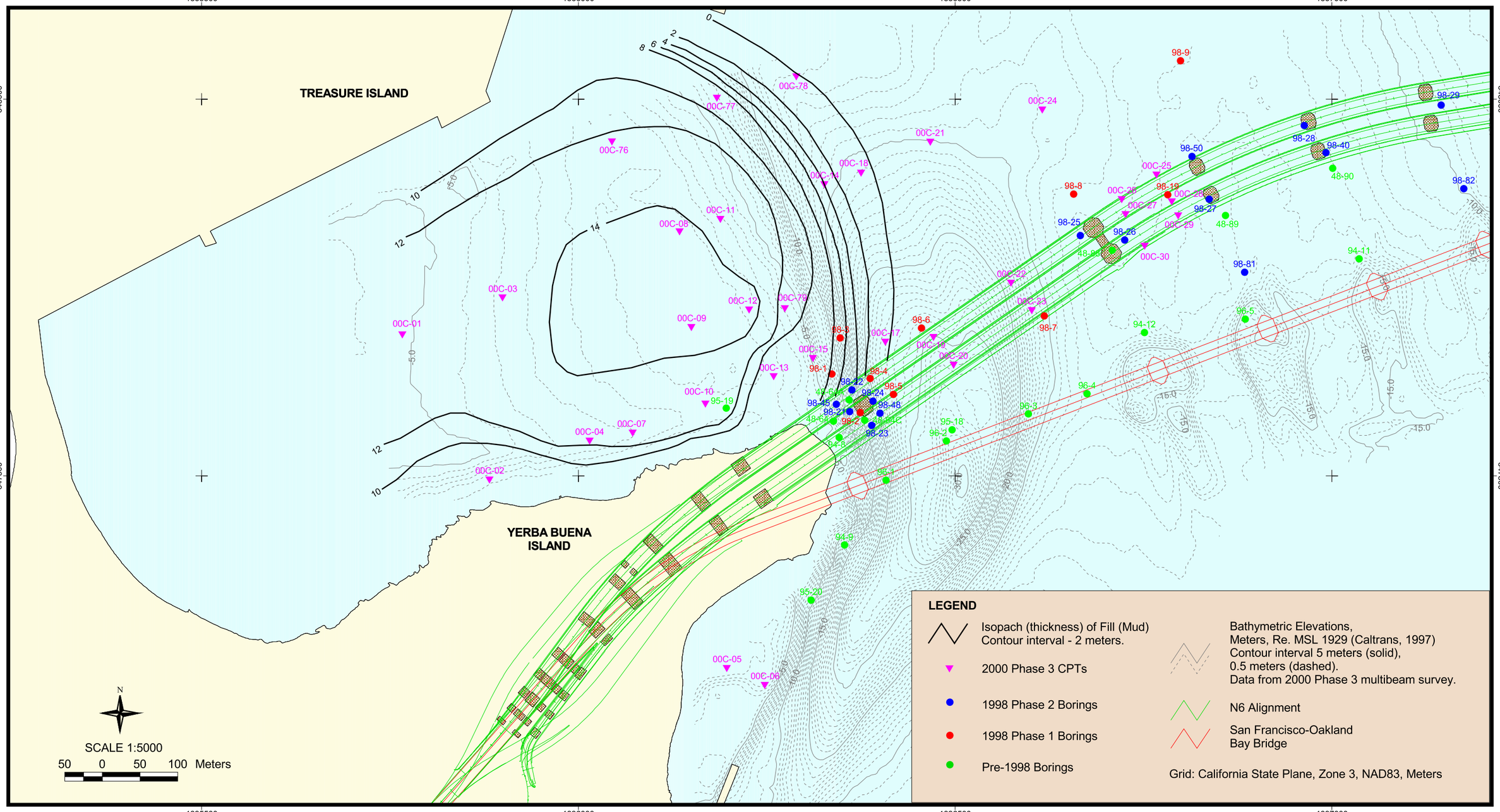


DREDGED AREA (1936-1937)
SFOBB East Span Seismic Safety Project

PLATE 5.8

Earth Mechanics

FUGRO

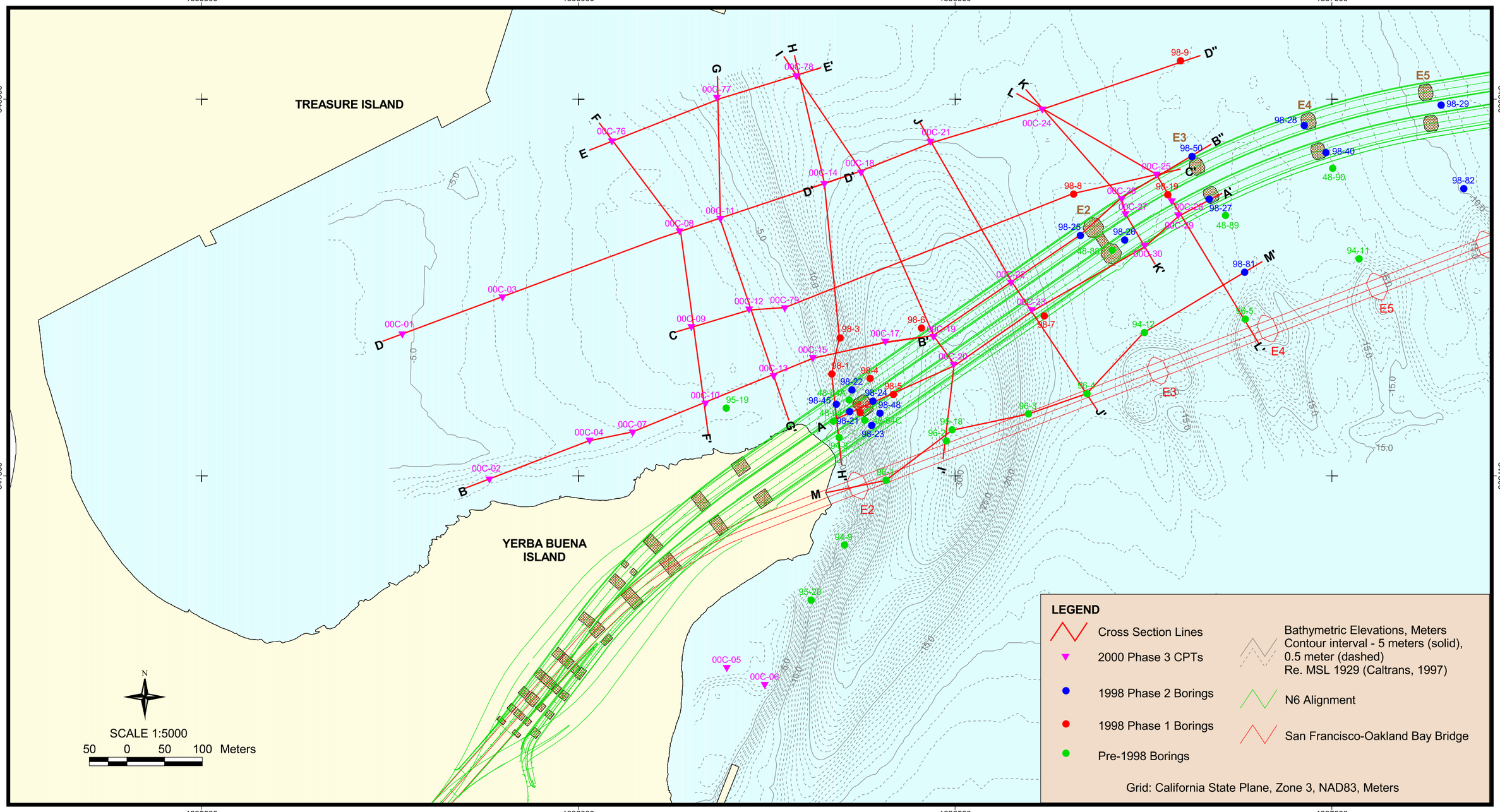


ISOPACH (THICKNESS) OF FILL (MUD)
SFOBB East Span Seismic Safety Project

PLATE 5.9

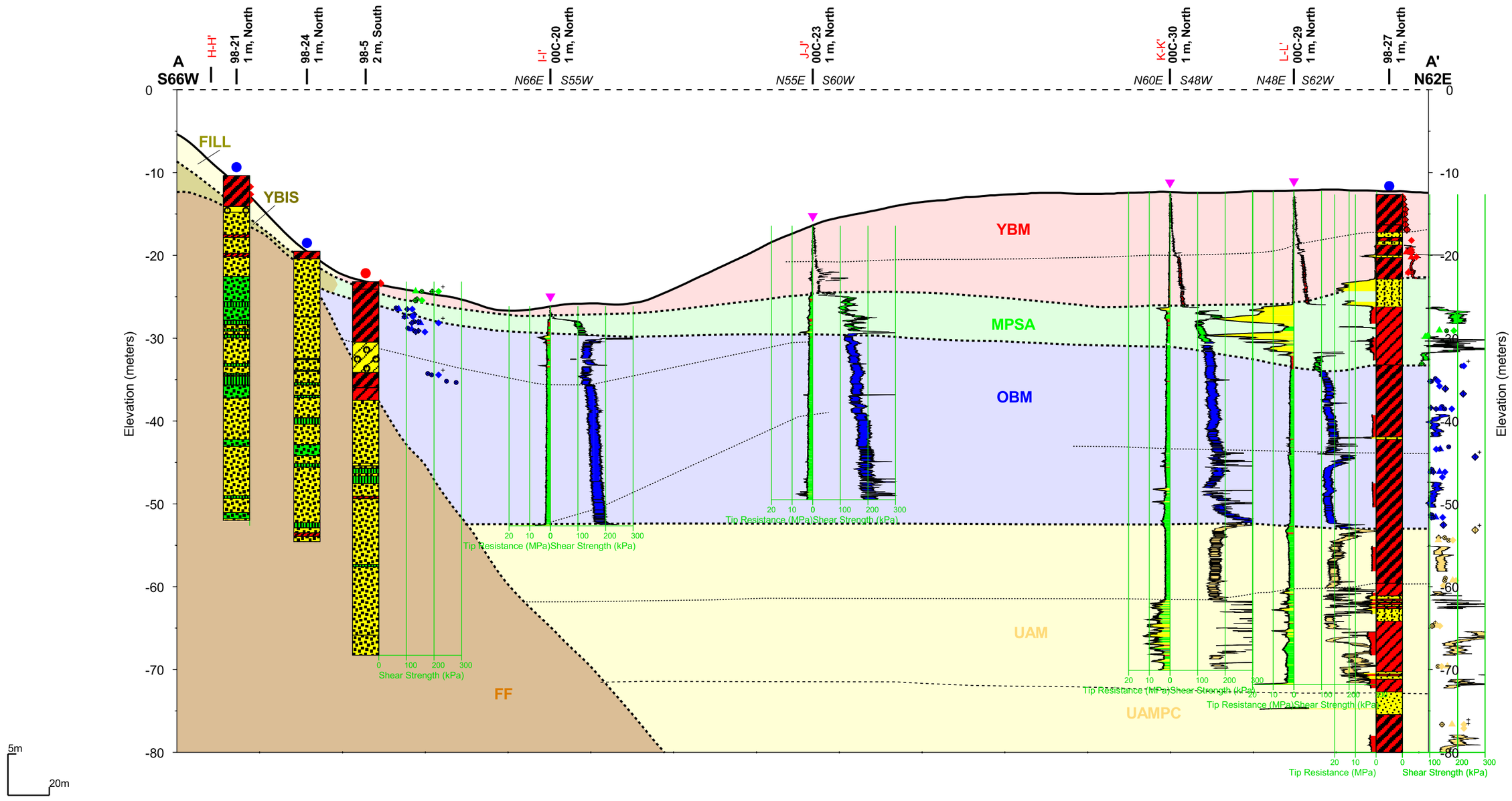
Earth Mechanics

FUGRO



CROSS SECTION LOCATIONS OFFSHORE YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.10



GENERAL NOTES:

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3) Lithology for pre-1998 borings are in some instances modified from those shown on the Caltrans Log of Test Boring sheets. Modifications were made based on subsequent laboratory test results and extrapolation from adjacent 1998 borings.

SHEAR STRENGTH SYMBOLS

- ▲ Unconsolidated Undrained (UU)
- □ Unconfined Compression (UC)
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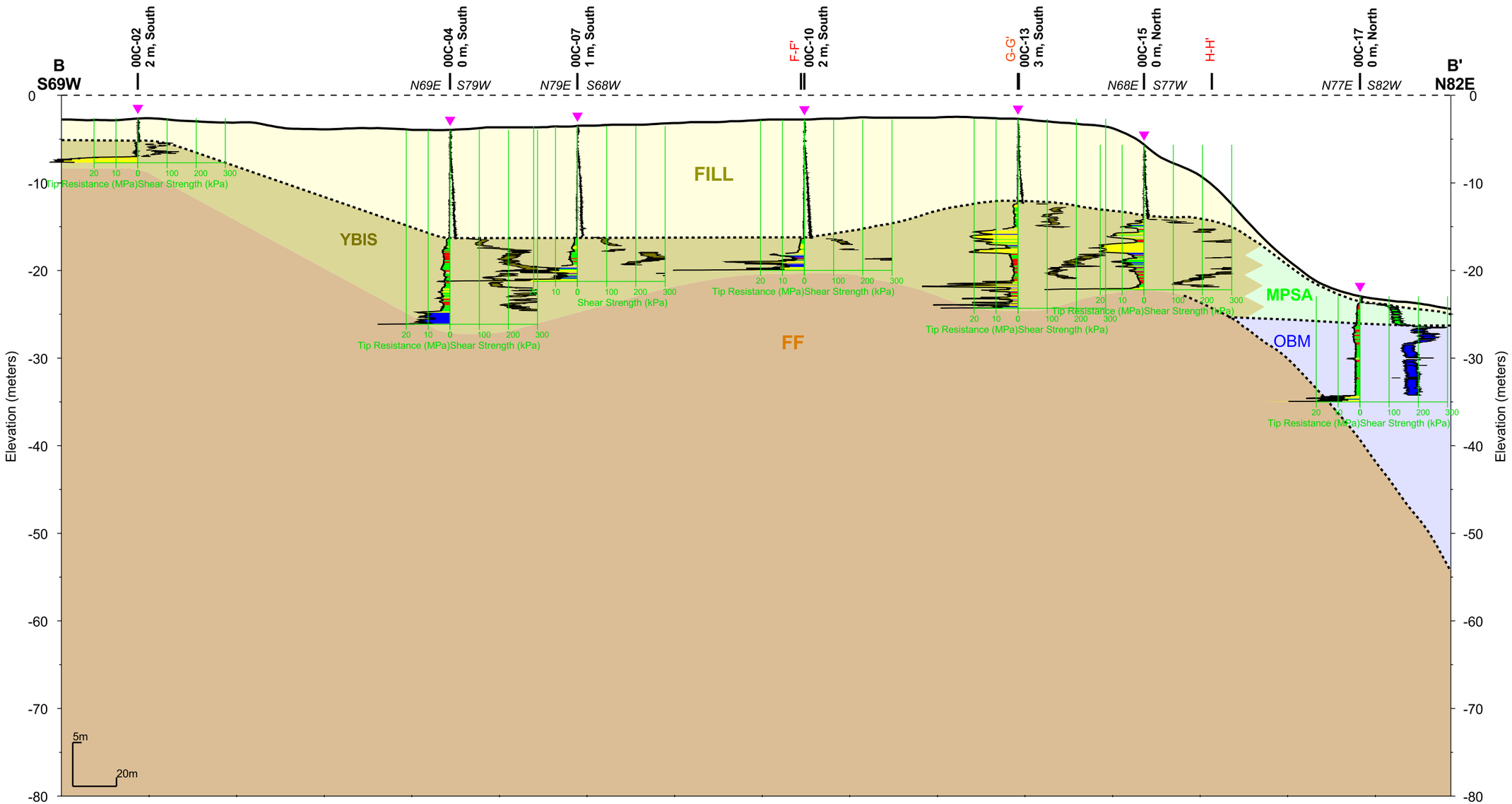
- ⊕ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

FILL	Fill	UAM	Upper Alameda Marine
YBM	Young Bay Mud	UAMPC	Upper Alameda Marine Paleochannel Sand
MPSA	Merritt-Posey-San Antonio Formations	FF	Franciscan Formation
YBIS	YBI Sediments		
OBM	Old Bay Mud		

SUBSURFACE CROSS SECTION A-A'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11a



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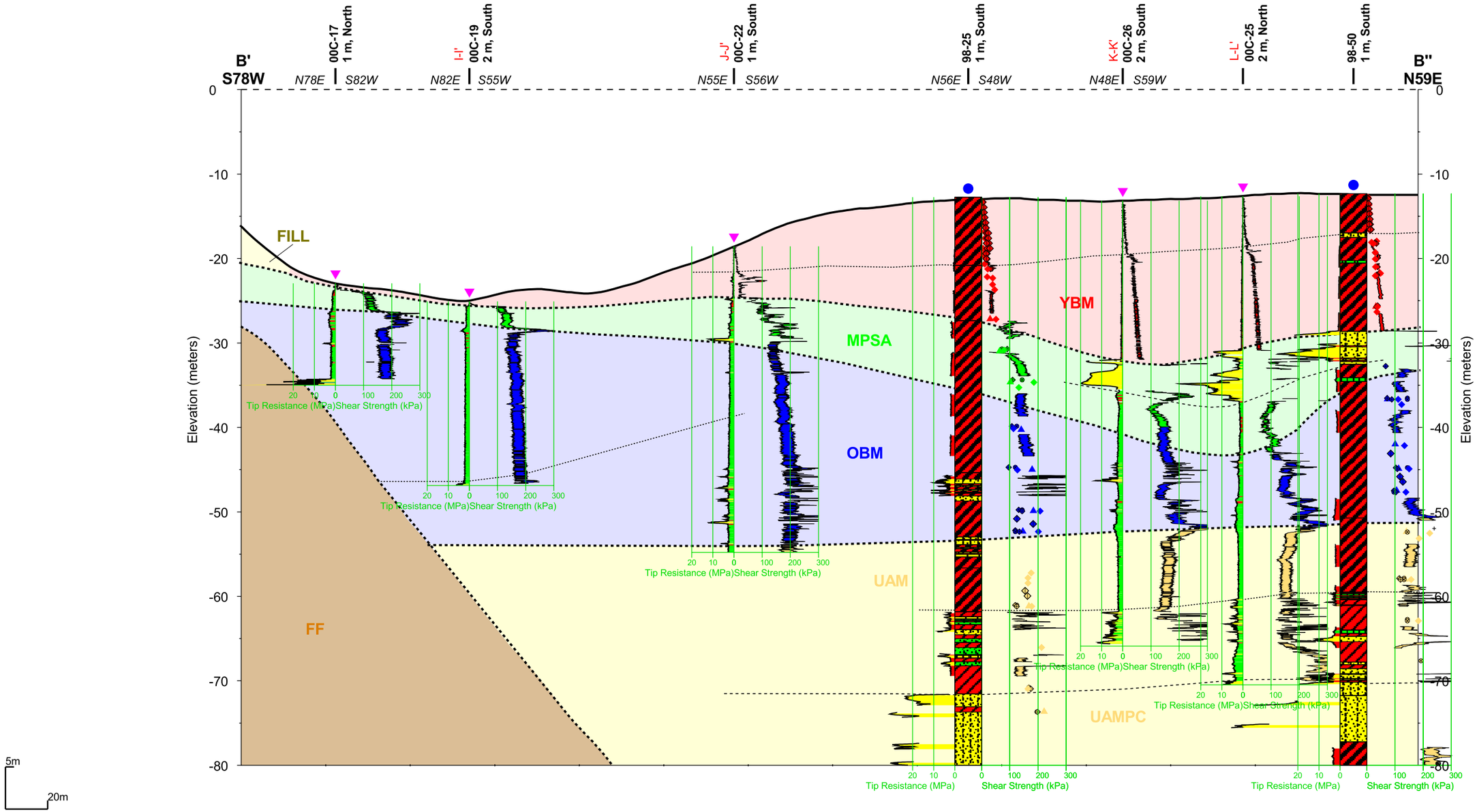
KEY TO GEOLOGIC UNITS

FILL	Fill
MPSA	Merritt-Posey-San Antonio Formations
YBIS	YBI Sediments
OBM	Old Bay Mud
FF	Franciscan Formation

SUBSURFACE CROSS SECTION B-B'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11b1



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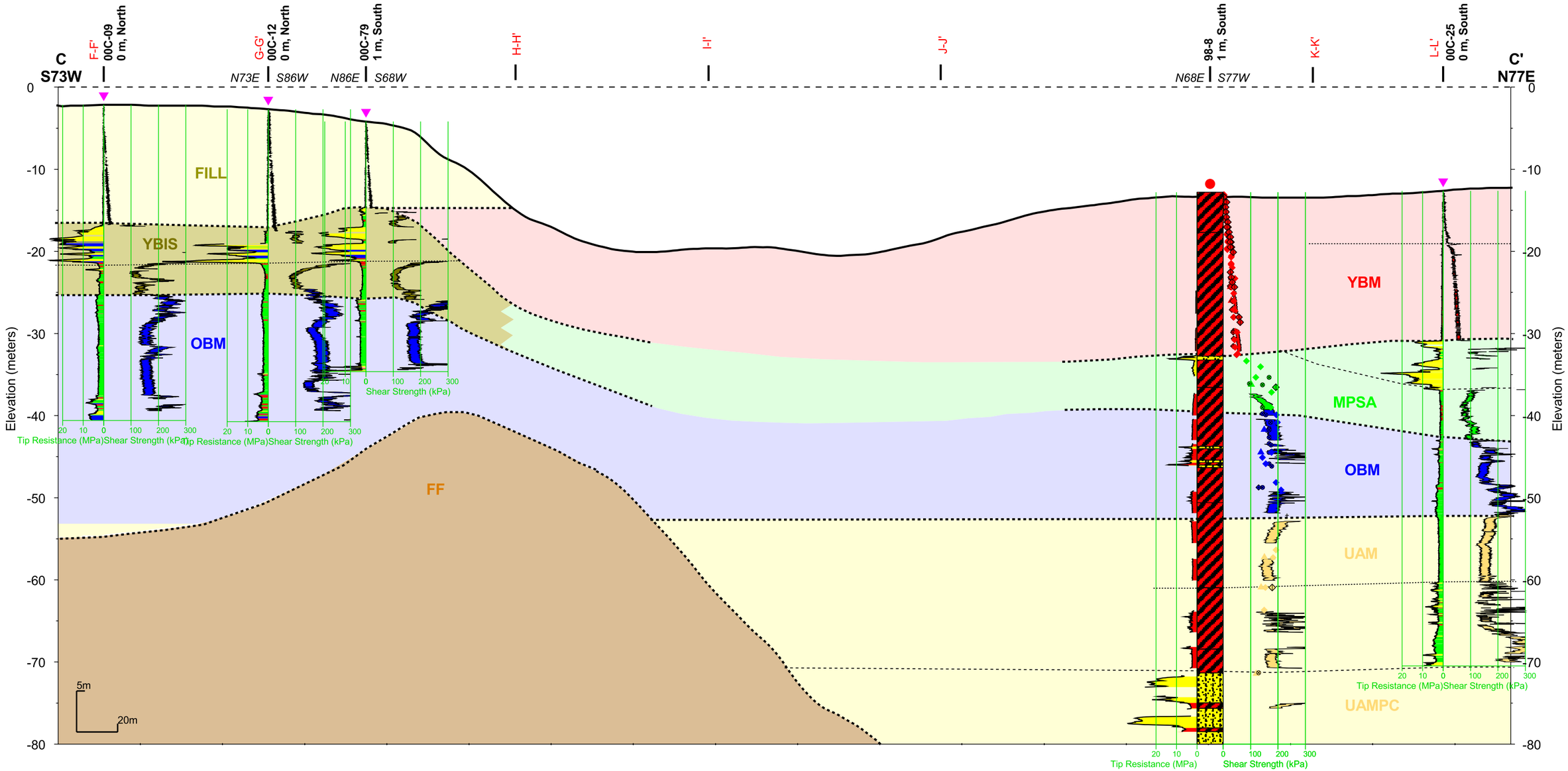
- ◇ Remote Vane (RV)
- \+ Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

FILL	Fill
YBM	Young Bay Mud
MPSA	Merritt-Posey-San Antonio Formations
OBM	Old Bay Mud
UAM	Upper Alameda Marine
UAMPC	Upper Alameda Marine Paleochannel Sand
FF	Franciscan Formation

SUBSURFACE CROSS SECTION B'-B''
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11b2



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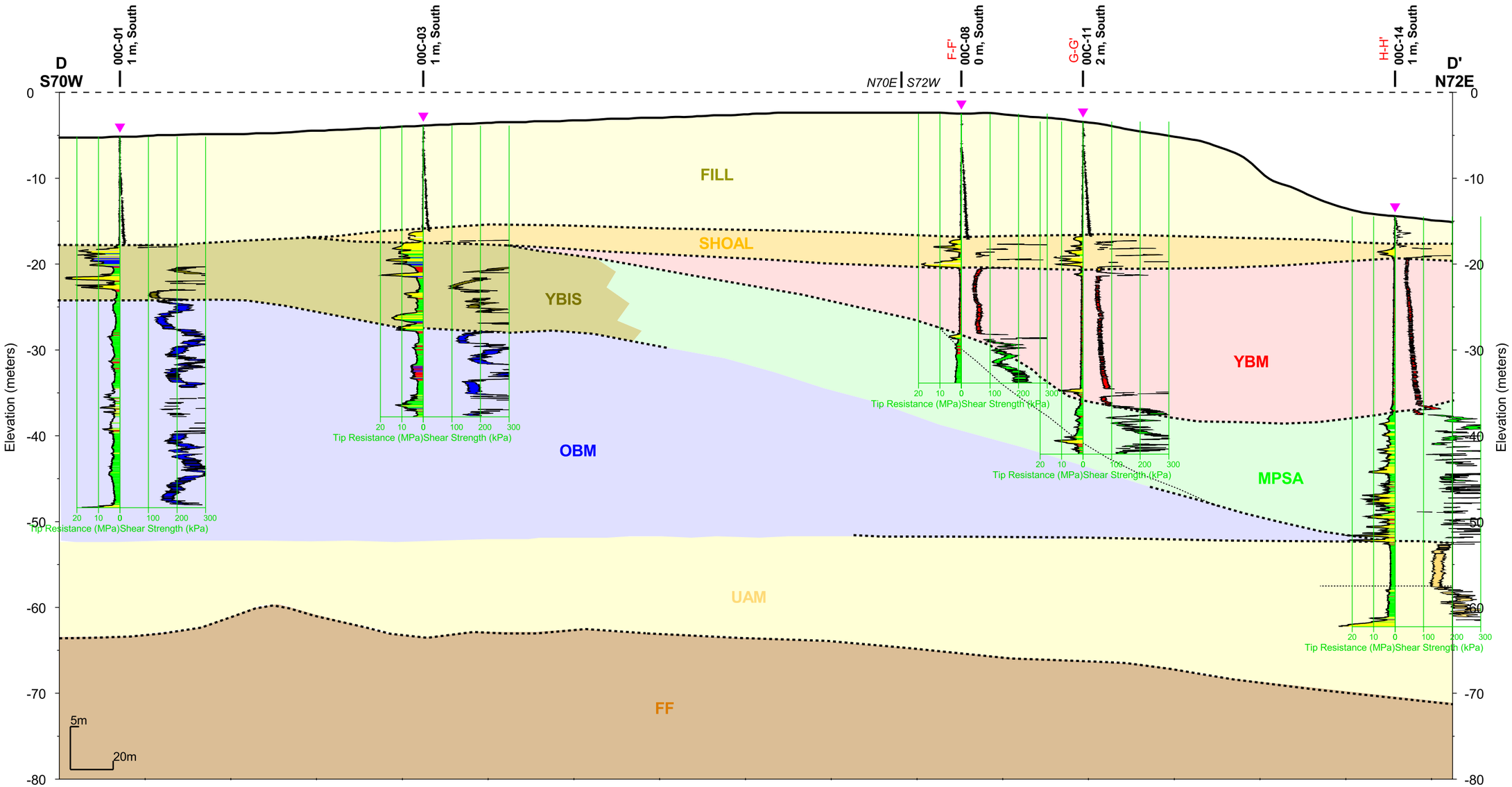
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

FILL	Fill	UAM	Upper Alameda Marine
YBM	Young Bay Mud	UAMPC	Upper Alameda Marine Paleochannel Sand
MPSA	Merritt-Posey-San Antonio Formations	FF	Franciscan Formation
YBIS	YBI Sediments		
OBM	Old Bay Mud		

SUBSURFACE CROSS SECTION C-C'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11c



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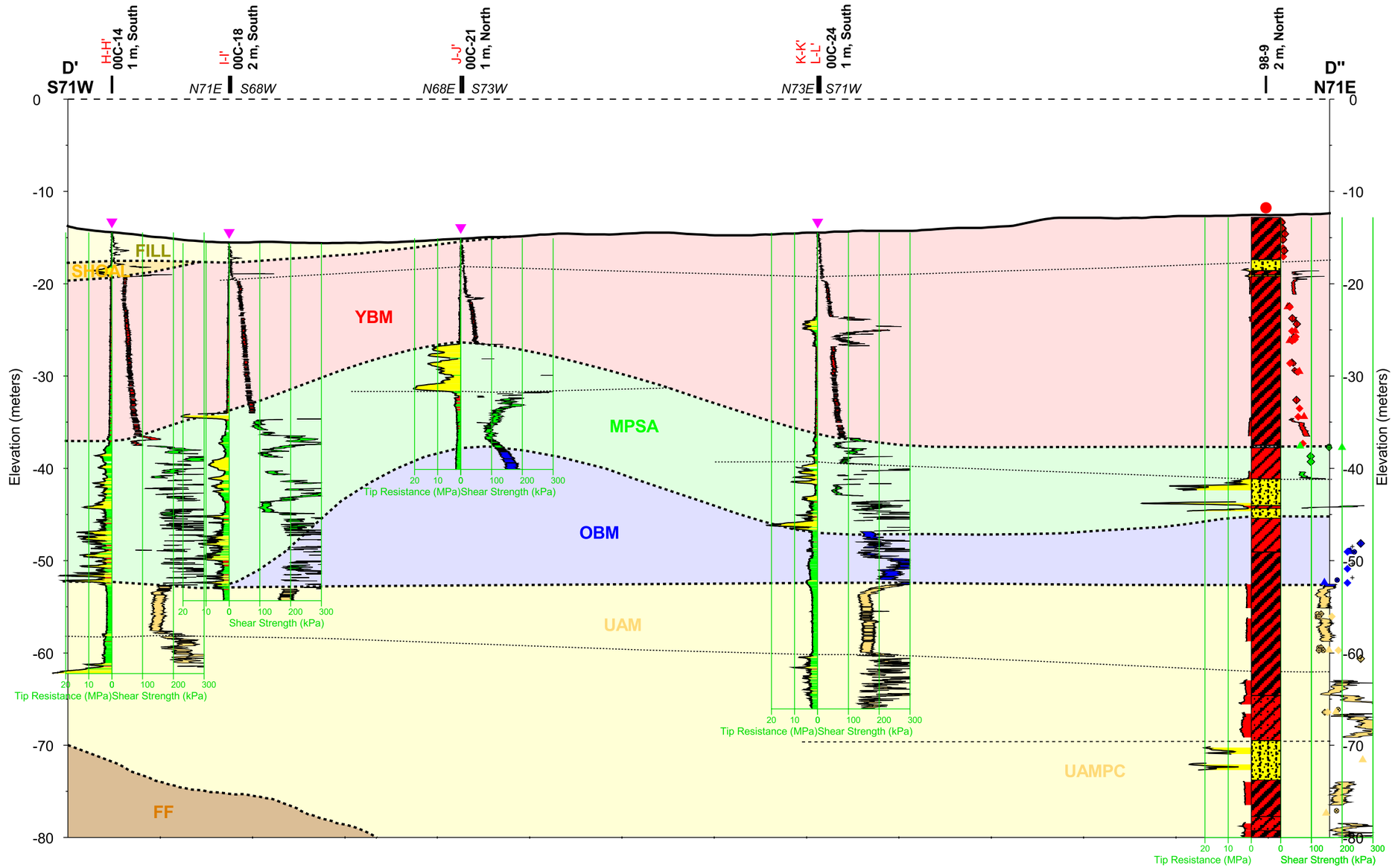
- ⊕ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

FILL	Fill	OBM	Old Bay Mud
SHOAL	Shoal Sand	UAM	Upper Alameda Marine
YBM	Young Bay Mud	FF	Franciscan Formation
MPSA	Merritt-Posey-San Antonio Formations		
YBIS	YBI Sediments		

SUBSURFACE CROSS SECTION D-D'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11d1



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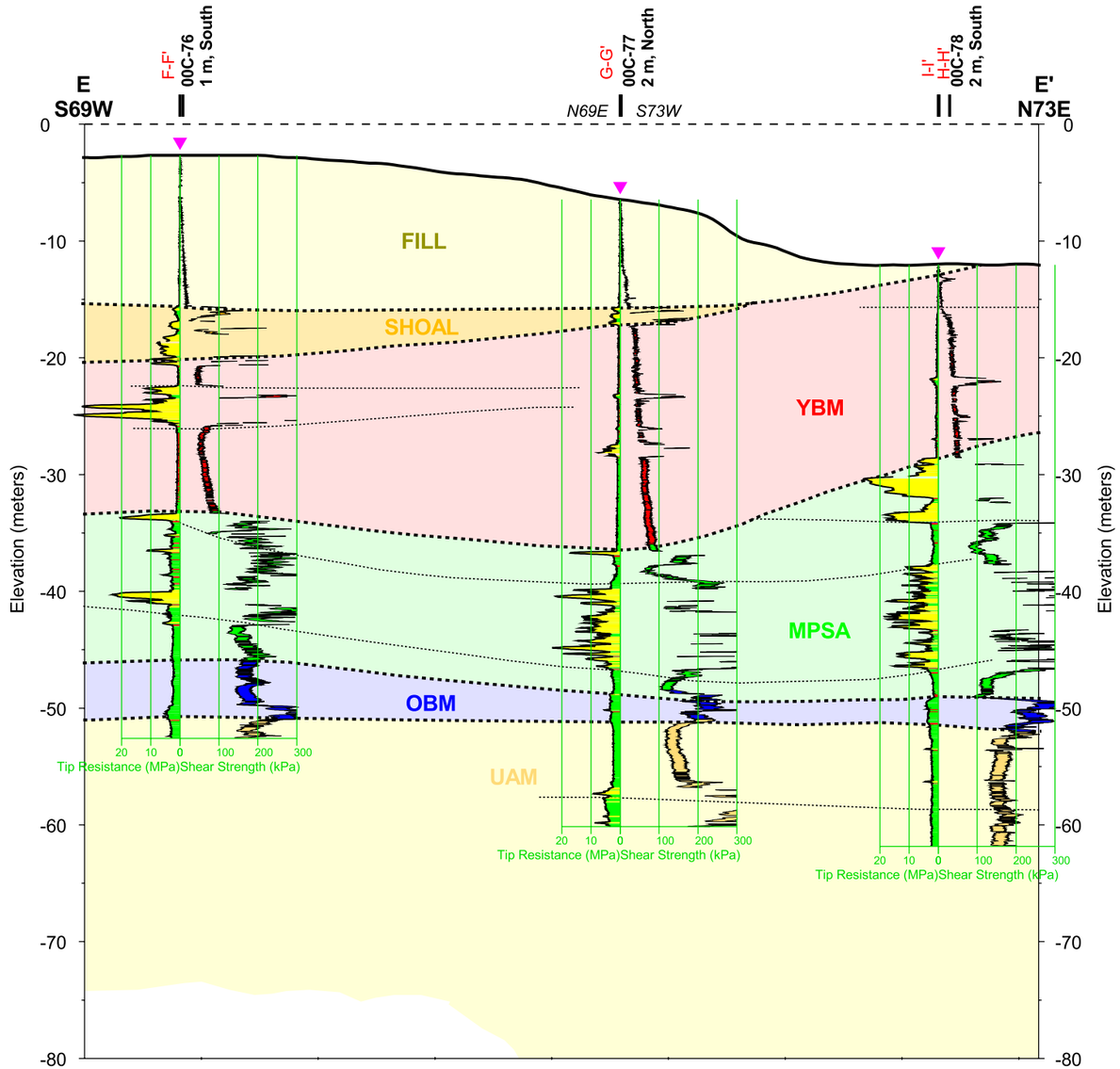
- ⊕ Torvane (TV)
- ◆ Miniature Vane (MV)
- ◇ Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

FILL	Fill	UAM	Upper Alameda Marine
SHOAL	Shoal Sand	UAMPC	Upper Alameda Marine Paleochannel Sand
YBM	Young Bay Mud	FF	Franciscan Formation
MPSA	Merritt-Posey-San Antonio Formations		
OBM	Old Bay Mud		

SUBSURFACE CROSS SECTION D'-D''
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11d2



