The offshore northern San Andreas fault:
Fault zone geometry from high-resolution sub-bottom profiling, seismic reflection, and bathymetric mapping with paleosiemic evidence for partial rupture synchronization with southern Cascadia

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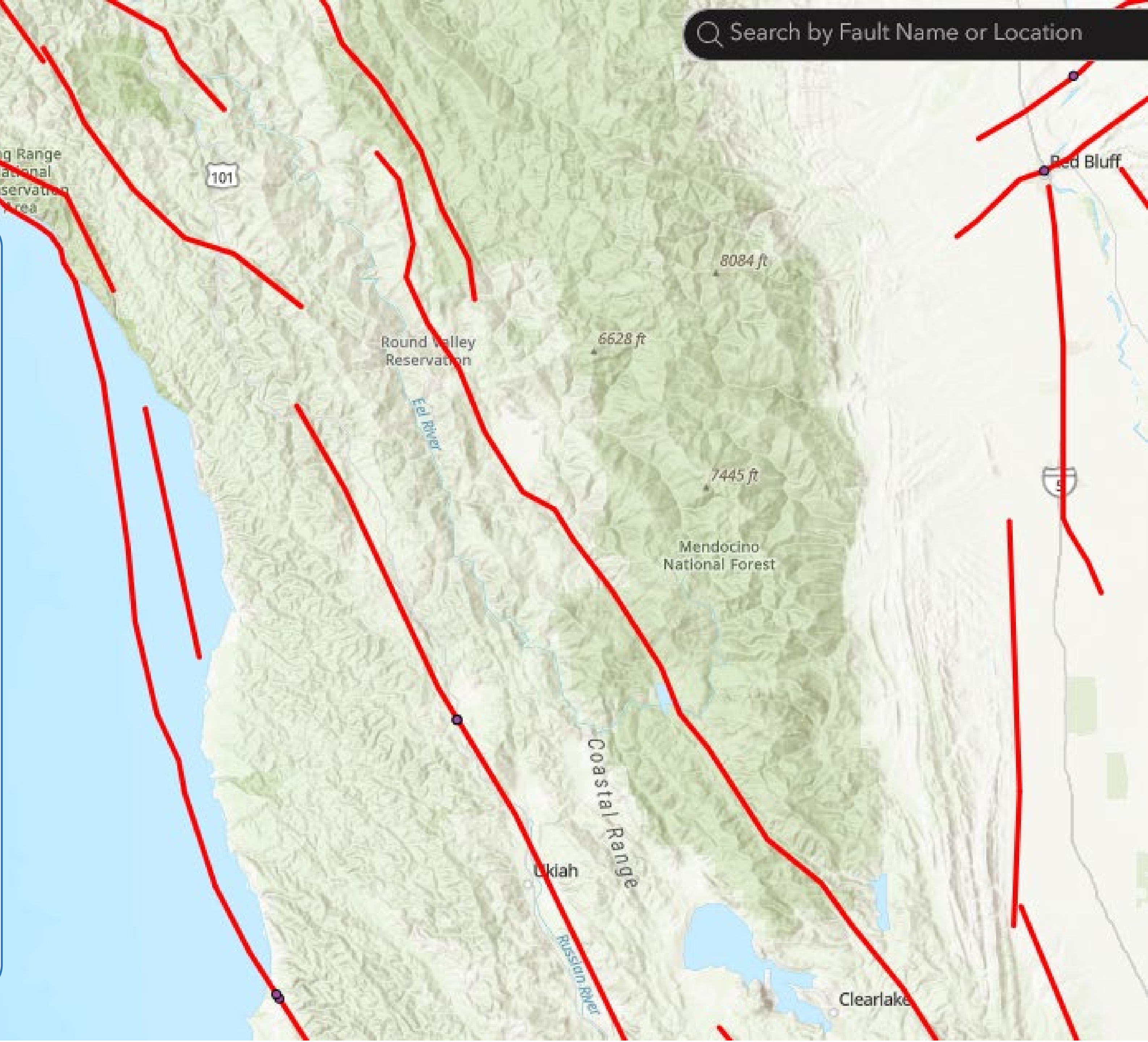
NSHM Fault Sources Northern California

- USGS National Seismic Hazard Model (NSHM) fault sections are the mapped, characterized sources used to forecast ground shaking nationwide.
- Each section carries a geometry (surface trace, dip, rake) plus a slip rate and recurrence estimate that drive the hazard calculation.
- Northern California is dominated by the San Andreas system: San Andreas, Maacama, Bartlett Springs, and Rodgers Creek–Hayward.



Quaternary Fault & Fold Database

- Faults with evidence of movement in roughly the last 1.6 million years. the source pool the NSHM draws from.
- Every trace carries age of last movement, slip rate, slip sense, mapping scale, and a literature citation.
- A line-type attribute flags positional certainty; many northern California offshore traces are only “approximately located.”

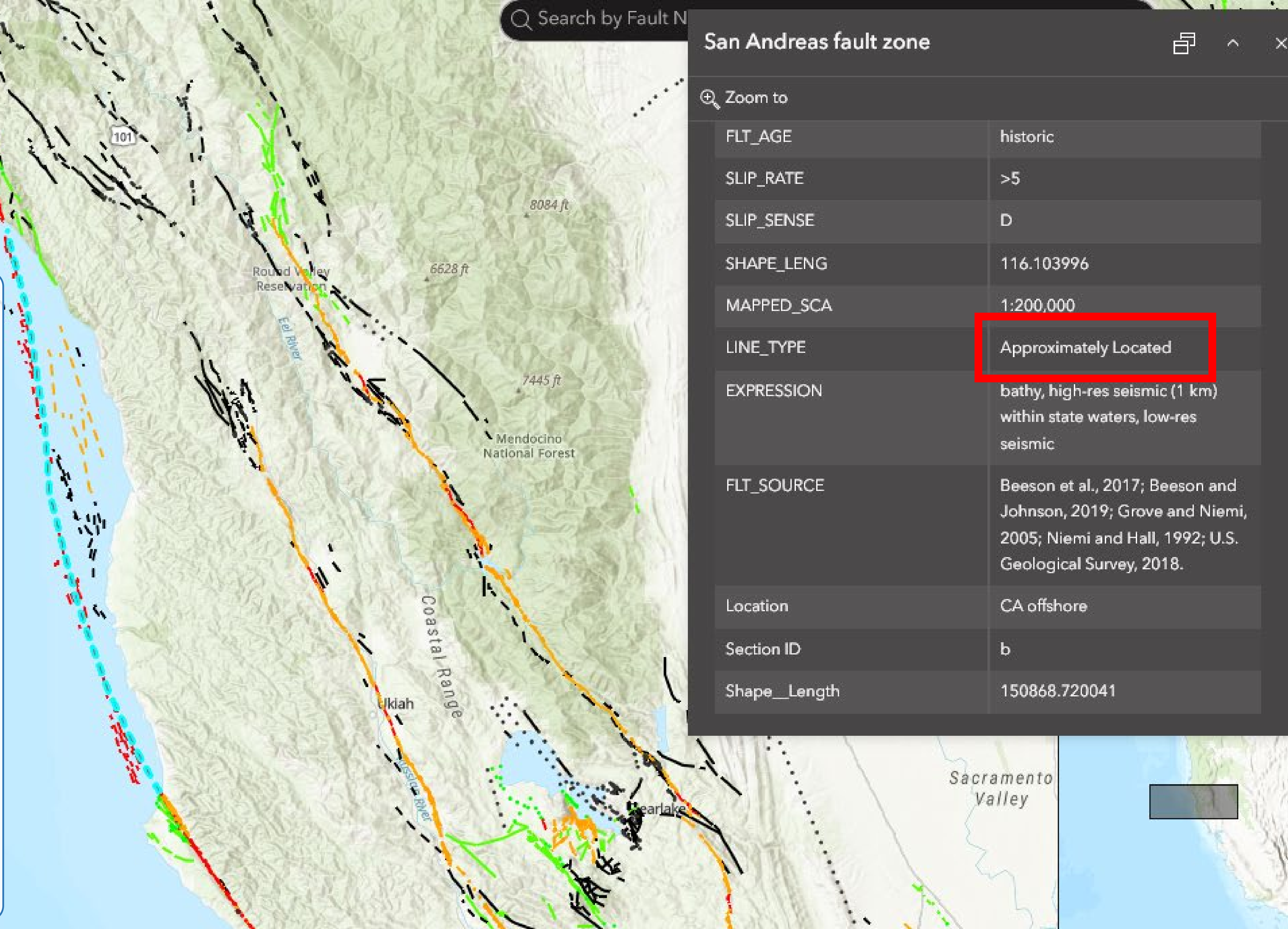


Figure 10. Topographic map derived from part of U.S. Geological Survey 15′ Point Delgada quadrangle. North of Kaluna Cliff, the location of the San Andreas fault is uncertain. Brown (1995) suggested that the San Andreas fault trends offshore; this study suggests a possible onshore northward-trending splay of the fault zone (dashed and queried). No 1906 rupture was reported north of Telegraph Hill. N indicates the location of notch between Saddle Mountain and Horse Mountain Ridge (Fig. 9). Box shows area of Figure 2. Contour interval is 152.5 m (500 ft).

