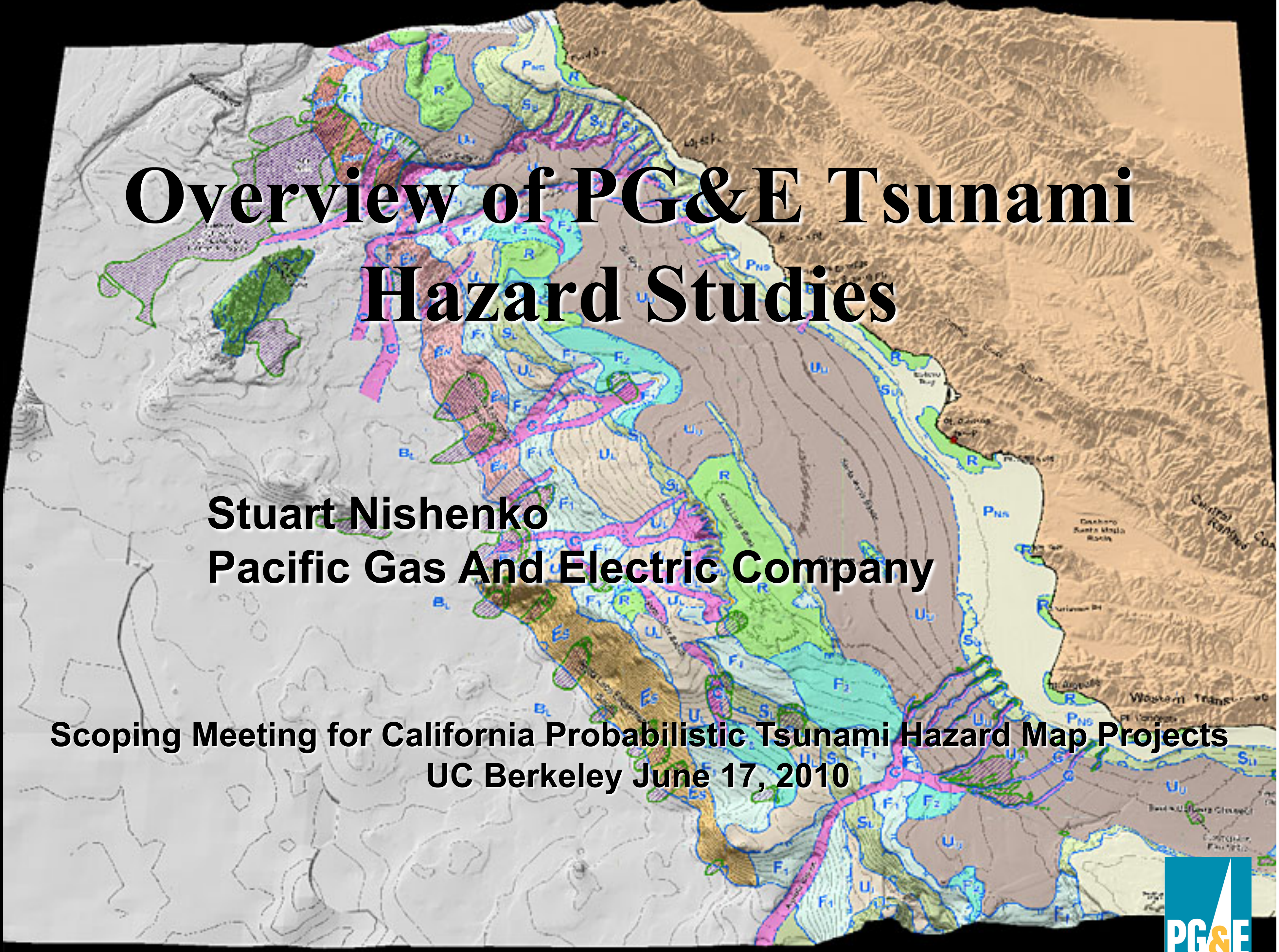


Overview of PG&E Tsunami Hazard Studies

Stuart Nishenko
Pacific Gas And Electric Company

Scoping Meeting for California Probabilistic Tsunami Hazard Map Projects
UC Berkeley June 17, 2010

Study Objectives

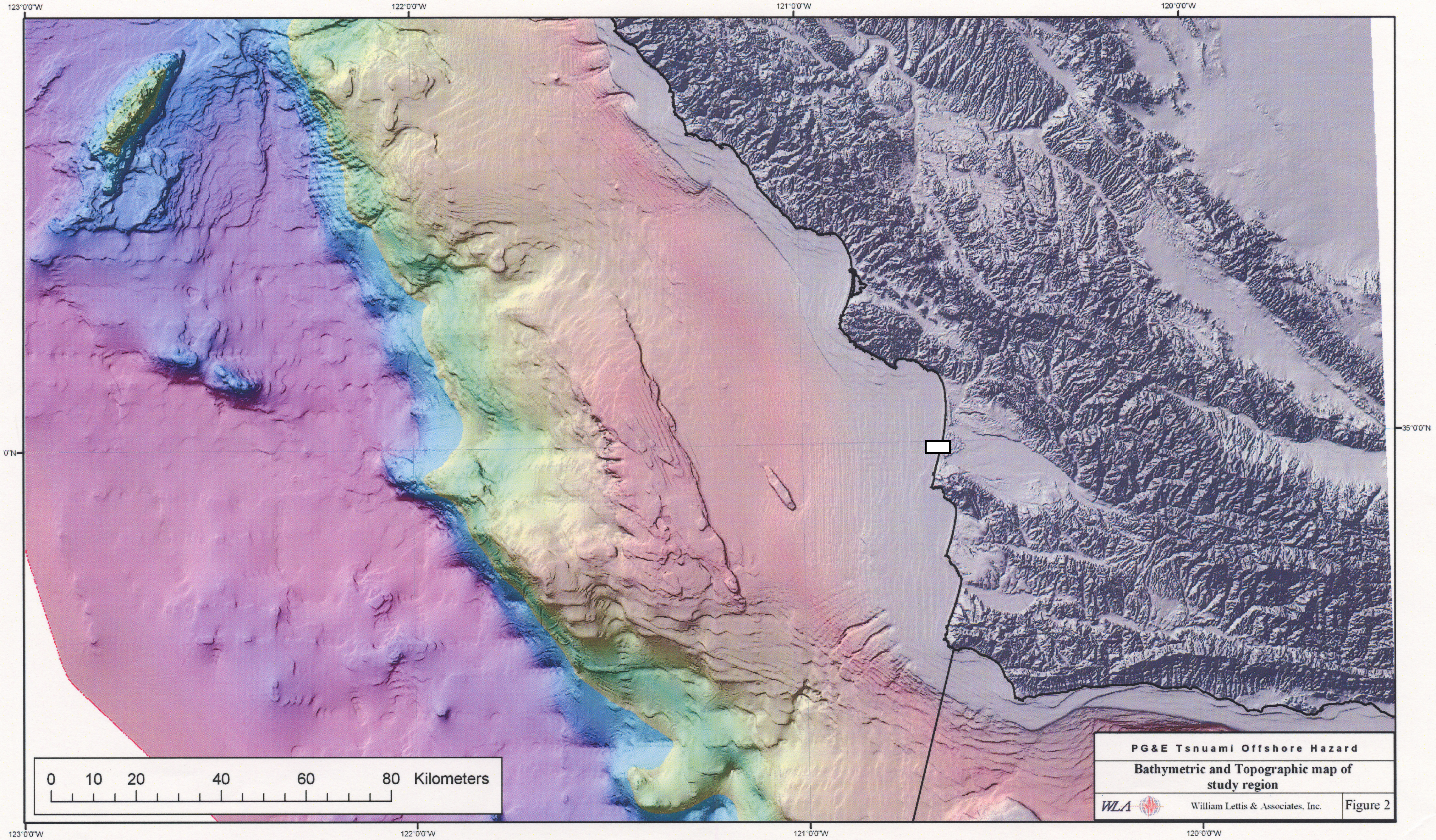
- Comprehensive compilation and review of available marine geophysical data offshore central California coast
- Develop GIS database
- Construct high resolution DEM
  - Aid in identification and characterization of local tsunami sources
  - Reference surface for tsunami modeling
- Evaluate location and size of potential slope failures in study region
- Develop scenario events and source parameter inputs for tsunami modeling (distant, regional, and local earthquakes, local submarine slides)
- Model tsunami runup/drawdown, flow velocity, inundation distance
- Develop framework for Probabilistic Tsunami Hazard Analysis (PTHA)