5m
20m

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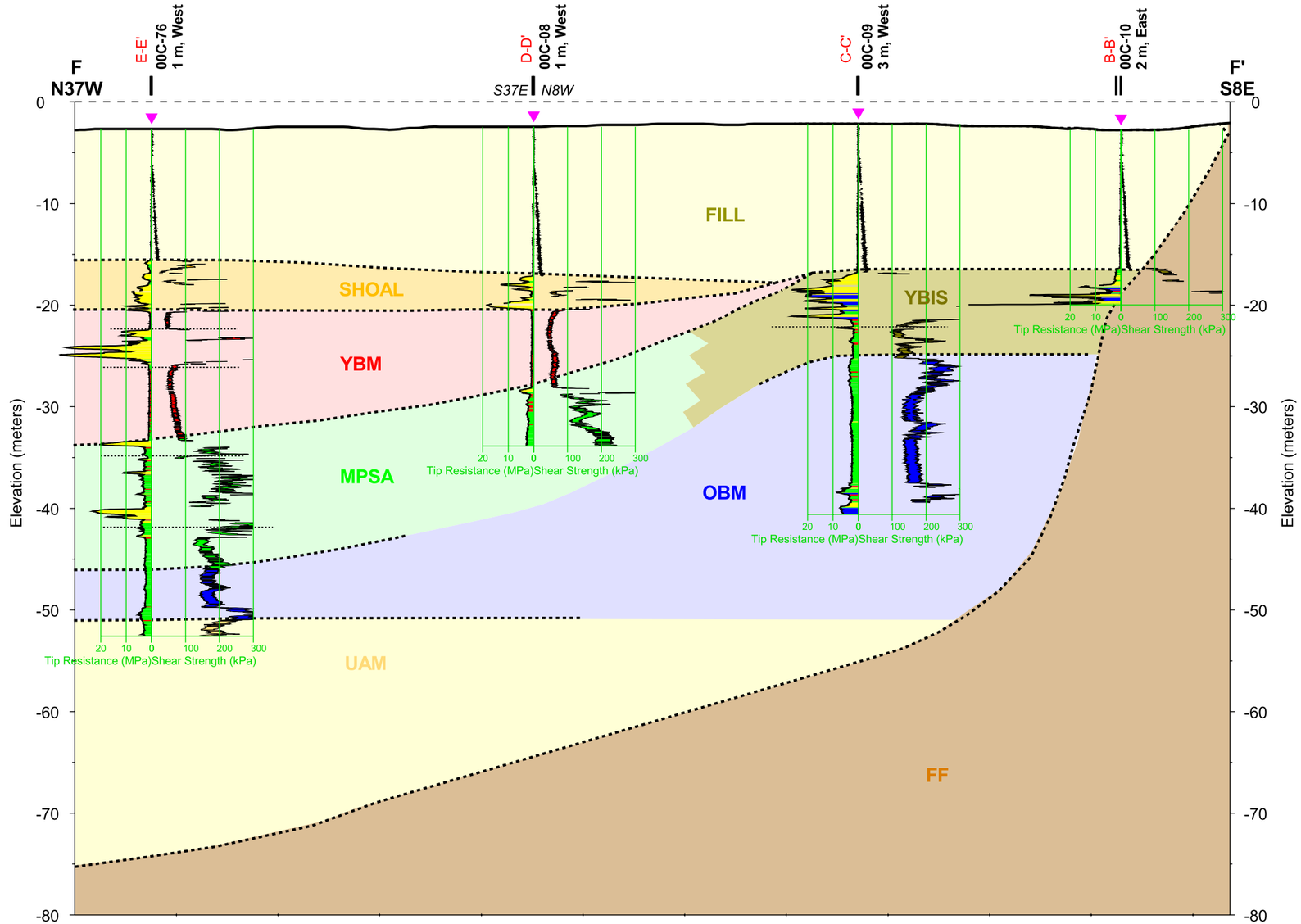
KEY TO GEOLOGIC UNITS

- FILL — Fill
- SHOAL — Shoal Sand
- YBM — Young Bay Mud
- MPSA — Merritt-Posey-San Antonio Formations
- OBM — Old Bay Mud
- UAM — Upper Alameda Marine

SUBSURFACE CROSS SECTION E-E'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11e



5m
20m

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- ⊗ Pocket Penetrometer (PP)
- Torvane (TV)
- ◆ Miniature Vane (MV)
- Remote Vane (RV)
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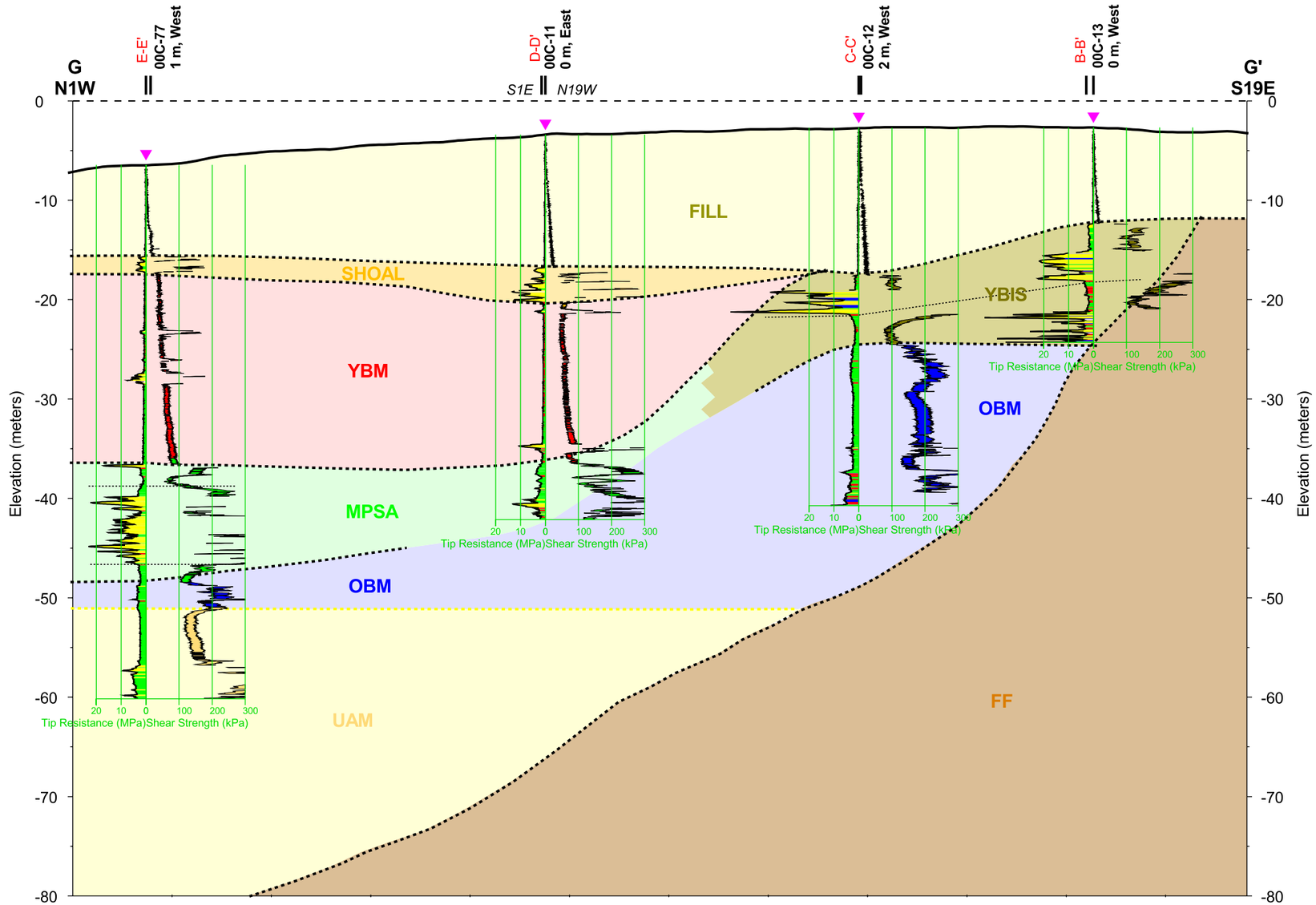
KEY TO GEOLOGIC UNITS

FILL	Fill	OBM	Old Bay Mud
SHOAL	Shoal Sand	UAM	Upper Alameda Marine
YBM	Young Bay Mud	FF	Franciscan Formation
MPSA	Merritt-Posey-San Antonio Formations		
YBIS	YBI Sediments		

SUBSURFACE CROSS SECTION F-F'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11f



5m
20m

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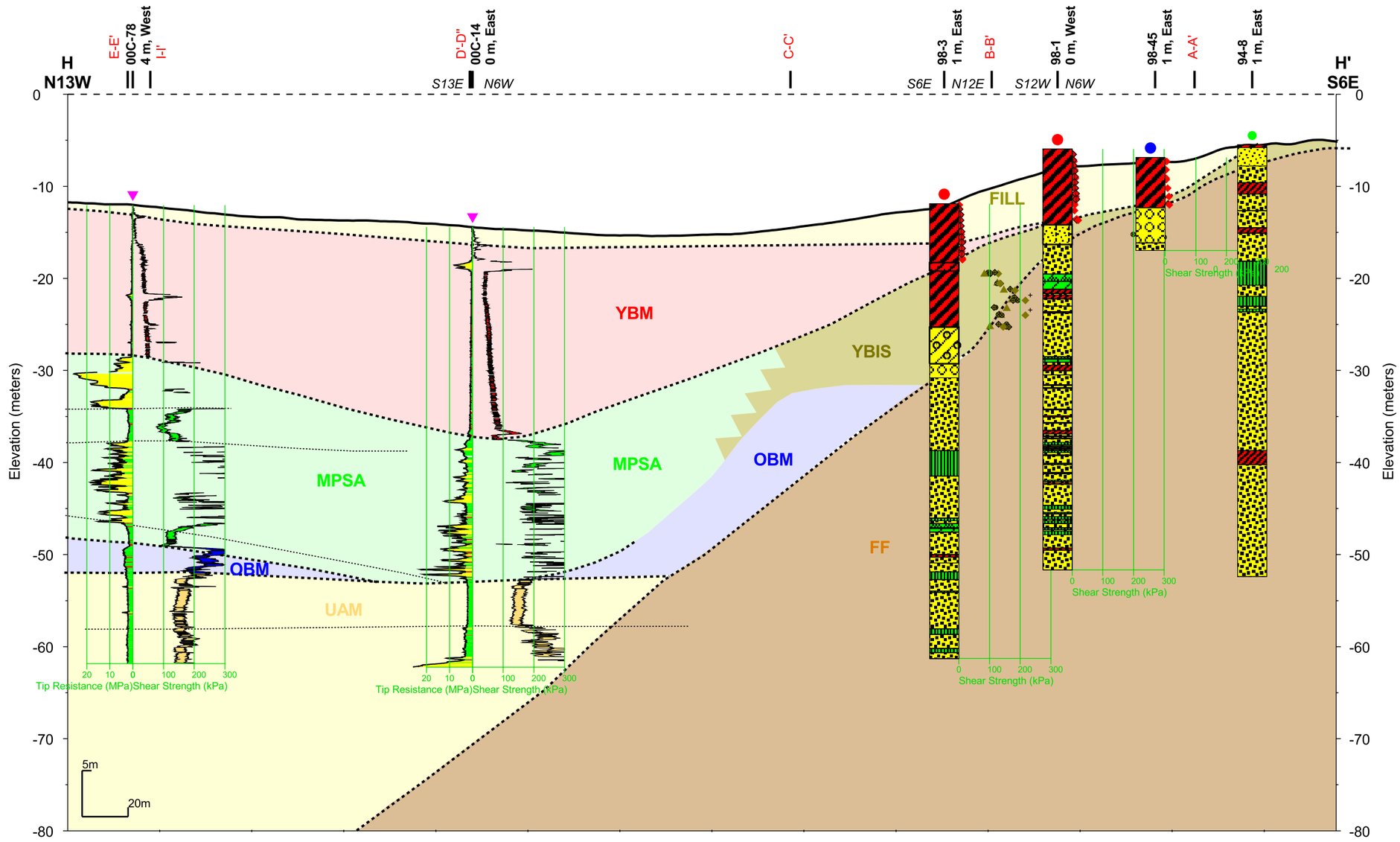
- Torvane (TV)
- ◆ Miniature Vane (MV)
- Remote Vane (RV)
- + Strength Exceeds Capacity of Measuring Device

KEY TO GEOLOGIC UNITS

FILL	Fill	OBM	Old Bay Mud
SHOAL	Shoal Sand	UAM	Upper Alameda Marine
YBM	Young Bay Mud	FF	Franciscan Formation
MPSA	Merritt-Posey-San Antonio Formations		
YBIS	YBI Sediments		

SUBSURFACE CROSS SECTION G-G'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11g



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- Torvane (TV)
- ◆ Miniature Vane (MV)
- Remote Vane (RV)
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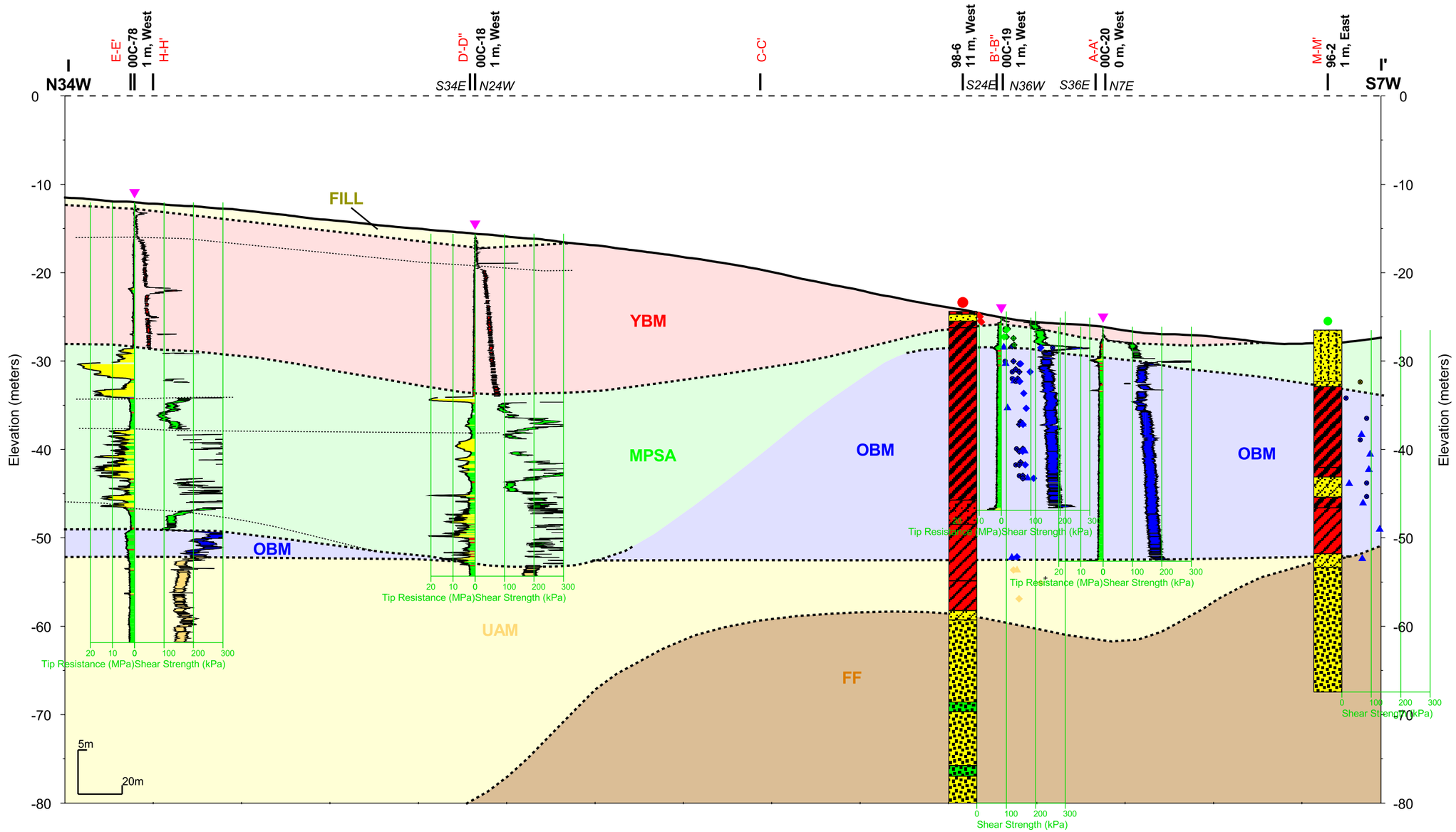
KEY TO GEOLOGIC UNITS

FILL	Fill	UAM	Upper Alameda Marine
YBM	Young Bay Mud	FF	Franciscan Formation
MPSA	Merritt-Posey-San Antonio Formations		
YBIS	YBI Sediments		
OBM	Old Bay Mud		

SUBSURFACE CROSS SECTION H-H'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11h



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- ◆ Miniature Vane (MV)
- Remote Vane (RV)
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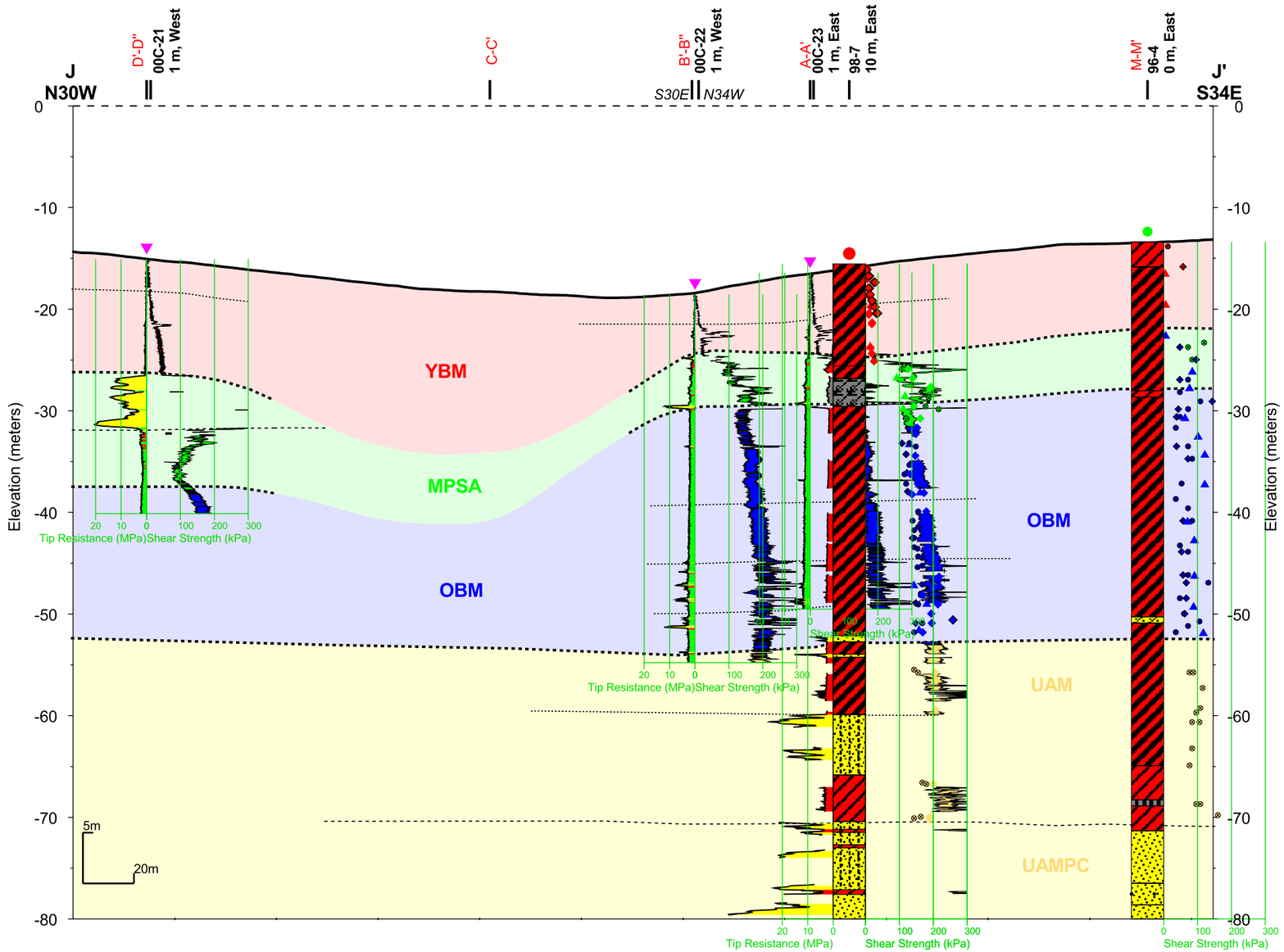
KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud
MPSA	Merritt-Posey-San Antonio Formations
OBM	Old Bay Mud
UAM	Upper Alameda Marine
FF	Franciscan Formation

SUBSURFACE CROSS SECTION I-I'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11i



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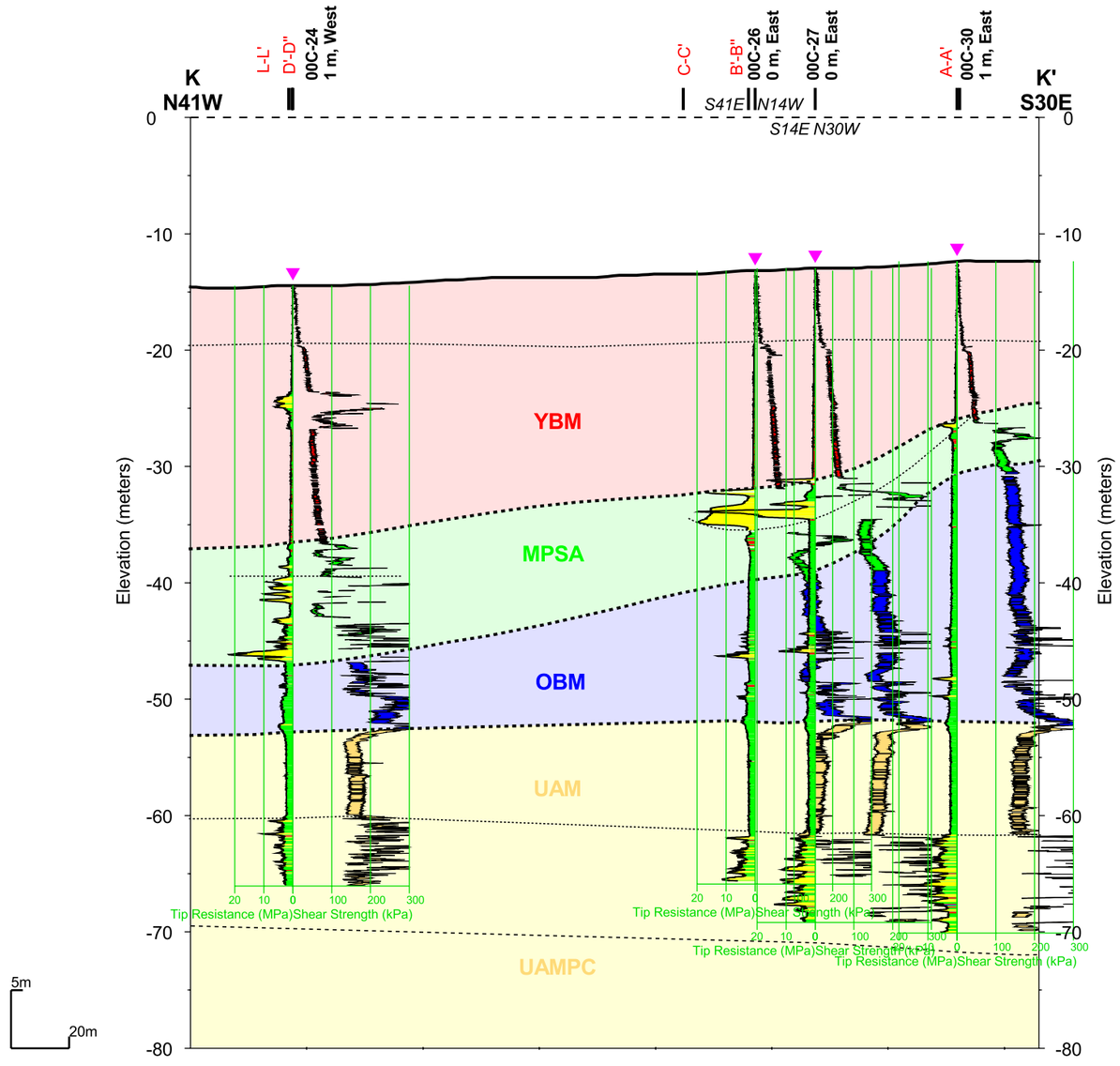
KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud
MPSA	Merritt-Posey-San Antonio Formations
OBM	Old Bay Mud
UAM	Upper Alameda Marine
UAMPC	Upper Alameda Marine Paleochannel Sand

SUBSURFACE CROSS SECTION J-J'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11j



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- Torvane (TV)
- ◆ Miniature Vane (MV)
- Remote Vane (RV)
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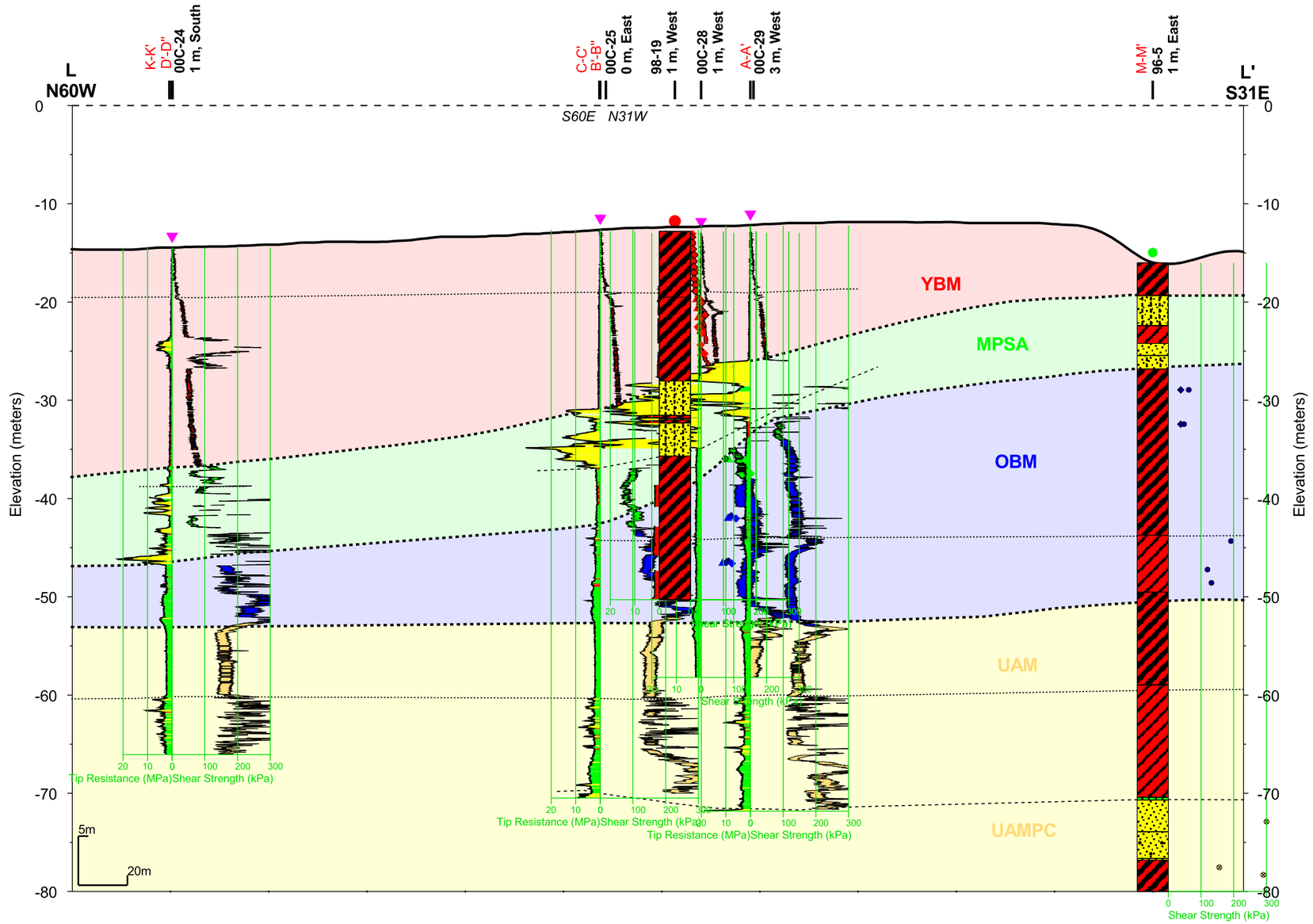
KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud
MPSA	Merritt-Posey-San Antonio Formations
OBM	Old Bay Mud
UAM	Upper Alameda Marine

SUBSURFACE CROSS SECTION K-K'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11k



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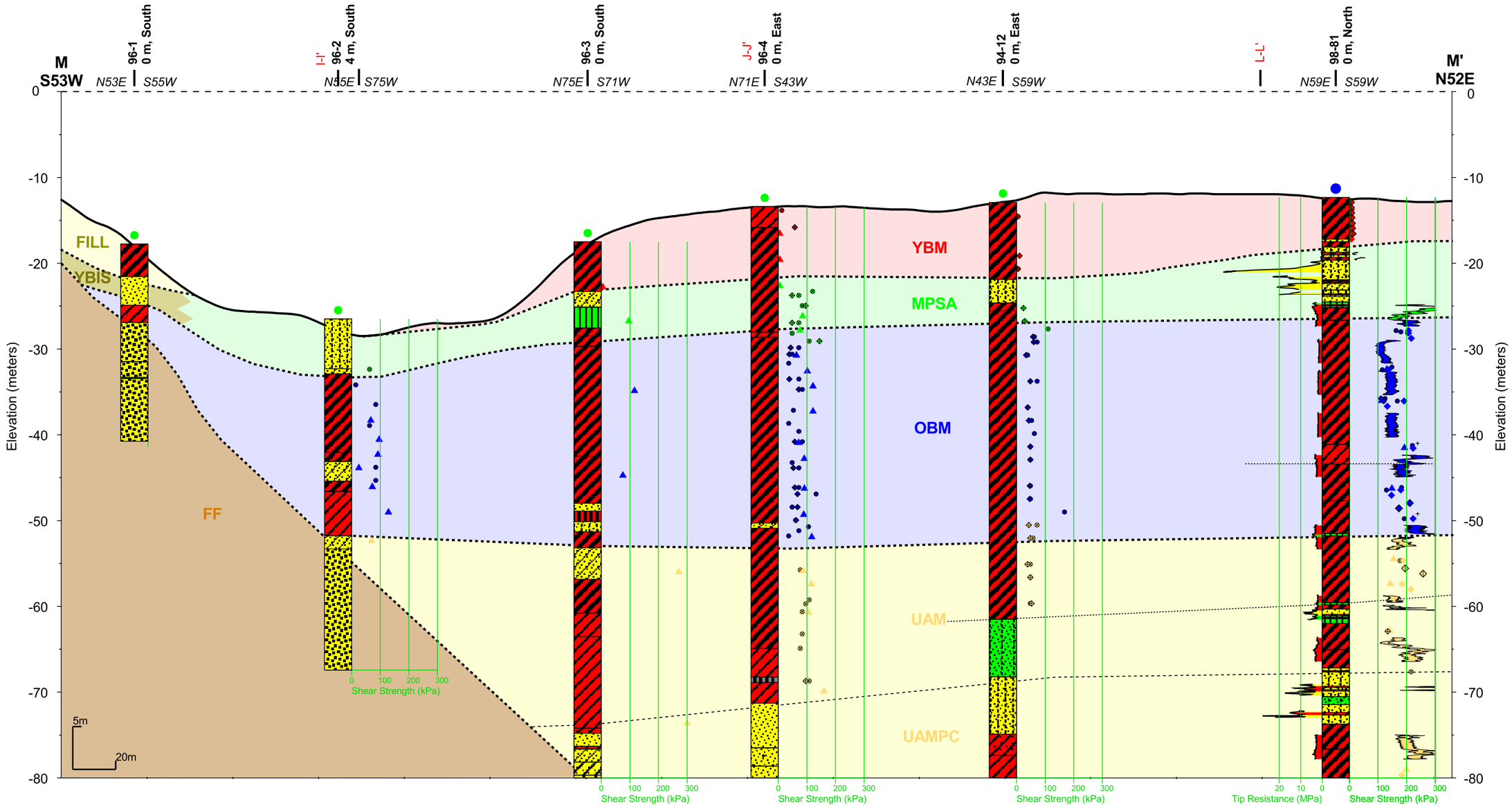
KEY TO GEOLOGIC UNITS

YBM	Young Bay Mud
MPSA	Merritt-Posey-San Antonio Formations
OBM	Old Bay Mud
UAM	Upper Alameda Marine
UAMPC	Upper Alameda Marine Paleochannel Sand

SUBSURFACE CROSS SECTION L-L'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11l



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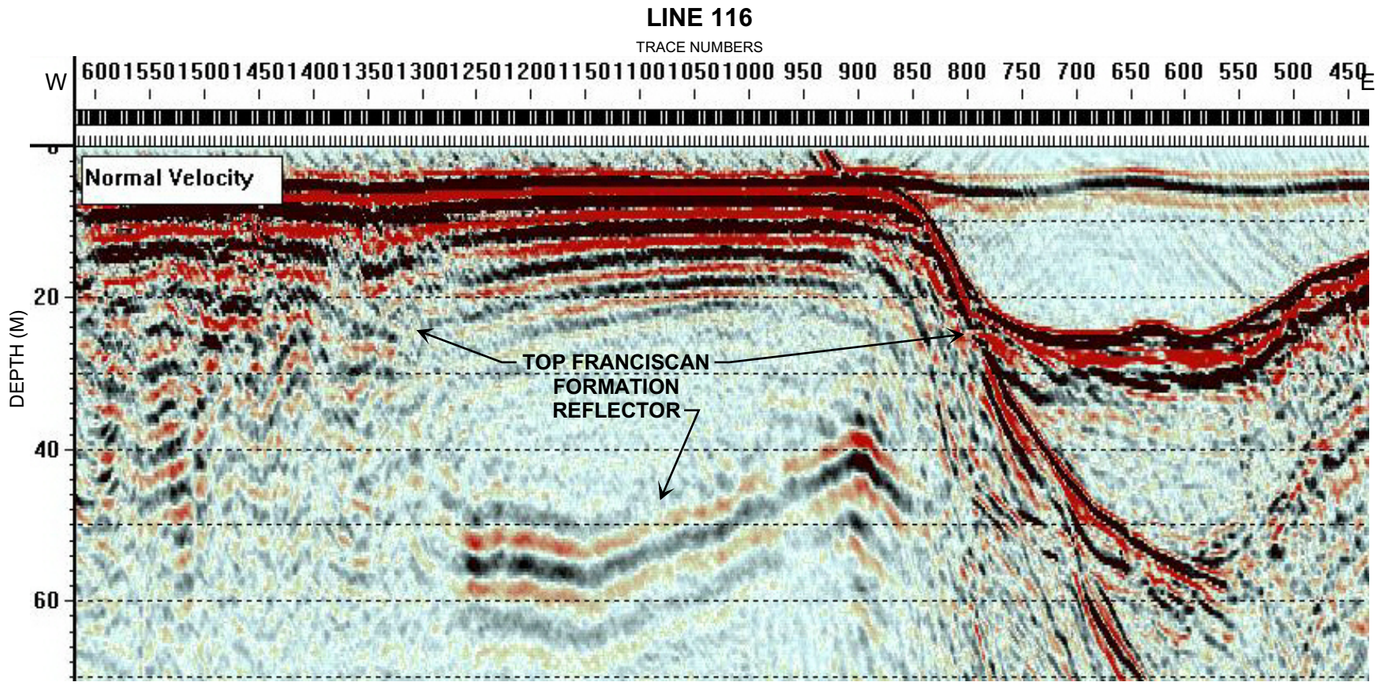
KEY TO GEOLOGIC UNITS

FILL	Fill	UAMPC	Upper Alameda Marine Paleochannel Sand
MPSA	Merritt-Posey-San Antonio Formations	FF	Franciscan Formation
YBIS	YBI Sediments		
OBM	Old Bay Mud		
UAM	Upper Alameda Marine		

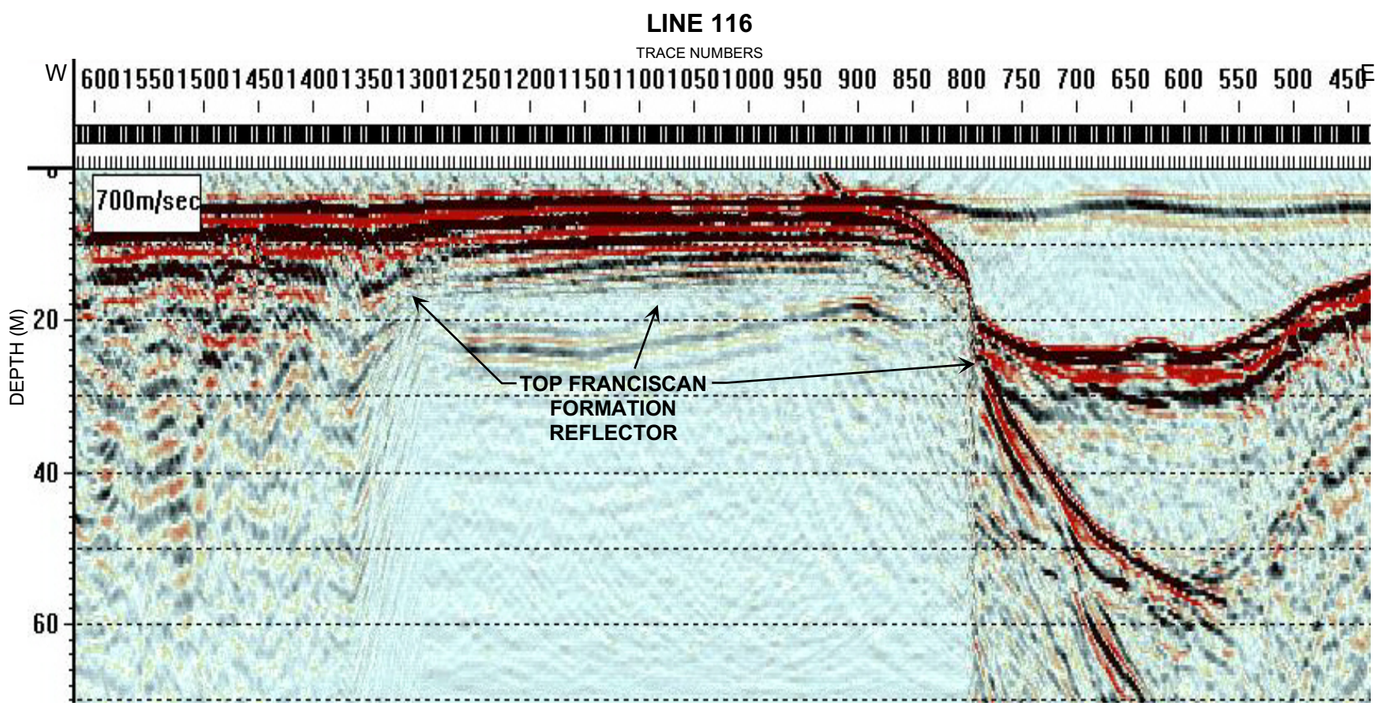
SUBSURFACE CROSS SECTION M-M'
With Undrained Shear Strength
SFOBB East Span Seismic Safety Project

PLATE 5.11m



Normal Velocity (1500 m/s) Example: Seismic data were processed using a stacking velocity of 1500 m/s for the entire water and sediment section. This is the shallow sediment velocity measured in borings along the N6 alignment. Depth conversion from reflection time to meters is also based on a velocity of 1500 m/s.

