The Cascadia Creeping Section: Structural Evidence for Heterogeneous Plate Coupling and Linkages to Geodesy and Paleoseismology

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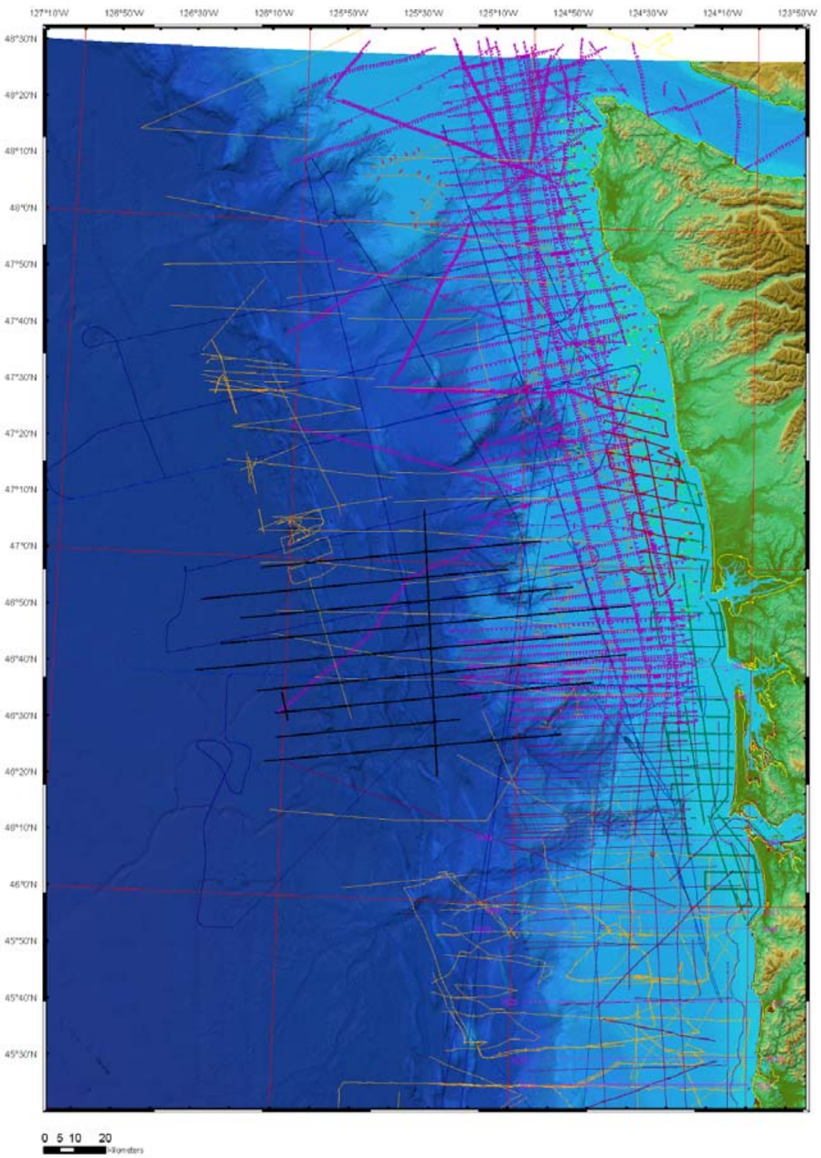
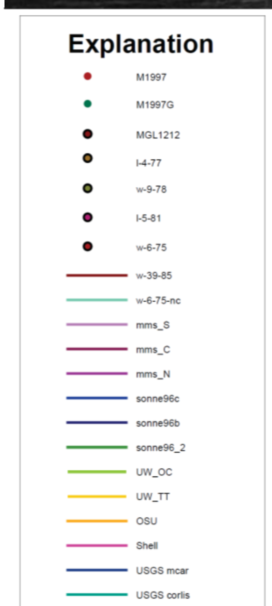
The objective was to revise and update a structural map of Cascadia, first done in 1994.

- Original mapping done in CAD system, but with mostly paper seismic records.
- Some large areas lacked multibeam bathymetric data
- New mapping with digital data
- Multibeam sonar mapping now nearly complete.
- Numerous additional high resolution surveys.



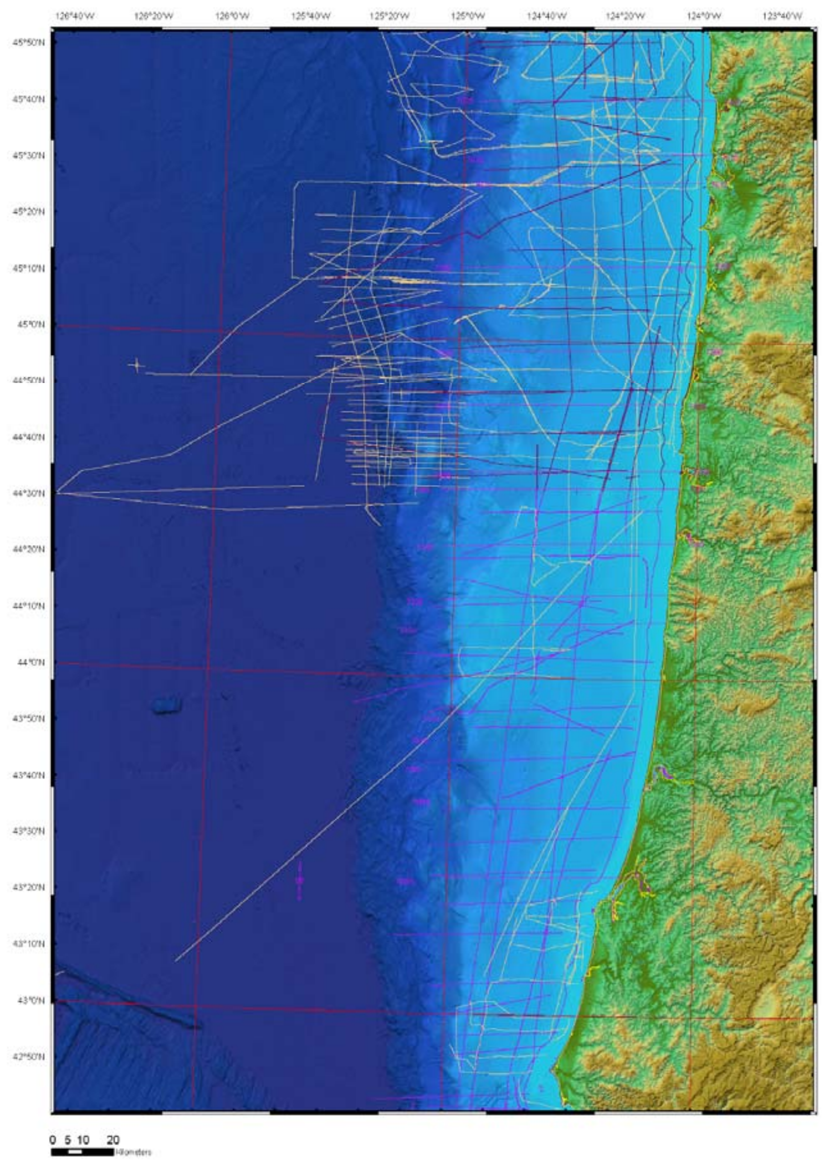
Datasets used included 21 primary surveys with migrated digital data.

15 additional surveys with analog data were used. In total, ~ 35,000 line km of seismic data were used.



A new bathymetric grid at 100 m resolution was created using data collected up to 2017. Numerous higher resolution multibeam bathymetry, backscatter and sidescan-sonar surveys were also used.

Submersible surveys and observations from ALVIN, SeaCliff, DELTA submersibles and the ROPOS ROV were also integrated.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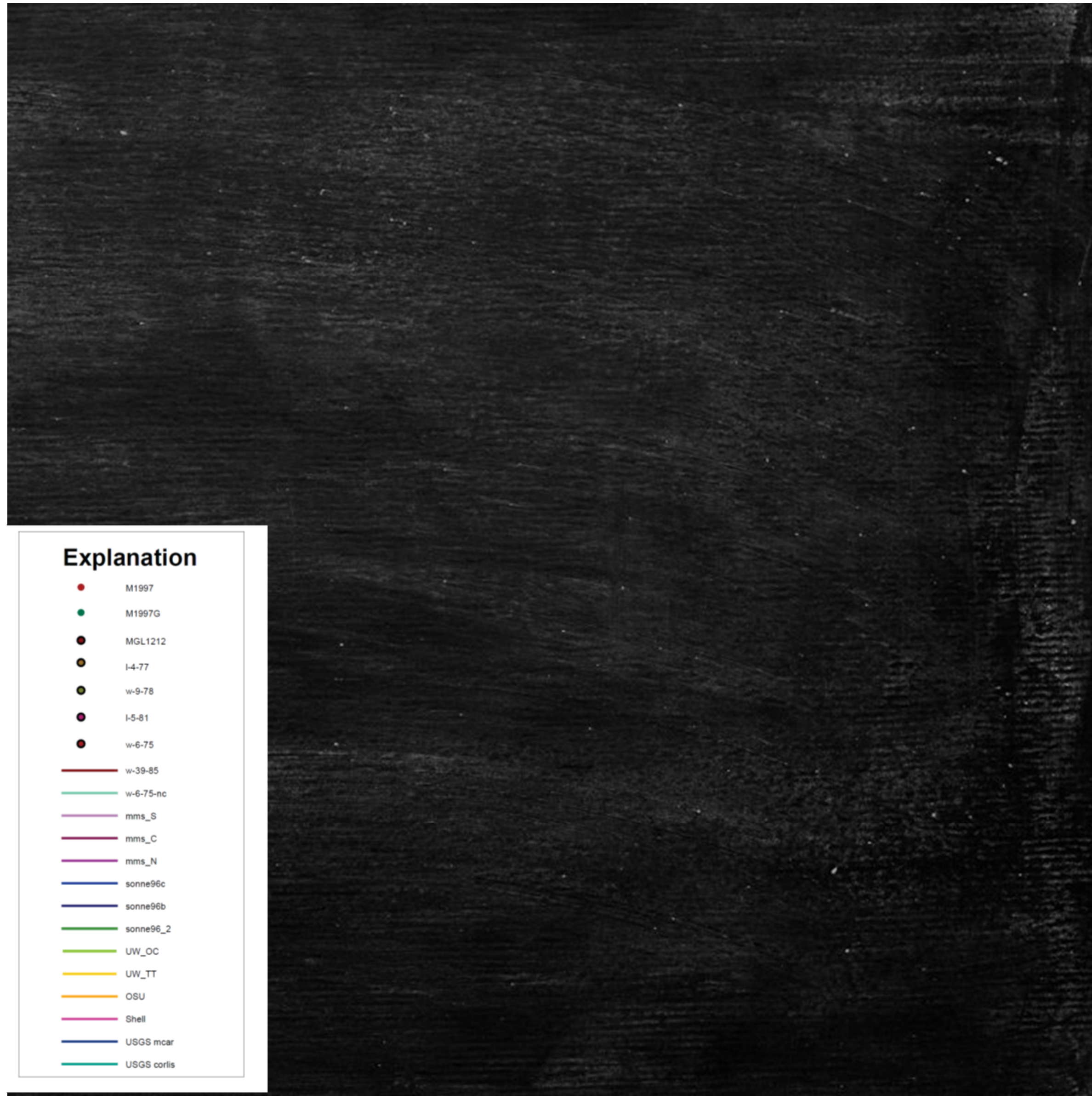
0 5 10 20
Kilometers