Study Objectives

- Construct high resolution DEM

  Aid in identification and characterization of local tsunami sources

  Reference surface for tsunami modeling

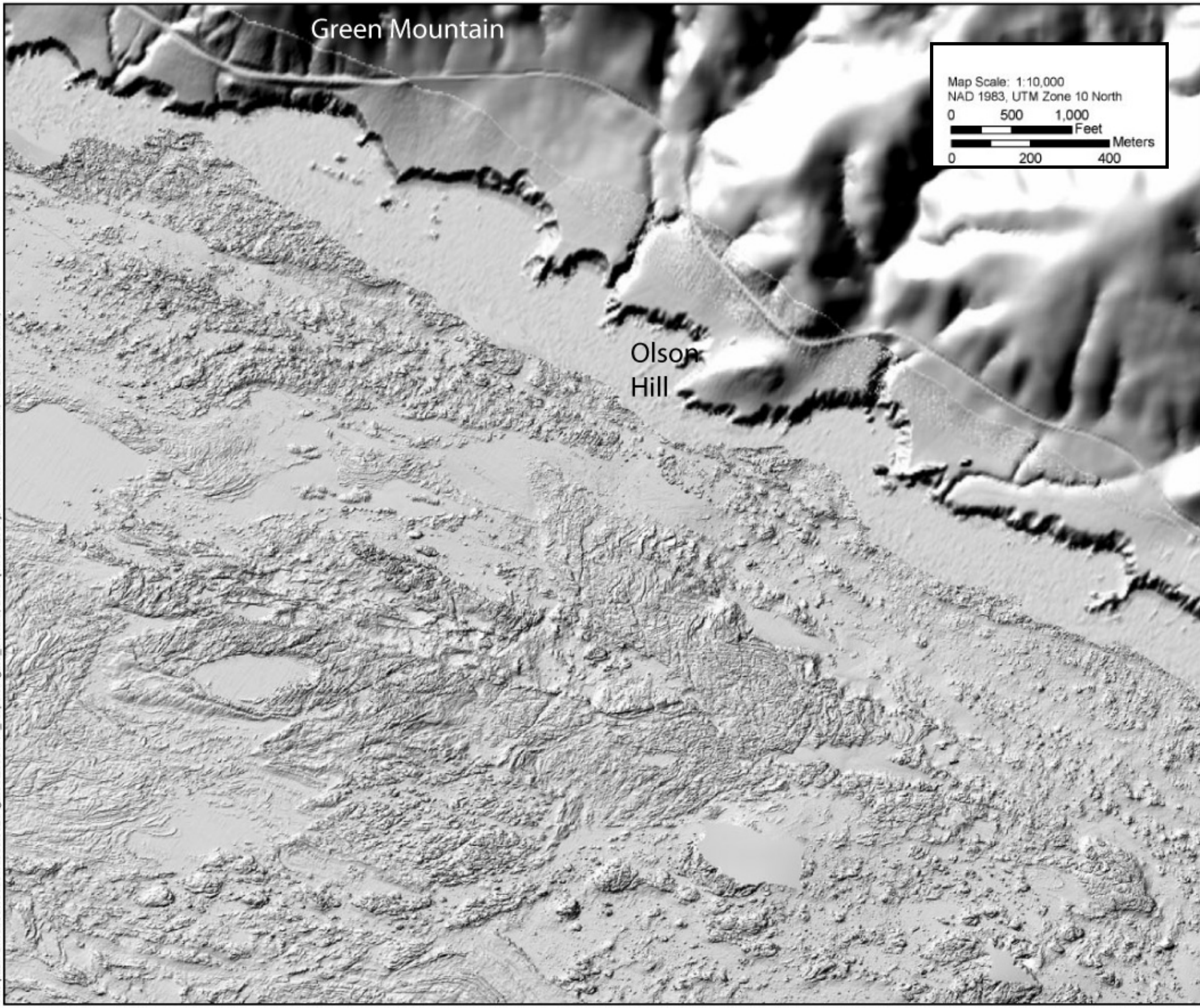


PG&E Tsnuami Offshore Hazard

Bathymetric and Topographic map of study region

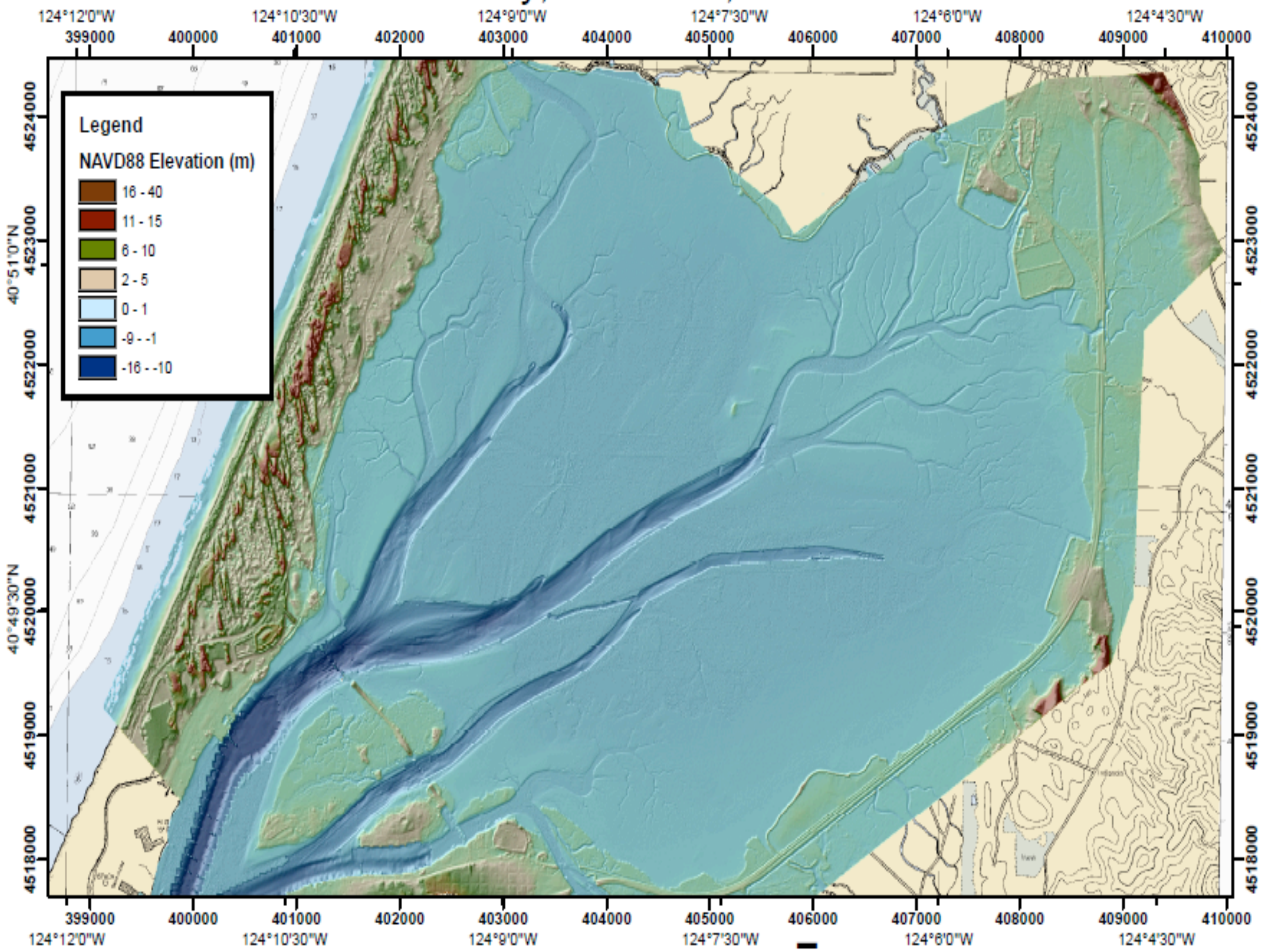
WLA William Lettis & Associates, Inc.

Figure 2



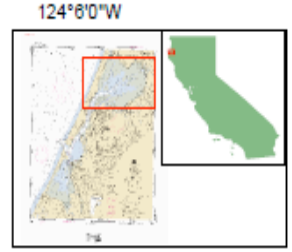
File path: S:\13800\13838\13838.002\Figures\20091114_Report\Figure_04.mxd; Date: [11/04/2009]; User:Serkan Bozkurt, AMEC Geomatrix, Inc.

Arcata Bay, Humboldt, California



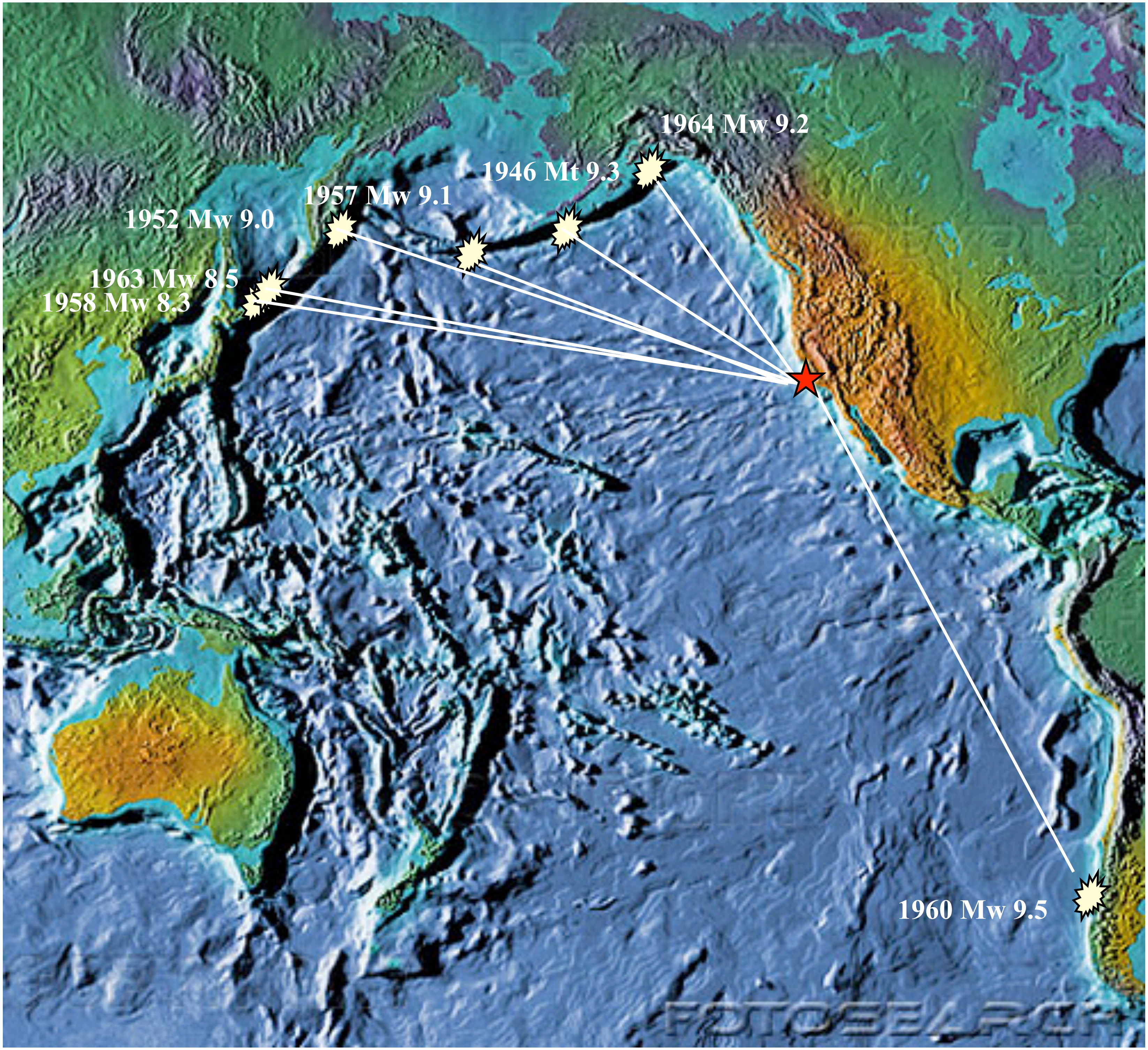
Fused Multibeam, LIDAR, and PHILLS bathymetry and topography in shaded relief
Image illumination: Azimuth 315°, Elevation: 45° Resolution: 5 m
Coordinate System: UTM 10N WGS 84, Vertical datum NAVD88
NOAA Chart 18622, soundings in feet
Multibeam source: CSUMB SFML, June 2005
LIDAR source: EarthData International, May 2002
PHILLS source: FERI, October 2004
Data fusion by Pat Iampietro, SFML, for CICORE