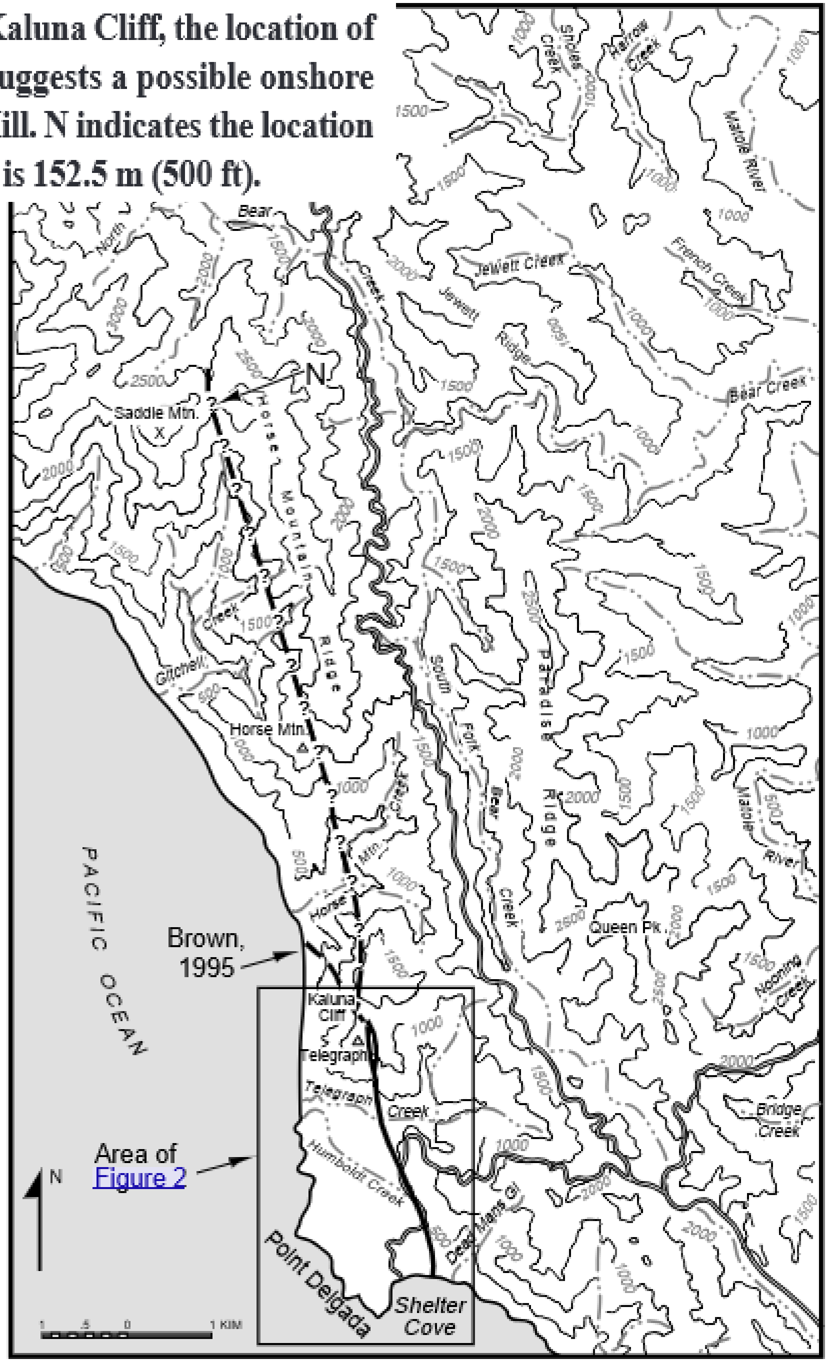


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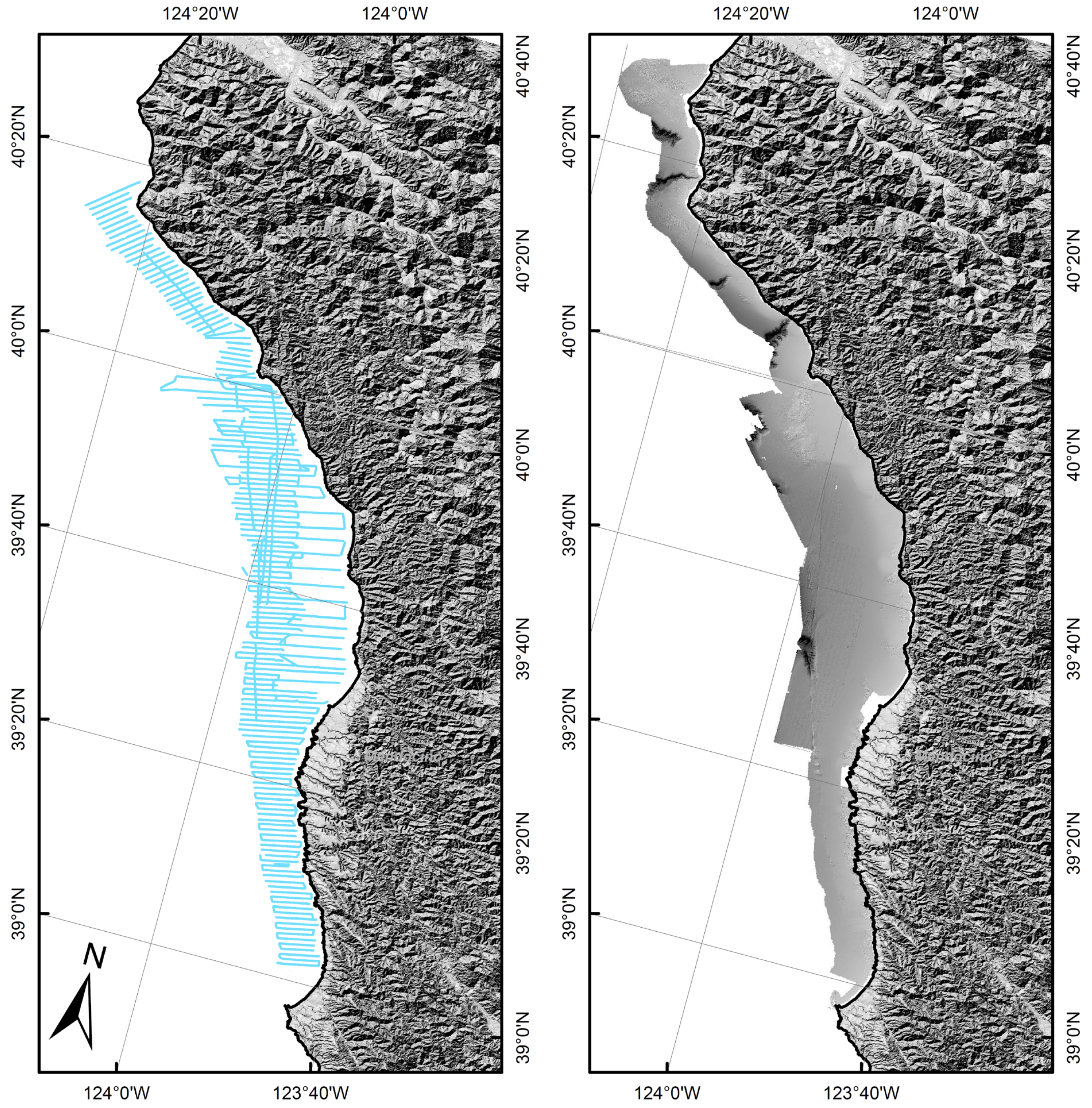
Figure 1. Map showing study area in relation to major tectonic features. SAF—San Andreas fault; CSZ—Cascadia subduction zone; CkSZ—Cooskie shear zone; MF—Mendocino fault; WGF—Whale Gulch fault. Marine seismic reflection lines show locations of offshore evidence of faulting, but whether the fault comes onshore near Shelter Cove is uncertain because reflection lines are more than 20 km south of Point Delgada. Compiled from Curray and Nason (1967) and McLaughlin et al. (1994). Box in inset map shows location of this region within California.



Multibeam, ~1,600 km^2

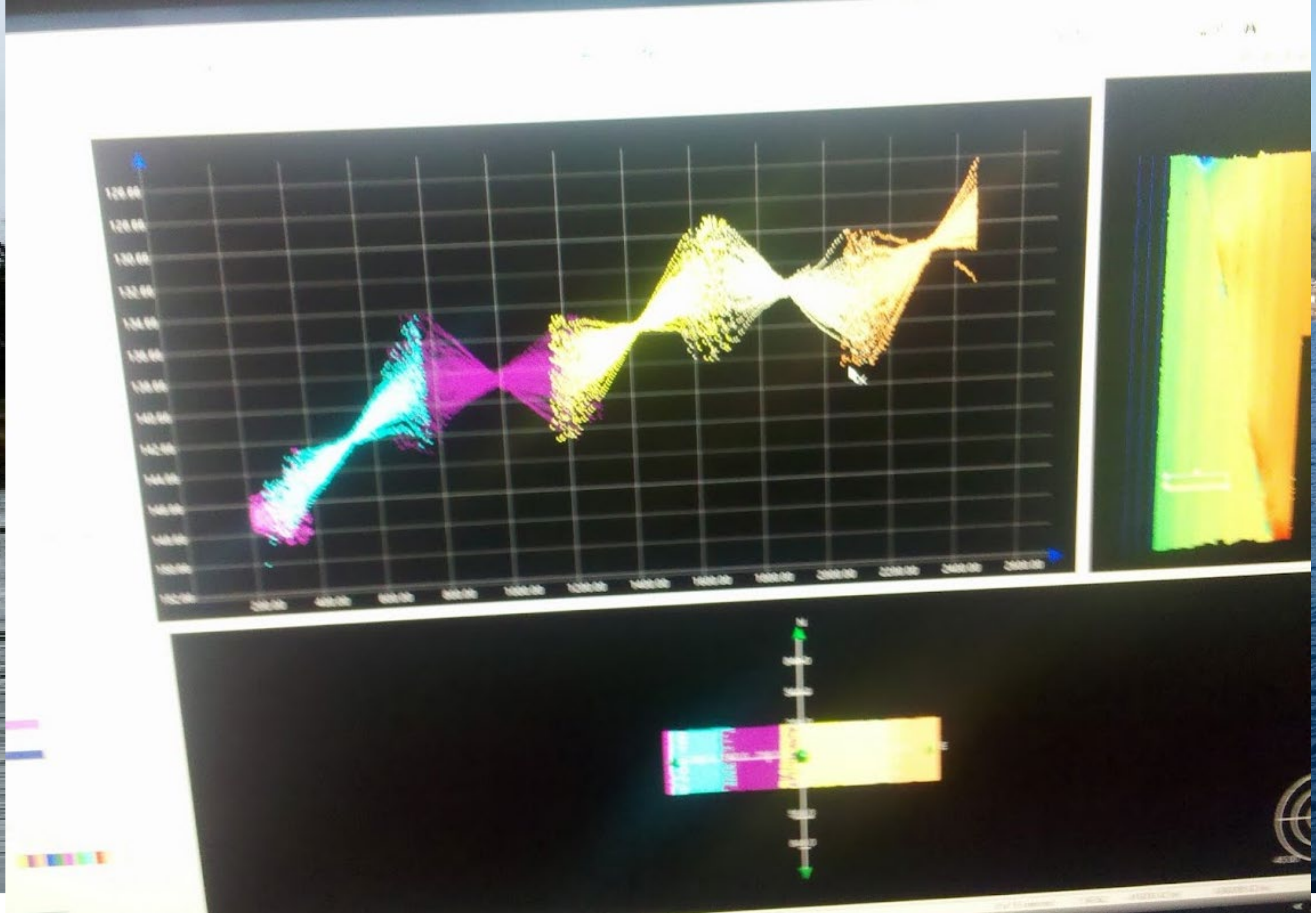
- OSU: 240 kHz Reson 8101. Fugro Pelagos: Reson 7125 at 200 and 400 kHz
- Gridded at 2 m inside state waters, 15 m outside

Seismic, 1,605 km

- Single-channel minisparker, 120 SAF crossings at ~1 km line spacing
- Source spectrum ~200 to 1,600 Hz, vertical resolution commonly ~1 m
- Shots every 0.5 s, 1 s on the deeper lines at the head of Noyo Canyon; at 4 to 4.5 kn that is a trace every 1 to 2 m
- Water depths mostly 50 to 150 m, as shallow as 10 m nearshore and to 500 m in Noyo Canyon
- Recorded to SEG-Y through a Triton Subbottom Logger
- Processed in SIOSEIS and Seismic Unix: bandpass, mute, AGC, water-bottom detect, swell correction. Interpreted in IHS Kingdom

Magnetics, 2012 only

- Geometrics G-882 cesium vapour magnetometer, south flank of Cape Mendocino only
- 500 m line spacing along the seismic tracks plus fill-in lines, 10 Hz, smoothed to ~10 m along-track to suppress minisparker noise
- Aeromagnetics from Langenheim et al. (2013), gridded at 50 m by minimum curvature



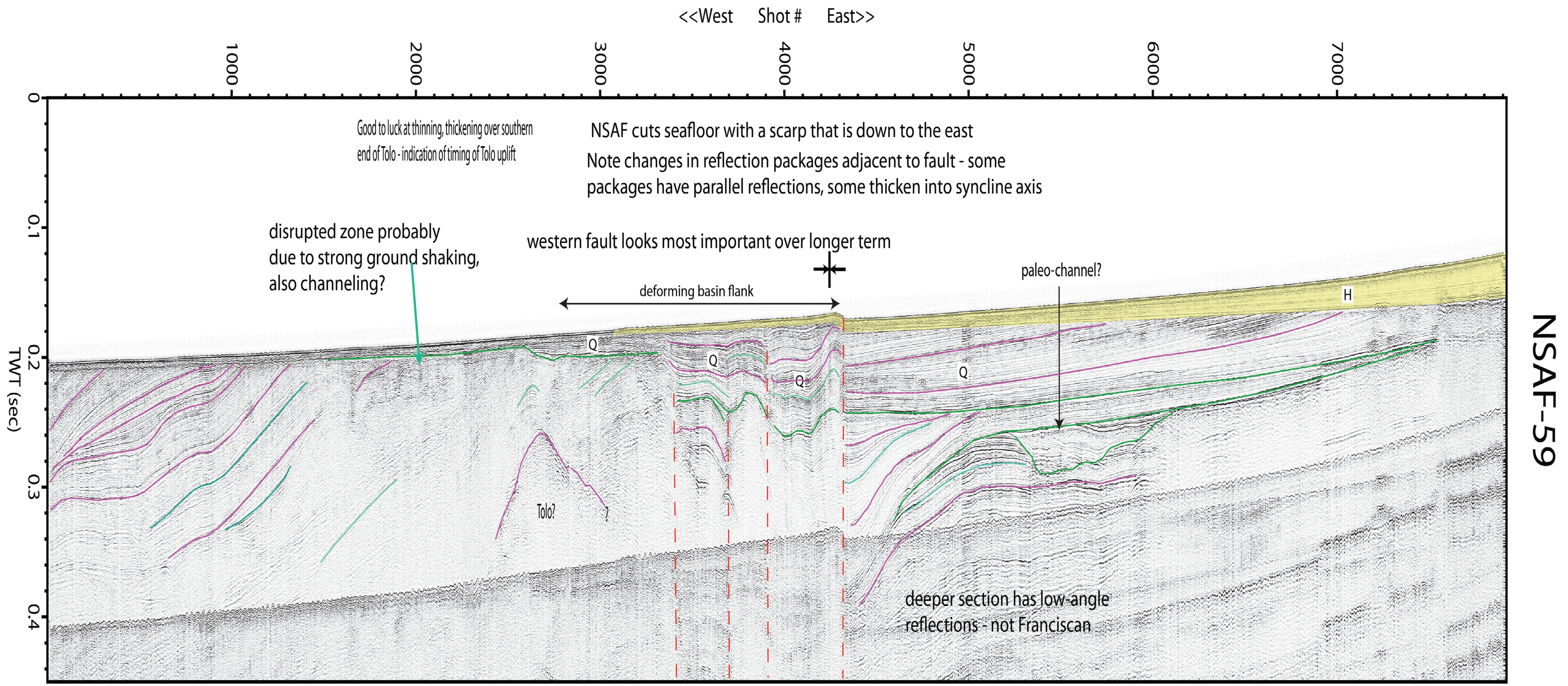
S/V Derek M. Baylis — 2010 and 2012 NSAF Campaigns