When the normal (1500 m/s) velocity is used for the area of fill, the top of Franciscan Formation bedrock reflector between fix points 825 and 1275 is between 40 and 50 meters and appears to be faulted on both sides.



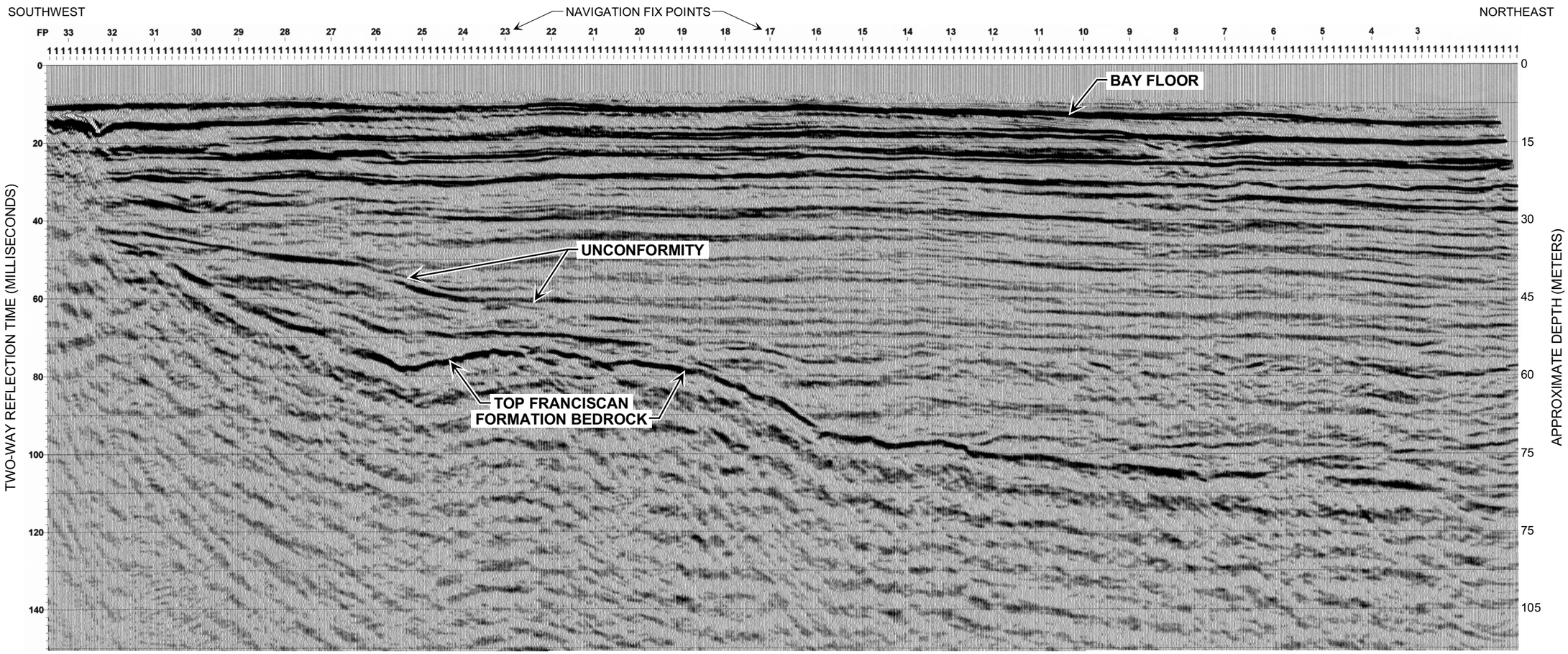
Slow Velocity (700 m/s) Example: Seismic data were processed using a stacking velocity of 700 m/s between fix points 825 and 1275, and 1500 m/s for the remainder of the record. The 700 m/s velocity was estimated to be the optimum stacking velocity in the area of fill (mud). The depth conversion used a velocity of 700 m/s for the 12 to 14 meters of fill between fix points 825 and 1275, and 1500 m/s for the remainder of the record.

When the slower (700 m/s) velocity is used for the area of fill, the top of Franciscan Formation bedrock reflector is between 18 and 24 meters and appears continuous with reflectors outside the fill area.

NOTE: Data are from 2000 Phase 3 2-D multichannel minisparker record of line 116. Refer to Map 4 for location of Line.

DEPTH CONVERSION EXAMPLES IN AREA OF FILL
SFOBB East Span Seismic Safety Project

98420054dep.dsf(1:2)



NOTES: 1. Approximate depth scale is based on a velocity of 1500 m/s for the velocity of sound in the sediment.

2. The saddle in the bedrock surface between fix points 25 and 26 may represent an old shear zone and/or erosional feature. The sediments immediately above the bedrock in the area between fix points 24 to 30 also may reflect uplift on the west, but there is no evidence of continuing deformation above the unconformity in the same area at 45 to 60 milliseconds (34 to 45 meters in depth).

3. See Maps 4 or 14 for Line location.

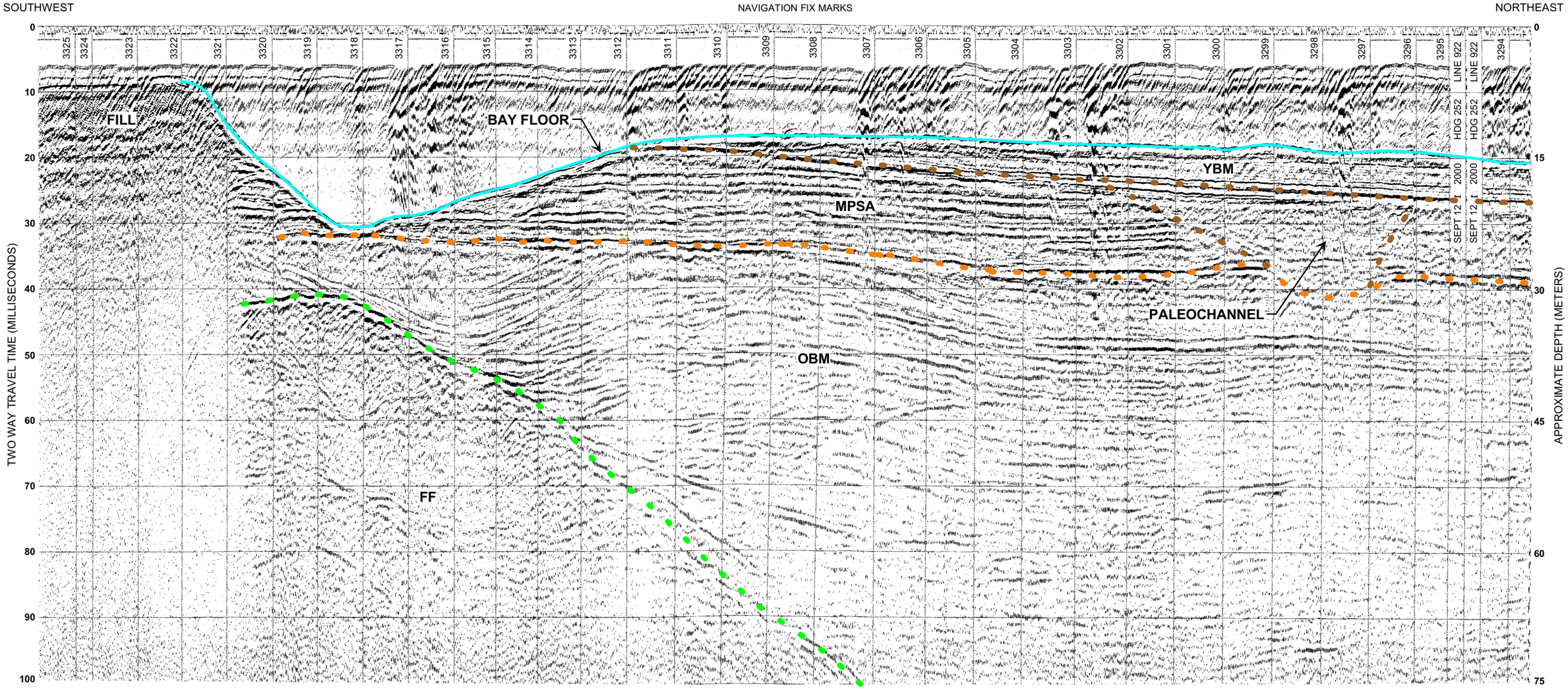
0 500 m
Horizontal Scale
Vertical Exaggeration ~11:1

MULTICHANNEL MINISPARKER
RECORD LINE 145
SOUTHEASTERN SIDE OF
YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.13a

98420054spar.dsf(1,2)

LINE 922



NOTES:

1) Loss of data at southwest end of record results from effects of fill (mud) offshore of Coast Guard Base.

2) See Map 4 (Plate 2.4) for location of line.

3) Refer to Plate 5.13c for multichannel data along nearby transect.

4) Vertical Exaggeration ≅ 4.5x.

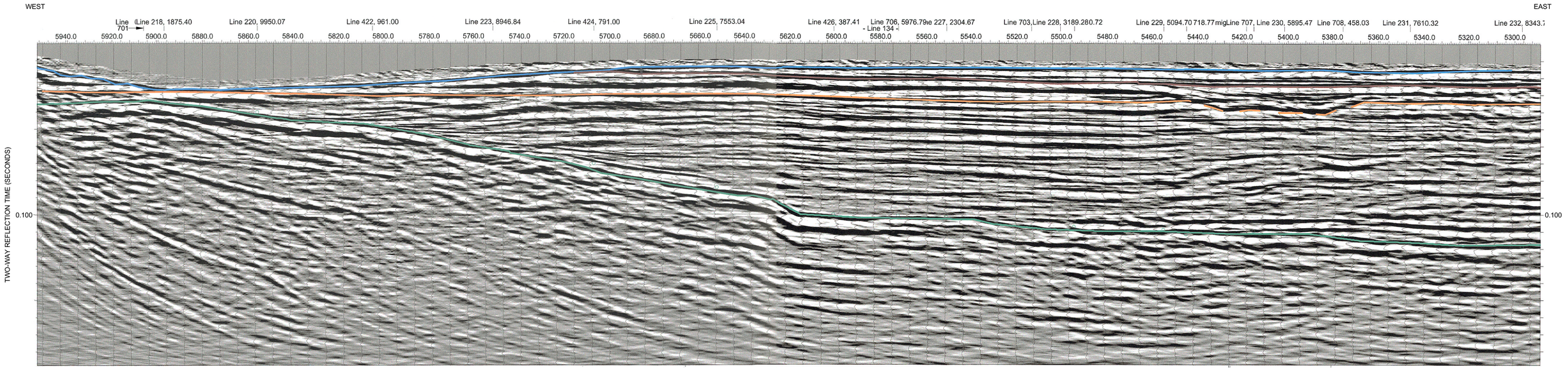
LEGEND

- Bay Floor
- Base of Young Bay Mud (YBM)
- Merritt-Posey-San Antonio Formations (MPSA)
- Top of Old Bay Mud (OBM)
- Top Franciscan Formation (FF)

BOOMER RECORD LINE 922
SFOBB East Span Seismic Safety Project

PLATE 5.13b

9842\0054boom.dsf(1:2)



LEGEND

- Bay Floor
- Base of Young Bay Mud
- Top of Old Bay Mud
- Top of Franciscan Formation Bedrock

NOTES:

1) Line 134 is approximately 20 meters north and parallel to Boomer Line 922 (Plate 5.13b).

2) There is no vertical exaggeration to this record indicating apparent folding of Old bay Mud horizons at the west end of Boomer Line 922 may be nested channels.

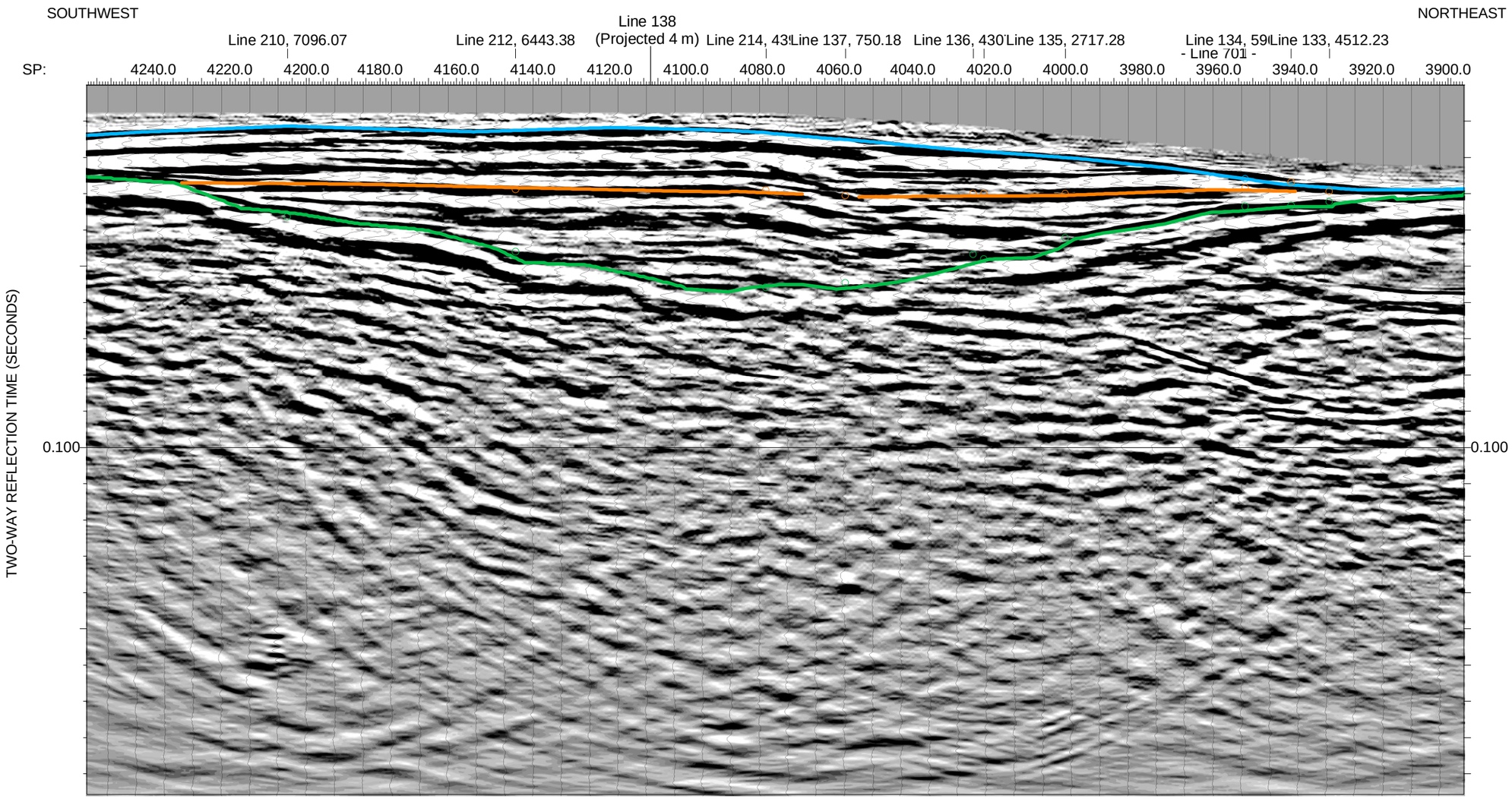
3) Step-like offset in bedrock reflector between intersection of Lines 225 and 426 with Line 134 is not reflected in overlying horizons. It may be a wave-cut terrace or a fault offset predating the sedimentation.

4) No evidence of faulting is interpreted in the sediment section.

MULTICHANNEL MINISPARKER
RECORD LINE 134
SOUTHEAST SIDE OF
YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.13c

98420054mul1.dsf(1.2)



LEGEND

- Bay Floor
- Top of Old Bay Mud
- Top of Franciscan Formation Bedrock

NOTES:

1) Line 701 is parallel to the southeast shoreline of Yerba Buena Island. Refer to Map 4 or 14 for Line location.

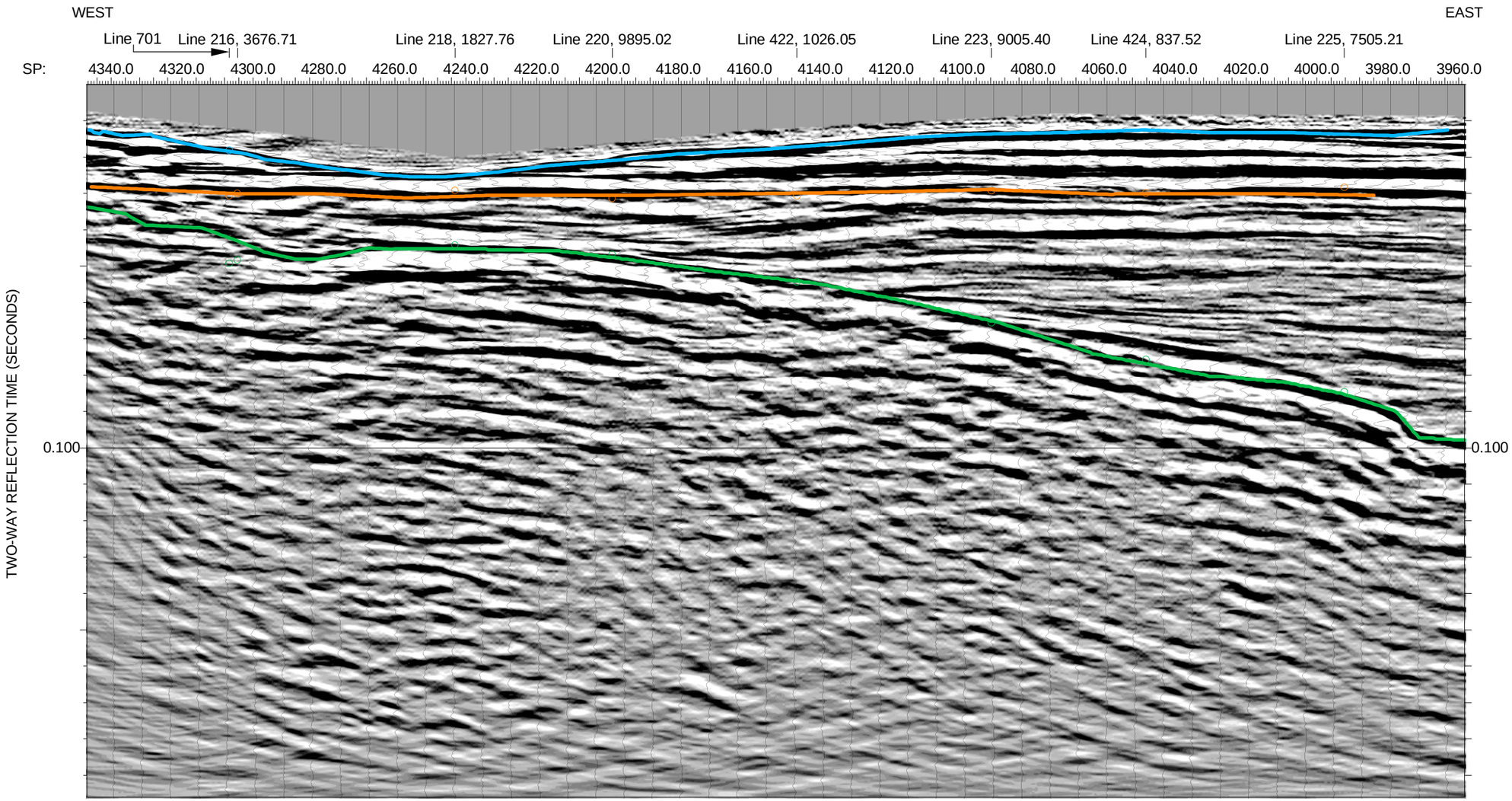
2) Sediment units lie in the "valley" between two bedrock ridges shown on Map 14 (Plate 5.14).

3) Possible break in Top of Old Bay Mud reflector appears to be related to interference and is not reflected in the bay floor or bedrock reflectors.

4) Refer to Plates 5.13c, 5.13e and 5.13f for other images of the same general area.

MULTICHANNEL MINISPARKER LINE 701
SOUTHEAST SIDE OF YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.13d



LEGEND

- Bay Floor
- Top of Old Bay Mud
- Top of Franciscan Formation Bedrock

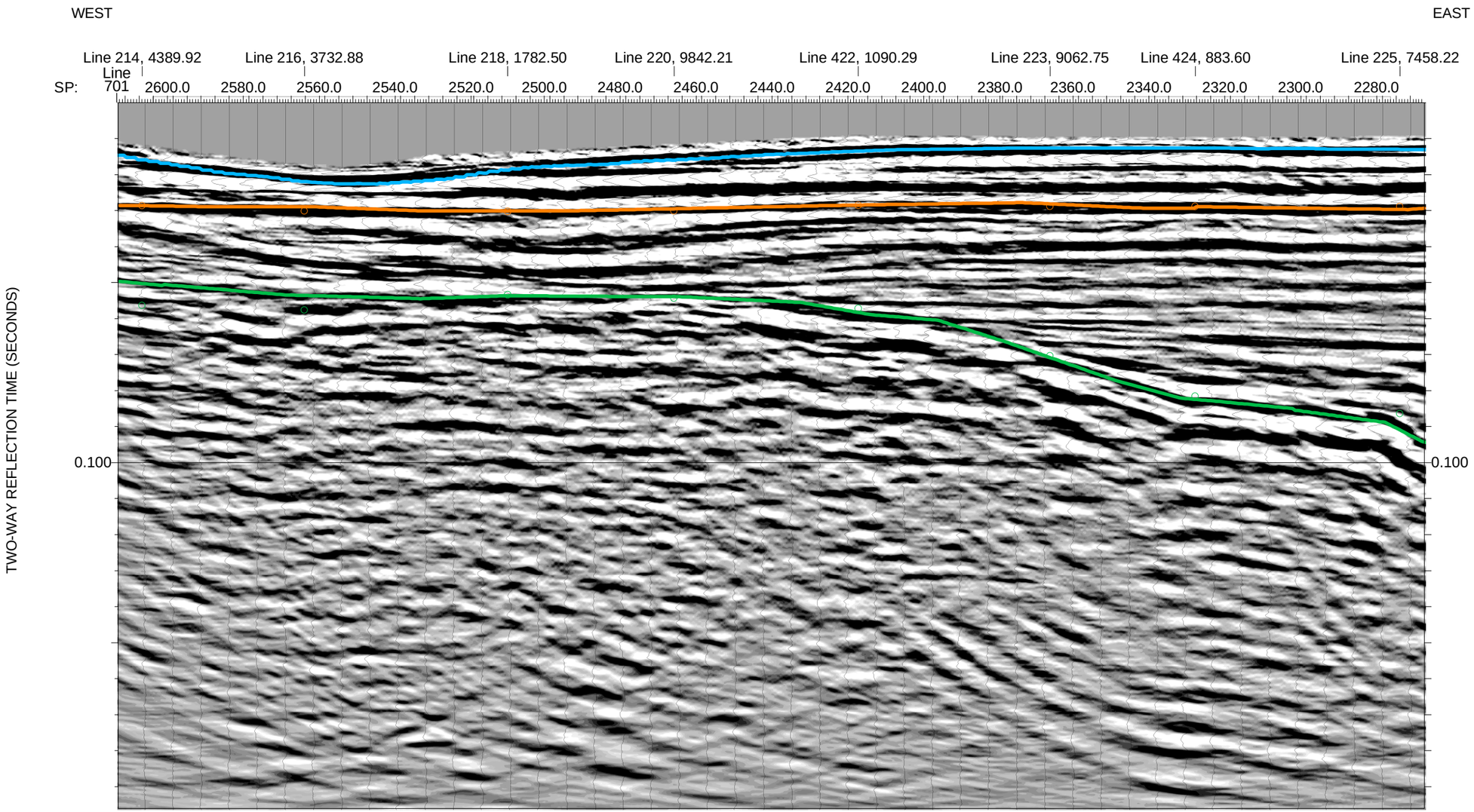
NOTES:

1) Line 136 crosses Line 701 north of the apparent discontinuity in the Top of Old Bay Mud horizon. See Map 4 or 14 for location of Line.

2) The top of bedrock is apparently channeled near the intersections with Lines 701 and 216, but there is no apparent offset of the Top of Old Bay Mud or overlying horizons.

MULTICHANNEL MINISPARKER LINE 136
SOUTHEAST SIDE OF YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.13e



LEGEND

- Bay Floor
- Top of Old Bay Mud
- Top of Franciscan Formation Bedrock

NOTES:

1) Line 138 ends about 4 meters east of Line 701. It runs south of Line 701. Any discontinuity in the sediment horizons on Line 701 caused by faulting trending from the Island should also disrupt the horizons on Line 138.

2) Neither the Top of Old Bay Mud nor the bedrock horizon on Line 138 appear offset by faulting.

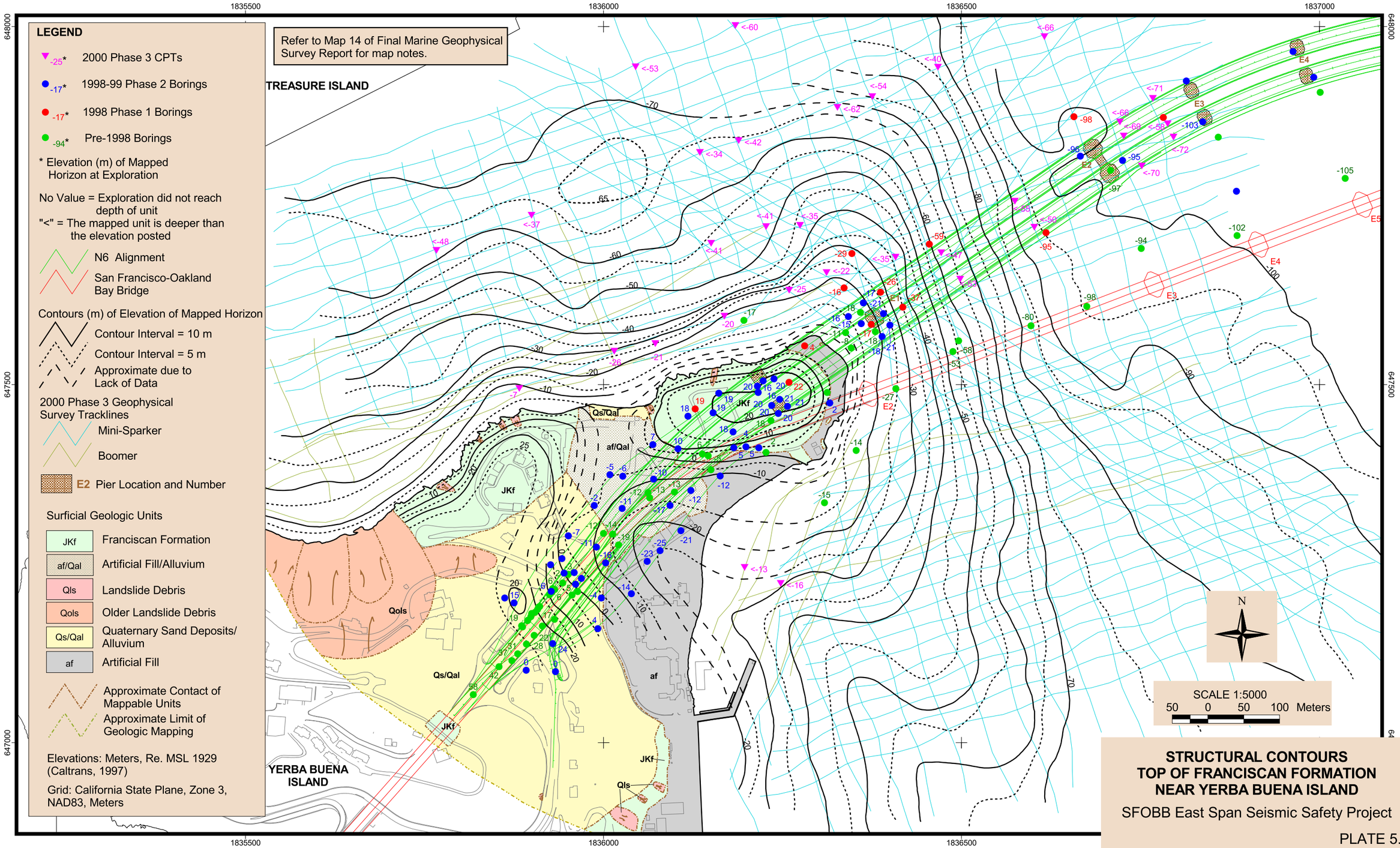
30 Refer to Map 4 for location of Line.

MULTICHANNEL MINISPARKER LINE 138
SOUTHEAST SIDE OF YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project

PLATE 5.13f

Earth Mechanics

FUGRO



STRUCTURAL CONTOURS
TOP OF FRANCISCAN FORMATION
NEAR YERBA BUENA ISLAND

SFOBB East Span Seismic Safety Project

PLATE 5.14

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SECTION 6.0
REFERENCES

6.0 REFERENCES

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APPENDIX A
1998 PHASE 1
2-D MARINE GEOPHYSICAL
SURVEY OPERATIONS

APPENDIX A
1998 PHASE 1 2-D MARINE GEOPHYSICAL SURVEY OPERATIONS

A.1 INTRODUCTION

A 2-D (two-dimensional) marine geophysical survey was conducted as the initial field exploration activity for the Fugro-Earth Mechanics investigations for the SFOBB East Span Seismic Safety Project. The objective of the survey was to map the bay floor and to image the subsurface geology beneath the proposed alignments for a new bridge. An additional objective of the 2-D survey was to identify parameters for the detailed 3-D seismic survey that would follow. The 2-D survey used an echo sounder and side scan sonar to map the bay floor and included both high-resolution subbottom profiler and sleeve-gun (air-gun) seismic reflection systems for imaging the subsurface geology.

The 2-D marine survey data were collected over a grid of survey lines. The shiptrack map showing the location of the survey lines is presented on Plate A.1. The seismic reflection data are referenced to the survey lines on which they were collected. Each line represents an individual seismic section that shows a series of reflections of seismic energy from the sub-surface sediment and rock horizons. Models of sub-surface geologic features are made by tracing the corresponding seismic reflectors along and between the individual seismic sections.

A.2 SUMMARY OF FIELD OPERATIONS

A.2.1 Systems and Schedule

Personnel and equipment departed Ventura on January 12 and arrived at the mobilization dock in Alameda on the same day. Mobilization of equipment aboard the 23-meter ocean research survey vessel, R/V *White Lightning*, was completed on the morning of January 15 and at-sea tests of the equipment were conducted that afternoon. Organizations and personnel who participated in the survey are listed in the "Personnel" section. Equipment mobilized for the 2-D survey consisted of a Differential Global Positioning System (DGPS) navigation system, an echo sounder, a side scan sonar and ISIS sonar data acquisition system, a CHIRP high-resolution subbottom profiler, and a digital multichannel sleeve-gun system for deep penetration reflection data acquisition. A self-recording tide gauge was installed on Yerba Buena Island to allow for reduction of echo sounder data to the project elevation datum, MSL 1929 (Caltrans, 1997). Further descriptions of the instrumentation are given in Section A.4.

Data acquisition began on January 16 and continued through January 22. A 1-day delay was experienced because of weather, and there were no delays due to equipment problems (Table A.1). Demobilization of the survey vessel was completed on January 23.

A.2.2 Survey Grid

Data were collected along a predetermined grid of lines. Seventy-three (73) primary lines (spaced at 50 meters) trended northwest-southeast and 17 tie lines (spaced at 100 meters) trended northeast-southwest (Plate A.1). The final positions of the survey lines are shown on the 2-D Survey Shiptrack Map at a scale of 1:5000 (Map 2) and on Plate A.1 at 1:10000. Sleeve-gun data were collected on a 100-meter grid consisting of alternate northwest-southeast lines (even-numbered lines) and on all tie lines. Sleeve-gun data also were collected on three diagonal lines across the east end of Yerba Buena Island. Data from all other systems were collected on all primary, tie, and diagonal lines. Several lines were rerun in order to improve the quality of data from one or more of the systems. These reruns are labeled with letters (e.g., 33A) following the line number on Map 2.

A.3 PERSONNEL

The following organizations and personnel participated in performing the 2-D Marine Geophysical Survey:

Organization	Individual	Title
Fugro West, Inc.	Jan Rietman Muriel Norton	Principal Geophysicist Senior Geophysicist
Fugro Survey Division	Jeff Carothers Eddie Stutts Joe Mucha Jeff Babbitt	Survey Project Manager Hydrographic Surveyor, Party Chief Hydrographic Surveyor Geophysical Technician
Subsea Systems, Inc.	Mike Barth	Project Manager Geophysical Acquisition
Datasonics	Carl Schubert	CHIRP System Operator
Sea Visual, Inc.	Terry Sullivan	ISIS Side Scan Sonar Operator
Westcoast Seaworks (R/V *White Lightning*)	Paula Brown Dave Stephens Steve Hart	Captain Captain Deckhand

A.4 INSTRUMENTATION

A brief description of each of the instrumentation systems is provided in the following paragraphs. The intent is to provide sufficient information to allow independent evaluation of the records from the various systems and to explain the real-time coordination between the various recordings. The layout of the equipment aboard the R/V *White Lightning* is shown in Plate A.2. Photographs of the operation are on Plates A.3a and A.3b.

A.4.1 Navigation and Positioning Systems

A wide-area DGPS was used to position the survey vessel. DGPS is a satellite-based positioning system operated by the U.S. Department of Defense. A "wide area" application operates with correction values applied to a stand-alone DGPS receiver from base stations located over large distances. DGPS corrections were supplied to the system using the STARFIX II network. This differential network, a nationwide system operated by John E. Chance and Associates (a Fugro subsidiary), broadcasts differential corrections via a communications satellite downlink to field receivers.

The STARFIX II system receives the range corrections from the onshore reference station network. This system is a nationwide, full-time DGPS broadcast system delivering corrections from an array of DGPS base stations positioned coast to coast. Ten base stations provide industry-standard formatted corrections to a Network Control Center (NCC) near Houston, Texas, where the corrections are decoded, checked, and repackaged in a highly efficient format for broadcast. The data modulate a spread spectrum sequence, which is then converted for transmission to a C-band communications satellite.

On the survey vessel, an antenna is coupled to a low noise amplifier, a downconverter, and the resulting signal applied to a STARFIX II Receiver/Processor. The receiver demodulates the data stream from the communications satellite to provide the user with a data set stream of DGPS correction messages.

The principal feature of the STARFIX II system is the way in which the signals are used. STARFIX II utilizes the broadcast data stream to compute an "optimized" RTCM SC-104 message for the DGPS receiver onboard, as though a base station were immediately adjacent to the user's receiver, which is commonly referred to as a "Virtual Base Station" system.

Computation of optimized corrections uses the broadcast ionosphere model to modify base station pseudo-range corrections, and to adjust the locally received pseudo-ranges for ionospheric delay. The DGPS almanac received over the STARFIX II system is used with the approximate user's position to compute satellite elevation and azimuth angles, which are required for ionospheric and tropospheric model calculations. Corrections from the base stations are weighted by their distance from the user's location and their elevation angles, and are then combined to produce a set of optimized corrections for the user position.

The "Virtual Base Station" approach provides a convenient mechanism with which to provide differential corrections to users with a variety of receivers. The STARFIX II system will provide position accuracy limited only by the user's DGPS receiver accuracy.

The vessel position information is linked to an onboard, Pentium-based personal computer running the Hypack navigational software. Hypack is an advanced PC-based Windows navigation system designed for both surface and subsurface vehicle positioning.

A helmsman's display continually updates the true vessel position, the tracklines, distances off line, and distances along line. Other common input/output (I/O) interfaces include connections to gyros, echo sounders, side scan sonar, fluxgate compasses, acoustic tracking systems, or virtually any receiver/sensor capable of a standard serial interface.

For this survey, the Hypack navigation system was interfaced to an onboard DGPS receiver consisting of a Trimble 132 12-channel receiver. The update rate is 1 second and the system has an accuracy of 1 meter root mean square (RMS) with DGPS corrections. The Trimble DGPS received ranging information from the same satellites as the reference stations. The STARFIX II system corrections are applied in the Trimble receiver to the satellite data to produce a corrected accurate position of the vessel in real-time. This differentially corrected position is then passed to the navigation computer.