Explanation
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M1997G
MGL1212
I-4-77
w-9-78
I-5-81
w-6-75
w-39-85
w-6-75-nc
mms_S
mms_C
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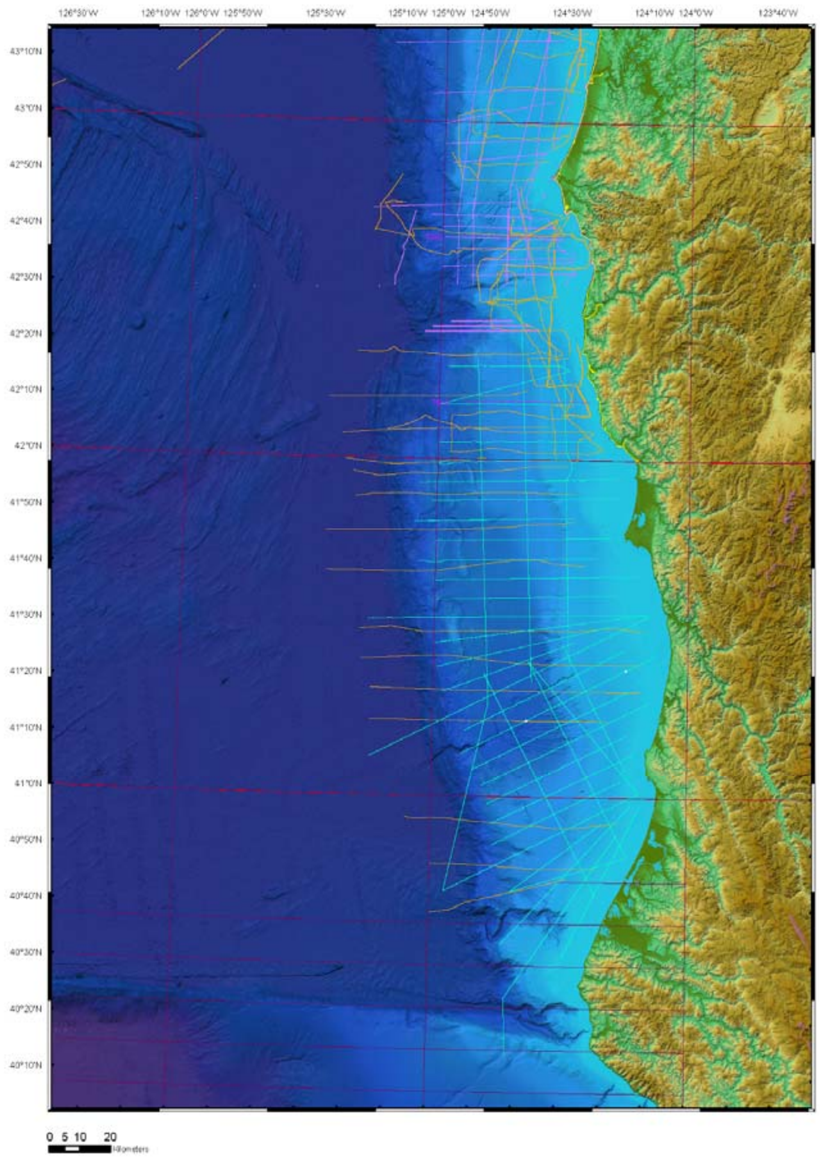
sonne96_2
UW_OC
UW_TT
OSU
Shell
USGS mcar
USGS corlis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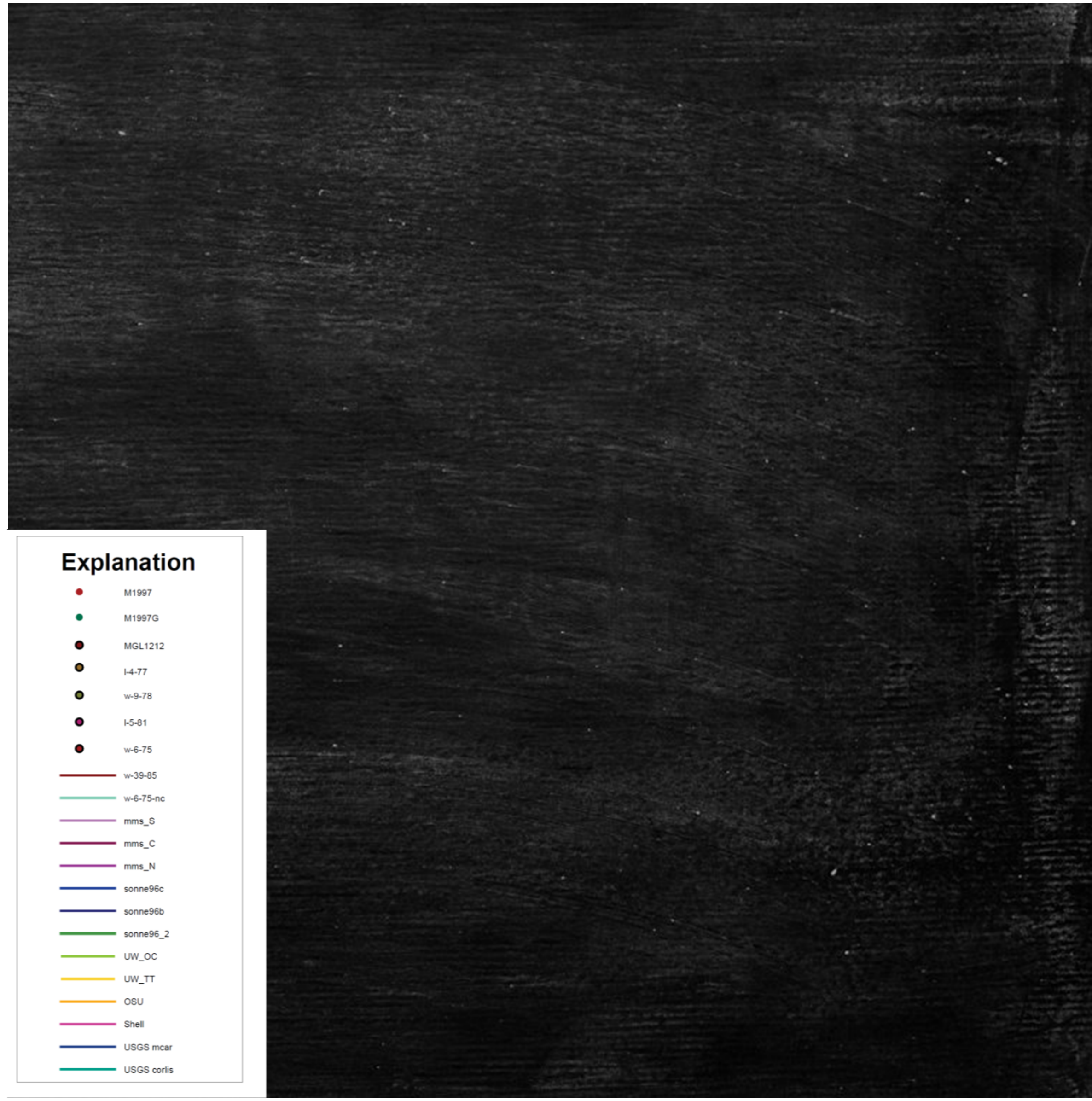
Kilometers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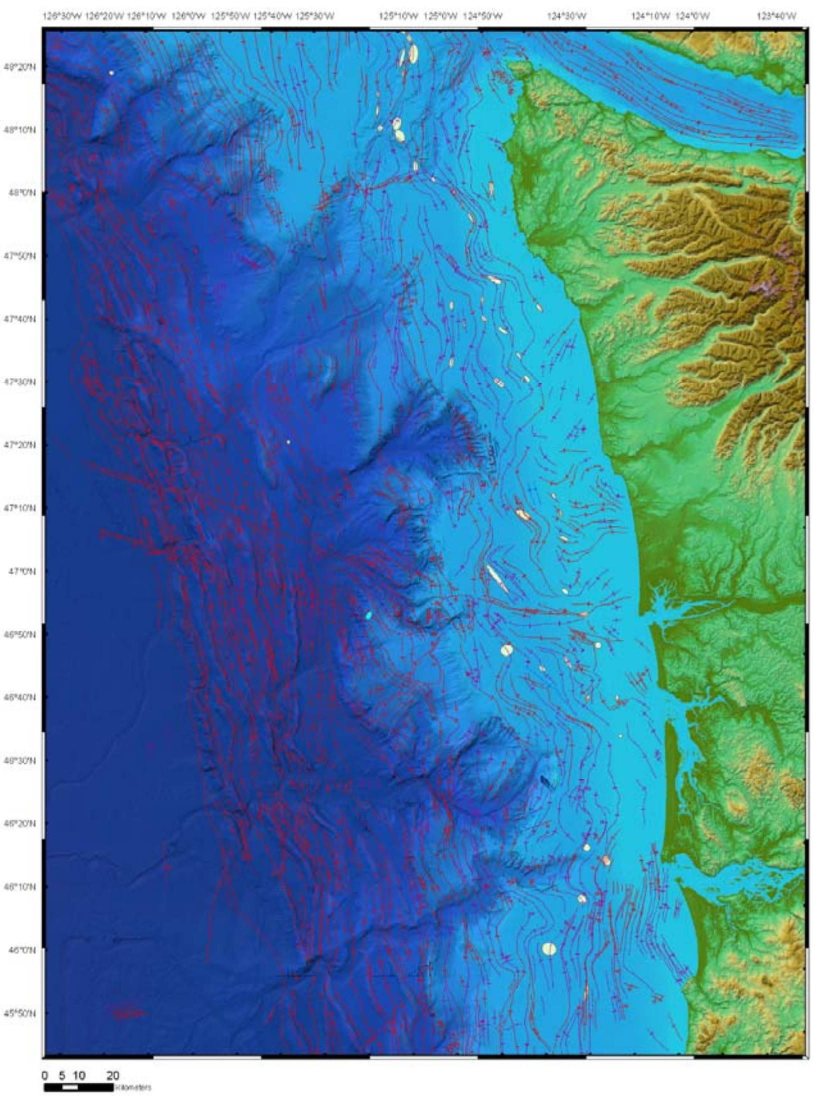
w-6-75-nc
mms_S
mms_C
mms_N
sonne96c
sonne96b
sonne96_2
UW_OC
UW_TT
OSU
Shell
USGS mcar
USGS corlis

Results

Structures were mapped in GIS using a simple metric of activity

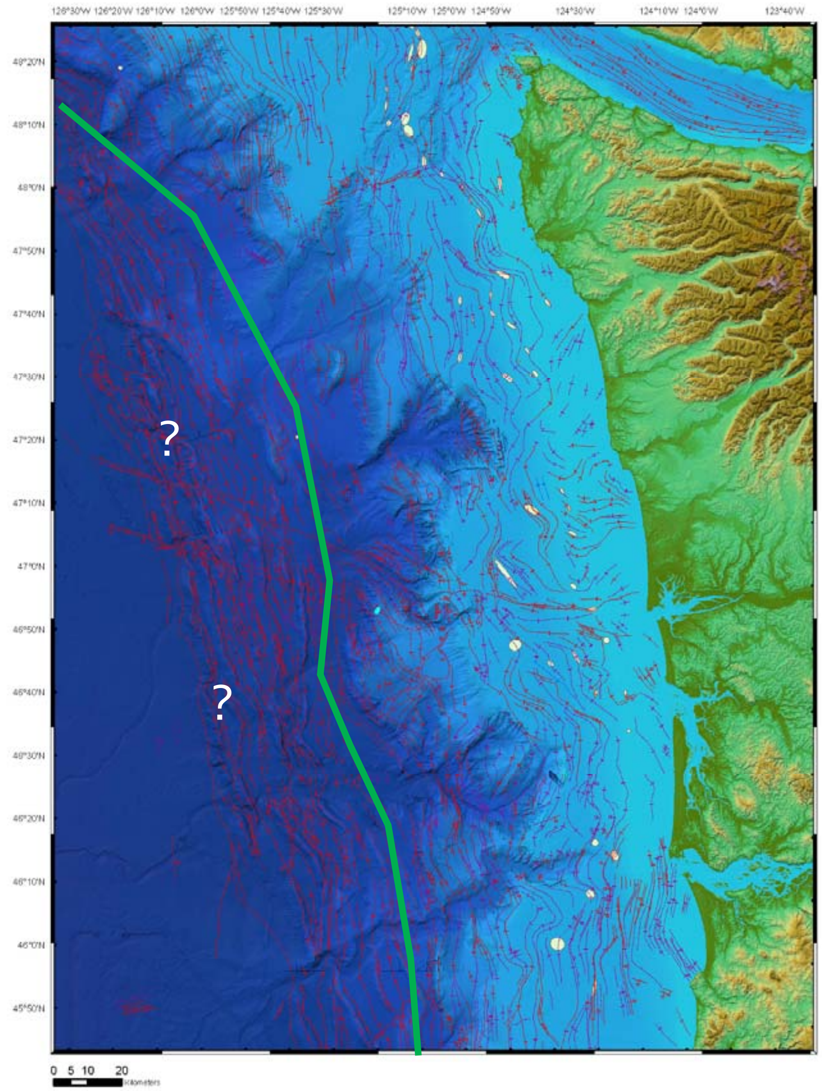
- Structures that broke the seafloor and offset near-surface materials were coded "Active". These are shown in red
- Structures that offset material near the surface but were overlapped by young undeformed sediments were coded "Late Quaternary" These are shown in purple
- All other structures were coded "Older". These are shown in blue.



Let’s take a tour of some selected features of interest…

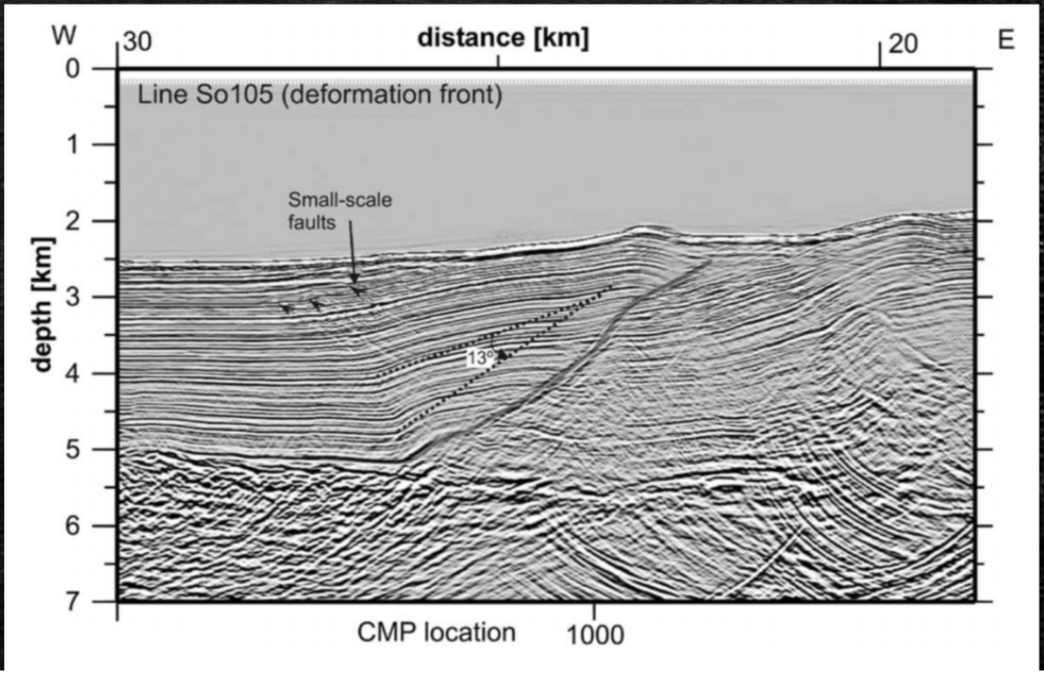
The Washington margin is quite a mess.

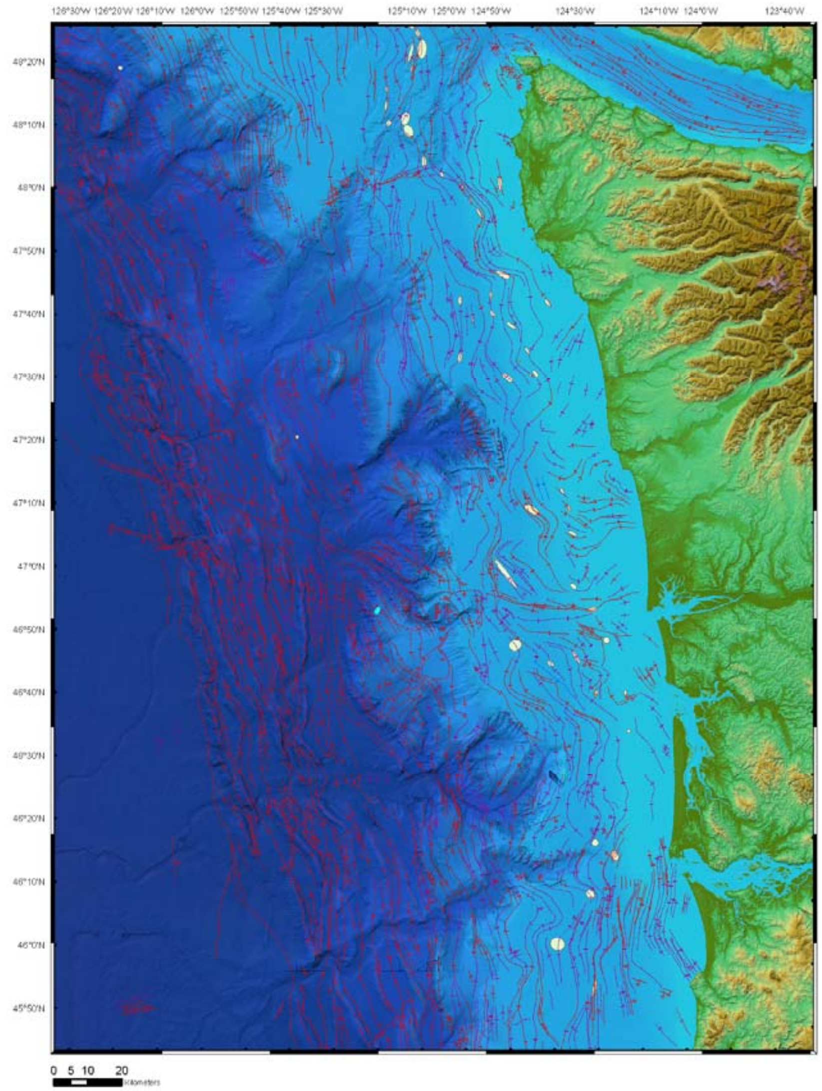
- Mixed vergence wedge
- Riddled with diapirs
- Very large listric normal faults transporting the upper slope seaward
- Transverse strike slip faults some times linked to onshore structures
- Incised by major canyon systems.