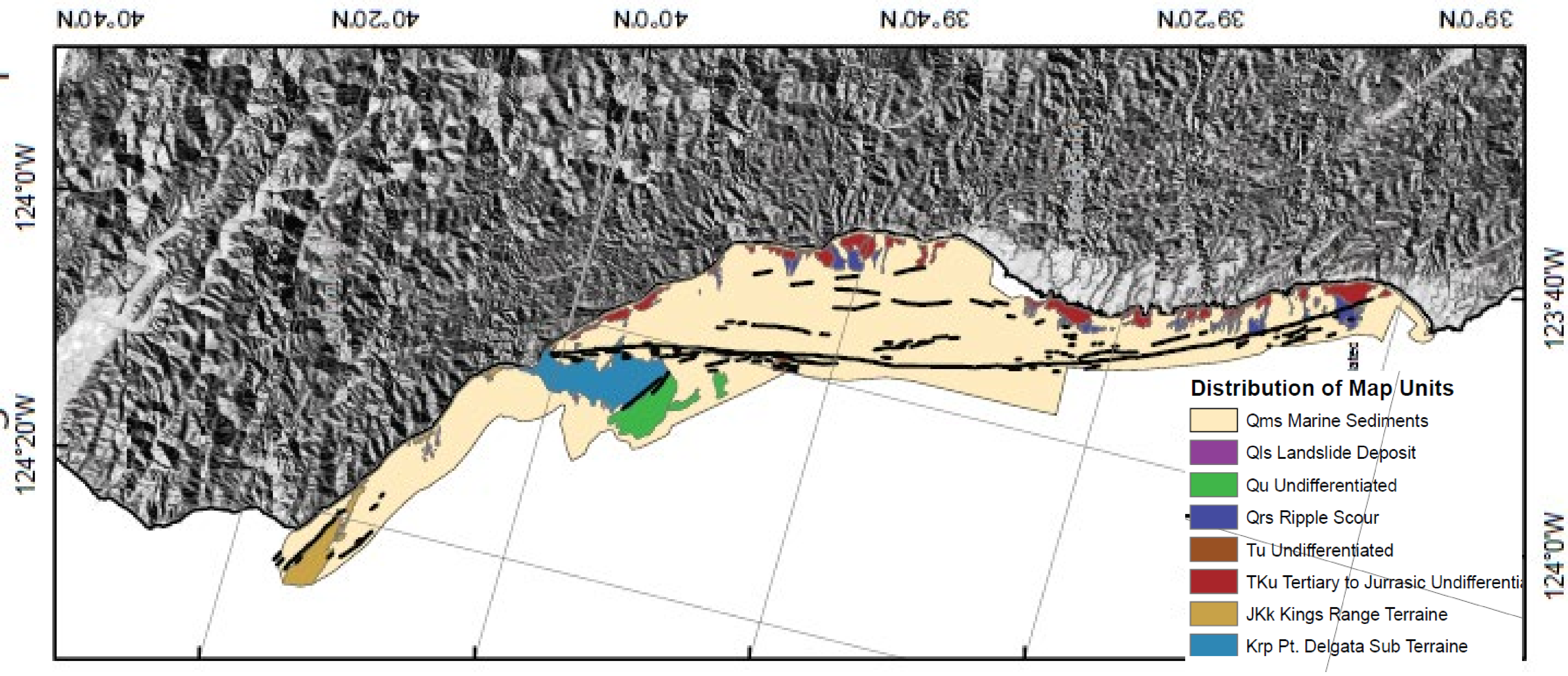
- 65-ft sail-powered research vessel; efficient hull and rig held average fuel burn near 1.6 gal/hr, a small fraction of a conventional research ship.
- Reson 8101 multibeam echosounder mounted on a purpose-built pole below the keel, clear of hull noise and bubble sweep.
- Minisparker and chirp seismic reflection run in tandem with the multibeam to image fault geometry and shallow stratigraphy.
- The 2010 (NOAA Ocean Exploration) and 2012 campaigns delivered the first comprehensive high-resolution mapping of the offshore northern San Andreas.

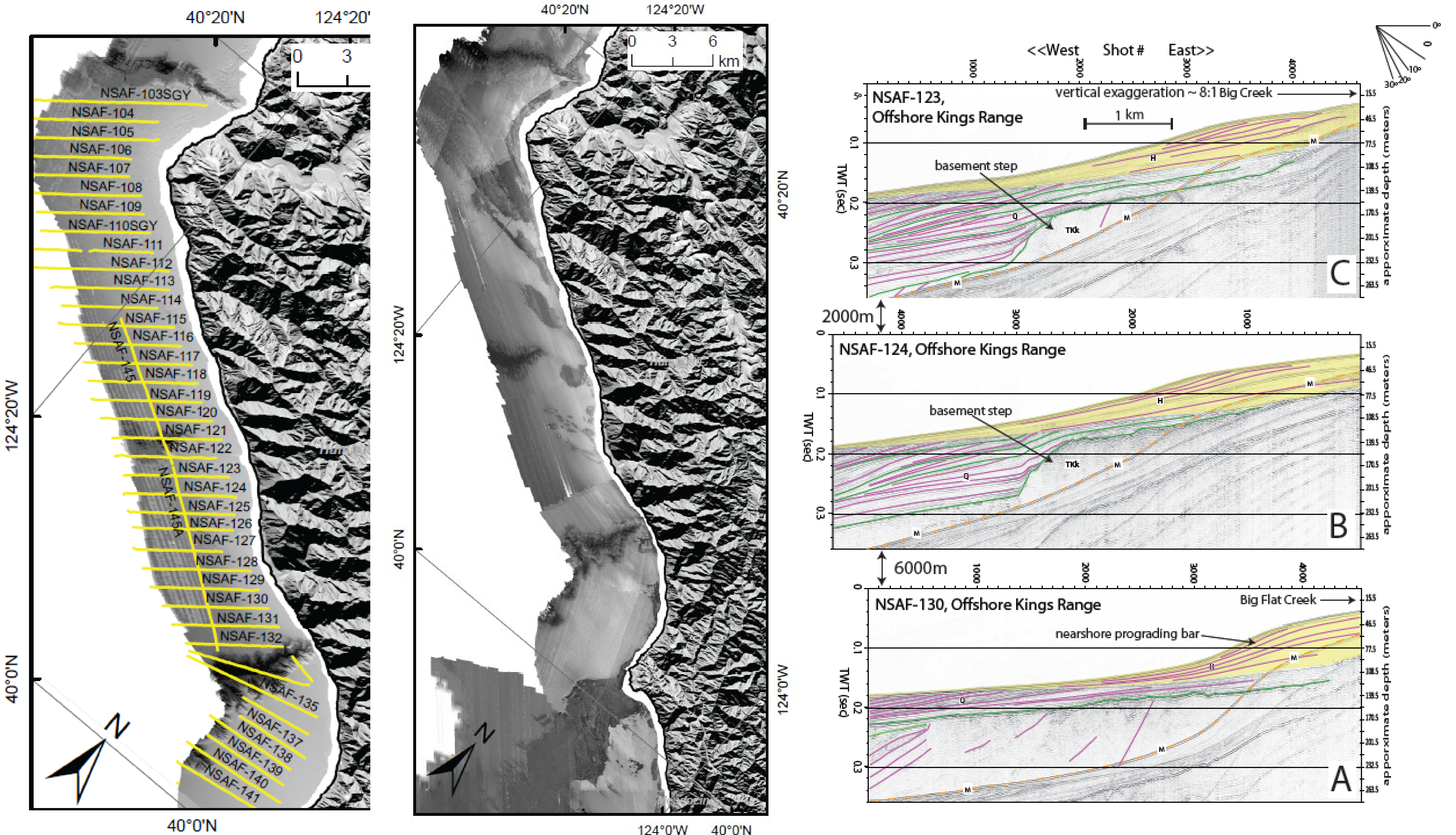
Sam Johnson, USGS retired

Chris Goldfinger,
OSU retired (mostly)

High quality single-channel seismic data resolves faulting and subsurface stratigraphy well.




40°40'N
40°20'N
40°0'N
39°40'N
39°20'N
39°0'N
124°0'W
124°20'W
123°40'W
124°0'W
Distribution of Map Units
Qms Marine Sediments
Qls Landslide Deposit
Qu Undifferentiated
Qrs Ripple Scour
Tu Undifferentiated
TKu Tertiary to Jurrasic Undifferenti
JKk Kings Range Terraine
Krp Pt. Delgata Sub Terraine


