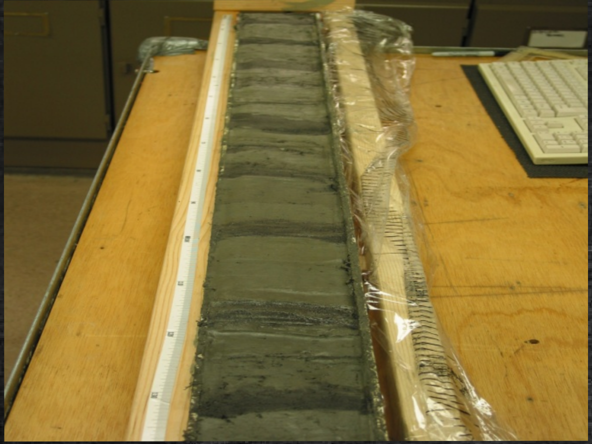
Integrating onshore and offshore paleoseismic data: a Bayesian model

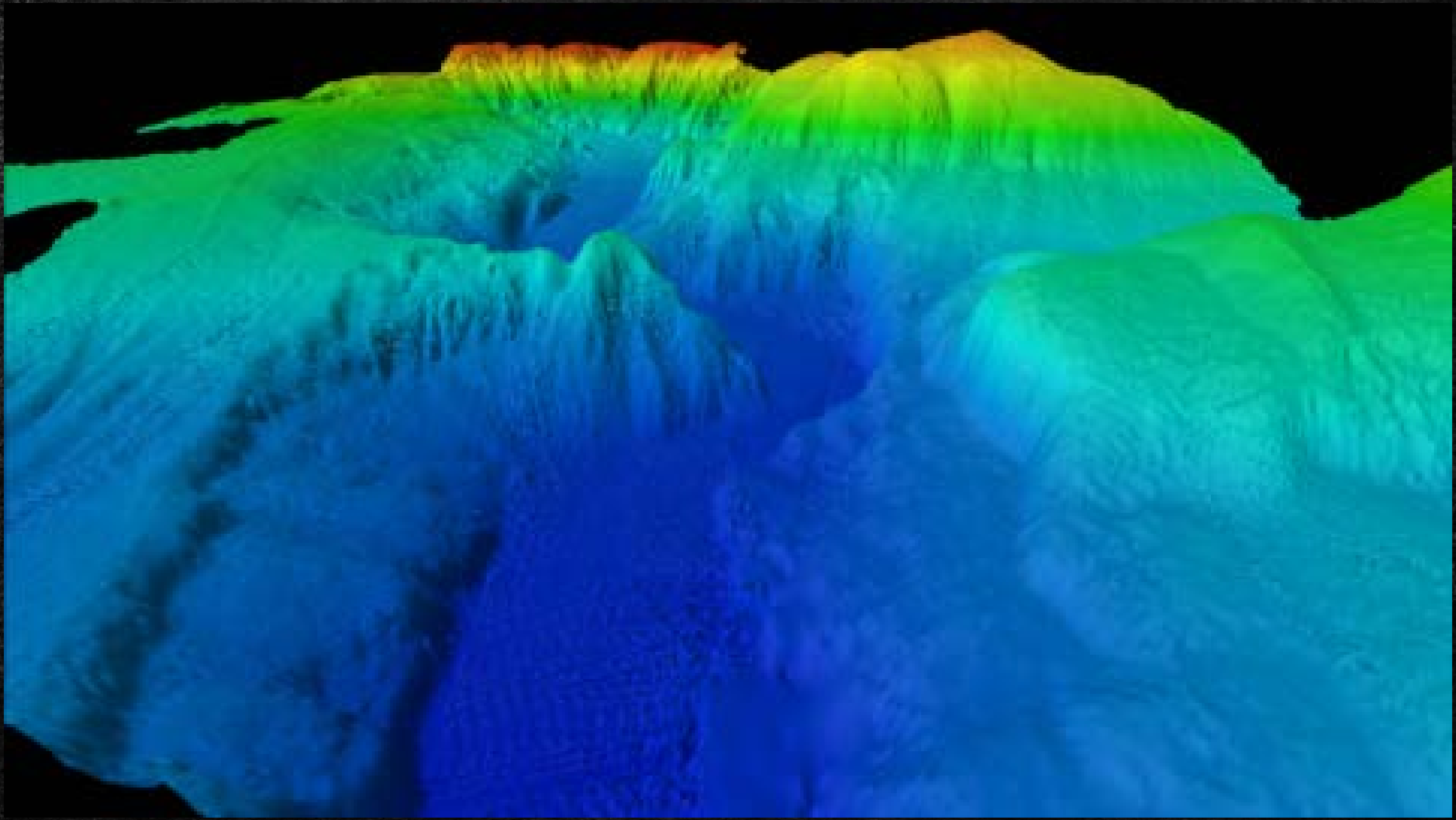
Chris Goldfinger[1], Steve Galer[1] Jeffrey Beeson[1], Ann E. Morey[1], Bran Black[1], C. Hans Nelson[2]

[1] *Oregon State University, College of Earth, Ocean and Atmospheric Sciences, 104 Ocean Admin. Bldg., Corvallis OR 97331, USA.*
gold@coas.oregonstate.edu

[2] *Instituto Andaluz de Ciencias de la Tierra (IACT) CSIC-Univ. de Granada Campus de Fuentenueva s/n 18002 Granada, Spain*
odp@ugr.es

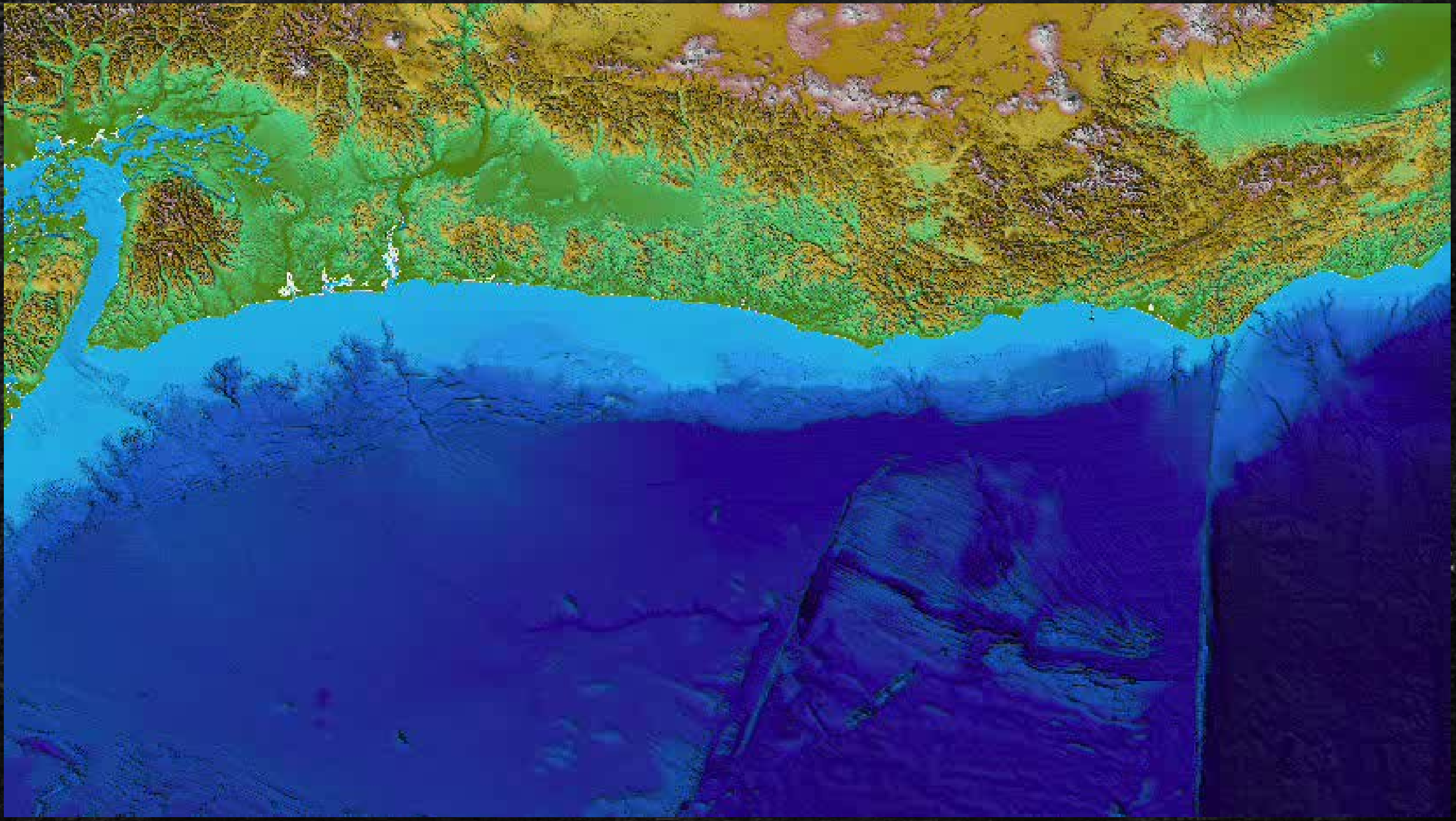



What actually happens during the earthquake?



What actually happens during the earthquake?

Synchronous turbidity currents are triggered within a few minutes of each other along the length of the margin



Turbidity Current Triggering Mechanisms

Tests of aerial extent can eliminate many possible triggering mechanisms.

Lack of land external sediment sources on the Cascadia and Sumatran outer slope and absence of cyclones near the equator eliminates storms (almost)

Extreme rarity eliminates impacts

- storm or tsunami wave loading/liquefaction
- sediment loading (trigger still needed)
- storm (hyperpycnal) discharge
- bolide impact
- great earthquakes
- crustal earthquakes
- tectonic over-steepening (trigger still needed)
- gas hydrate destabilization (trigger still needed)

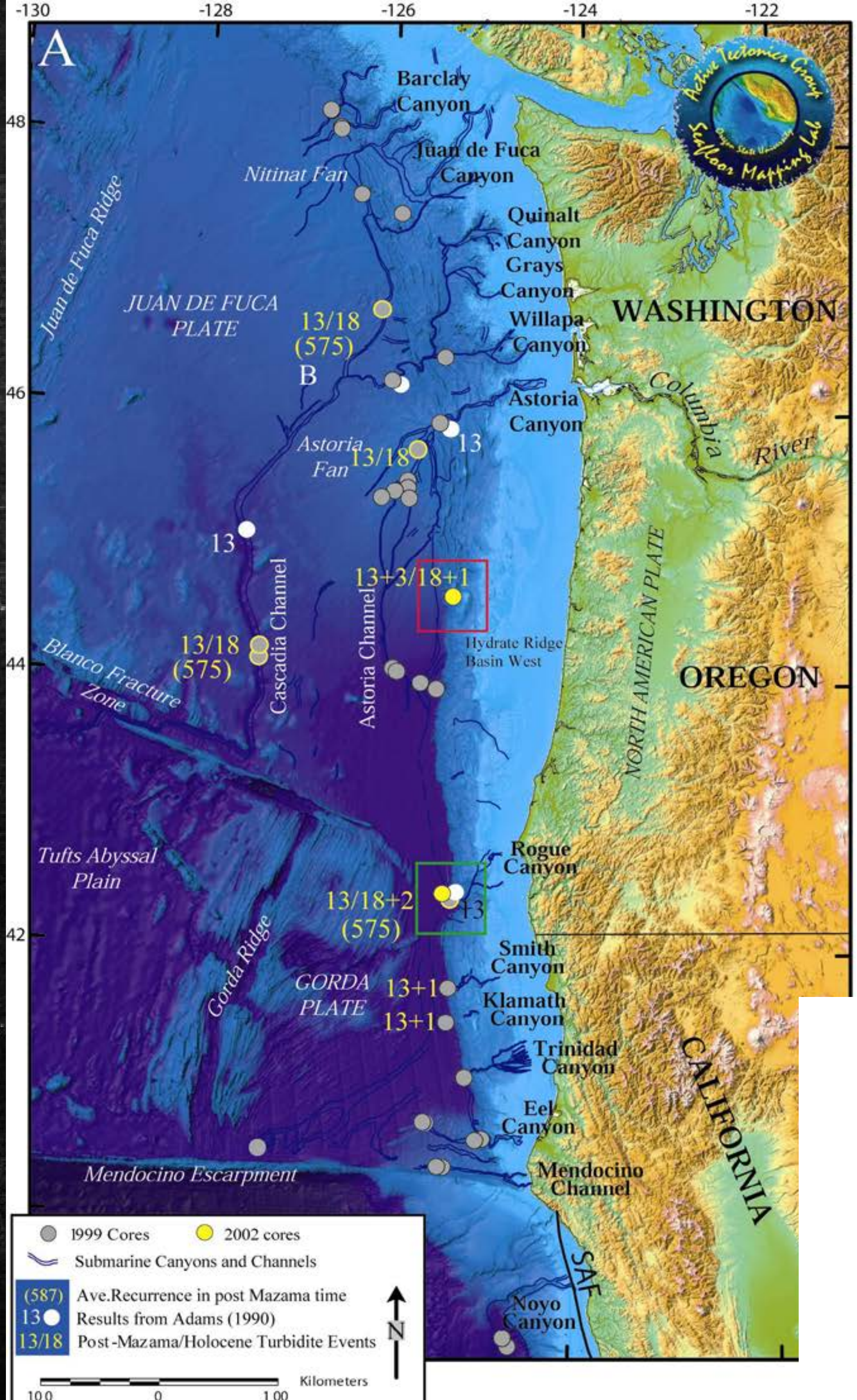
So our primary criteria for distinguishing earthquakes are

1) Aerial extent
2) Synchroneity, and
3) Sedimentology.

Synchronous means within a few minutes to hours at most…

^{14}C dating gets us only to within a few decades…. So how do we constrain relative timing to within a few minutes?

Cheat!



Turbidite Paleoseismology:

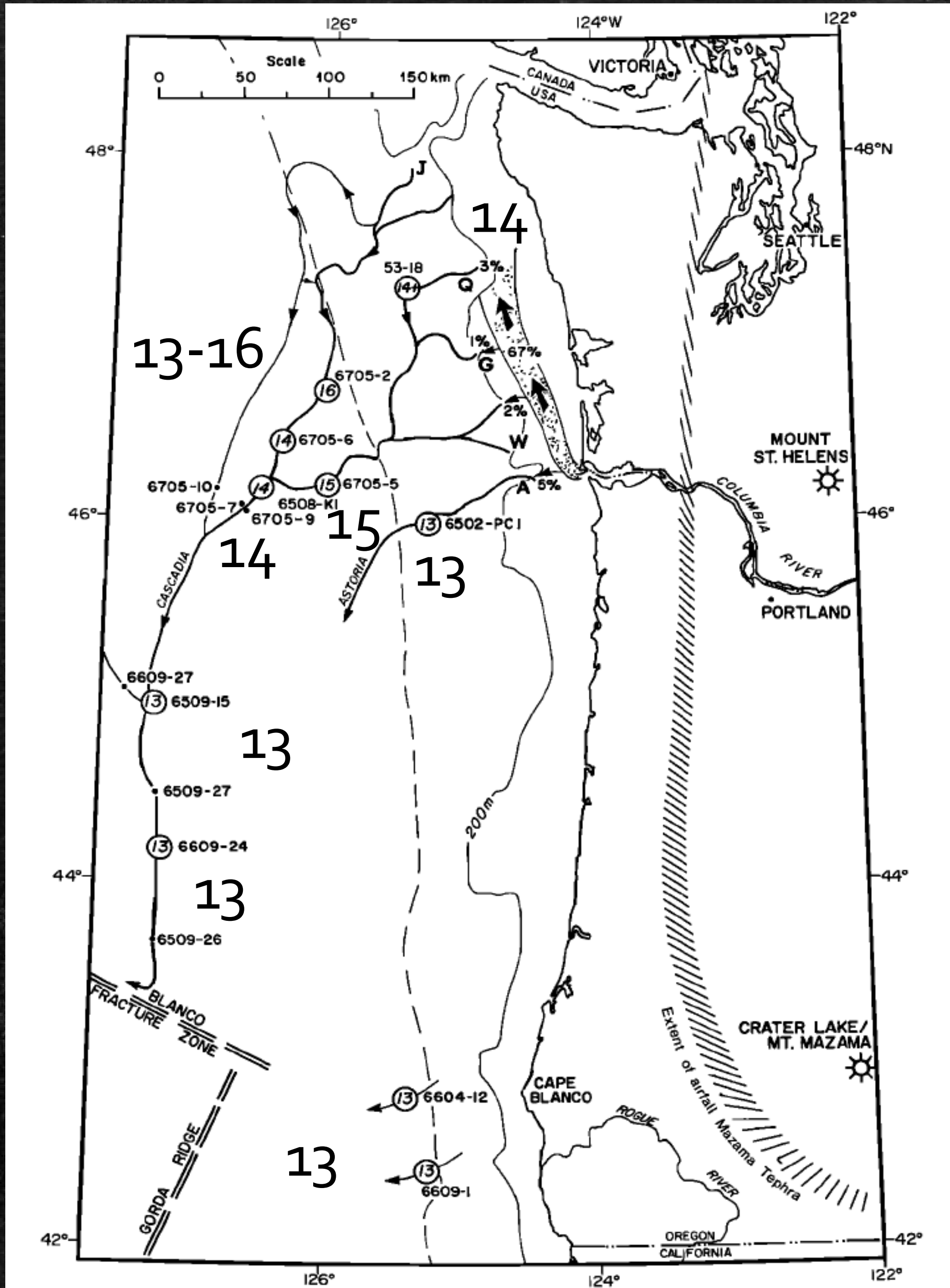
Extending the earthquake record

Cascadia Core Sites:

1999 = gray, 2002 = yellow

Older existing cores = white

Washington Channels defined by 12 days of multibeam survey, now un-classified!



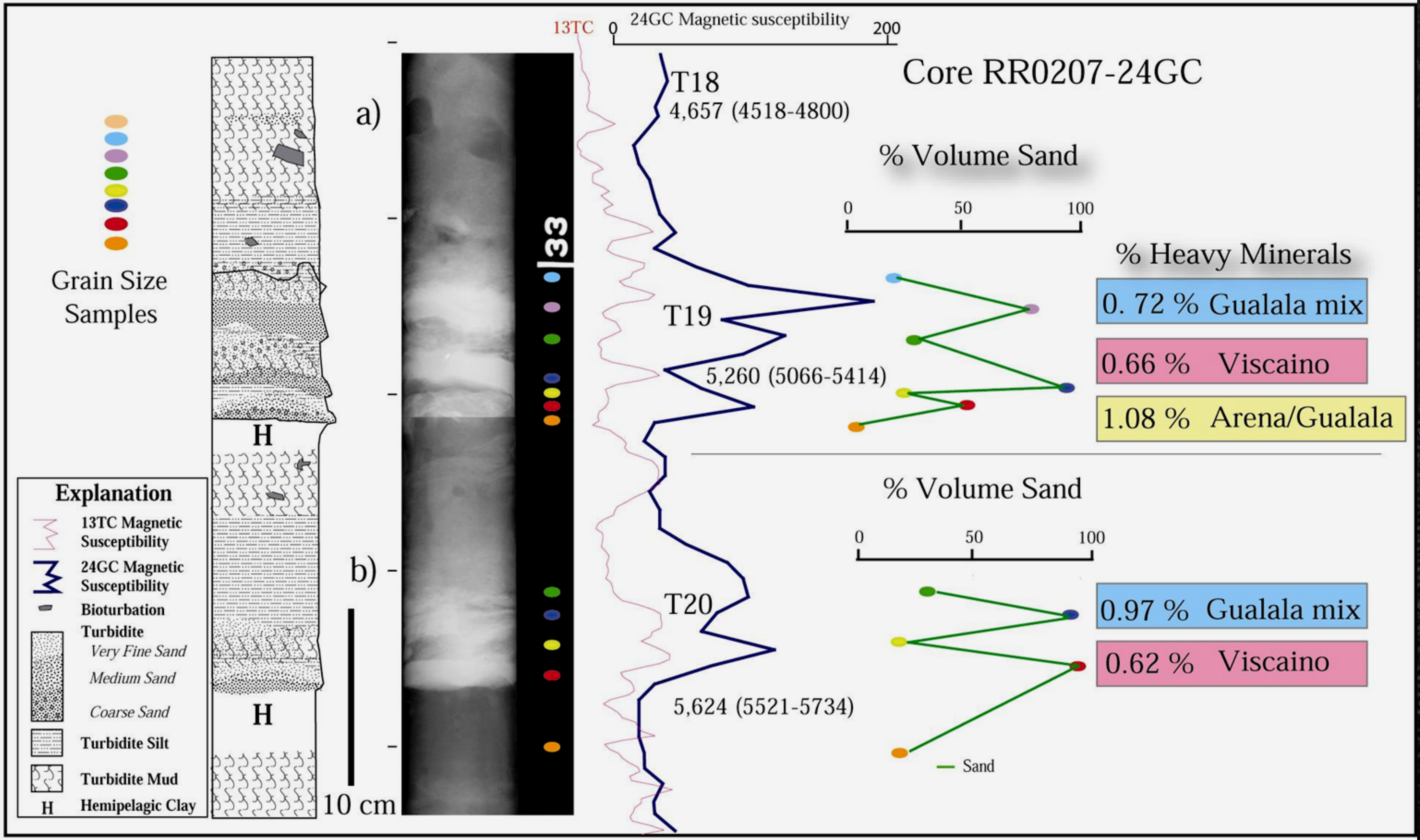
Early tests for earthquake origin. Hats off to John Adams 1984-1990

While brilliant, and this strategy has been successful, much more is needed for confidence in definition of channel systems and stratigraphy!

These cores were collected by OSU and UW investigators and students using Loran (~ .25 nm uncertainty) with PDR and occasional TRANSIT fixes.

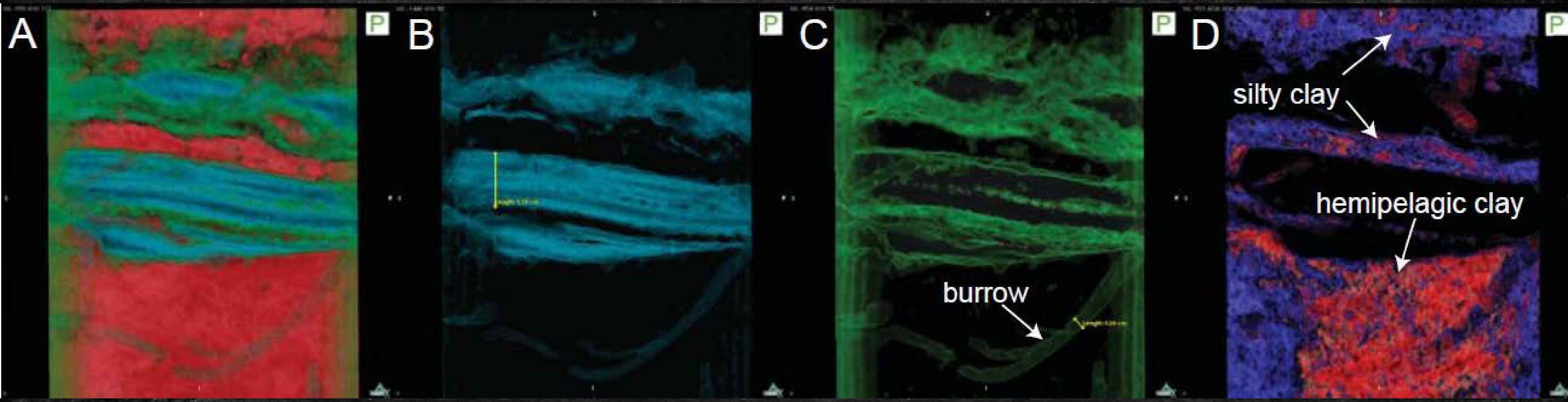
Detailed correlations are constructed from high-resolution physical property data collected from the cores, including magnetic susceptibility (high and low), gamma density, P-wave velocity, resistivity, and CT imagery.

Francois Charlet



In addition to the confluence test, we correlate turbidites between remote sites to establish continuity, and test for synchronous triggering.