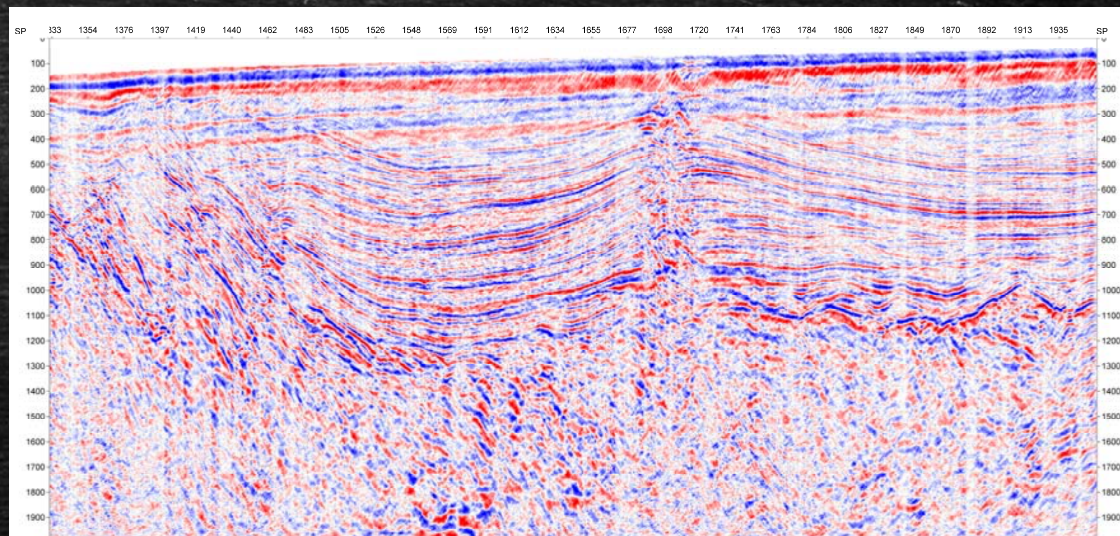
- Mixed vergence wedge: Everything west of the green line is landward vergent

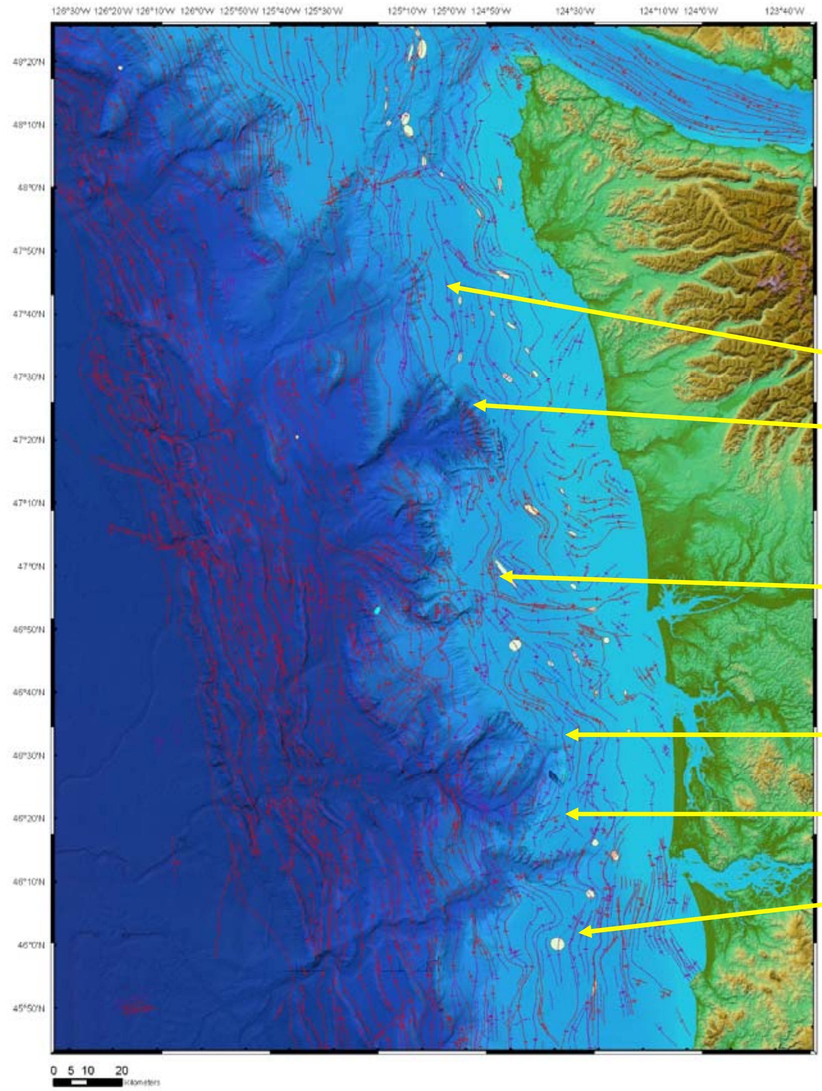
Landward vergence is presumed to overlie High pore fluid pressures (though new work suggests possibly not (Tobin et al.,this meeting)



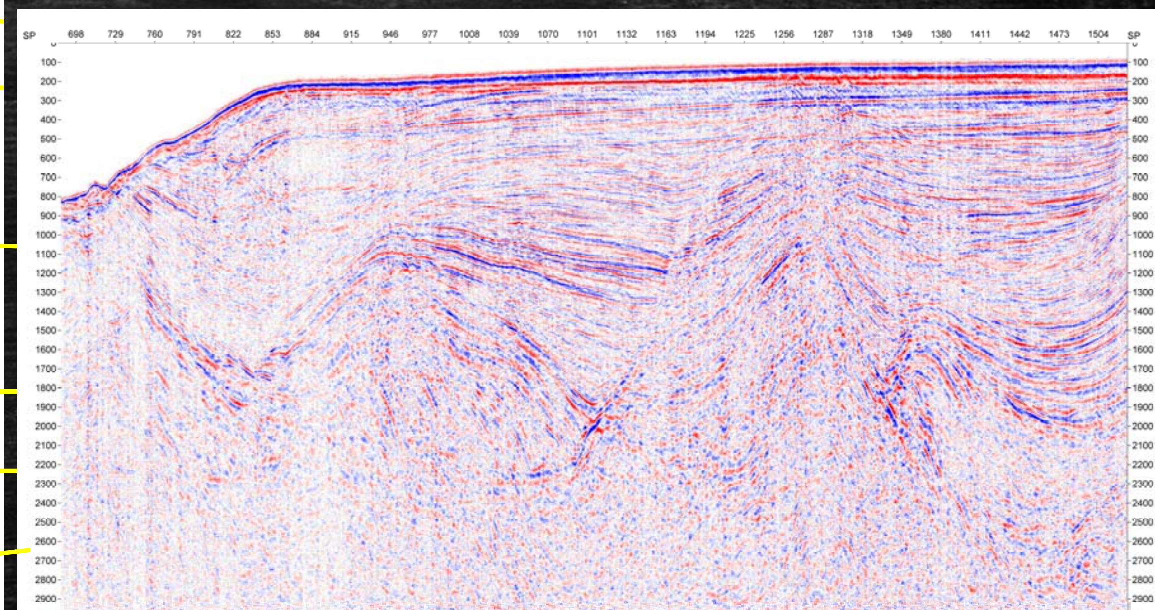


- Riddled with diapirs

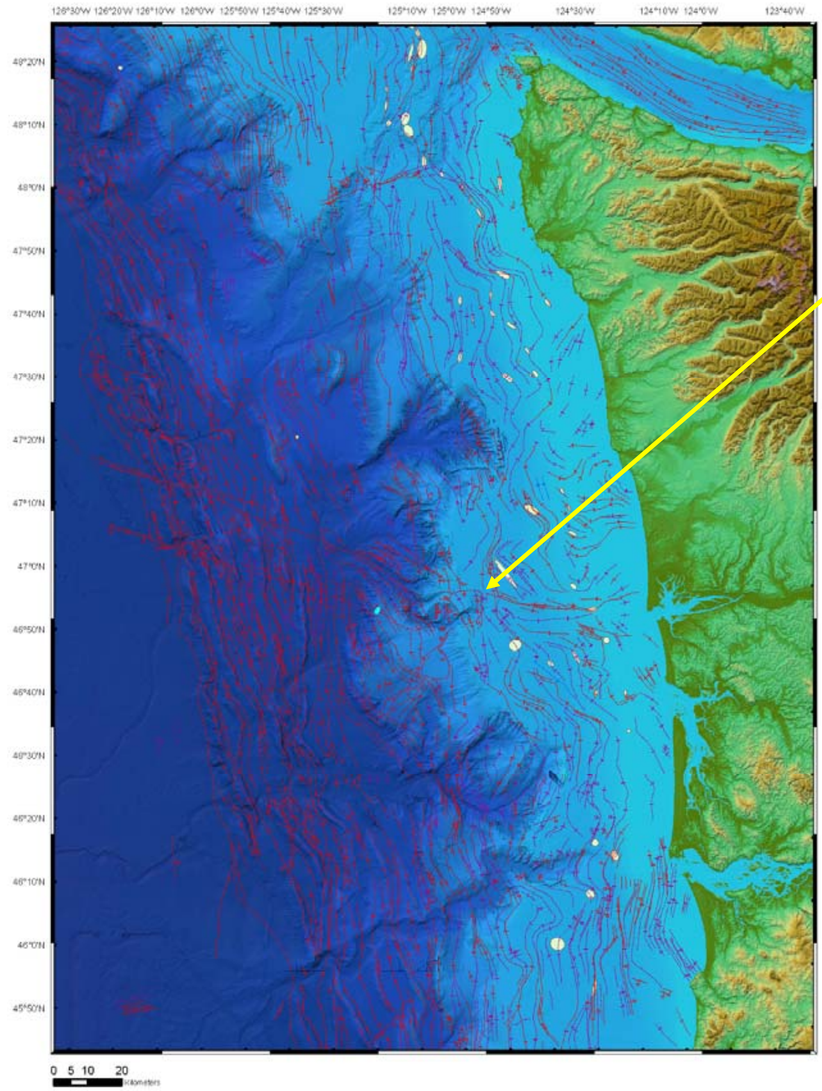




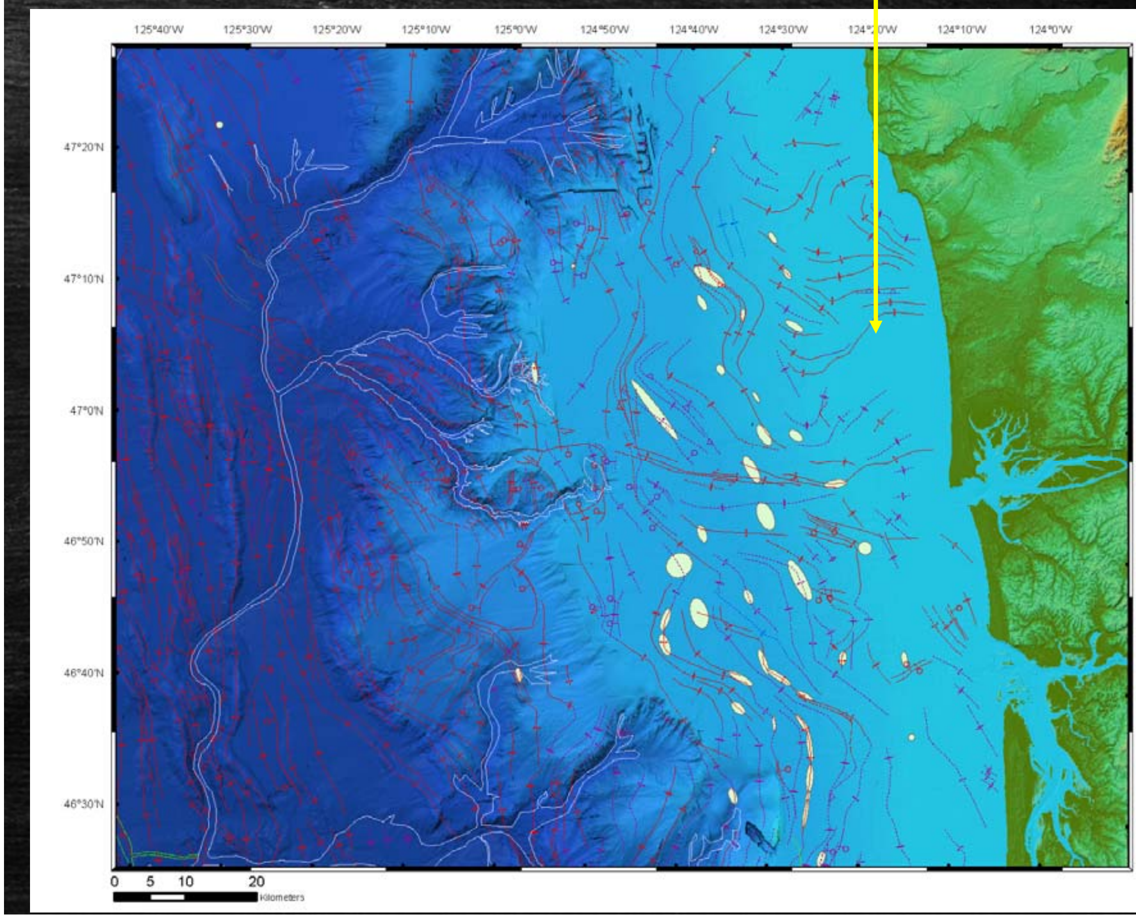
- Very large listric normal faults transporting the upper slope seaward