40°20'N
124°20'
0
3
NSAF-103SGY
NSAF-104
NSAF-105
NSAF-106
NSAF-107
NSAF-108
NSAF-109
NSAF-110SGY
NSAF-111
NSAF-112
NSAF-113
NSAF-114
NSAF-115
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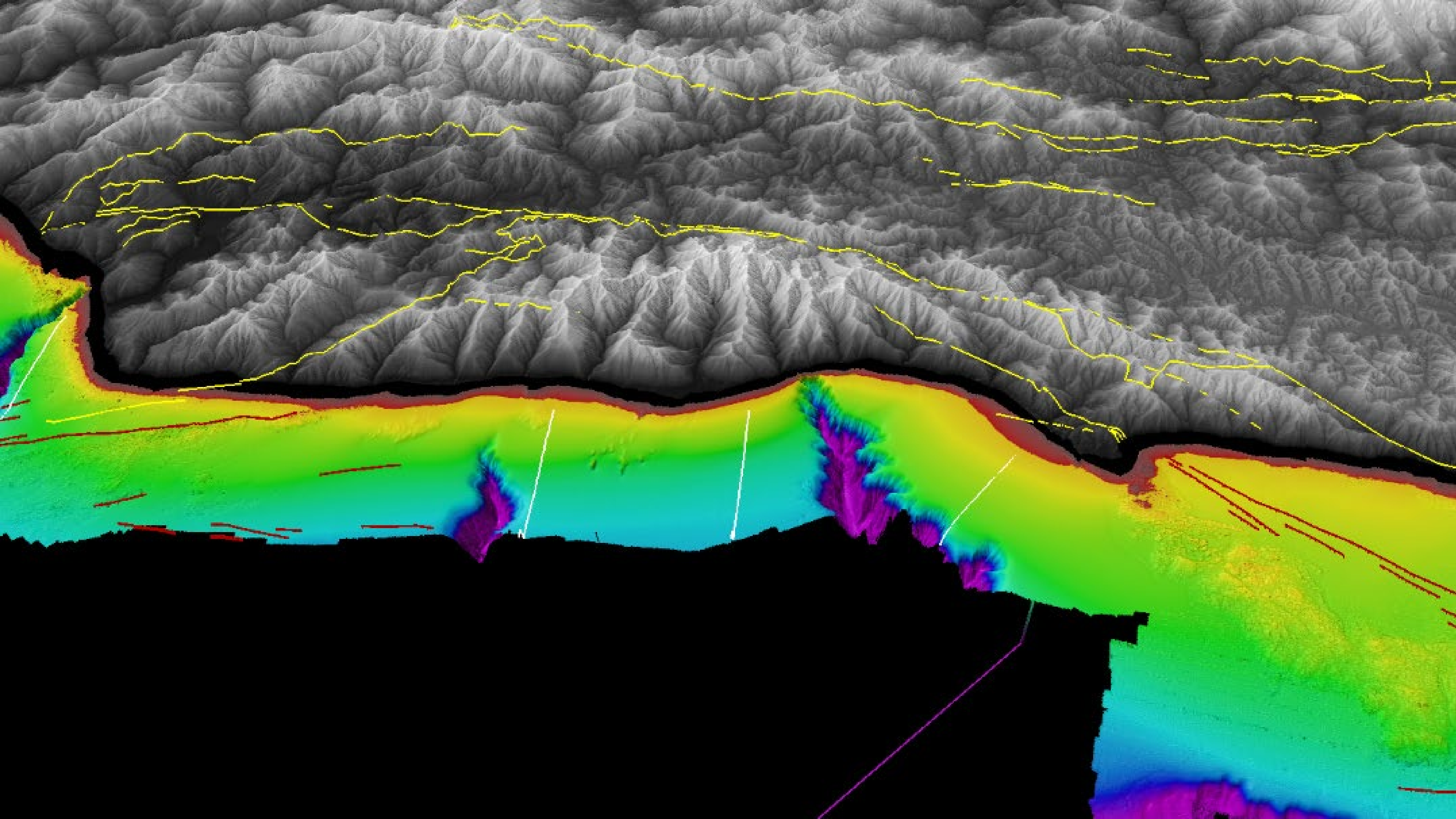
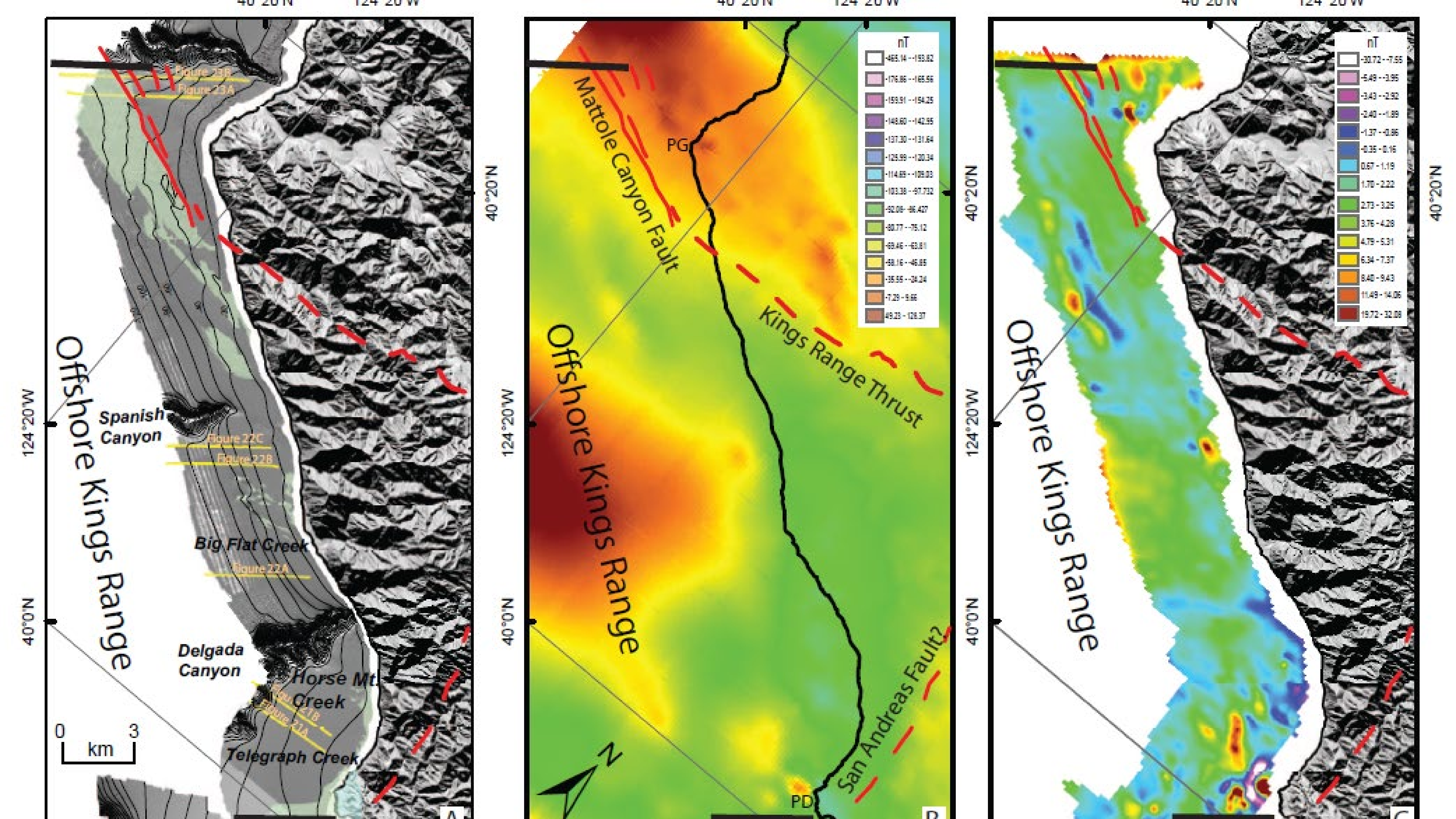
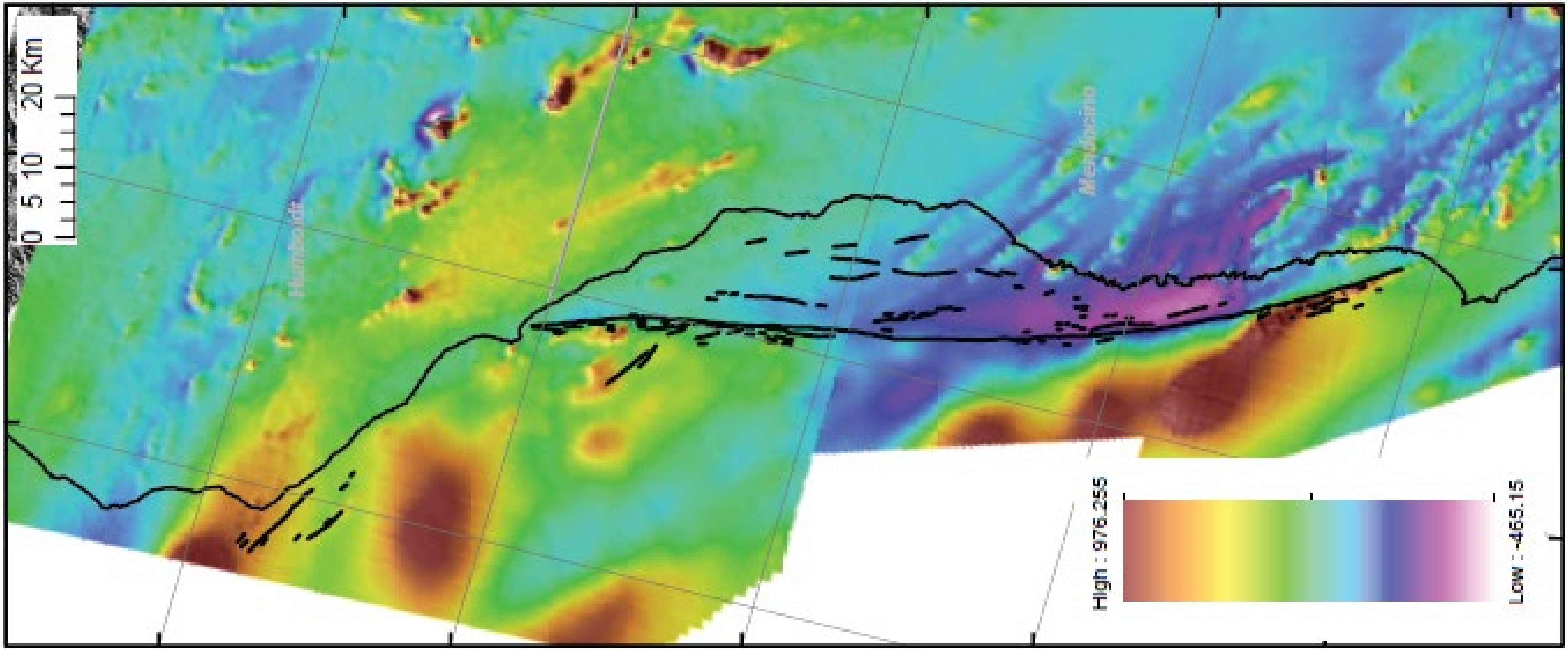
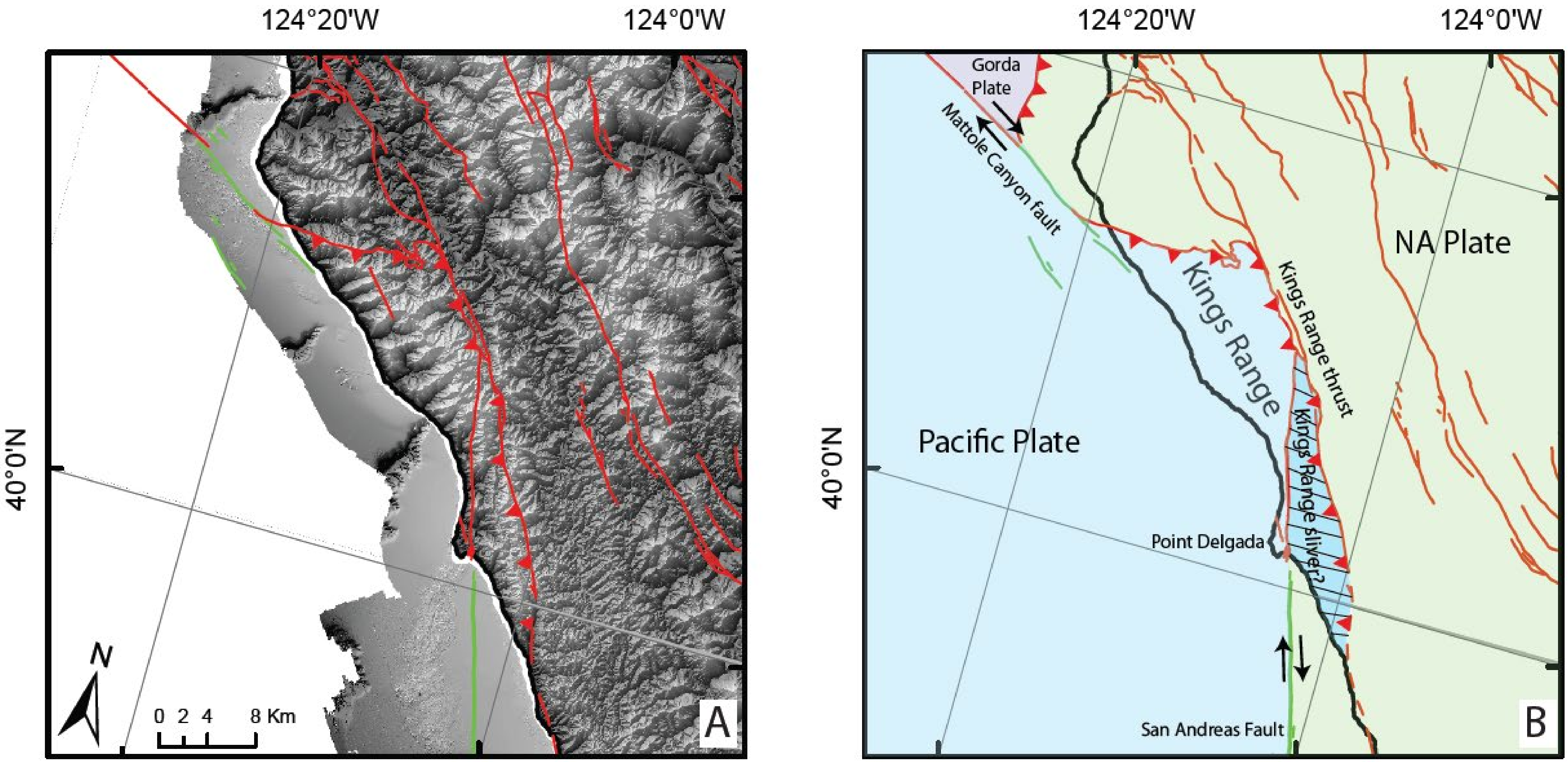
NSAF-137
NSAF-138
NSAF-139
NSAF-140
NSAF-141
NSAF-145
NSAF-145A
124°20'W
40°0'N
N
40°20'N
124°20'W
0 3 6
km
40°20'N
124°20'W
40°0'N
124°0'W
124°0'W
40°0'N
N
<<West Shot # East>>
NSAF-123,
Offshore Kings Range
vertical exaggeration ~ 8:1 Big Creek
1 km
basement step
TWT (sec)
approximate depth (meters)
C
2000m
NSAF-124, Offshore Kings Range
basement step
B
6000m
NSAF-130, Offshore Kings Range
Big Flat Creek
nearshore prograding bar
A





40°20'N
124°20'W
Figure 23B
Figure 23A
Spanish Canyon
Figure 22C
Figure 22B
Big Flat Creek
Figure 22A
Delgada Canyon
Horse Mt. Creek
Telegraph Creek
0 3
km
Offshore Kings Range
40°0'N
A
nT
Mattole Canyon Fault
PG
Kings Range Thrust
San Andreas Fault?
PD
N
B
C


0 5 10 20 Km
Humboldt
Mendocino
High : 976.255
Low : -465.15



124°20'W
124°0'W
40°0'N
N
0 2 4 8 Km
A
Gorda Plate
Mattole Canyon fault
NA Plate
Kings Range
Kings Range thrust
Kings Range sliver?
Pacific Plate
Point Delgada
San Andreas Fault
B

R/V SALLY RIDE

SBP29 Sub-Bottom Profiler

including Comparison to Kndusen & AUVs

MBES & SBP Acquisition

San Diego to Newport, Oregon

August – September 2024

Scripps Institution of Oceanography – Office of Naval Research

Daniel "DanO" Orange

U.C. Santa Cruz / Integral Consulting / ONE (Oro Negro Exploration LLC)

Tolu Akande, Ola Oshikoya, Simon Tipton & Anand Hiroji

University of Southern Mississippi

Maddy Lucas, Clay Whittaker, Les Bender, James Gibson & Eli Silver

U. Washington | NAVO (ret.) | Deep Blue Analysis | U.T. Austin | UC. Santa Cruz

Kongsberg SBP29 Sub-Bottom Profiler: New to the UNOLS Fleet

Next-generation narrow-beam sub-bottom profiler, successor to the SBP 120 / SBP 300, integrated with the EM 124 / EM 304 multibeam echosounders already installed on UNOLS vessels.

2–9 kHz sweep

Wideband chirp with improved range resolution, usable to full ocean depth.

3° × 3° beams

Dedicated transmit array in 3°, 6° or 12° configurations (96 elements at 3°).

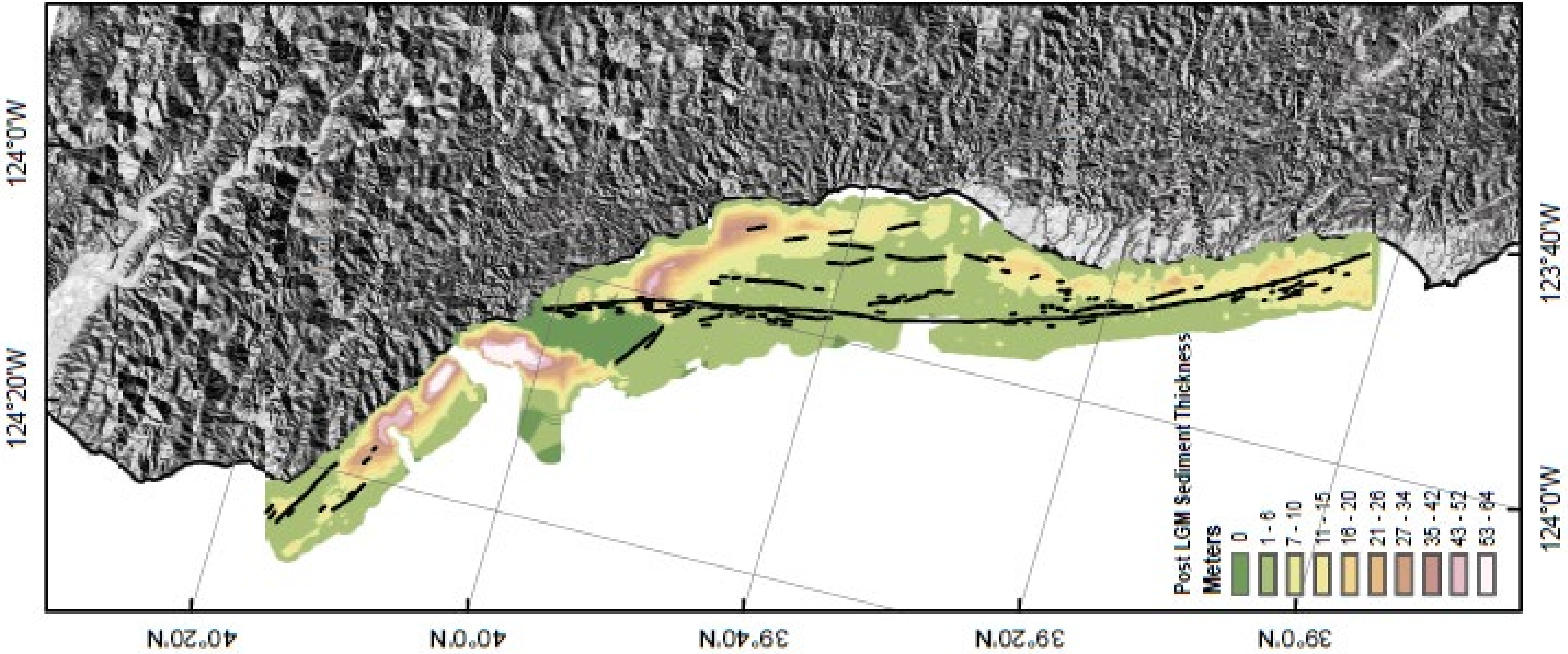
Slope robustness

Multiple across-track beams and steerable transmit angles hold returns on dipping strata.