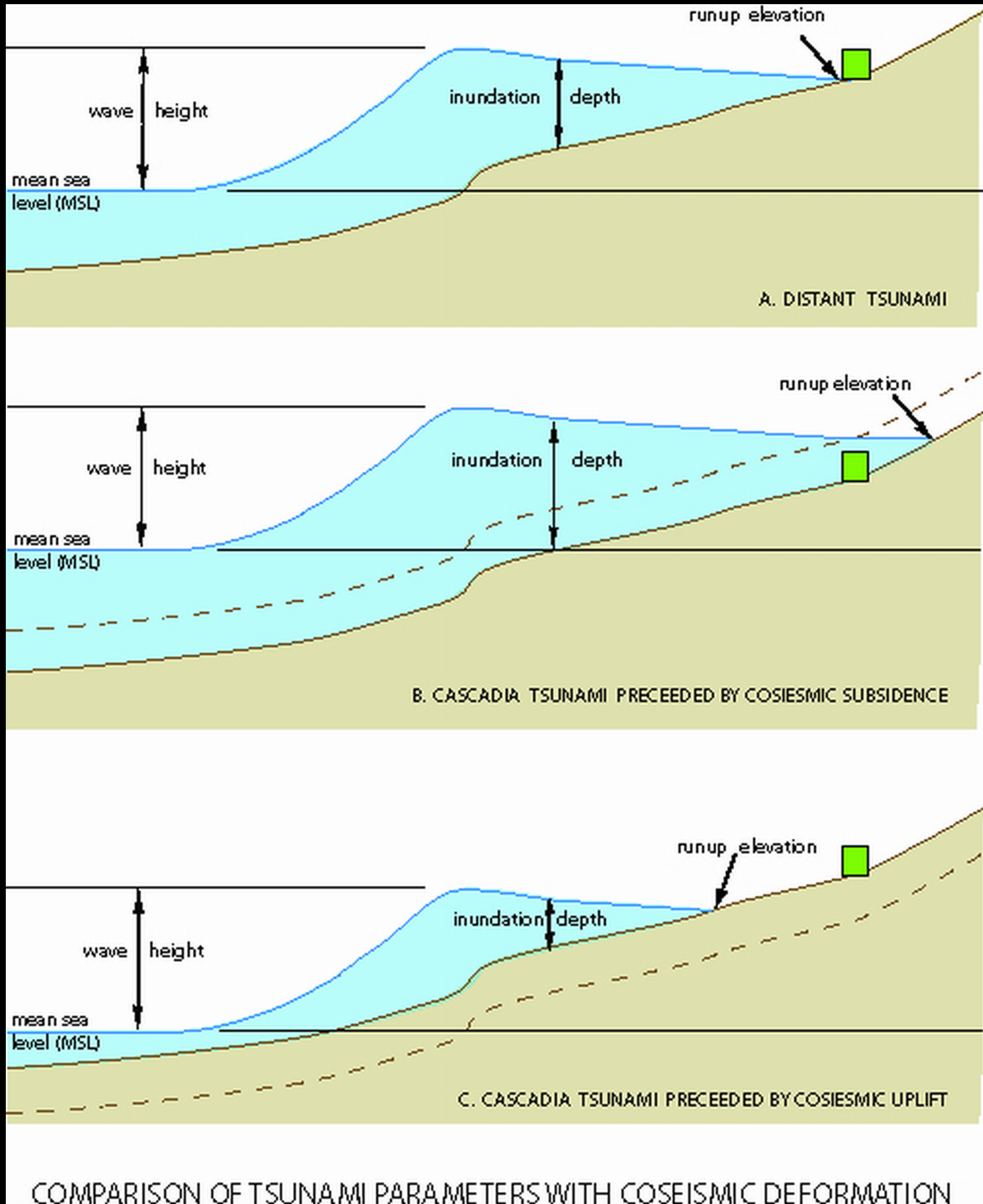
0 0.5 1 2 3
Kilometers
0 0.5 1 2
Miles



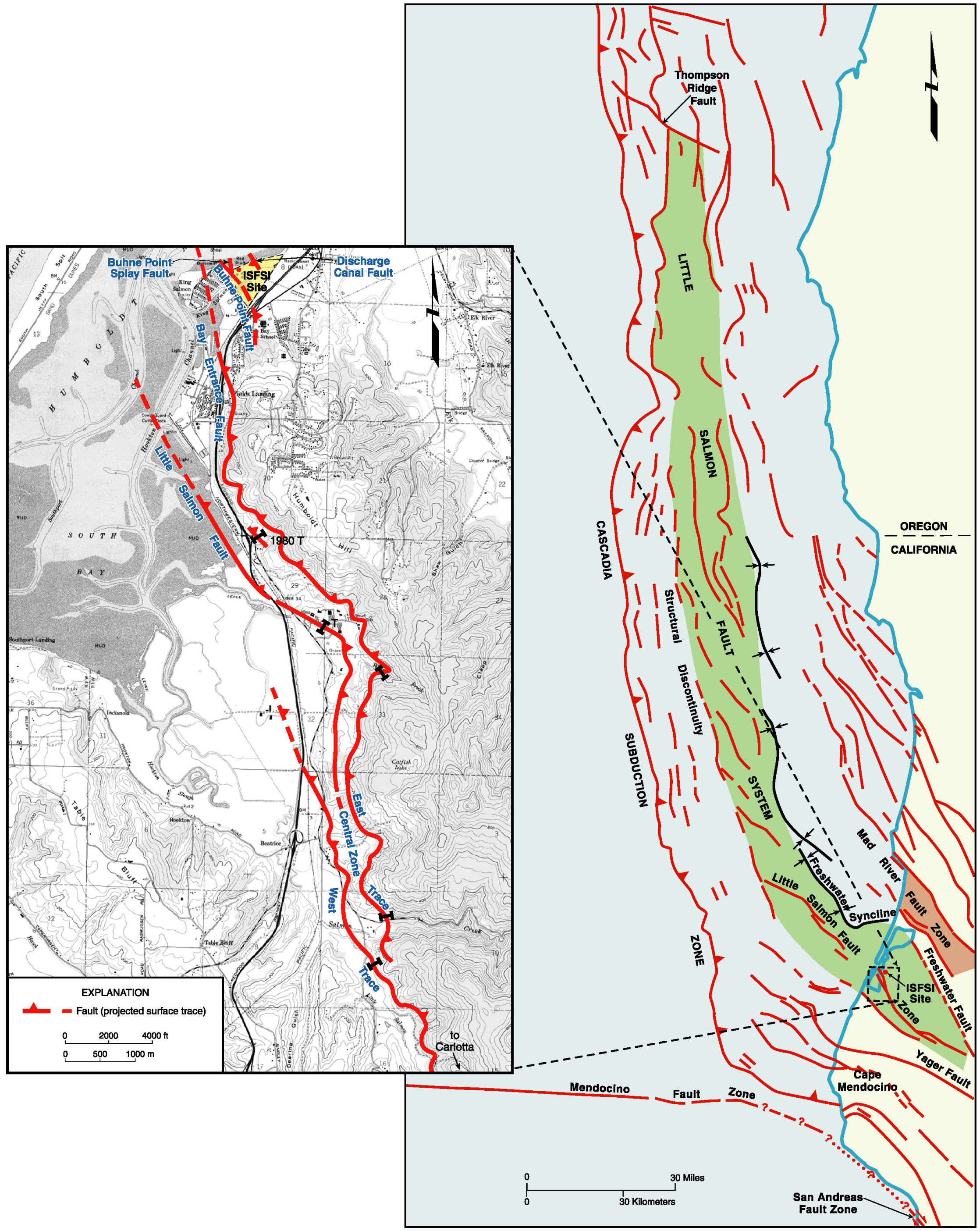
Study Objectives

- Develop scenario events and source parameter inputs for tsunami modeling (distant, regional, and local earthquakes, local submarine slides)

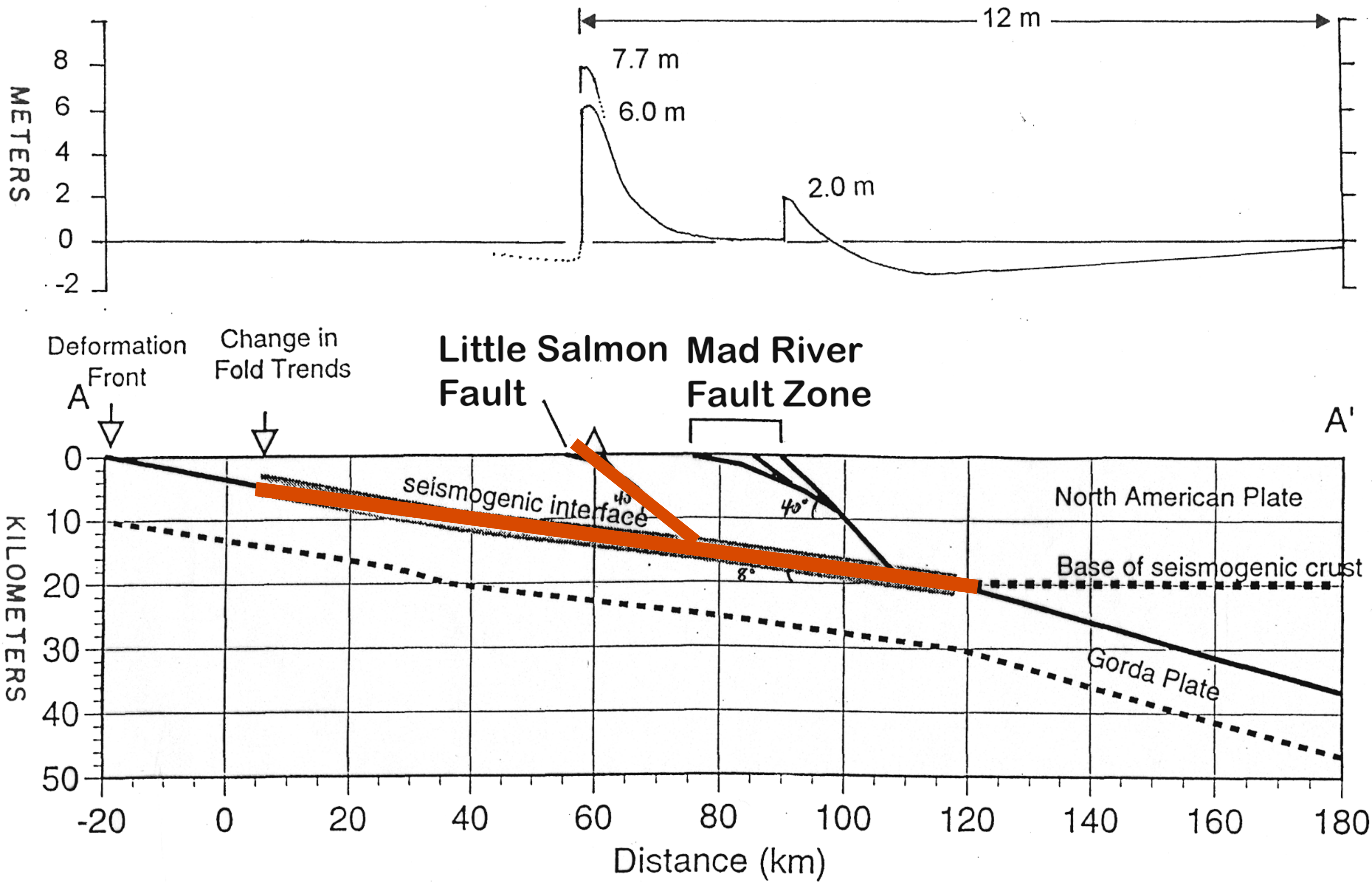

1964 Mw 9.2
1946 Mt 9.3
1957 Mw 9.1
1952 Mw 9.0
1963 Mw 8.5
1958 Mw 8.3
1960 Mw 9.5
FOTOSEARCH

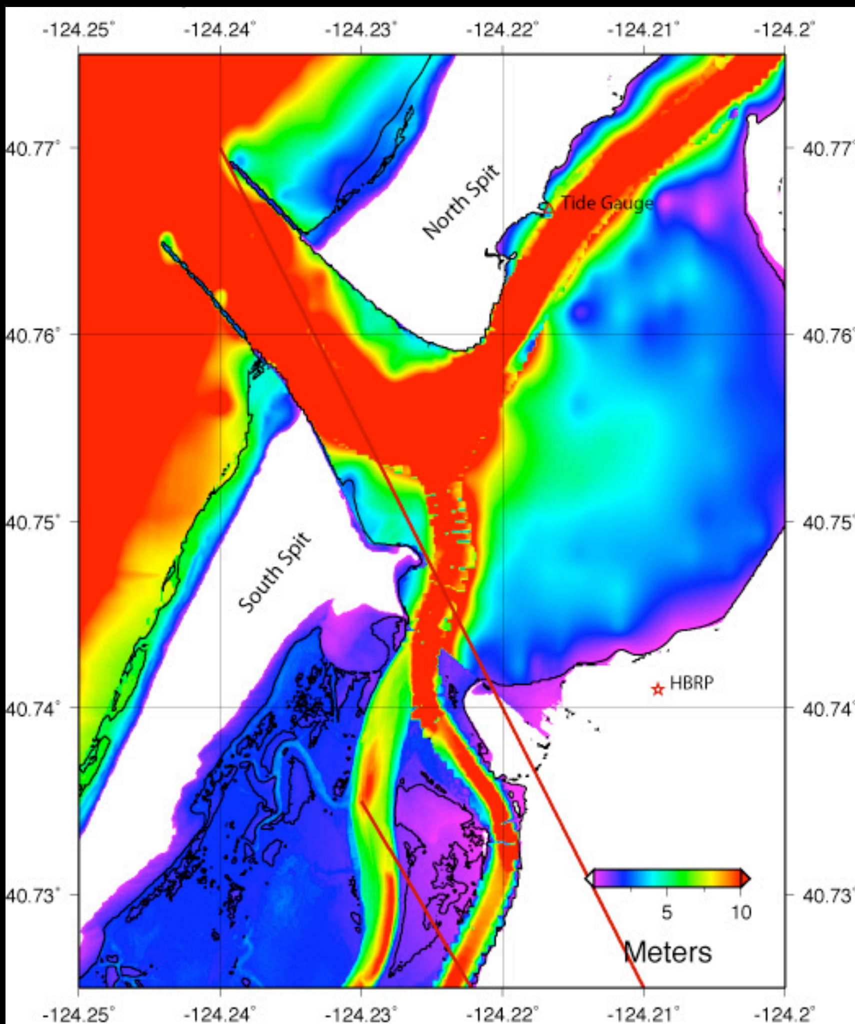

runup elevation
wave height
inundation depth
mean sea level (MSL)
A. DISTANT TSUNAMI
runup elevation
wave height
inundation depth
mean sea level (MSL)
B. CASCADIA TSUNAMI PRECEEDED BY COSIESMIC SUBSIDENCE
runup elevation
wave height
inundation depth
mean sea level (MSL)
C. CASCADIA TSUNAMI PRECEEDED BY COSIESMIC UPLIFT
COMPARISON OF TSUNAMI PARAMETERS WITH COSEISMIC DEFORMATION

Synchronous Rupture of Cascadia Subduction and Little Salmon Faults

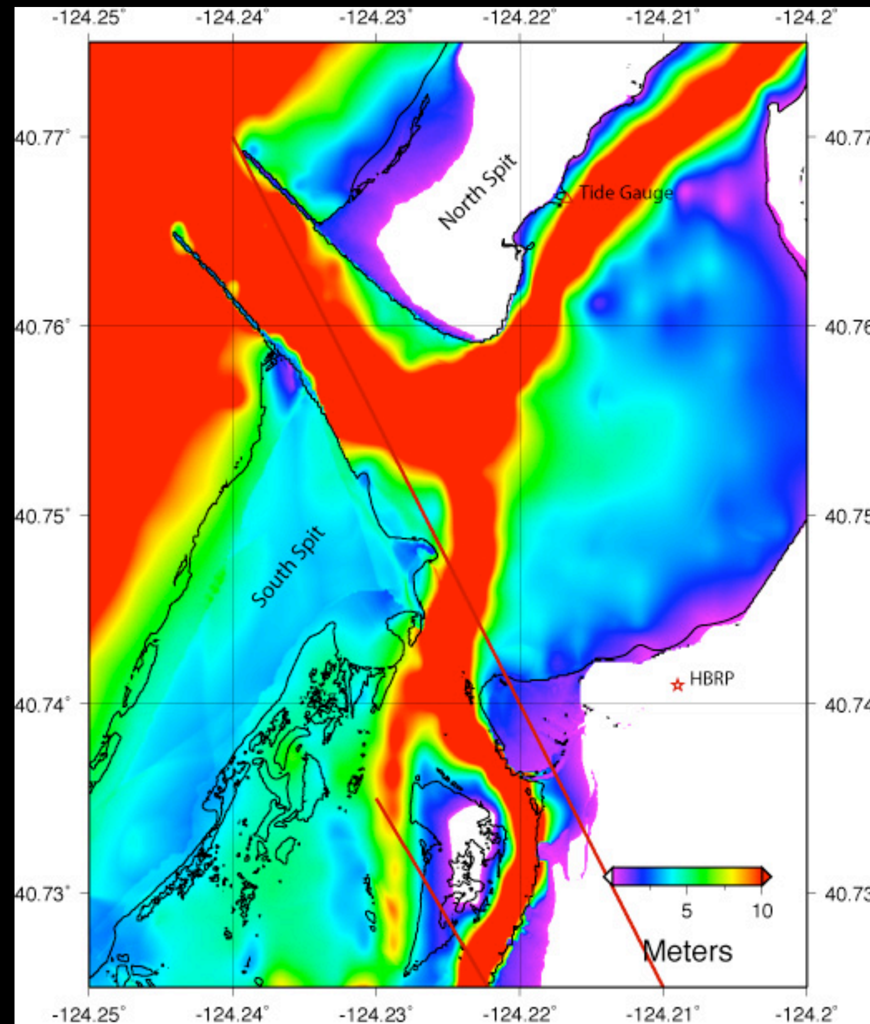


PG&E


12 m
7.7 m
6.0 m
2.0 m
METERS
8
6
4
2
0
-2
Deformation Front
Change in Fold Trends
Little Salmon Fault
Mad River Fault Zone
A
A'
seismogenic interface
40°
8°
North American Plate
Base of seismogenic crust
Gorda Plate
KILOMETERS
0
10
20
30
40
50
-20
0
20
40
60
80
100
120
140
160
180
Distance (km)