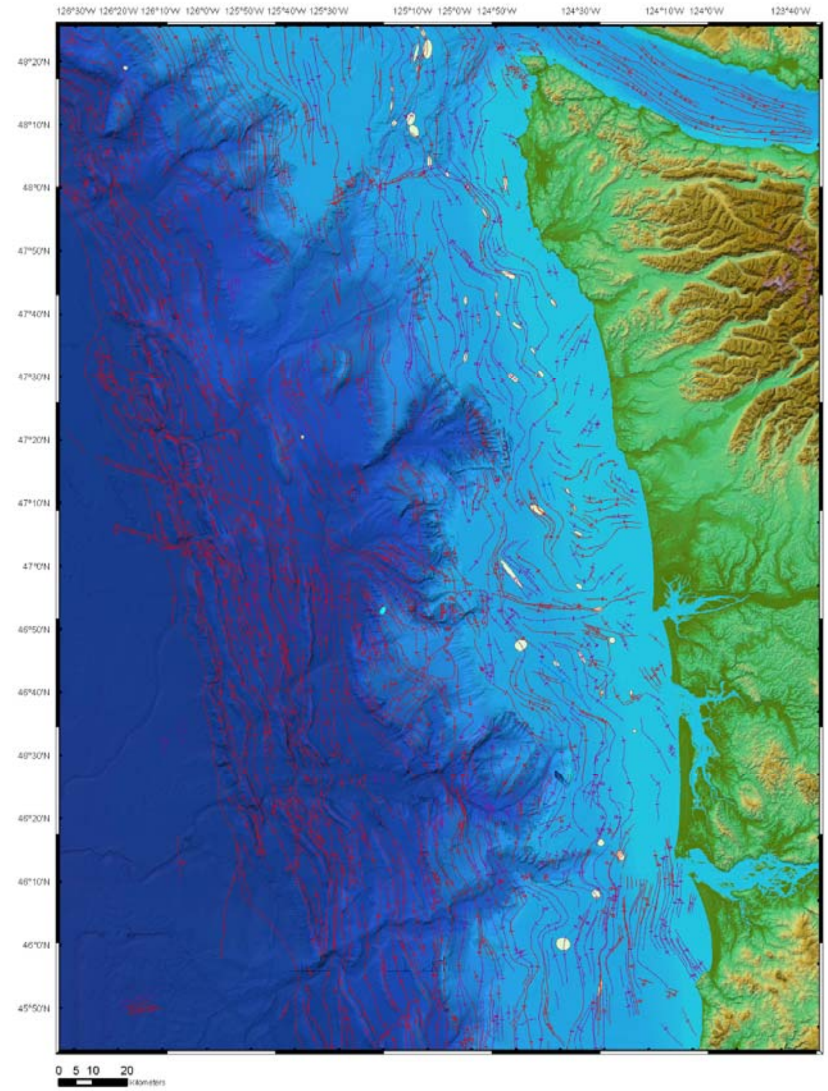


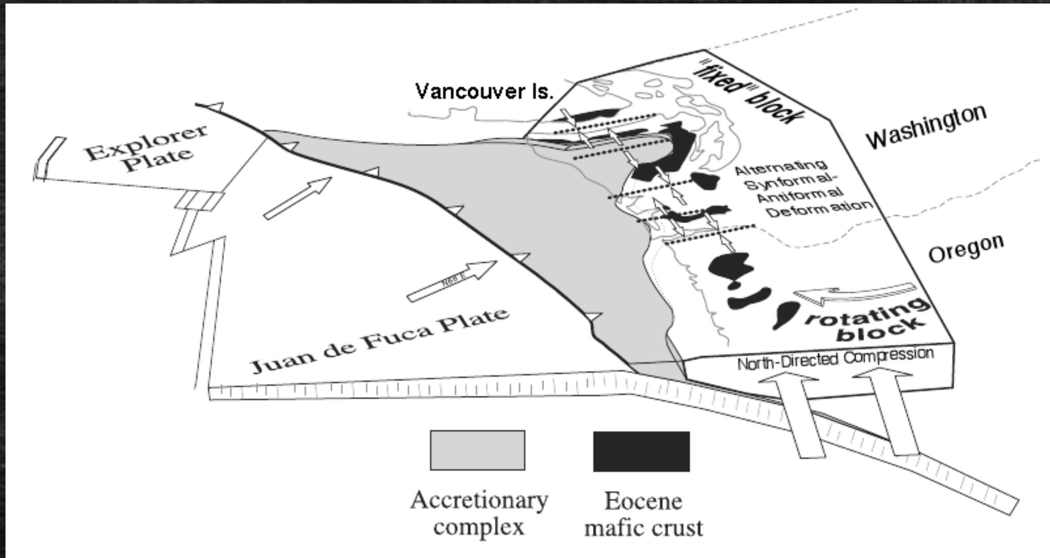
See McNeill et al., 1997 JGR



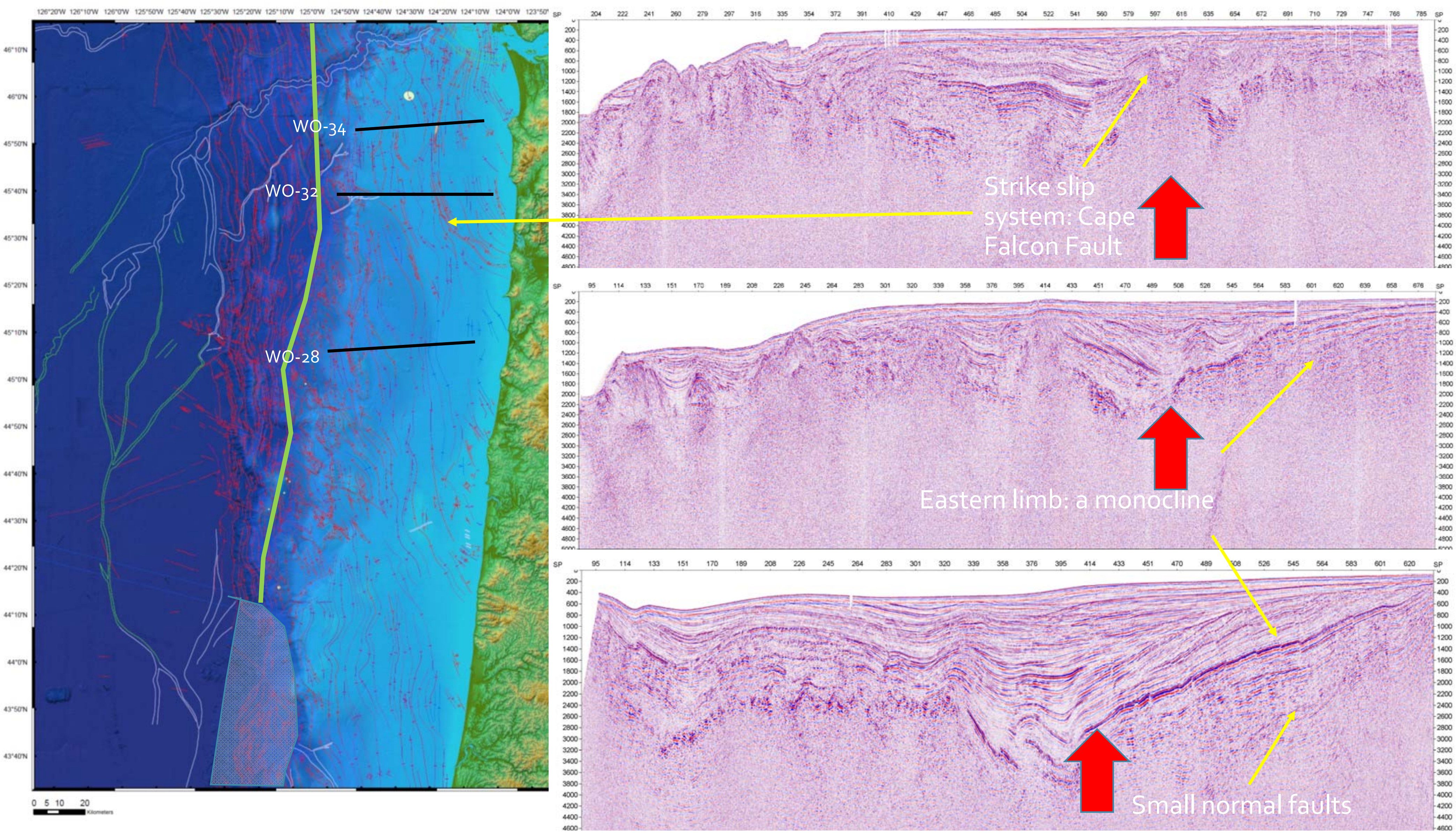
- Transverse strike slip faults sometimes linked to onshore structures

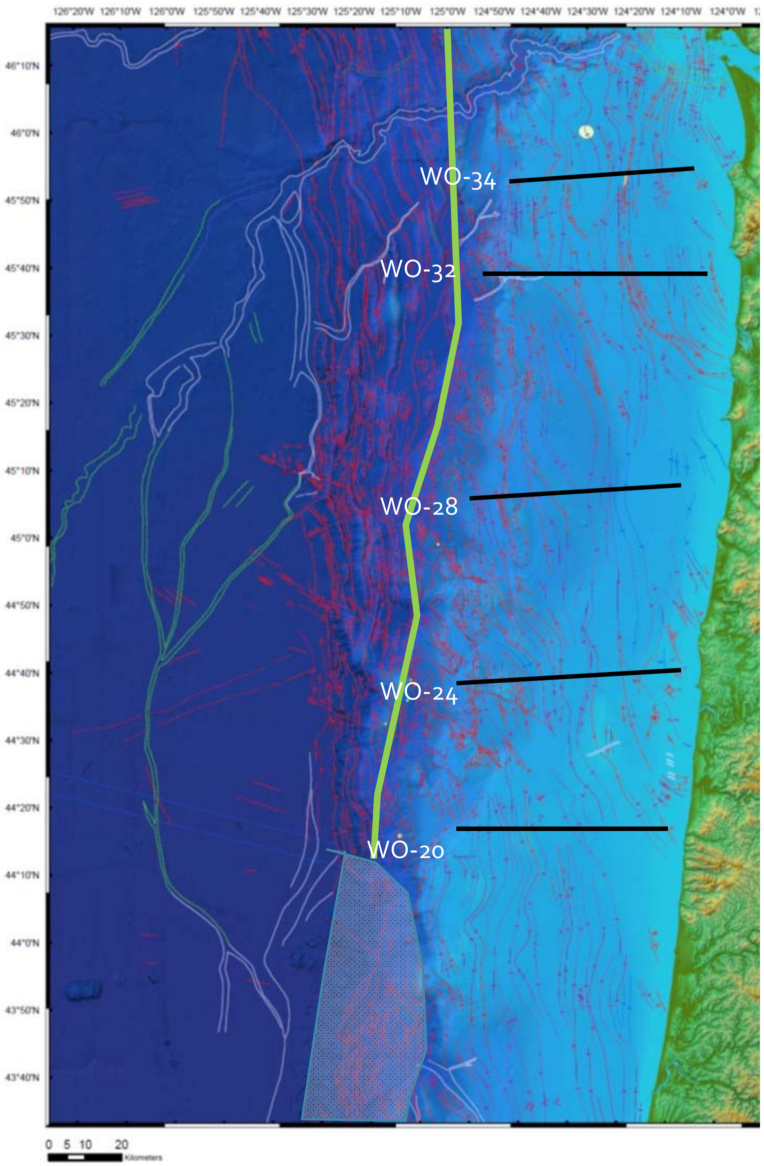






N-S compression driven by oblique subduction results in stress rotation from margin parallel in much of the forearc, to margin normal offshore. This stress rotation may be mappable in the orientations and activity rates of structures offshore.


WO-34
WO-32
WO-28
Strike slip system: Cape Falcon Fault
Eastern limb: a monocline
Small normal faults