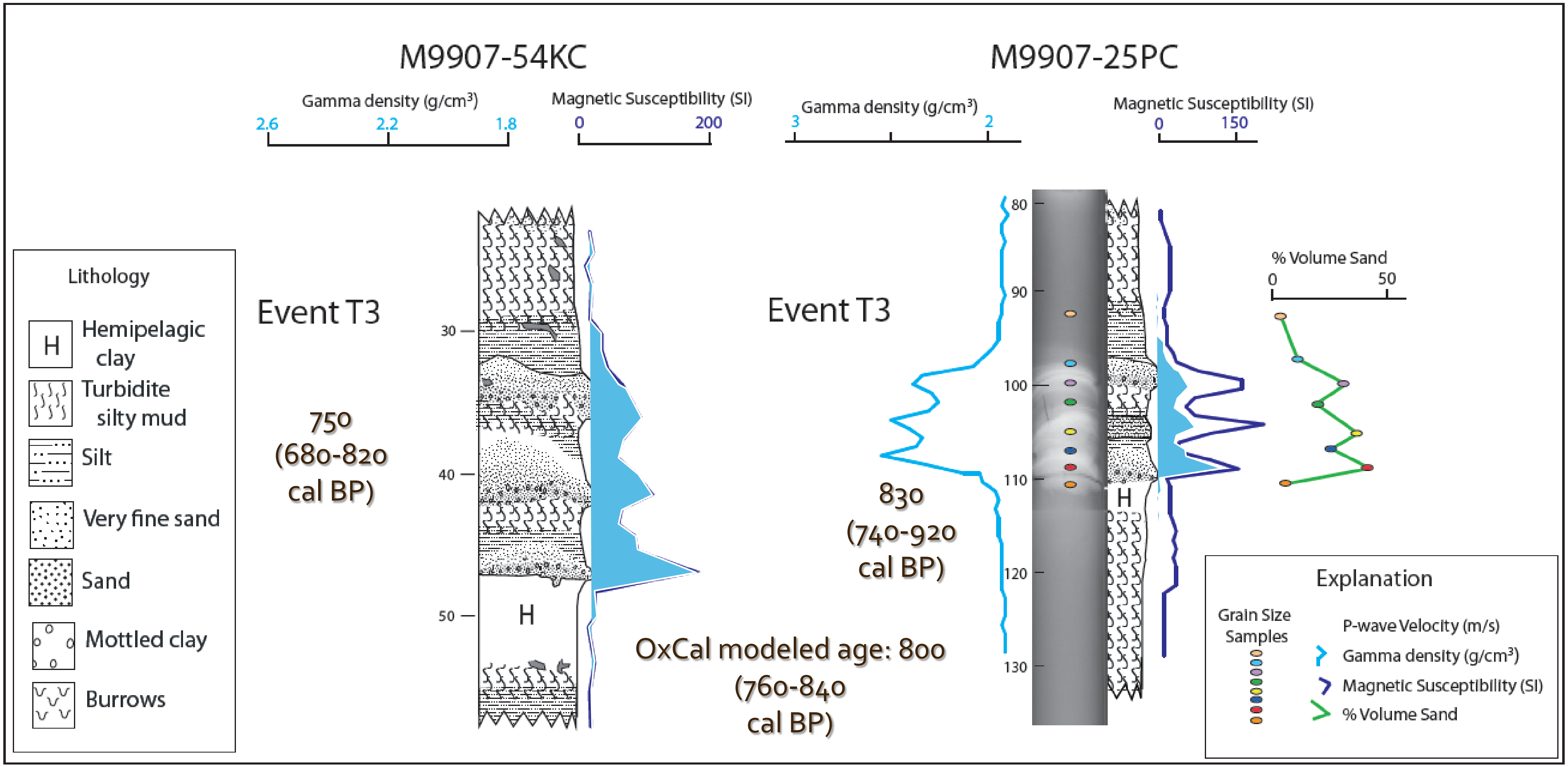
Correlations are made on the basis of grain-size/physical property “fingerprints” within a ^{14}C age framework



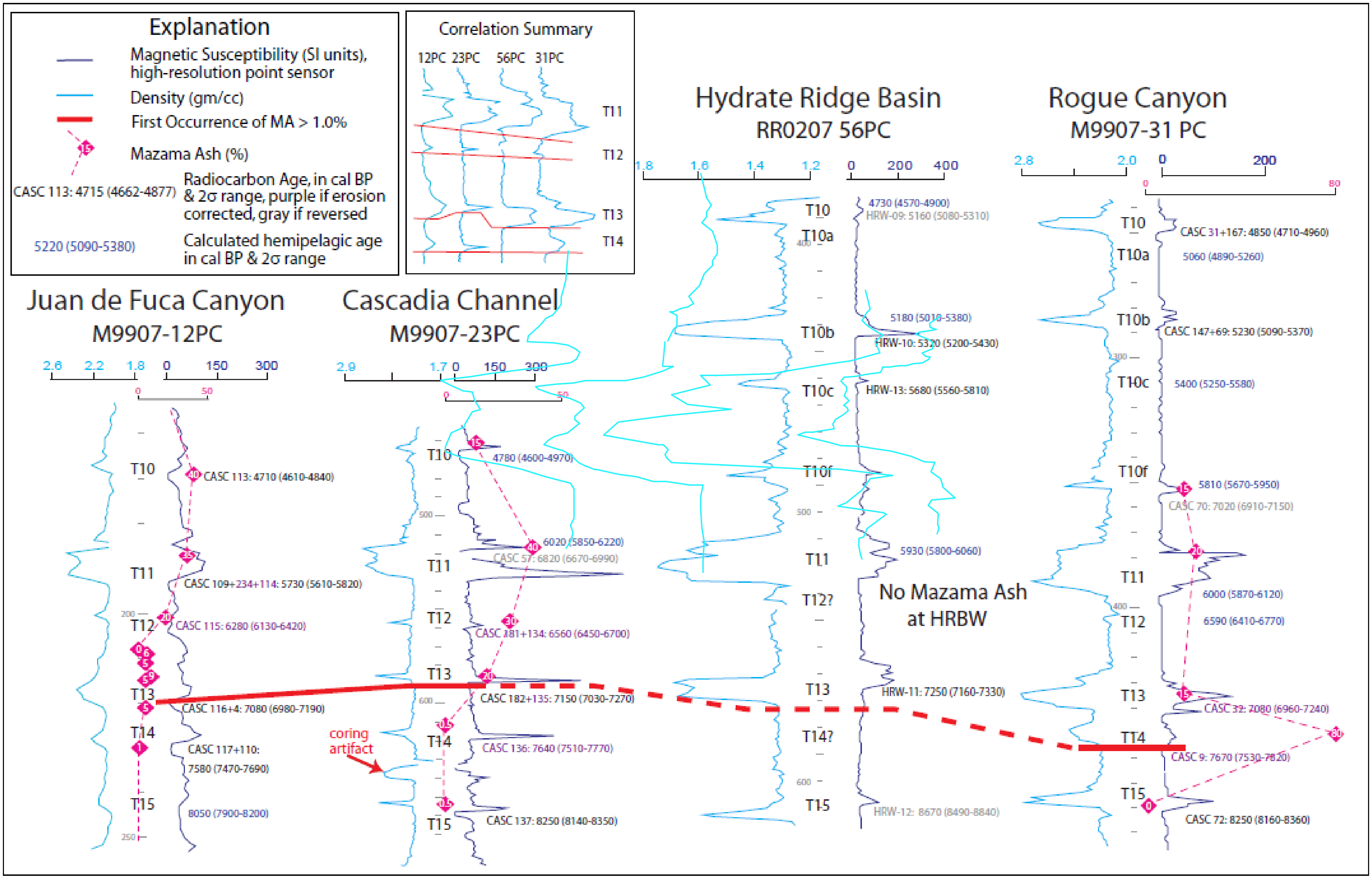
CT imagery is invaluable for understanding turbidite structure and defining stratigraphic boundaries in detail. This image breaks out the sand fraction, the silt fraction, and the hemipelagic clay by their respective CT density values.

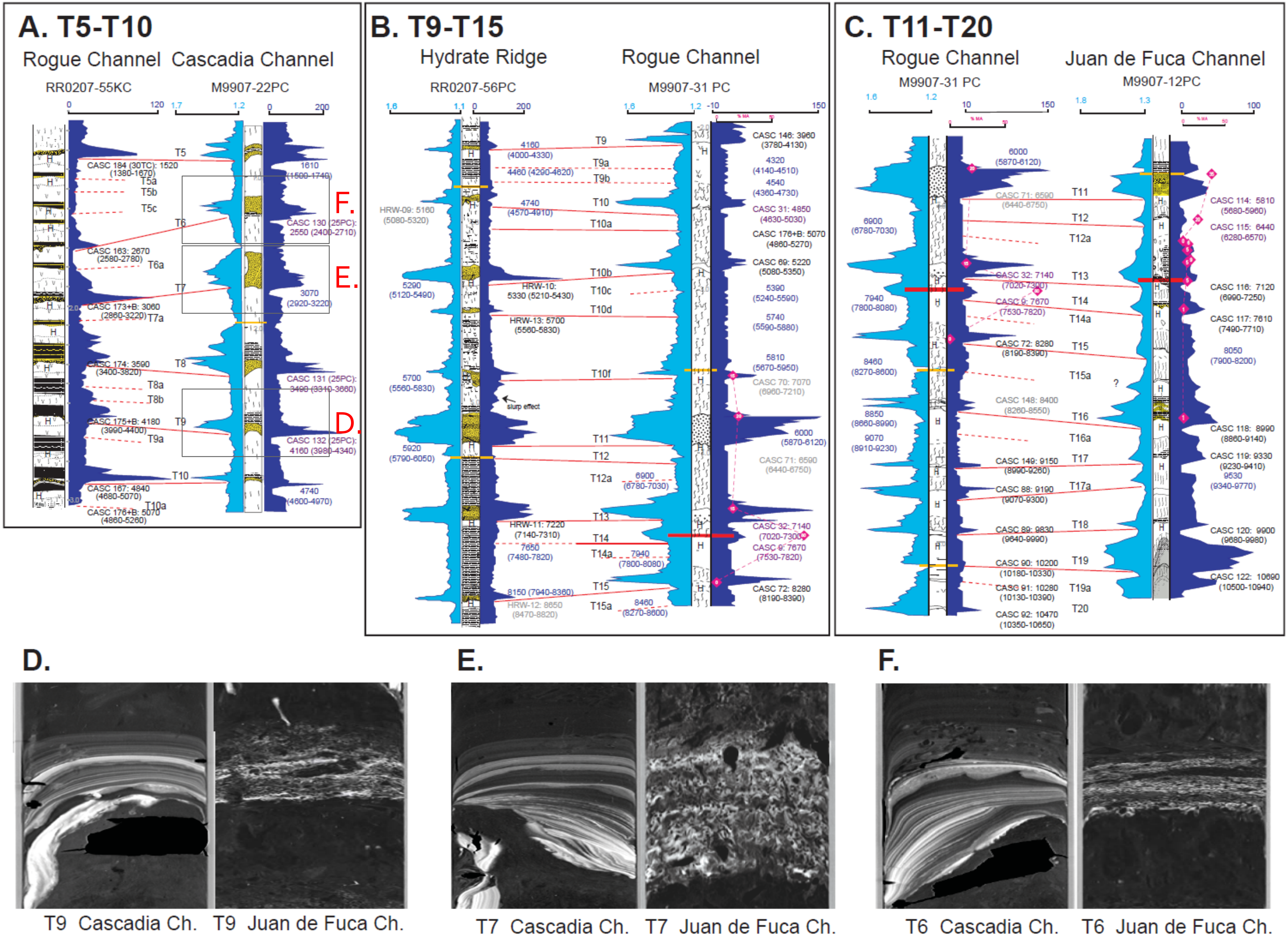
The CT can reveal such subtle features as a worm burrow which is apparently lined with material slightly more dense than its surroundings (biogenic clay)

CT movie…



Looking closely, the main structure of these turbidites is a series of fining upward "pulses" (Bouma A-C) capped by a fining upward tail. The pulsing structure is commonly maintained through channel confluences, and between isolated sites as shown by this example from two cores 300 km apart, with source areas 420-500 km apart. These channels never meet.


Explanation
Magnetic Susceptibility (SI units), high-resolution point sensor
Density (gm/cc)
First Occurrence of MA > 1.0%
Mazama Ash (%)
CASC 113: 4715 (4662-4877)
Radiocarbon Age, in cal BP & 2σ range, purple if erosion corrected, gray if reversed
5220 (5090-5380)
Calculated hemipelagic age in cal BP & 2σ range
Correlation Summary
12PC 23PC 56PC 31PC
T11
T12
T13
T14
Juan de Fuca Canyon
M9907-12PC
Cascadia Channel
M9907-23PC
Hydrate Ridge Basin
RR0207 56PC
Rogue Canyon
M9907-31 PC
No Mazama Ash at HRBW
coring artifact
CASC 113: 4710 (4610-4840)
CASC 109+234+114: 5730 (5610-5820)
CASC 115: 6280 (6130-6420)
CASC 116+4: 7080 (6980-7190)
CASC 117+110: 7580 (7470-7690)
8050 (7900-8200)
4780 (4600-4970)
6020 (5850-6220)
CASC 57: 6820 (6670-6990)
CASC 181+134: 6560 (6450-6700)
CASC 182+135: 7150 (7030-7270)
CASC 136: 7640 (7510-7770)
CASC 137: 8250 (8140-8350)
4730 (4570-4900)
HRW-09: 5160 (5080-5310)
5180 (5010-5380)
HRW-10: 5320 (5200-5430)
HRW-13: 5680 (5560-5810)
5930 (5800-6060)
HRW-11: 7250 (7160-7330)
HRW-12: 8670 (8490-8840)
CASC 31+167: 4850 (4710-4960)
5060 (4890-5260)
CASC 147+69: 5230 (5090-5370)
5400 (5250-5580)
5810 (5670-5950)
CASC 70: 7020 (6910-7150)
6000 (5870-6120)
6590 (6410-6770)
CASC 32: 7080 (6960-7240)
CASC 9: 7670 (7530-7820)
CASC 72: 8250 (8160-8360)
T10
T10a
T10b
T10c
T10f
T11
T12
T12?
T13
T14
T14?
T15



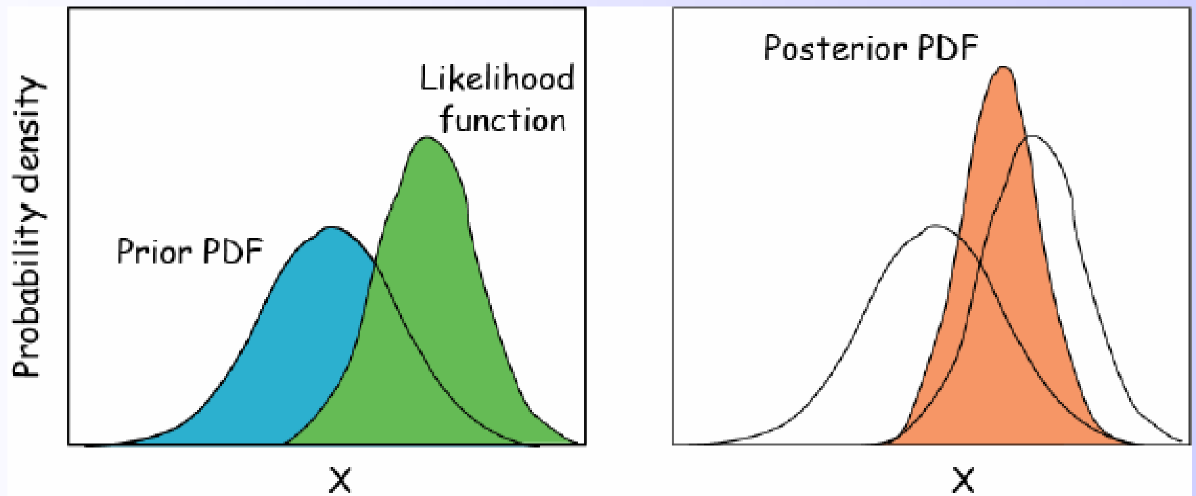
A. T5-T10
Rogue Channel
Cascadia Channel
RR0207-55KC
M9907-22PC
B. T9-T15
Hydrate Ridge
Rogue Channel
RR0207-56PC
M9907-31 PC
C. T11-T20
Rogue Channel
Juan de Fuca Channel
M9907-31 PC
M9907-12PC
F.
E.
D.
slurp effect
D.
E.
F.
T9 Cascadia Ch.
T9 Juan de Fuca Ch.
T7 Cascadia Ch.
T7 Juan de Fuca Ch.
T6 Cascadia Ch.
T6 Juan de Fuca Ch.

Now we'll develop the Bayesian model to assess the tests for turbidite correlation. We'll use the Washington margin as our example

But first…. A Short Time-Out for Statistics!

Bayes' theorem

All information is expressed in terms of probability density functions



Bayes' rule (1763)

Conditional PDFs

Assumptions

$$p(\boldsymbol{m}|\boldsymbol{d}, I) \propto p(\boldsymbol{d}|\boldsymbol{m}, I) \times p(\boldsymbol{m}|I)$$