Serial links between the geophysical sensors and the Hypack system result in an exchange of information between the systems. For example, the echo sounder transmits digital depth soundings to the navigation system for logging of depth soundings while the navigation system transmits a closure at each fix position for marking the paper records.

A.4.2 Bathymetry System

An ODOM Hydrographic Systems, Inc., Echotrac DF-3200 survey grade echo sounder was used to acquire bathymetric data during survey operations. The DF-3200 echo sounder collects analog paper records as well as digitized depth information for output to a data logger or navigational computer. Digital depth data were logged direct to the navigation computer along with date, time, and position for post-processing and mapping. The system includes a recording unit with a built-in digitizer and transceiver, and a side-mounted transducer. The unit utilizes a combination of dynamic gating and velocity fit to track the true bottom through advanced microprocessor technology.

The acoustic pulse is generated with a Model OHS 200 transducer that operates with a beam width of 2.75 degrees at 200 kilohertz (kHz). The shipboard transceiver automatically adjusts power output in proportion to the return signal, thereby yielding a clear, unambiguous record in shallow as well as deep water. The self-adjusting power varies from 1 to 225 watts at 200 kHz. Return signals are optimized by Time Varied Gain and Automatic Gain Control.

Bathymetric data were collected during all survey operations as routine procedure. At the start of each survey day, the speed of sound in seawater was determined with a sound velocimeter and verified with standard "bar-check" methods. This velocity was entered together with the transducer draft to yield a depth value in meters that was displayed on the echo sounder and logged to the navigation computer.

High density, bathymetric soundings were recorded at approximately 0.30 second along each hydrographic survey line. At average ship speeds of 3.0 to 3.5 knots, this resulted in depth

soundings at approximately 0.5-meter intervals. This closely spaced bathymetric coverage between fix positions produced a very accurate profile of the seafloor bathymetry. Tidal corrections were applied in post-processing after the tide gauge data were downloaded and correlated with the survey data.

A.4.3 Self-Recording Tide Gauge

A Coastal Mini-Tide self-recording tide gauge was installed prior to commencing survey operations. The gauge was installed on the U.S. Coast Guard dock on Yerba Buena Island. The tide gauge was secured to existing pilings and the elevation for the sensor established using conventional vertical survey techniques to third order accuracy or better. The leveling was conducted utilizing a NIKON AS automatic level. The following U.S. Army Corps of Engineers (USACOE) vertical control point was utilized to establish the tide gauge elevation. All elevations on the project are referenced to MSL 1929 datum

- USACOE Benchmark "Buoy": Elevation = +2.737 meters
- Tide Gauge Sensor: Elevation = -1.454 meters

MSL 1929 datum for the project site is 0.942 meter above mean lower low water (MLLW) as stated in a Caltrans memorandum dated December 17, 1997 (Caltrans, 1997).

A.4.4 Side Scan Sonar System

An EG&G Model 260 digital recording dual frequency (100/500 kHz) side scan sonar system was used to acquire seabed imagery together with a Triton Technology ISIS processing system. The sonar imagery was acquired along all survey lines.

The EG&G sonar system consists of a transceiver/graphic recorder unit, Kevlar tow cable, and towfish. The towfish transmits and receives acoustic energy via two transducers located along each side of the towfish body. The Model 260 system emits a 500 kHz acoustic pulse directed towards the seafloor. The acoustic energy reflected back to the transducers is converted into electronic signals within the towfish and sent back to the recorder via the multi-conductor tow cable. The Model 260 recorder processes, amplifies, and displays the returned signals as a trace on mylar-based thermal paper. As each successive signal is displayed on the recorder, a graphic representation of the seafloor is constructed, thus producing a record appearing similar to a continuous aerial photograph.

A Triton Technology ISIS sonar data acquisition and image processing station was used in conjunction with the EG&G sonar to record raw sonar data, facilitate data processing, and expedite the sonar mosaic construction. The ISIS acquisition system recorded sonar data to an optical disk along with navigational information. These data were displayed shipboard with slant range and speed correction applied.

A.4.5 Sonar Data Acquisition System

The Triton Technology ISIS sonar data acquisition and image processing system was integrated with the EG&G side scan sonar and navigation systems to display and record the sonar images. The sonar data are processed and displayed on a high-resolution color monitor and recorded to an optical disk. First the system stored the data to disk and then sampled and reduced the processed data to 8 bits for display on a 1280x1024-pixel monitor. The workstation records the full dynamic range of the sonar data on a high-density optical disk via a small computer standard interface (SCSI). The system's image processing capability greatly simplifies and speeds up the sonar record interpretation using sophisticated data processing and display techniques. It is also integrated with the navigation system to allow the position of the towfish and the position of individual seafloor targets to be determined in real time.

The system features an intuitive Windows user interface combined with compensations for many of the sources of distortion in side scan sonar imagery. Target measurement and analysis functions allow the operator to extract (at any time during playback or recording) a full resolution image of an individual seafloor target or feature.

Standard processing and display features include: automatic and manual bottom tracking, contrast stretching, slant range correction, range gate delay and duration specification, scale line overlay, and zoom functions. The system provides compensation of side scan sonar distortions including speed variations, slant range, altitude, heading, beam pattern, and grazing angle. The system operates in both RECORD mode for data acquisition and real-time image processing, and PLAYBACK mode for image processing and data analysis.

The system was integrated with the navigation computer to provide real-time towfish positions, speed, and navigation fix marks, which also are recorded at the appropriate time on the recorder for subsequent post-processing of the sonar data.

A.4.6 CHIRP Subbottom Profiler System

A Datasonics Model CAP 6600 CHIRP-II subbottom profiler was utilized to collect shallow seismic reflection data for the project (Plate A.3a). The Datasonics subbottom profiler is a wide band, swept FM pulse subbottom system that is phase and amplitude compensated. It generates cross sectional images of the seabed and collects digital normal incidence reflection data over many frequency ranges. The system transmits an FM pulse that is linearly swept over a spectrum frequency range (also called a "chirp pulse"), such as 2 to 16 kHz over 20 milliseconds.

The acoustic return received at the hydrophone is match filtered with the outgoing FM pulse, thereby generating a high-resolution image of the subbottom stratigraphy. This phase and amplitude compensation corrects for variations in the frequency response of the sonar system. The bottom/subbottom signals are received using a small line array of hydrophones. Matched

filtering, combined with correlation signal processing, produces enhanced resolution and numeric data representative of the bottom and subbottom materials. The system is comprised of a shipboard transceiver, signal processor and monitor, and a towed vehicle.

The system was integrated with the navigation computer to provide real-time towfish positions, speed, and event/fix marks, which are also recorded at the appropriate time on the recorder for subsequent post-processing of the seismic data.

A.4.7 Sleeve-Gun System

The major components of the sleeve-gun system are a sleeve-gun source, a multichannel streamer (cable), an analog recording system, and a digital recording system. They are briefly explained below and further specifications are listed in Table A.2. The towing arrangement is shown on Plate A.2. Operational photographs are shown on Plates A.3a and A.3b.

Seismic Source - Halliburton/GSI Sleeve Gun. A single, 10-cubic-inch Halliburton Sleeve Gun was used for the 2-D survey. Because of air supply limitations, the gun was plugged to 5 cubic inches. This allowed the gun to be fired at a 2-second repetition rate. The gun was rigged with a buoy to maintain a tow depth of approximately 1 meter. It was towed from the starboard side of the stern at a distance of 19.95 meters from the navigation antenna. The gun was fired by a Syntron GCS-90 gun controller. The GCS-90 also sensed the actual fire time using a timing coil built directly into the gun. This allowed the timing accuracy to be controlled within ±300 microseconds. Bandwidth of the gun source was approximately 40 to 700 Hz.

Multichannel Streamer Array - Teledyne B-1. Seismic data were received using a Teledyne 12-channel hydrophone array. Group length of each channel was 3.125 meters for a total active length of 37.5 meters. Each channel contained 10 hydrophones equally spaced within the group. The array was towed from the port side of the stern at a distance of 26.5 meters from the navigation antenna to the center of the near trace. Tow depth was approximately 1 to 2 meters.

Analog Recording System - EPC Model 1086 Thermal Recording System. The near trace output from the hydrophone array was derived through the input amplifier of the OYO DAS-1. This signal was processed using a TSS 301 time-varied gain amplifier and a Krohnhite 3550 filter set to a bandwidth of 160 to 400 Hz. The analog data were recorded on an EPC 1086 graphic recorder at a scale of 250 milliseconds. Navigation fixes were applied to the recorder at an interval of 50 meters.

Digital Recording System - OYO DAS-1. The OYO DAS-1 recording system was configured for 12 data channels and one auxiliary channel. Data were recorded at a sample rate of 0.25 millisecond (250 microseconds) and a record length of 0.75 second (750 milliseconds). An internal filter was set for a low-cut frequency of 40 Hz and a high-cut frequency of 2,000 Hz. In order to verify accurate timing information, the auxiliary channel recorded the time break

from the Syntron gun controller. The seismic data were recorded on Digital Linear Tape (DLT) in SEG D 8048 format.

A.5 QA/QC PROGRAM

Prior to beginning field operations for the 2-D survey, a QA/QC program was developed and provided to Caltrans. The intent of the program was to provide a framework for the execution of the survey and a method for field evaluation of the acceptability of the acquired data within the limits imposed by the instrumentation systems and the site conditions. The methods and decisions were focused on providing information required to meet the interpretation objectives of the survey relative to definition of the site geology. The QA/QC program was overseen by a Registered Geophysicist who was aboard the survey vessel. A copy of the program was distributed to all instrument operators and explained to them and the ship's crew by the Party Chief prior to the data acquisition phase.

The key elements of the QA/QC program are: 1) onboard review of all records by the geophysicist, 2) descriptions of the required field logs to be maintained by each operator, 3) set operational and data quality criteria for termination of a survey line or rerunning a portion of the line with one or more systems, and 4) detailed calibration procedures for the various systems.

A.6 FIELD DATA TYPES AND FORMATS

Data from all systems except the navigation system were recorded in both analog and digital formats. The navigation data were recorded only digitally, but are plotted on Map 2. The field data and associated operator logs are in the following formats:

a. Navigation
   - Reproducible Shiptrack and Cultural Features map at scale of 1:2000 on two sheets.
   - Shiptrack map at scale of 1:5000 (Map 2)
   - Tape with X,Y,Z (tide corrected Z) data every second

b. Tide Gauge
   - Tides recorded every 10 minutes relative to MLLW

c. Echo Sounder
   - Original analog record (not tide corrected)
   - Navigation tape with corrected depths

d. Side Scan Sonar
   - Original analog records
   - Optical tapes from the ISIS system with slant range and depth corrections applied

e. CHIRP System
   - Original analog records
   - Optical tapes for playback of the field records

f. Sleeve-Gun System
   - Single-channel analog monitor records from all lines
   - Shot monitor records used in QA at an approximate 100-shot interval
   - Copies of the digital field tapes, 8 millimeter, Society of Exploration Geophysicists (SEG) D format

A.7 NAVIGATION DATA REDUCTION AND SHIPTRACK MAP PRODUCTION

Navigation data recorded during the project were edited for spurious positions and plotted as navigation post-plot (shiptrack) maps. Individual navigation fix marks are plotted and labeled on the Shiptrack Map and Cultural Features (Map 2). This map served as the base map for the geophysical data interpretation. Final navigation data are provided on Map 2 at a scale of 1:5000 in this report. Reproducible mylar copies of the 1:2000-scale sheets were also provided to Caltrans.

The following horizontal and vertical datums and map parameters are used for all maps in this report. Units used throughout the report and maps are meters.

Parameters	Horizontal Data	Vertical Data
Ellipsoid	Geodetic Reference System of 1980 (GRS80)	--
Datum	North American Datum 1983 (NAD83)	MSL 1929 (Caltrans, 1997); see below
Projection	Lambert California Zone	--
Latitude of Origin	36°30′00.00″ N	--
Longitude of Origin	120°30′00.00″ W	--

Note: MSL = mean sea level

A.8 REFERENCES

California Department of Transportation (Caltrans) (1997), Internal Caltrans Memorandum dated December 17 from SFOBB Investigations Section to Office of Structure Design, Subject: Addendum - Vertical Datum, Caltrans File Nos. 04-SF-80, 04-0434A1, C1, E1, F1, G1, Project Nos. 3, 4, 5, 6, 8, 21, Bridge No. 33-0025.

Day Number	Date	Day of Week	Phase	Activity
1	12-Jan-98	Monday	2-D	Travel/Mobilization
2	13-Jan-98	Tuesday	2-D	Mobilization
3	14-Jan-98	Wednesday	2-D	Mobilization
4	15-Jan-98	Thursday	2-D	Mobilization/Testing
5	16-Jan-98	Friday	2-D	Acquiring Data
6	17-Jan-98	Saturday	2-D	Acquiring Data
7	18-Jan-98	Sunday	2-D	Waiting on Weather
8	19-Jan-98	Monday	2-D	Acquiring Data
9	20-Jan-98	Tuesday	2-D	Acquiring Data
10	21-Jan-98	Wednesday	2-D	Acquiring Data
11	22-Jan-98	Thursday	2-D	Acquiring Data - Complete 2-D
12	23-Jan-98	Friday	2-D	Demobilization 2-D

Operations Summary:

Total Days = 12
Data Acquisition Days = 6 for 2-D
Days Waiting on Weather = 1 for 2-D
Travel/Mob/Testing/Demob Days = 5 for 2-D

SUMMARY OF FIELD OPERATIONS
1998 PHASE 1 2-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

TABLE A.1

1. Seismic Recording System -- OYO DAS-1

   a. Number of Channels 12
   b. Record Length .....750 milliseconds
   c. Sample Rate .....0.25 millisecond
   d. Filter Parameters .....40 to 2,000 Hz
   e. Recording Media .....Digital Linear Tape (DLT)
   f. Recording Format .....SEG D 8048
   g. Time Break.....Syntron GCS-90 TB to Aux 1

2. Seismic Source -- Halliburton Sleeve-Gun

   a. Volume.....5 cubic inches
   b. Frequency Spectrum.....30 to 700 Hz
   c. Tow Depth.....1 meter
   d. Offset From Stern.....10.2 meters
   e. Offset From Antenna.....9.75 meters
   f. Gun Controller.....Syntron GCS-90
   g. Firing Rate .....2 seconds
   h. Timing Accuracy.....100 microseconds
   i. Timing Specification.....±300 microseconds
   j. Detection Method .....Internal Timing Coil

3. Multichannel Streamer Array – Teledyne

   a. Number of Channels 12
   b. Group Interval .....3.125 meters
   c. Phones per Group.....10
   d. Hydrophone Type.....Teledyne B-1
   e. Tow Depth.....Approximately 1 to 2 meters
   f. Offset, Near Channel to Stern.....10.2 meters
   g. Offset, Near Channel to Antenna .....19.95 meters

4. Analog Recording System -- EPC Recorder

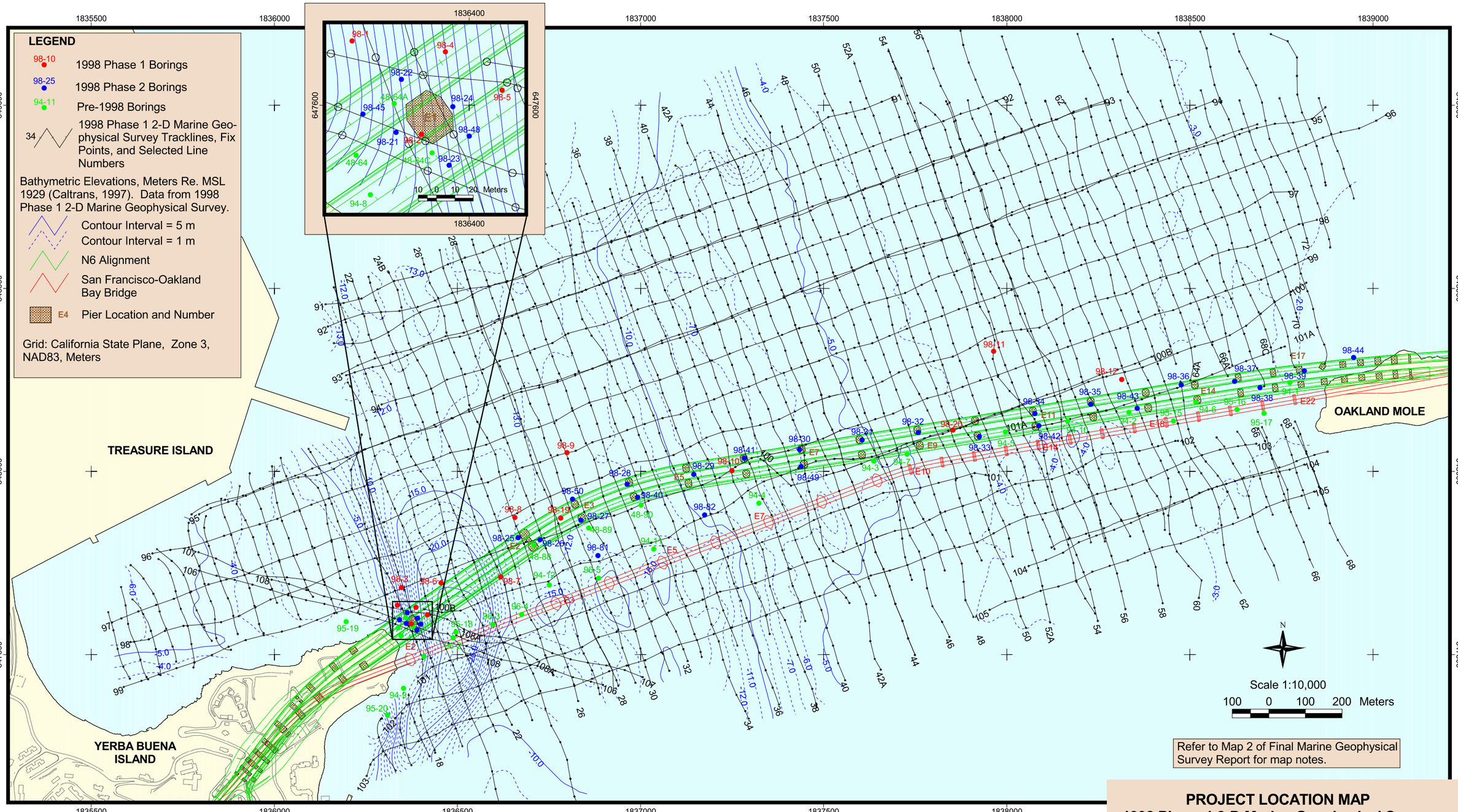
   a. Near-Trace Input .....Derived through DAS-1
   b. TVG Amplifier.....TSS 301
   c. Filter .....Krohnhite Model 3550
   d. Filter Bandwidth .....160 to 400 Hz
   e. Graphic Recorder.....EPC 1086, Thermal
   f. Scale .....250 milliseconds
   g. Fix Interval.....50 meters

DETAILED SPECIFICATIONS FOR
1998 PHASE 1 2-D MULTICHANNEL SLEEVE-GUN SYSTEM
SFOBB East Span Seismic Safety Project

TABLE A.2

Earth Mechanics

FUGRO

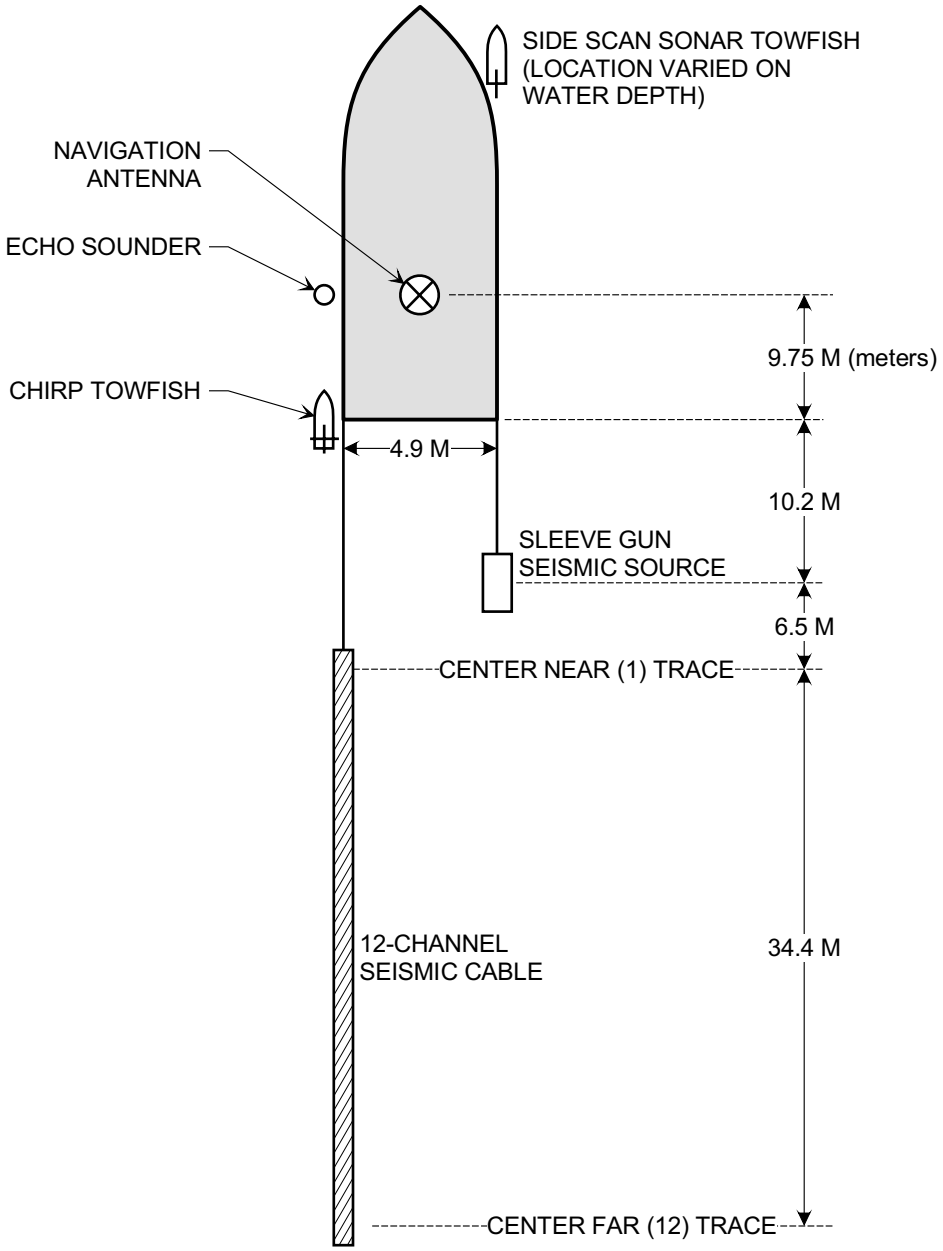


Refer to Map 2 of Final Marine Geophysical Survey Report for map notes.

PROJECT LOCATION MAP
1998 Phase 1 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

PLATE A.1

R/V *WHITE LIGHTNING*



Not to Scale

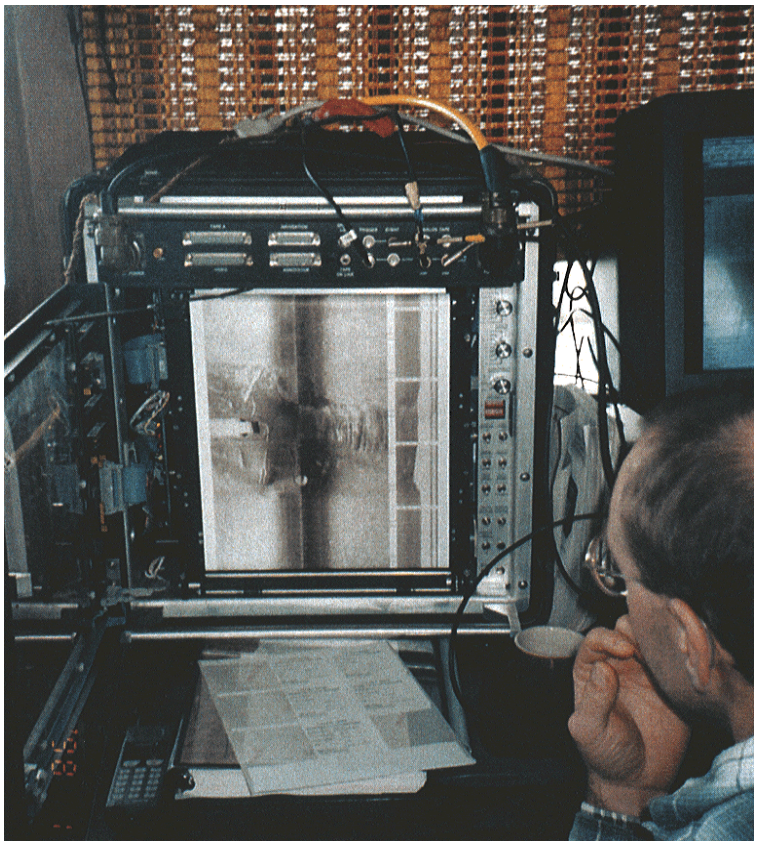
INSTRUMENTATION LAYOUT
1998 Phase 1 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

PLATE A.2

Deploying sleeve gun and tail buoy.

Datasonics CHIRP towfish on deck.

FIELD OPERATIONS PHOTOGRAPHS
1998 Phase 1 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project



Sidescan sonar console showing recording of bridge pier.

Instrumentation room onboard the R/V *White Lightning.*

FIELD OPERATIONS PHOTOGRAPHS
1998 Phase 1 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

APPENDIX B
1998 PHASE 1
3-D MARINE GEOPHYSICAL
SURVEY OPERATIONS

APPENDIX B
1998 PHASE 1 3-D MARINE GEOPHYSICAL SURVEY OPERATIONS

B.1 INTRODUCTION

A 3-D (three-dimensional) marine geophysical seismic reflection survey was conducted immediately following the two-dimensional (2-D) survey described in Appendix A. The objective of the 3-D survey was to provide increased spatial coverage of the subsurface soil and rock horizons. The 3-D survey parameters were designed to image the deeper horizons, sand layers in the Upper and Lower Alameda Formations, and Franciscan Formation bedrock that could be bearing surfaces for a pile-supported structure.

The term 3-D survey is used for geophysical surveys designed for the collection of seismic data over an area with the objective of determining spatial relations in three dimensions as opposed to their apparent components along survey lines of a 2-D survey. The data from a 3-D survey constitute a volume, as opposed to individual sections from a 2-D survey. The conduct of a 3-D survey requires closer survey line spacing and seismic energy source (shot) intervals than a 2-D survey, and greater control over the positioning of both the seismic source and recording cables. A 3-D survey is designed to produce a more accurate delineation of subsurface geologic features than can be achieved by a 2-D survey. Further information about the nature of 3-D geophysical surveys may be found in Sheriff and Geldhart (1995).

This Appendix provides details of the 3-D marine geophysical survey field operations, procedures, personnel, and instruments. Plate B.1 shows the area covered by the Phase 1 3-D Marine Geophysical Survey.

B.2 SUMMARY OF FIELD OPERATIONS

B.2.1 Schedule and Operations

Mobilization for the 3-D sleeve-gun survey began on January 24, 1998, and continued through an at-sea test of the equipment on January 31. During the mobilization period, there were over 3 days of marginal weather that limited the amount of testing that could be accomplished. The high sea state did not permit proper deployment and balancing of four cables, thus limiting the amount and quality of testing that could be accomplished.

Actual data acquisition began on January 31 and continued through February 28, 1998. During this period, there was a 1-day delay due to equipment problems related to a boat generator, and another delay of over 10 days when surveying could not be done because of weather and sea state conditions (Table B.1). Equipment was demobilized from the survey vessel from March 1 through March 4, 1998.

Operations were conducted from the 23-meter ocean research vessel, R/V *White Lightning*. Plate B.2 shows the relative location of the major items of geophysical equipment used during field operations. A Differential Global Positioning System (DGPS) was used for navigation. The DGPS system was supplemented with an inertial motion reference system, a multitasking navigation-line control system, and a Fanbeam™ laser tracking system. This complex integrated navigation and control system was required because of the close line spacing, the need for close and accurate shot-point intervals based on distance between points, and the need to accurately track the position of the seismic source and the four seismic streamers.

Water depths and tides were recorded with an ODOM Echotrac DF-3200 echo sounder and a Coastal Mini-Tide self-recording gauge. The seismic source consisted of an array of four sleeve guns, and data were recorded on two to four 16-channel streamers (cables) (Plate B.2). The number of streamers used on a given line varied with external conditions (e.g., proximity of the seismic line to piers, the island or other fixed objects, and sea conditions such as local currents). Plates B.3a to B.3c depict the deployment of the various components of the navigation and seismic system during survey operations.

B.2.2 Survey Plan and Coverage

Three-dimensional surveys are divided into discrete areas called bins. The recorded seismic data traces are sorted into the bins according to reflection midpoint locations for each shot-geophone (channel) pair. The resulting traces that fall into a given bin are then summed (stacked) to obtain the output trace for the particular bin. The number of traces in the bin prior to summing is called the fold. The original survey plan called for the seismic lines to be run in a northwest-southeast direction with a line spacing of 12.5 meters. The guns were to be fired at a fixed 6.25-meter interval along the lines. Geophone group (channel) spacing was 6.25 meters in each cable (Plate B.2). Under ideal conditions, this plan would provide 8-fold or greater coverage on a bin spacing of 6.25 meters depending on the number of cables and channels in each cable.

The survey plan was adhered to over much of the survey area (Map 3). However, in the cove area north of Yerba Buena Island, it was necessary to run survey lines in a northeast direction because of limited turning radius for northwest-trending lines. Supplementary lines also were run subparallel to the bridge to fill in areas that could not be covered by northwest-trending lines because of the bridge piers and other obstructions. Strong currents, especially near the existing bridge piers, caused cable feathering and shiptrack deviations from preplanned tracklines. Limited spacing between bridge piers reduced the number of cables that could be used in the eastern part of the survey area and resulted in the survey vessel turning offline early to avoid tangling the cables in the pier areas. These latter factors combined to significantly reduce the fold from the planned value in many parts of the survey area. Further details of the final survey bin coverage are discussed in Appendix D - Navigation, Bathymetric, and Seismic Data Processing.

B.3 PERSONNEL

The following organizations and personnel participated in performing the 3-D sleeve-gun survey:

Organization	Individual	Title
Fugro West, Inc.	Jan Rietman Muriel Norton	Principal Geophysicist Senior Geophysicist
Fugro Survey Division	Joe Mucha Kevin Morse Jeff Babbitt Gilbert Suarez	Hydrographic Surveyor Hydrographic Surveyor Hydrographic Surveyor Hydrographic Surveyor
Subsea Systems, Inc.	Mike Barth John Roth Steven Lockhart	Project Manager Geophysical Acquisition Senior Geophysical Observer Sleeve-Gun and Compressor Mechanic
EnSoCo, Inc.	Allan King Tim Woodring	System Programmer Operator
MDL Technologies, Inc.	Lionel Cortes	Technician
Westcoast Seaworks (R/V *White Lightning*)	Dave Stephens Steve Hart	Captain Deckhand

B.4 INSTRUMENTATION

B.4.1 Water Depth and Tide Measurements

Water depths and tides were recorded to correct the zero (0) time on the seismic trace recordings to the project vertical datum, MSL 1929. This correction, up to ±2 meters, was necessary because much of the survey area was in shallow water of less than 5 meters (Map 3). These data were not used to construct a bathymetry map as that task had been previously completed as part of the Phase 1 2-D Marine Geophysical Survey.

Bathymetry System. As a routine procedure, an ODOM Hydrographic Systems, Inc. Echotrac DF-3200 survey grade echo sounder was used to acquire bathymetric data during all survey operations. At the start of each survey day, the speed of sound in seawater was determined with a sound velocimeter and verified with standard "bar-check" methods. This velocity was entered together with the transducer draft to yield a depth value in meters. Analog paper records as well as digitized depth information were continuously recorded, and digital depth data were logged directly to the navigation computer along with date, time, and position for post-processing and mapping.

The echo sounder acoustic pulse was generated with a Model OHS 200 transducer, operating with a beam width cross section of 2.75 degrees at 200 kHz. The shipboard transceiver automatically adjusts power output in proportion to the return signal, thereby yielding a clear,

unambiguous record in shallow as well as deep water. The self-adjusting power varies from 1 to 225 watts at 200 kHz, and time-varied gain and automatic gain control optimize return signals.

High-density bathymetric soundings were recorded at approximately 0.30-second intervals along each hydrographic survey line. At average ship speeds of 3.0 to 3.5 knots, this resulted in depth soundings at approximately 0.5-meter intervals. This closely spaced bathymetric coverage between fix positions produced a very accurate profile of the seafloor bathymetry. Tidal corrections were applied in postprocessing, after the tide gauge data were downloaded and correlated with the survey data.

Self-Recording Tide Gauge. A Coastal Mini-Tide self-recording tide gauge was installed on the U.S. Coast Guard dock on Yerba Buena Island prior to commencing survey operations. The tide gauge was secured to existing pilings, and the elevation for the sensor established using conventional vertical survey techniques to at least a third order accuracy. The leveling was conducted utilizing a NIKON AS automatic level. The following U.S. Army Corps of Engineers (USACOE) vertical control point was utilized to establish the tide gauge elevation.

- USACOE Benchmark Buoy: Elevation = +2.727 meters
- Tide Gauge Sensor: Elevation = -1.454 meters

All elevations on the project are referenced to MSL 29 datum which is 0.942 meter above mean lower low water (MLLW) as stated in a Caltrans memorandum dated December 17, 1997 (Caltrans, 1997).

B.4.2 Vessel Positioning System

A TSS Position and Orientation System for Marine Vessels (POS/MV) 320 system was utilized for accurate vessel positioning during the 3-D survey. This system included a Global Positioning System (GPS) and the STARFIX II DGPS correction network integrated with an Inertial Navigation System (INS).

GPS and STARFIX II. GPS is a satellite-based positioning system operated by the U.S. Department of Defense. Differential corrections were supplied to the system using the STARFIX II network, a nationwide system operated by John E. Chance and Associates (a Fugro subsidiary), that broadcasts differential corrections via communications satellite downlink to field receivers. (For a complete description of the DGPS and STARFIX II networks, see Section A.4.1 of this report.)

TSS POS/MV 320. The POS/MV 320 system combined GPS/DGPS with rugged, high-quality inertial sensors to deliver a full 6 degrees-of-freedom position and orientation solution for marine survey vessels. The POS/MV 320 outputs all motion variables at a rate of 100 Hz, which made it possible to maintain a virtually continuous fix on the position, orientation, velocity, and acceleration of the ship at all times. The complete motion variables measured by the

TSS POS/MV 320 are position (latitude and longitude), velocity (north, east, and vertical), roll, pitch, true heading, heave, and the three-dimensional acceleration and angular rate vectors. The system measures true heading with an accuracy of 0.05 degree, roll and pitch with an accuracy of 0.035 degree, and heave with an accuracy of 5 percent. The POS/MV 320 system heading drift has been proven to be less than 1 degree per hour in the event of a loss of GPS signal.

The inertial system provided accurate positioning information when the survey vessel was beneath the SFOBB East Span Bridge, where differential correction signals from the satellite downlink were susceptible to blockage. The POS/MV 320 system position data were interfaced with the EnSoCo navigation control system (Section B.4.3) to provide the high accuracy heading reference required by the 3-D survey.

B.4.3 Navigation Control System

EnSoCo, Inc. Nautica Navigation System. The Nautica navigation system is a true multitasking navigation and line control system that works with all industry-standard positioning systems. Up to 8 hybrid Lines of Positions (LOPs) from a total of 128 LOPs may be used to define the geodetic positions of 64 objects. Nautica is menu and window driven for ease of operator use. All raw and filtered data acquired by the system are time-tagged, assuring coherency, and logged to hard disk and/or tape.

Active navigation buoys, magnetic compasses, acoustics, and optical-tracking (laser) systems were combined in a network solution to determine positions of the streamers (receivers) and sources in real time for the 3-D survey. These positions were integrated directly into Nautica. All position fixes for the survey were computed using a least-squares adjustment. Multiple video displays were used to monitor data quality in real time.

Fanbeam™ MKIII Laser Radar System. The MDL Fanbeam™ MKIII Laser Radar System (Plate B.3c) is a repetitive, high-accuracy positioning unit that is capable of tracking marine vessels, gun array and streamer floats, and other targets. Using prismatic reflectors as targets, the radar system has a maximum range of more than 2,000 meters with an accuracy of 10 to 20 centimeters. Comprised of a rotating head mounted on a gearbox encoder assembly, the unit was remotely controlled by cable from a universal control or personal computer containing customized software.

The laser radar unit put out pulses at 5,000 Hz, allowing multiple returns to be registered for each target. The unit scanned at a rate of 50 degrees per second, thus allowing virtually continuous monitoring of the streamer's distance and bearing.

Seismic streamer and seismic source tracking was integrated directly into Nautica. Active navigation buoys, magnetic compasses, acoustics, and optical-tracking (laser) systems are combined in a network solution to determine positions of the streamers (receivers) and sources in real time.

Multiple video displays were used to monitor data quality in real time. Nautica is menu and window driven for ease of operator use. All raw and filtered data acquired by the system was time-tagged, assuring coherency, and logged to hard disk and/or tape.

B.4.4 Seismic Data Acquisition System

The major components of the data acquisition system were the seismic source (Plate B.3a), the streamer arrays (Plate B.3b), the near-trace monitor, the digital recording system, and the binning system. They are briefly described below and detailed specifications are given in Table B.2.