WO-34
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WO-24
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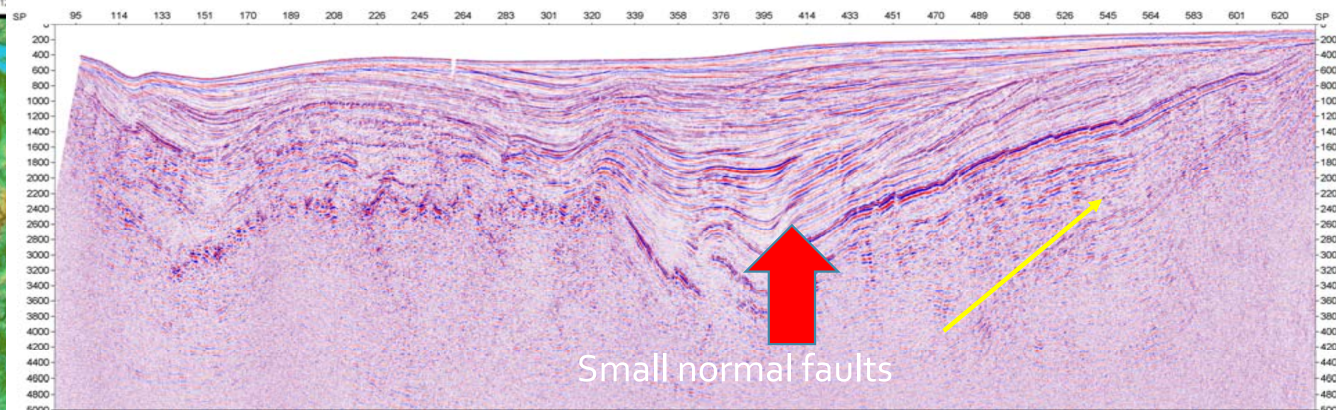
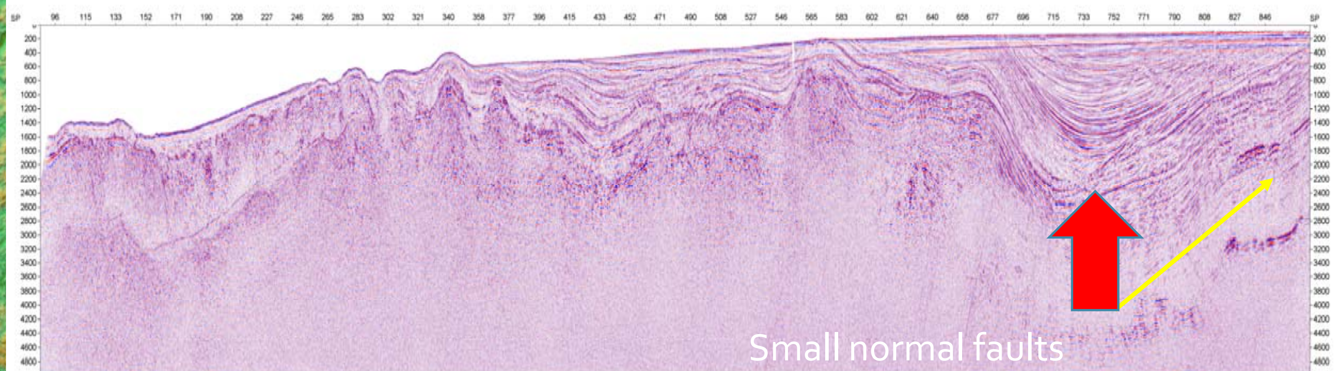
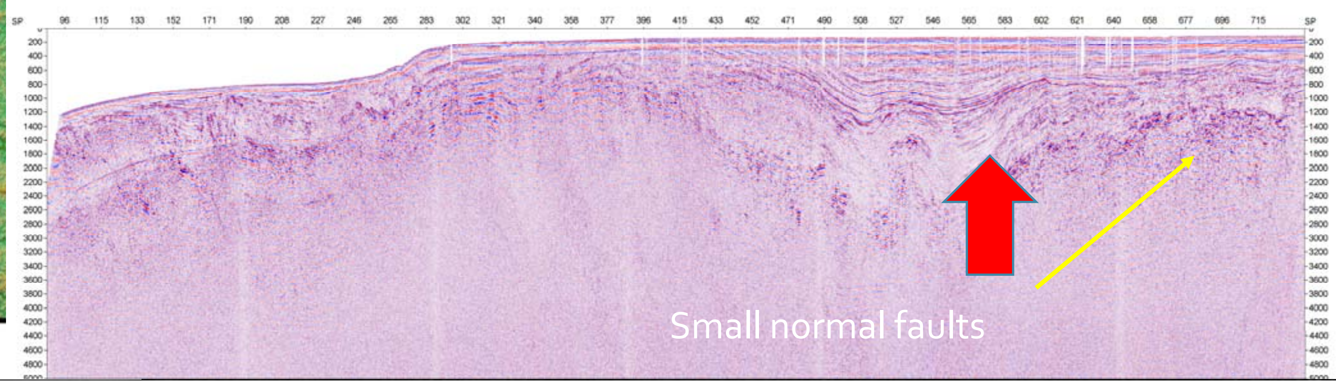
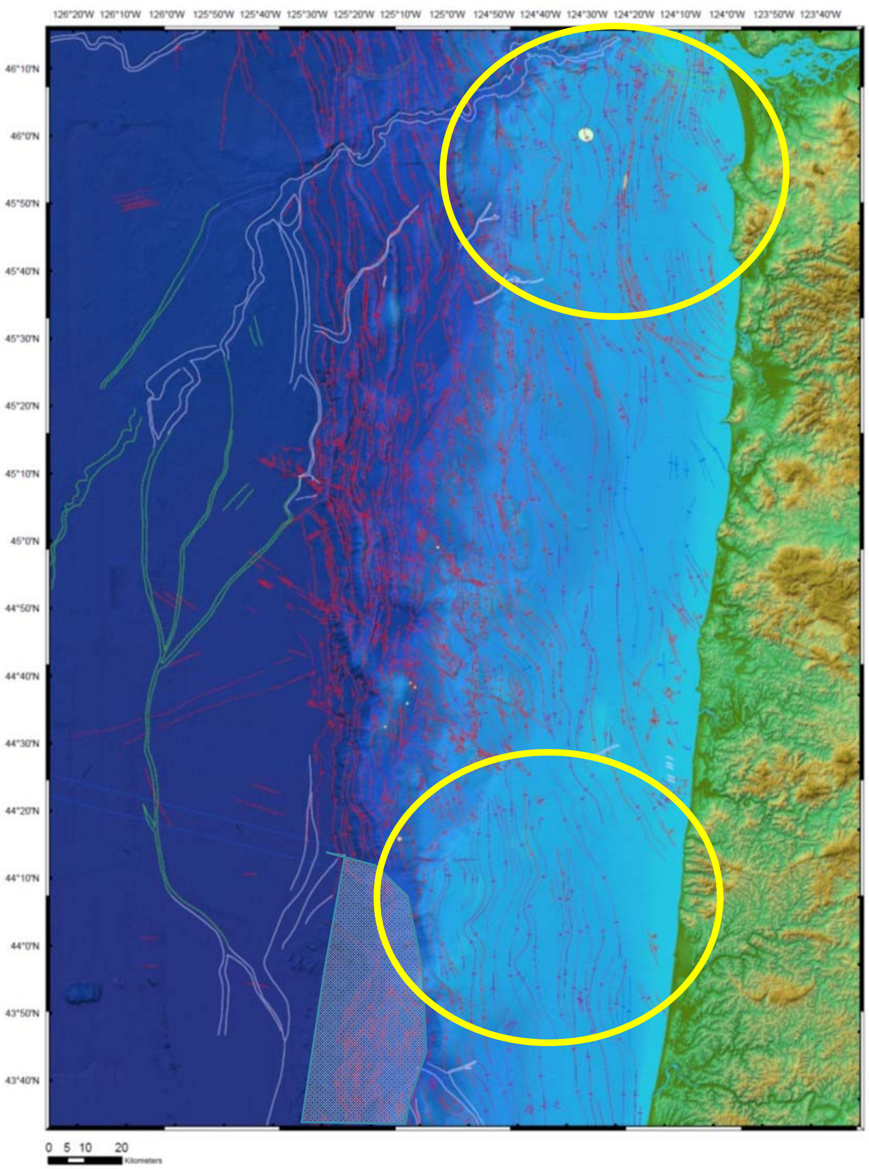
Kilometers


Small normal faults

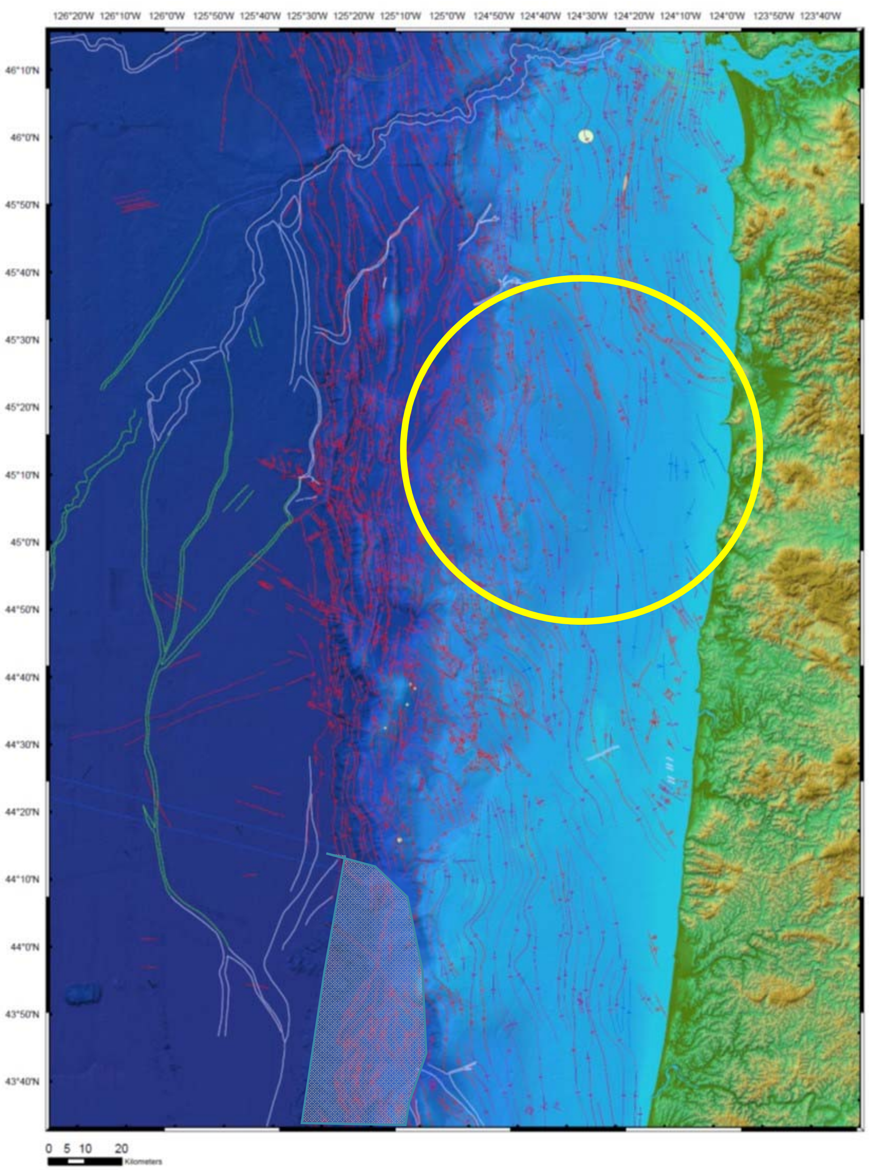

Small normal faults


Small normal faults



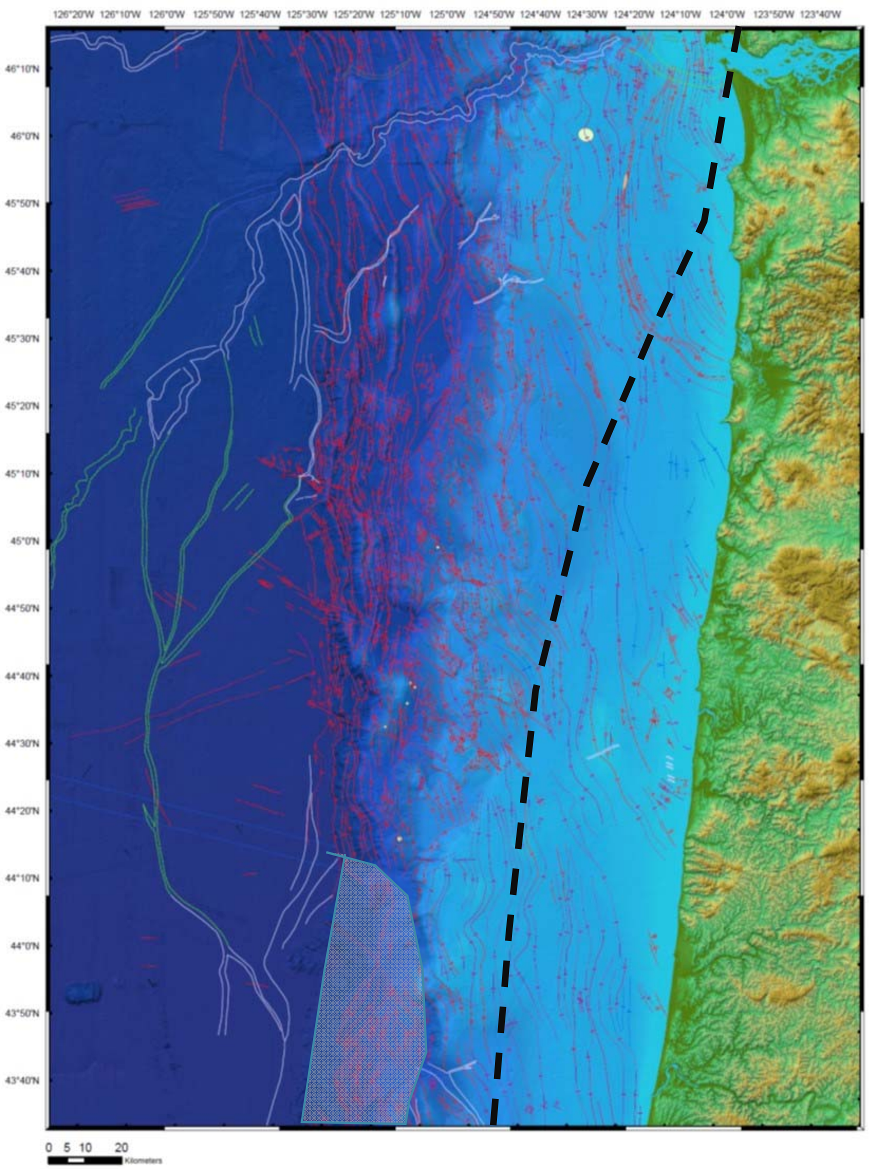
Yellow areas are uplifted submarine banks

1. High structural density
2. Long term uplift (~ 1 km)
3. Tight folds
4. Many active structures
5. Normal faulting landward, compressional seaward



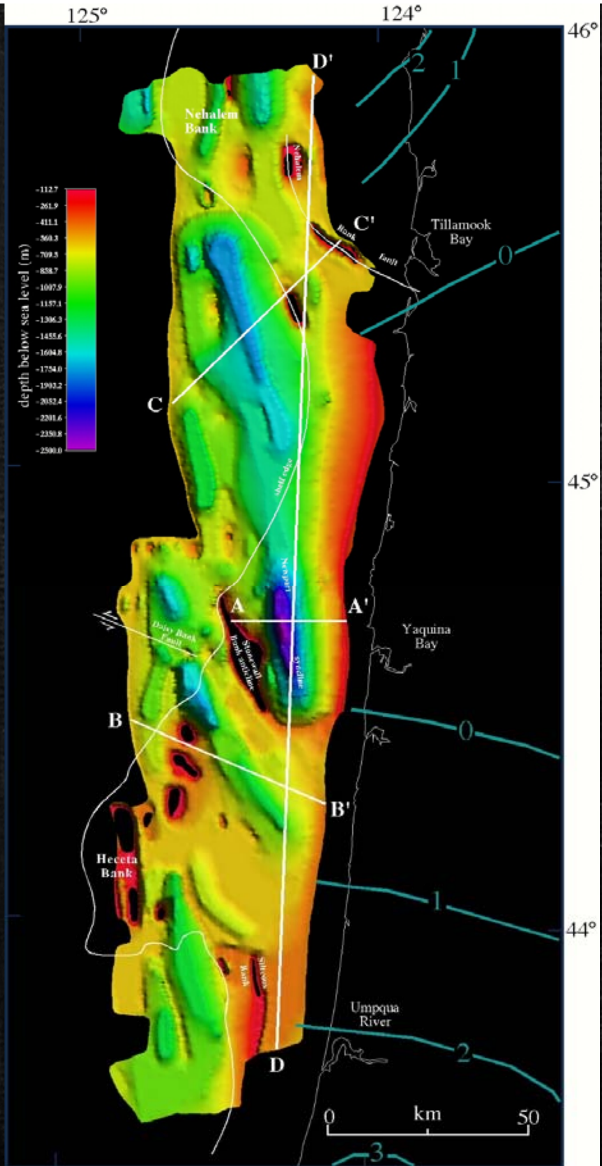
In contrast, this area characterized by:

1. Low structural density
2. Open folds
3. Long term subsidence or neutral
4. Few active structures
5. Normal faulting landward, compressional seaward



The stress transition in map view.