data

model parameters

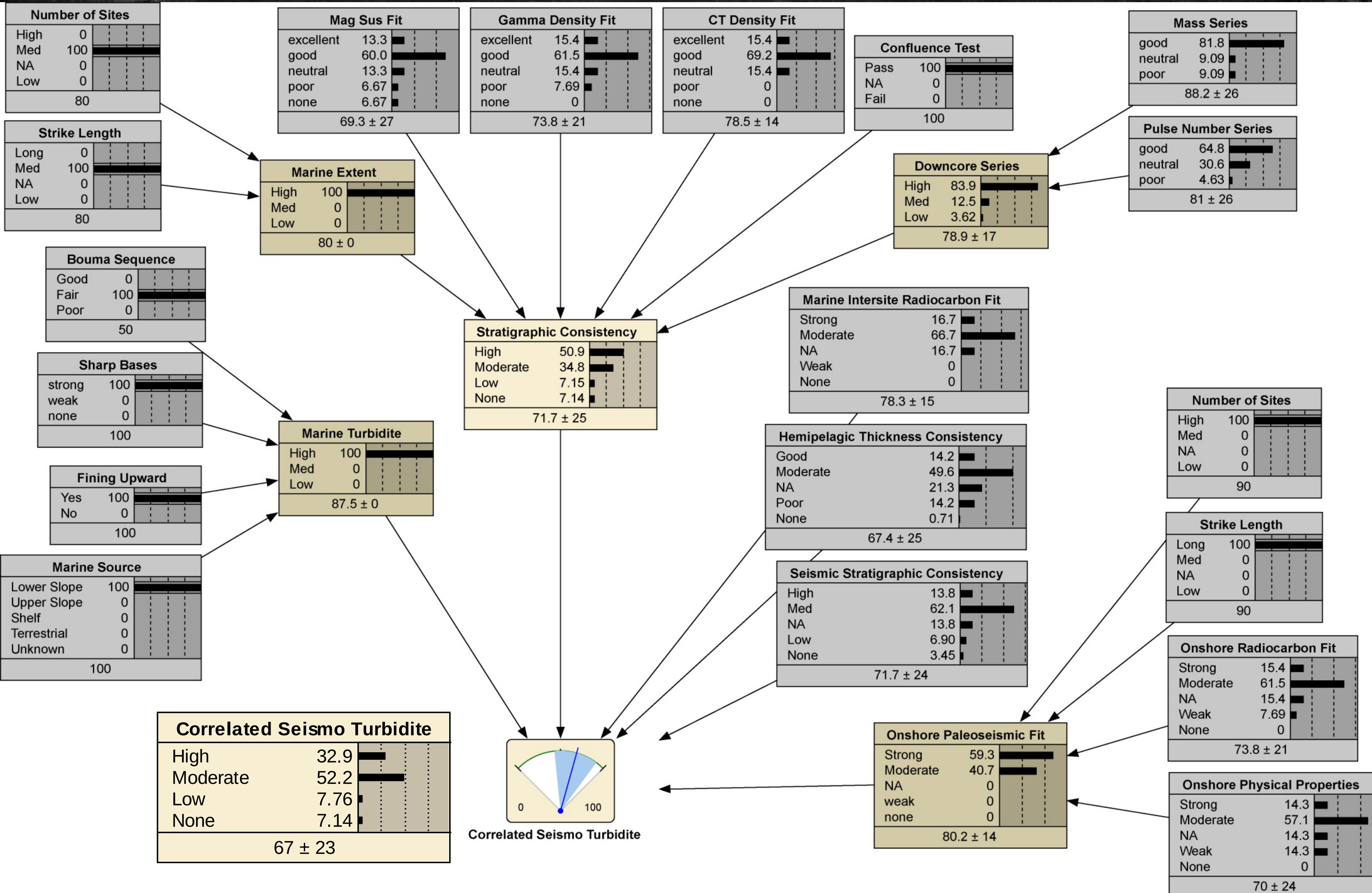
1702-1761

Posterior probability density $\propto$ Likelihood x Prior probability density

What is known after the data are collected

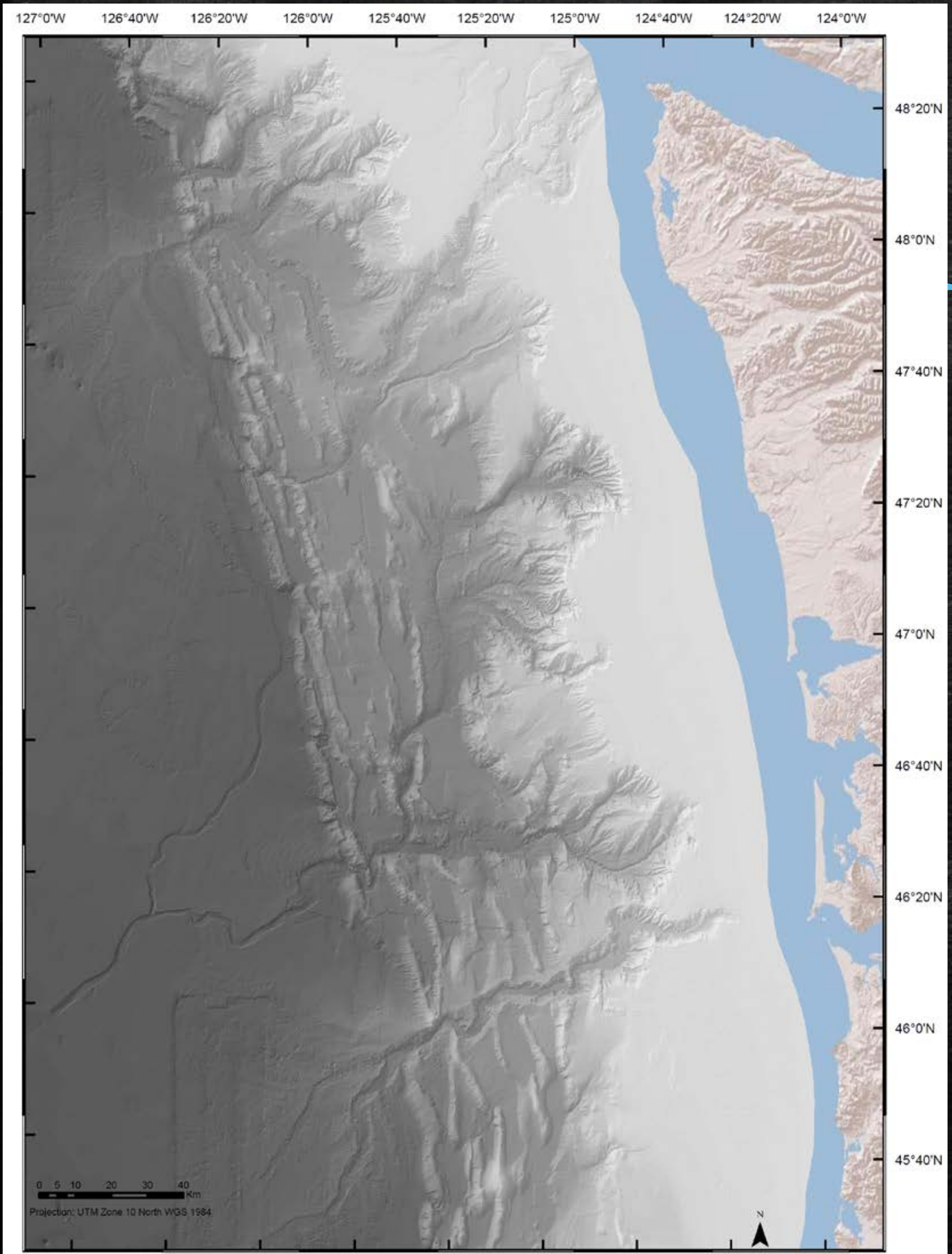
Measuring fit to data

What is known before the data are collected



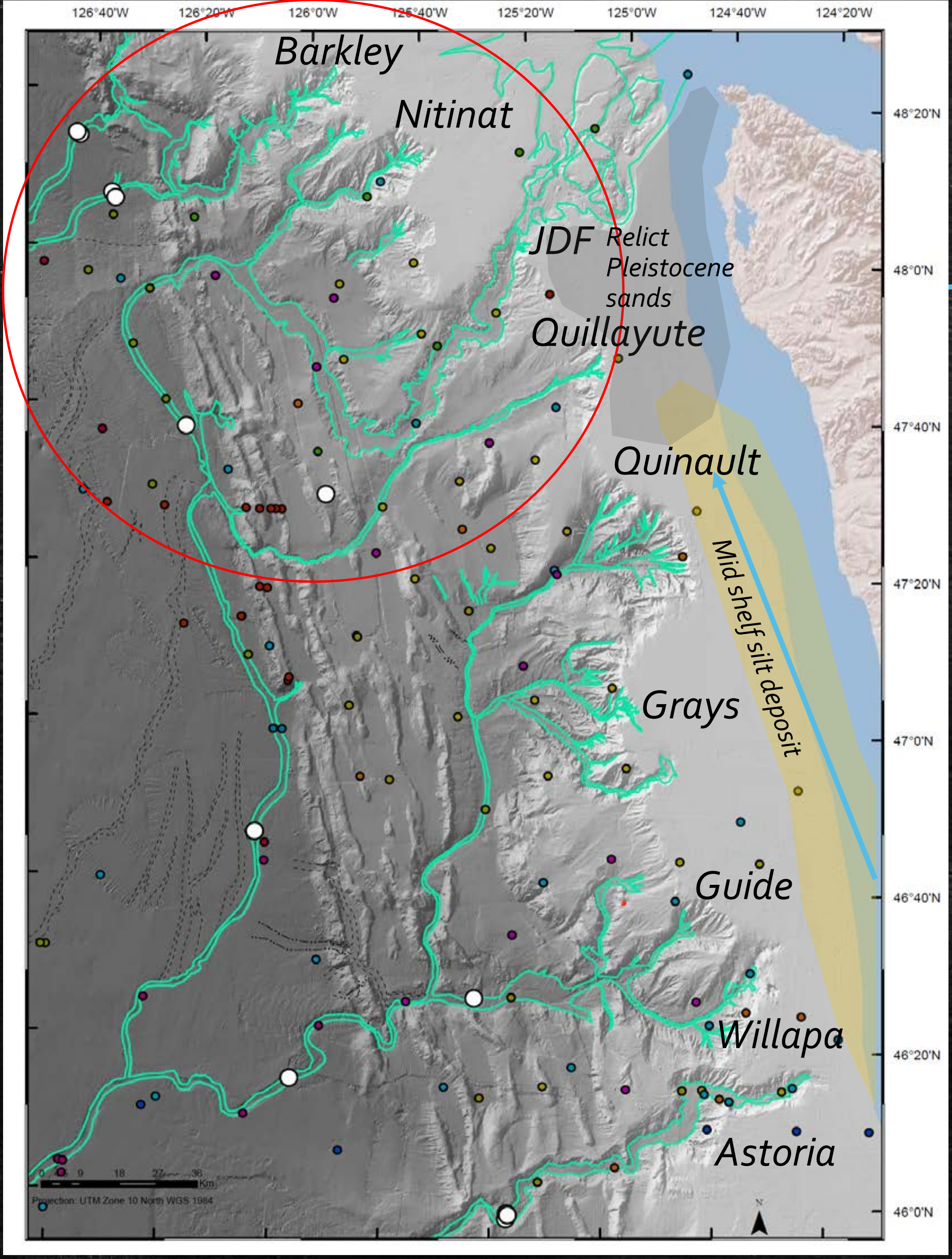
Bayesian Probabilities of earthquake origin under uncertainty

Every model follows the same rule: garbage in, garbage out.   So we'll spend most of the talk looking at the depositional details and the data…



Northern Cascadia

Nearly complete multibeam (various resolutions) now exists. OSU cruises 1992-2012 cover ~ 80% of the continental slope of Washington. Other sources cover major portions of the southern Canadian slope.

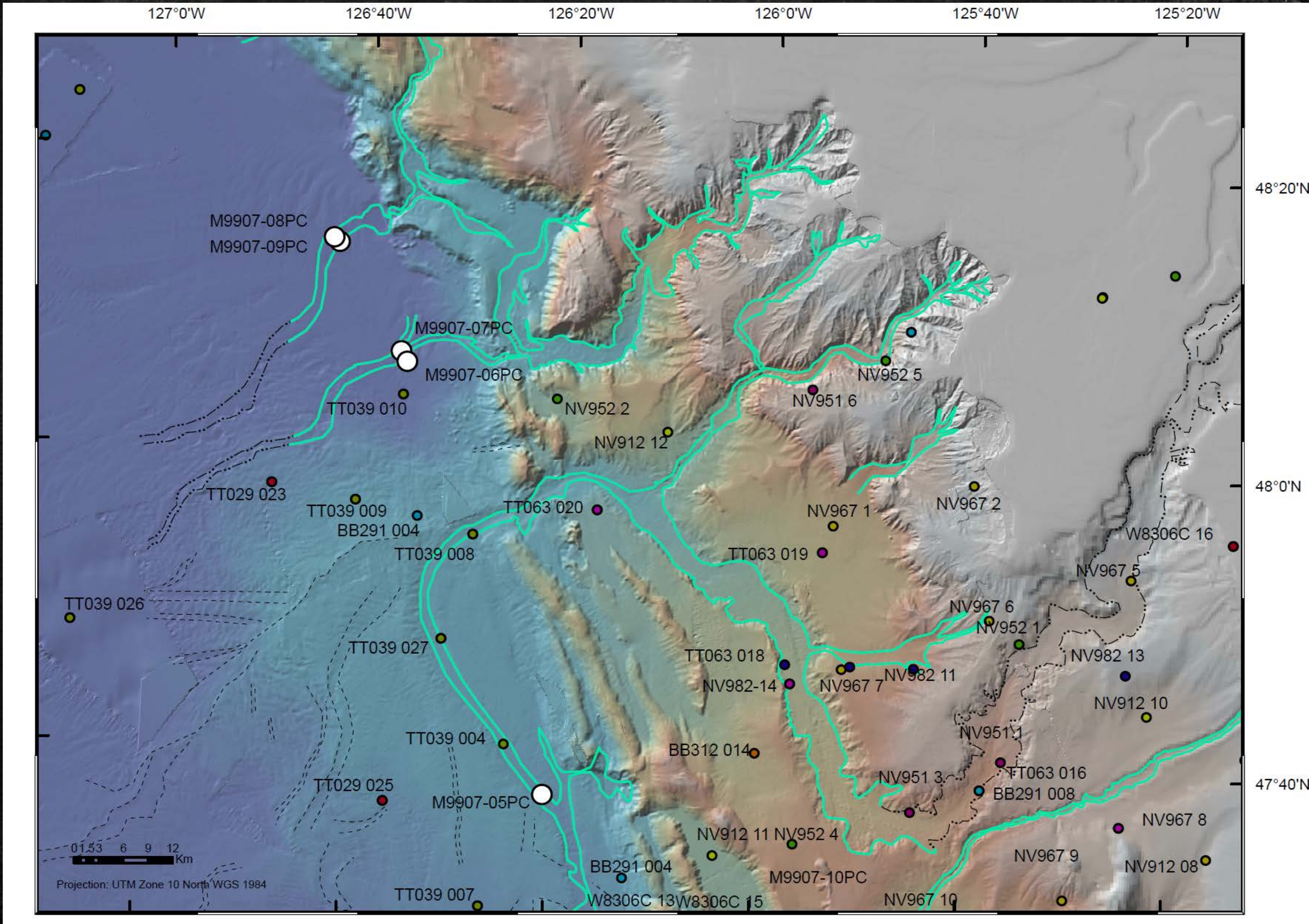


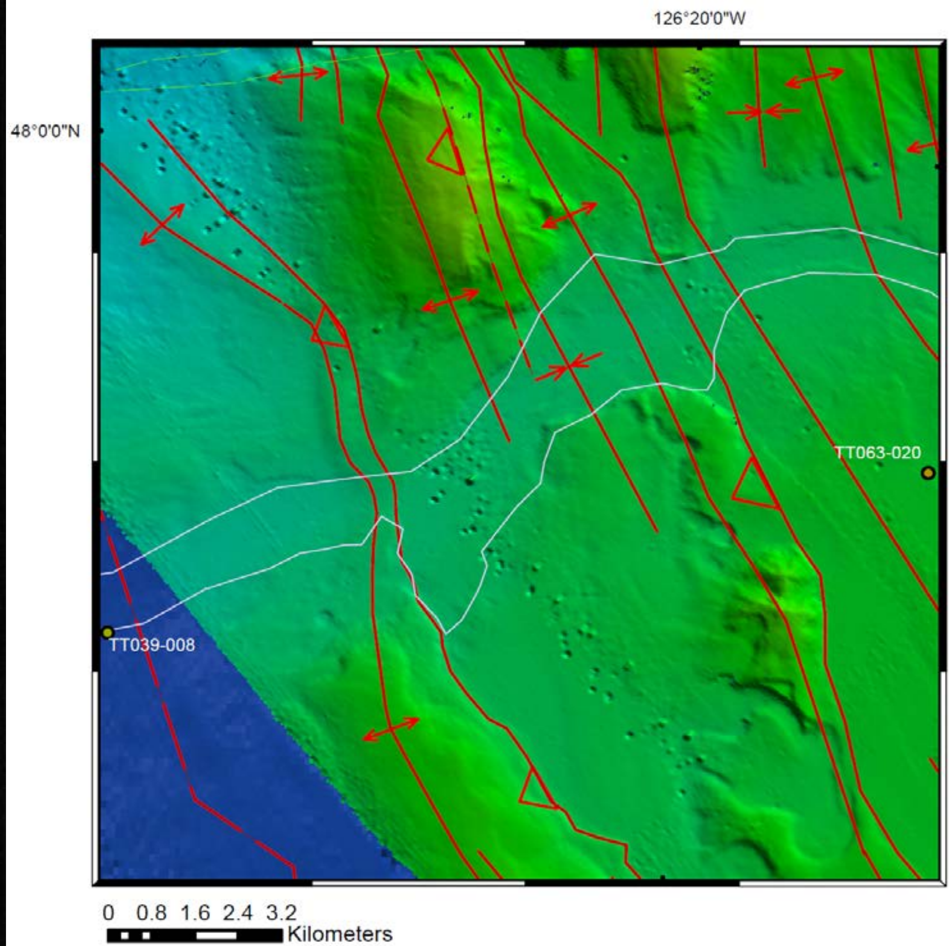
Northern Cascadia

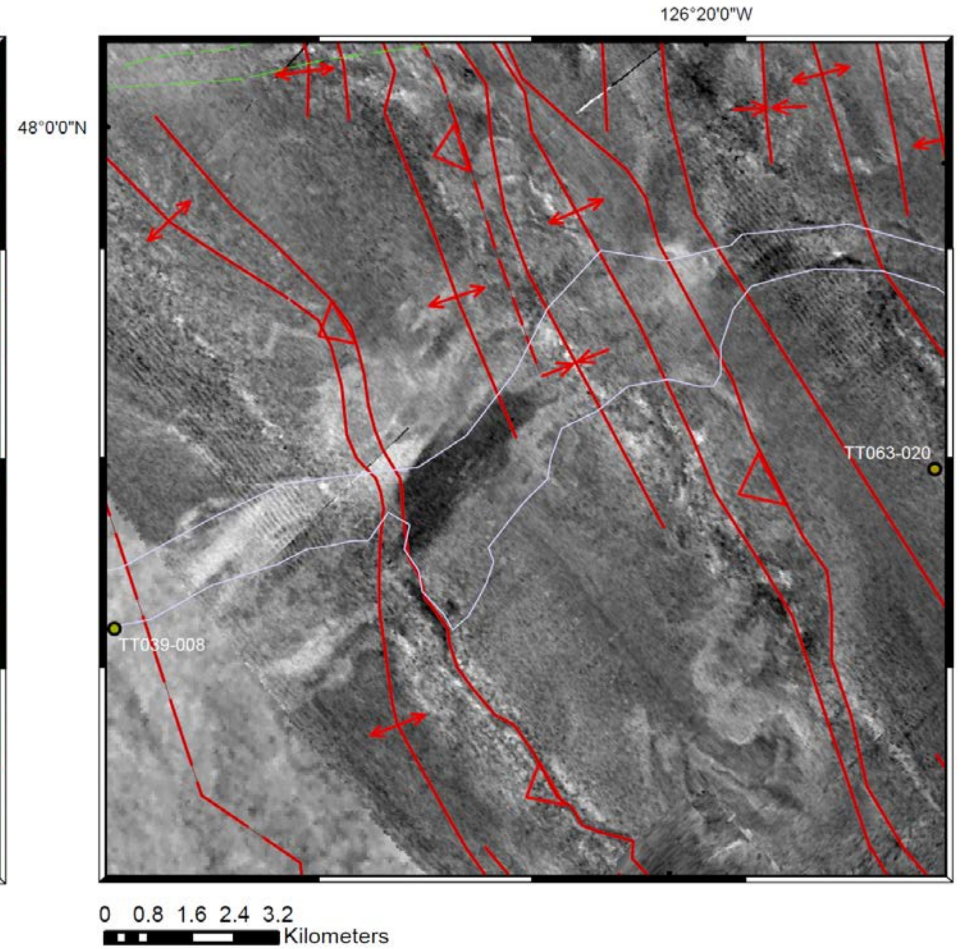
Let's examine some of the complexities in the Cascadia system, and how they can be used to advantage, (or not!)

All existing cores are shown, our primary cores (Professional Paper 1661-F) in white.

All of these systems are more or less relict since the late deglacial/early Holocene.

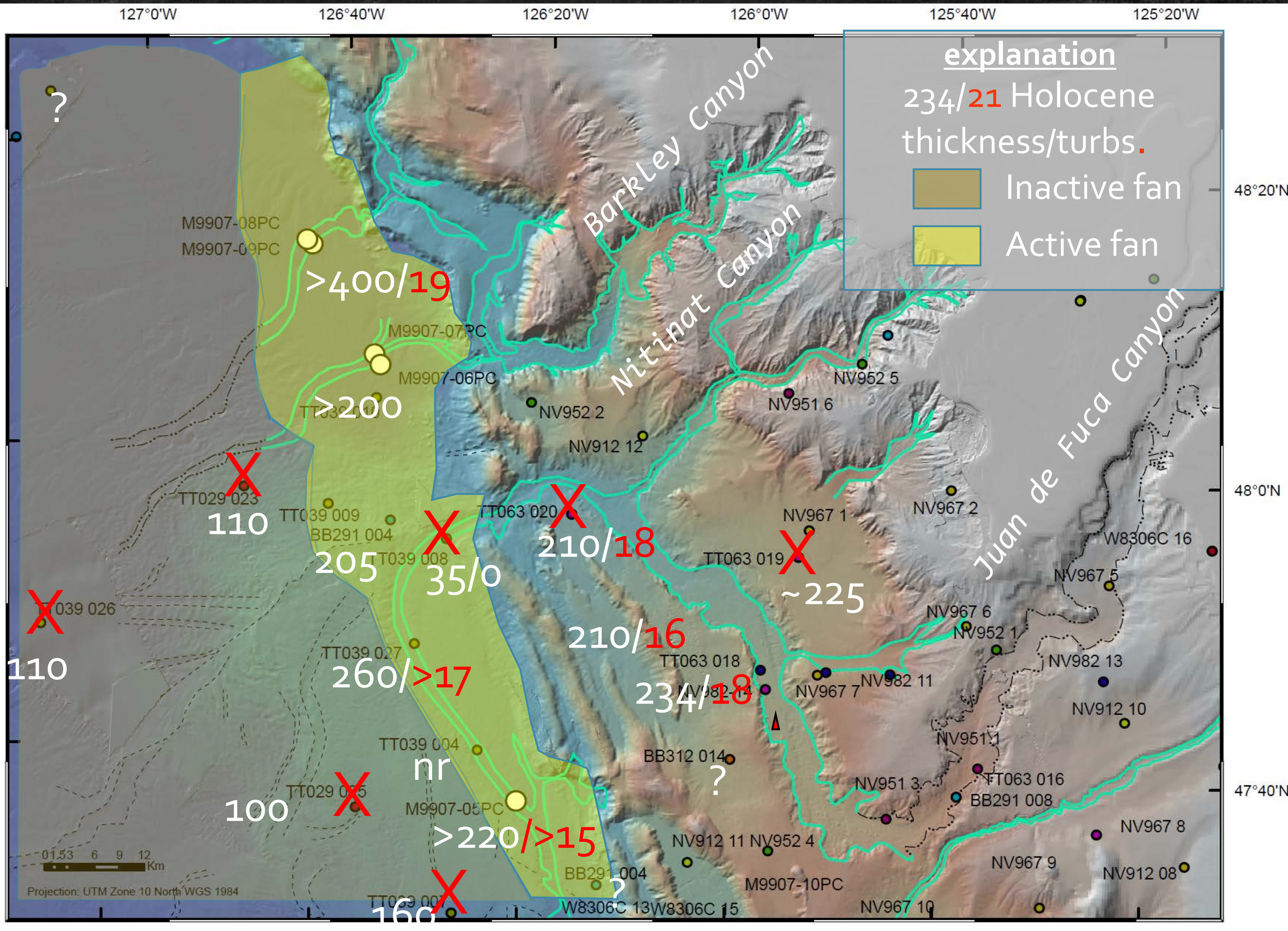

127°0'W
126°40'W
126°20'W
126°0'W
125°40'W
125°20'W
48°20'N
48°0'N
47°40'N
M9907-08PC
M9907-09PC
M9907-07PC
M9907-06PC
TT039 010
NV952 2
NV912 12
NV952 5
NV951 6
TT029 023
TT039 009
BB291 004
TT039 008
TT063 020
NV967 1
NV967 2
TT063 019
W8306C 16
NV967 5
TT039 026
NV967 6
NV952 1
TT039 027
TT063 018
NV982-14
NV967 7
NV982 11
NV982 13
NV912 10
TT039 004
BB312 014
NV951 1
TT063 016
TT029 025
M9907-05PC
NV951 3
BB291 008
NV912 11
NV952 4
NV967 8
NV967 9
NV912 08
BB291 004
M9907-10PC
TT039 007
W8306C 13
W8306C 15
NV967 10
0 1.5 3 6 9 12 Km
Projection: UTM Zone 10 North WGS 1984



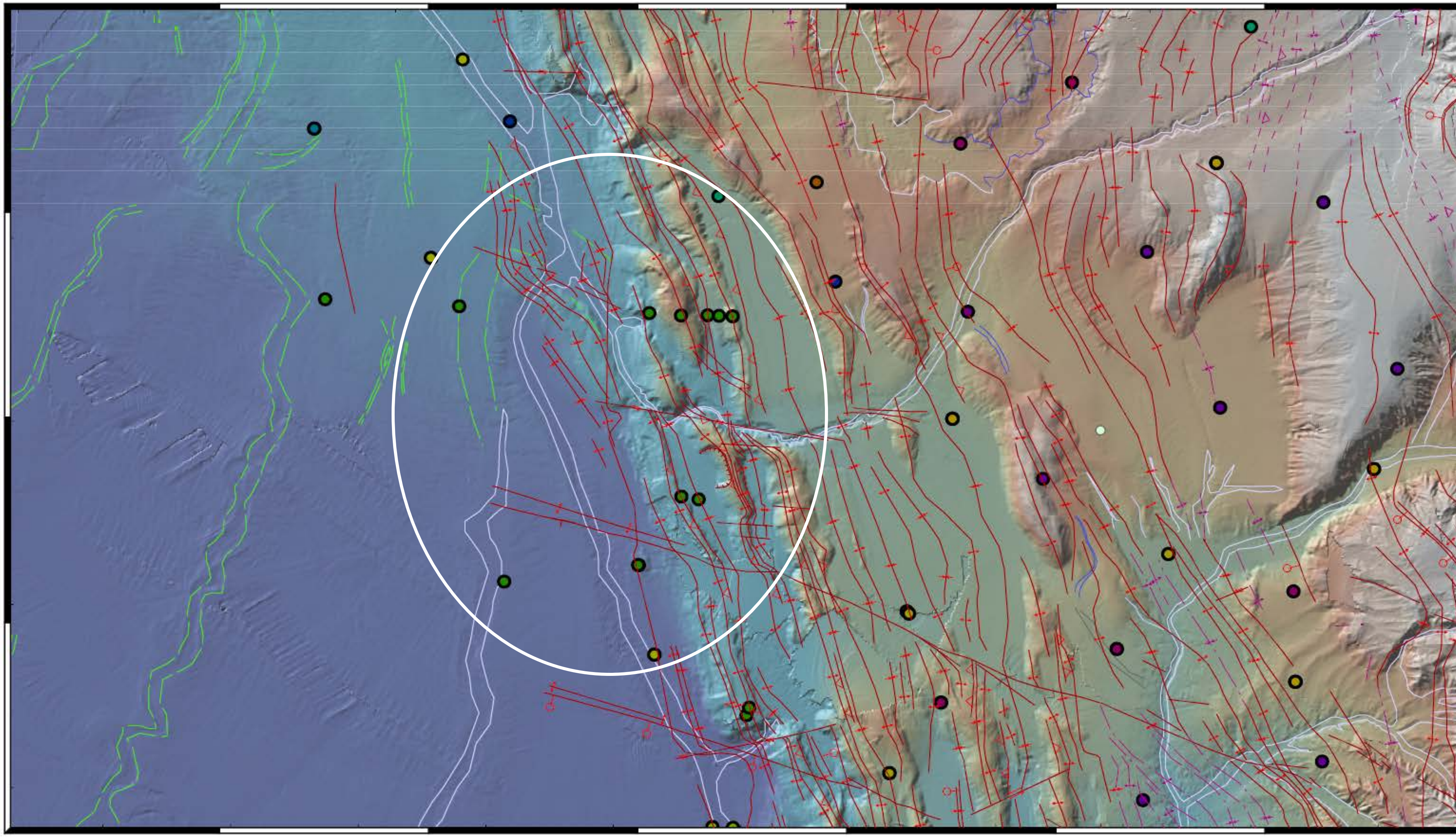


Partial blockage and Holocene turbidity current response, frontal thrust, JDF outlet, Nitinat Fan Apex.