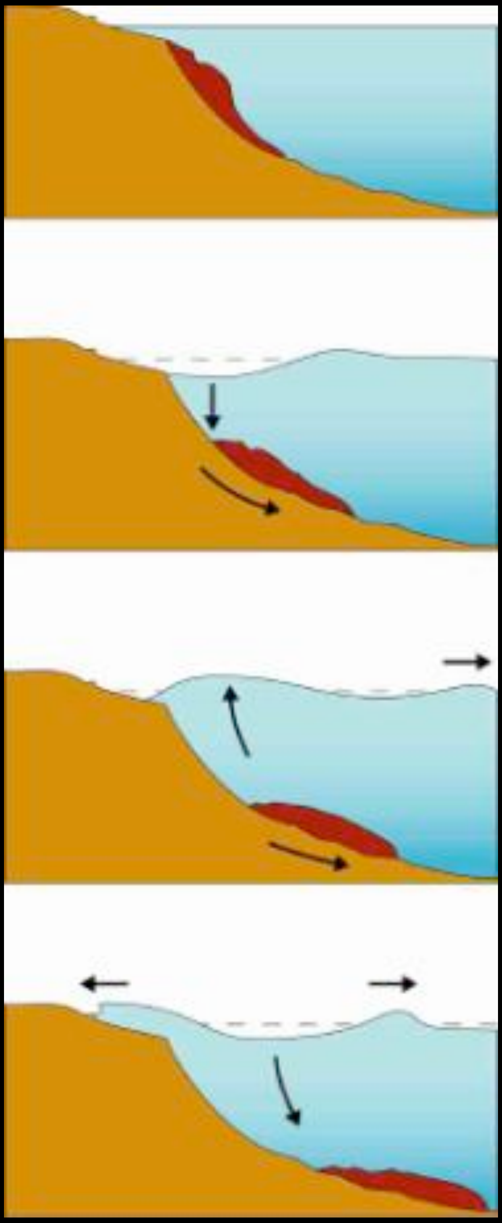
CICORE DEM



USGS DEM

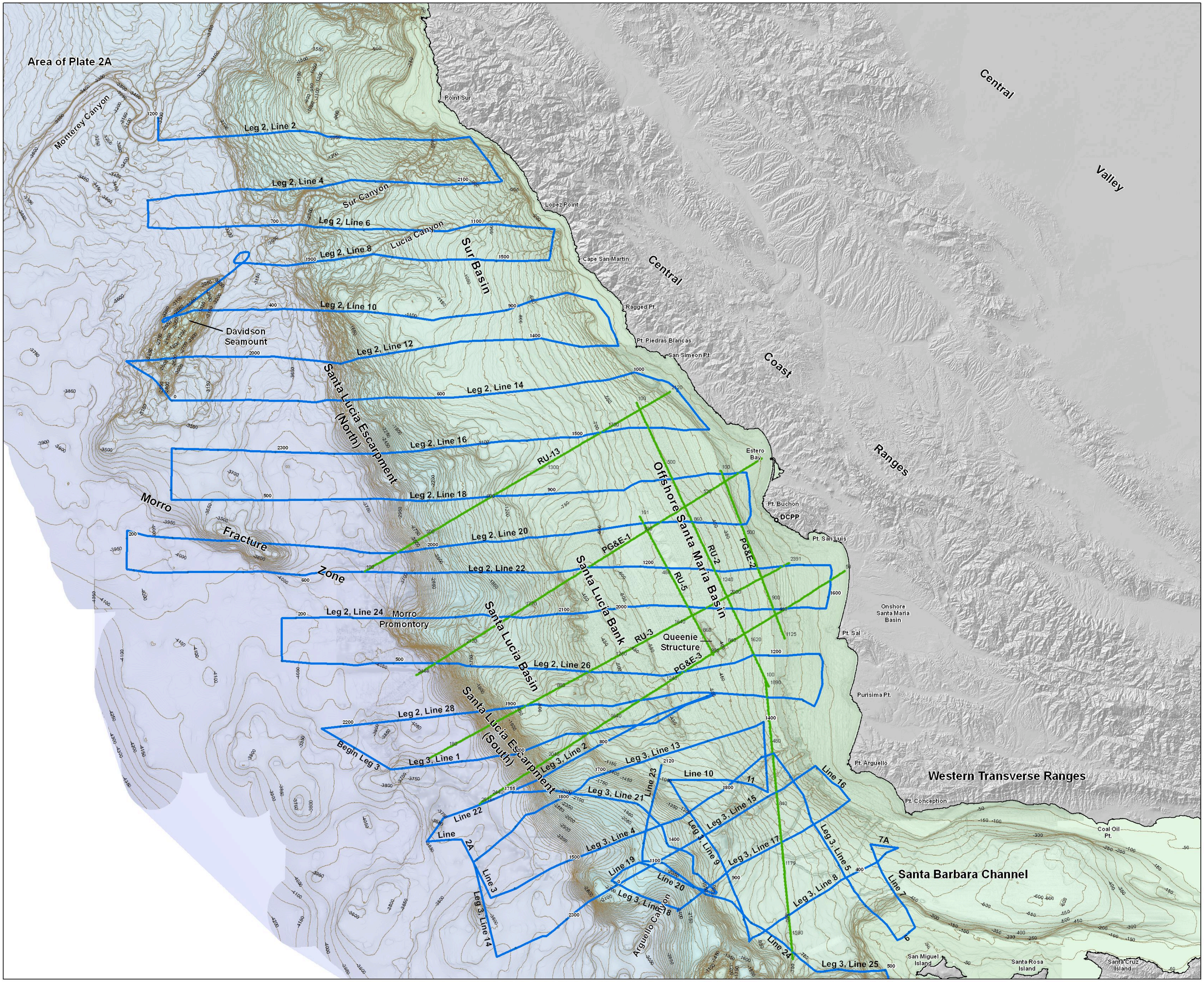
Cascadia- Little Salmon Fault Model

Submarine Landslides



Study Objectives

- Evaluate location and size of potential slope failures in study region



Area of Plate 2A
Monterey Canyon
Point Sur
Central
Valley
Leg 2, Line 2
Leg 2, Line 4
Sur Canyon
Lopez Point
Leg 2, Line 6
Lucia Canyon
Leg 2, Line 8
Sur Basin
Cape San Martin
Central
Leg 2, Line 10
Ragged Pt.
Davidson Seamount
Pt. Piedras Blancas
San Simeon Pt.
Leg 2, Line 12
Coast
Santa Lucia Escarpment (North)
Leg 2, Line 14
Leg 2, Line 16
RU-13
Estero Bay
Ranges
Offshore Santa Maria Basin
Leg 2, Line 18
Morro
Pt. Buchon
DCPP
Fracture
Leg 2, Line 20
PG&E-1
RU-2
PG&E-2
Pt. San Luis
Zone
Leg 2, Line 22
Santa Lucia Bank
RU-5
Leg 2, Line 24
Morro Promontory
Santa Lucia Basin
Onshore Santa Maria Basin
Pt. Sal
RU-3
Queenie Structure
PG&E-3
Leg 2, Line 26
Santa Lucia Escarpment (South)
Purisima Pt.
Leg 2, Line 28
Begin Leg 3
Leg 3, Line 1
Leg 3, Line 2
Leg 3, Line 13
Pt. Arguello
Western Transverse Ranges
Line 22
Line 10
11
Line 16
Leg 3, Line 21
Leg 3, Line 15
Pt. Conception
Line 2A
Leg 3, Line 4
Leg 3, Line 9
Leg 3, Line 6
Coal Oil Pt.
7A
Leg 3, Line 17
Line 3
Line 19
Line 20
Leg 3, Line 8
Santa Barbara Channel
Line 7
Leg 3, Line 18
Leg 3, Line 14
Arguello Canyon
Line 24
Leg 3, Line 25
San Miguel Island
Santa Rosa Island
Santa Cruz Island

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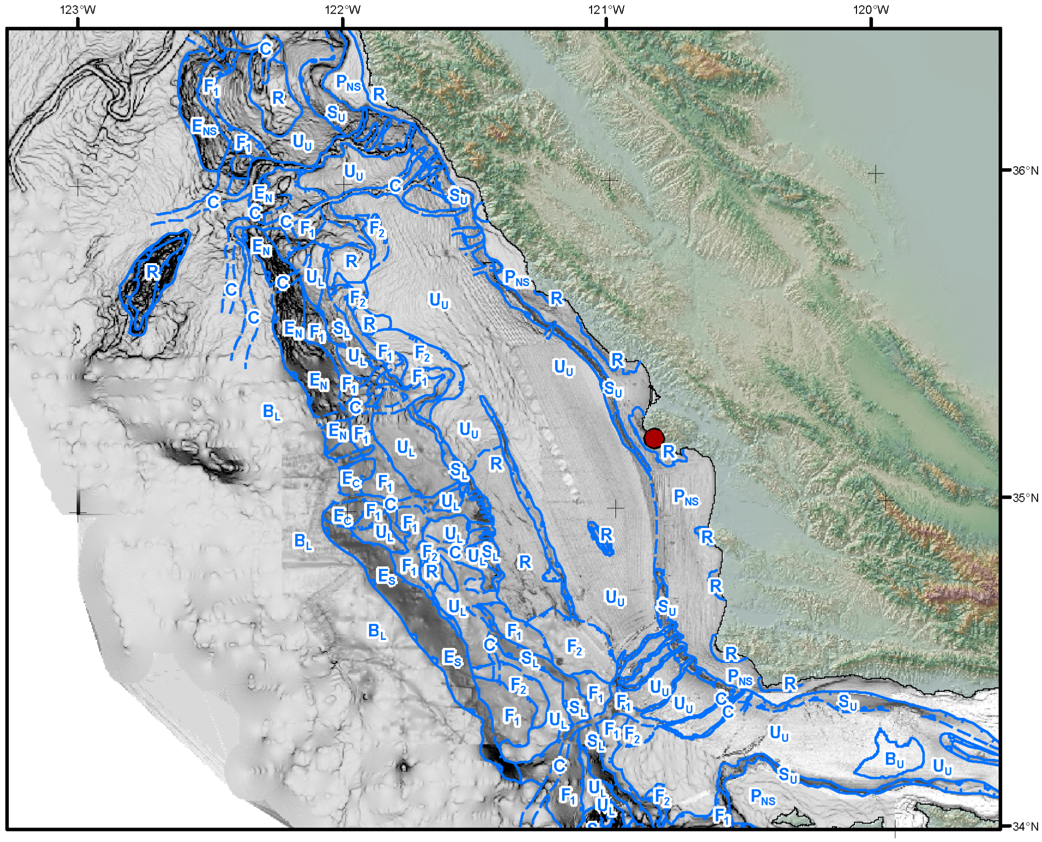


Explanation

● Diablo Canyon Power Plant (DCPP)

Geomorphic Domains

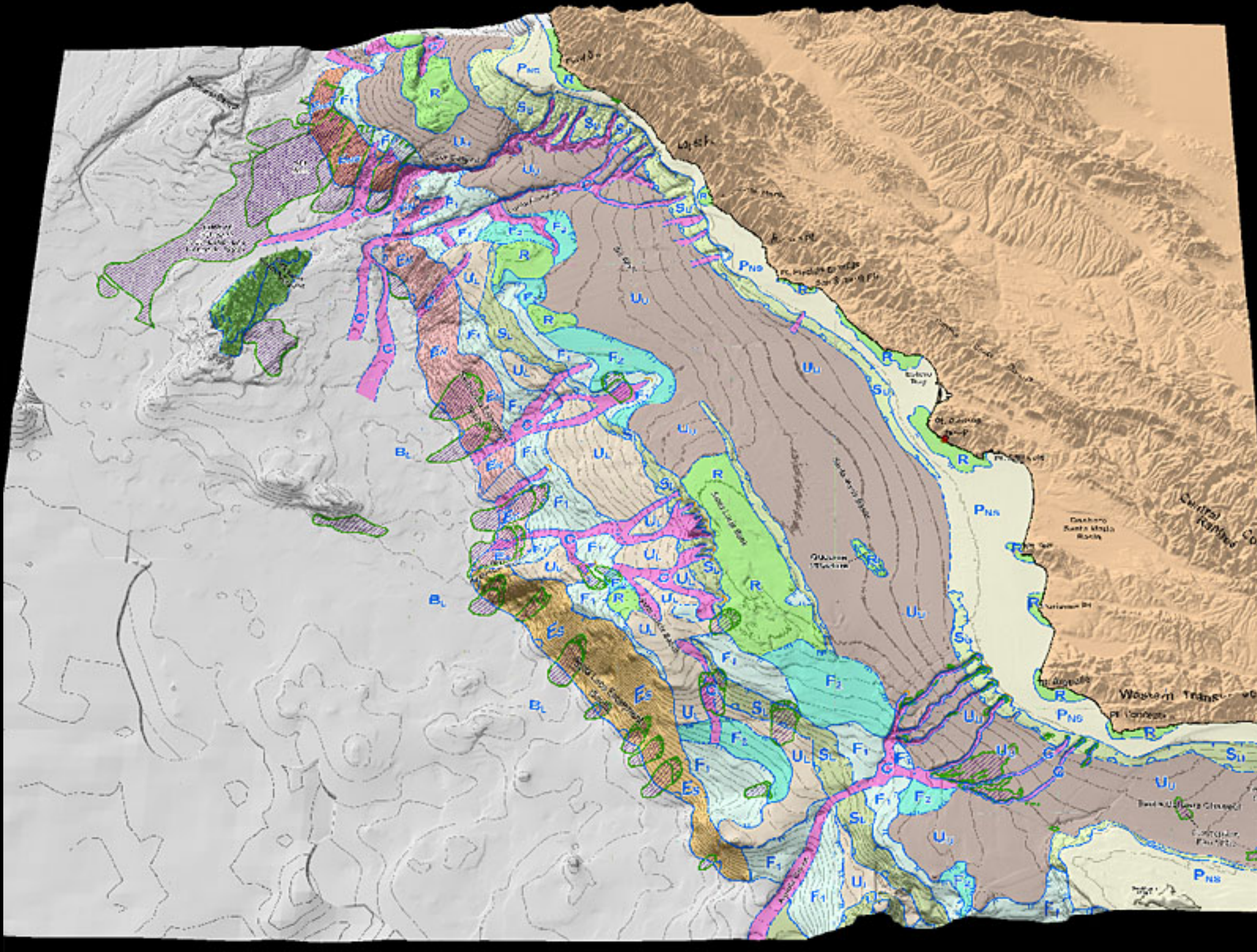
B_L Basin – Abyssal Plain
B_U Basin – Upper Continental Slope
C Submarine Canyon
E_C Central Santa Lucia Escarpment
E_N Northern Santa Lucia Escarpment
E_{NS} Northern Santa Lucia Escarpment (Sur Region)
E_S Southern Santa Lucia Escarpment
F_1 Upper Scarp Facet 1
F_2 Upper Scarp Facet 2
P_{NS} Nearshore Platform
R Elevated Rock Platform
S_L Bathymetric Scarp - Lower Continental Slope
S_U Bathymetric Scarp - Upper Continental Slope
U_L Non-Faceted Uplands – Lower Continental Slope
U_U Non-Faceted Uplands – Upper Continental Slope