Poor correspondence with the Siletzia western limit (Black)

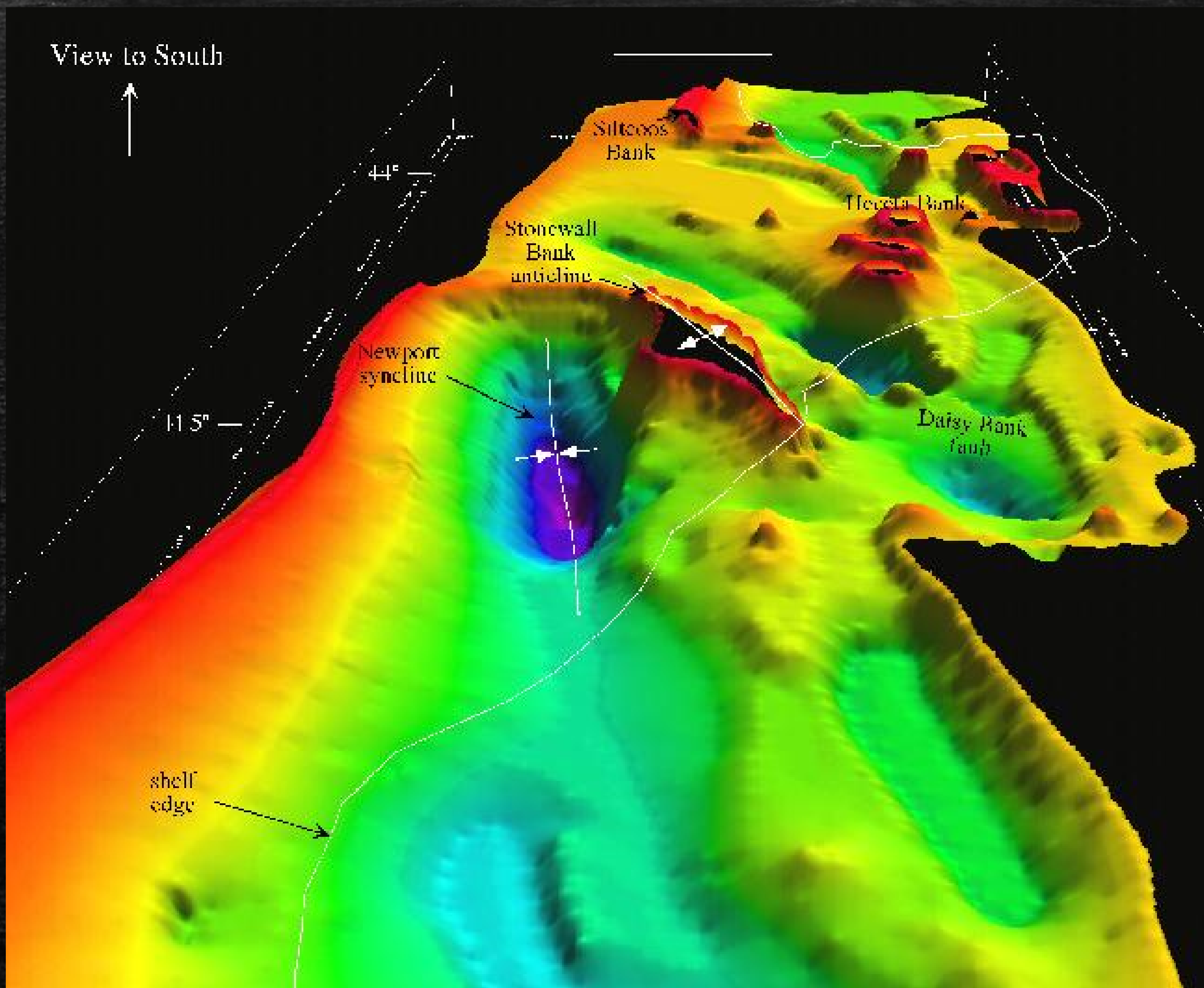


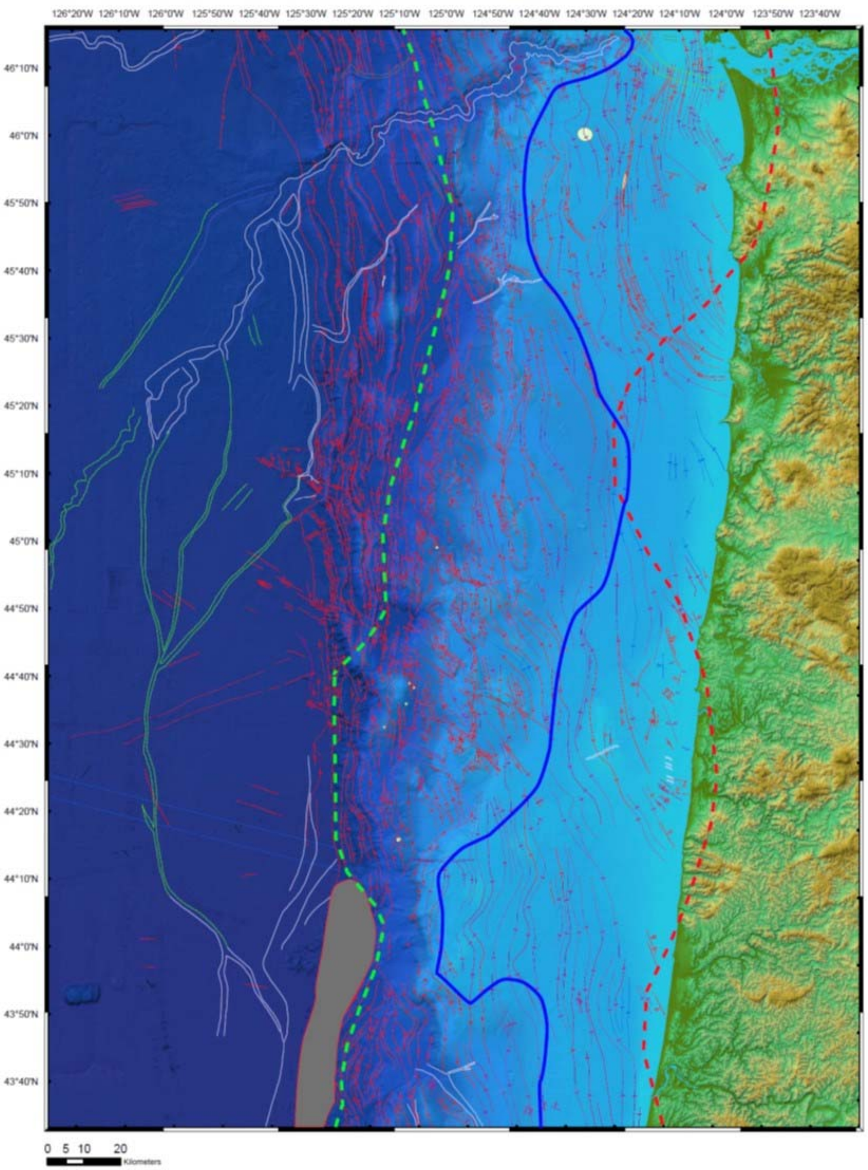
Structure contour map of a Miocene unconformity below the shelf and upper slope of central and northern Oregon.

The origin of this unconformity remains unknown. Even whether it was subaerial or submarine is not clear.

Nevertheless, it illustrates the highly variable deformation and subsidence/uplift along strike.

The uplift rate contours onshore are one of the early realizations of levelling data by Mitchell et al. (1994).


View to South
Siltcoos Bank
44°
Heceta Bank
Stonewall Bank anticline
Newport syncline
44 5°
Daisy Bank fault
shelf edge

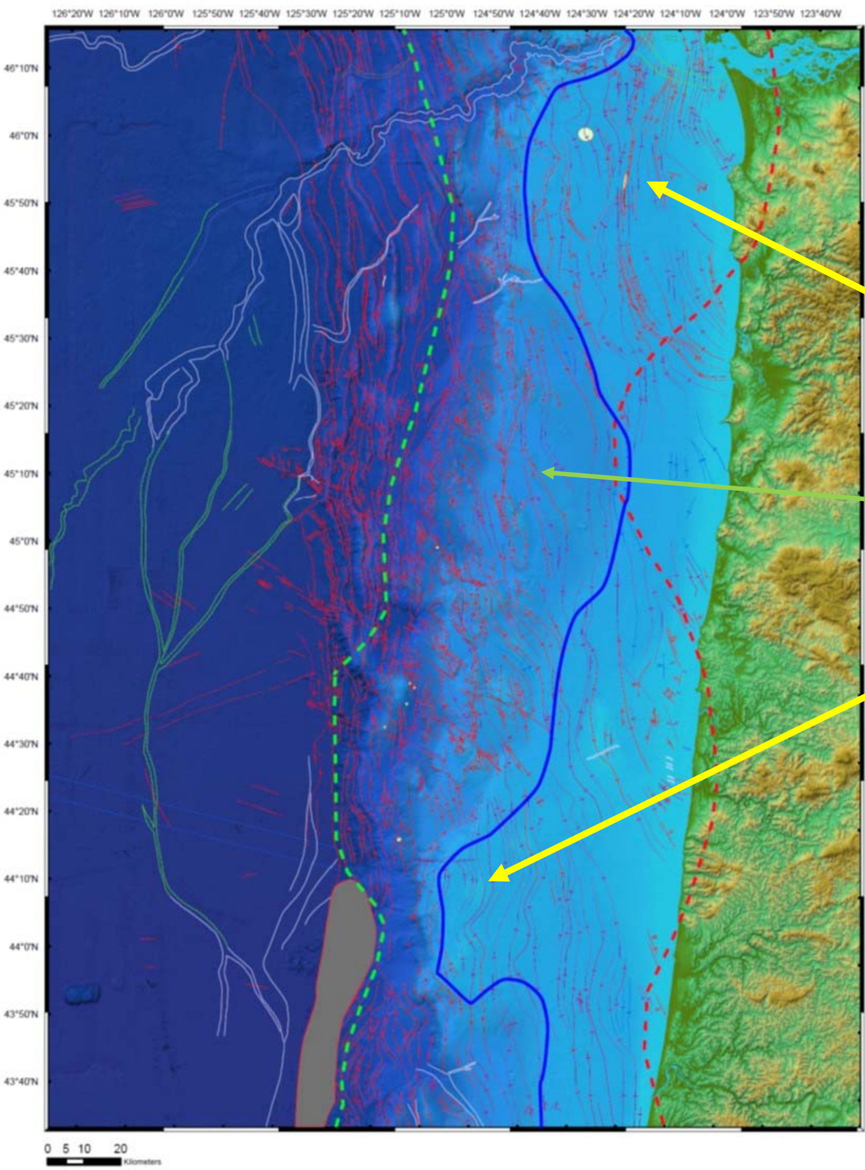


The stress transition in map view.