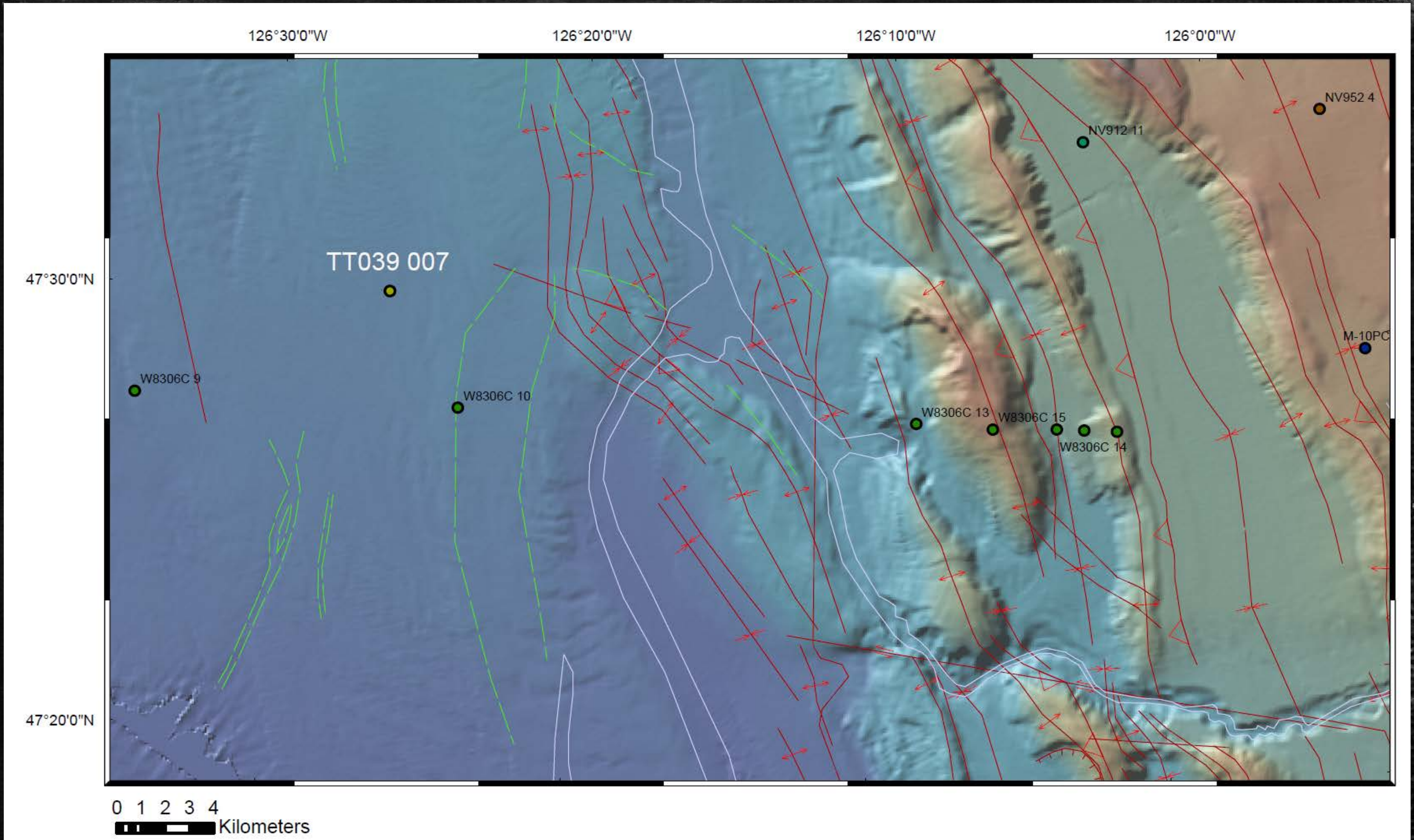
Visible in the backscatter are the fine grained pool behind the landward vergent thrust fault blockage, crevasse-splay spillover to the north, and sand tongue continuing down JDF Channel.



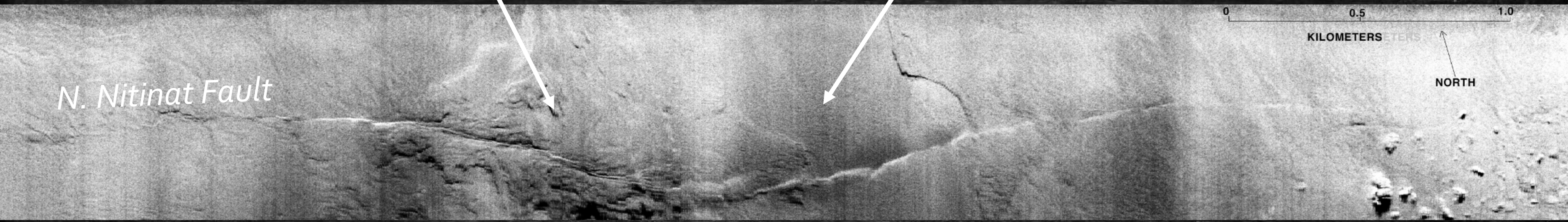
127°0'W
126°40'W
126°20'W
126°0'W
125°40'W
125°20'W
48°20'N
48°0'N
47°40'N
explanation
234/21 Holocene thickness/turbs.
Inactive fan
Active fan
Barkley Canyon
Nitinat Canyon
Juan de Fuca Canyon
M9907-08PC
M9907-09PC
>400/19
M9907-07PC
M9907-06PC
>200
NV952 2
NV912 12
NV952 5
NV951 6
TT029 023
110
TT039 009
BB291 004
205
TT039 008
35/0
TT063 020
210/18
TT063 019
~225
NV967 1
NV967 2
W8306C 16
NV967 5
NV967 6
NV952 1
TT039 026
110
TT039 027
260/>17
210/16
TT063 018
234/18
NV967 7
NV982 11
NV982 13
NV912 10
NV951 1
TT039 004
nr
BB312 014
?
TT029 025
100
M9907-05PC
>220/>15
NV951 3
TT063 016
BB291 008
NV967 8
NV912 11
NV952 4
NV967 9
NV912 08
BB291 004
M9907-10PC
W8306C 13
W8306C 15
NV967 10
160
?
Km
Projection: UTM Zone 10 North WGS 1984



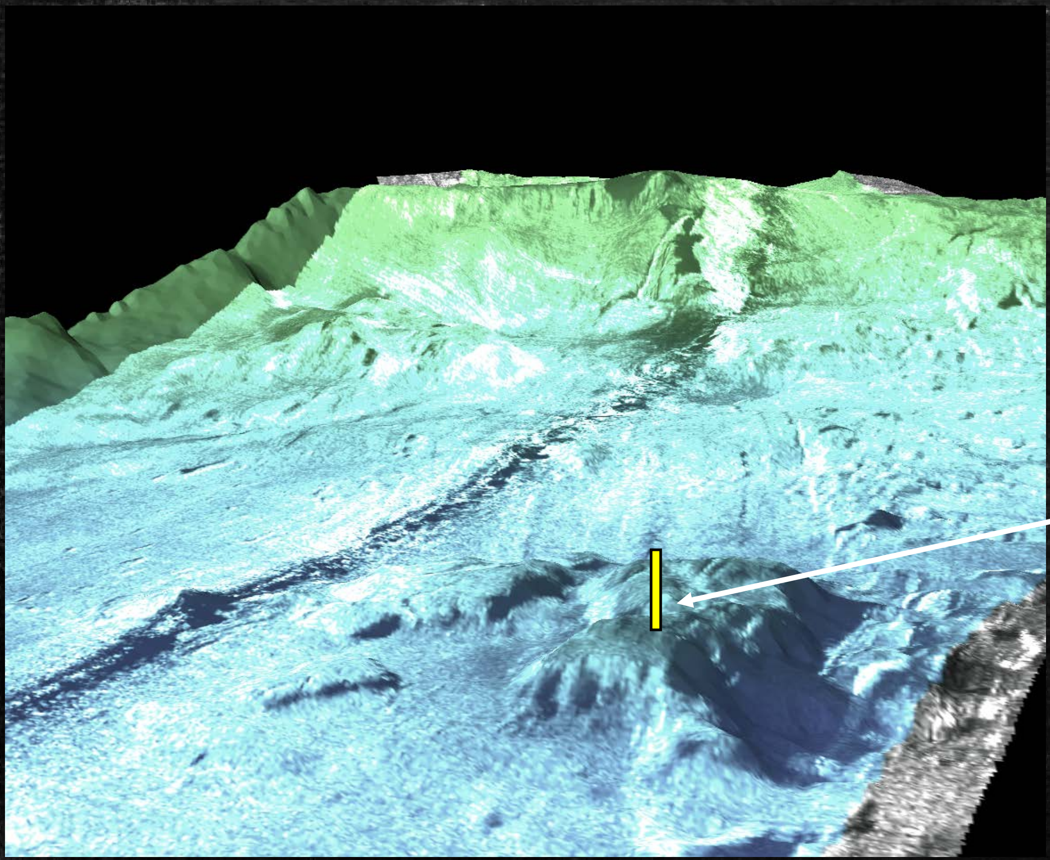
Central WA margin: Quillayute confluence, landslides and fault intersections



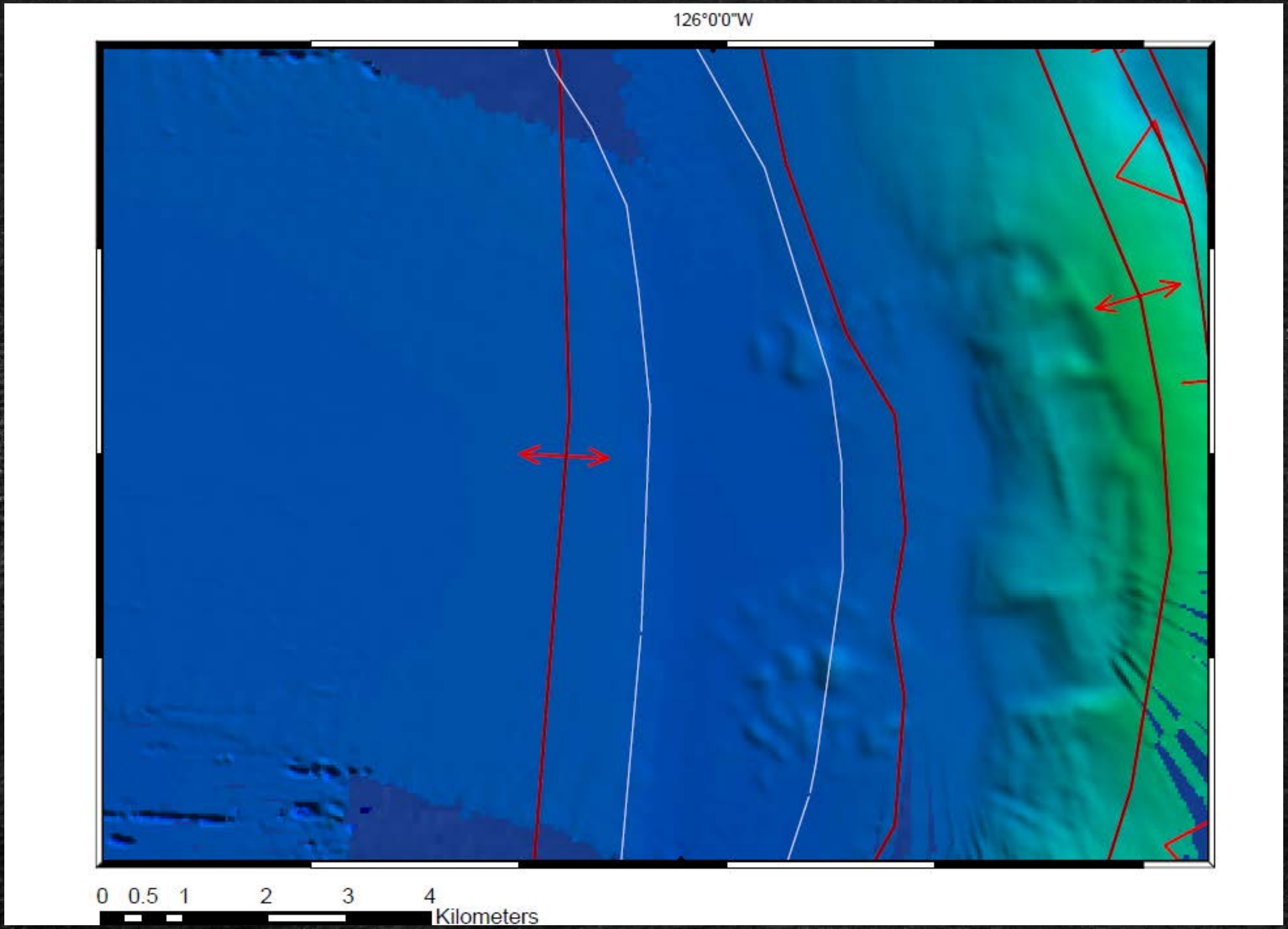
Looking closer, we see a very complex intersection with the frontal landward vergent thrust, partial blockage of Quillayute Canyon and the JDF Channel.



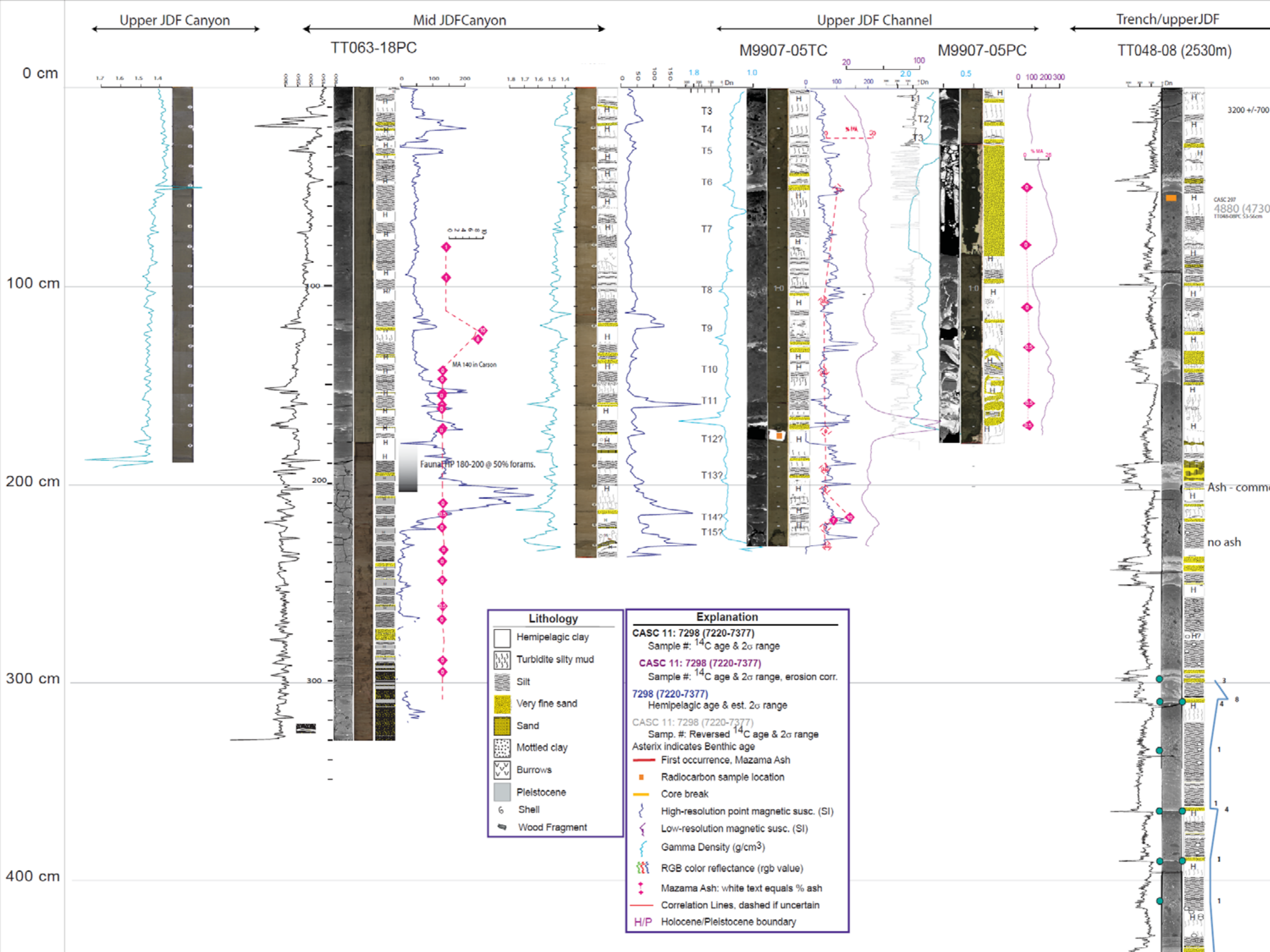
North Nitinat Fault. SeaMARC 1A image shows fault, mud volcano, and channel deflection



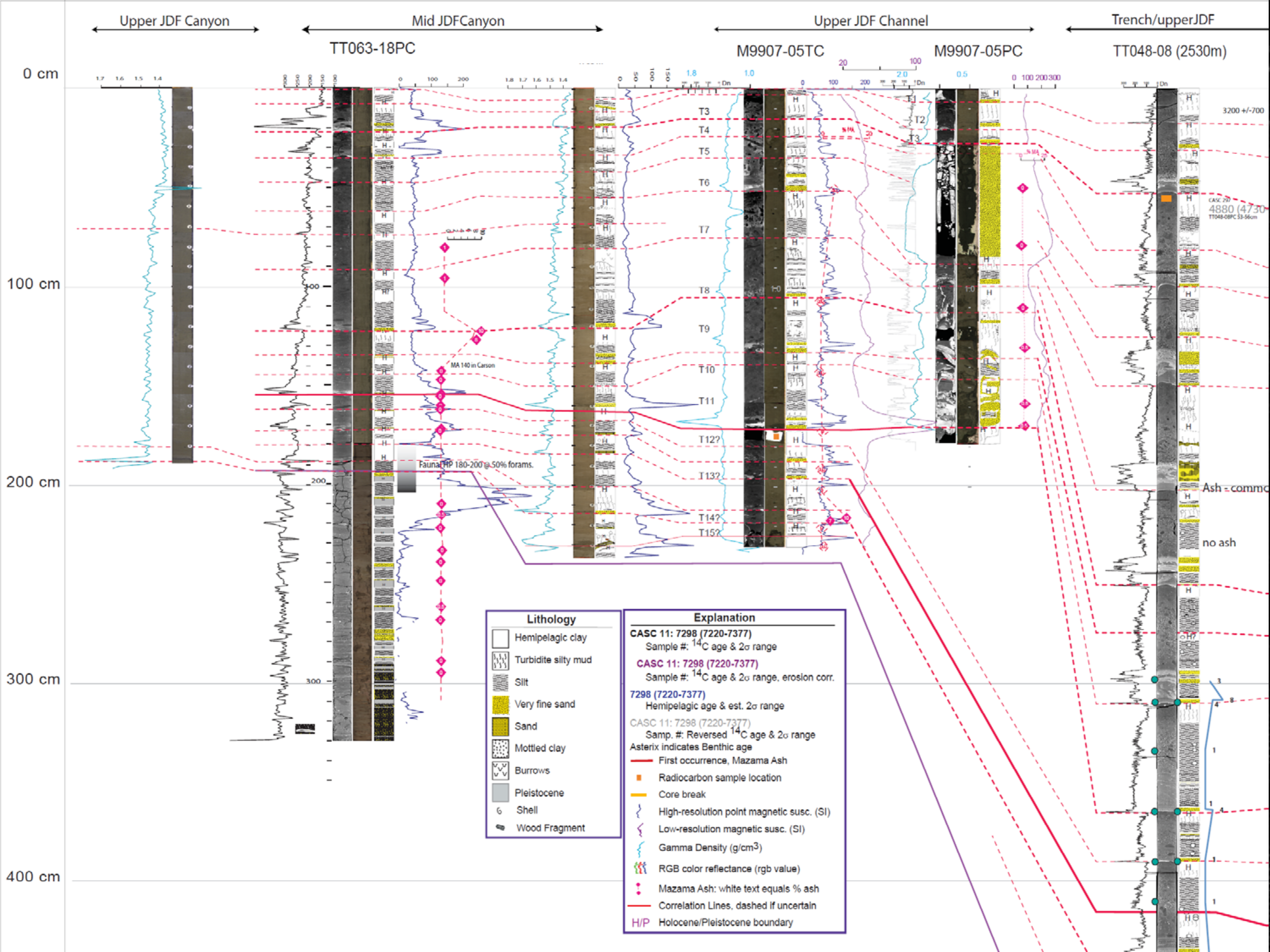
Core W8306c-02. Hemipelagic sediment overlying this slide block (just 1 km south of the upper image) suggests age is ~ 2000 BP



And further south, two more landslides are in JDF channel. Just downstream, our primary JDF core (M9907-12PC has a relatively thin Holocene section less than 3 m.



Upper JDF Canyon
Mid JDFCanyon
Upper JDF Channel
Trench/upperJDF
TT063-18PC
M9907-05TC
M9907-05PC
TT048-08 (2530m)
0 cm
100 cm
200 cm
300 cm
400 cm
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12?
T13?
T14?
T15?
T1
T2
MA 140 in Carson
Fauna HP 180-200 @ 50% forams.
3200 +/-700
4880 (4730
Ash - comm
no ash
Lithology
Hemipelagic clay
Turbidite silty mud
Silt
Very fine sand
Sand
Mottled clay
Burrows
Pleistocene
Shell
Wood Fragment
Explanation
CASC 11: 7298 (7220-7377)
Sample #: 14C age & 2σ range
CASC 11: 7298 (7220-7377)
Sample #: 14C age & 2σ range, erosion corr.
7298 (7220-7377)
Hemipelagic age & est. 2σ range
CASC 11: 7298 (7220-7377)
Samp. #: Reversed 14C age & 2σ range
Asterix indicates Benthic age
First occurrence, Mazama Ash
Radiocarbon sample location
Core break
High-resolution point magnetic susc. (SI)
Low-resolution magnetic susc. (SI)
Gamma Density (g/cm3)
RGB color reflectance (rgb value)
Mazama Ash: white text equals % ash
Correlation Lines, dashed if uncertain
H/P Holocene/Pleistocene boundary