Composite echogram

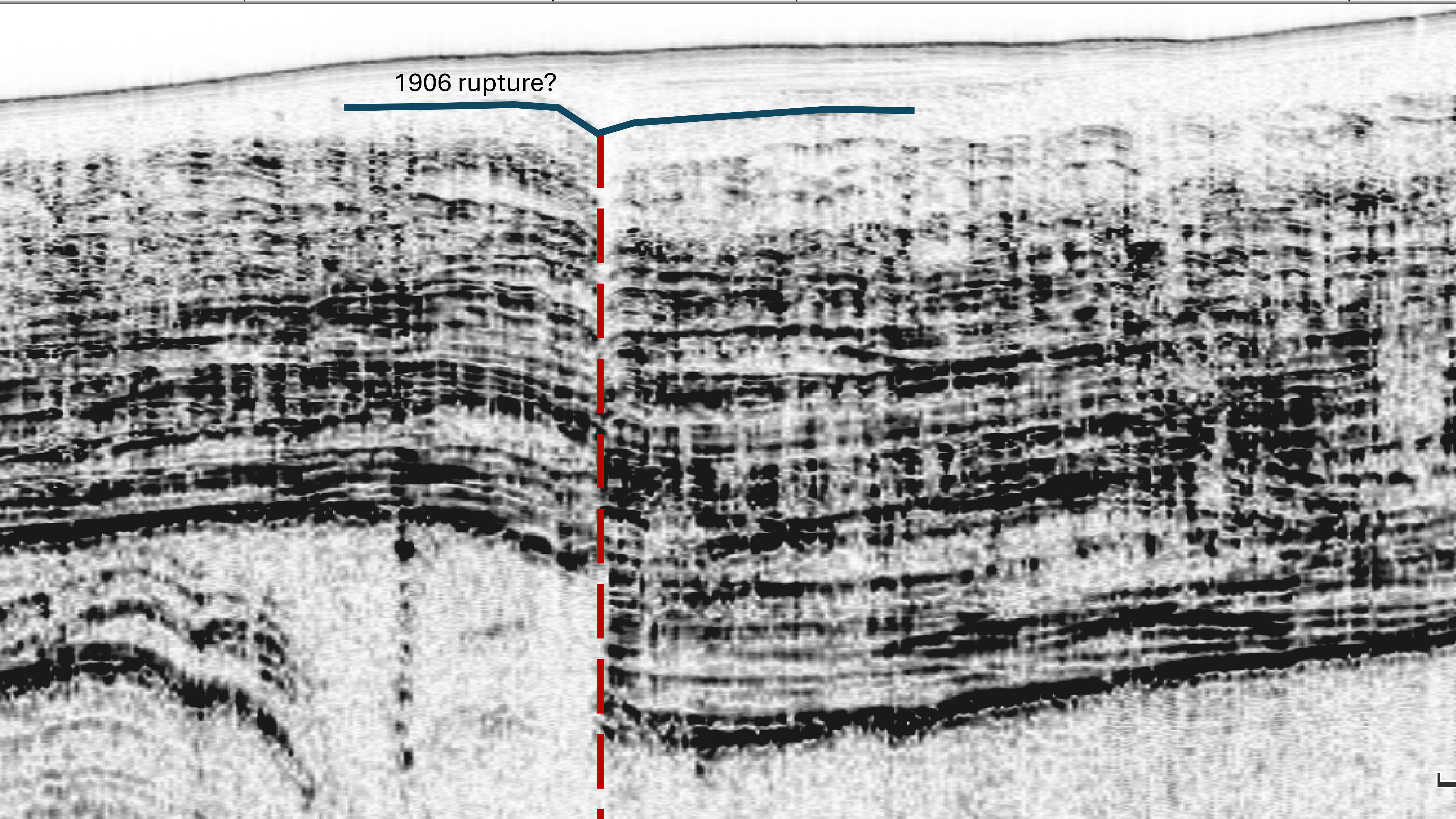
Best signal-to-noise traces from all beams merged into one section.

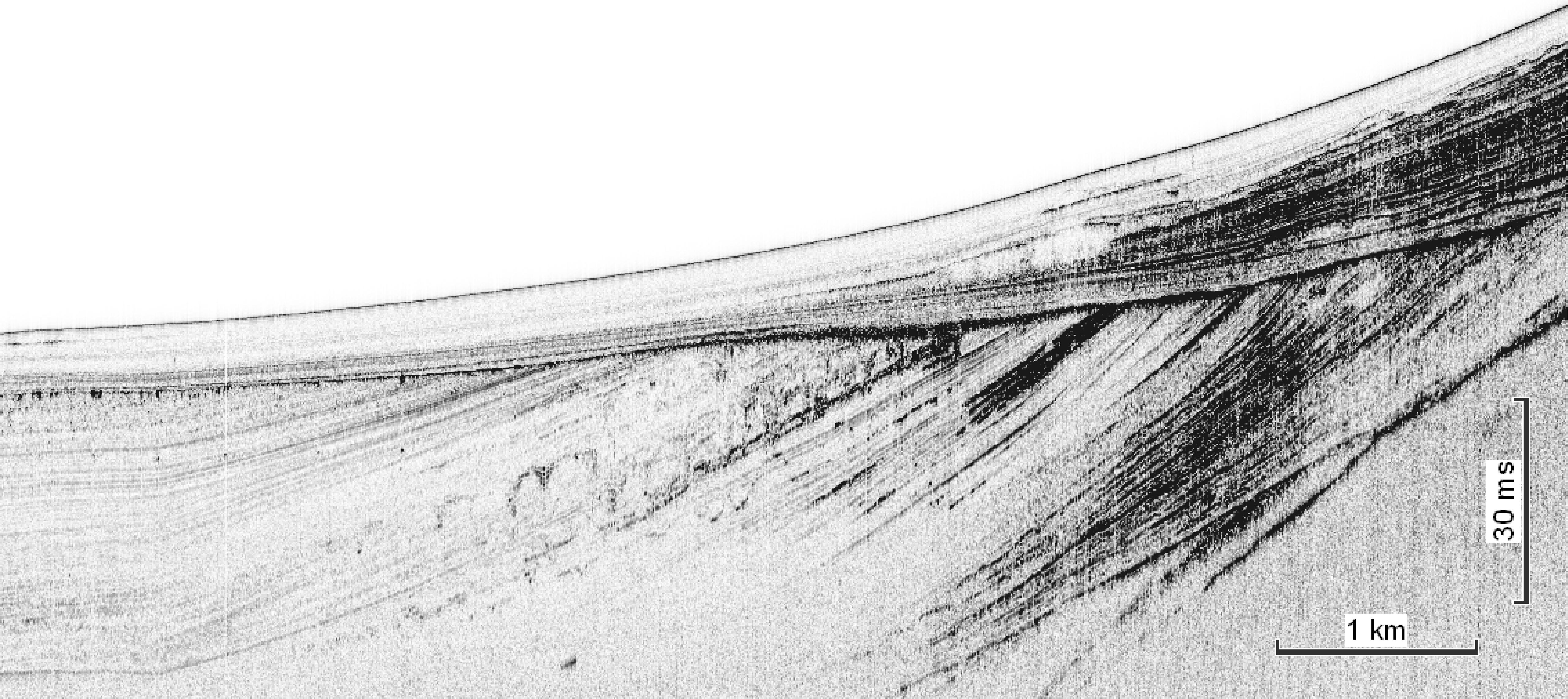
- Operates simultaneously with the multibeam, a sub-bottom section on every mapping line.
- Echoes received through the existing EM 124 / EM 304 receiver; no separate receive hardware.
- Penetration of hundreds of metres, depending on sediment type.
- Fleet-wide installation (mostly)

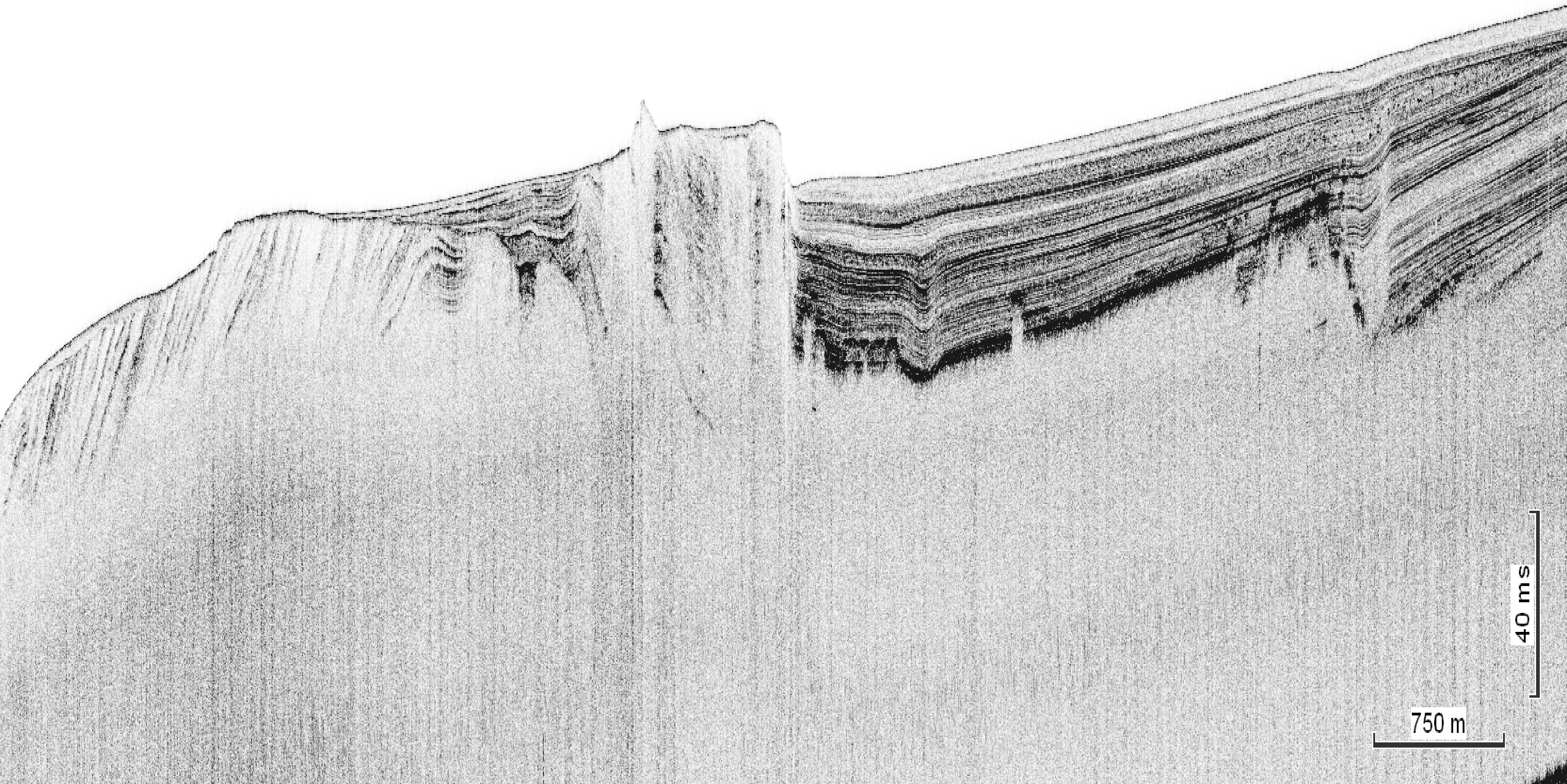


Post-LGM Sediment Thickness, Point Arena to Point Delgada

- Unit H thickness ranges from 0 to 64 m and is highly variable, not a uniform shelf blanket.
- Thickest fill sits in fault-bounded transtensional basins such as Noyo basin.
- Bedrock platforms and transpressional uplifts carry thin to no post-LGM cover.
- Depocenter migration implies SAF lateral slip of 10–19 mm/yr over the past ~350 k.y.


1906 rupture?


30 ms
1 km


40 ms
750 m

EarthScope Northern California Lidar Project

Welcome Guest (Sign In)

Overview

The EarthScope Northern California Lidar project acquired high resolution lidar topographic data along major active faults in the Northern San Andreas Fault system, as part of the EarthScope Facility project funded by the National Science Foundation (NSF).