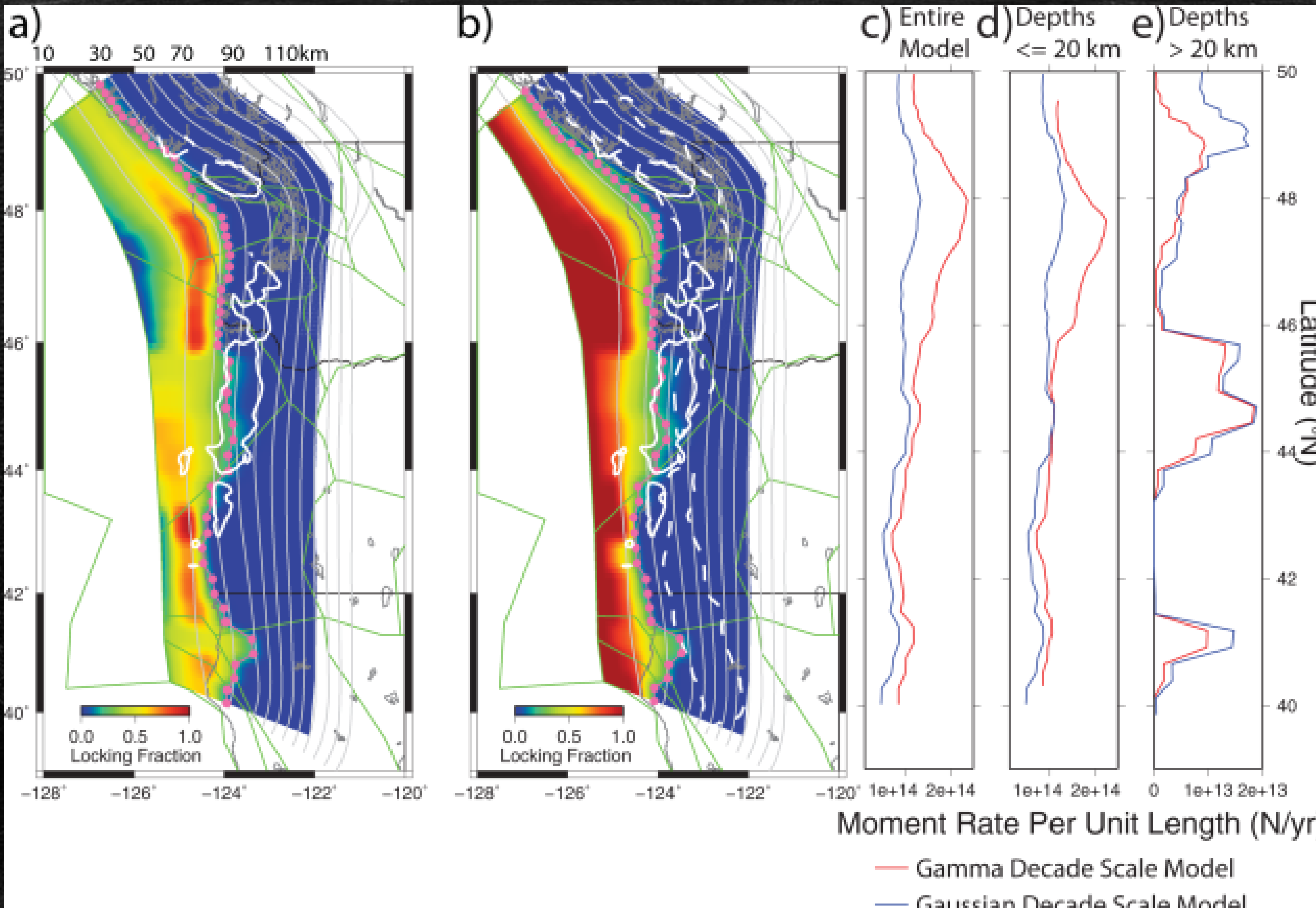
Updip transition in Green Dash

Downdip Transition in Red Dash

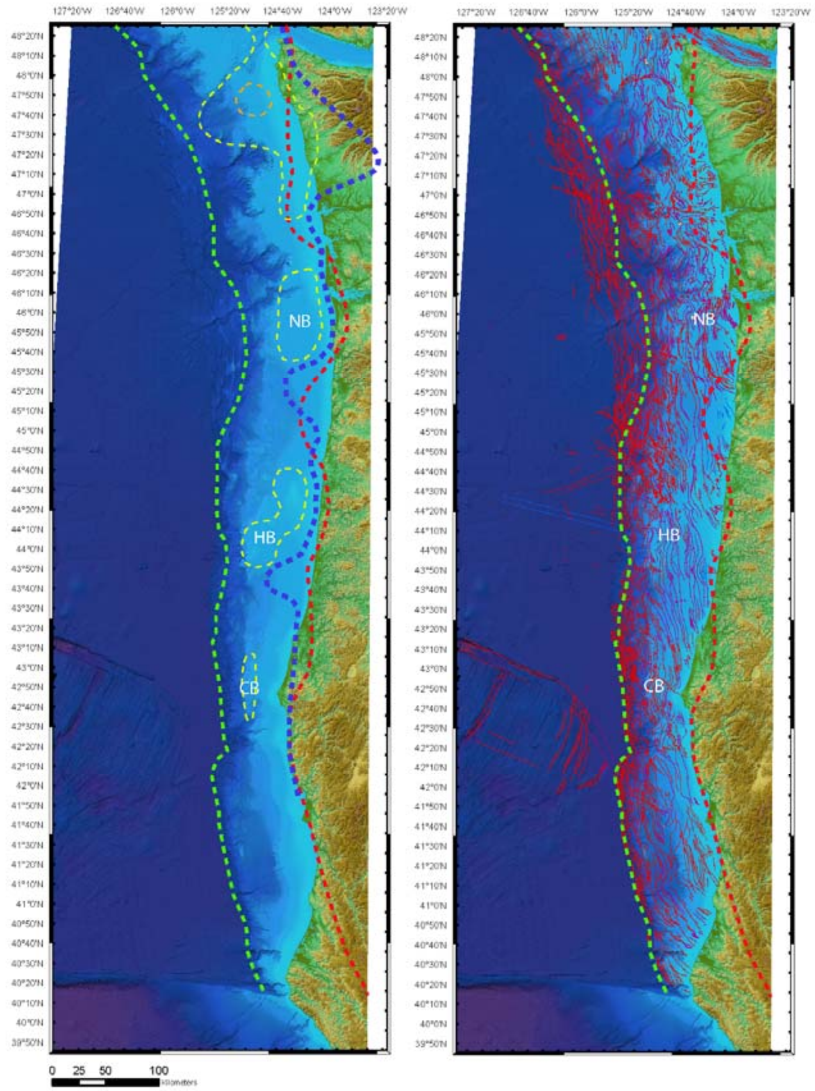
Shelf Edge in Blue



Two highly deformed areas with numerous active structures bound an area very lightly deformed.



a)
10 30 50 70 90 110km
50° 48° 46° 44° 42° 40°
0.0 0.5 1.0
Locking Fraction
-128° -126° -124° -122° -120°
b)
0.0 0.5 1.0
Locking Fraction
-128° -126° -124° -122° -120°
c) Entire Model
d) Depths <= 20 km
e) Depths > 20 km
1e+14 2e+14
1e+14 2e+14
0 1e+13 2e+13
50 48 46 44 42 40
Latitude (°N)
Moment Rate Per Unit Length (N/yr)
Gamma Decade Scale Model
Gaussian Decade Scale Model

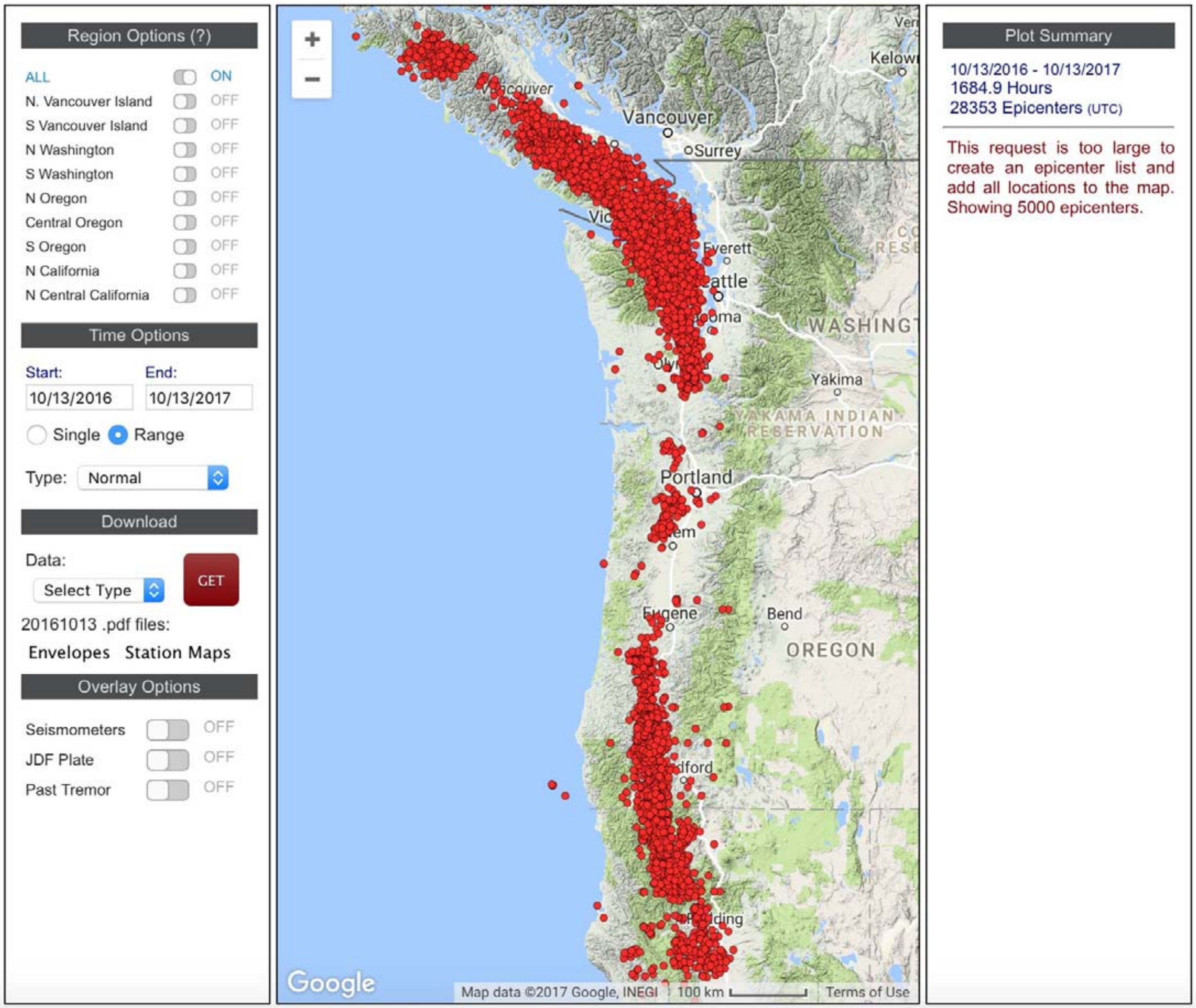


Comparing the eastern edge of GPS locking of Schmalzle et al. (2014), the structural transition tracks it fairly well in Oregon, but diverges in Washington.

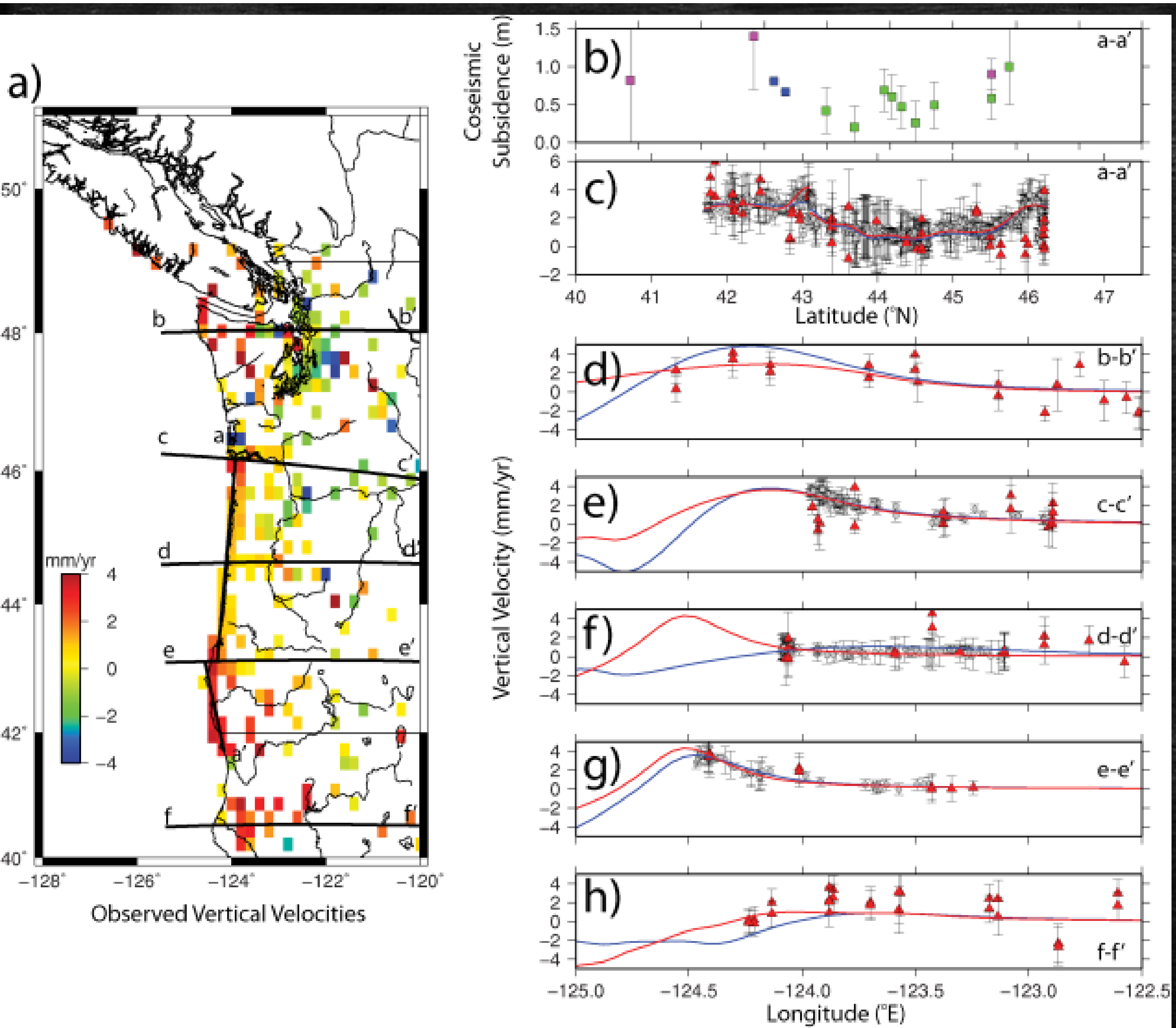
The pervasive normal faulting and strong N-S compression contributing to Olympic uplift may be shifting the transition far offshore.

In Oregon, the transition is broadly compatible with locking on the GPS timescale.

Locked patches at Nehalem and Heceta Banks are suggested and supported by Post Miocene uplift. ~ 1 km in the case of Heceta Bank (Kulm and Fowler 1974).



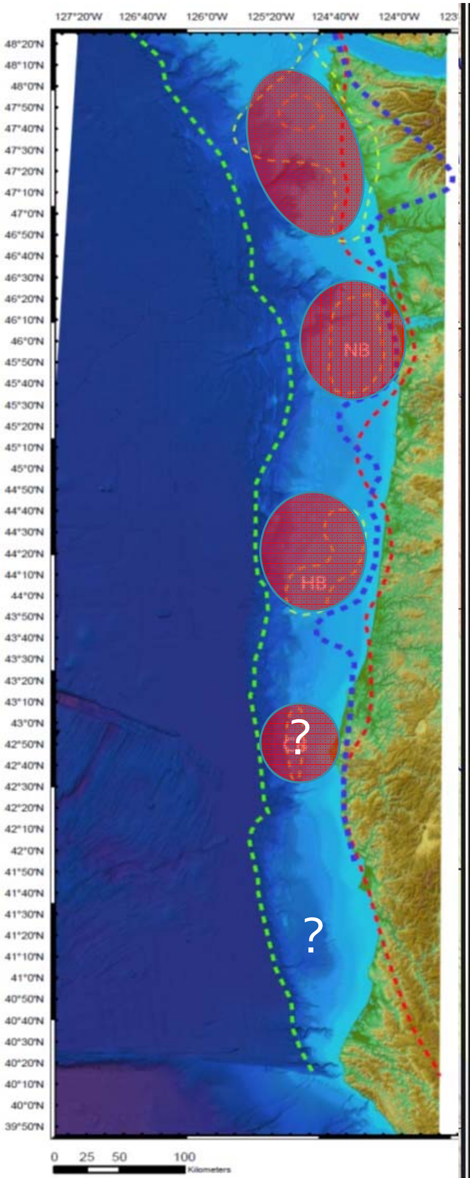
Tremor density is reduced in the Oregon creeping section, and in SW Washington

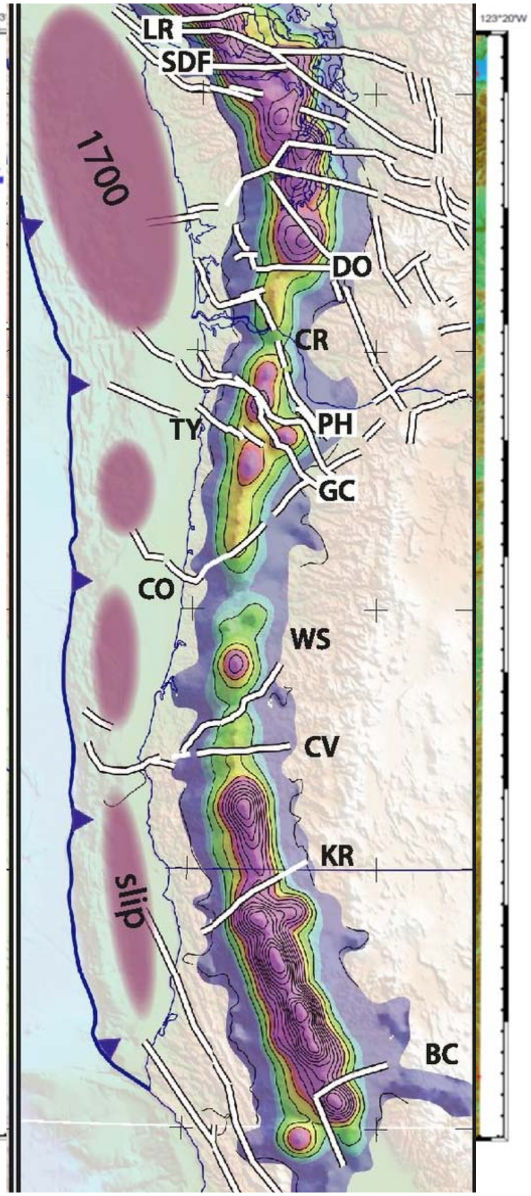


Levelling lines are flat in the creeping section, tilting eastward elsewhere.