Upper JDF Canyon
Mid JDFCanyon
Upper JDF Channel
Trench/upperJDF
TT063-18PC
M9907-05TC
M9907-05PC
TT048-08 (2530m)
0 cm
100 cm
200 cm
300 cm
400 cm
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12?
T13?
T14?
T15?
T1
T2
T3
3200 +/-700
4880 (4730
MA 140 in Carson
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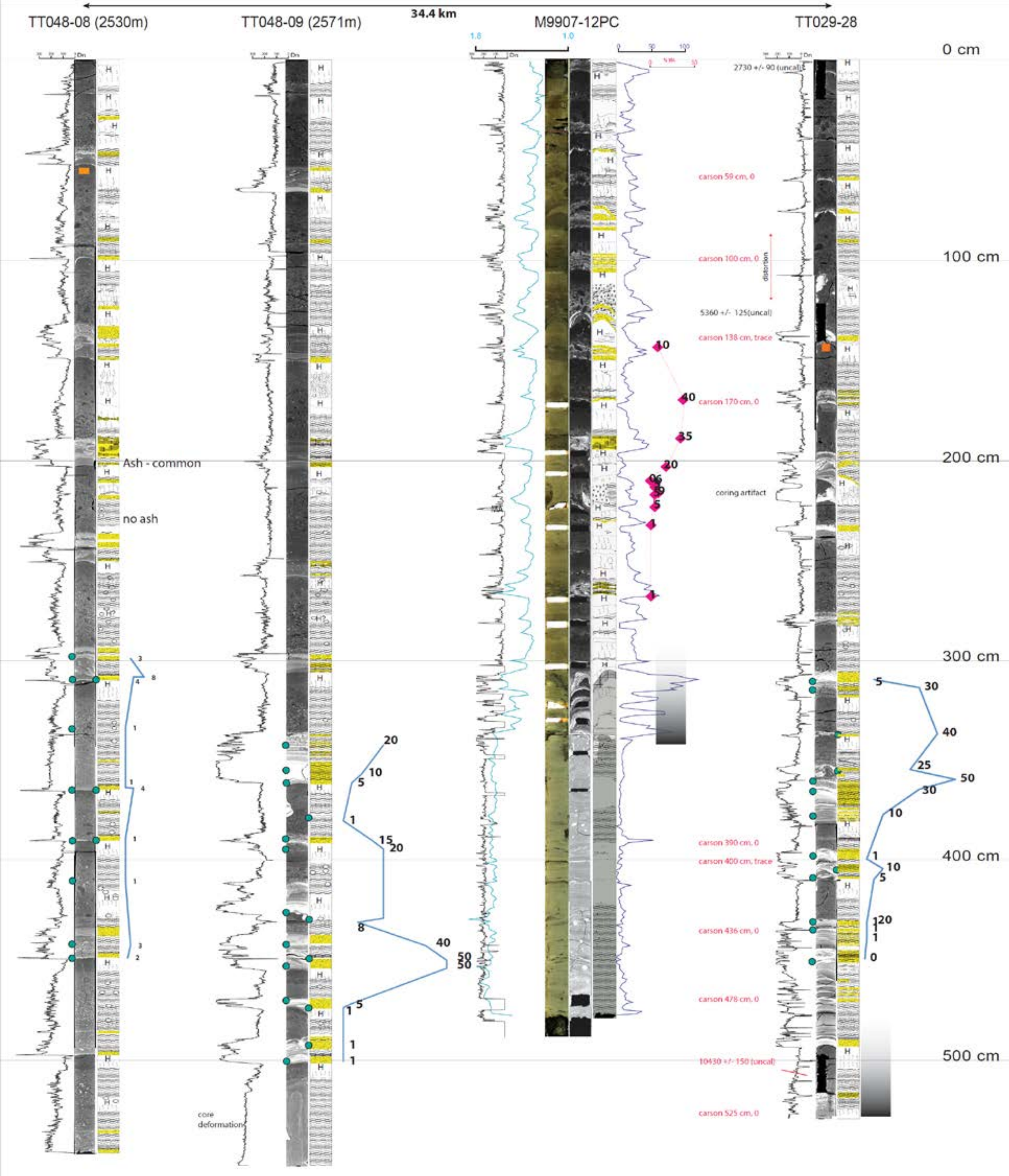
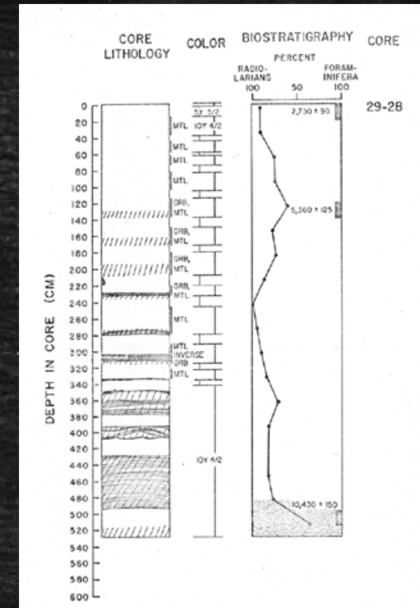
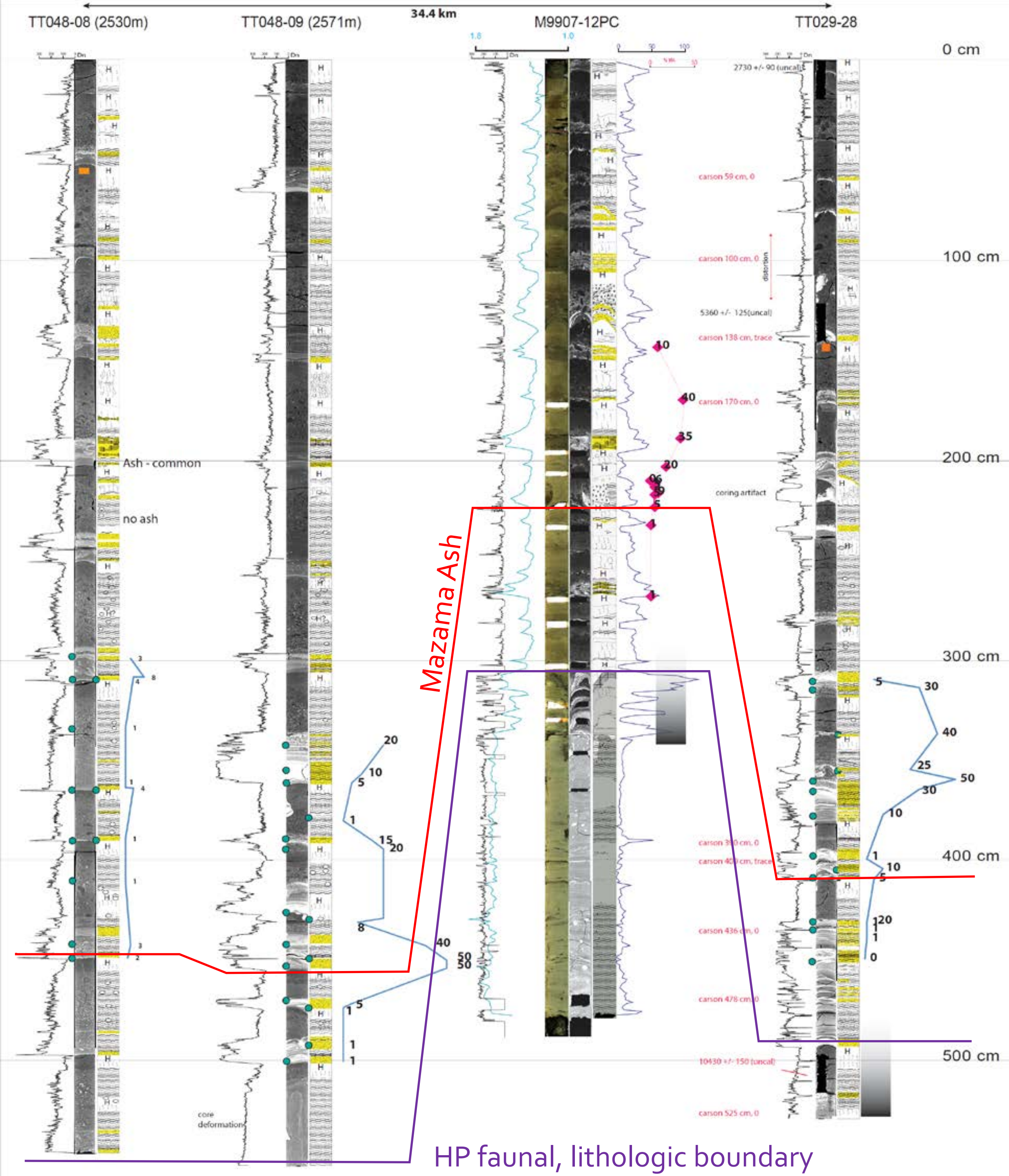




Carson (1971) used by Atwater shows 10 Holocene turbidites and no ash in 29-28. The actual count is 18 Holocene beds, and 14 above the prominent ash (S. Galers work).

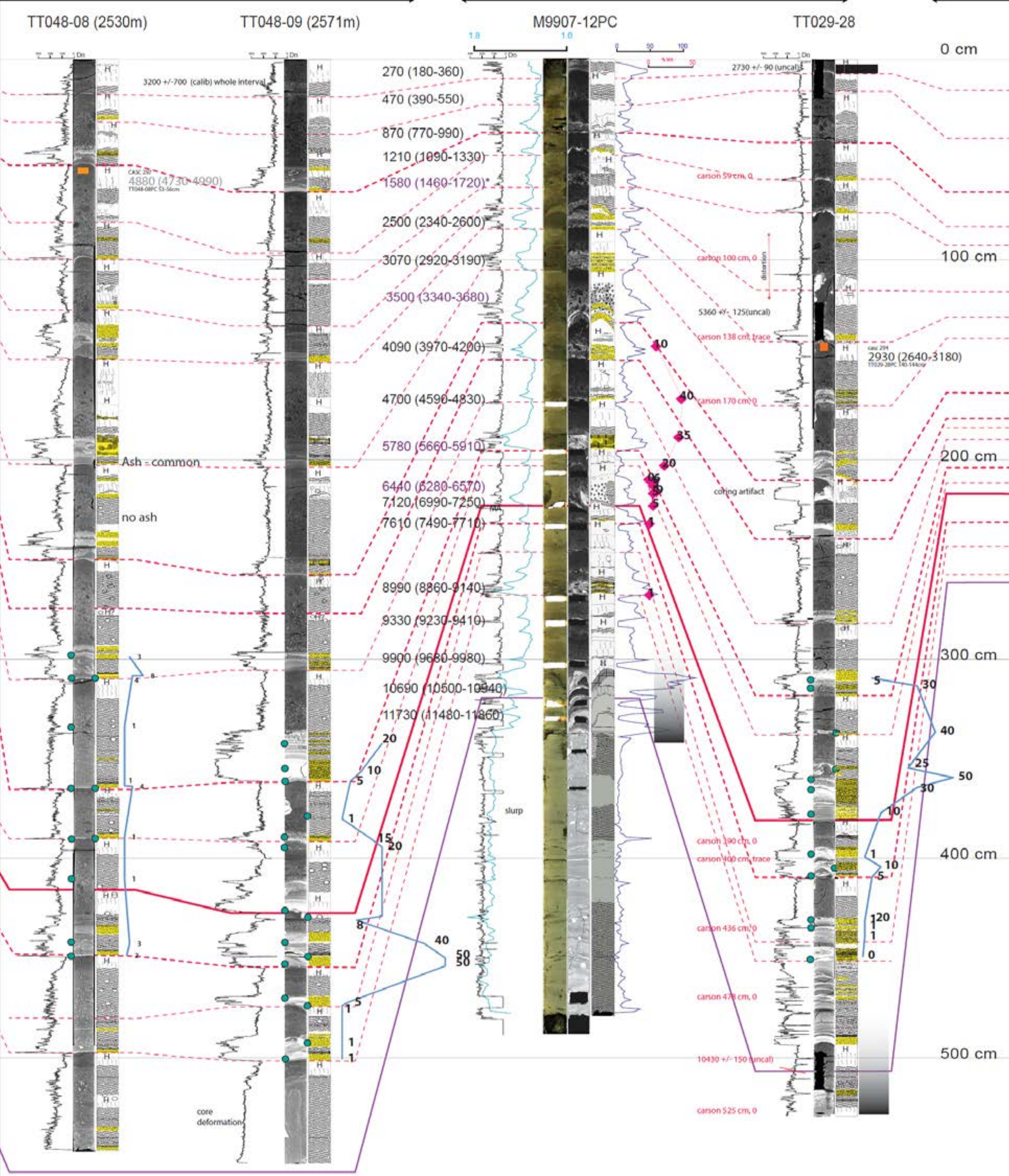
Similarly the old logs show 14 Holocene beds in TT048-08, and 13 in TT048-09 when the actual count is 17 Holocene and 15 above the ash.



Using CT data and more ash analysis from this project, we observe 18-19 Holocene beds in these cores, and 13-15 above the Mazama ash which is abundant in 3 and sparse in one core.

The difference with the old visual logs is due to using CT data. Visual logging is inadequate (unless beds are coarse grained).

Additionally, ash presence and abundance is very spotty and irregular. Note Carson (1971) missed the ash in TT29-28 altogether.



Provisional correlation using all constraints.

1) High variability in ash percent

2) Some cores have significant ash in event correlated to regional T14, suggesting airfall on the slope.

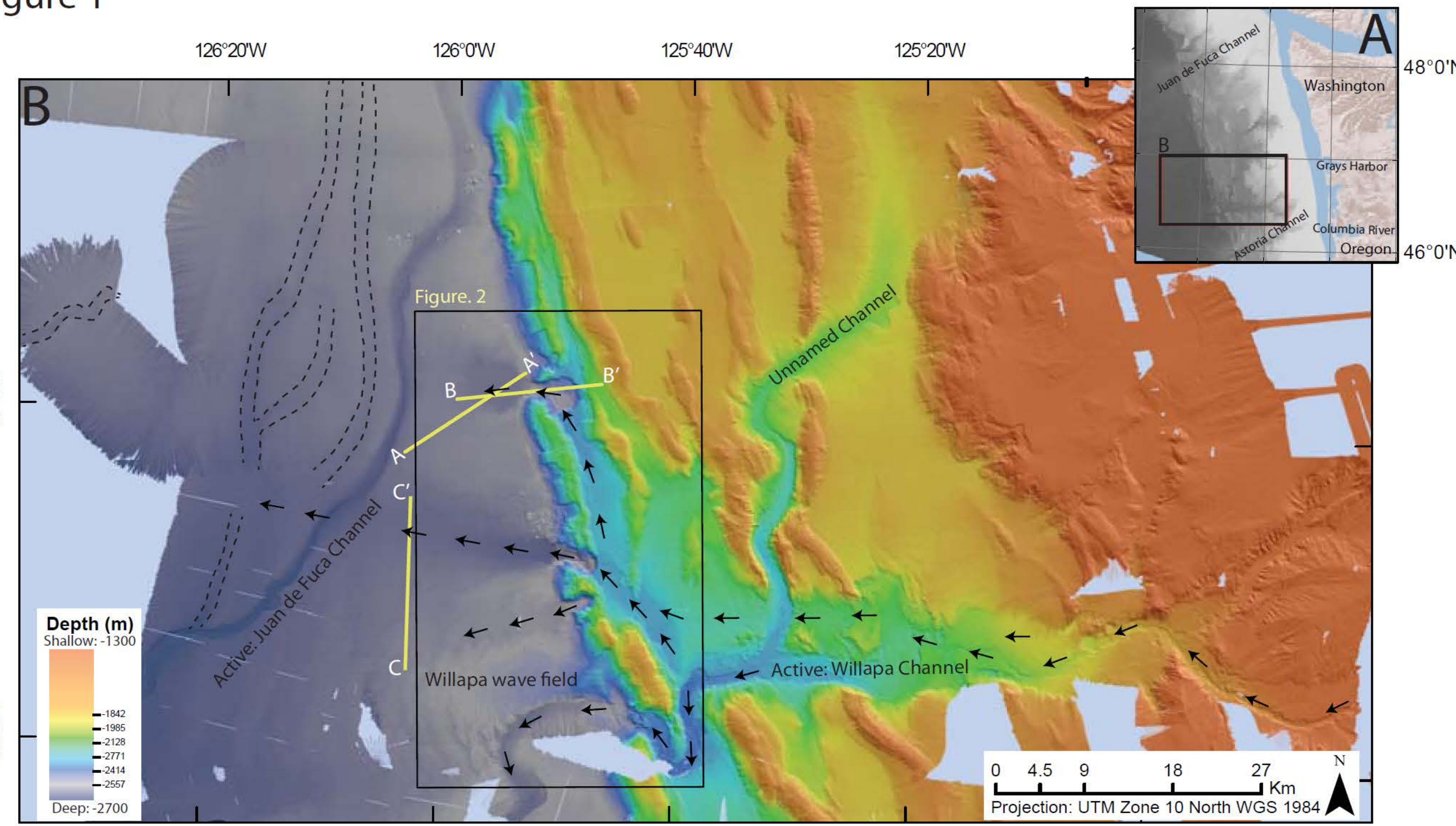
3) Virtually no variability seen in turbidite bed count.

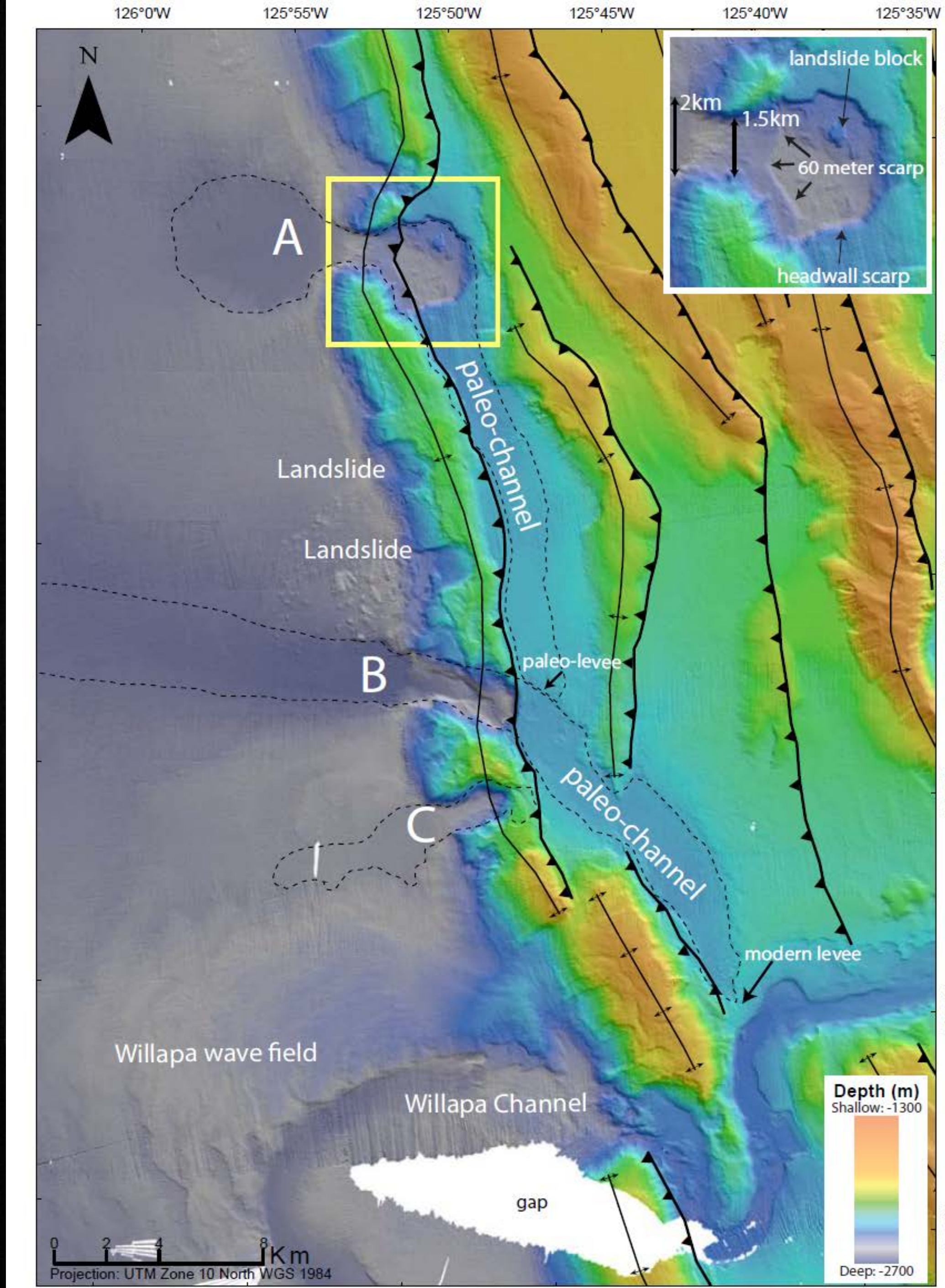
4) Lithostratigraphic correlation less effective in proximal environments

5) Proposed variability (Atwater) not in evidence.

These two paleochannels were mapped as inactive in 1999…

Figure 1

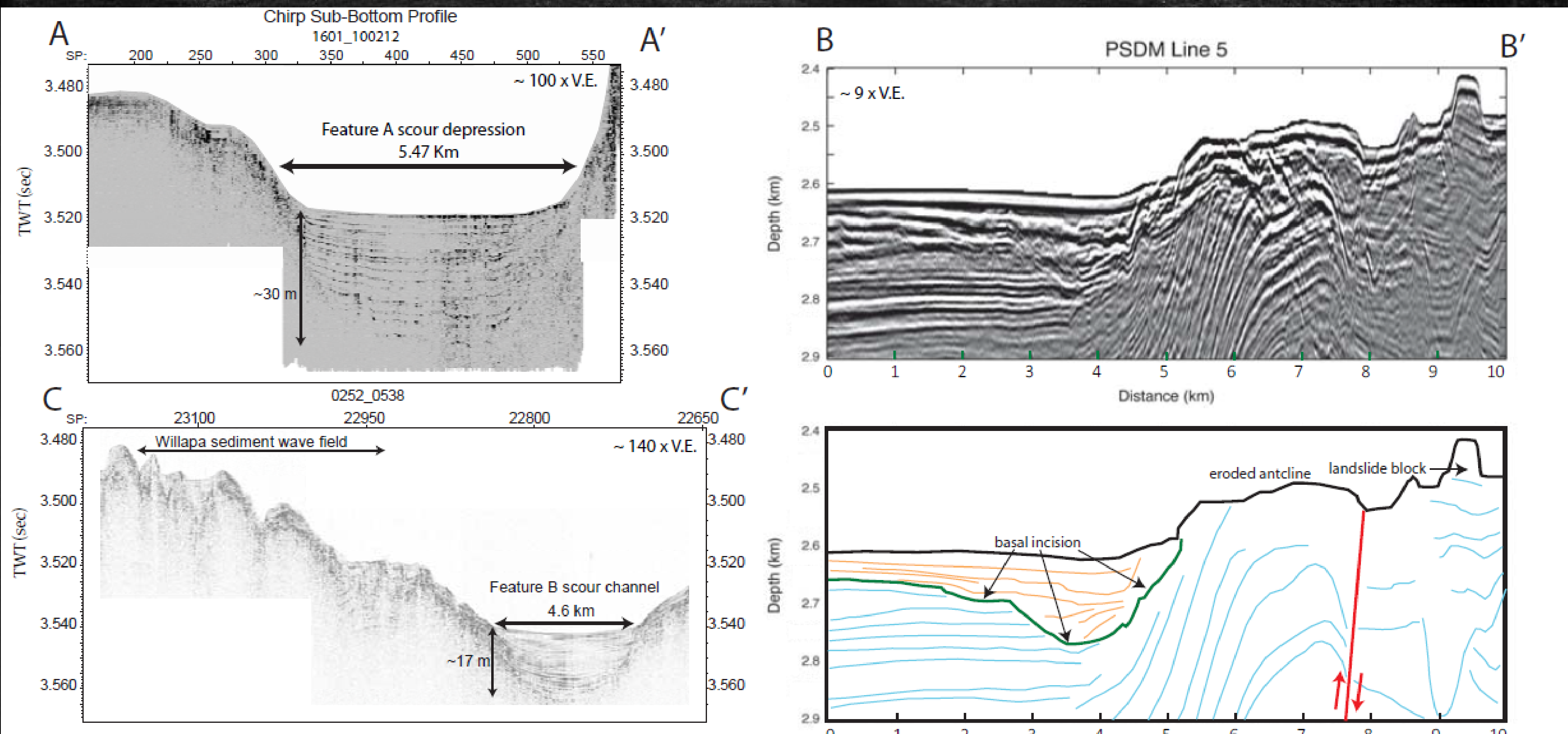


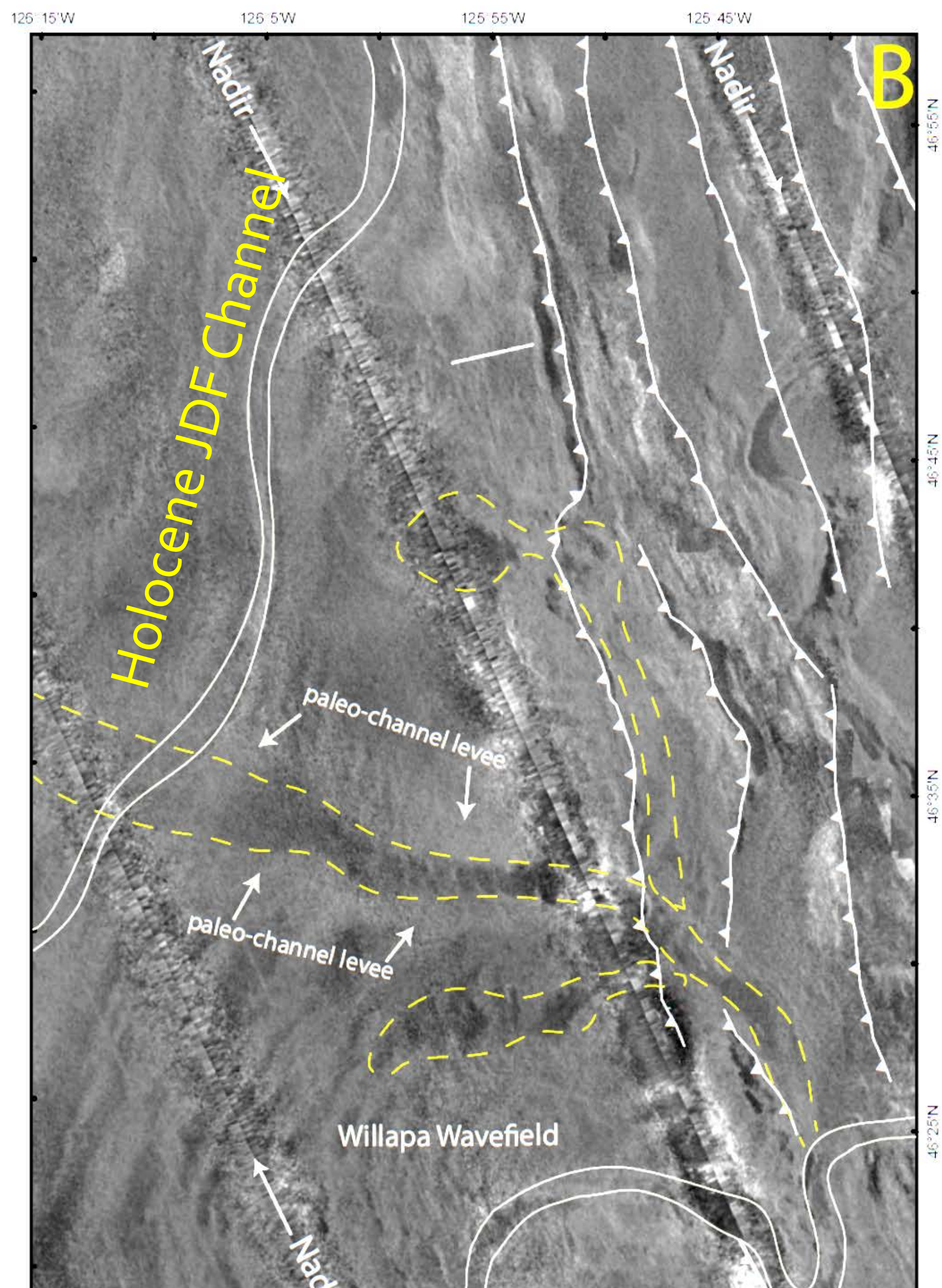


- The two features "A" and "B" extend westward across the fall line at nearly right angles, indicating a high flow regime