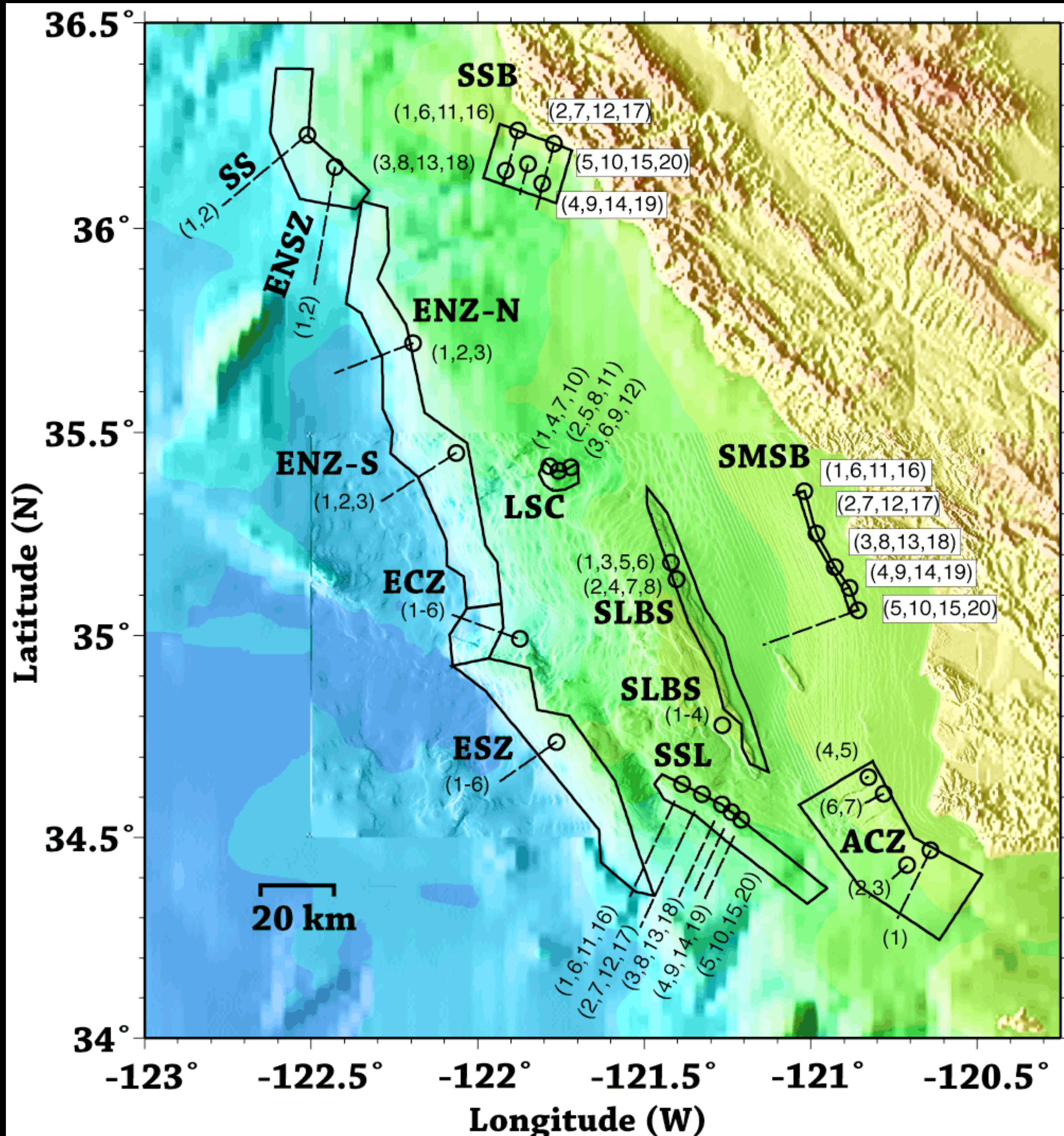
See Plate 2A for explanation of symbols

0 50 100 Kilometers

CRITERIA USED TO EVALUATE SUBMARINE LANDSLIDE POTENTIAL FOR SELECTED SOURCE ZONES

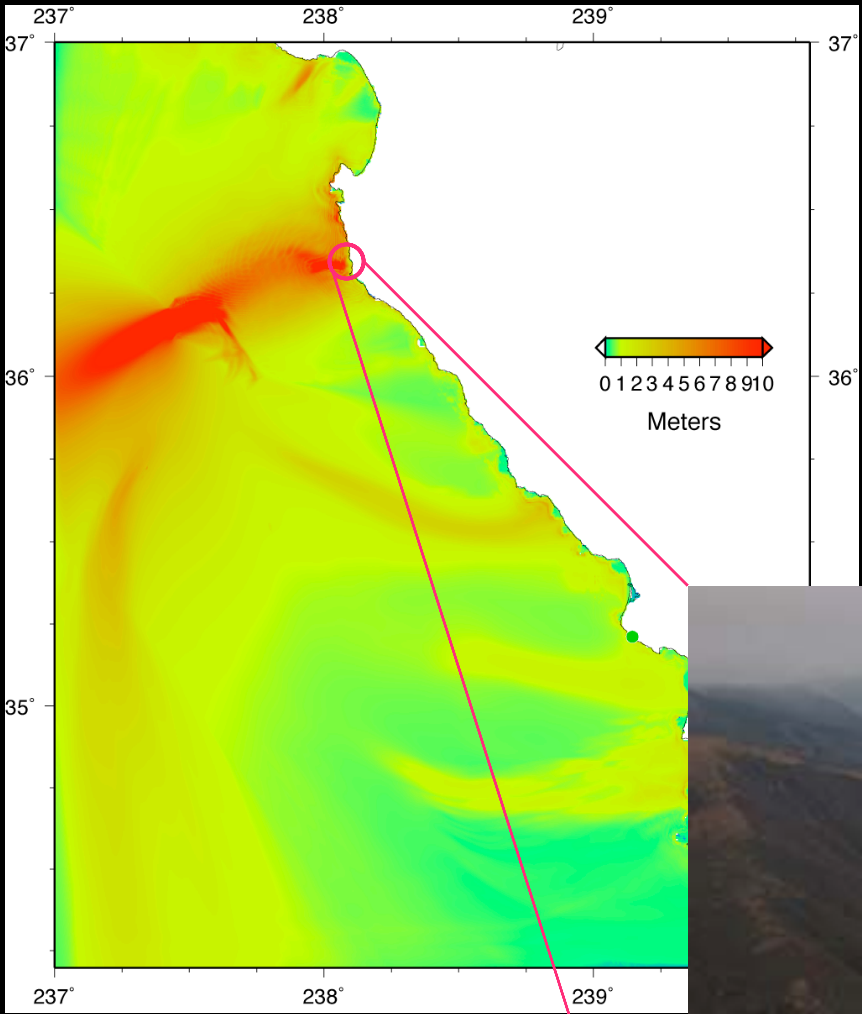
Characteristic	Landslide Potential [L_T]		
	Low	Moderate	High
Geomorphic Domain	Bedrock Platform Basin Non-faceted uplands	Tectonic Scarp Bathymetric Scarp Submarine Canyon Erosional Facet	Tectonic Scarp Bathymetric Scarp Submarine Canyon
Relief	Low (< 50 m)	Moderate (> 50 m to 500 m)	High (>500 m)
Slope Angle	Low (< 2°)	Moderate (2-10°)	High (>10°)
Structural Setting- Presence of Active tectonic features	None	Possible association with nearby active fault or fold.	Yes- active fault or growing fold in headwall region
Presence of slip plane or favorably dipping geologically weak layer	No	Maybe	Yes
Hydrologic Environment (Fluid Flow)	None	Evidence for gas saturated sediments over broad regions (pockmarks,)	Localized overpressured gas conditions High pore water pressure Piping Gas or fluid seeps
Sedimentation Environment	Low rate	Moderate	High rate
Erosion or undercutting	No	Moderate	Channel environment or area of active sea floor erosion occurring
Type of sediment underlying slope	Bedrock or overconsolidated sediment	Consolidated sediment	
Geologic Evidence for previous mass wasting [scale of features]	None or evidence for creeping or small scale mudflows or debris flows	Evidence for translational slides	Evidence for translational slides and slumps
Expected Type of Mass Movement	Rock toppling Rock falls and avalanches Thin sediment or mudflows Creep	Debris Avalanche Debris Flow Translational slides Down-dropped blocks	Translational slides Rotational slides (slumps) Complex compound mass movement features


Central Coast Ranges
Western Transverse
Pt. Arguello
Pt. Conception
B_L



36.5°
36°
35.5°
35°
34.5°
34°
Latitude (N)
-123°
-122.5°
-122°
-121.5°
-121°
-120.5°
Longitude (W)
SSB
(1,6,11,16)
(2,7,12,17)
(3,8,13,18)
(5,10,15,20)
(4,9,14,19)
SS
(1,2)
ENSZ
(1,2)
ENZ-N
(1,2,3)
(1,4,7,10)
(2,5,8,11)
(3,6,9,12)
ENZ-S
(1,2,3)
LSC
SMSB
(1,6,11,16)
(2,7,12,17)
(3,8,13,18)
(4,9,14,19)
(5,10,15,20)
(1,3,5,6)
(2,4,7,8)
SLBS
ECZ
(1-6)
SLBS
(1-4)
ESZ
(1-6)
SSL
(4,5)
(6,7)
ACZ
(2,3)
(1)
(1,6,11,16)
(2,7,12,17)
(3,8,13,18)
(4,9,14,19)
(5,10,15,20)
20 km