Seismic Source Geoquip Q-10 Sleeve-Gun Array. The seismic source consisted of four Halliburton sleeve guns in a compact towed array. Due to limitations of the high-pressure air supply, each gun was plugged to a volume of 5 cubic inches and only three of the guns were fired at a time. The array was towed from the center of the stern at a fixed depth of 1 meter and at an offset from the navigation antenna of 29.59 meters. The source bandwidth was 30 to 600 Hz. A Syntron GCS-90 gun controller sensed the firing time of each gun and automatically adjusted the timing so that the guns were fired within ±300 microseconds of each other. Source positioning was monitored using the MDL Fanbeam™ laser system described above. A prism was mounted at the center of the source array above water. The 500 Hz pulse rate of the laser system allowed for practically continuous recording of the range and bearing from the source array to the positioning antenna.

Streamer Arrays. This survey utilized from two to four analog streamers (Teledyne 29850 cables), each with a capacity of 16 channels. The group length of each channel was 6.25 meters. In some locations, restrictions in turning radius and strong tidal currents resulted in reducing the number of cables from four to two. The cables were towed at a fixed distance from the stern, using towing booms mounted on the port and starboard sides of the vessel. Refer to the 3-D layback diagram for additional details (Plate B.2). Each cable was equipped with two Digicourse Model 5001 cable levelers (Plate B.3b) mounted fore and aft of the active arrays. The cable levelers controlled the depth of each cable and monitored the cable heading. This information was transmitted at each shot to the navigation-binning computer so that position of each receiver group could be calculated. Additionally, the tail buoy for each cable was equipped with a prism array (Plate B.3b). The position of the tail buoys was continuously monitored by the MDL Fanbeam™ laser system (Plate B.3c).

Near-Trace Monitor. In order to observe data quality, a near-trace monitor recording was made during survey operations. One channel of the streamer array (typically channel 1 from the outer port cable) was processed using a TSS 360 time-varied gain amplifier/filter. The bandwidth of the filter was 160 to 400 Hz. The processed analog signal was recorded on an EPC 1086 graphic recorder at a record length of 250 milliseconds. Navigation fixes were sent to the

recorder every 100 meters, or approximately one fix every 56 seconds at an average vessel speed of 3.0 to 3.5 knots.

Seismic Recording System. The OYO DAS-1 digital recording system was configured to allow a maximum of 64 data channels and one auxiliary channel to be recorded. Due to changes in the streamer configurations during the survey, combinations of 64, 32, and 24 channels varied with the number of streamers, either two or four, being used. The DAS-1 was configured for a sample rate of 0.25 millisecond and a record length of 750 milliseconds. The internal acquisition filter was set for a bandwidth from 3 to 2,000 Hz. To verify timing accuracy, the time break from the Syntron gun controller was applied to the DAS-1 auxiliary channel. The data were recorded in SEG D 8048 format using an external DLT drive. Additionally, the file number from the DAS-1 was serially transmitted to the navigation binning system after each shot.

Navigation Binning System. EnSoCo, Inc., of Houston, Texas, provided the Nautica binning system and computer operator. This system calculated the position of all source/receiver points by acquiring data from the DGPS navigation system and applying the offsets generated by the MDL Fanbeam™ laser (for source and cable tailbuoy positions) and the Digicourse cable levelers (for receiver positions). The binning system also calculated the 6.25-meter distance interval for each seismic shot.

Data from the DGPS POS/MV 320, the Digicourse system, Fanbeam™ laser, echo sounder, and file number from the OYO DAS-1 were recorded on disk and tape after each shot. Additionally, the binning software provided a real-time display of the subsurface coverage in the survey area so that any gaps in coverage could be observed and infilled with additional lines.

B.5 QA/QC PROCEDURES FOR THE 3-D MARINE SURVEY

Quality Assurance/Quality Control (QA/QC) procedures were established and distributed to Caltrans and to geophysical system operators prior to the survey. The intent of the QA/QC program was to provide a framework for the execution of the survey, as well as a method for evaluation of the acceptability of the acquired geophysical data while in the field. The methods and decisions should be understood in the context of providing the required information, while meeting the interpretational objectives of the survey, relative to the definition of the site geology.

QA/QC procedures were developed by Project Management and implemented onboard the survey vessel by either the Project Geophysicist (PG) or survey Party Chief (PC) for Geophysical Data Acquisition. The key components of the QA/QC procedures were instrumentation tests, documentation, and criteria for termination of data collection.

B.5.1 Instrumentation Tests

Navigation and Binning System. In order to assure proper operation of the 3-D binning process, criteria were set for the continued operation of the Nautica Navigation System components.

- **Fanbeam™ Laser** - The Fanbeam™ laser monitored the source and four streamer tailbuoy positions. The requirements were that the source position was operational at all times, and at least two of the four tailbuoy positions were operative.
- **Compass/Depth Birds** - Two compass/depth birds were utilized on each cable, one at the front and one at the rear of the active section. Seven of the eight compasses were required to be operational at all times.
- **Echo Sounder** - The echo sounder information was required to be continuously recorded.
- **Navigation System** - Data from the inertial system or gyro and DGPS instruments were required to be recorded continuously.

Seismic System. Testing of the major components of the seismic system was done at the beginning of each survey day and at other times as necessary.

- **OYO DAS-1 Quality Control Test** - Concurrent with survey initialization, the PC or PG or designated on-board staff member supervised instrument quality control tests on the digital recording system used during the survey. These tests were recorded on magnetic tape or disk and documented. Initial and daily instrument field tests were made relative to: direct current voltage (DC) offset, noise, gain accuracy, crosstalk, and total harmonic distortion. Additional tests were also requested at the discretion of the PC or PG.
- **Seismic Cable Tests** - Daily tests were conducted to determine the electrical condition of the seismic cable. Tests included leakage and continuity. Unusable traces were defined as no output, excessive DC offset so as to degrade the dynamic range of that trace, a noise level exceeding the noise limitations (greater than 5 microbars RMS), or leakage to ground or between pairs greater than 0.5 megohm. Average leakage on all channels could not exceed 1 megohm. Polarity checks were made at the beginning of the project and whenever a section or lead-in was replaced or repaired.
- **Sleeve-Gun Tests** - Sleeve-gun air pressure was maintained at 1,800 pounds per square inch (psi) or greater and source repeatability and synchronization were tested to verify they were within 250 microseconds.

- **Shot Monitor Records** - A monitor read-after-write seismogram was recorded at the beginning of every line and at a maximum of 250-meter intervals thereafter. The monitor seismograms displayed hydrophone response from all detector groups as well as time break, file number, and system timing. Each monitor record was labeled with the corresponding shot point number. A fixed gain monitor record was taken periodically to verify uniform hydrophone response. When real-time monitoring was not available, the stored seismograms were made while offline.

B.5.2 Documentation

Chronological Log. The survey PC or designated on-board staff member kept a daily chronological log of events. This log included information pertaining to: survey line production, production interruptions and explanations, daily testing, routine instrument servicing, equipment troubleshooting, deployment and retrieval of equipment, ship departure, transit and arrival times, and all deviations from normal operating procedures. This log was reviewed and approved by either the PC or PG daily

Observer Reports. The seismic recording crew kept a detailed daily Observer Report. In order to assist processing of the data, such items that pertained to normal daily recording operations were frequently logged, as was any deviation from, or interference with, normal procedures. Items that were logged included, but were not limited to: all observer sheet header information, shot point numbers, reel numbers, file numbers, weather, water depths, missed shots, average ambient cable noise evaluation at beginning and end of line under normal tow depths and speed, navigational malfunctions, etc. Also, navigational fixes and corresponding file numbers were recorded on observer reports at a nominal 50-meter interval.

Near-Trace Monitor Records. A single channel seismic record was made with a line scan recorder that displayed one near trace and was annotated with the following: line number, direction of shooting, shot point numbers, time delays (if any), area, client vessel, and scales used. Event marks to this record were marked from a signal from the navigation system at a nominal interval of 50 meters. The PC or PG continuously monitored the near-trace record.

Cable/Source/Equipment Diagram. A cable/source/equipment diagram was included with each data shipment showing all deployed positions, depths, offsets, stepback, trace spacing and bird. Stepbacks were computed from the navigation antenna, not the stern of the vessel. Plate A.1 is an example of this type of diagram.

Binning Diagram. Data coverage was verified using the binning system during offline processing. The bin test size was 6.25 meters with a minimum of 8-fold per bin. An updated diagram was produced at the end of each day of surveying.

B.5.3 Criteria for Termination of Data Collection

Based on the following operating criteria, the PC/PG terminated the data collection for the day, aborted a survey line, and identified the tracklines or portions of tracklines that needed to be re-run:

- A fishing boat, sailboat, or shipping vessel obstructed the path of the survey vessel.
- An essential component of the primary navigation system did not function properly, an unverified calibration occurred, or the system experienced a temporary loss of DGPS signal.
- The echo sounder was temporarily inoperative.
- A trackline deviated from the planned location in an amount sufficient to negate survey bin coverage.
- There were more than two unusable traces out of sixteen on any cable. The unusable channels could not be adjacent.
- The seismic source air pressure or timing circuits did not meet specifications.
- The sea state or instrumental noise degraded seismic records below acceptable standard, as could be determined from the monitor records reviewed by the PC/PG (criteria for terminating daily surveying and/or re-running lines).

B.6 FIELD DATA TYPES AND FORMATS

Data from all systems except the navigation system were recorded in both analog and digital formats. The navigation data were recorded only digitally, but are plotted on Map 3. The field data are in the following formats::

a. Navigation
   - Shiptrack map at scale of 1:5000 (Map 3)
   - Tape with X,Y,Z (tide corrected Z) data every second

b. Tide Gauge
   - Tides recorded every 10 minutes relative to MLLW

c. Echo Sounder
   - Original analog record (not tide corrected)
   - Navigation tape with corrected depths

f. Sleeve-Gun System
   - Single-channel analog monitor records from all lines
   - Shot monitor records used in QA at an approximate 100-shot interval

- Copies of the digital field tapes, 8 millimeter, Society of Exploration Geophysicists (SEG) D format

B.7 REFERENCES

California Department of Transportation (Caltrans) (1997), Internal Caltrans Memorandum dated December 17 from SFOBB Investigations Section to Office of Structure Design, Subject: Addendum - Vertical Datum, Caltrans File Nos. 04-SF-80, 04-0434A1,C1,E1,F1,G1, Project Nos. 3, 4, 5, 6, 8, 21, Bridge No. 33-0025.

Sheriff, R.E., and Geldart, L.P. (1995), Exploration Seismology, Second Edition, Cambridge University Press, New York, NY, pp. 592.

Day Number	Date	Day of Week	Activity
1	24-Jan-98	Saturday	Mobilization
2	25-Jan-98	Sunday	Mobilization
3	26-Jan-98	Monday	Mobilization
4	27-Jan-98	Tuesday	Mobilization
5	28-Jan-98	Wednesday	Mobilization/Testing
6	29-Jan-98	Thursday	Testing in marginal weather
7	30-Jan-98	Friday	Testing in marginal weather
8	31-Jan-98	Saturday	Testing/Acquiring Data/Waiting on Weather
9	1-Feb-98	Sunday	Waiting on Weather
10	2-Feb-98	Monday	Acquiring Data/Waiting on Weather
11	3-Feb-98	Tuesday	Acquiring Data
12	4-Feb-98	Wednesday	Acquiring Data
13	5-Feb-98	Thursday	Waiting on Weather
14	6-Feb-98	Friday	Waiting on Weather
15	7-Feb-98	Saturday	Waiting on Weather
16	8-Feb-98	Sunday	Acquiring Data
17	9-Feb-98	Monday	Acquiring Data
18	10-Feb-98	Tuesday	Waiting on Weather
19	11-Feb-98	Wednesday	Acquiring Data
20	12-Feb-98	Thursday	Waiting on Weather
21	13-Feb-98	Friday	Equipment Malfunction
22	14-Feb-98	Saturday	Acquiring Data/Waiting on Weather
23	15-Feb-98	Sunday	Acquiring Data
24	16-Feb-98	Monday	Waiting on Weather
25	17-Feb-98	Tuesday	Acquiring Data
26	18-Feb-98	Wednesday	Acquiring Data
27	19-Feb-98	Thursday	Waiting on Weather
28	20-Feb-98	Friday	Acquiring Data
29	21-Feb-98	Saturday	Waiting on Weather
30	22-Feb-98	Sunday	Acquiring Data
31	23-Feb-98	Monday	Waiting on Weather
32	24-Feb-98	Tuesday	Acquiring Data
33	25-Feb-98	Wednesday	Acquiring Data
34	26-Feb-98	Thursday	Acquiring Data
35	27-Feb-98	Friday	Acquiring Data
36	28-Feb-98	Saturday	Acquiring Data
37	1-Mar-98	Sunday	Demobilization
38	2-Mar-98	Monday	Demobilization
39	3-Mar-98	Tuesday	Demobilization
40	4-Mar-98	Wednesday	Demobilization

Operations Summary:

Total Days = 40
Data Acquisition Days = 15
Days Waiting on Weather = 10
Days With Combined Acquisition Time and Weather Time = 3
Equipment Downtime Days = 1
Mobilization/Testing/Demobilization = 11

1998 PHASE 1 3-D MARINE GEOPHYSICAL SURVEY OPERATIONS SUMMARY

SFOBB East Span Seismic Safety Project

TABLE B.1

1. Seismic Recording System -- OYO DAS-1 With Expansion Module

a. Number of Channels ..... 96 max; combinations of 64, 32 and 24 used during survey
b. Record Length ..... 750 milliseconds
c. Sample Rate ..... 0.25 millisecond
d. Acquisition Filter..... 3 to 2,000 Hz
e. Recording Media..... Digital Linear Tape (DLT)
f. Recording Format ..... SEG D 8048
g. Time Break..... Syntron GCS-90 TB to Aux 1

2. Seismic Source -- Geoquip Q-10 Sleeve-Gun Array

a. Number of Guns..... 4 max, 3 used due to air capacity
b. Volume per Gun/Total..... 5 cubic inches each, 15 total
c. Tow Depth..... 1 meter
d. Frequency Spectrum..... 30 to 700 Hz
e. Offset to Stern..... 29.59 meters
f. Offset to Navigation Antenna ..... Refer to Plate 4.1
g. Tracking System ..... MDL Fanbeam™ Laser
h. Gun Controller..... Syntron GCS-90
i. Timing Accuracy ..... 100 microseconds
j. Synchronization Specification ..... ±300 microseconds
k. Synchronization Method ..... Internal timing coil
l. Firing Rate ..... 6.25 meters, controlled by navigation system

3. Streamer Array

a. Streamer Type ..... Teledyne 28950
b. Group Interval ..... 6.25 meters
c. Phones per Group..... 10
d. Number of Channels ..... 16 max per cable; combinations of 16, 12, and 11 used during survey
e. Number of Cables ..... 4 max; 2 or 4 used during survey
f. Depth & Compass..... Digicourse 5011 cable levelers fore and aft each active array
g. Tail Buoy Tracking ..... MDL Fanbeam™ Laser

4. Near-Trace Monitor

a. Channel Monitored..... Near trace of port outer cable
b. Graphic Recorder..... EPC 1086
c. Amplifier/Filter ..... TSS Model 360 TVG amp
d. Filter Frequency ..... 160 to 400 Hz
e. Record Length ..... 250 milliseconds
f. Fix Interval ..... 100 meters

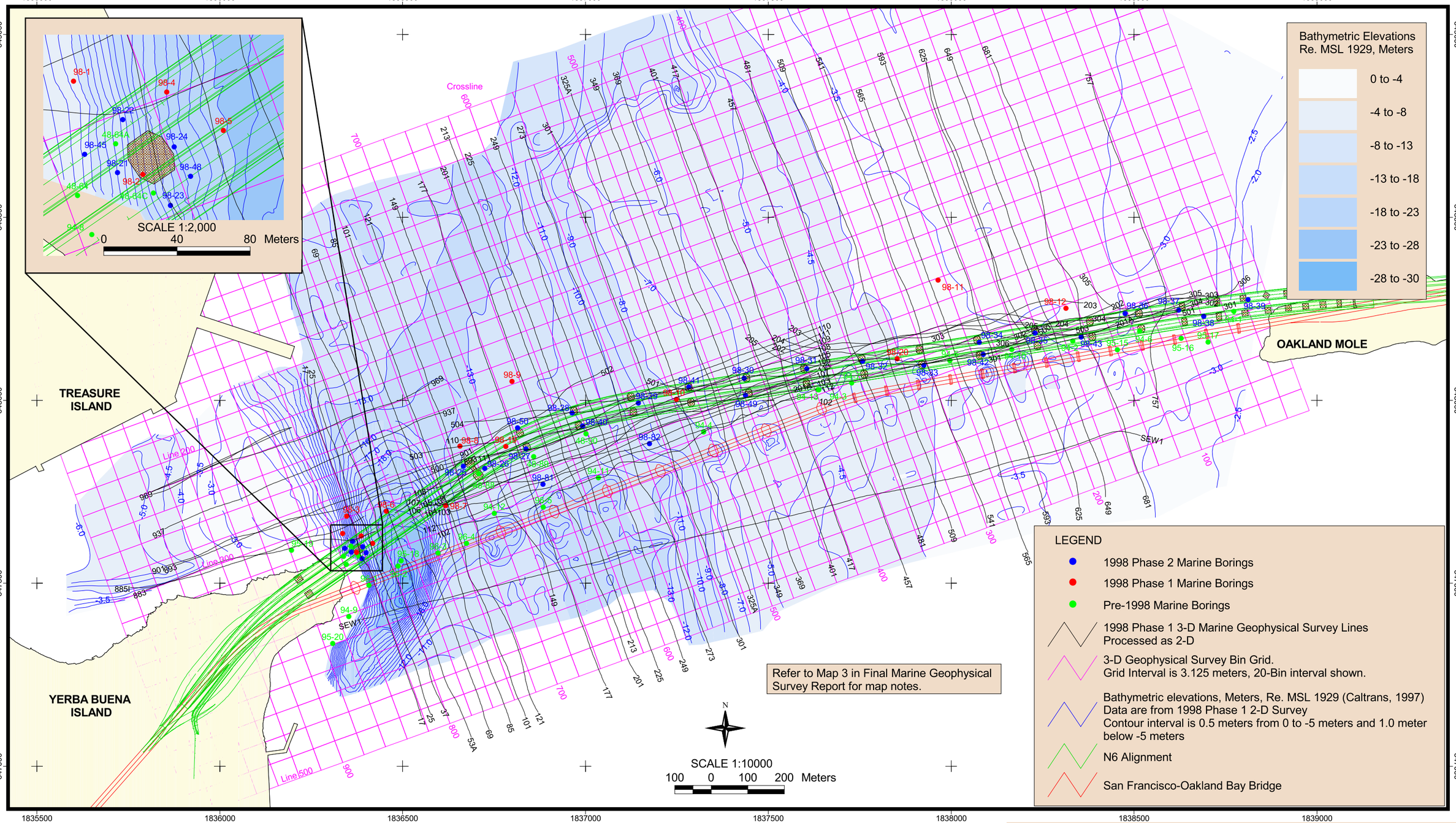
5. Binning System

a. Equipment Type..... EnSoCo Nautica System
b. Primary Navigation..... DGPS (Section 2.3.1)
c. Equipment Interfaced..... Digicourse Cable levelers
MDL Fanbeam™ Laser
Syntron Gun Controller
OYO DAS-1 (file number)
POS/MV DGPS System

DETAILED SPECIFICATIONS FOR 3-D MULTICHANNEL SLEEVE-GUN SYSTEM
SFOBB East Span Seismic Safety Project

Earth Mechanics

FUGRO



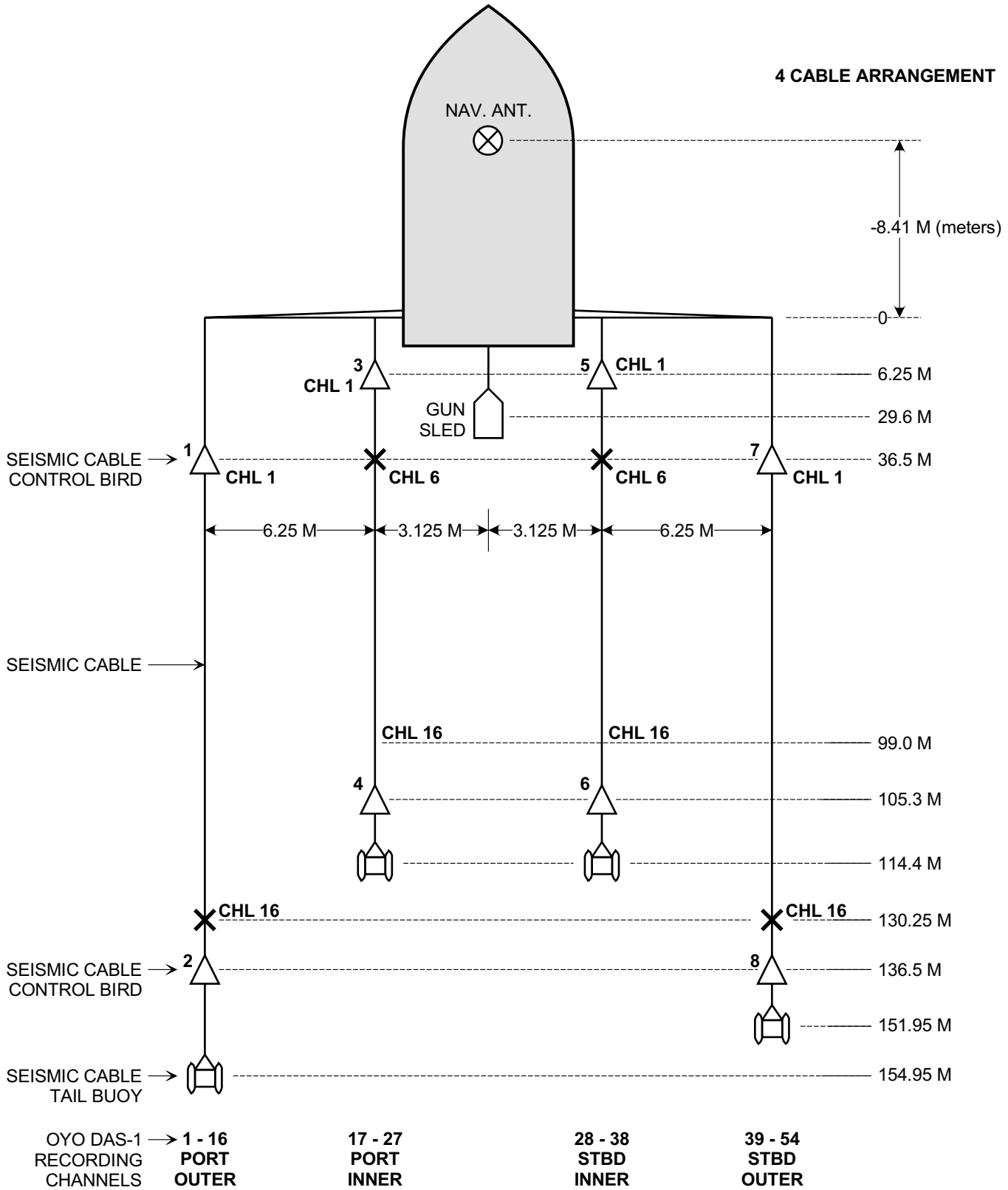
DATABASE MAP

1998 Phase 1 3-D Marine Geophysical Survey

SFOBB East Span Seismic Safety Project

PLATE B.1

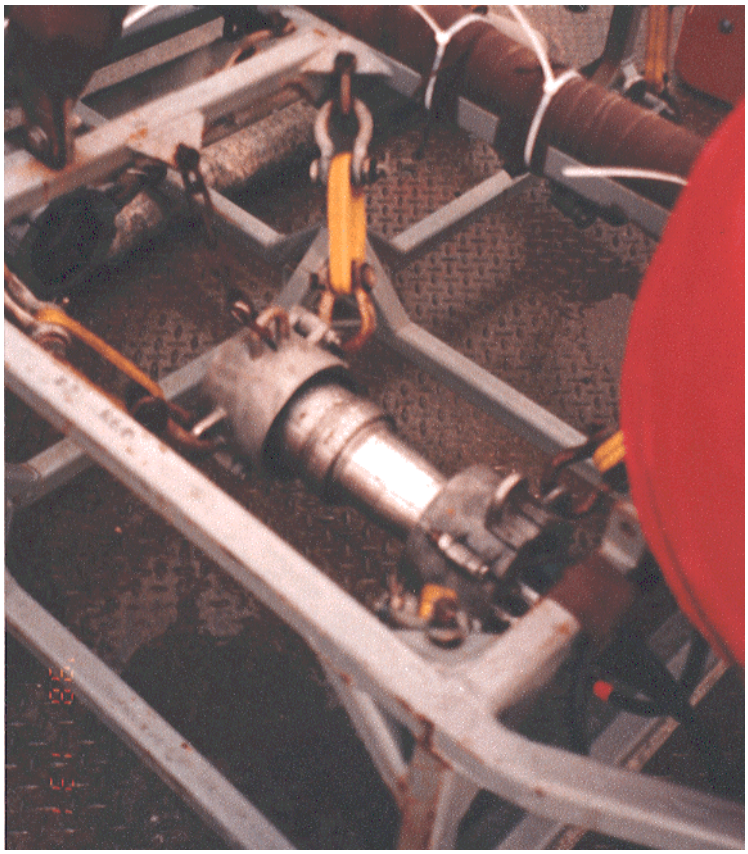
R/V *WHITE LIGHTNING*



Not to Scale

INSTRUMENTATION LAYOUT
1998 Phase 1 3-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

9842\0054srvy.dsf,p2

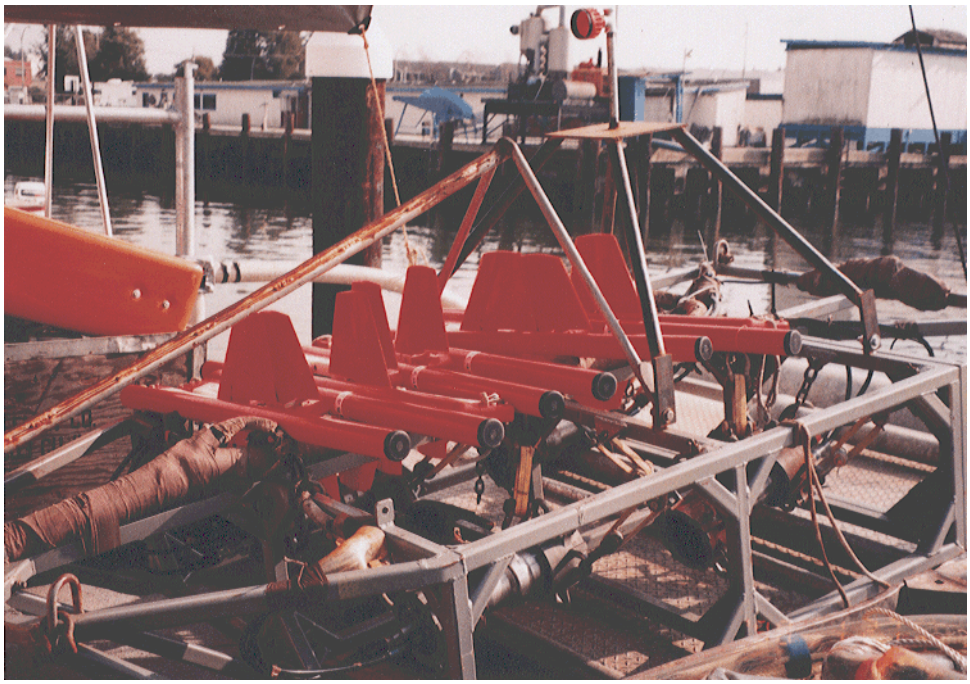


Halliburton sleeve gun (10-cubic-inch capacity, plugged to 5 cubic inches) in Q-10 gun sled.

Deploying Q-10 gun sled array off stern.

FIELD OPERATIONS PHOTOGRAPHS
1998 Phase 1 3-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

9842\0054pht2.dsf,p1



Gun sled with Digicourse Model 5010 compass birds.

Tail buoys with prisms atop coiled hydrophone cables.

FIELD OPERATIONS PHOTOGRAPHS
1998 Phase 1 3-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

Fan beam laser aimed at gun sled. Four tail buoys and chase boat in distance.

Survey boat R/V *White Lightning* with paravanes, gun sled, and four tail buoys behind.

FIELD OPERATIONS PHOTOGRAPHS
1998 Phase 1 3-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

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APPENDIX C
2000 PHASE 3
2-D MARINE GEOPHYSICAL SURVEY OPERATIONS

APPENDIX C
2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY OPERATIONS

C.1 INTRODUCTION

The 2000 Phase 3 two-dimensional (2-D) marine geophysical survey was designed to provide detailed stratigraphic and structural information in the area offshore the northeast end of Yerba Buena Island. The primary survey system consisted of a minisparker seismic energy source with a 24-channel hydrophone cable. Nearshore data were collected with a bay cable system using the minisparker source and a 48-channel cable that was laid on the Bay floor. Near-surface, high-resolution data were collected in the nearshore area using a boomer seismic energy source with a single-channel hydrophone cable.

The minisparker energy source has a higher frequency signal than the sleeve guns used for the 1998 Phase 1 2-D and three-dimensional (3-D) surveys. The higher frequency signal provides greater resolution of subbottom reflectors, but does not achieve the depth of investigation of the lower frequency energy sources. The 24-channel cable had more channels and a closer channel spacing than cables used on the previous surveys. These factors increased the horizontal resolution of the data and provided greater fold resulting in an increase in the signal-to-noise ratio compared to the sleeve-gun surveys. The short, single-channel boomer system cable allowed for increased survey vessel maneuverability in the nearshore areas and enabled data collection in areas that were not accessible with the longer cable.

The 2-D marine survey data were collected over a grid of survey lines (see Plate C.1). Since this was a 2-D survey, the seismic reflection data are relative to the survey lines on which they were collected. Each survey line represents an individual seismic section that shows a series of reflections of seismic energy from the subsurface sediment and rock horizons. Models of subsurface geologic features are made by tracing the corresponding seismic reflectors along and between the individual seismic sections.

C.2 SUMMARY OF FIELD OPERATIONS

C.2.1 Systems and Schedule

Personnel and equipment departed Ventura on September 5, 2000, and arrived at the mobilization dock in Alameda on the same day. Mobilization of equipment aboard the 13-meter motor vessel, M/V *White Squall*, was completed on the morning of September 6, and at-sea tests of the equipment were conducted that afternoon. Organizations and personnel who participated in the survey are listed in Section C.3. Equipment mobilized for the 2-D survey consisted of a Differential Global Positioning System (DGPS) navigation system, an echo sounder, a digital multichannel minisparker system, a digital multichannel bay cable system, and an analog single-channel boomer system. A self-recording tide gauge was installed on Yerba Buena Island to

allow for reduction of echo sounder data to the project elevation datum, MSL 1929 (Caltrans, 1997). Further descriptions of the instrumentation are given in Section C.4.

Data acquisition began on September 7 and continued through September 12, 2000. There were no delays due to weather or equipment problems (see Table C.1). The afternoon of September 9 was spent re-mobilizing for the bay cable operation. Demobilization of the survey vessel was completed on September 12, 2000.

C.2.2 Survey Grid

The multichannel minisparker data were collected along both a predetermined grid of lines and along diagonal lines added during the field program. The minisparker program consisted of 38 primary lines (spaced at 25 meters) trending southwest-northeast and 32 tie lines (spaced at 50 meters) trending northwest-southeast. Strong tidal currents swept the hydrophone cable toward the existing bridge piers, resulting in several lines running perpendicular to the existing bridge alignment that could not be run as close to the piers as planned. Several lines running diagonally to the survey grid were added to provide coverage under the existing bridge.

The bay cable survey consisted of three deployments of the cable (primary lines) on the Bay floor adjacent to the northeast point of Yerba Buena Island. For each deployment of the cable, nine lines were run with the seismic source. The source lines were parallel to the bay cable and spaced at 20-meter intervals. Two of the bay cable deployment lines were in the cove to the north of Yerba Buena Island, and the other one was to the south of the island offshore from the Yerba Buena Coast Guard Station. The locations of the three primary lines are shown on Plate C.1 and Map 4. Refer to Appendix D for an explanation of bay cable survey processing and final reflection line locations.

Thirteen boomer lines were run both north and south of the island. The positions of these lines were chosen in the field during the survey operations.

The final positions of the survey lines are shown on Map 4 (the 2000 Phase 3 2-D Marine Geophysical Survey Shiptrack Map) at a scale of 1:2000 and at a reduced scale on Plate C.1. Several lines were rerun in order to improve the quality of data or due to obstructions by other vessels. These reruns are labeled with numbers incremented by 200 (e.g., line 319 is a rerun of line 119 and line 424 is a rerun of line 224).

C.3 PERSONNEL

The following organizations and personnel participated in performing the 2000 Phase 3 2 D Marine Geophysical Survey:

Organization	Individual	Title
Fugro West, Inc.	Jan Rietman Frederick Arnold	Principal Geophysicist Field Geophysicist
Fugro Survey Division	Jim Grant Eddie Stutts Shawn Johnson	Survey Manager Hydrographic Surveyor Hydrographic Surveyor
Subsea Systems, Inc.	Mike Barth Muriel Norton	Geophysical Acquisition Manager Geophysical Technician
Westcoast Seaworks (M/V *White Squall)*	Duke Combs Steve Hart Chase Caldwell	Captain Deckhand Deckhand (only during bay cable operation)
Westcoast Seaworks (R/V *White Lightning*) used only for bay cable operation	Scott Francis Steve Hart	Captain Deckhand (only during bay cable operation)

C.4 INSTRUMENTATION

A brief description of each of the instrumentation systems is provided in the following paragraphs. The intent is to provide sufficient information to allow independent evaluation of the records from the various systems and to explain the real-time coordination between the various recordings. The layouts of the equipment aboard the M/V *White Squall* and the R/V *White Lightning* are shown on Plates C.2a through C.2c. Photographs of the operation are shown on Plates C.3a and C.3b.

C.4.1 Navigation and Positioning Systems

A TSS Position and Orientation System for Marine Vessels (POS/MV) 320 system was utilized for accurate vessel positioning during the 2000 Phase 3 2-D Marine Geophysical Survey. This system included a Global Positioning System (GPS) and the STARFIX II DGPS correction network integrated with an Inertial Navigation System (INS).

GPS and STARFIX II. GPS is a satellite-based positioning system operated by the U.S. Department of Defense. A "wide area" application operates with correction values applied to a stand-alone DGPS receiver from base stations located over large distances. DGPS corrections were supplied to the system using the STARFIX II network. This differential network, a nationwide system operated by John E. Chance and Associates (a Fugro subsidiary), broadcasts differential corrections via a communications satellite downlink to field receivers. (For a complete description of the DGPS and STARFIX II networks, see Section A.4.1 of this report.)

TSS POS/MV 320. The POS/MV 320 system combined GPS/DGPS with rugged, high-quality inertial sensors to deliver a full 6 degrees-of-freedom position and orientation solution for marine survey vessels. The POS/MV 320 outputs all motion variables at a rate of 100 Hz, which made it possible to maintain a virtually continuous fix on the position, orientation, velocity, and acceleration of the ship at all times. The complete motion variables measured by the TSS POS/MV 320 are position (latitude and longitude), velocity (north, east, and vertical), roll,

pitch, true heading, heave, and the three-dimensional acceleration and angular rate vectors. The system measures true heading with an accuracy of 0.05 degree, roll and pitch with an accuracy of 0.035 degree, and heave with an accuracy of 5 percent. The POS/MV 320 system heading drift has been proven to be less than 1 degree per hour in the event of a loss of GPS signal.

The inertial system provided accurate positioning information when the survey vessel was beneath the SFOBB East Span Bridge, where differential correction signals from the satellite downlink were susceptible to blockage.

C.4.2 Bathymetry System

As a routine procedure, an ODOM Hydrographic Systems, Inc. Echotrac DF-3200 survey grade echo sounder was used to acquire bathymetric data during all survey operations. At the start of each survey day, the speed of sound in seawater was determined with a standard "bar-check" method. This velocity was entered together with the transducer draft to yield a depth value in meters. Analog paper records as well as digitized depth information were continuously recorded, and digital depth data were logged directly to the navigation computer along with date, time, and position for post-processing.

The echo sounder acoustic pulse was generated with a Model OHS 200 transducer, operating with a beam width cross section of 2.75 degrees at 200 kHz. The shipboard transceiver automatically adjusts power output in proportion to the return signal, thereby yielding a clear, unambiguous record in shallow as well as deep water. The self-adjusting power varies from 1 to 225 watts at 200 kHz, and time-varied gain and automatic gain control optimize return signals.

High-density bathymetric soundings were recorded at approximately 0.30-second intervals along each hydrographic survey line. At average ship speeds of 3.0 to 3.5 knots, this resulted in depth soundings at approximately 0.5-meter intervals. This closely spaced bathymetric coverage between fix positions produced a very accurate profile of the seafloor bathymetry. Tidal corrections were applied in postprocessing, after the tide gauge data were downloaded and correlated with the survey data.

C.4.3 Self-Recording Tide Gauge

A Coastal Mini-Tide self-recording tide gauge was installed prior to commencing survey operations. The gauge was installed on the U.S. Coast Guard dock on Yerba Buena Island. The tide gauge was secured to existing pilings and the elevation for the sensor established using conventional vertical survey techniques to third order accuracy or better. The leveling was conducted utilizing a NIKON AS automatic level. The following U.S. Coast and Geodetic Survey (USC&GS) vertical control point was utilized to establish the tide gauge elevation.