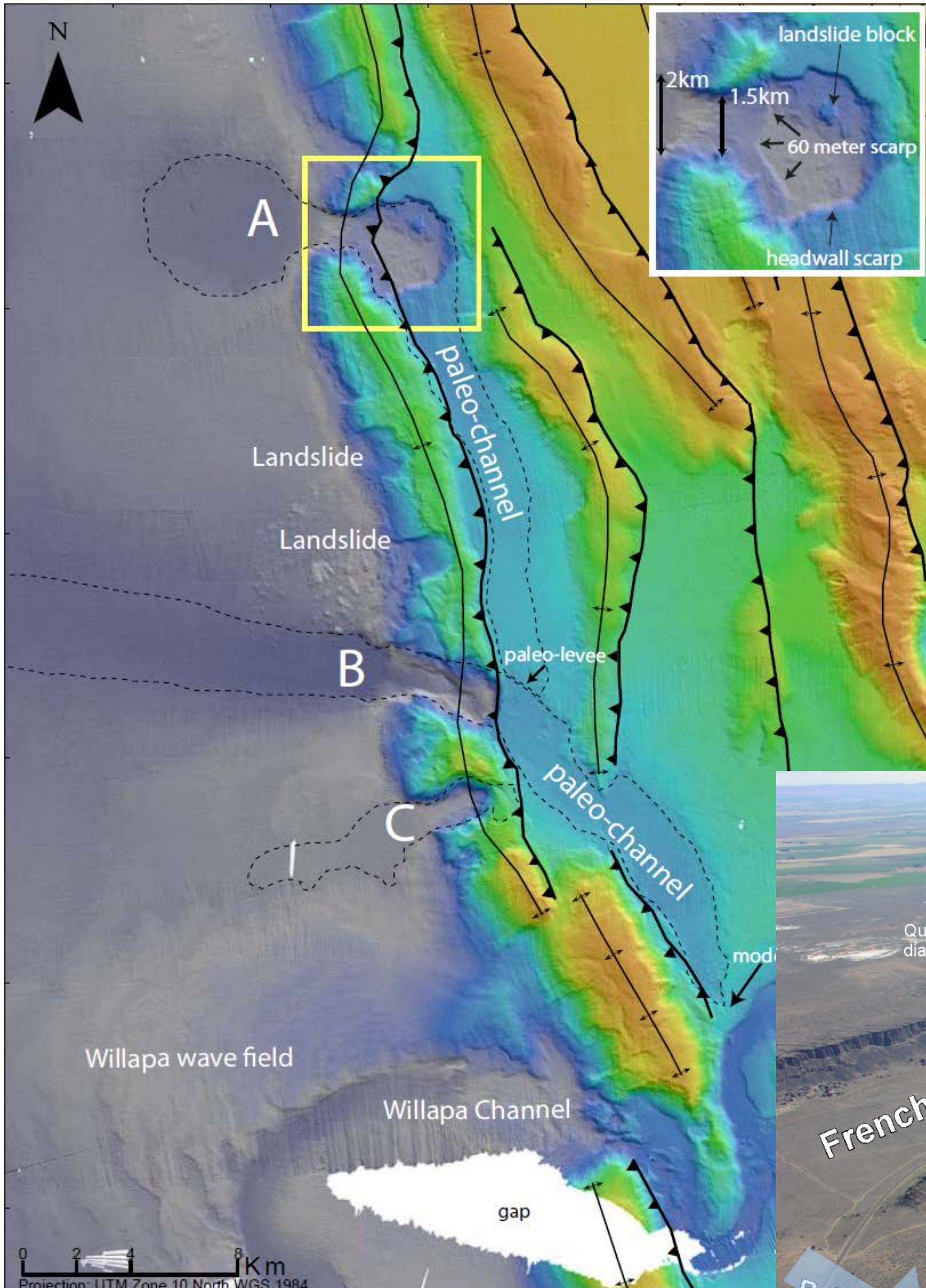
- J. Beeson et al 2013, in revision.

These features are not landslide related, they are incised into the abyssal plain, and have no landslide blocks. They most resemble plunge pools, but do not have the vertical drop required of plunge pools.

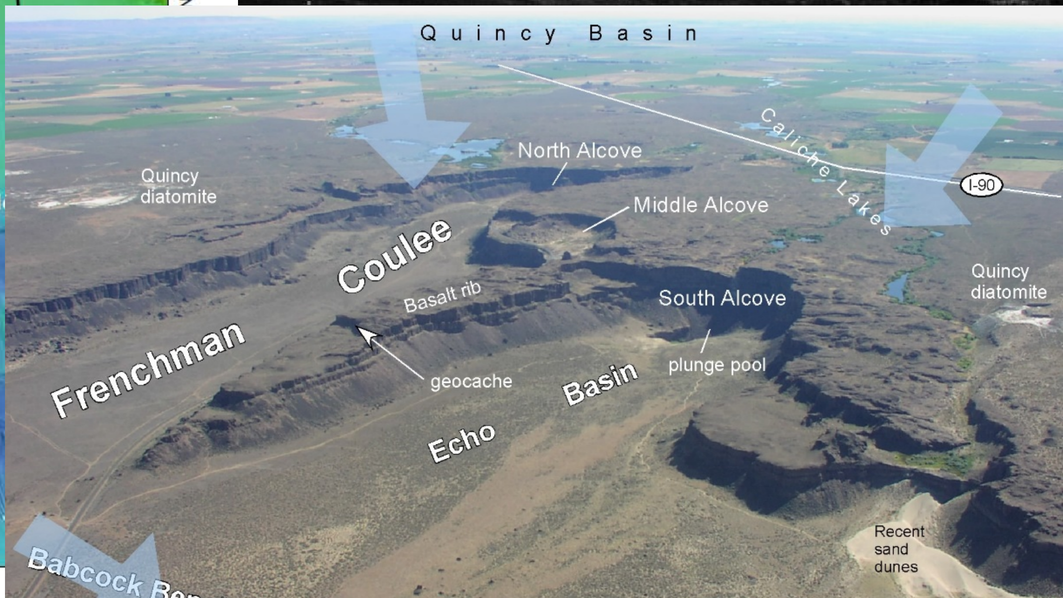




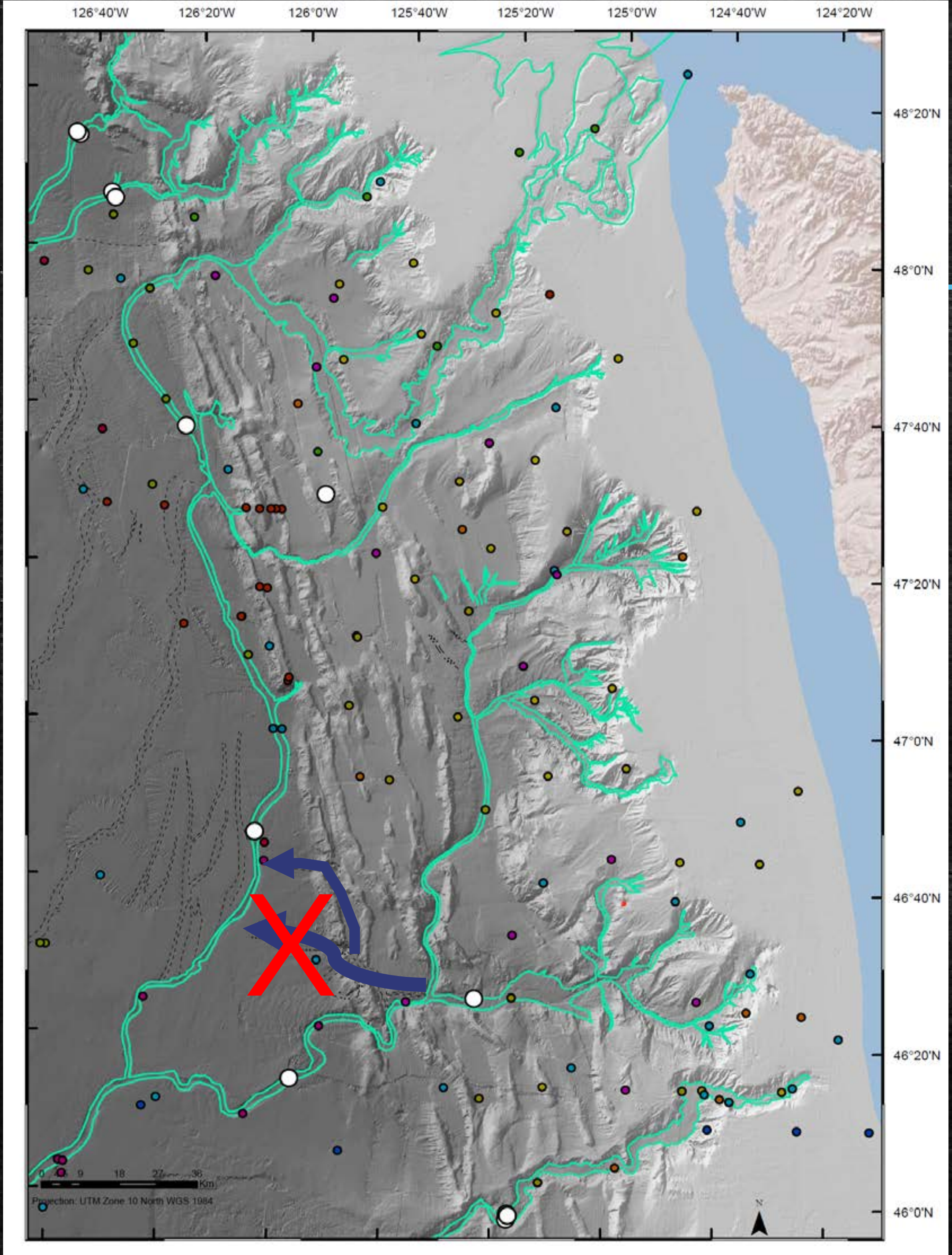
Ages are constrained by crosscutting relationships to be late Pleistocene. The are inactive in the Holocene, as originally mapped.



- The two features "A" and "B" are interpreted as submarine "coulees" similar to those observed onshore and most likely related to the Missoula flooding events of the deglacial period.



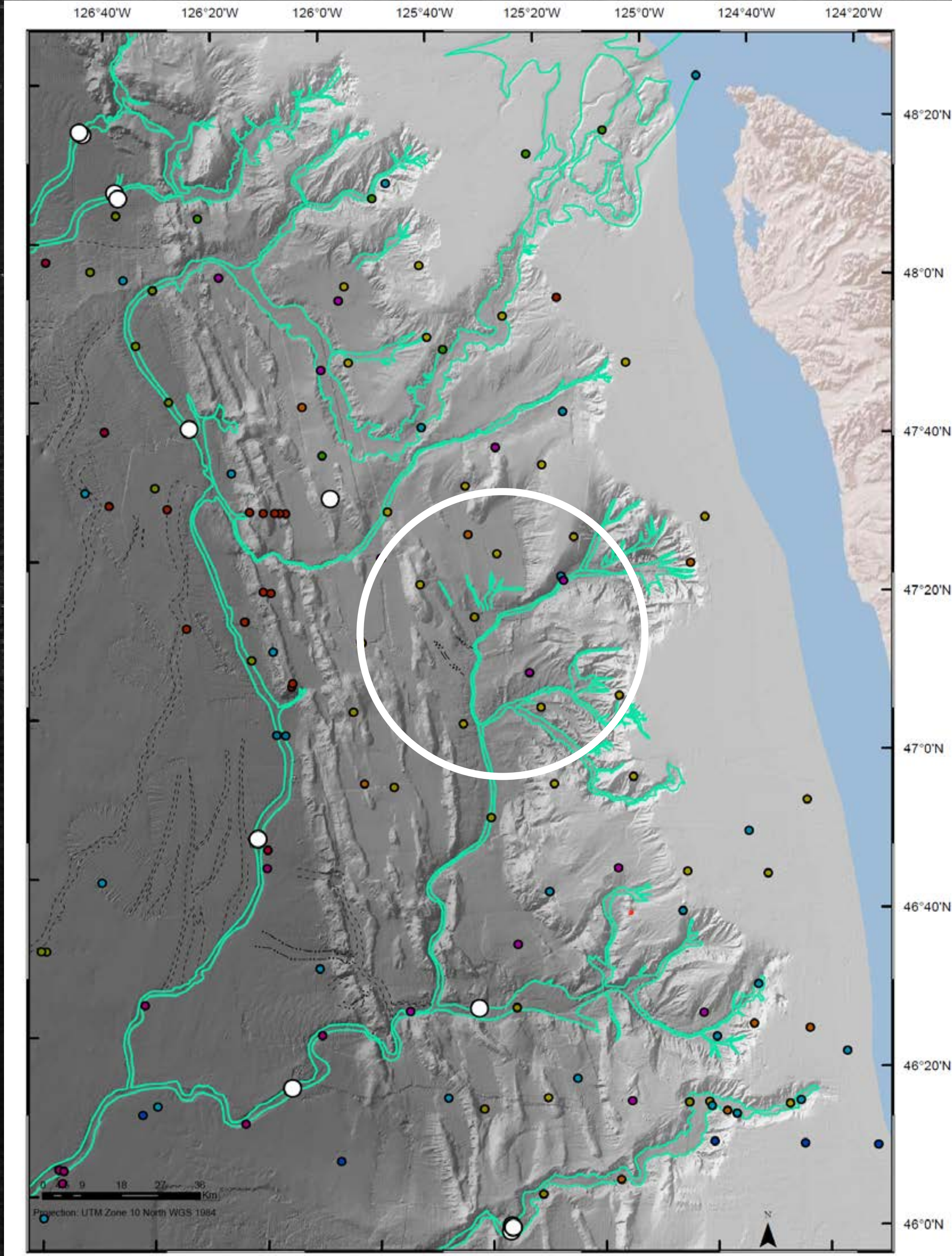
Cascadia



Alternative Holocene channel?

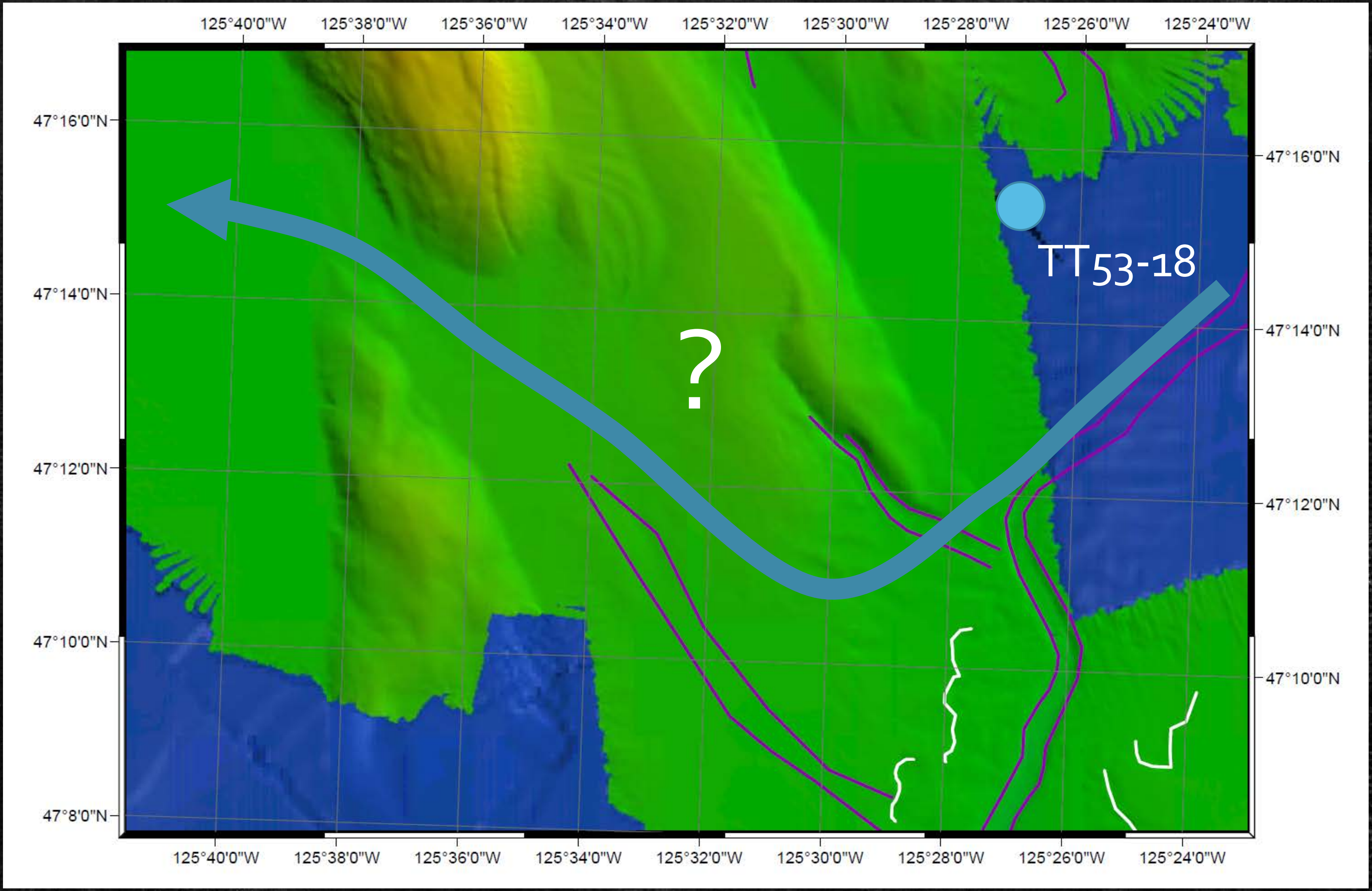
In the Missoula outbursts yes, not significant in the Holocene.

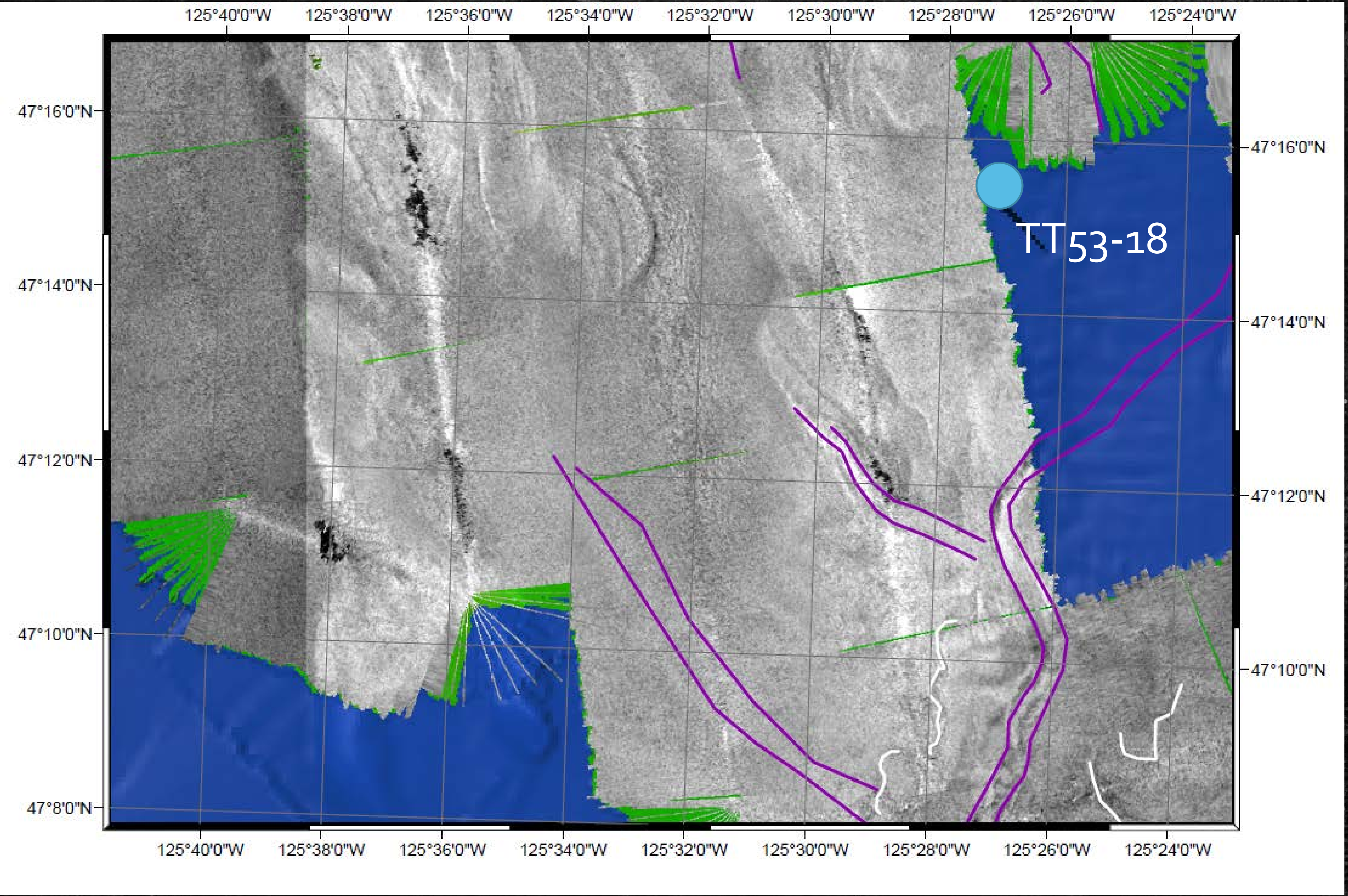
But in any case, not relevant to the confluence test as this notional input is below the key core sites.

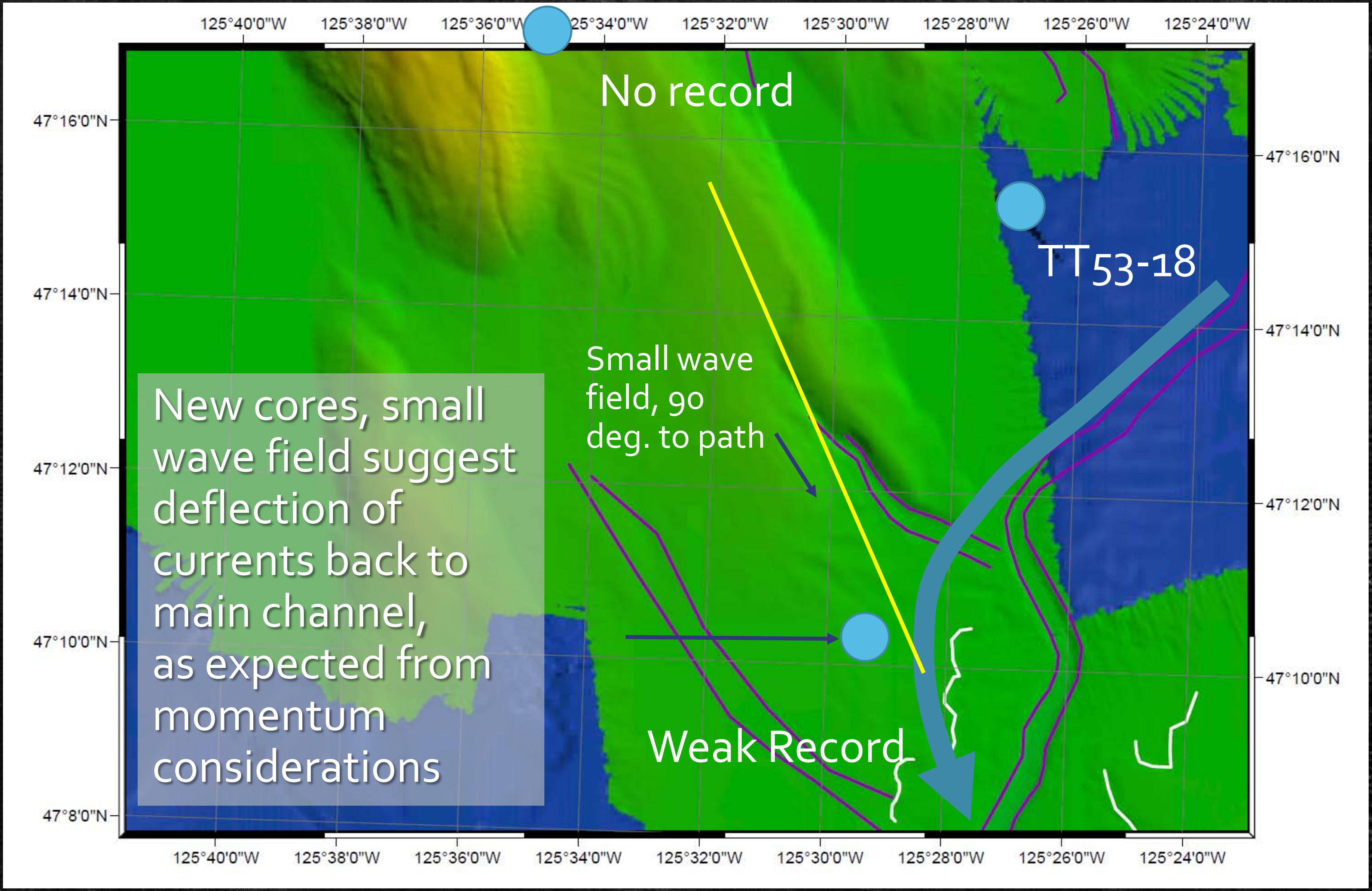


Cascadia

Upper slope canyons funnel turbidity currents into a margin parallel channel as wedge growth has made the upper slope/lower slope break the lowest point in the wedge.