Sur Slide runup



El Sur Ranch site

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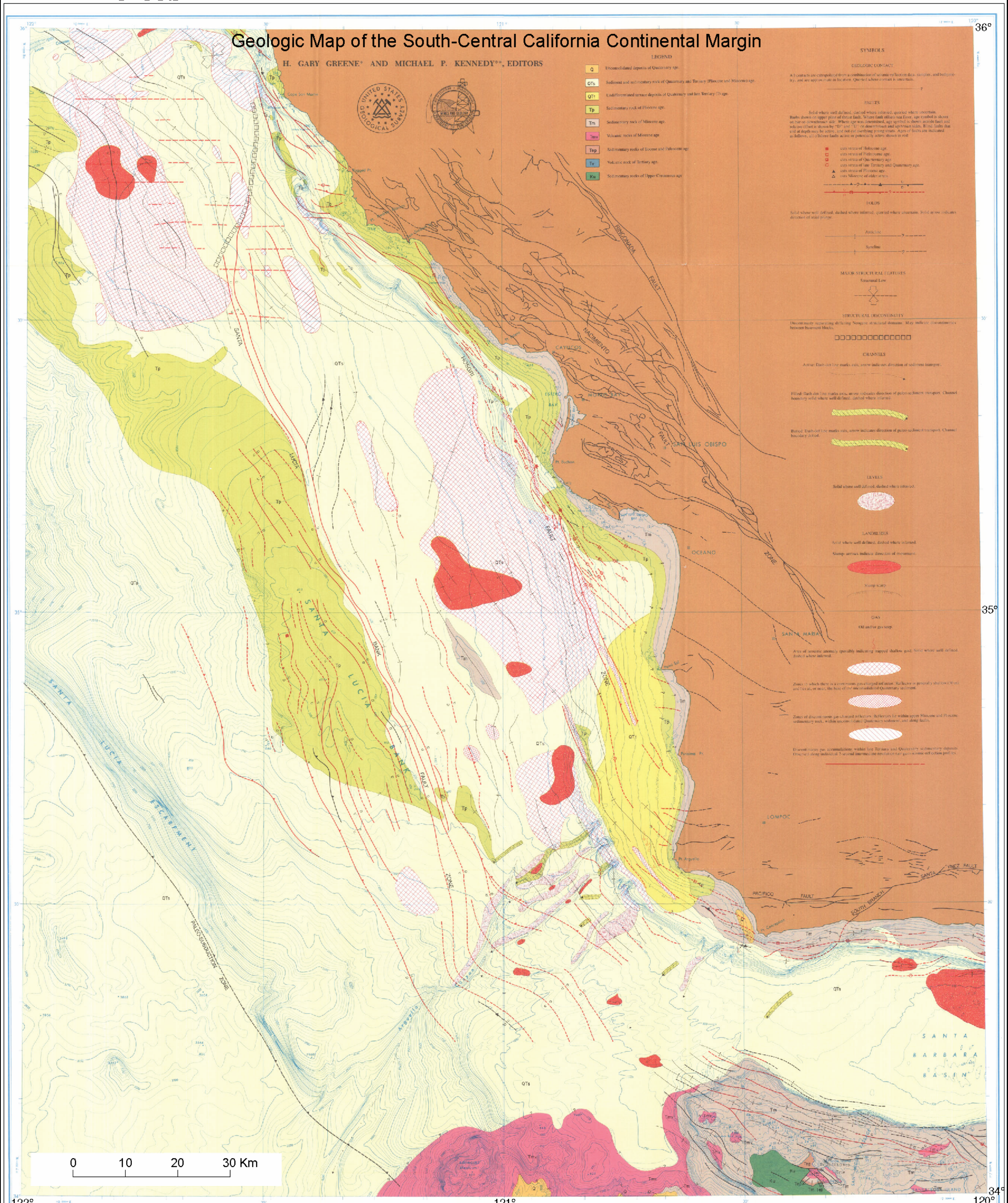
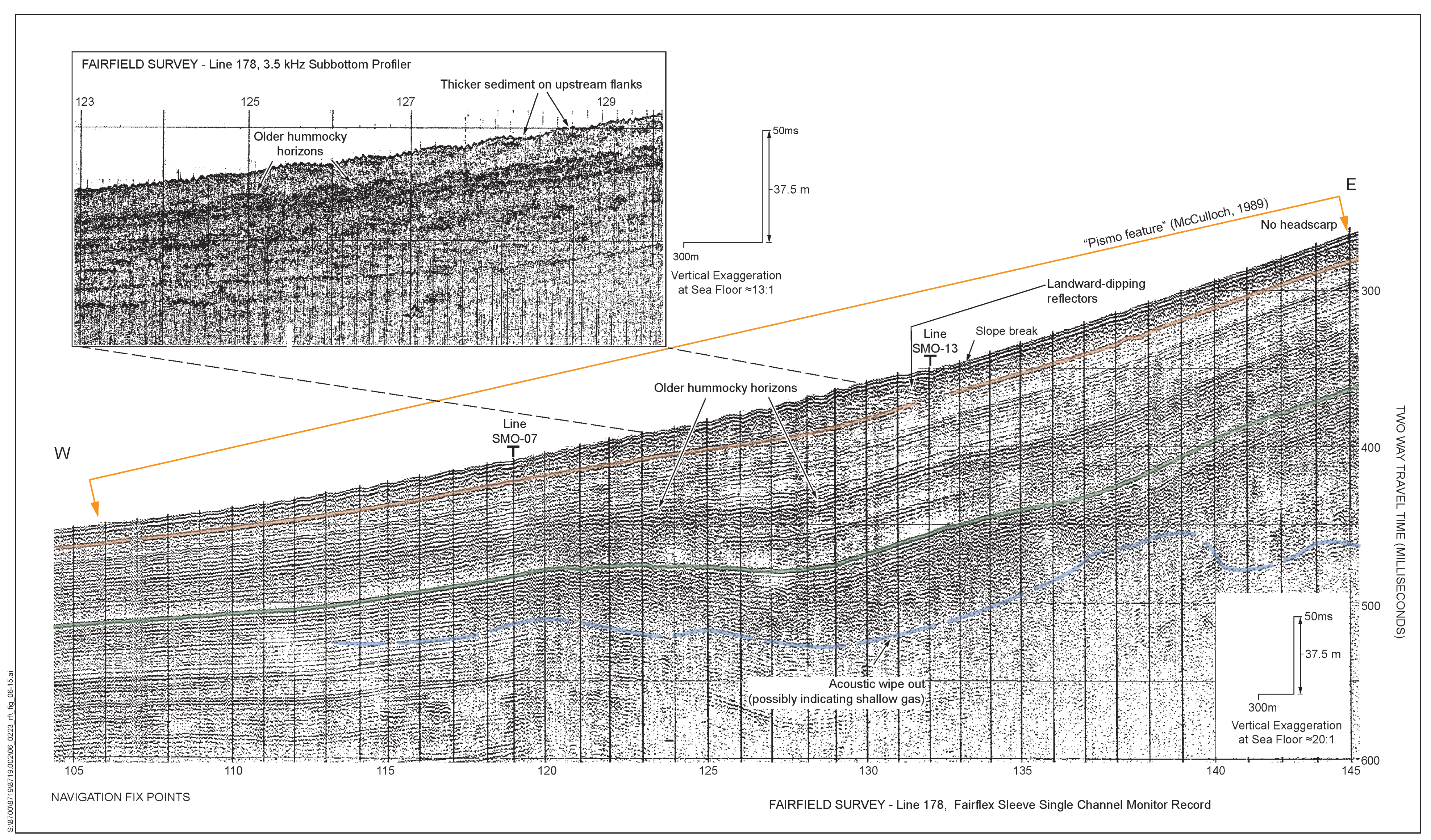
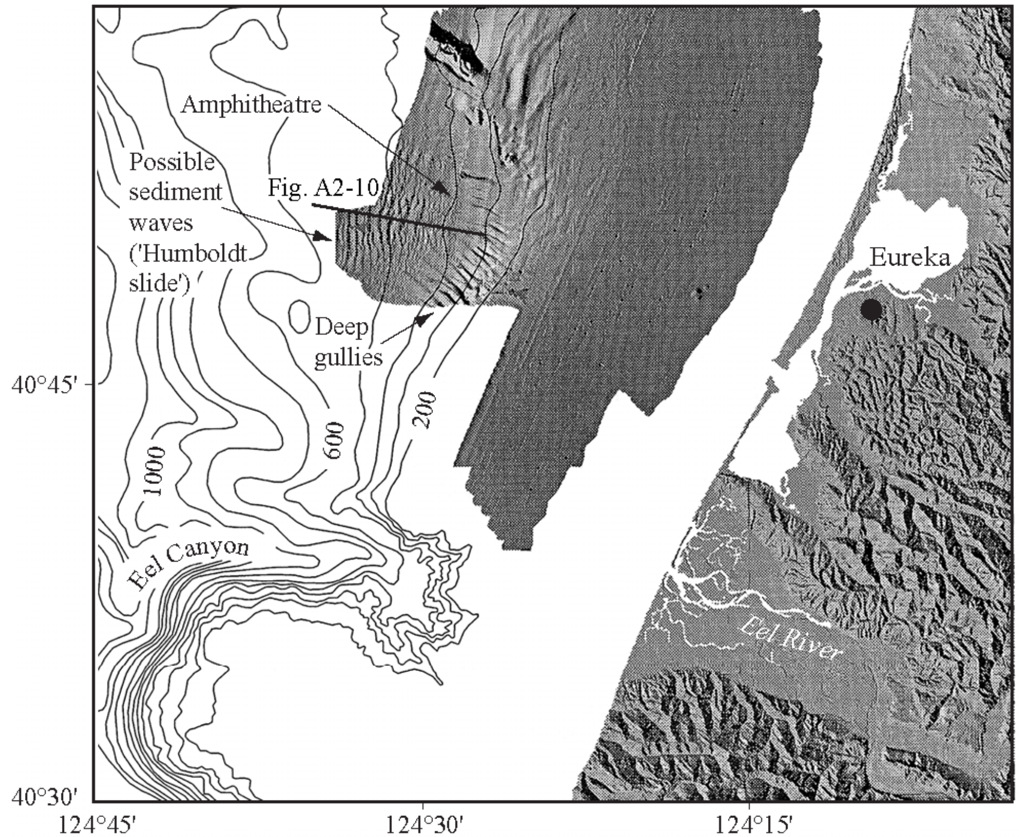
“PISMO SLIDE”



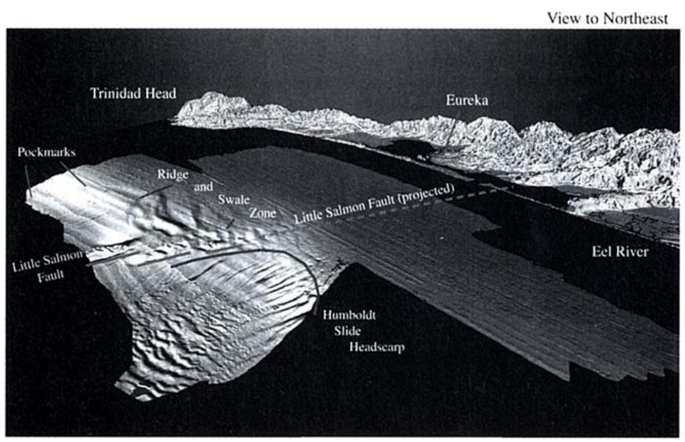
From McCulloch (1989)


FAIRFIELD SURVEY - Line 178, 3.5 kHz Subbottom Profiler
Thicker sediment on upstream flanks
123
125
127
129
Older hummocky horizons
50ms
37.5 m
300m
Vertical Exaggeration at Sea Floor ≈13:1
E
"Pismo feature" (McCulloch, 1989)
No headscarp
Landward-dipping reflectors
Line SMO-13
Slope break
Older hummocky horizons
Line SMO-07
W
300
400
500
600
TWO WAY TRAVEL TIME (MILLISECONDS)
50ms
37.5 m
300m
Vertical Exaggeration at Sea Floor ≈20:1
Acoustic wipe out (possibly indicating shallow gas)
105
110
115
120
125
130
135
140
145
NAVIGATION FIX POINTS
FAIRFIELD SURVEY - Line 178, Fairflex Sleeve Single Channel Monitor Record
S:\8700\8719\8719.002\06_0223_rfi_fig_06-15.ai

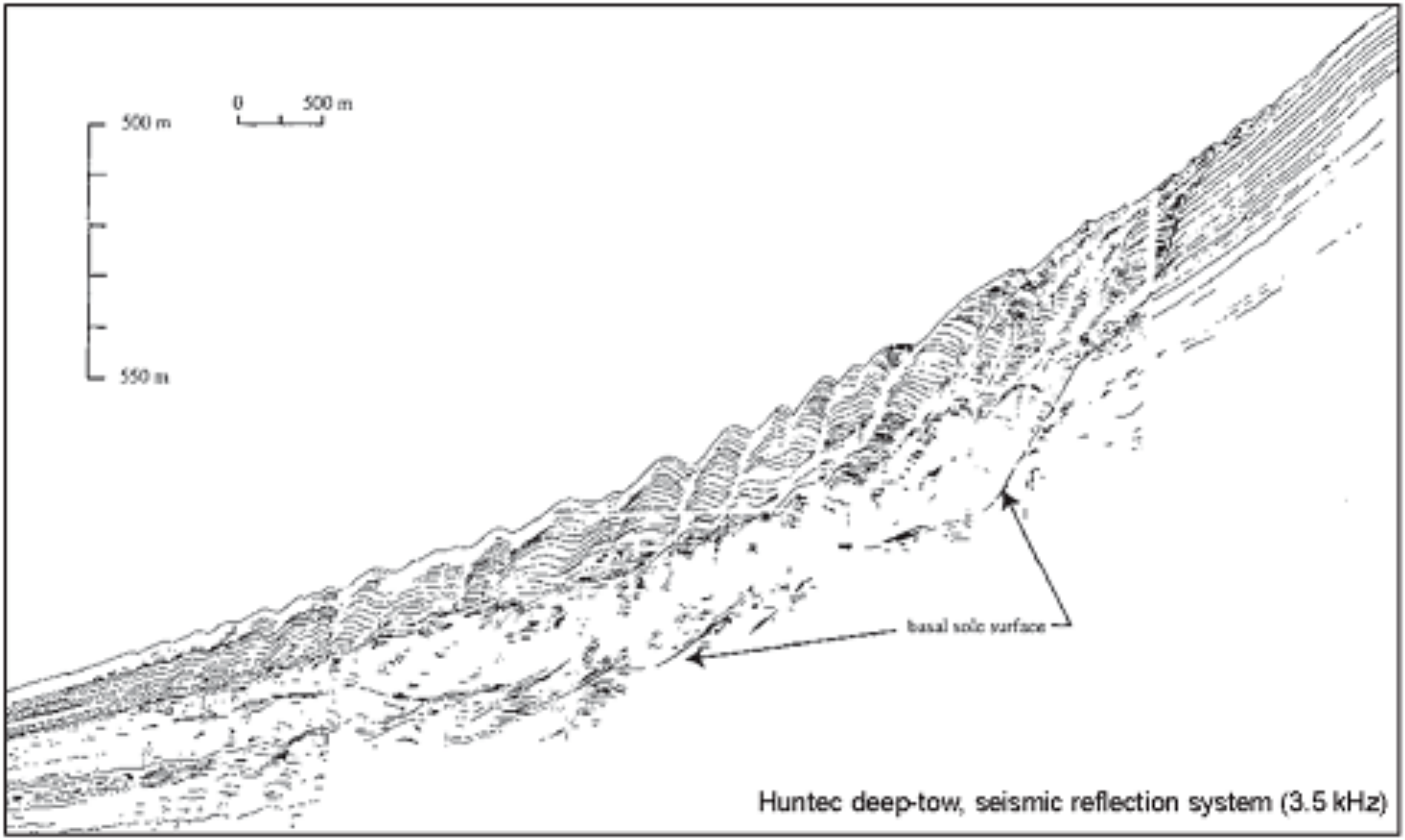
S:\8700\8719\8719.002\06_0223_rf_fig_A2-08.ai