- USC&GS Benchmark "Receive Reset": Elevation = +3.707 meters (MLLW)
- Tide Gauge Sensor: Elevation = -1.507 meters (MLLW)

MSL 1929 datum for the project site is 0.942 meter above mean lower low water (MLLW) as stated in a Caltrans memorandum dated December 17, 1997 (Caltrans, 1997).

C.4.7 Seismic Data Acquisition System

The major components of the data acquisition system were a seismic source, a single or multichannel hydrophone cable, a digital recording system, and/or an analog recording system. For the Phase 3 2-D Marine Geophysical survey, two types of seismic sources were used: a minisparker and a boomer plate. Three different cables were used: a 24-channel towed hydrophone cable, a 48-channel bay cable, and a single-channel towed hydrophone cable. They are briefly explained below and further specifications are listed in Table C.2. The towing arrangement is shown on Plates C.2a through C.2c. Operational photographs are shown on Plates C.3a and C.3b.

Seismic Sources. The minisparker seismic source was used for the multichannel survey, including the bay cable survey. The minisparker is composed of 40 sparking tips enclosed in a metal triangular cage with an attached float (Plate C.3a). The minisparker system emits a signal with a nominal frequency range of 40 to 850 Hz with peak energy at about 350 to 400 Hz. The minisparker provided excellent data quality except in areas of thick or gassy Young Bay Mud or in areas where dredging or filling had previously occurred. The minisparker is towed at a depth of 0.3 to 0.5 meter and fired at a rate of 0.5 second with a 300J source power.

The boomer seismic source was used for the single-channel nearshore survey. The boomer system emits a broadband pulse with a nominal frequency range of 500 to 4,000 Hz with peak energy near 800 to 1,000 Hz. The boomer signal is ideal for resolution and penetration of sand and non-gassy mud sediment horizons. The system provided data of excellent quality in areas where the surficial Young Bay Mud was less than 7 meters thick. However, the signal penetration is limited both by gravel beds and gas in the sediments and in areas where dredging and filling had disrupted the Bay floor sediment. Reflections from the boomer source were achieved from depths of over 60 meters. The boomer was towed at a depth of about 0.3 meter and fired at a rate of 0.25 second with a 100J source power.

Hydrophone Cables. The 24-channel hydrophone cable was housed in a cable filled with silicon fluid. Each receiver group consisted of five Benthos Geopoint hydrophones. The group interval was 1.6 meters and active cable length was 37.5 meters between the centers of the near (channel 1) trace and far (channel 24) trace. The cable was towed from the starboard stern with the center of the near trace approximately 5.7 meters astern of the seismic source. Tow depth was approximately 1 meter.

The 48-channel bay cable was designed to rest on the Bay floor. Each group consisted of a single hydrophone. The hydrophones were spaced 9.1 meters apart. The total length of the cable was over 450 meters. Both ends were weighted with anchors to hold them in place. A navigation fix was taken at each hydrophone location as the cable was lowered to the Bay floor.

The positions of the hydrophones were used by the seismic processor in conjunction with the shot locations to determine the common midpoints of each trace.

During the boomer survey, a single-channel hydrophone cable was used. The single-channel cable consisted of 12 Geopoint hydrophones spaced 0.3 meter apart. The total active length of the cable is 3.65 meters. The cable was towed from the port stern; the center phone was 9.4 meters behind the stern of the vessel. Tow depth was approximately 0.5 meter deep.

Data Recording Systems. Both digital (OYO DAS-1) and analog (EPC Model 1086) recording systems were used for this survey. The instrumentation and methods used for the multichannel and bay cable work were the same as that used in the 1998 Phase 1 2-D survey except for the filters applied. An internal filter was set for a low-cut frequency of 30 Hz and a high-cut was not applied. Refer to Appendix A for details of the recording system.

The boomer survey was only recorded on the analog EPC recorder. Data was amplified and filtered through a TSS 360 Shallow Seismic Processor. Data were recorded at a record length of 0.200 second (200 milliseconds). Fix marks were supplied from the navigation system on 25-meter intervals.

C.5 QA/QC PROGRAM

The QA/QC used for this survey was the same as that used in the previous surveys, except for onshore processing. An onshore processor was incorporated into the QA/QC program to immediately process some of the survey lines as they came in from the boat. This processing was done to insure that the systems were working properly and that the best quality data was obtained under the given geologic conditions. Refer to Appendix A for details of the QA/QC program.

C.6 FIELD DATA TYPES AND FORMATS

Data from multichannel systems (minisparker and bay cable) were recorded in both analog and digital formats. Data from the boomer system and the bathymetry system were recorded only in analog format. The navigation data were recorded only digitally, but are plotted on Map 4. The field data are available in the following formats:

a. Navigation
   - Shiptrack map at scale of 1:2000 (Map 4)
   - Tape with X,Y,Z (tide corrected Z) data every second

b. Tide Gauge
   - Tides recorded every 10 minutes relative to MLLW

c. Echo Sounder
   - Original analog record (not tide corrected)
   - Navigation tape with corrected depths

d. Multichannel System (minisparker and bay cable)
   - Single-channel analog monitor records from all lines
   - Copies of the digital field tapes, 8 millimeter, Society of Exploration Geophysicists (SEG) D format

e. Single-channel System (boomer)
   - Single-channel analog records from all lines

C.7 REFERENCES

California Department of Transportation (Caltrans) (1997), Internal Caltrans Memorandum dated December 17 from SFOBB Investigations Section to Office of Structure Design, Subject: Addendum - Vertical Datum, Caltrans File Nos. 04-SF-80, 04-0434A1, C1, E1, F1, G1, Project Nos. 3, 4, 5, 6, 8, 21, Bridge No. 33-0025.

Day Number	Date	Day of Week	Activity
1	5-Sept-00	Tuesday	Travel/Mobilization
2	6-Sept-00	Wednesday	Mobilization/Testing
3	7-Sept-00	Thursday	Acquiring Minisparker Data
4	8-Sept-00	Friday	Acquiring Minisparker Data
5	9-Sept-00	Saturday	Acquiring Minisparker Data/Re-mobilize for Bay Cable
6	10-Sept-00	Sunday	Acquiring Bay Cable and Boomer Data
7	11-Sept-00	Monday	Acquiring Bay Cable Data
8	12-Sept-00	Tuesday	Acquiring Minisparker and Boomer Data - Complete 2-D - Demobilization

Operations Summary:

Total Days = 8
Data Acquisition Days = 6
Days Waiting on Weather = 0
Travel/Mob/Testing/Demob Days = 2.5

SUMMARY OF FIELD OPERATIONS
2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

TABLE C.1

1. Seismic Recording System -- OYO DAS-1

   a. Number of Channels 24
   b. Record Length .....200 milliseconds
   c. Sample Rate .....0.25 millisecond
   d. Filter Parameters .....30 Hz
   e. Recording Media .....Digital Linear Tape (DLT)
   f. Recording Format .....SEG D 8048
   g. Time Break.....Syntron GCS-90 TB to Aux 1

2. Seismic Source – Minisparker

   a. Number of Tips.....40
   b. Source Power.....300 Joules
   c. Frequency Spectrum.....40 to 850 Hz
   d. Tow Depth.....0.3 meter
   e. Offset From Stern.....10.8 meters
   f. Offset From Navigation Reference .....19.5 meters
   g. Firing Rate .....0.25 seconds

3. Seismic Source – Boomer

   a. Source Power.....100 Joules
   b. Frequency Spectrum.....500 to 4000 Hz
   c. Tow Depth.....0.3 meters
   d. Offset From Stern.....4.3 meters
   e. Offset From Navigation Reference.....13.0 meters
   f. Firing Rate .....0.25 seconds

4. 24-Channel Hydrophone Cable

   a. Number of Channels 24
   b. Group Interval .....1.5 meters
   c. Phones per Group.....5
   d. Hydrophone Type.....Benthos Geopoint
   e. Tow Depth.....Approximately 1 meter
   f. Offset, Near Channel to Stern.....16.5 meters
   g. Offset, Near Channel to Navigation Reference.....25.2 meters

5. Single-Channel Hydrophone Cable

   a. Number of Hydrophones.....12
   b. Hydrophone Spacing.....0.3 meters
   c. Hydrophone Type.....Geopoint
   d. Tow Depth.....Approximately 1 meter
   e. Offset, Center of Array .....9.4 meters
   f. Offset, Center of Array .....18.1 meters

6. 48-Channel Bay Cable

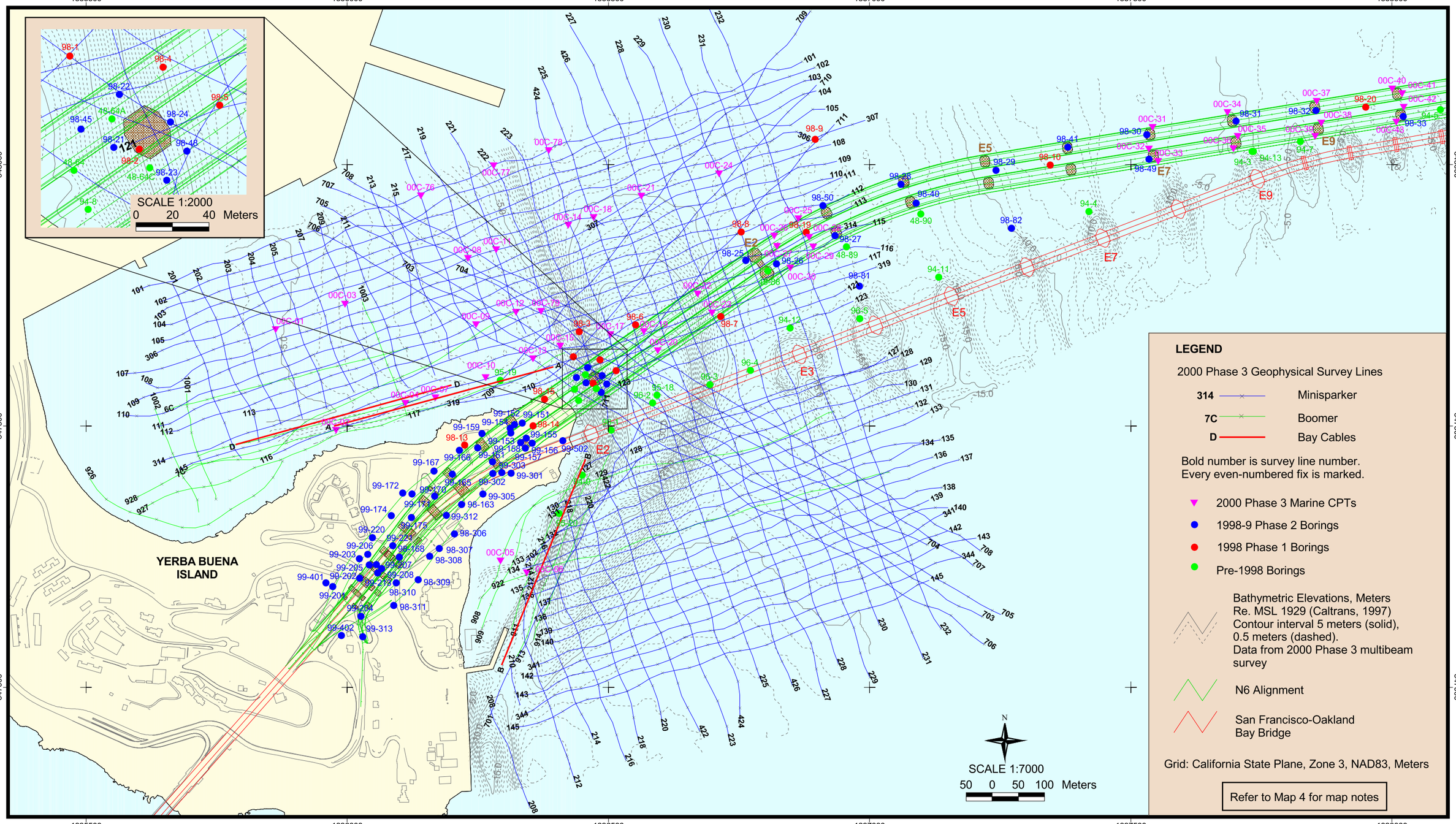
   a. Number of Hydrophones.....48
   b. Hydrophone Spacing.....9.1 meters
   c. Tow Depth.....Fixed to Bay Floor

DETAILED SPECIFICATIONS FOR
2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

TABLE C.2

Earth Mechanics

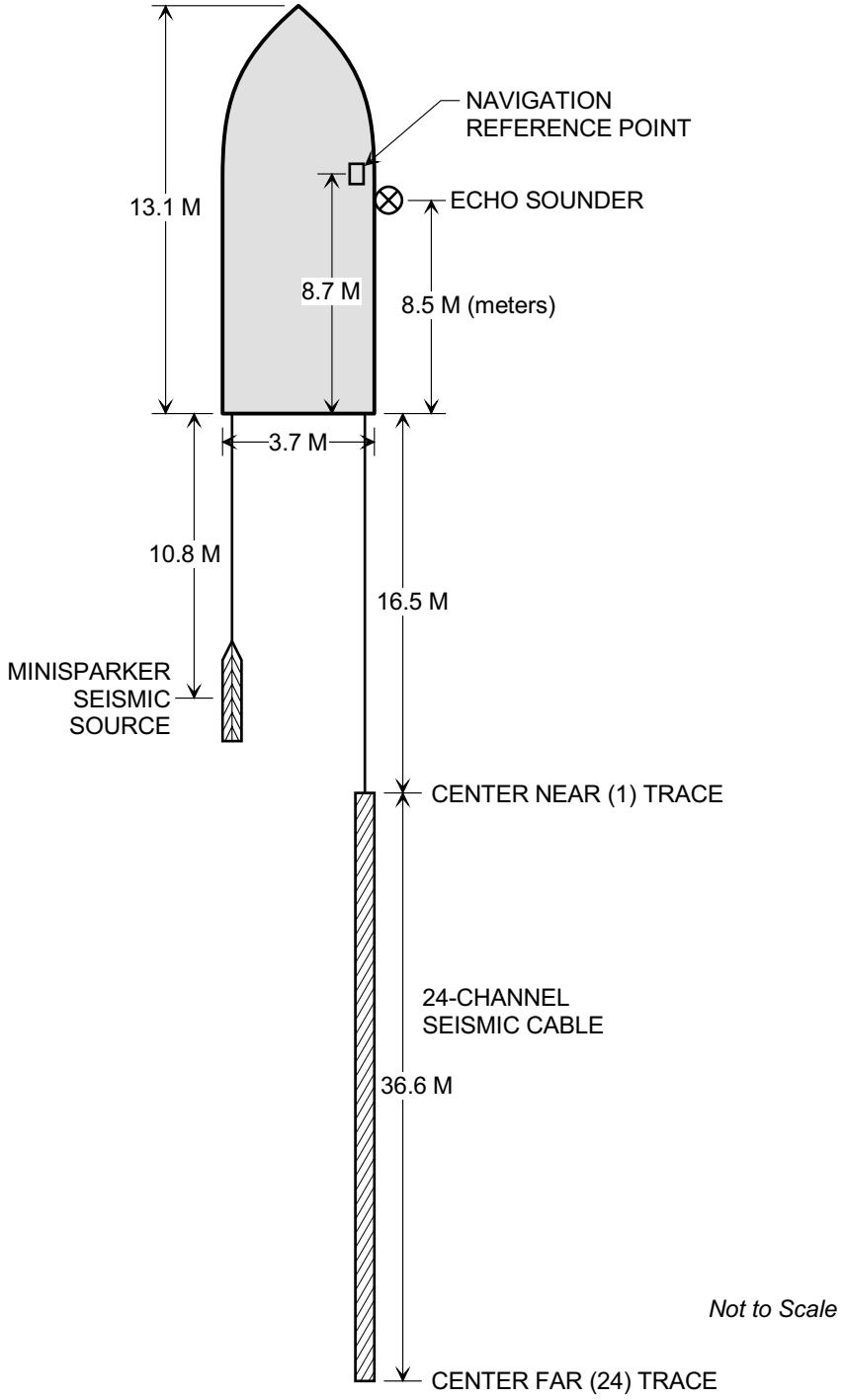
FUGRO



DATABASE MAP, 2000 PHASE 3 2-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

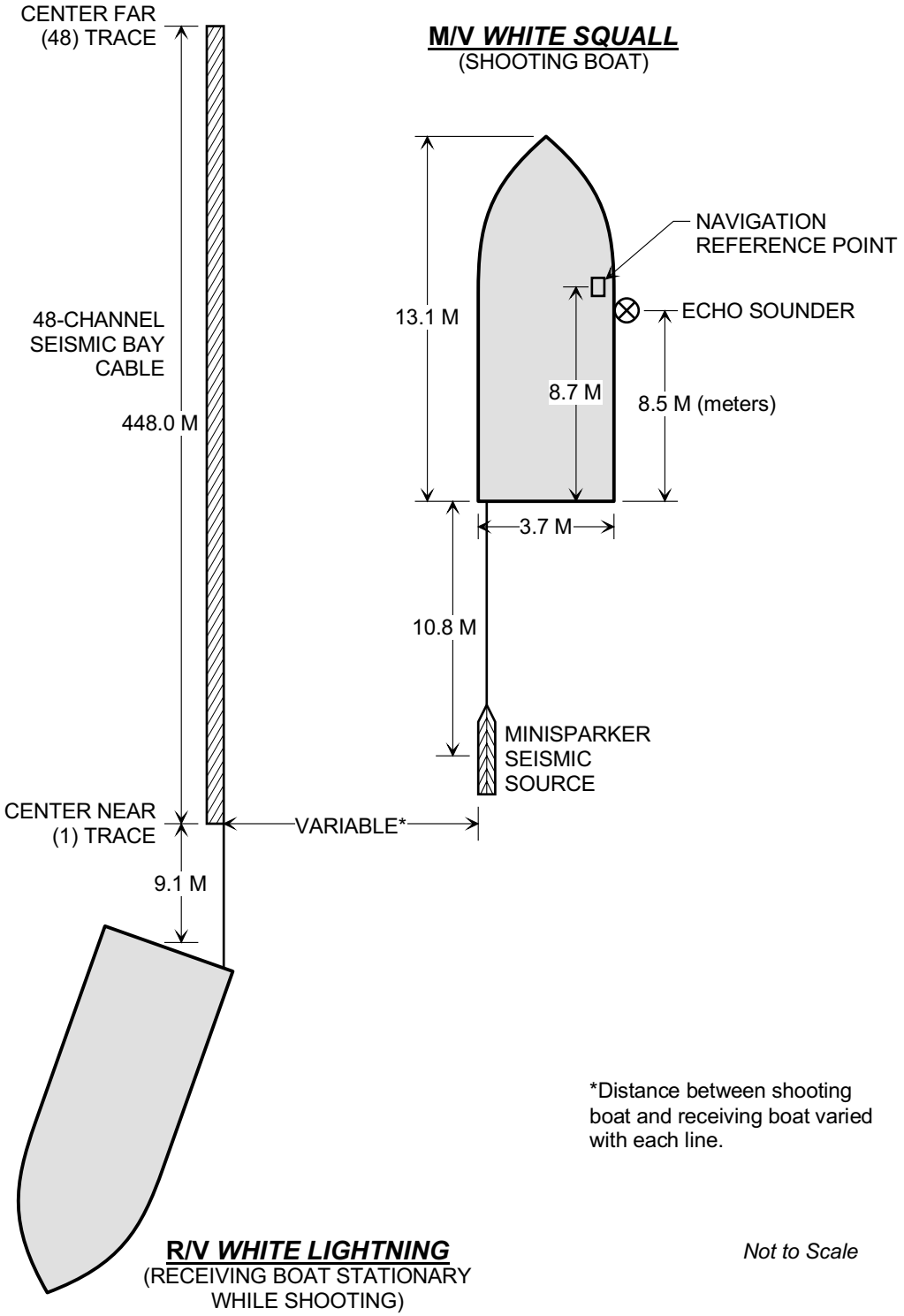
PLATE C.1

M/V *WHITE SQUALL*



INSTRUMENTATION LAYOUT, MINISPARKER SURVEY
2000 Phase 3 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

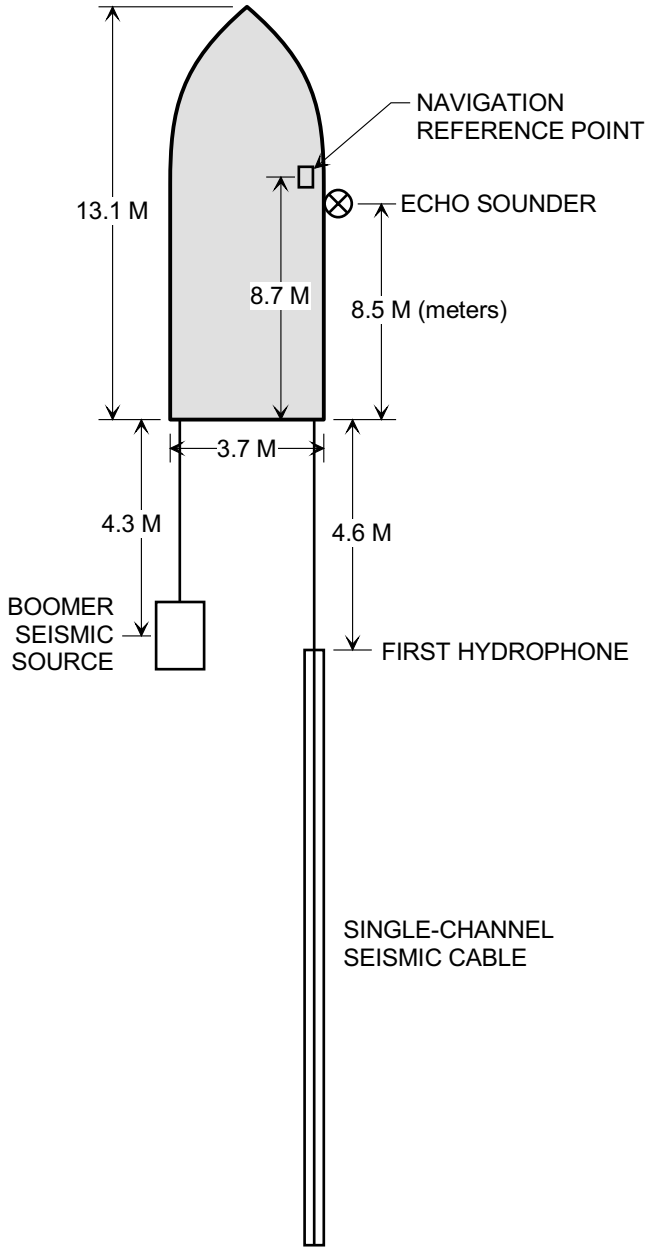
PLATE C.2a



INSTRUMENTATION LAYOUT, BAY CABLE SURVEY
2000 Phase 3 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

PLATE C.2b

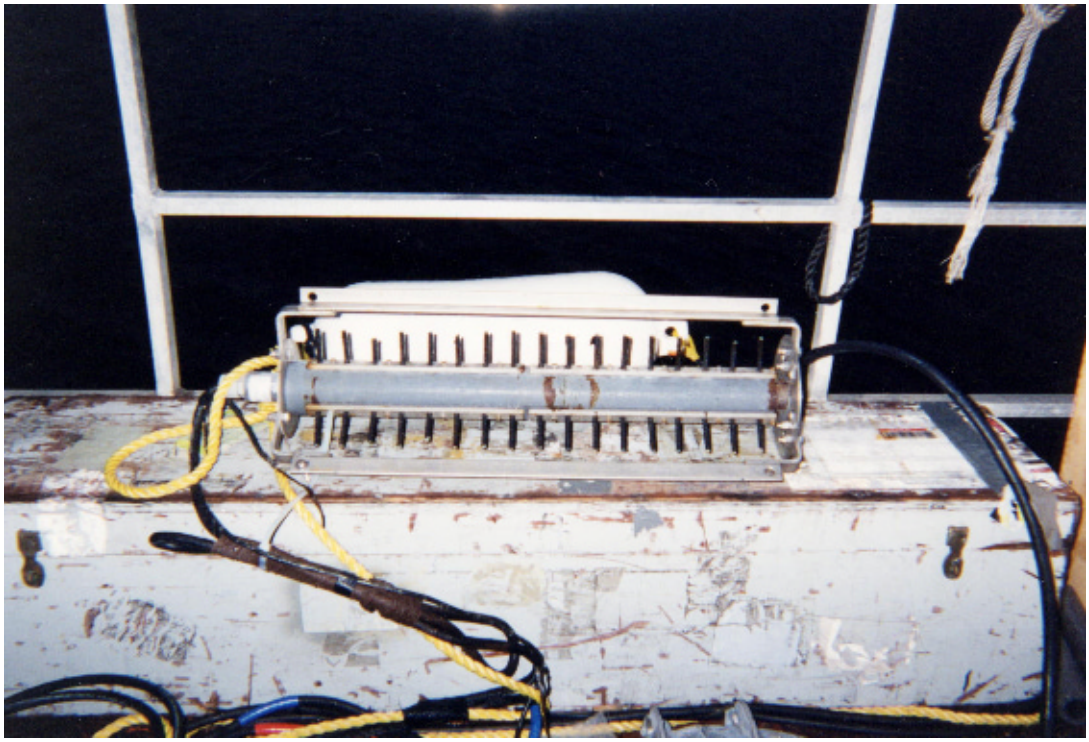
M/V WHITE SQUALL



Not to Scale

INSTRUMENTATION LAYOUT, BOOMER SURVEY
2000 Phase 3 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

PLATE C.2c

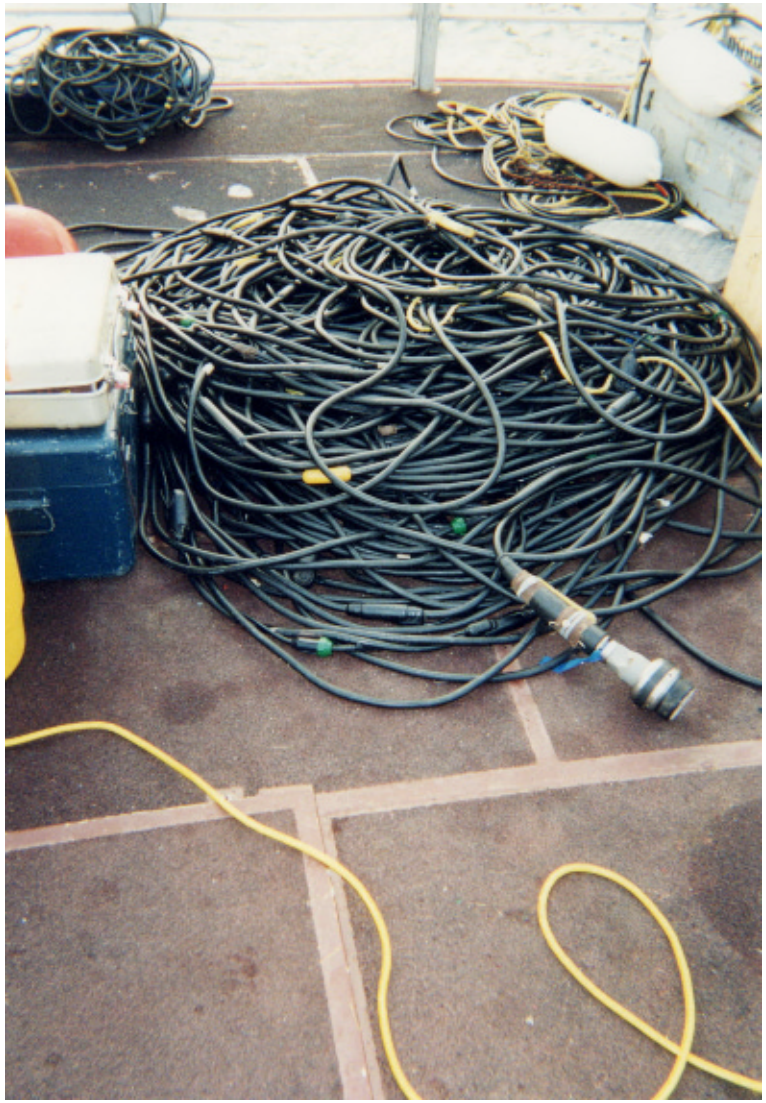


Minisparker seismic source (40 sparking tips, 300 J output).

R/V *White Lightning* used as receiving boat during bay cable operation.

FIELD OPERATIONS PHOTOGRAPHS
2000 Phase 3 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

9842\0054pht2.dsf,p4



Bay cable on deck (48 channels, 9.1 m group spacing).

Deployment of bay cable from M/V *White Squall.*

FIELD OPERATIONS PHOTOGRAPHS
2000 Phase 3 2-D Marine Geophysical Survey
SFOBB East Span Seismic Safety Project

APPENDIX D
NAVIGATION, BATHYMETRIC, AND SEISMIC DATA PROCESSING

APPENDIX D
NAVIGATION, BATHYMETRIC, AND SEISMIC DATA PROCESSING

D.1 INTRODUCTION

This appendix presents the basic details of the processes that were used to convert digitally recorded field data into the maps and seismic sections contained in the report. It is intended for those who may, in the future, have a need to use the basic field data to make additional maps, to integrate the navigation or bathymetric data with other data sets, or to reprocess the seismic reflection data.

D.2 SHIPTRACK AND GEOTECHNICAL DATABASE MAPS

Geographic coordinates of the seismic survey vessels were determined from the DGPS positioning systems described in Appendices A, B, and C. Positions were digitally recorded at 1-second intervals during the seismic field surveys. At a nominal survey speed of 4 knots, the 1-second interval represents approximately 2 meters of separation between recorded positions (fixes). The positions of all Phase 1, 2, and 3 geotechnical explorations were also determined using the DGPS system.

Coordination between geophysical data and positioning data was established by two different methods depending on whether the geophysical data were recorded digitally or only on an analog recorder.

Multichannel seismic reflection data were digitally recorded on the OYO DAS-1 system. The geographic coordinates were also digitally recorded on the OYO DAS-1 seismic data recorder at every shot point (seismic file). The seismic processor used these data along with the energy source and receiver cable geometry to calculate the location of the common midpoints for source-receiver pairs. Navigation fix marks are printed on the paper copies of the 1998 Phase 1 2-D survey seismic records. The seismic data from the Phase 1 3-D survey and Phase 3 2-D survey are in digital format (SEG-Y) for use on a seismic workstation. In the SEG-Y format, geographic coordinates are contained in the header for each trace record.

The navigation system also sent a signal to all onboard analog recorders. The signal placed a "fix mark" on the records at a nominal 50-meter interval. Analog recorders were used for the high-resolution subbottom profilers (CHIRP and boomer systems), side scan sonar, and the multichannel system near-trace monitor used for data quality control. The CHIRP and side scan sonar data also were recorded on optical tapes along with navigation data for limited post-survey processing and playback. The fix marks on the analog recorders were manually annotated with the fix number. The layback of the seismic source and receiver (Appendices A, B, and C) must be taken into account when correlating analog data with the shiptrack maps.

The digitally recorded navigation data (fixes) were edited for spurious positions. The fixes were then plotted and labeled to produce a navigation post-plot map. Fixes are plotted at nominal intervals of 25 or 50 meters depending on the scale of the maps. Points associated with a given survey line are connected, and the individual lines are also labeled. These shiptrack maps serve as the base for the bathymetric and geophysical data interpretation maps. The following horizontal and vertical datums and map parameters were used to produce all base maps for the geophysical surveys. Metric units are used on the maps and throughout the report.

Parameters	Horizontal Data	Vertical Data
Ellipsoid	Geodetic Reference System of 1980 (GRS80)	--
Datum	North American Datum 1983 (NAD83)	MSL 1929 (Caltrans, 1997) (0.942 meter above MLLW)
Projection	Lambert California Zone	--
Latitude of Origin	36°30′00.00″ N	--
Longitude of Origin	120°30′00.00″ W	--

Separate shiptrack and database maps were produced for each of the three surveys in the SFOBB investigation. The database maps generally show only the supplementary data (e.g., bathymetry and geotechnical explorations) that were completed at the time of the survey. The Bay floor cultural features and buried utilities are shown only on the Phase 1 2-D survey map. Labeling of survey line and fix mark numbers varies between maps depending on the scale of the map.

D.3 BATHYMETRIC DATA

Two bathymetric surveys were conducted during the course of this investigation. Bathymetric data were collected along all high-resolution survey lines during the 1998 Phase 1 2-D geophysical survey. This data set formed the basis for the Bay floor maps shown in the previous geophysical survey reports. A multibeam bathymetric survey was conducted as part of the 2000 Phase 3 2-D geophysical survey. The multibeam data were integrated with the 2-D survey data and tidal flat survey data to form the final bathymetric map for this report (Map 1).

D.3.1 1998 Phase 1 2-D Survey Bathymetry

The echo sounder data were digitally recorded together with navigational data. Recorded values were corrected for tidal variations and reduced to the National Geodetic Vertical (mean sea level [MSL] 1929) using the tidal elevations recorded at Yerba Buena Island during the project (Appendix A). MSL 1929 for the project site is 0.942 meter above MLLW as stated in a Caltrans memorandum dated December 17, 1997 (Caltrans, 1997).

The raw echo sounder data include highs and lows ("peaks and troughs") associated with ship motion (pitch, roll, and heave) as the boat and transducer are lifted and dropped by the

waves. To compensate for variations in soundings that are not related to Bay floor topography, the data were digitally edited using a smoothing curve. The smoothing curve reduces the amplitudes of the peaks and troughs to approximately two-thirds of their original value. Those data were reviewed and the smoothed soundings imported into Terramodel digital terrain modeling software and contoured. The contour interval is 0.5 meter from El. 0 to El. -5.0 meters and 1.0 meter below El. -5.0 meters. Final bathymetric contours from the 1998 Phase 2-D survey are shown on Maps 2 and 3 of this report.

D.3.2 Multibeam Survey Bathymetry

A multibeam bathymetry survey was conducted as one of the 2000 Phase 3 investigations. The survey covered the N6 alignment and the area of the 2000 Phase 3 geophysical survey offshore eastern Yerba Buena Island. The multibeam bathymetry is shown on Maps 1 and 4 of this report. On Map 1, the multibeam data are integrated with the 1998 Phase 1 bathymetry to show a composite of Bay floor elevations over the entire area of the geophysical investigations. On Map 4, the multibeam data offshore Yerba Buena Island are shown at a larger scale than Map 1. Refer to Appendix E for additional details of the survey, instrumentation, and processing.

D.4 1998 PHASE 1 2-D MULTICHANNEL SLEEVE-GUN PROCESSING

Two phases of processing were applied to the original 2-D seismic reflection data. The initial processing in March 1998 was based on relatively standard procedures applied to seismic exploration data sets. When this processing did not produce the desired record resolution and quality, additional processing was undertaken in May 1998 using different software. The differences in techniques and results are described below.

D.4.1 Initial Processing, March 1998

Sleeve-gun data were digitally recorded using a 12-channel cable and an OYO DAS-1 recording system (Appendix A). Initial data processing was performed by Reservoir Definition, Inc. (RDI), of Houston, Texas.

Test processing indicated that dissolved gas in the sediment seriously degraded the quality of the seismic records in some areas. Although special techniques were applied to mitigate these effects, there was often insufficient energy from the 5-cubic-inch sleeve gun to penetrate the gassy sediment and resolve any deeper layering. Since it was already known that greater penetration was being achieved with the multi-gun array in the 3-D survey, initial processing of some of the 2-D lines was deferred. All east-west tie lines, diagonal lines, north-south lines in the western one-third, and selected lines from the eastern two-thirds of the survey area were included in the initial processing sequence. As part of the QA/QC program, the testing, velocity analysis, and initial processing were reviewed by the project Registered Geophysicist in Houston.

The following processing sequence was applied during the initial processing of the sleeve-gun records:

1. Demultiplex the SEG-D format field tapes
2. Trace scaling
3. Spectral balance (30 to 475 Hz)
4. Filter (40 to 450 Hz)
5. Deconvolution (minimum-phase wavelet)
6. Interactive velocity analysis
7. Normal moveout corrections
8. Common midpoint stack, 6-fold
9. Fx deconvolution
10. Trace scaling, AGC = 0.05 second
11. Band pass filtering (100 to 400 Hz)
12. Migration

An example of an original processed line is shown in the bottom half of Plate D.1.

D.4.2 Reprocessing for Shallow Horizons

The initial phase of processing described above included a relatively standard sequence of processing subroutines used in the geophysical exploration industry. Those routines were designed to enhance reflections from deeper horizons, such as the top of the Franciscan Formation. However, these same routines often muted or washed out the higher frequency reflections from within the near-surface units such as the Young Bay Mud and Merritt Sand. This is evident in the seismic lines illustrated at the bottom of Plate D.1.

Testing of alternative processing approaches and routines, therefore, was undertaken with the specific objective of enhancing the quality of the upper 100 milliseconds of the seismic record. This section of the record may include primarily reflections from the top of the Lower Alameda Alluvial sediments, undifferentiated Old Bay Mud/Upper Alameda Marine sediments, Merritt Sand, and Young Bay Mud. Near Yerba Buena Island and the cove, the upper 100 milliseconds of the record also include the Franciscan Formation. However, the primary emphasis was placed on identifying the top of the Old Bay Mud and younger sediments. As a result of the testing, a different processor, Transylvania Geophysical Corporation (TGC), was chosen for the second generation processing to enhance the shallower reflectors.

The basic differences in the reprocessing compared to original processing are:

- Only data from the six near channels were used. Data from channels 7 through 12 were dropped from the processing.
- Automatic gain control (AGC) and Fx deconvolution were not used.

- A corrected value was used for the shot/receiver geometry, which resulted in better stacking velocities.
- A different algorithm was used to associate navigation fixes with seismic traces, which reduced minor mis-ties at line crossings.
- A "2-sum" procedure was used to enhance continuity of flat-lying reflectors.