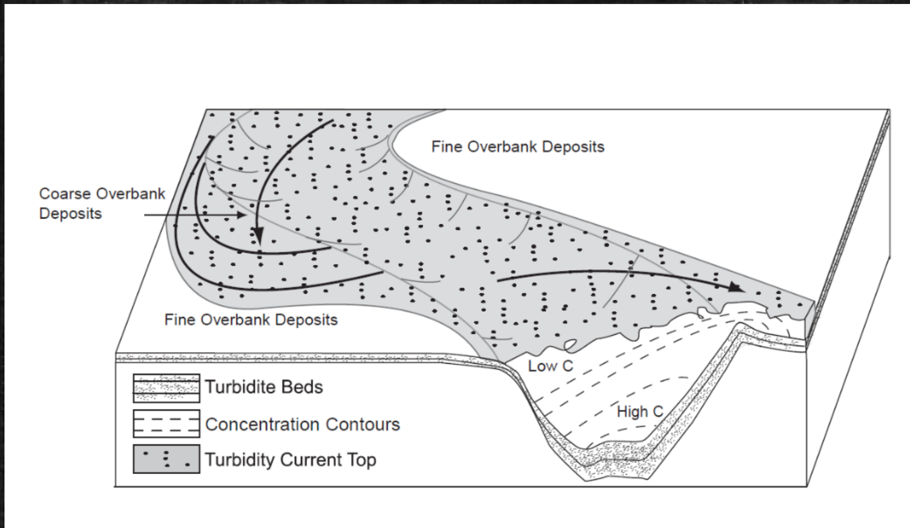

125°40'0"W
125°38'0"W
125°36'0"W
125°34'0"W
125°32'0"W
125°30'0"W
125°28'0"W
125°26'0"W
125°24'0"W
47°16'0"N
47°14'0"N
47°12'0"N
47°10'0"N
47°8'0"N
TT53-18
?


125°40'0"W
125°38'0"W
125°36'0"W
125°34'0"W
125°32'0"W
125°30'0"W
125°28'0"W
125°26'0"W
125°24'0"W
47°16'0"N
47°14'0"N
47°12'0"N
47°10'0"N
47°8'0"N
TT53-18

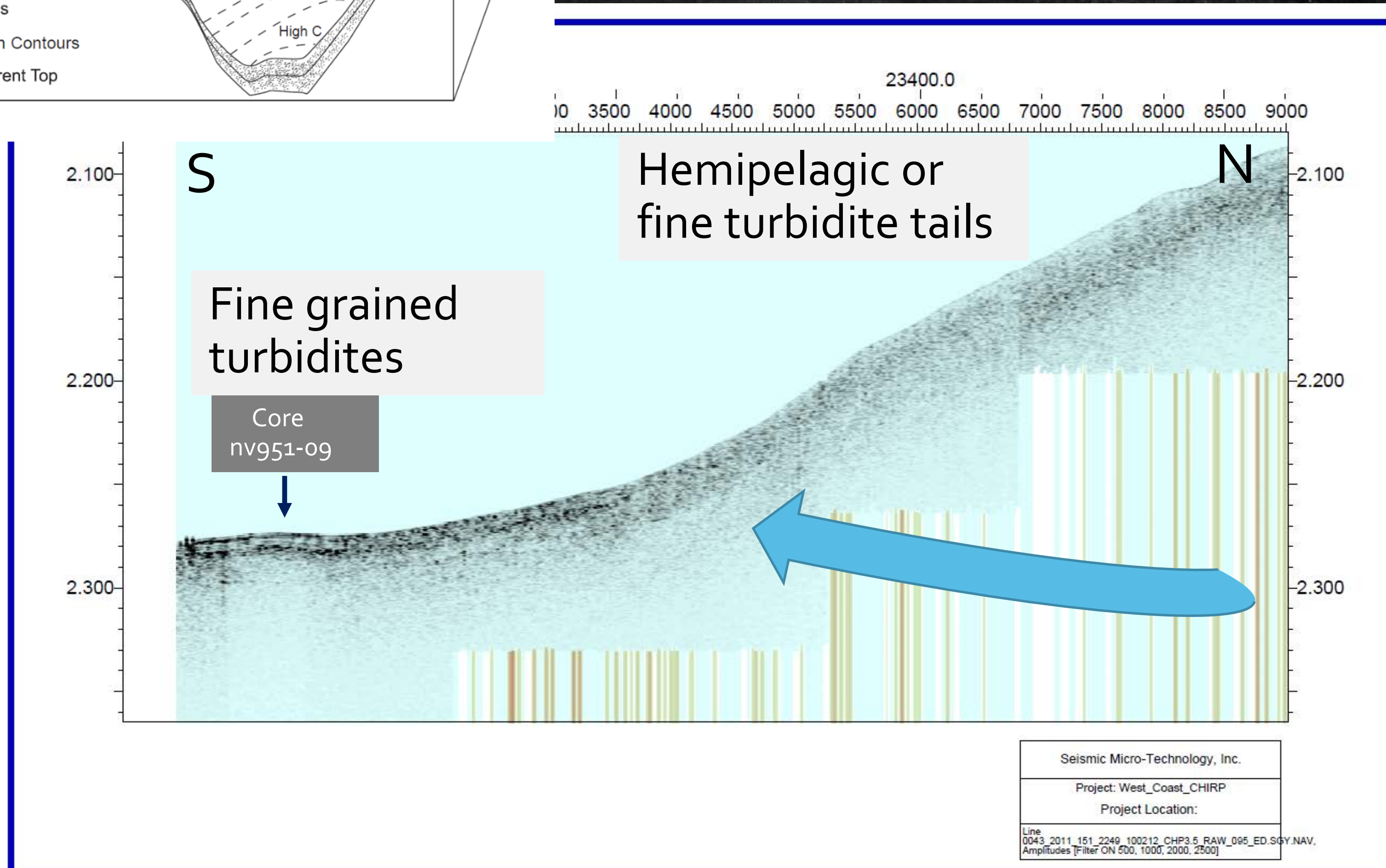


No record
TT53-18
Small wave field, 90 deg. to path
New cores, small wave field suggest deflection of currents back to main channel, as expected from momentum considerations
Weak Record
125°40'0"W
125°38'0"W
125°36'0"W
125°34'0"W
125°32'0"W
125°30'0"W
125°28'0"W
125°26'0"W
125°24'0"W
47°16'0"N
47°14'0"N
47°12'0"N
47°10'0"N
47°8'0"N

Classic overbank wavefield at a submarine channel bend

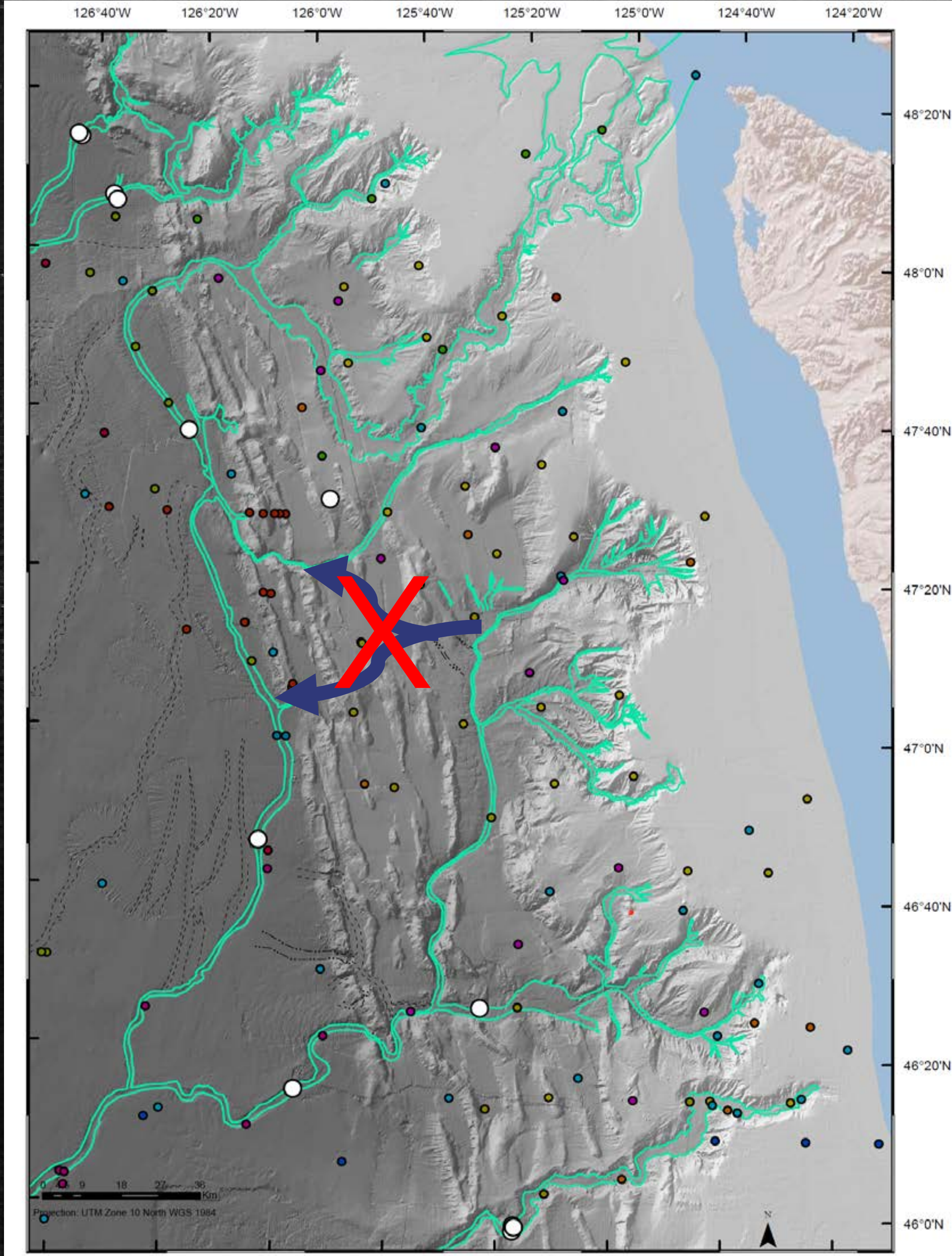


N



Monte Carlo search inversion for best fit to core stratigraphy

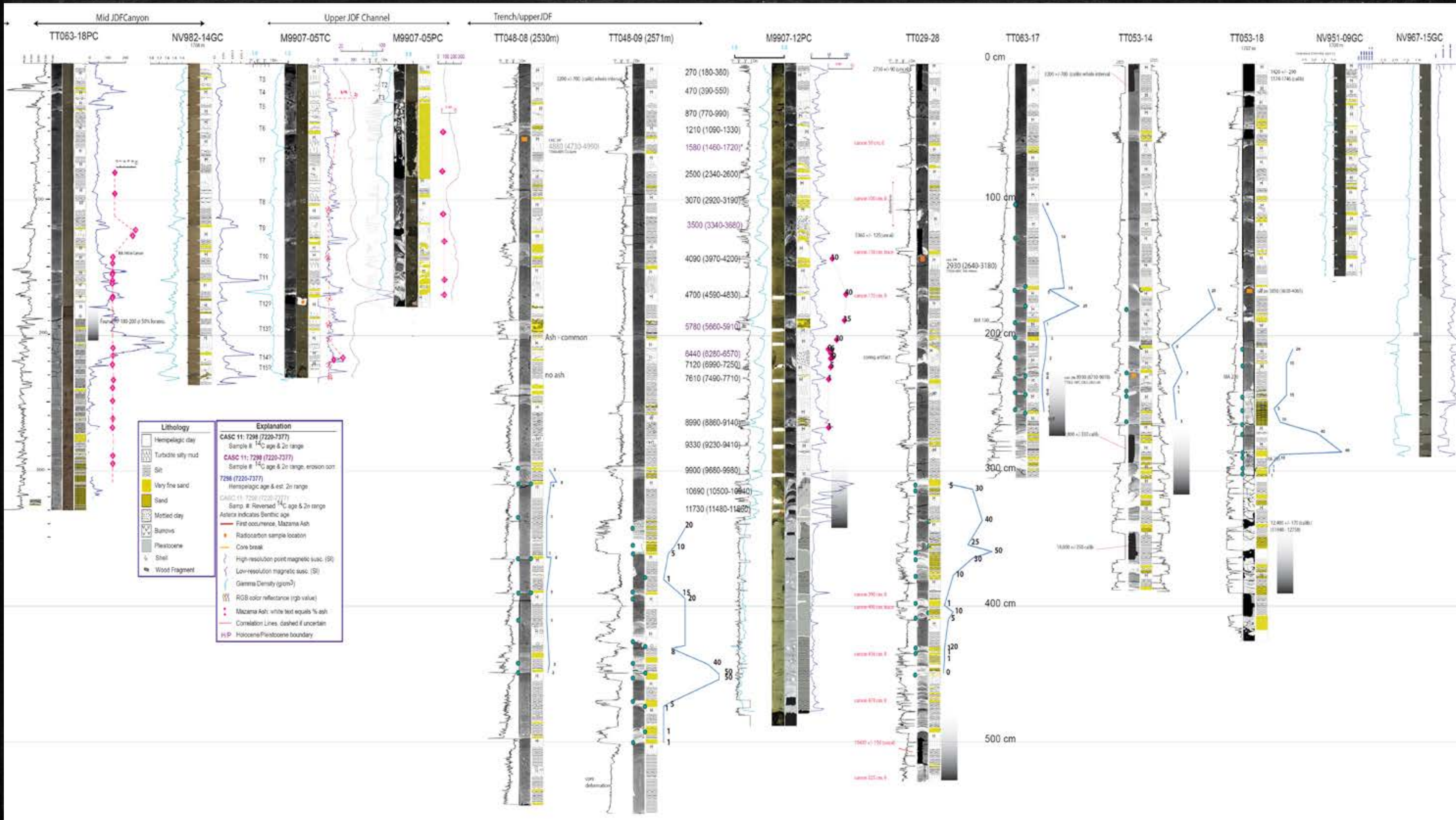
Move 2014a based on Waltham et al., 2008



Cascadia

It might be possible to feed a little flow-stripped material into the Quillayute Basin.

Over the top of the accretionary prism and into the JDF Channel is not a possible pathway.



Thin sections in upper canyon

Expanded above obstruction

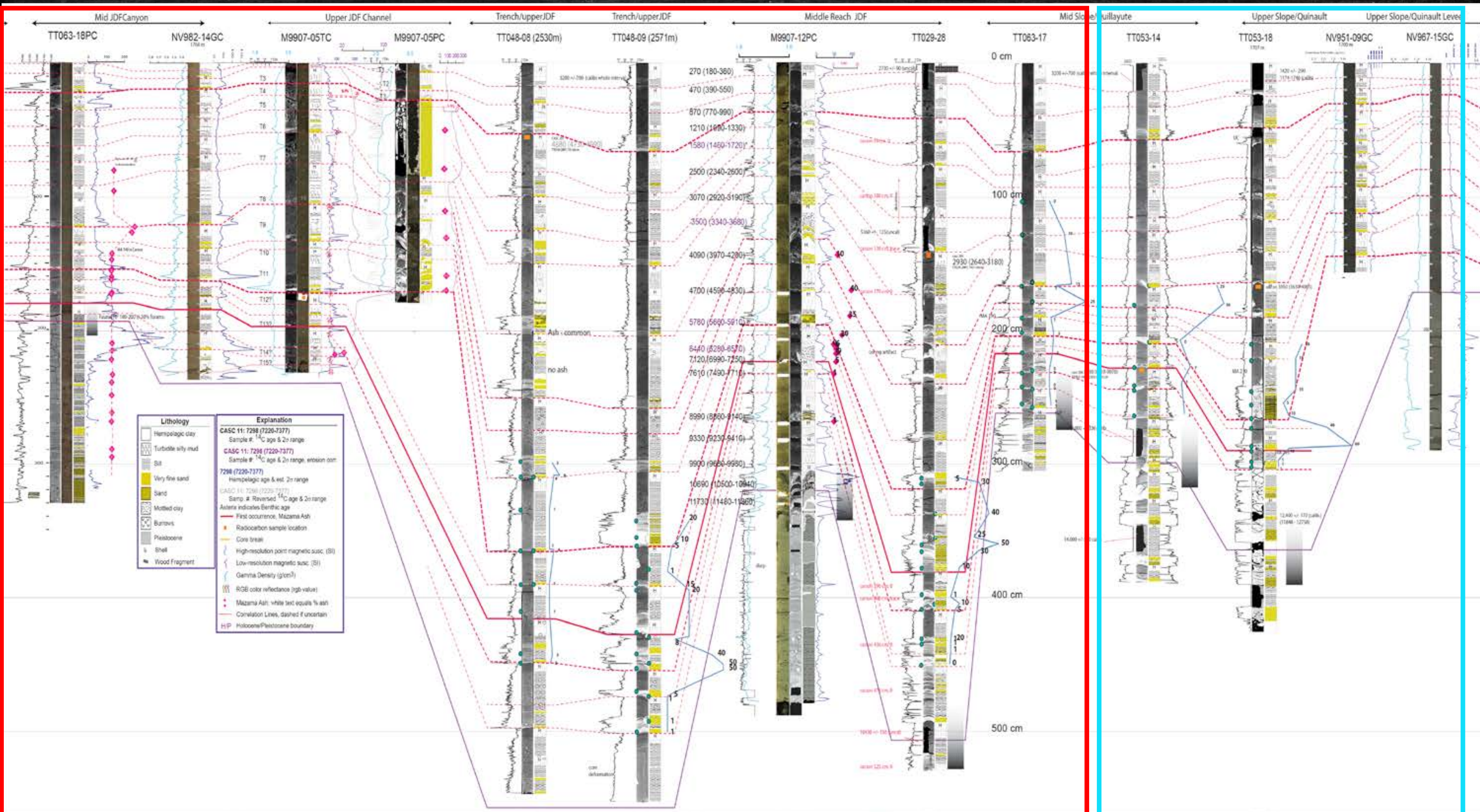
Compressed below obstruction

Thick sections in lower channel

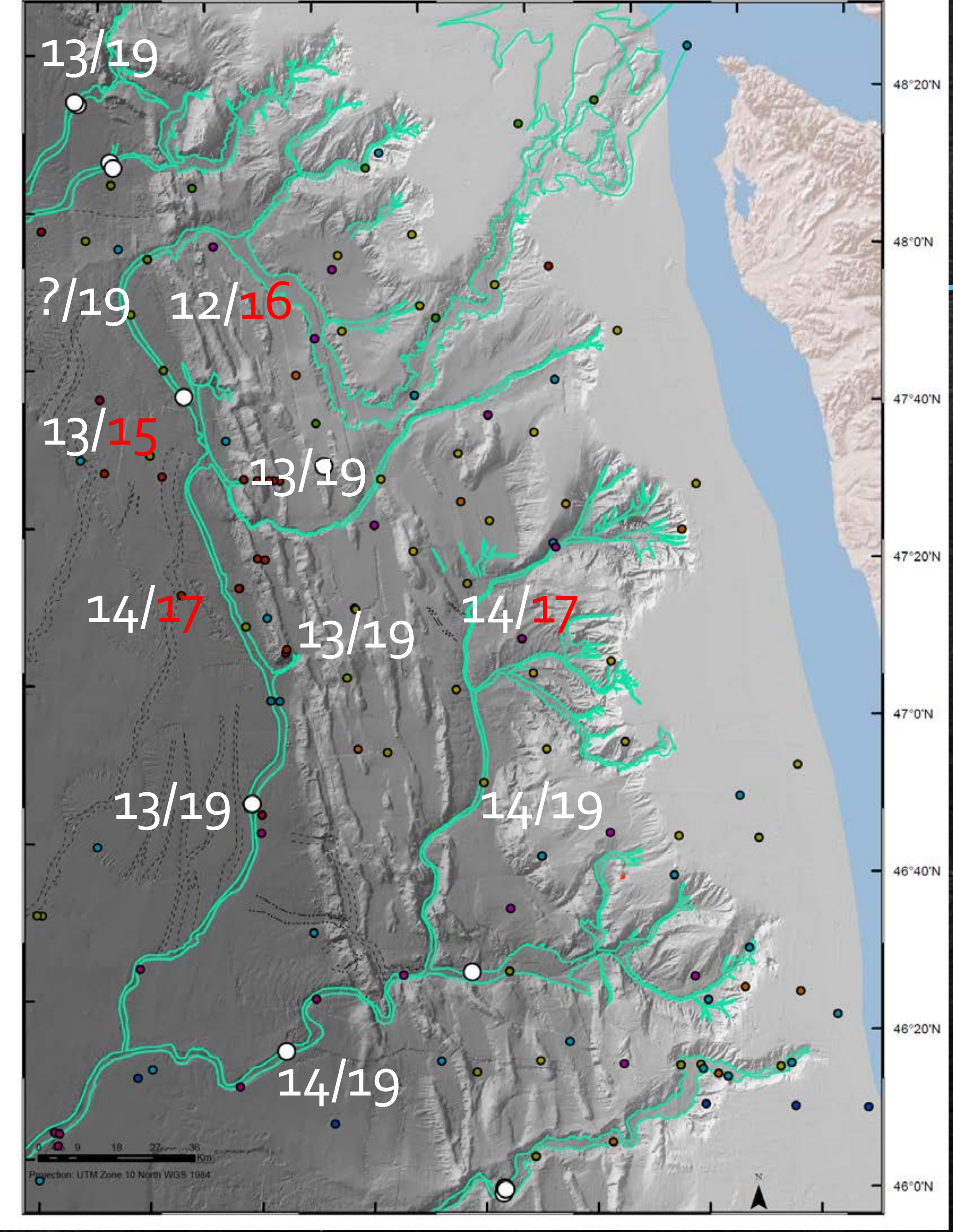
Thickening and coarsening downstream! Consistent with seismic trigger (but not required)

Western systems

Eastern systems



New expanded analysis suggests a rather simple signal of 19-20 Holocene turbidites in the along the northern margin in independent canyon/channel systems, supporting the original confluence test



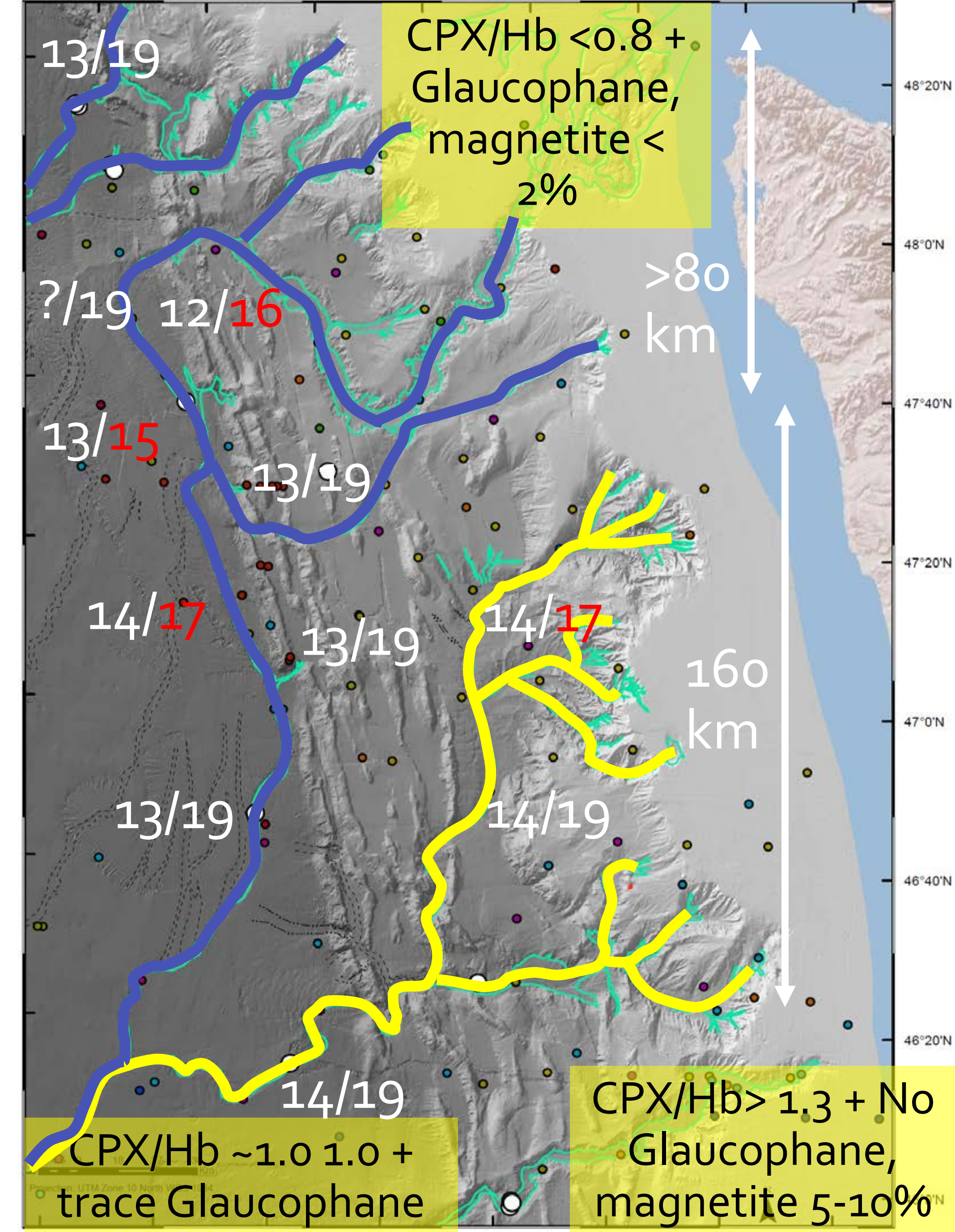
Two major independent Systems:

A consistent record for the most part, with occasional missing section at the Holocene-Pleistocene boundary.