Publications associated with this dataset can be found at NCALM's Data Tracking Center

Platform: Airborne Lidar
Full Metadata

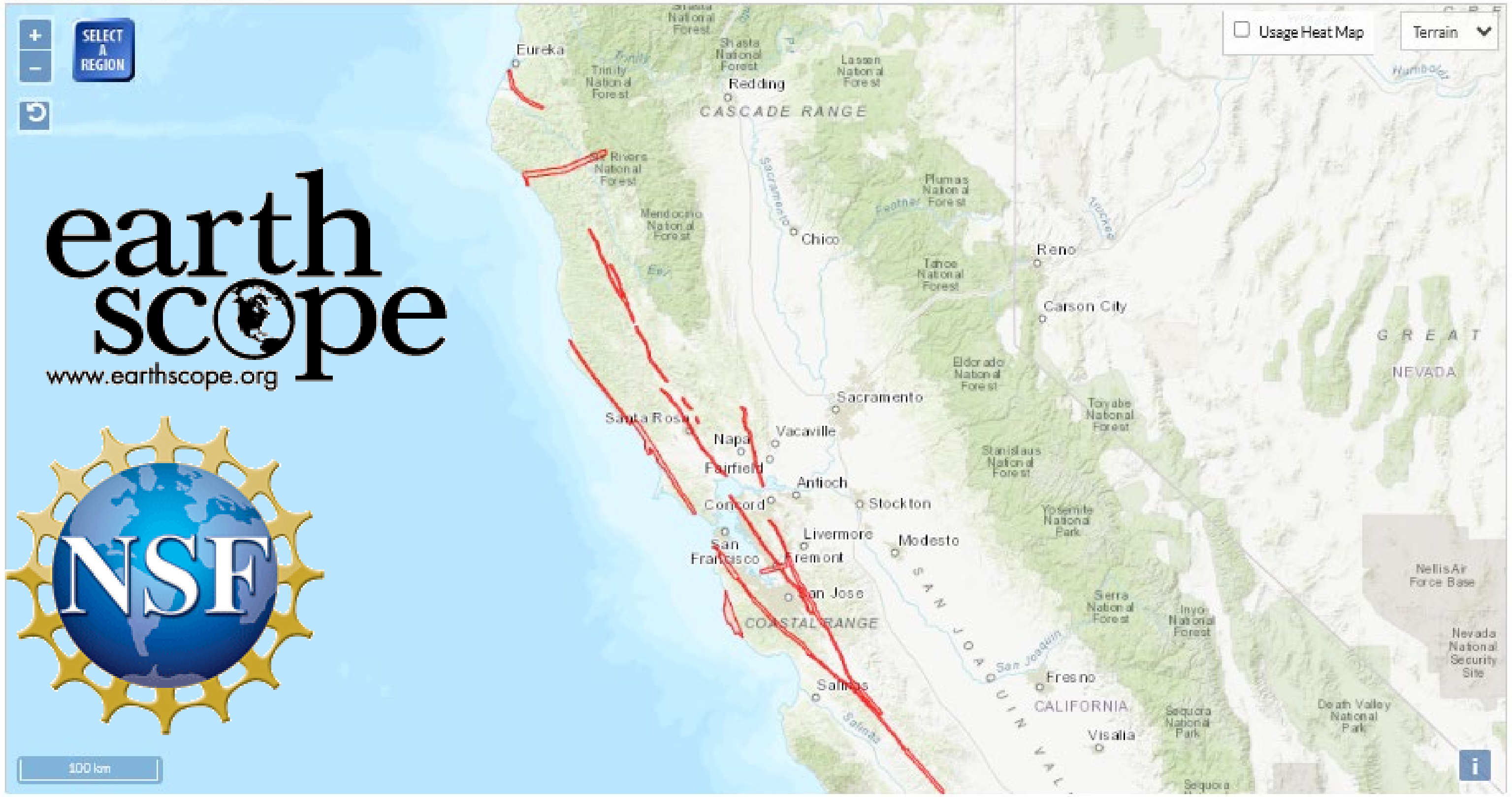
Survey Area: 2,448 km^2
Data Citation

Raster Resolution: 0.5 meter
Use License: CC BY 4.0

Survey Date: 03/21/2007 - 04/17/2007
Funder: NSF *Partners:* EarthScope, UNAVCO *Collector:* NCALM

Other Available Data Products: Point Cloud | Google Earth Imagery File | Raster Bulk Download

Select area of data to process:



Collection Overview: The EarthScope Northern California Lidar project acquired high resolution airborne laser swath mapping imagery along major active faults as part of the EarthScope Facility project funded by the National Science Foundation (NSF). Between this project and the previously conducted B4 project, also funded by NSF, the entire San Andreas fault system has now been imaged with high resolution airborne lidar, along with many other important geologic features. EarthScope is funded by NSF and conducted in partnership with the USGS and NASA. GeoEarthScope is a component of EarthScope that includes the acquisition of aerial and satellite imagery and geochronology. EarthScope is managed at UNAVCO.

https://portal.opentopography.org/datasetMetadata?otCollectionID=OT.052008.32610.1

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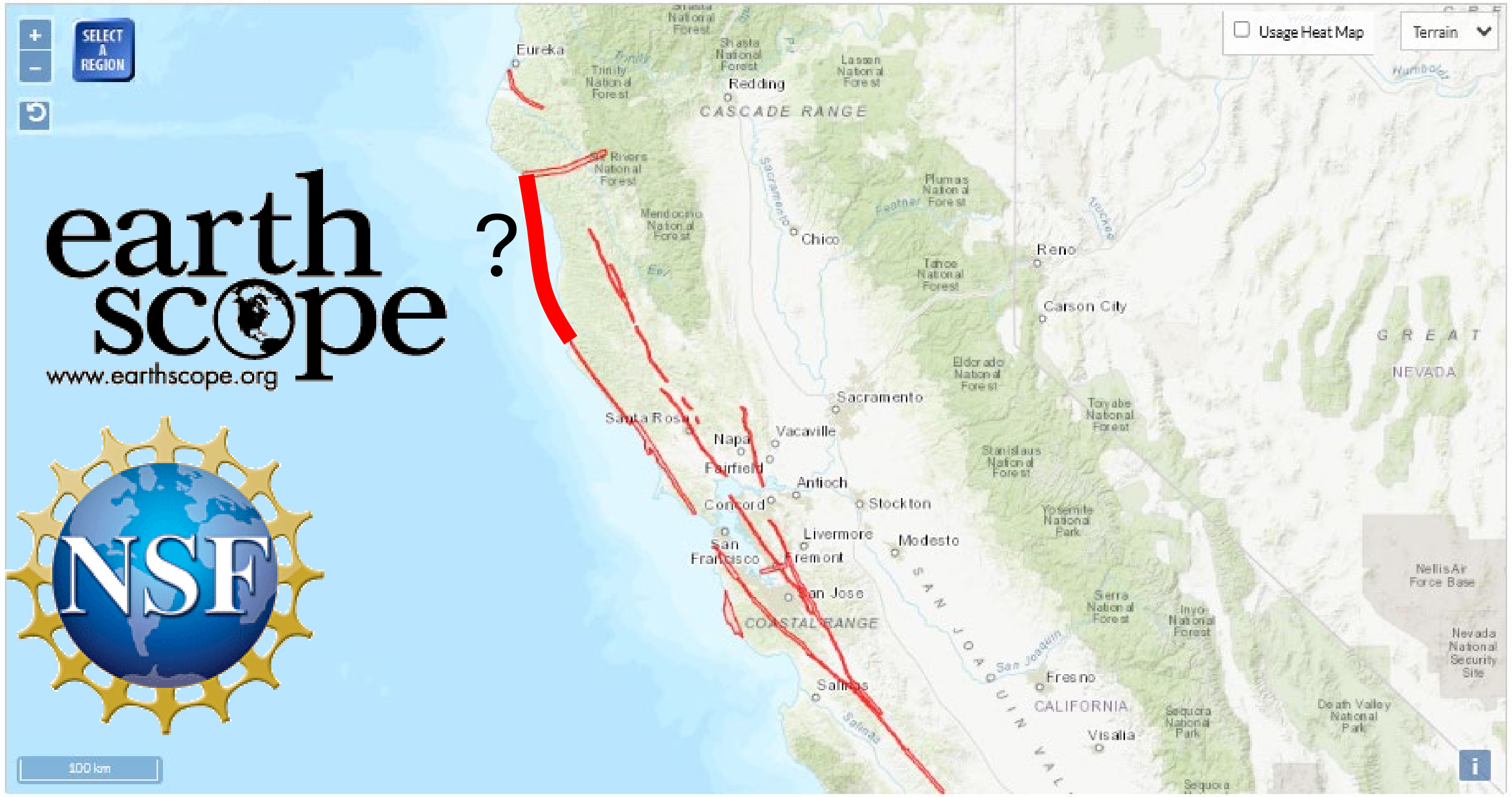

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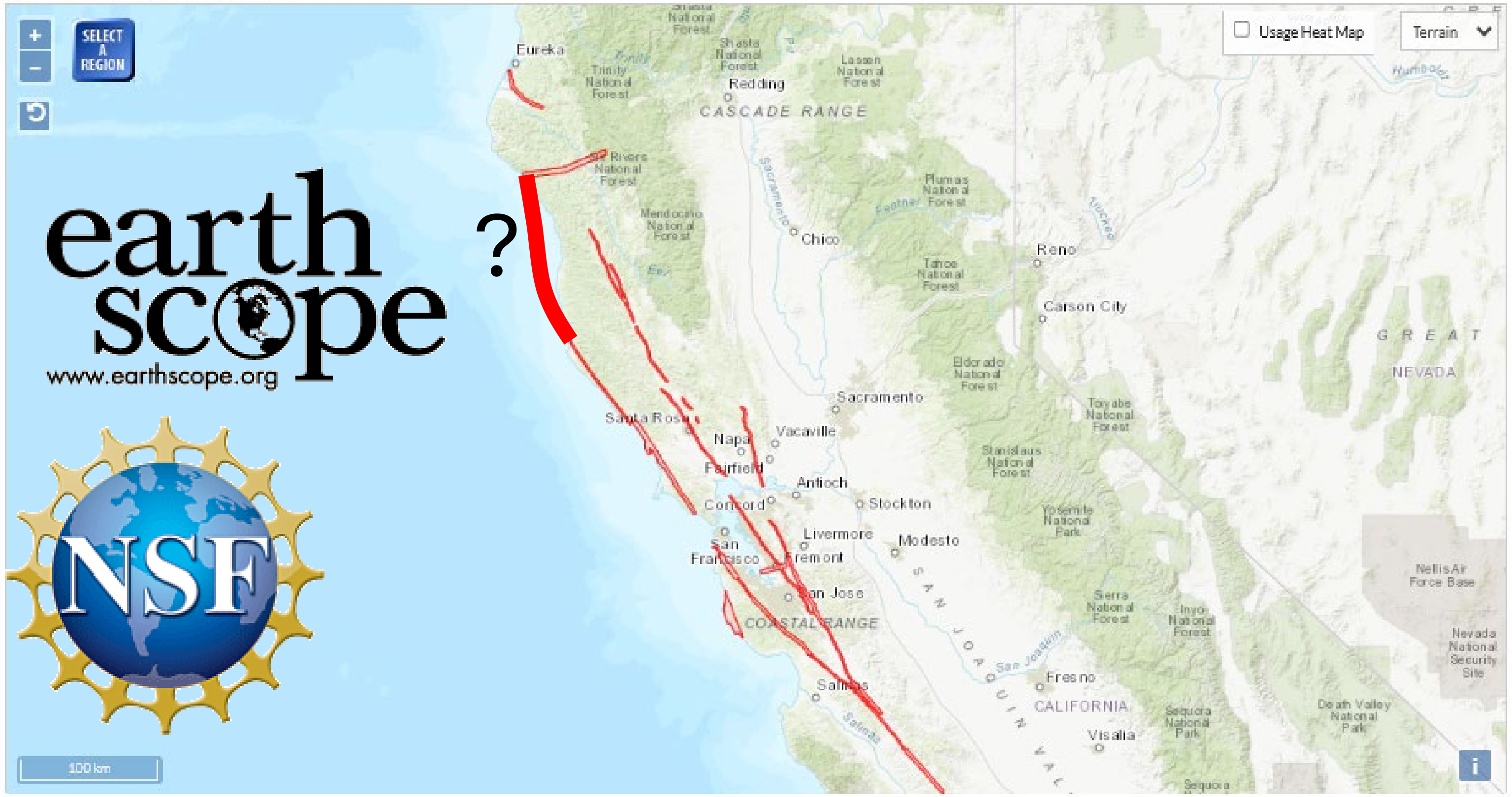

Recommendation

- The offshore NSAF warrants the same data standard as the onshore fault system continuous, high-resolution imaging on par with the EarthScope and B4 lidar coverage.
- The 2010 and 2012 Baylis surveys were opportunistic: pole-mounted sonar on a sailing vessel, variable line spacing, and sea-state limits. Useful, but not a definitive baseline.
- A purpose-built survey should pair full-coverage high-resolution multibeam with co-registered sub-bottom profiling along the entire offshore trace.
- A targeted, dense SBP network across fault bends, transtensional basins, and bedrock platforms would resolve Quaternary tectonic deformation and slip history.
- Offshore fault geometry and slip-rate constraints robust enough to feed the Quaternary Fault Database and the NSHM.