The improvements in the shallow portion of the seismic records as a result of the reprocessing are evident in Plate D.1 and the examples of 2-D reprocessed records included with this report. Examination of Plate D.1 shows several prominent improvements including better definition of the Bay bottom reflection in shallow water, reduction of water bottom multiples, enhanced imaging of reflectors within the upper 50 milliseconds beneath the water bottom, and better resolution of some reflectors within the gassy zone. Although not specifically designed for the deeper reflectors, the reprocessed records occasionally provided images of the Franciscan Formation reflector within the gassy zones that were not evident on the original processed records.

D.5 1998 PHASE 1 3-D MULTICHANNEL SLEEVE-GUN DATA PROCESSING

D.5.1 Introduction

Three-dimensional surveys are designed to obtain data uniformly distributed over an area to accurately locate the geologic features that produce the seismic images. As discussed in Appendix A, the conduct of a 3-D survey requires closer survey line spacing and seismic energy (shot) intervals than a corresponding 2-D survey, and greater control over the positioning of both the source and the cables containing the receiver groups.

Although the 3-D seismic data are collected along survey lines as in 2-D surveys, multiple cables are used resulting in a set of closely spaced and overlapping data lines. When the 3-D data are processed, they constitute a volume as opposed to linear sections from a 2-D survey. The surface area of a 3-D survey is divided into discrete areas called bins. The recorded seismic data traces are sorted into the bins according to reflection midpoint locations for each shot-geophone (channel) pair. The traces, once sorted into bins, are independent from the survey lines from which they were collected. The resulting traces that fall into a given bin are then summed (stacked) to obtain the output trace for that particular bin. The number of traces in the bin prior to summing is called the fold. The original survey plan, described in Appendix A, was designed to obtain a minimum of 8-fold coverage with a bin spacing of 6.25 meters. Bin coverage was monitored throughout the field survey. The final field-produced bin diagrams for 6.25-meter bins showed dense data coverage north of the existing bridge, except in areas near the piers and adjacent to Yerba Buena Island (Plates D.2 and D.3).

Processing of test lines by RDI from the 3-D Marine Geophysical Survey data began while the survey was in progress. Since sufficient data for 3-D processing were not yet available

to create a data volume, the initial testing was limited to processing the first few survey lines as 2-D lines and comparing their data quality with the 2-D lines from same area. The same processing sequences were used as previously used for the 2-D lines (Section D.4.1). Improvements in data quality were noted in the area of signal penetration and better definition of the basement reflector at reflection times up to 100 milliseconds. These improvements were attributed to the greater energy and cleaner acoustic pulse of the multi-gun array used in the 3-D survey.

When the first 3-D data volume was produced, the expected improvements in data quality were not present and the initial seismic processor, RDI, began a 4-month-long period of testing and analysis to determine the cause of poor data quality for the 3-D data volume. When RDI was unsuccessful in identifying or resolving the problem, a new processor, Transylvania Geophysical Corporation, Inc. (TGC), was retained to research the problem. TGC quickly identified the problem as arising from inaccurate location of the source-receiver common midpoints provided by the Navigation Control System contractor. This in turn resulted in improper trace-bin assignments for data from many of the traces. The nature of this problem, its resolution, and subsequent seismic processing are discussed in the following sections of this Appendix.

D.5.2 Navigation Data Editing and Processing

The Navigation Control System contractor, EnSoCo, provided the Nautica Navigation System. This system accepted data from the DGPS-gyro vessel positioning system provided by Fugro Survey, the Fanbeam™ laser tracking system that tracked the position of the seismic source and receiver cable tail buoys, and the two Digicourse cable levelers on each cable. The purpose of the post-survey processing of the navigation data was to calculate the X, Y coordinates for each of the common midpoints (CMPs) of the recorded traces. Since there were over 42,000 shots during the course of the survey, and each shot was recorded on 32 to 64 channels, there were close to 2 million CMPs and associated coordinate pairs.

As stated in the introduction, the seismic processor (TGC) determined that many of these points were not located with sufficient accuracy for a high-resolution survey. EnSoCo reviewed the data and further determined that on many lines (primarily those trending east to west, parallel to and near the existing bridge), the laser positions of the source and cable tail buoys were unusable for post-processing. The specific reason for the inaccurate and missing tail buoy data is not known, but it may have resulted from cable feathering from strong currents carrying the targets outside the Fanbeam™ range.

To recover as much data as possible, EnSoCo used a "fixed-tow" model and the Digicourse compasses to provide source and receiver locations. Historically, this model has been used successfully in exploration surveys where bin dimensions were larger than in the SFOBB survey. Unfortunately, the model and resulting positions were not of sufficient accuracy

for use with the smaller bin sizes for the SFOBB survey. This error primarily affected the far traces (channels 9-16) on the east-west lines north of the bridge, where the tail buoys were not accurately tracked and also the near traces on a few lines where the tracking of the source position was lost.

Since accurate positions could not be recovered, EnSoCo identified lines and fix ranges where the errors occurred and the affected traces were eliminated from further processing by the seismic contractor (TGC).

D.5.3 3-D Seismic Data Processing

The initial processing steps for the 3-D seismic trace data were similar to those used in the 2-D processing described in Section D.4.2. Refer to Table D.1 for a description of the processing steps listed below (the descriptions in Table D.1 are modified from Sheriff [1991]):

- Demultiplex the SEG-D format field tapes
- Exponential gain recovery
- Deconvolution (spiking, operator length 40 milliseconds)
- Trace balance (scaling)
- Interactive velocity analysis
- Normal moveout corrections

Once the initial processing steps were completed for each trace, the traces were assigned to bins (see Table D.1). The bin grid was designed to be approximately parallel to the western part of the existing bridge (Piers E2 to E10). With this orientation, the lines of the bin grid would be approximately parallel to the primary survey shiptrack lines that ran between the bridge piers. The crosslines of the bin grid would be subparallel to the in-fill lines that were run parallel to the bridge and those in the cove area between Yerba Buena and Treasure Islands.

The seismic processor's (TGC) initial binning using a 6.25-meter grid produced a higher quality data volume than had been obtained by the previous processor (RDI), but still lacked the desired resolution in images of the sediment horizons in the upper 50 meters of section. Further testing showed that the near-surface data quality could be improved by eliminating all far-trace data (channels 9 to 16) and reducing the bin grid size to 3.125 meters. The grid coordinates for the 3.125-meter binning were selected as follows:

Grid Corner	Bin Line	Bin Crossline	Easting	Northing
Northwest	0	1050	1835360	648316
Northeast	0	6	1838426	649432
Southeast	543	6	1839006	647837
Southwest	543	1050	1835940	647837

These are the corners of the 3.125-meter bin grid shown on the maps and plates accompanying this report.

The final steps in the processing included stacking and normalizing the traces in the bins and 3-D migration. Further information on the binning and seismic data processing can be found in Sheriff and Geldhart (1995). The resulting 3-D data volume was produced in October 1998 and used for analyses by The KINGDOM Suite interpretation program described in the Final Report, Section 2.6.

Reducing the size of the bin grid from 6.25 meters to 3.125 meters and eliminating far traces significantly reduced the number of traces that were placed in the incorrect bins. This in turn reduced the signal amplitude smearing that occurs when seismic traces that are not from the same common midpoint are summed together in the stacking process. The downside of this process was that the fold (the number of traces being summed in a bin) was significantly reduced and many bins were left without data. These empty bins appear as blank vertical lines or blank bars (series of adjacent lines) on the seismic records illustrated in the report that were produced from the 3-D data volume. Loss of the far-offset traces also reduced the reflection amplitudes from the deeper layers below 100 milliseconds (El. -75 meter).

Plates D.2 and D.3 show the 6.25-meter binning coverage in the main survey area and the cove between Yerba Buena and Treasure Islands, respectively. Plate D.4 shows the fold counts (data coverage) for the 3.125-meter binning. The decrease in data density that results in some areas from the use of the smaller bin is evident from comparisons of the plates. The fold count from the 3.125 binning ranged from 0 to 37 with the highest density coverage in the west between Piers E2 and E4 and north of the existing bridge. Fold count along the N6 alignment west of crossline 400 in Plate D.4 is generally in the range of 5 to 11 and decreases to 6 or less east of crossline 400.

D.5.4 Limited Processing of 3-D Lines as 2-D Lines

Two-dimensional data are not subject to the same stringent positioning requirements as needed to produce a high-resolution 3-D data volume. A number of 3-D lines were chosen to be processed as 2-D lines in order to make use of some of the data that were eliminated from the 3-D processing and to fill in between lines from the earlier 2-D survey. In 2-D processing, only one of the cables was used on each line and the number of channels used ranged from 6 to 10. The 2-D data processing sequence is similar to that listed above for the 3-D processing, except there is no binning and common midpoints are calculated from the source and receiver positions, assuming that the cables were in a straight line behind the boat. This assumption appeared to be valid for the 6 to 10 channels nearest the boat on east-west-trending lines, and for most channels on north-south-trending lines that were run against the current. However, processing showed that the far-offset channels from the east-west-trending lines deviated sufficiently from a straight line and could not be included in either the 3-D or 2-D data sets.

The 3-D lines processed as 2-D lines are shown on Map 3 of this report. A comparison of relative data quality between 2-D survey lines from the January 1998 2-D survey and the February 1998 3-D survey is shown in Plate D.5. The same processing sequence was used for the two lines. The 3-D line provides a better definition of the Franciscan Formation bedrock surface at about 100 milliseconds and increased resolution of the sediment reflectors above 100 milliseconds. The 3-D lines processed as 2-D lines were used extensively in updating the structural contour maps of sediment horizons of the Top of Lower Alameda Alluvial Sediments, Near Top of Old Bay Mud, and Base of Young Bay Mud.

D.6 2000 PHASE 3 2-D AND BAY CABLE SURVEY DATA PROCESSING

Three different seismic reflection systems were used during the 2000 Phase 3 investigations (Appendix C). A 24-channel minisparker system was used over 90 percent of the survey area. The nearshore areas were surveyed with a single-channel boomer and a 48-channel bay cable system. The single channel boomer used an analog recorder and the data were not subject to post-survey processing. Processing of the multichannel systems is discussed below.

D.6.1 2-D Multichannel Minisparker Data Processing

The minisparker data were collected with a 24-channel cable producing 12-fold coverage. Transylvania Geophysical Corporation, Inc., processed the data in October 2000. The processing sequence was similar to that described in Section D.4.1. However, since a higher frequency source was used in the 2000 Phase 3 2-D survey than in the 1998 Phase 1 2-D survey, several of the steps described in Section D.4.2 were not required and it was possible to use all 24 channels providing 12-fold coverage. Plate D.6 is an example of a processed sparker line. The processing sequence is listed below and further descriptions are provided in Table D.1.

- Demultiplex the SEG-D format field tapes
- Exponential gain recovery
- Deconvolution (spiking, operator length 40 milliseconds)
- Trace balance (scaling)
- Interactive velocity analysis
- Normal moveout corrections
- Common midpoint stack, 12-fold
- Fx predictive filtering (40 to 850 Hz)
- Stolt-type f-k migration

D.6.2 Bay Cable Data Processing

The objective of the bay cable survey was to image the top of the bedrock in the offshore area immediately adjacent to the northeast end of Yerba Buena Island. The geometry for the bay cable survey lines is illustrated in Appendix C. For each of the three bay cable layouts on the

Bay floor, several source lines were run at various offsets. The actual locations of the data lines are midway between the bay cable spread and the offset source lines. The field navigator determined the position of the bay cable receivers and the shot points, but the seismic processor calculated the final coordinates of the processed lines.

The seismic data processing sequence was the same as listed above for the minisparker survey except that the filter range was 10 to 450 Hz. The bay cable had 48 channels spaced at 9.1 meters and the source firing spacing interval was 1.2 seconds (approximately 3 meters at a boat speed of 4 knots). The resulting stack is about 40 fold, but varies slightly along each individual line.

Plate D.7 is an example of a processed bay cable line. The shooting line was offset about 40 meters from the bay cable line. The lack of data in the upper 40 milliseconds of the record represents the one-way travel time from the source to the receivers on the bay bottom. Note that there is no bay bottom reflection since the cable was lying directly on the bottom. However, the reflection from the top of the Franciscan Formation bedrock is very strong.

D.7 GLOSSARY AND REFERENCES

D.7.1 Glossary

Seismic data collection and processing have an extensive vocabulary of terms with specific meanings as applied in the geophysical industry. Table D.1 provides a description of a few of the terms used in the discussions of data processing in Appendix D. Table D.1 is not meant to be a complete list of all the terms and the descriptions are restricted to the context of their usage in Appendix D. For detailed descriptions of the seismic processing procedures, refer to Sheriff (1991) or Sheriff and Geldart (1995).

D.7.2 References

California Department of Transportation (Caltrans) (1997), Internal Caltrans Memorandum dated December 17 from SFOBB Investigations Section to Office of Structure Design, Subject: Addendum - Vertical Datum, Caltrans File Nos. 04-SF-80, 04-0434A1, C1, E1, F1, G1, Project Nos. 3, 4, 5, 6, 8, 21, Bridge No. 33-0025.

The following two references provide further descriptions of the processes referred to in this appendix:

Sheriff, R.E. (1991), Encyclopedic Dictionary of Exploration Geophysics, Society of Exploration Geophysicists, Tulsa, OK, pp. 376.

Sheriff, R.E., and Geldart, L.P. (1995), Exploration Seismology, Second Edition, Cambridge University Press, New York, NY, pp. 592.

Terms	Description (as used in the context of Appendix D)
Automatic gain control (AGC)	An automatic system of controlling amplification or attenuation of a seismic trace to compensate for variations in input signal strength.
Bin, binning	One of a set of discrete areas into which a survey area is divided. In a 3-D survey area data traces are sorted into bins depending on midpoint or reflecting point locations. The process of correlating seismic traces with specific bins.
Channel	A single series of interconnected devices (geophones or hydrophones) through which data can flow from a source to recorder.
Common-midpoint (CMP)	Having the same midpoint between source and receiver. Sometimes called common-reflection point and common-depth point. A multichannel survey is designed so many source-receiver combinations have the same CMP.
Crossline	The direction at right angle to the direction in which the data were acquired. A vertical (seismic) section extracted from a 3-D data volume in the crossline direction.
Deconvolution	Any one of several processes designed to restore a wave-shape to the form it had before it underwent a linear filtering action. The objective is to nullify objectionable effects (such as multiple reflections, ghosts, ringing) of an earlier filtering action.
Demultiplex	The process of separation of multichannel data recorded on a single channel (multiplexed) back into individual channels of data.
Filter, filtering	A part of a system that discriminates against some of the information entering it. In seismic processing filtering is done with a digital filter usually to eliminate undesirable frequencies or amplitudes.
f-k	A prefix for the frequency-wave number domain. Applied to both filtering and migration.
Fold, fold count	The multiplicity of CMP data. If the CMP is the same for 12 traces the data is referred to as 12 fold.
Geophone, hydrophone or phone	The instrument (receiver) used to transform seismic energy into an electrical voltage. A geophone is sensitive to particle motion (ground shaking) and used on land, a hydrophone is sensitive to pressure and used in water.
In-line	Along a survey line. For a 3-D survey may imply the direction in which the data were acquired or may be an arbitrary direction.
Migration (seismic)	An inversion operation involving placing reflections and diffractions at their true subsurface locations on the seismic records.
Mis-tie	The difference of values (e.g. water bottom or seismic reflectors) at identical points on intersecting seismic lines or of values determined by independent methods.
Normal moveout	The variation of seismic reflection arrival times from the same point due to different source-receiver distances (offsets).
SEG-D, SEG-Y	Standard data formats available from publications by the Society of Exploration Geophysicists (SEG)
Shotpoint, shot	The location of a source of seismic energy release. Originally applied to dynamite explosions (shots) but also used for other sources such as air-guns, sparkers, etc.
Stack, stacking	A composite record made by combining traces from different records. Common-midpoint stack is the sum of traces corresponding to the same CMP. The objective is to improve the signal to noise ratio.
Trace (seismic)	The record from one shot from one seismic channel.
Wavelet	A seismic pulse usually consisting of only a few cycles.

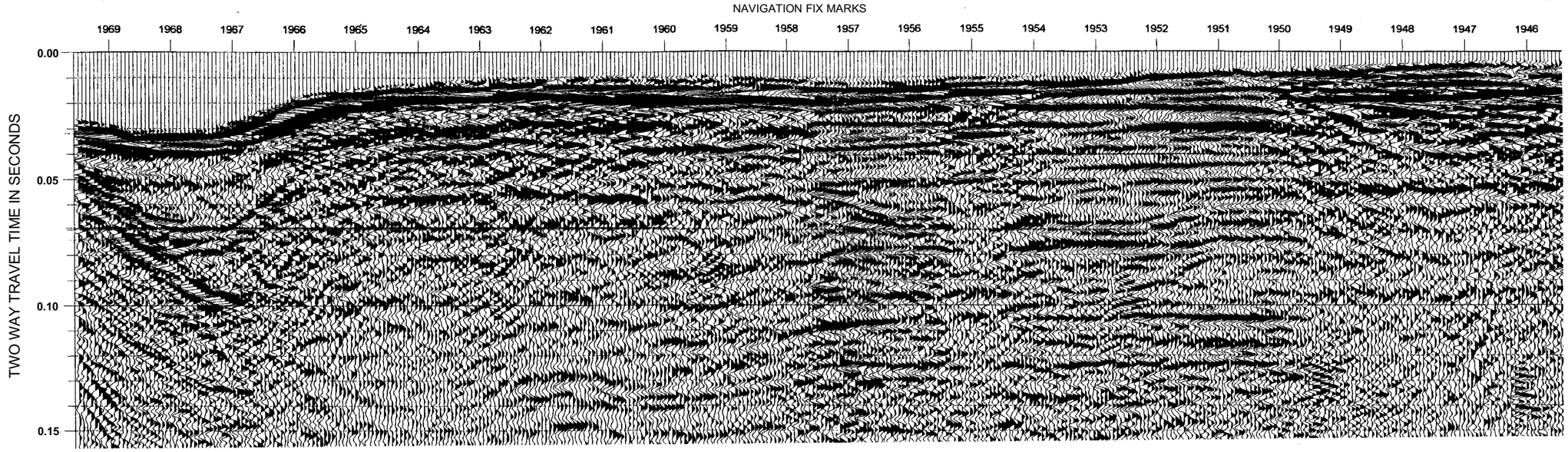
GLOSSARY OF TERMS USED IN DISCUSSION OF SEISMIC PROCESSING
1998 PHASE 1 3-D MARINE GEOPHYSICAL SURVEY
SFOBB East Span Seismic Safety Project

TABLE D.1

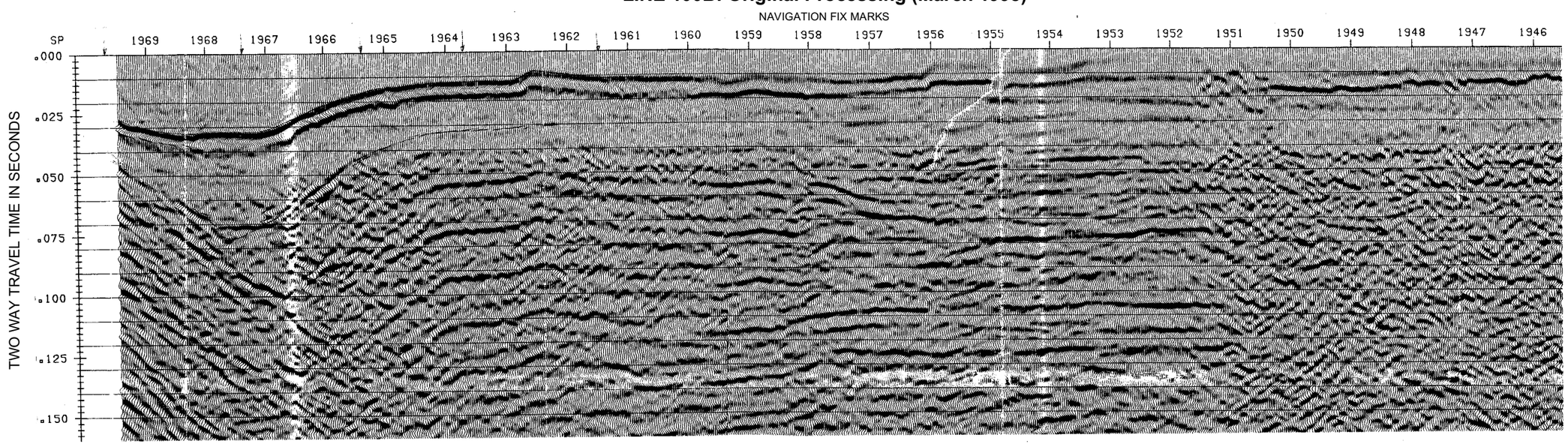
Earth Mechanics FUGRO

LINE 100B: Reprocessed Record (May 1998)

WEST EAST



LINE 100B: Original Processing (March 1998)



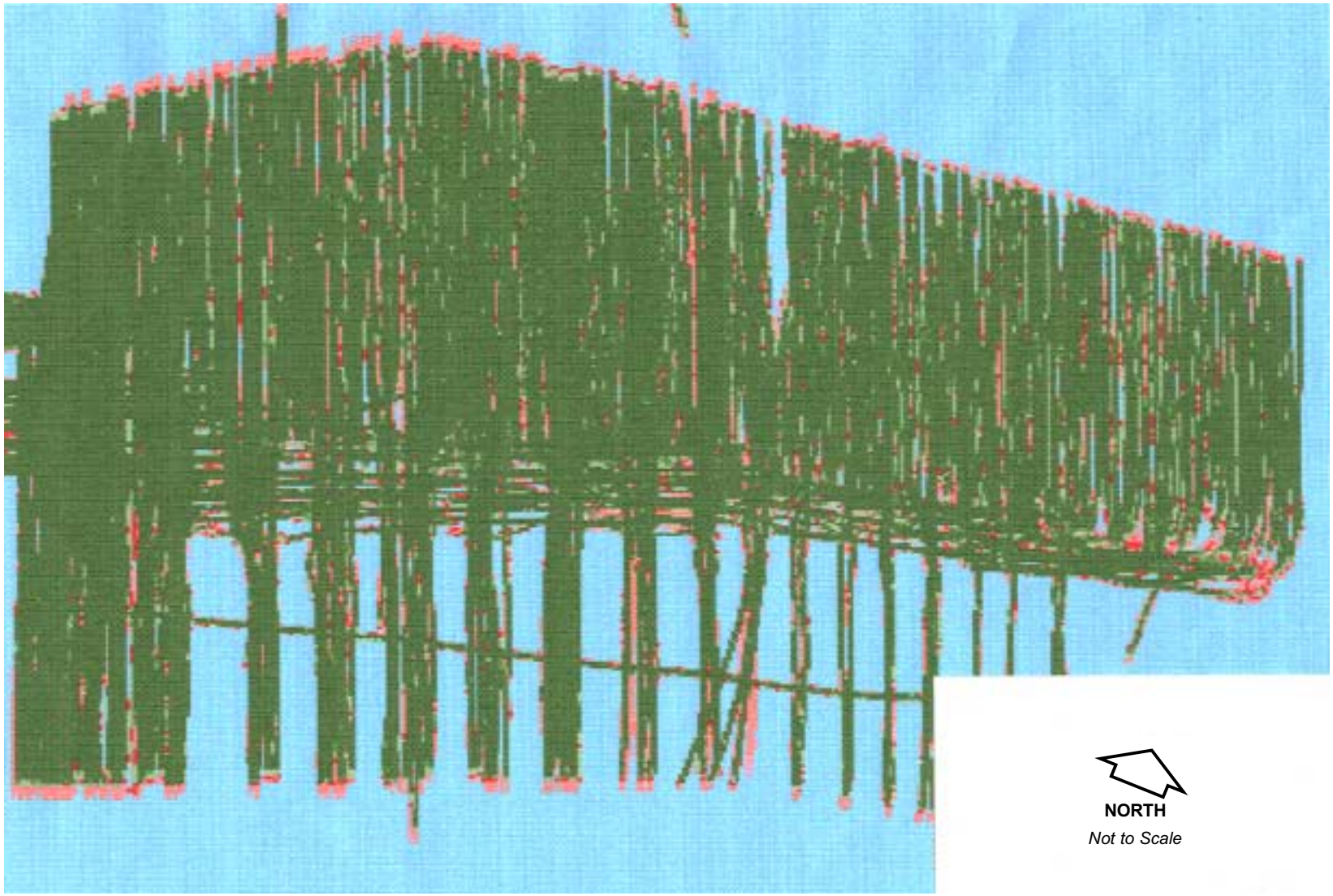
NOTES: 1) Refer to Section D.4 for discussion of reprocessing techniques.

2) Upper, reprocessed record shows significant improvements in:
   a) Indentification of Bay bottom reflection,
   b) Reduction of water bottom multiple reflections,
   c) Resolution of reflectors within the upper 50 milliseconds of section beneath Bay bottom, and
   d) Resolution of shallow reflectors within the gas zone east of fix point 1952.

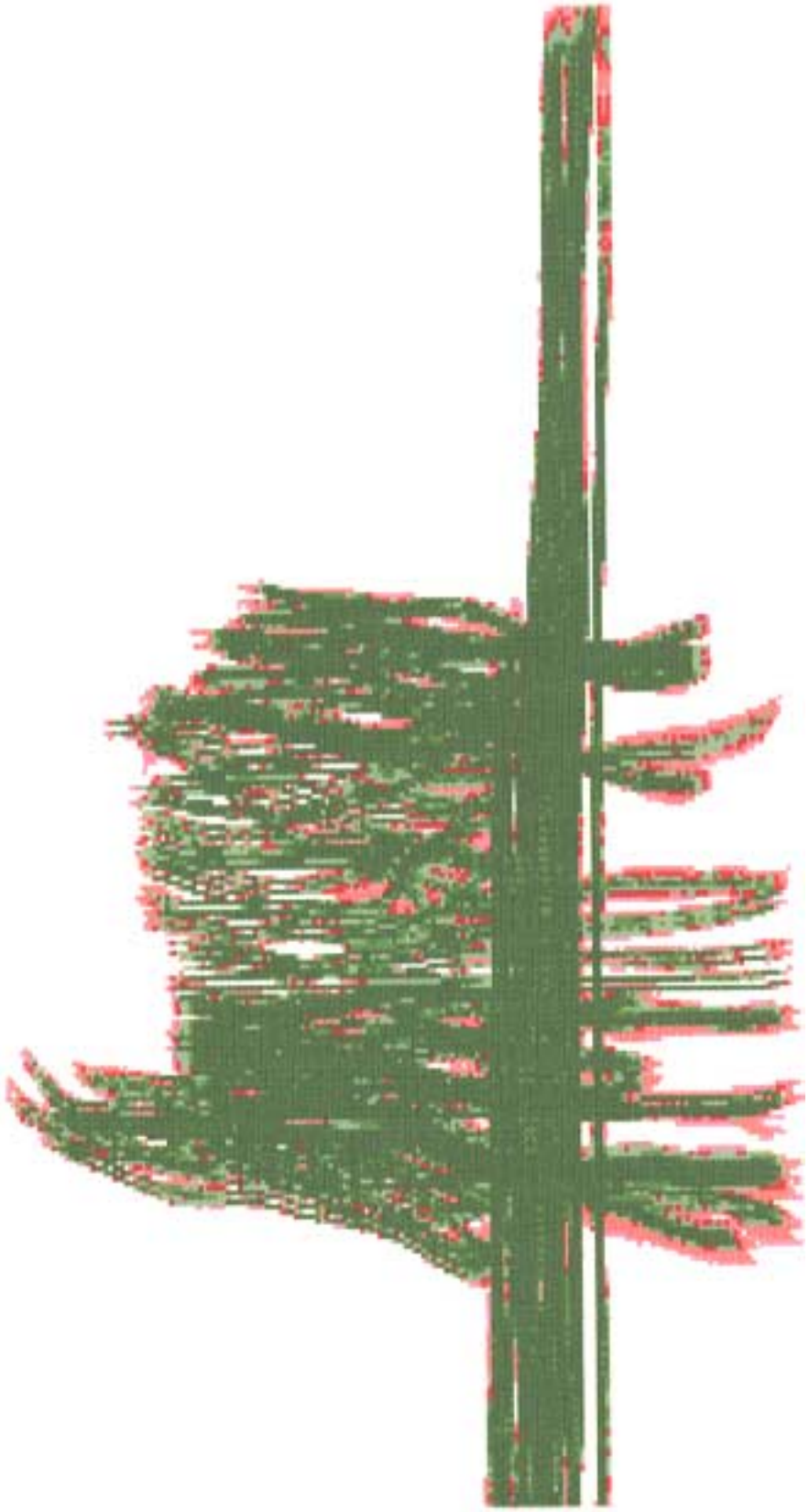
2-D PROCESSING COMPARISON
SFOBB East Span Seismic Safety Project

PLATE D.1

9842\0054recs.dsf(1.2)



3-D SURVEY COVERAGE, MAIN SURVEY AREA
6.25-METER BINNING, ALL OFFSETS
SFOBB East Span Seismic Safety Project

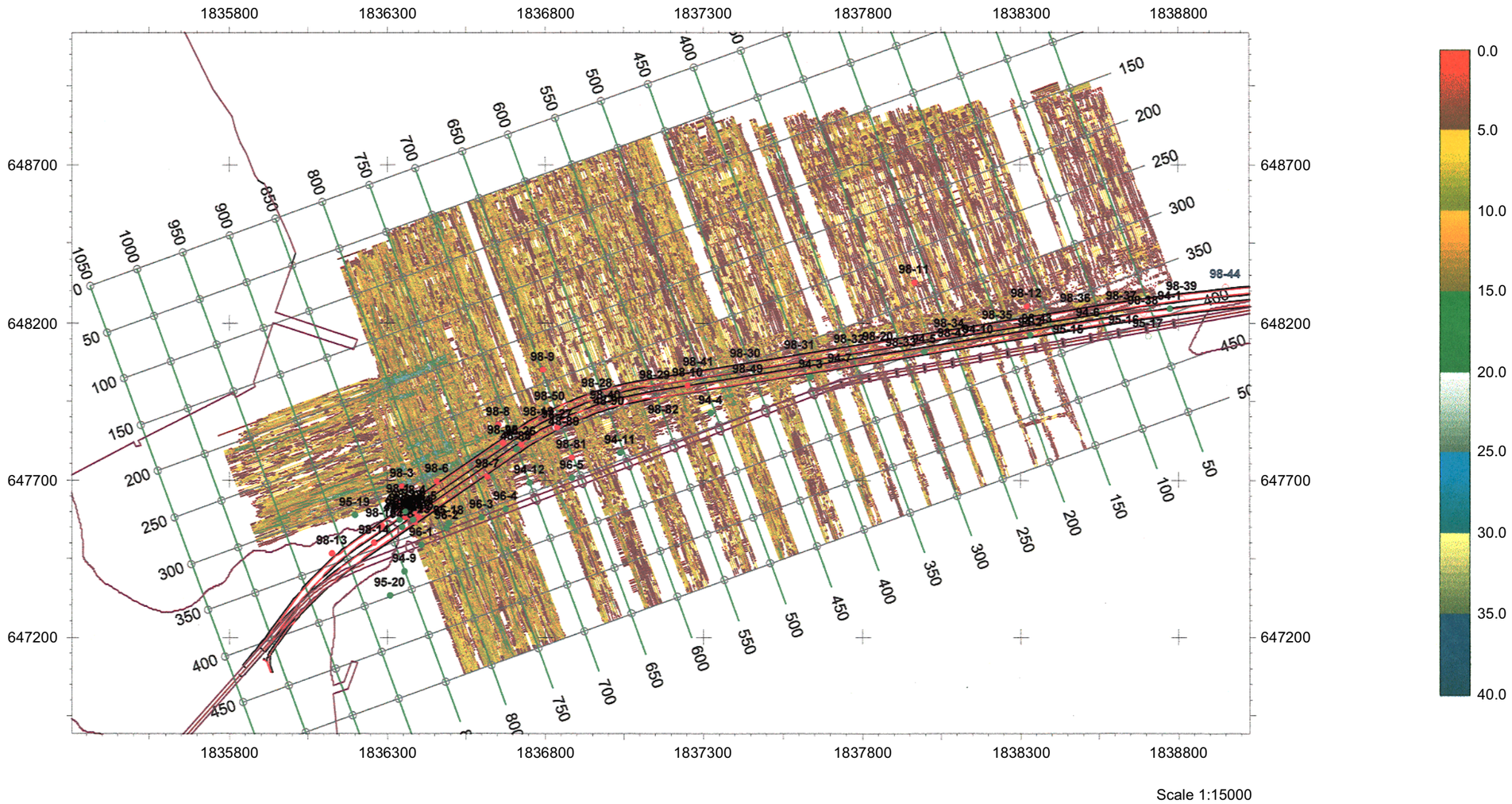


NORTH

Not to Scale

3-D SURVEY COVERAGE, COVE AREA
6.25-METER BINNING, ALL OFFSETS
SFOBB East Span Seismic Safety Project

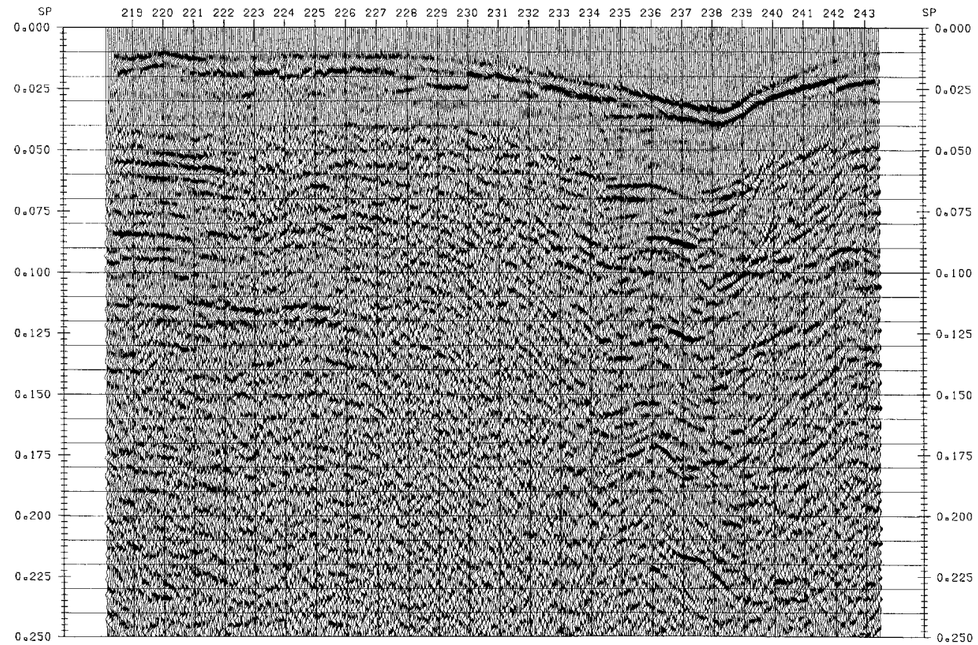
PLATE D.3



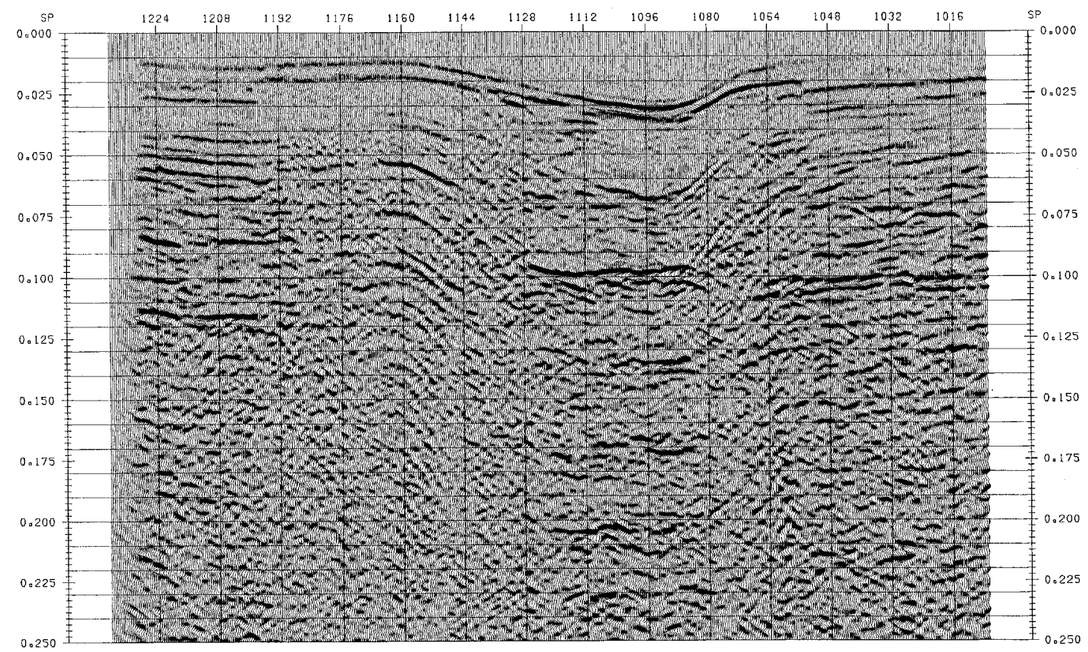
3-D SURVEY, 3.125-METER BIN FOLD COUNT
SFOBB East Span Seismic Safety Project

PLATE D.4

NORTHWEST **LINE 22** SOUTHEAST



NORTHWEST **LINE 73I2** SOUTHEAST



NOTES:

1. Both lines were collected approximately along the same line using a multichannel streamer.

2. The lines have been aligned to show the same features and are at the same scales.

3. The source for 2-D survey line 22 was a single sleeve gun for 3-D survey line 73I2, a multiple-gun array was used. Processing sequences were identical.