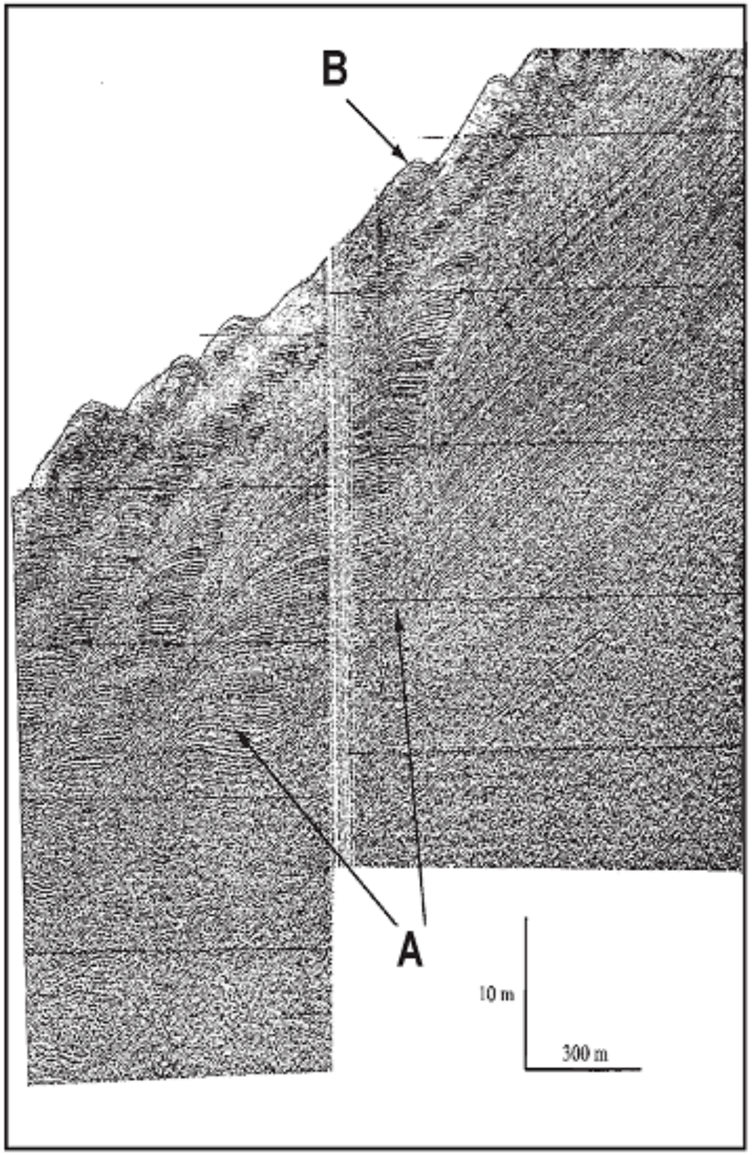
Modfied from Lee et. al, (2002)



From Orange et. al, (1999)

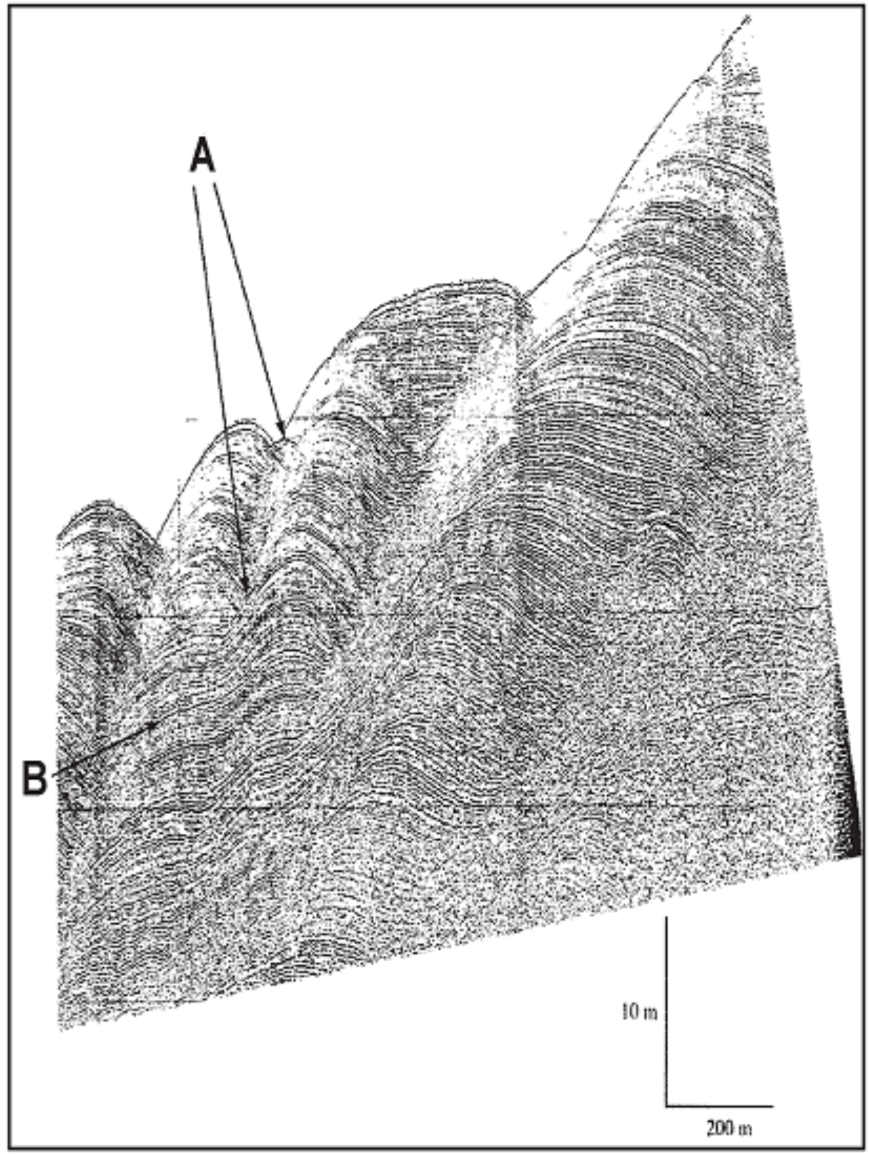


From Gardner et al. (1999)



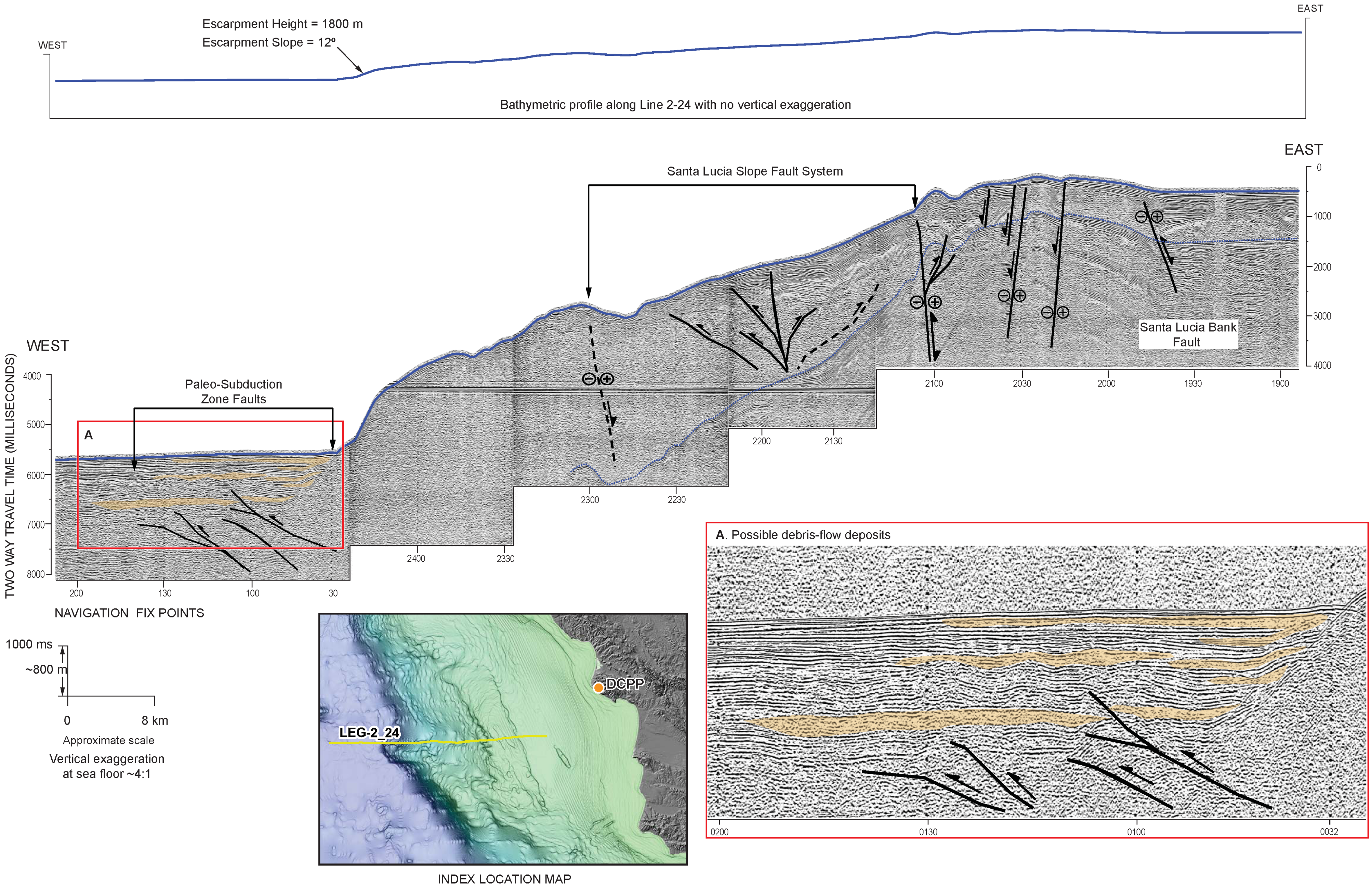
a) Note that strata can be traced across a feature interpreted to be a "fault." The uppermost wave field (B), represent the most recent period of sediment wave deposition.)

From Lee et al. (2002)

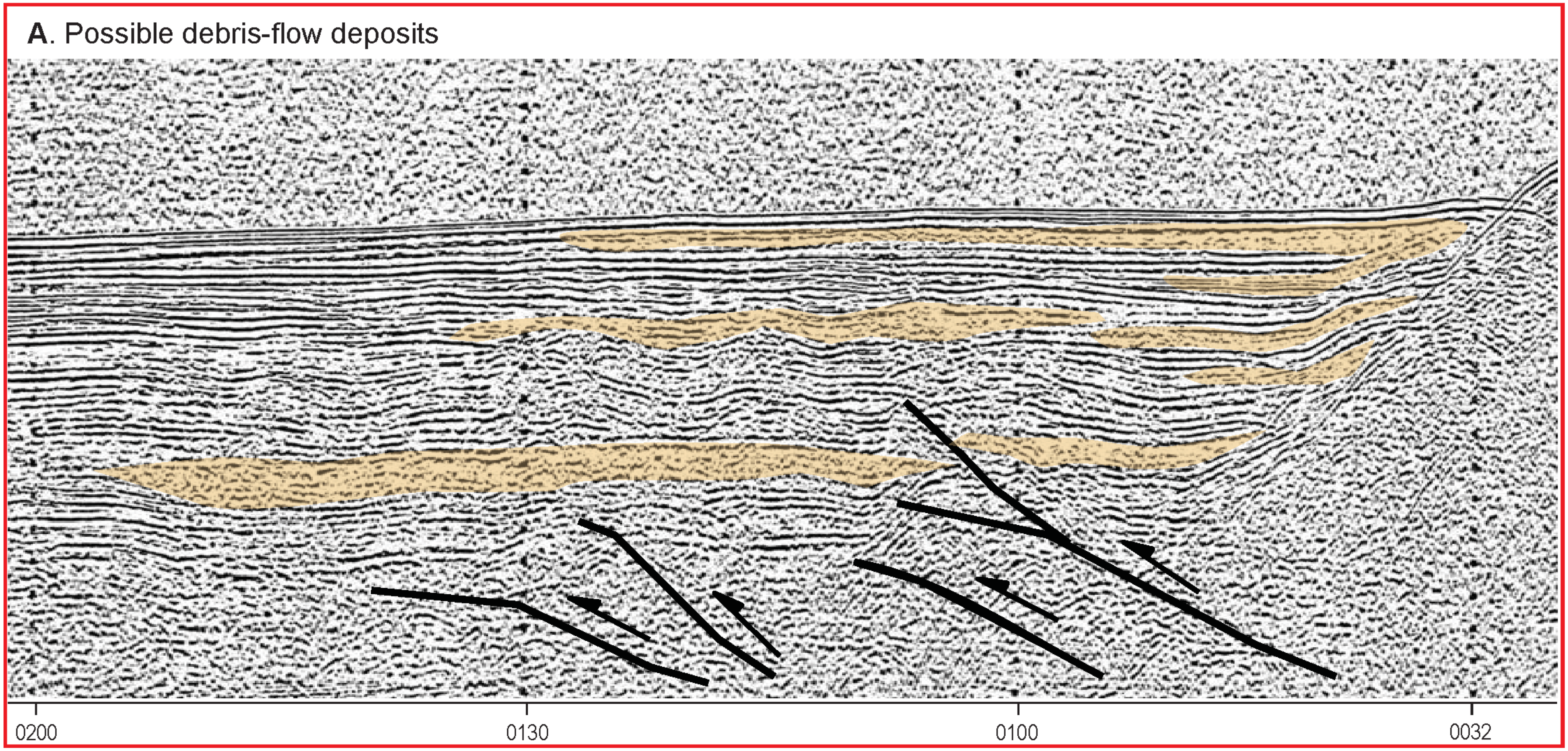


b) Huntec sub-bottom image of waves within main body of 'Humboldt slide', showing: (A) A zone that separates two waves decreases in offset downsection, counter to most structural faults. (B) At depth, internal reflectors can be traced across the two units, where upsection at A the continuity cannot be traced through the hyperbola. If a fault is present upsection, the displacement must be transferred parallel to bedding and over the "folded" strata above B.