GEOSPHERE

GEOSPHERE, v. 21, no. 6

https://doi.org/10.1130/GES02857.1

23 figures; 3 tables; 1 set of supplemental files

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Unravelling the dance of earthquakes: Evidence of partial synchronization of the northern San Andreas fault and Cascadia megathrust

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ABSTRACT

Previous paleoseismic work has suggested a possible stress triggering relationship between the Cascadia subduction zone and the northern San Andreas fault based on similar event timings. Turbidite successions correlated to both systems may support this hypothesis. Historic earthquakes in 1980 and 1992 in the Cascadia subduction zone and the 1906 earthquake on the northern San Andreas fault left turbidite records that are temporally well constrained by bomb-carbon–supported age-depth models. The 1906 event bed clearly appears on both sides of the triple junction, as may the 1992 bed. This demonstrates that northern San Andreas fault events have triggered turbidity currents in the southernmost Cascadia subduction zone, and vice versa. Turbidite successions in the southernmost Cascadia subduction zone and the Northern San Andreas fault prior to 1906 have similarities in timing and stratigraphy. During the past ~3100 yr, 18 likely earthquake-generated turbidite beds have been deposited in the southern Cascadia subduction zone. In Noyo Channel, along the northern San Andreas fault, 19 likely earthquake-generated beds were deposited during the same period. Ten of the Cascadia subduction zone beds have a close temporal association with the likely earthquake-generated beds in Noyo Channel. The radiocarbon age medians differ by an average of 63 yr (standard deviation = 51 yr). Eight of 10 of the beds with substantial temporal overlap with major Cascadia subduction zone events have a distinctive thick, inverted doublet stratigraphy in Noyo Channel along the northern San Andreas fault, while beds without timing similarities, including the 1906 earthquake bed, do not. These unusually thick doublets have a lower silty unit directly overlain by a robust sandy unit, commonly with an intervening erosional unconformity. Doublets are also observed in the southern Cascadia subduction a less robust upper unit, and some have the upper unit embedded in the tail of the lower unit. The doublet stratigraphy in Noyo Channel commonly fades southward along the northern San Andreas fault, while that on the Cascadia subduction zone side fades northward. The recurrence rate of major events near the triple junction is not the additive rate of both faults but is similar to the rate for either fault alone, implying the doublet beds represent pairs of beds from each fault, stacked together. We infer that the stratigraphy is best explained by earthquakes on both systems spaced closely in time, beginning with the Cascadia subduction zone, as opposed to aftershock sequences, hydrodynamic generation, or other causes. The Holocene sequence of closely stacked stratigraphic pairs may represent direct evidence of stress triggering and partial synchronization of these two great faults for the latest Holocene, with the possibility of significant interaction at earlier times.

INTRODUCTION AND PREVIOUS WORK

Stress transfer and subsequent triggering of one fault or segment by another is now a well-established principle, having been observed in a variety of settings (Stein, 1999; Parsons et al., 1999; Toda et al., 2011). Observations and model forecasts of this phenomenon come from instrumental records and have become part of seismological research. However, only a single modern forecast of one great earthquake triggering another has been made, in Sumatra (McCloskey et al., 2005), which subsequently occurred. Evidence in the paleoseismic record for triggering of great events is limited to the last few hundred years in Sumatra (Meltzner et al., 2010; Philibosian et al., 2017). The lack of such records may be due to the short length of the instrumental

Goldfinger et al. (2025): Partial Synchronization of the NSAF and Cascadia

Analysis

- correlating deep-sea turbidite records across the Mendocino Triple Junction.
- Cores spanning ~3,100 years, read with CT imaging and radiocarbon age-depth models.
- Historic beds from 1906 (NSAF) and 1980/1992 (Cascadia) calibrate the chronology.

Results

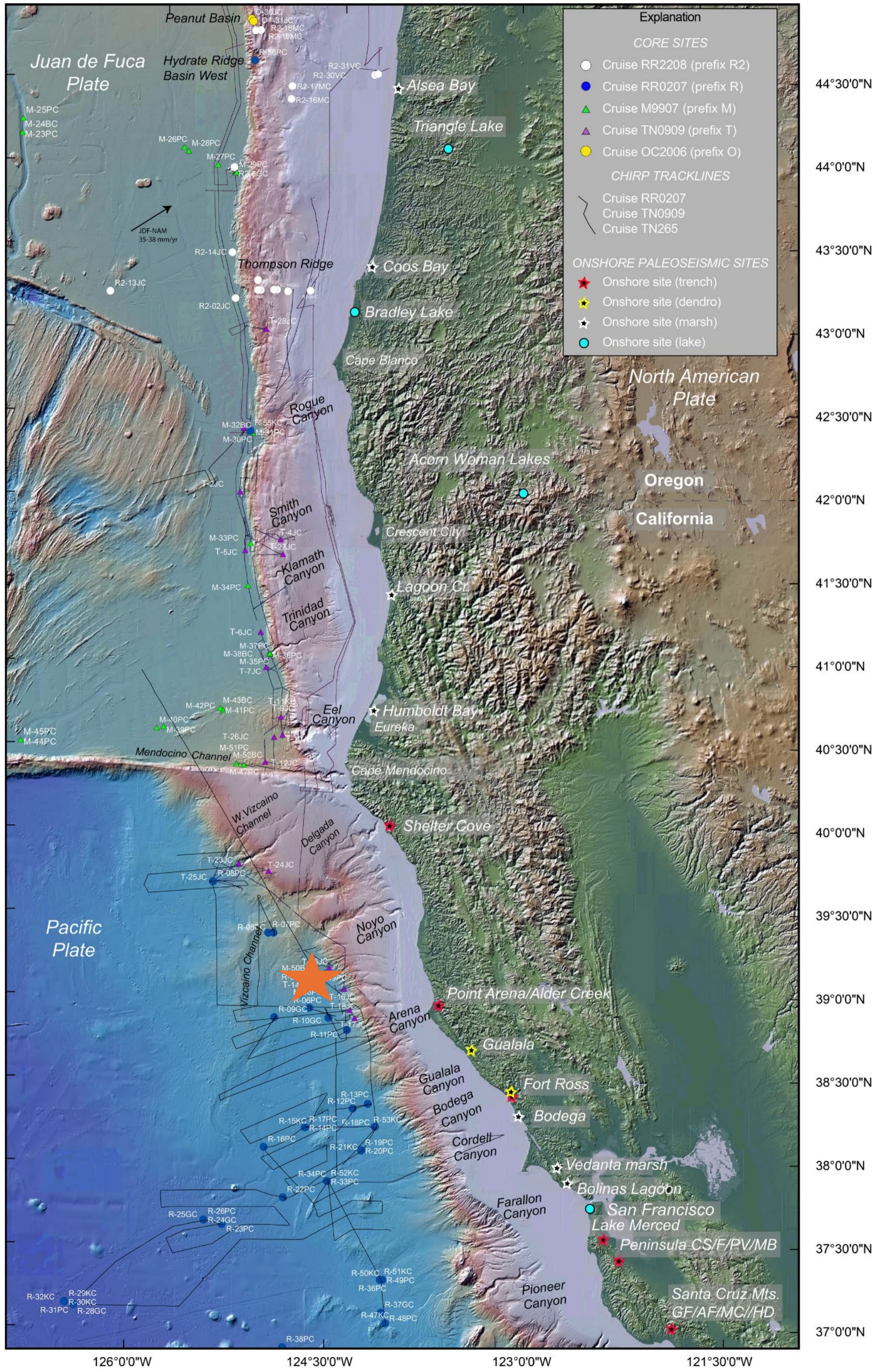
- Just over half of 18 southern Cascadia turbidites pair in time with NSAF events.
- Near the triple junction, recurrence is not additive — it matches either fault alone.
- Three cases in 1,500 years, most recently 1700 CE, imply ruptures minutes to hours apart.

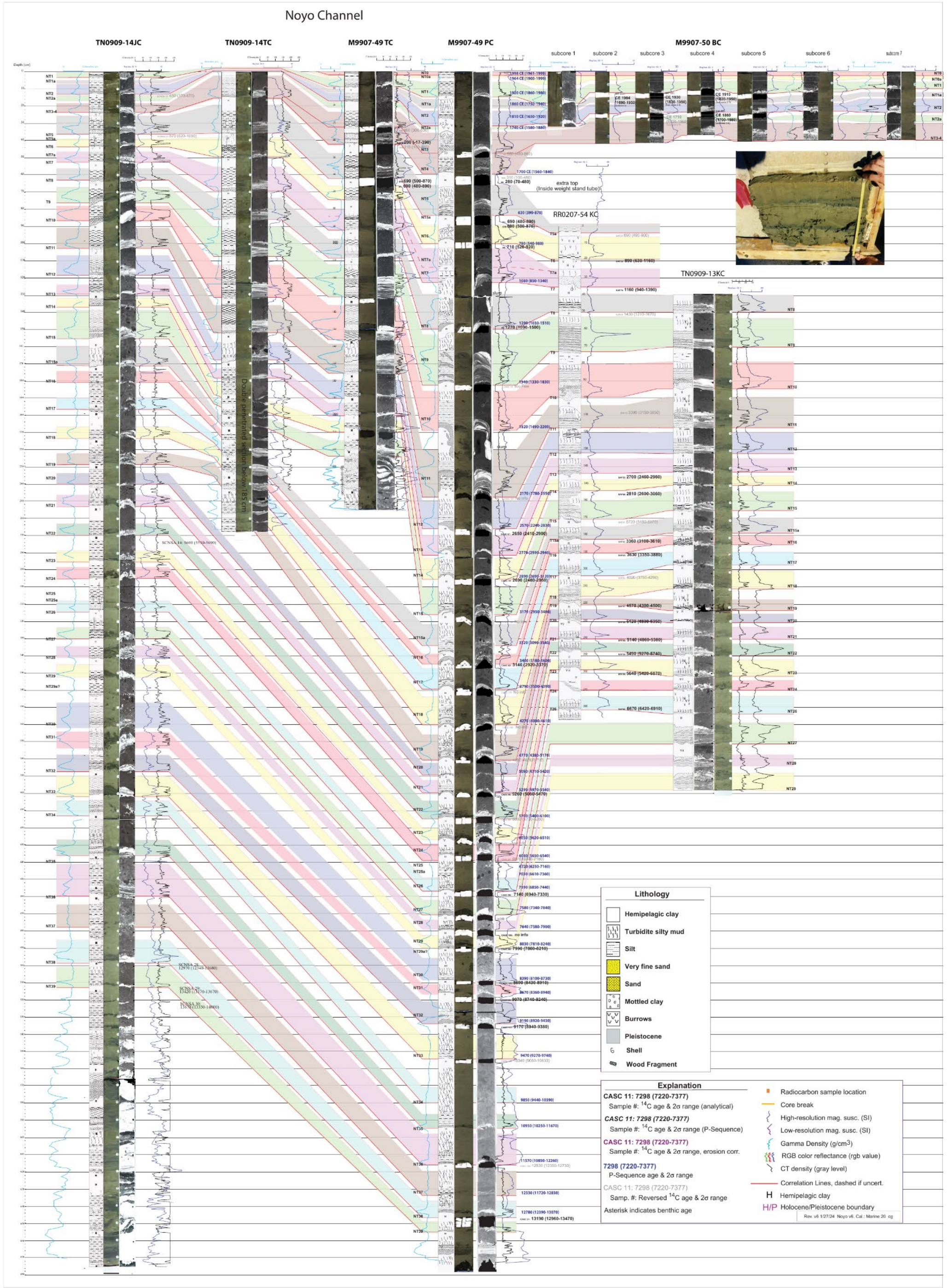
Turbidite depositional model

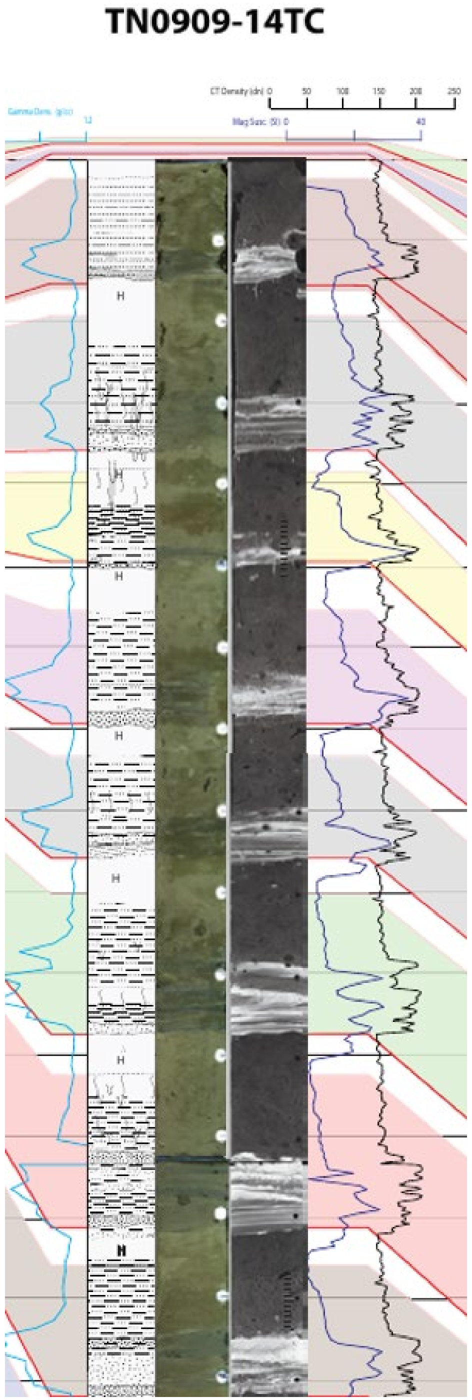
- “Doublet” beds are two stacked turbidites, one sourced from each fault system.
- Inverted stratigraphy shows the second flow arrived before the first had settled.
- Triggering works both ways across the triple junction.