4. The improved record quality of 73I2 results from a higher energy source and a "cleaner" acoustic pulse from the multiple-gun array.

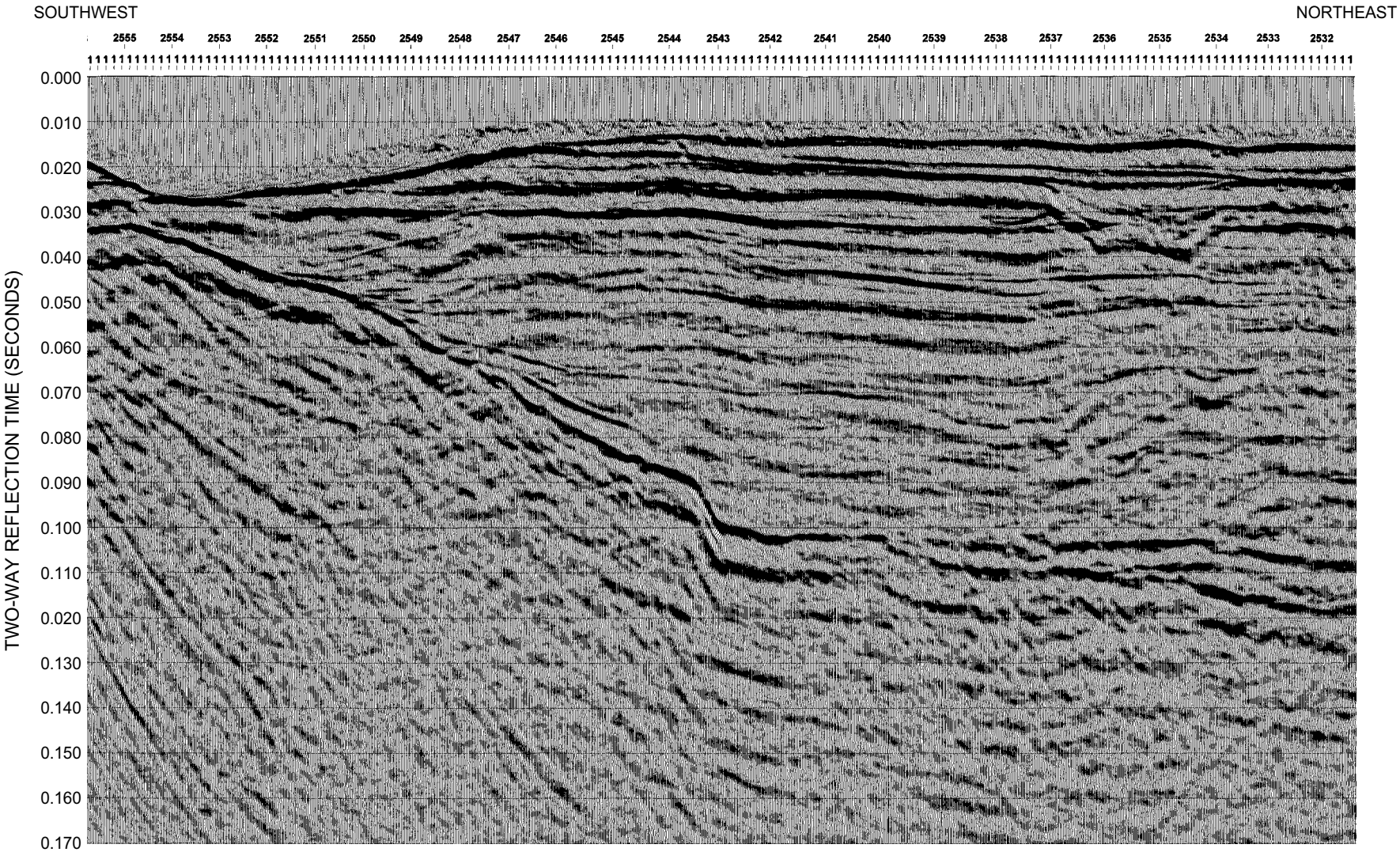
5. Refer to discussion in Section D.5.4.

COMPARISON OF 2-D AND 3-D PROCESSED SLEEVE-GUN RECORDS
SFOBB East Span Seismic Safety Project

PLATE D.5

9842\0054proc.dsf(1,2),p1

SFOBB Task Order No. 5
Project No. 98-42-0054



24-channel minisparker line, southwest side of Yerba Buena Island. Note the greater resolution of buried channels, on-lap horizons, and bedrock reflectors compared to other data examples in this appendix.

PROCESSED MINISPARKER RECORD EXAMPLE

SFOBB East Span Seismic Safety Project

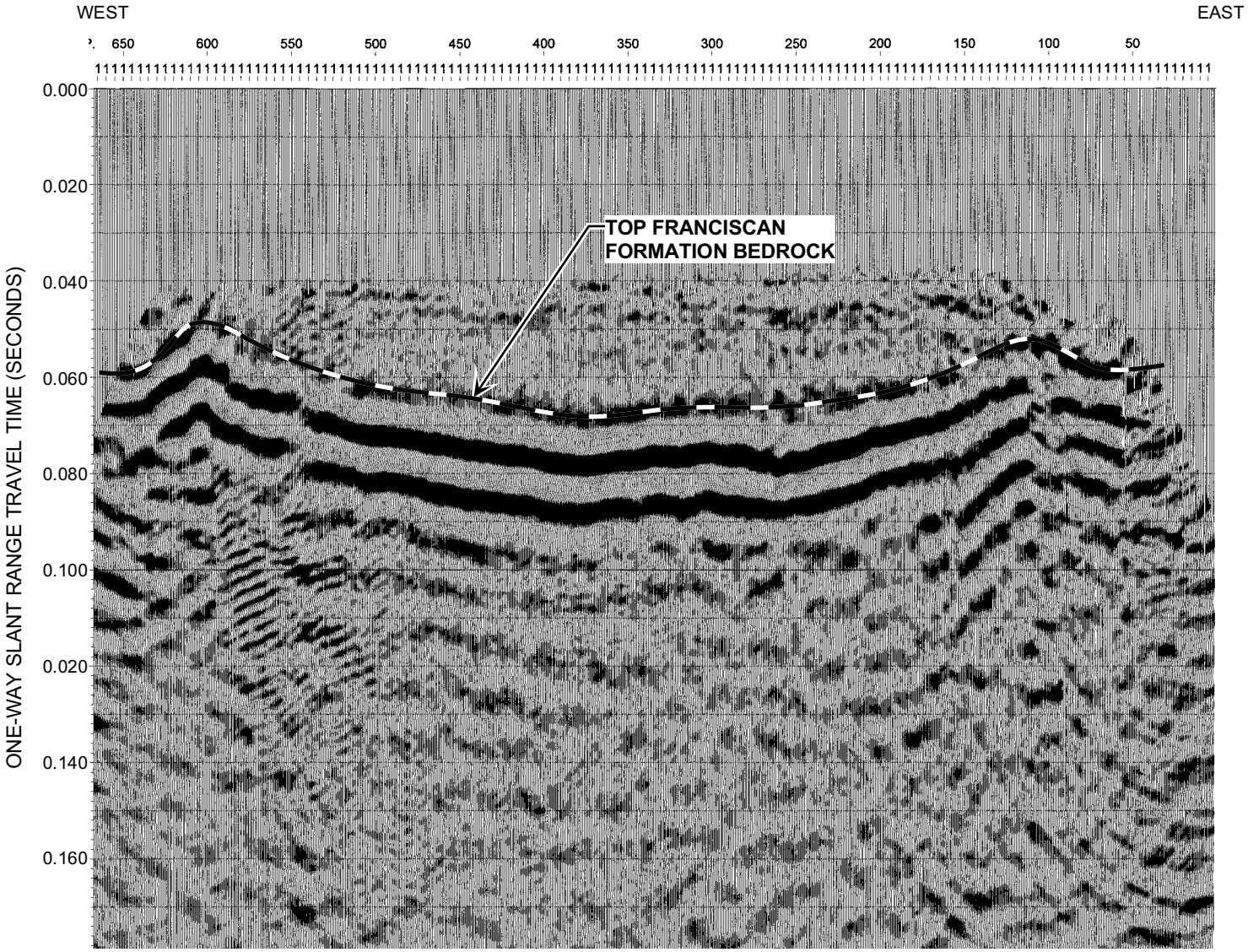
Earth Mechanics

FUGRO

PLATE D.6

9842\0054proc.dsf(1,2),p2

SFOBB Task Order No. 5
Project No. 98-42-0054



Bay cable Line 1003, northeast side of Yerba Buena Island.

PROCESSED BAY CABLE RECORD EXAMPLE

SFOBB East Span Seismic Safety Project

Earth Mechanics

FUGRO

PLATE D.7

APPENDIX E
2000 PHASE 3 BATHYMETRIC SURVEY OPERATIONS AND DATA PROCESSING

APPENDIX E
2000 PHASE 3 BATHYMETRIC SURVEY OPERATIONS AND DATA PROCESSING

E.1 INTRODUCTION

Two bathymetric surveys were performed during the 2000 Phase 3 investigations. A multibeam (swath) survey was conducted between the Oakland Mole and Yerba Buena Island and around the eastern end of the island (Plate E.1). A single beam survey was conducted in the tidal flat area on the north side of the Oakland Mole. The objective of both surveys was to obtain more detailed bathymetric data in potential construction areas than was available from the 1998 Phase 1 survey described in Appendix A.

The advantage of using a multibeam system lies in the measurement precision and data coverage. The multibeam system surveys a swath of the seafloor with each pass of the survey vessel. This swath mapping results in a continuous image of a strip of the Bay floor (Plate E.2). The swath width is dependent on the depth of the water. Survey trackline spacing is adjusted to provide overlapping coverage of the swaths to insure 100-percent coverage of the Bay floor in the survey area. The multibeam survey of the N6 alignment and Yerba Buena Island area resulted in over 92 million individual soundings.

In comparison, conventional single-beam bathymetric data are limited to soundings along the individual shiptrack lines over which the survey was conducted. The single-beam 1998 Phase 1 bathymetric survey was run on a 50-by-100-meter grid. Estimates of Bay floor elevations within the grid are based on interpolations from soundings along the survey (grid) lines. Both the 1998 Phase 1 and 2000 Phase 2 bathymetric data are shown on 1:5000 scale maps accompanying the report. Although the overall area in which the multibeam survey was conducted was smaller than that of the 1998 Phase 1 survey, the multibeam survey provided much greater detail of Bay floor features along the N6 alignment. This increase in precision is best observed by comparison of the contour patterns of the scour channels around the existing bridge piers (Map 1 - multibeam data, and Map 2 - single-beam data).

The shallow water depths of the tidal flat area on the north side of the Oakland Mole precluded the use of the multibeam system. It was necessary to use a very shallow draft vessel (inflatable rubber boat), a small shallow draft transducer, and two-man crew to collect data in this area. The area covered by the tidal flat survey is shown on Plate E.3.

E.2 MULTIBEAM SURVEY

E.2.1 Multibeam Bathymetry Field Operations

The Phase 3 multibeam bathymetry survey was conducted on May 14-18, 2000. Multibeam data acquisition was performed from aboard the M/V *Julie Ann*, Fugro's 7.9-meter shallow water geophysical survey vessel. Mobilization of the multibeam equipment systems onto the vessel was conducted at Fugro's Ventura facility. The vessel was hauled on a trailer from Ventura to Oakland with all equipment systems installed. The multibeam survey lines were designed to cover the N6 alignment corridor, with the primary survey lines running parallel to the design route. Perpendicular survey lines supplemented the primary lines, in part for correlation purposes, but also to better define the scour around the existing Bay Bridge support columns. This survey line configuration provided comprehensive bridge route corridor survey coverage.

Field operations started May 14, 2000, with the survey and installation of the tide gauge. Vessel-based multibeam data acquisition began on May 16 and concluded on May 18. Data evaluation and processing followed thereafter.

Multibeam data were collected continuously along survey lines nominally spaced 10 to 15 meters apart. Navigation, motion, and multibeam data were continuously recorded to a Reson 6042 data acquisition system. Navigation and motion data were provided from a TSS POS/MV 320 inertial motion reference system while multibeam data were provided from Reson Model 8101 multibeam sonar.

A Coastal Micro-Tide self-recording tide gauge was installed on the U.S. Coast Guard dock on Yerba Buena Island prior to commencing survey operations. The tide gauge was secured to existing pilings, and the elevation for the sensor established using conventional vertical survey techniques to at least a third order accuracy. The leveling was conducted utilizing a NIKON AS automatic level. The U.S. Coast and Geodetic Survey (USC&GS) vertical control point was utilized to establish the tide gauge elevation.

- USC&GS Benchmark "Receive Reset": Elevation = +3.707 meters (MLLW)
- Tide Gauge Sensor: Elevation = -1.507 meters (MLLW)

All elevations on the project are referenced to MSL 1929 datum that is 0.942 meter above mean lower low water (MLLW) as stated in a Caltrans memorandum dated December 17, 1997 (Caltrans, 1997).

Prior to each day's survey, a comprehensive calibration was carried out to calibrate the different components of the multibeam system. The multibeam calibration accurately measures the angular mounting components of the correction sensors (roll, pitch, and yaw) – compensating for errors in these measurements is required to enable accurate surveys. The calibration test is a

data collection and processing procedure to calibrate these angles along with position system latency.

During survey operations, all correction sensor and multibeam data were time tagged and logged with the 6042 data acquisition system. At the start of each survey day, speed of sound in seawater was determined by a sound velocimeter profile. Additionally "bar check" calibrations were carried out for the multibeam system. Correction sensor calibration factors and sensor offsets are applied during data collection. Sound velocity profile data and tide corrections were applied in post-processing and correlated with the survey data.

Fugro personnel on this survey included:

Individual	Title
Shawn Johnson – RLS, Certified Hydrographer	Project Manager / Data Processing
Kevin Morris	Vessel Data Collection
Jeff Babbitt	Vessel Data Collection
Joe Mucha	Tide Gauge Installation

E.2.2 Multibeam Survey Instrumentation

The integrated multibeam bathymetric survey system included the components listed below. Descriptions of the instruments are given in this section and a schematic diagram of the integrated layout is shown on Plate E.2.

- Reson Seabat 8101 Multibeam Bathymetric Sonar
- TSS POS/MV 320 DGPS/Inertial Reference System
- Reson R6042 Multibeam Data Acquisition System
- Coastal Micro-Tide Tide Gauge
- AML SV-Plus Water Column Sound Velocimeter
- Hysweep Multibeam Software Processing Systems
- Survey Vessel

Reson Seabat 8101 Multibeam Sonar. The 8101 sonar transmits a fan beam with a vertical beam width of 1.5 degrees at 240 kHz. The 101 simultaneous-receive beams have a vertical beam width of 15 degrees, and a horizontal beam width of 1.5 degrees. Convolution of the transmit and receive beam patterns will result in 101 individual beams with a square beam width of 1.5 degrees providing total 150 degree swath coverage.

The 101 beams are sampled at intervals corresponding to 1.25-centimeter range resolution, and the intensity data is displayed in full real time together with the readout of the detected bottom. This ability to display the raw sonar data gives the operator excellent quality

control facilities. Apart from an instant quality check, the sonar intensity image and the corresponding digitized bottom samples can be recorded on a VCR for future use and documentation. It also allows the operator to detect features that cannot be described in the reduced data set.

The 101 detected bottom samples are read out on a serial port at up to 30 times a second. The format is X, Z relative to the acoustical center of the sonar head. Compensation for heave, pitch, and roll, as well as navigation, is done externally.

TSS POS/MV 320 GPS/Inertial Motion Reference System. The POS/MV delivers full 6 degrees-of-freedom position and orientation solutions for marine survey vessels. The POS/MV outputs all motion variables at a high rate: position, velocity, heave, roll, pitch, true heading, acceleration vectors, angular rate vectors. The system combines GPS/DGPS with rugged high-quality inertial sensors. The system measures true heading together with roll and pitch to 0.5-degree accuracy or better under dynamic conditions including hard turns and rapid acceleration/deceleration with heave accuracy of 5 centimeters or 5 percent, all in real time.

Reson 6042 Multibeam Data Acquisition System. The 6042 combines hardware and software designed and developed to enable comprehensive collection and QC of multibeam bathymetric data. The operator is in full control of each area of the Seabat 6042 process from data storage to information display. Numerous predefined windows are available to view collected and corrected multibeam data, single/dual profiles, plan view, 3D wiggle, and waterfall type displays can be selected. The Seabat 6042 time-tags all received sensor data to an accuracy of 1 millisecond, interfaces to a Grid Coordinate System, and stores all raw data for instant, replay, or chart transfer to the chart mapping system.

Applied Microsystems SV Plus Sound Velocimeter. The SV Plus velocimeter is a lightweight, rugged, intelligent profiler that records high-resolution sound velocity profiles of a water column to depths of 5,000 meters. Sound velocity is measured directly using acoustic time of flight sensor rather than calculated from CTD measured parameters. The SV Plus offers the options of logging data continuously, at user-selected depth increments, time increments, sound velocity increments, or upon request.

Software Systems. Hypack software programs were utilized to record and process the multibeam data. The Hypack MS Windows computer system provides navigation capability during the survey and interfaces with the positioning system (DGPS) and heading sensor (Gyro). The Hysweep program provides calibration, playback, editing, and binning capability of the multibeam data. At the conclusion of field data collection, the Seabat 6042 downloads the survey data to the Hysweep programs for post-survey processing.

E.2.3 Multibeam Data Processing and Mapping

Fugro West, Inc., in Ventura performed processing and mapping of the multibeam data. Two primary data processing software systems were used to process and present the multibeam data. Hysweep (by Coastal Oceanographics) was used to edit and bin the raw multibeam data set consisting typically of millions of discrete XYZ (geographic coordinates and water depth) data points. The software was utilized to bin (see glossary in Appendix D) the data set prior to modeling and contouring of the data. Terramodel and Terravista Digital Terrain Modeling (DTM) software packages by Spectra Precision were used to contour and generate 3-D models of the edited bathymetry data (Plate E.4) and produce the final maps. Processing procedures and mapping are further described below:

- Raw multibeam data collected with the Reson 6042 system were converted and exported into Hypack format using the Reson R6042 software program. Tide and sound velocity correction data files were developed separately in the Hypack program from observed tidal measurements and sound velocimeter data. Data coverage was verified using Hypack Replay mode. In this operation, a matrix file was constructed to form a suitable post-editing data bin grid. For this project, a 2-meter-square bin size was selected.
- The Multibeam Editor function of Hysweep is then used to merge and edit the raw multibeam data with the tide, sound velocity profile, heading, and motion sensor data. These operations result in edited XYZ data points referenced to MLLW. Valid data points were selected based on using data quality assessments made by the Reson 8101 system. Only Quality 3 data are accepted, data points registered as Quality 0 through 2 were discarded from the data set. The corrected XYZ data points are then imported into the Sort and Mapper functions and merged with the BIN Matrix file. Edited data are then processed into suitable grid size with the average of the grid readings placed in the center of the grid cell to create the final data set.
- The final data set is then imported into Terramodel software to view the initial XYZ data set and to apply any datum adjustments that are necessary. For the SFOBB project, XY coordinates were transformed from UTM WGS84 to California State Plane, Zone 3 coordinates. Water depths were transformed from MLLW to the project vertical datum, MSL 1929.
- The Terramodel program was used to generate the final bathymetric contours, charts, and 3-dimensional models and to export data to other GIS platforms. Plate E.4 is an example of a 3-D view of a part of the multibeam survey data.

E.3 OAKLAND MOLE TIDAL FLAT SURVEY

E.3.1 Tidal Flat Survey Field Operations

On August 23 and 24, 2000 Fugro conducted a shallow water bathymetry survey of the tidal flat area along the north side of the Oakland Mole. The survey extended from as near to shore as possible out to approximately 200 meters offshore of the Oakland Mole and covered from about 90 meters west of the end of the Mole extending eastward approximately 900 meters.

Fugro's 12-foot inflatable survey boat was mobilized with a portable Trimble DGPS navigation, an Odom 3200 precision echo sounder, and a computer data collection system to the Emeryville marina on August 23, 2000. A self-recording tide gauge was installed at the Coast Guard station on Yerba Buena Island to provide tidal correction information for the survey. Following mobilization, all systems were tested and calibrated in the harbor and the boat was secured for the night.

On August 24, 2000, the survey boat departed from Emeryville for the project area at 07:00 and the survey commenced at 07:50 at the western end of the Mole. Survey operations were completed at 10:00 that same day and the vessel returned to the Emeryville marina and demobilized. The survey consisted of 33 survey lines spaced at 30-meter intervals and oriented perpendicular to the north side of the Mole. A total of 6 kilometers of data were collected from Fugro's 12-foot inflatable survey boat.

Throughout the survey, navigation position data were logged on disk and simultaneous event-closures were sent at each fix point to the echo sounder recorder placing an event mark on the analog record. Echo sounder records were annotated with fix numbers and scale changes. Navigation fixes were taken every 50 meters along survey tracklines.

Vessel speed averaged approximately 3 to 4 knots. High-density bathymetric soundings were recorded at approximately 0.20-second intervals (about one-and-a-half feet) along each survey line. This closely spaced bathymetric coverage between fix positions produced a very accurate profile of the seafloor bathymetry. Well-tuned systems, good weather conditions, and careful piloting of the survey boat resulted in excellent quality data being collected during this survey.

Fugro personnel on this survey included:

Individual	Title
Jim Grant	Project Manager
Joe Mucha	Survey Technician, Data Collection
Robinson Hughes	Survey Technician, Data Collection
Jeff Carothers	Data Processing and Mapping

E.3.2 Tidal Flat Survey Instrumentation

The following instrumentation was used on the tidal flat survey:

- Odom model DF3200 precision echo sounder (Appendices A, B and C)
- Trimble DGPS navigation system
- Coastal Mini-Tide self-recording tide gauge (Appendix B)
- Hypack navigation software (Appendices A, B, C, and Plates E2.2 and E2.3)

The echo sounder, tide gauge, and software are described in previous appendices. The Trimble navigation system is the basic part of the previously described DGPS navigation system, but for this survey was not integrated with the POS M/V motion sensor system.

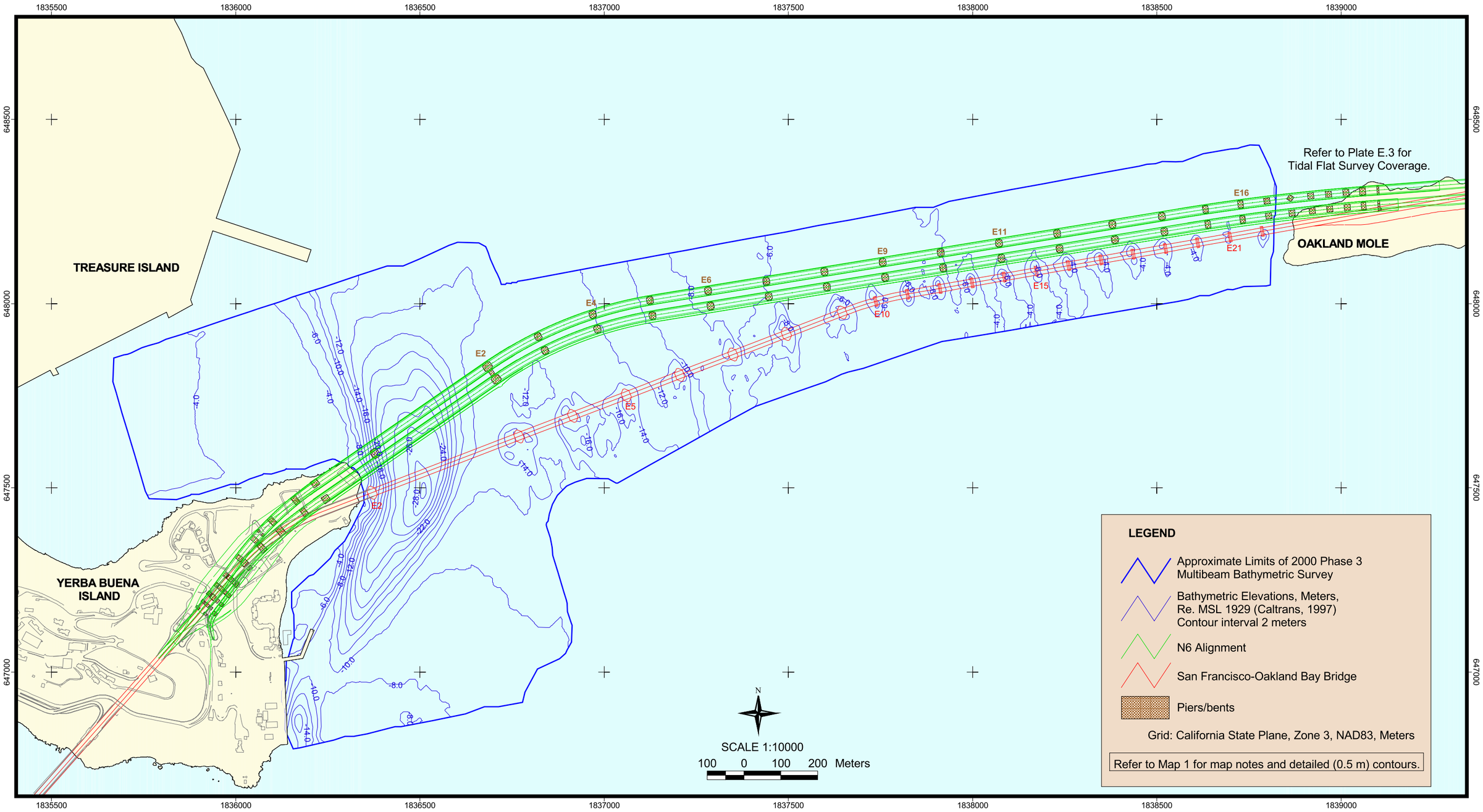
E.3.3 Tidal Flat Survey Data Processing and Mapping

Raw bathymetric data were checked for spurious readings, smoothed, corrected for tidal variations, and reduced to MLLW datum. Tidal corrections were based on data recorded at Yerba Buena Island during the survey and referenced to U.S. Coast & Geodetic Survey monument "Receive Reset 1970" located on the concrete pier at the Yerba Buena Coast Guard Station. The monument elevation is El. +3.71 meters (MLLW) (El. +2.76 meters, NGVD 29). Data were exported from the Hypack navigation software as an ASCII file.

A 0.942-meter level shift was applied to the bathymetric elevations to change the vertical datum from MLLW to the project datum, MSL 1929 (Caltrans 1997). The final XYZ data set was imported to an ArcView CAD package for contouring and merging with the data from the adjacent multibeam survey. The contoured data are shown on Plate E.3 and Map 1.

E.4 REFERENCES

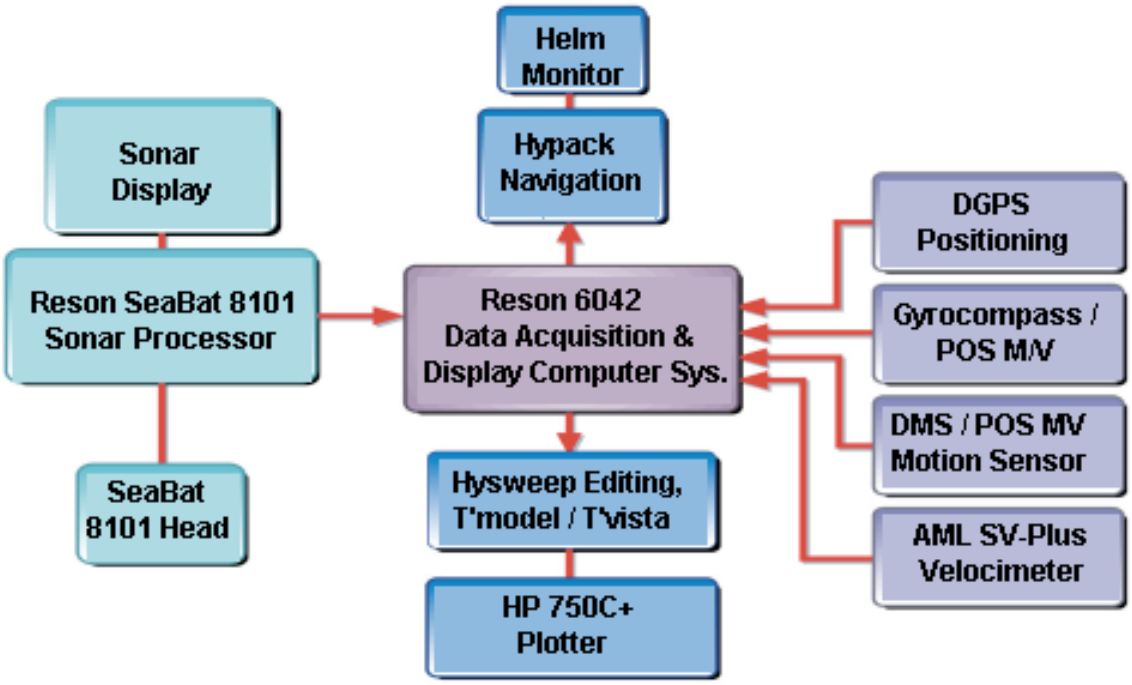
California Department of Transportation (Caltrans) (1997), Internal Caltrans Memorandum dated December 17 from SFOBB Investigations Section to Office of Structure Design, Subject: Addendum - Vertical Datum, Caltrans File Nos. 04-SF-80, 04-0434A1, C1, E1, F1, G1, Project Nos. 3, 4, 5, 6, 8, 21, Bridge No. 33-0025.



PROJECT LOCATION MAP
2000 Phase 3 Multibeam Bathymetry Survey
SFOBB East Span Seismic Safety Project

PLATE E.1

Example of the swath survey concept.



Schematic diagram of integrated instrumentation layout.

SCHEMATIC DIAGRAMS
2000 Phase 3 Multibeam Bathymetry Survey
SFOBB East Span Seismic Safety Project

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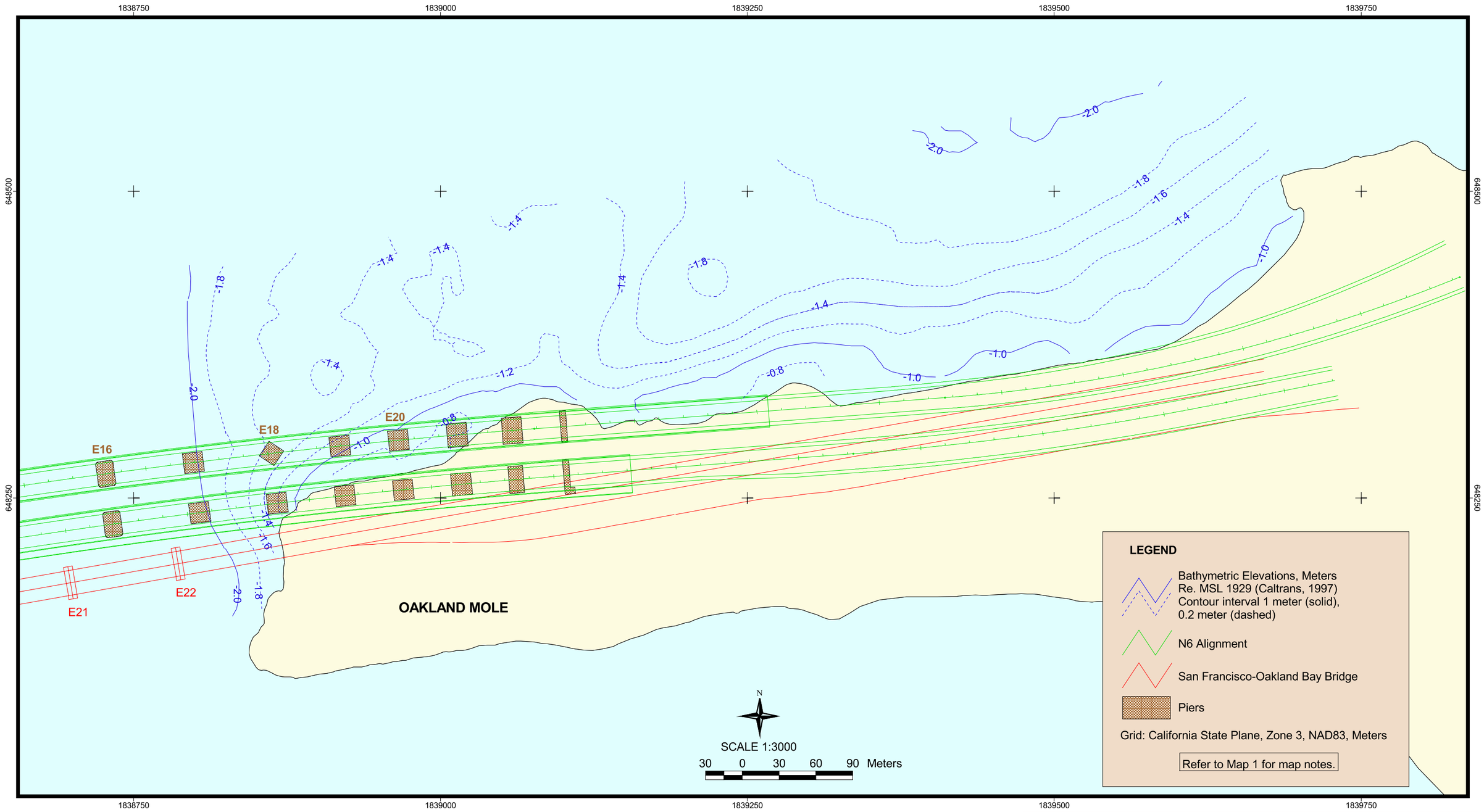
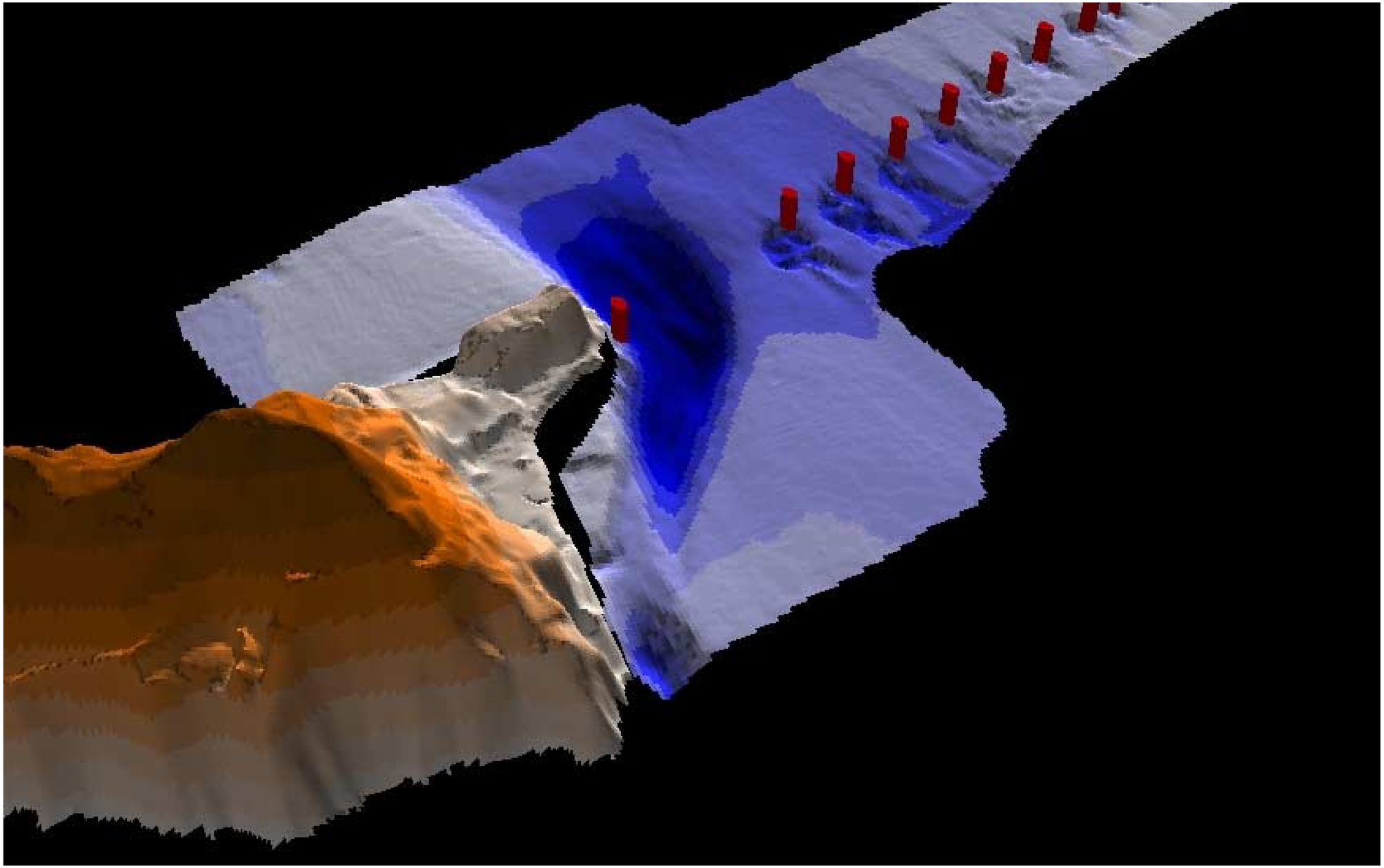


PROJECT LOCATION MAP
2000 Phase 3 Tidal Flat Bathymetry Survey
SFOBB East Span Seismic Safety Project

PLATE E.3



3-D VIEW OF MULTIBEAM BATHYMETRY FROM YERBA BUENA ISLAND
SFOBB East Span Seismic Safety Project