[redacted]



[redacted]



A. Possible debris-flow deposits
0200
0130
0100
0032

Buried Debris Flows

Acoustic horizons that lack coherent internal layering

Ages

Thickness of overlying horizontally layered sediment

Holocene hemipelagic sedimentation rate of 15 cm/ 1000 yr

Gutmacher and Normark (1993) for the Sur slide

Rates

200,000 to 1,000,000 yrs

Thickness

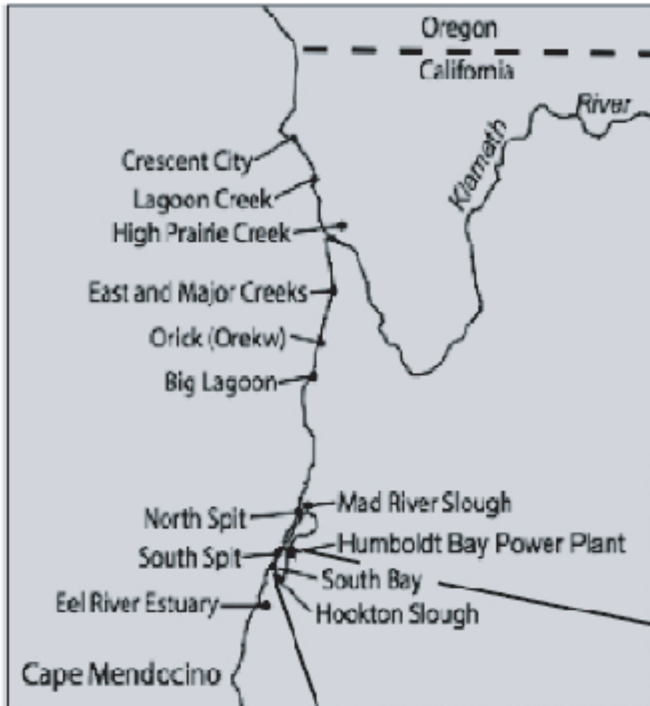
Greater thickness at northern end of Escarpment (100- 300 m)

Decreasing through the central and southern Escarpment

Study Objectives

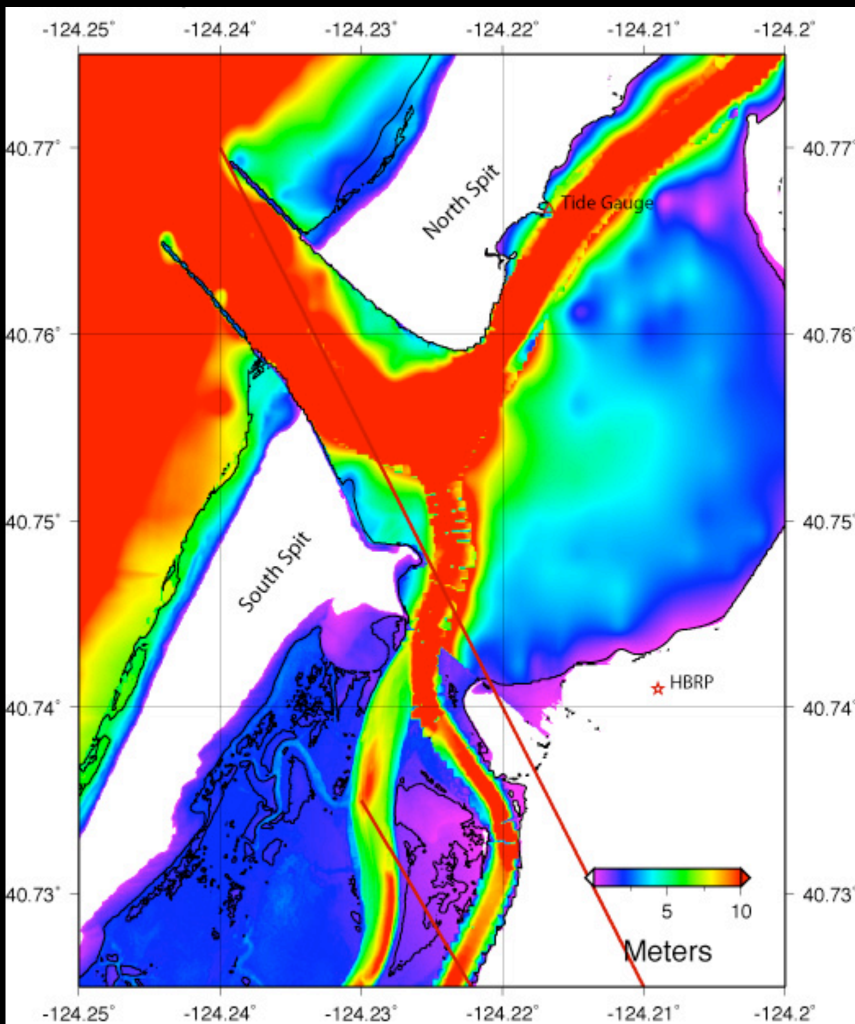
- Develop scenario events and source parameter inputs for tsunami modeling (distant, regional, and local earthquakes, local submarine slides)

    - Use paleoseismology studies to constrain tsunami run up models

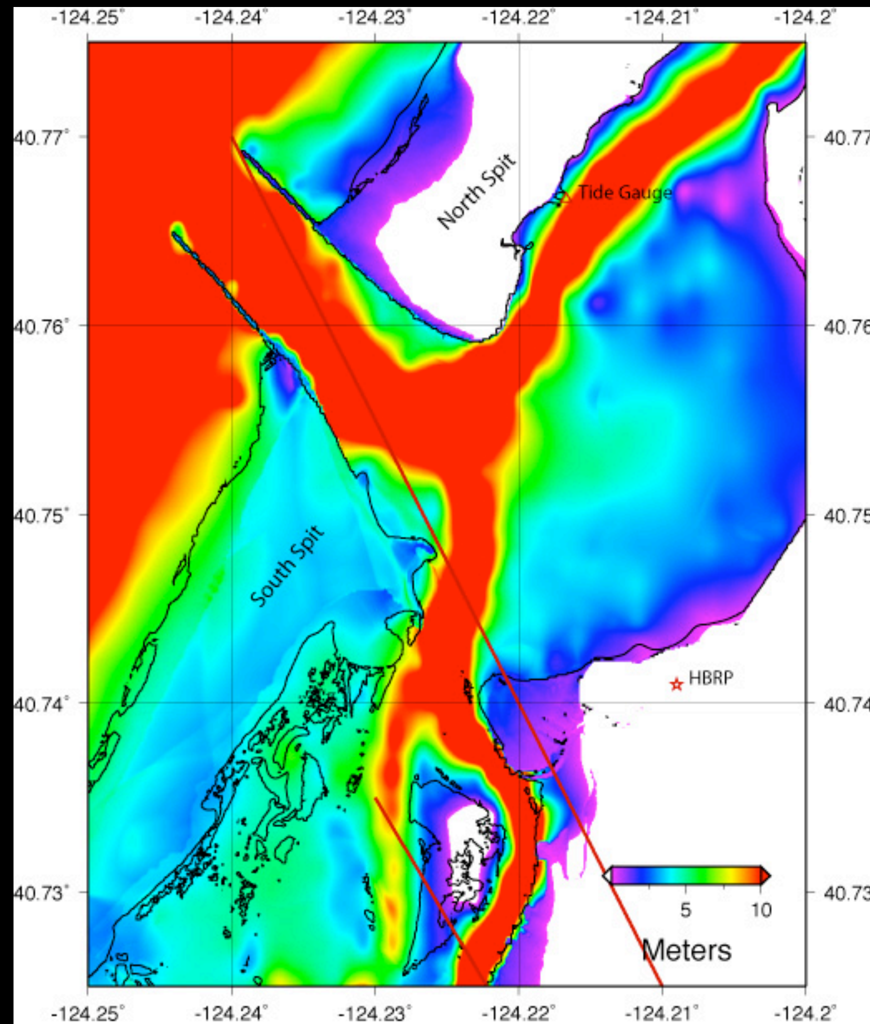


A Paleotsunami sites northwestern Califronia

B Paleotsunami sites in South Bay



CICORE DEM

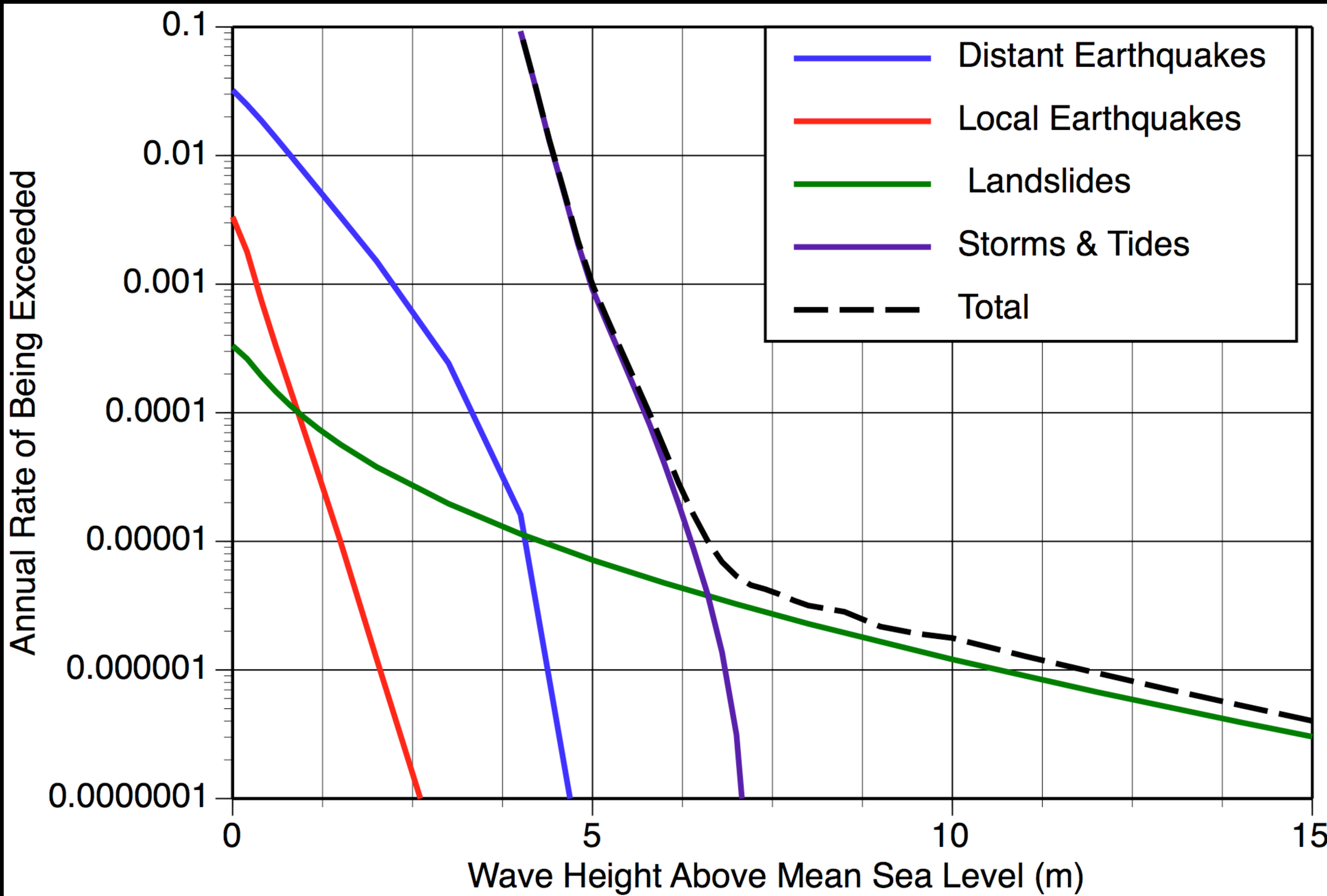


USGS DEM

Cascadia- Little Salmon Fault Model

Study Objectives

- Model tsunami runup/drawdown, flow velocity, inundation distance
- Develop framework for Probabilistic Tsunami Hazard Analysis
  - Include aleatory variability of tsunami sources
  - Include offshore landslides in addition to earthquakes
  - Include effects of storms and tides in PTHA



Distant Earthquakes
Local Earthquakes
Landslides
Storms & Tides
Total
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
Annual Rate of Being Exceeded
0
5
10
15
Wave Height Above Mean Sea Level (m)

Next Steps

- High resolution bathymetry

- Characterization of sources –
  - Circum Pacific sources
  - multibeam surveys for landslides

- Current meters – beyond wave height

Thank You !