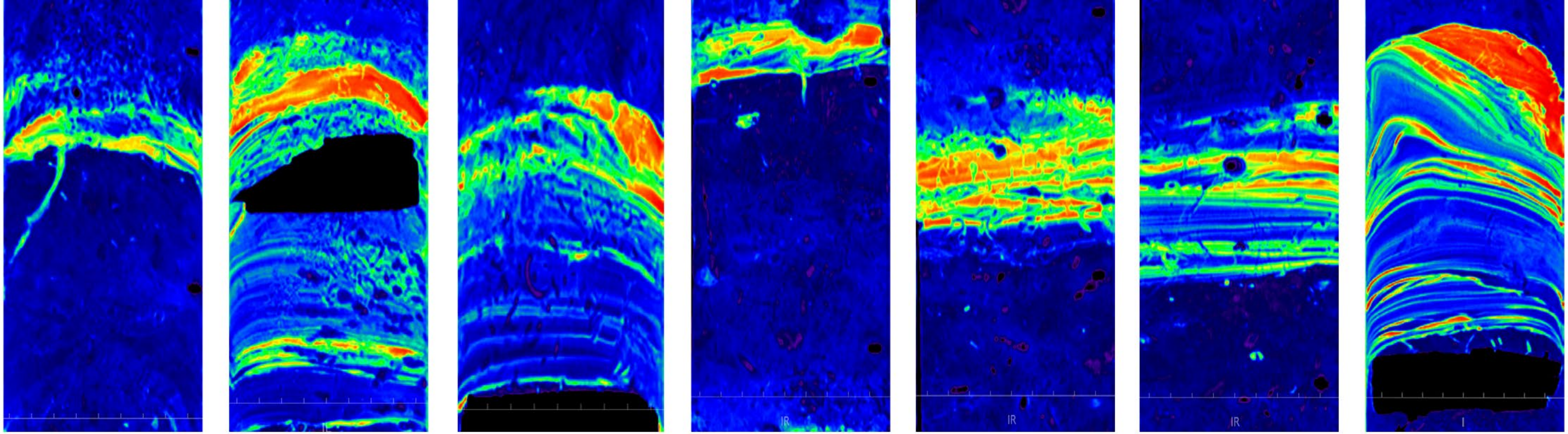
Implications

- A Cascadia megathrust rupture may promptly trigger the northern San Andreas.
- Compound scenario affecting nearly the entire U.S. Pacific coast at once.
- Raises the value of dense offshore imaging and coring to test the triggering hypothesis.

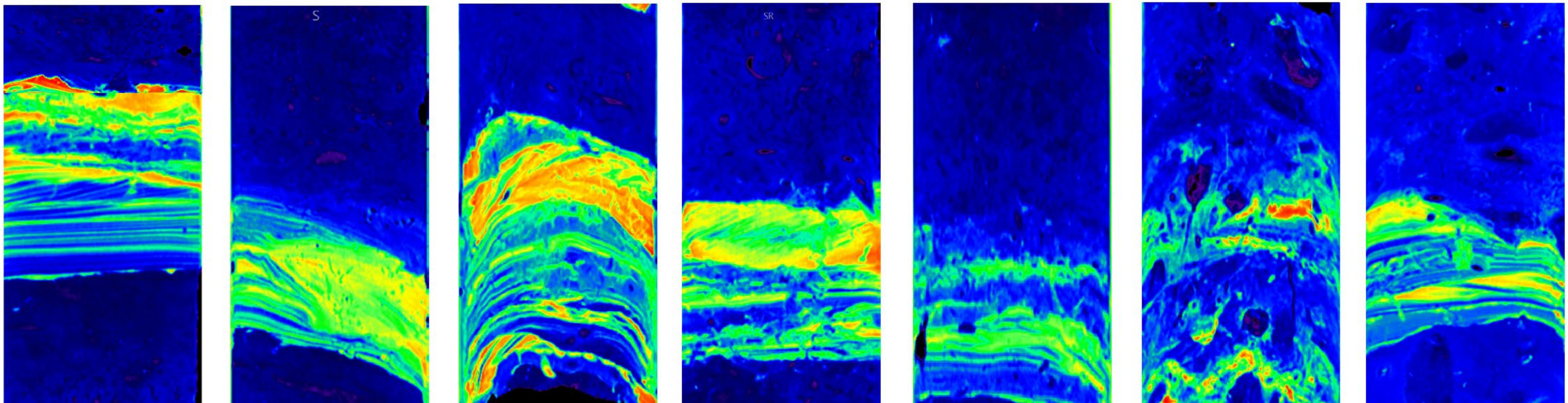

Explanation
CORE SITES
Cruise RR2208 (prefix R2)
Cruise RR0207 (prefix R)
Cruise M9907 (prefix M)
Cruise TN0909 (prefix T)
Cruise OC2006 (prefix O)
CHIRP TRACKLINES
Cruise RR0207
Cruise TN0909
Cruise TN265
ONSHORE PALEOSEISMIC SITES
Onshore site (trench)
Onshore site (dendro)
Onshore site (marsh)
Onshore site (lake)
Juan de Fuca Plate
Peanut Basin
Hydrate Ridge Basin West
JDF-NAM 35-38 mm/yr
Thompson Ridge
Alsea Bay
Triangle Lake
Coos Bay
Bradley Lake
Cape Blanco
Rogue Canyon
North American Plate
Acorn Woman Lakes
Oregon
California
Smith Canyon
Crescent City
Klamath Canyon
Lagoon Cr.
Trinidad Canyon
Eel Canyon
Humboldt Bay
Eureka
Mendocino Channel
Cape Mendocino
W Vizcaino Channel
Delgada Canyon
Shelter Cove
Pacific Plate
Noyo Canyon
Vizcaino Channel
Point Arena/Alder Creek
Arena Canyon
Gualala
Gualala Canyon
Fort Ross
Bodega Canyon
Bodega
Cordell Canyon
Vedanta marsh
Bolinas Lagoon
Farallon Canyon
San Francisco
Lake Merced
Peninsula CS/F/PV/MB
Pioneer Canyon
Santa Cruz Mts. GF/AF/MC//HD
44°30'0"N
44°0'0"N
43°30'0"N
43°0'0"N
42°30'0"N
42°0'0"N
41°30'0"N
41°0'0"N
40°30'0"N
40°0'0"N
39°30'0"N
39°0'0"N
38°30'0"N
38°0'0"N
37°30'0"N
37°0'0"N
126°0'0"W
124°30'0"W
123°0'0"W
121°30'0"W


Noyo Channel
TN0909-14JC
TN0909-14TC
M9907-49 TC
M9907-49 PC
M9907-50 BC
subcore 1
subcore 2
subcore 3
subcore 4
subcore 5
subcore 6
subcore 7
RR0207-54 KC
TN0909-13KC
Lithology
Hemipelagic clay
Turbidite silty mud
Silt
Very fine sand
Sand
Mottled clay
Burrows
Pleistocene
Shell
Wood Fragment
Explanation
Radiocarbon sample location
Core break
High-resolution mag. susc. (SI)
Low-resolution mag. susc. (SI)
Gamma Density (g/cm3)
RGB color reflectance (rgb value)
CT density (gray level)
Correlation Lines, dashed if uncert.
Hemipelagic clay
Holocene/Pleistocene boundary
Asterisk indicates benthic age

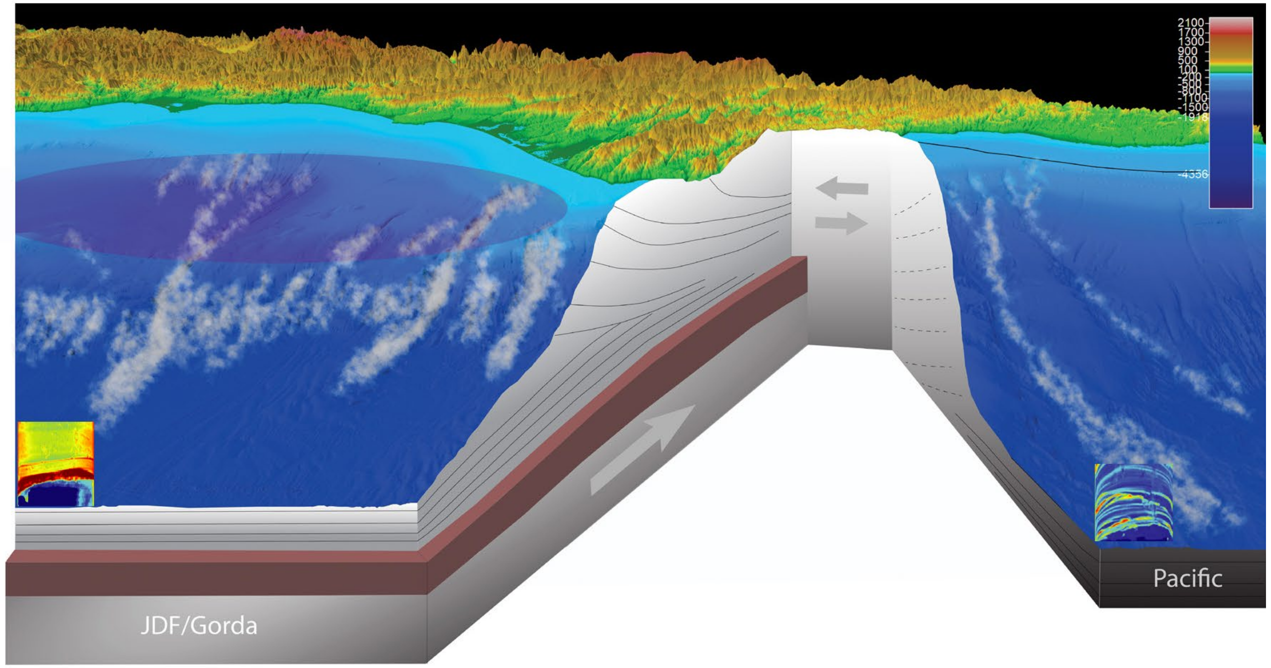

TN0909-14TC
CT Density (dn)
Mag Susc (SI)
Gamma Dens. (g/cc)
H



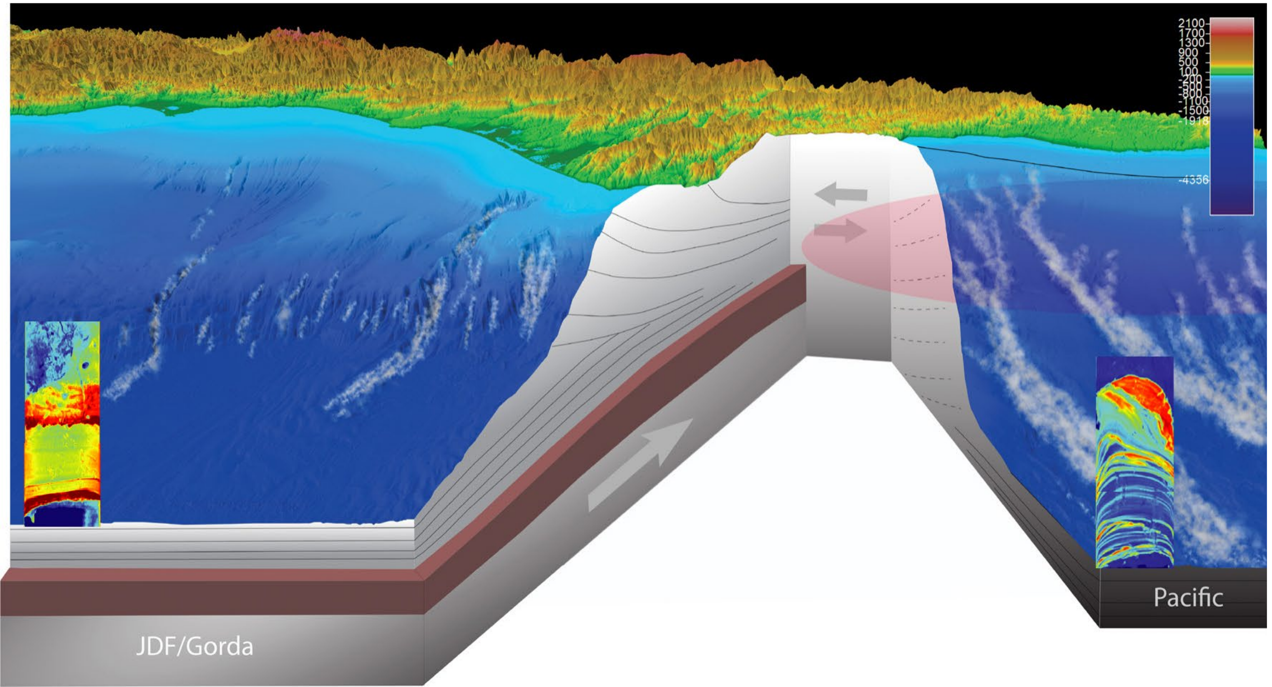
TN0909-14TC NT-10 | TN0909-14TC NT-10 | M9907-49PC NT-11 | TN0909-14TC NT-11 | TN0909-14TC NT-12 | TN0909-14TC NT-15 | M9907-49PC NT-16



A.



B.



How the Doublet Model Works

- Cutaway 3D block through the Mendocino Triple Junction: the Gorda / Juan de Fuca plate subducting on the north side, the Pacific plate and the San Andreas on the south.
- The framed insets are CT images of sediment cores, one from each side of the junction; bright colors mark coarse, high-density turbidite sand.
- **Panel A,** a Cascadia megathrust rupture shakes the southern subduction zone, and only the Cascadia-side core records a fresh turbidite bed.
- **Panel B ,** the San Andreas ruptures shortly after (highlighted segment), and the southern core now carries a second bed stacked on the first.
- Because the second flow arrives before the first has finished settling, the pair is preserved as a doublet with inverted grading rather than two separate beds.
- That stacking is the physical argument for closely spaced ruptures, and it explains why recurrence near the junction matches one fault rather than the sum of both.

Wrap-Up it up jeff.
The Offshore Northern San Andreas

- **Is there an offshore strand linking the San Andreas to the Mendocino Triple Junction?** To date no such structure has been imaged.
- **Have we cornered the fault into the surf zone north of Shelter Cove, offshore the King Range?** Possibly, whether that zone can be imaged is the open technical question.
- From Point Arena to Shelter Cove the San Andreas is a narrow, continuous offshore strand roughly 1 km wide.
- With modern mapping and imaging tools, a comprehensive 3D view of active deformation along this offshore section is achievable.
- More coring and paleoseismic investigation is needed to refine correlations and age dating, and to test the synchronous-rupture scenario.
- Better fault models mean better stress-transfer and earthquake-triggering models.