Schmalzle et al., 2014

http://onlinelibrary.wiley.com/doi/10.1002/2013GC005172/full#ggge20419-fig-0005

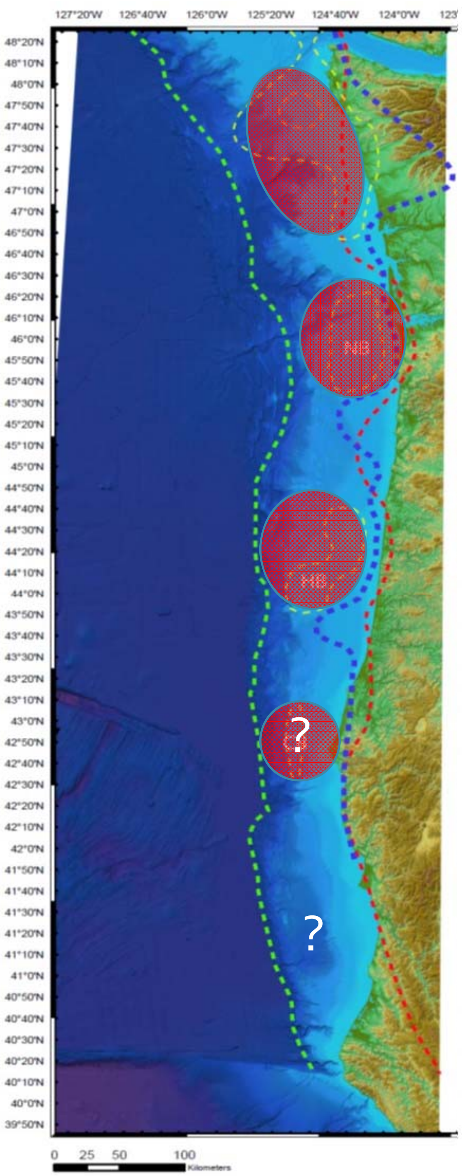


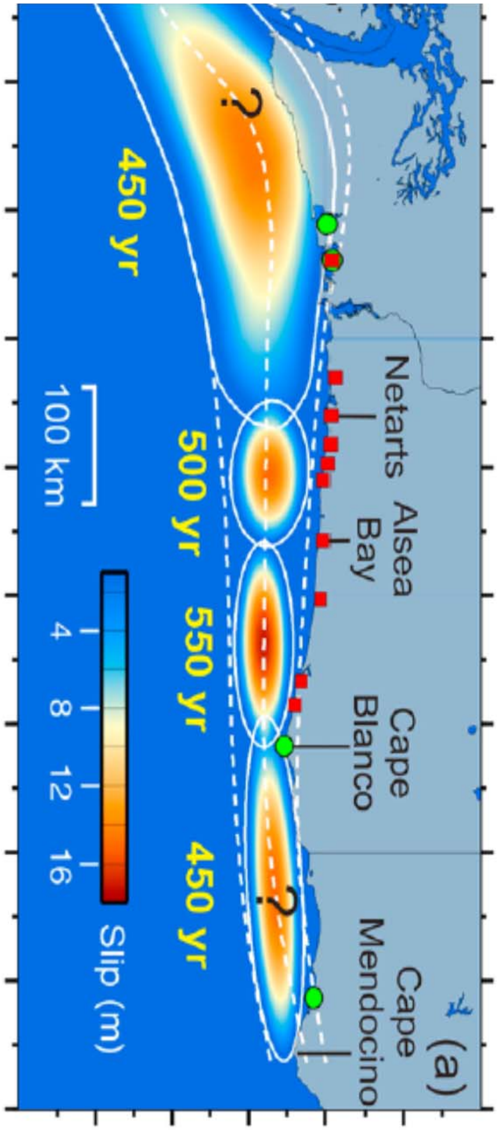


A long-term locking pattern suggested by structure, and compatible with both GPS and levelling surveys.

The model is similar to Wells et al., 2017 in the north, but essentially the opposite in SW Washington and Oregon.

The structure model is not very diagnostic in California.

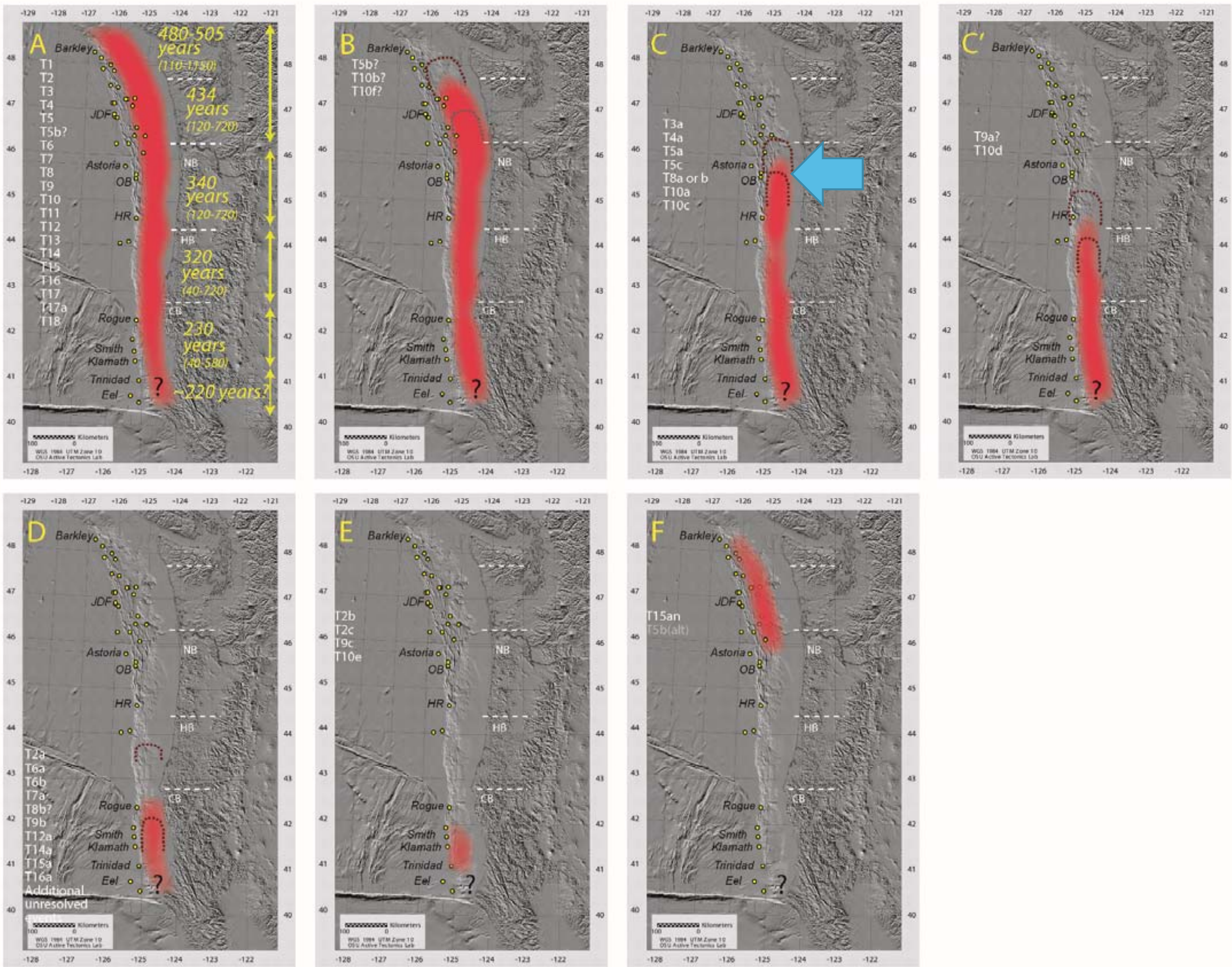




The fit to the forward model of Wang et al., 2013 for the AD 1700 earthquake is not particularly good.

However, some of this might be explained by either:

1. The AD 1700 earthquake just not a that representative of long term locking.
2. Structural locking hypothesis is wrong
3. The zero isobase crosses the coast at angles near Netarts and Alsea Bays, making this interp. potentially compatible in at least some places with subsidence data. Also, the subsidence model is somewhat spatially aliased.

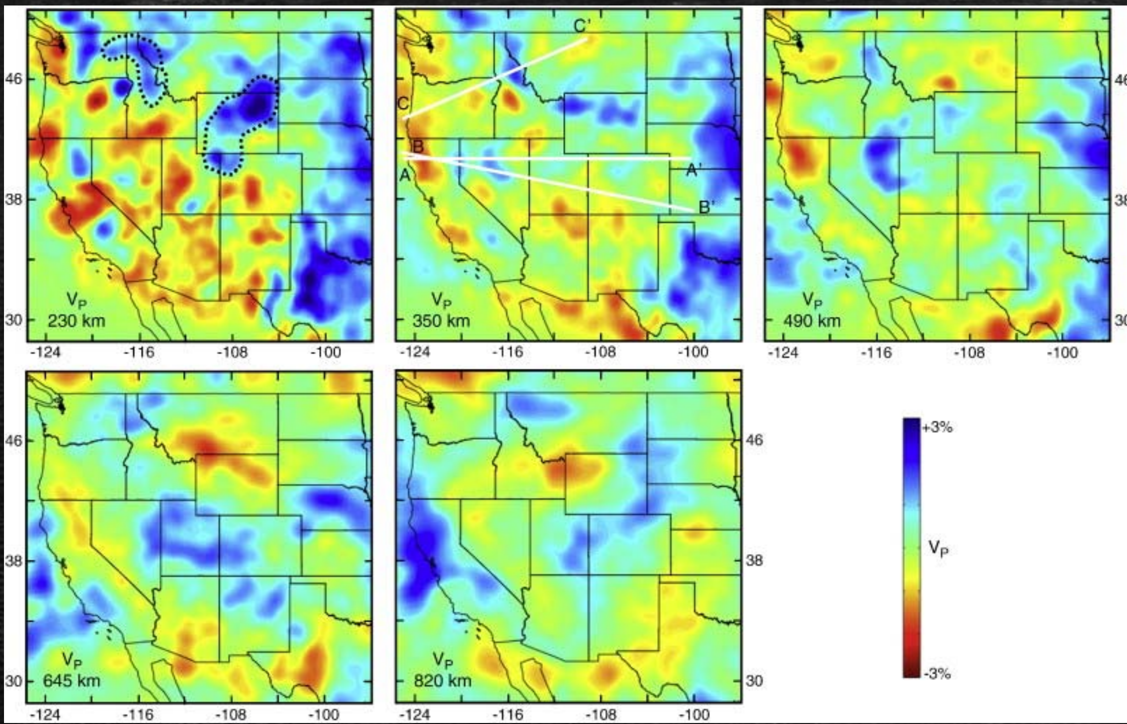


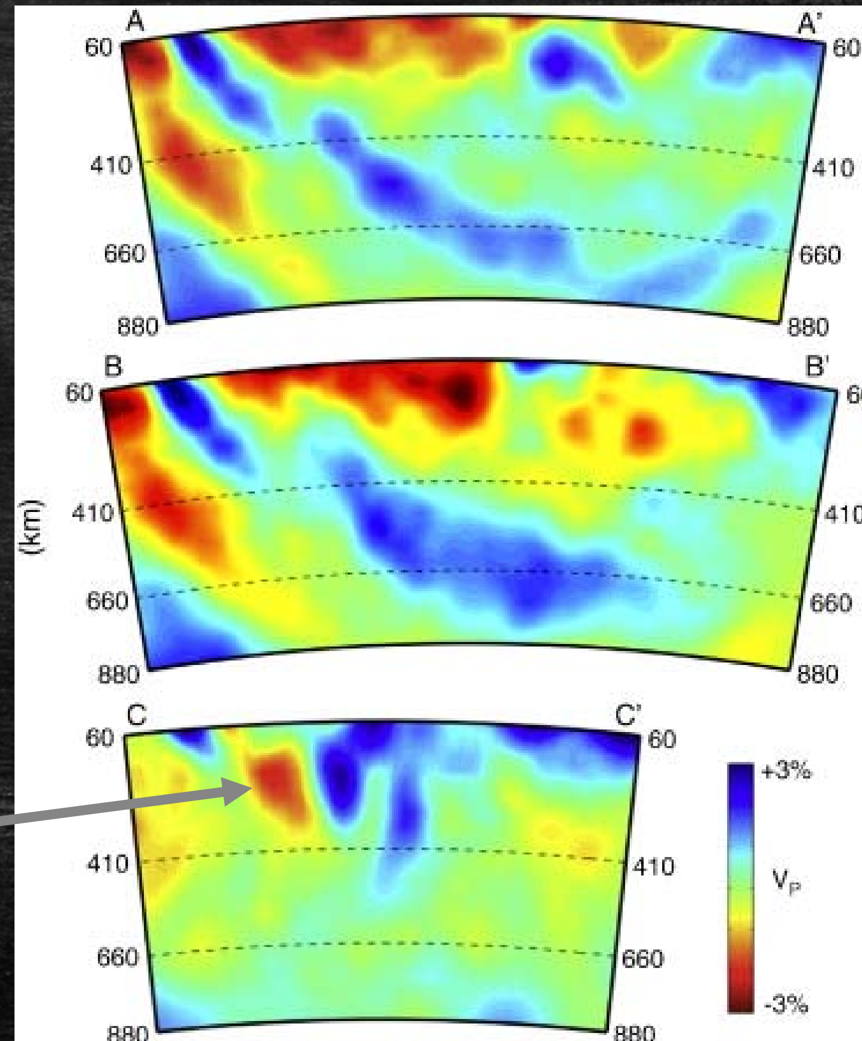
A significant termination of ruptures may occur between Hydrate Ridge and Astoria canyon, which roughly corresponds to the creeping section

Low coupling, why?

Some suggestions from Schmalzle et al. 2014):

- JDF slab “hole” at depth, reduced slab pull (Schmandt and Humphries 2010)
- Fluid cap related to thickened Siletzia terrane
- Large slow earthquakes





The slab hole

Schmandt and Humphries, 2010

Summary of the evidence

Low coupling suggested by:

- Post-Miocene structural evidence of reduced basal traction
- Persistent reduced subsidence ~ 6600 year paleoseismic record
- Levelling data, little uplift or arcward tilt
- GPS vertical, low uplift
- GPS horizontal (joint inversion) seaward position and or broad weak transition zone.
- No evidence of thinner turbidites or reduced tsunami inundation in the creeping section.

Conclusions

Post-Miocene structural patterns suggest strong basal shear at Nehalem and Heceta submarine Banks. With a possible creeping section in N. Oregon

The low coupling corresponds to the low GPS coupling in most models, flat levelling lines, low geodetic uplift rates and paleoseismic terminations.

Why is it creeping? Multiple possibilities.

Thank you!