First number is turbidites above the Mazama Ash, second number is Holocene turbidites, red if erosion detected.

Consistency of the Washington margin turbidite record across multiple turbidite systems

Core	H/P	Mazama	Correl. T13	visual logs	notes
JDF					
TT63-18	**16**	**12**	?	**4/7**	missing section at base of Holocene?
TT63-20	**14**	**11**	?	**8-9 Holo.**	CT analysis not complete
TT39-27	**19**	**?**	?	**4 Holo.**	No ash reported in Carson 1971, new analysis pending
TT39-06	**20**	**?**	13	**2 Holo.**	No ash reported in Carson 1971, new analysis pending
TT48-09	**17**	**14**	14	**15 Holo.**	HP not quite reached
TT48-08	**17**	**14**	14	**15 Holo.**	HP not quite reached
M9907-05TC	**15**	**13**	13	**6**	core overpentrated? 2 events missing from top. H/P not reached
M9907-12PC	**19**	**13**	13	**12/17**	
TT029-28	**18**	**14**	14	**10**	
Quinault-Willapa					
TT053-18	**18**	**16**	14	**13/15**	possible missing section at base of Holocene
Quillayute					
TT063-17	**18**	**16**	14	**5/11**	possible missing section at base of Holocene
TT053-14	**18**	**16**	14	**8/12**	possible missing section at base of Holocene
Cascadia					
M990722-25PC	**19**	**13**	**13**	**12/18**	

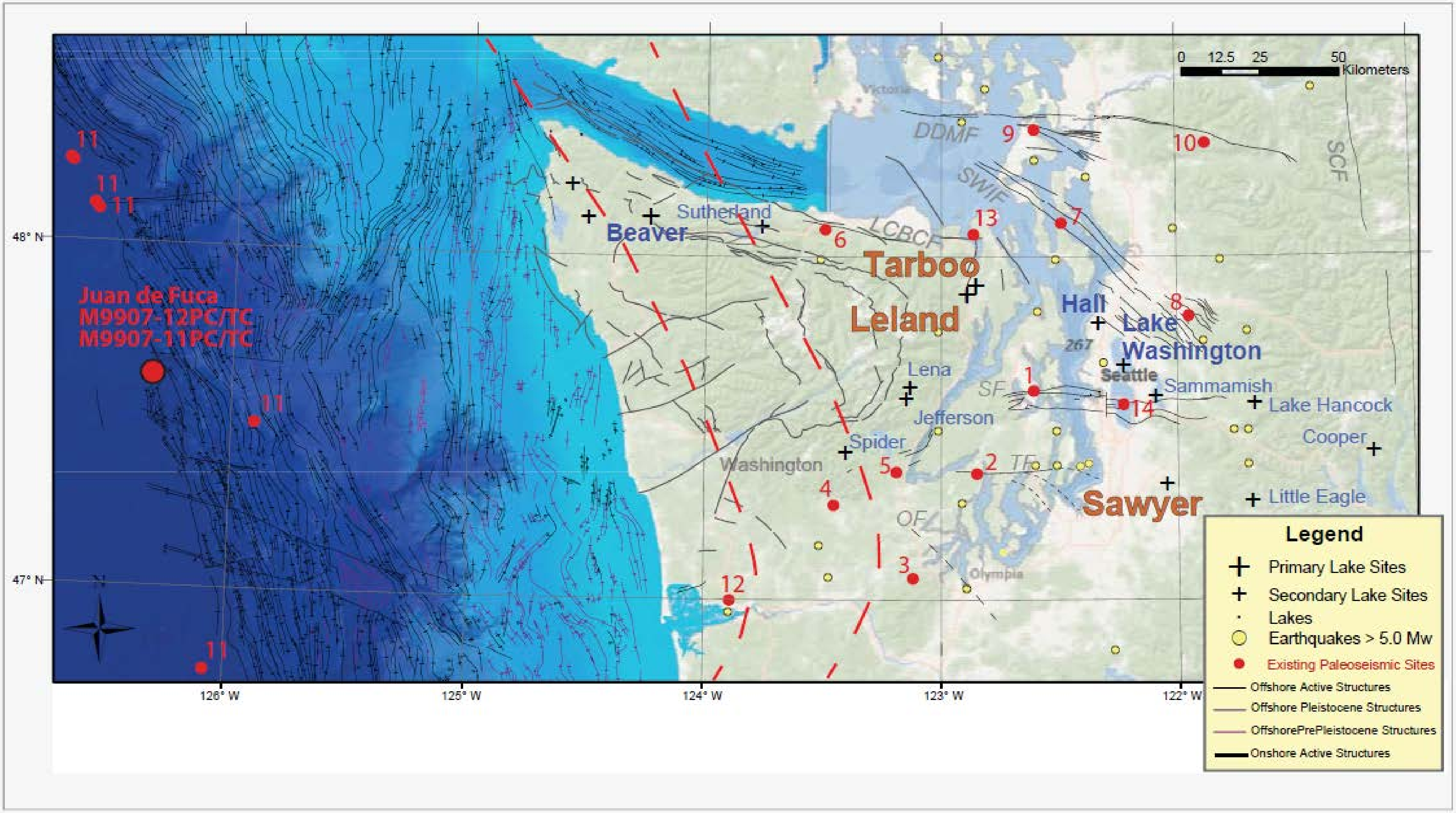


The confluence:

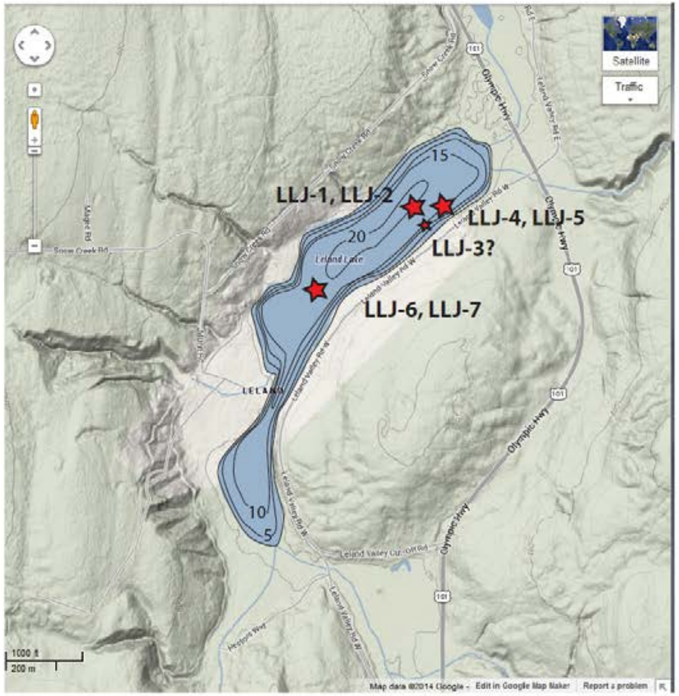
A mixed signal.

Heavy mineral tracers distinguish northern and southern sources and preclude significant input to JDF from Quinault Canyon.

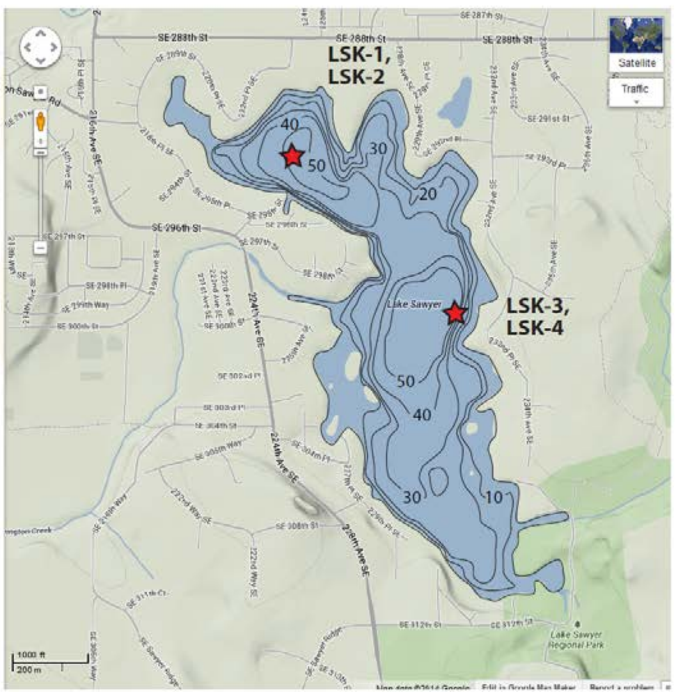
Direct comparison between offshore and onshore evidence in forearc Lakes.

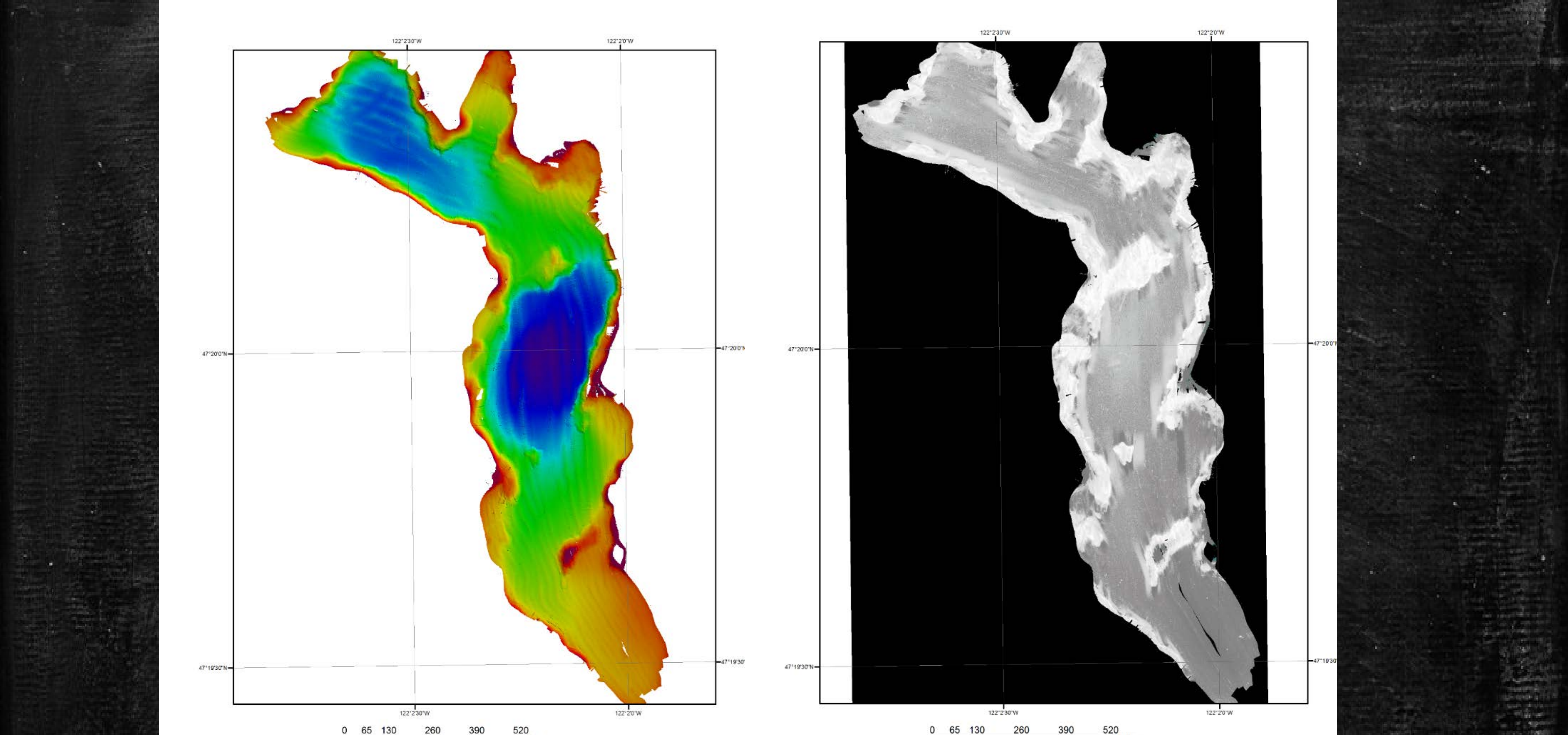


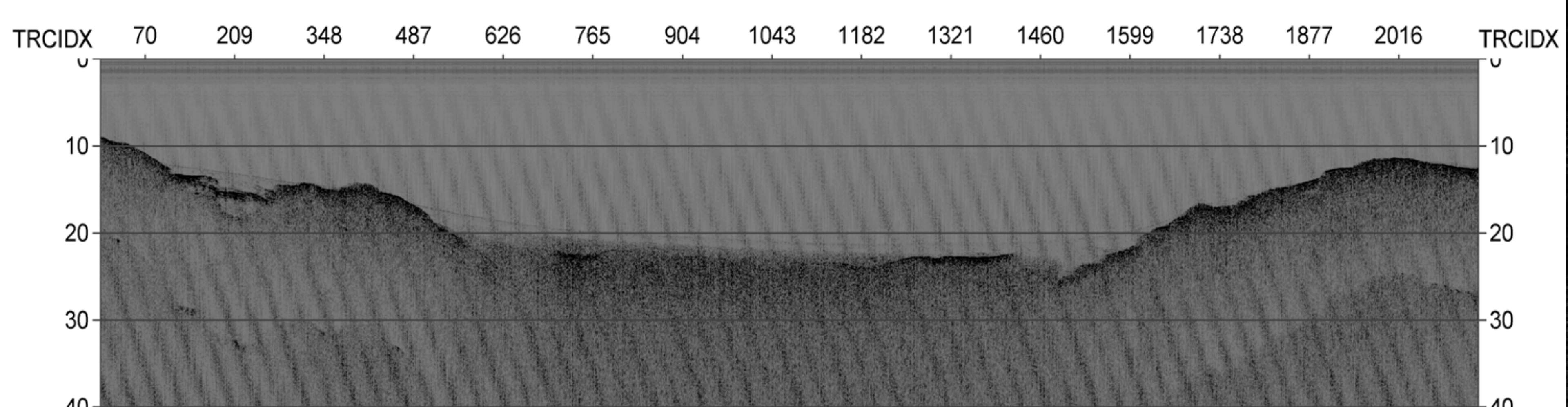
Goldfinger, Morey, Sherrod et al.

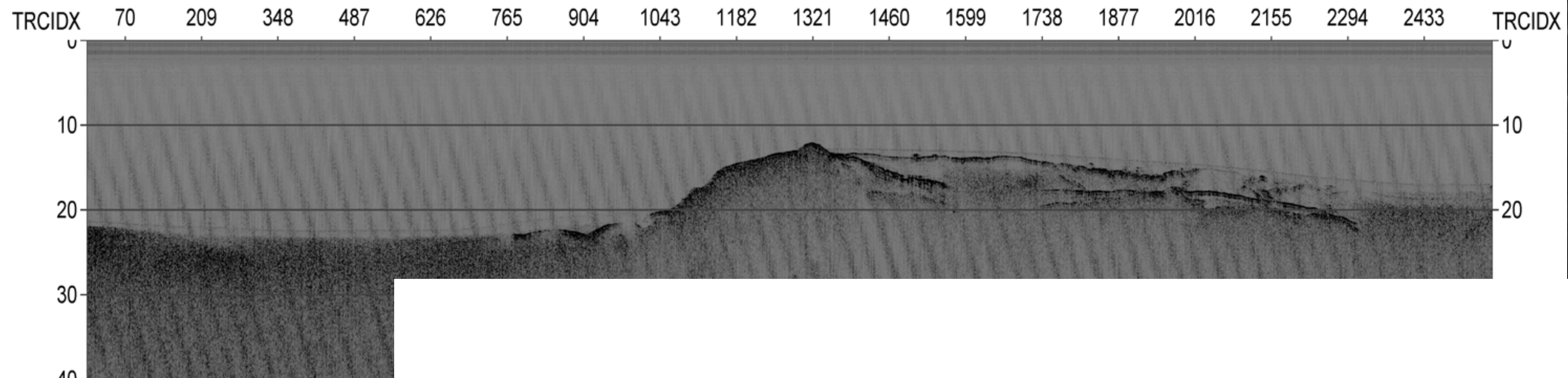

Satellite
Traffic
LLJ-1, LLJ-2
LLJ-4, LLJ-5
LLJ-3?
LLJ-6, LLJ-7
15
20
10
5
Leland Lake
Olympic Hwy
1000 ft
200 m
Map data ©2014 Google
Edit in Google Map Maker
Report a problem

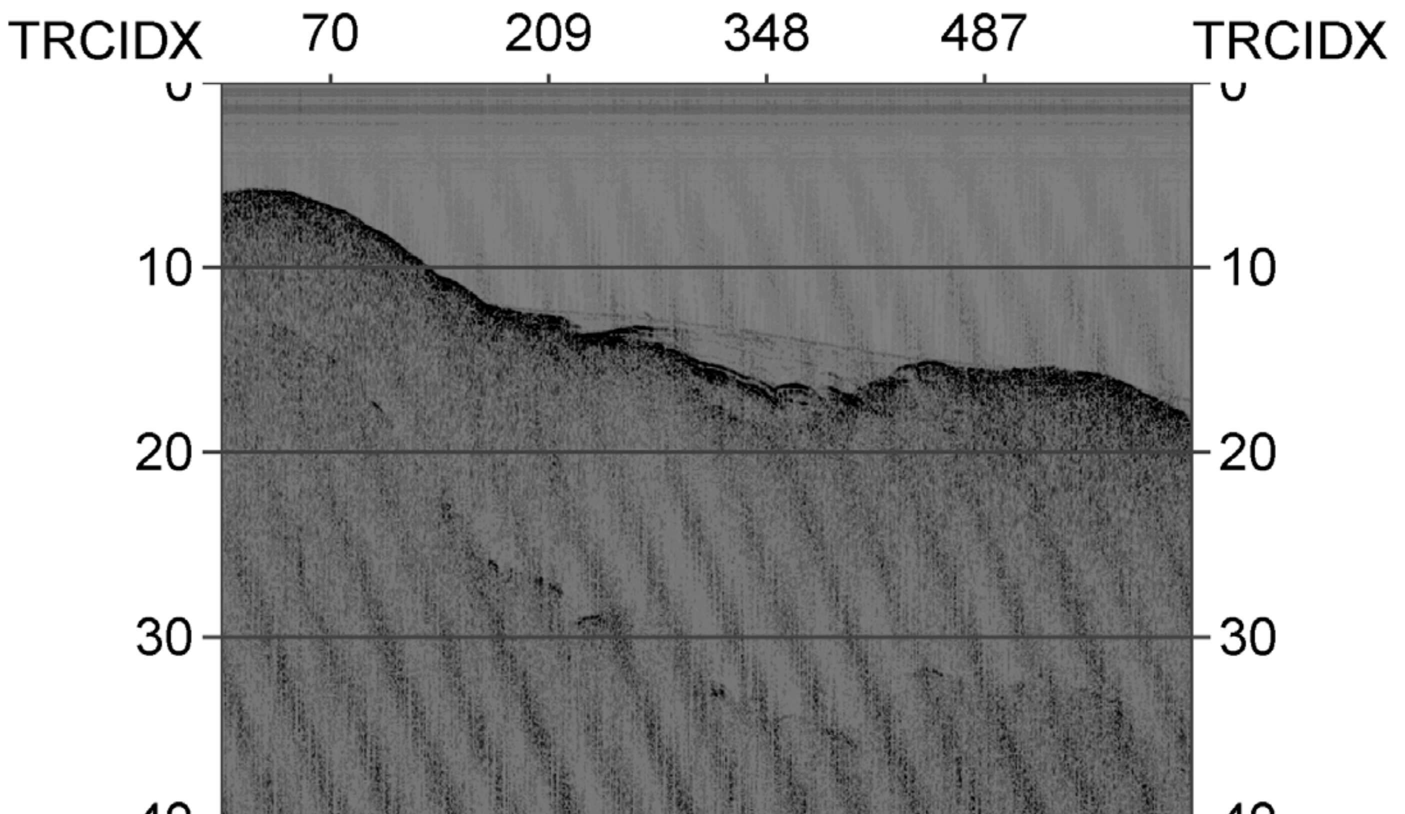

OSU-COAS RESEARCH
ALUMAWELD
TALON
60

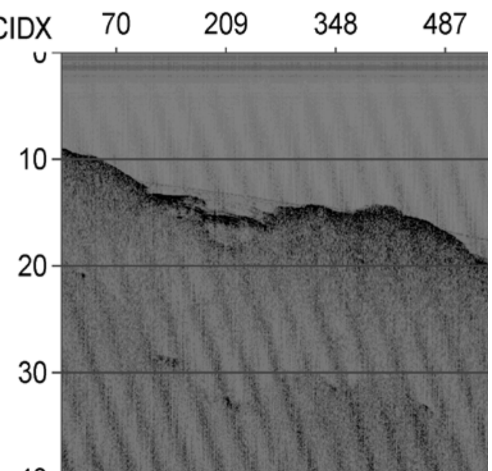

Satellite
Traffic
SE 288th St
SE 296th St
LSK-1,
LSK-2
LSK-3,
LSK-4
40
50
30
20
50
40
30
10
Lake Sawyer
224th Ave SE
Lake Sawyer Regional Park
1000 ft
200 m

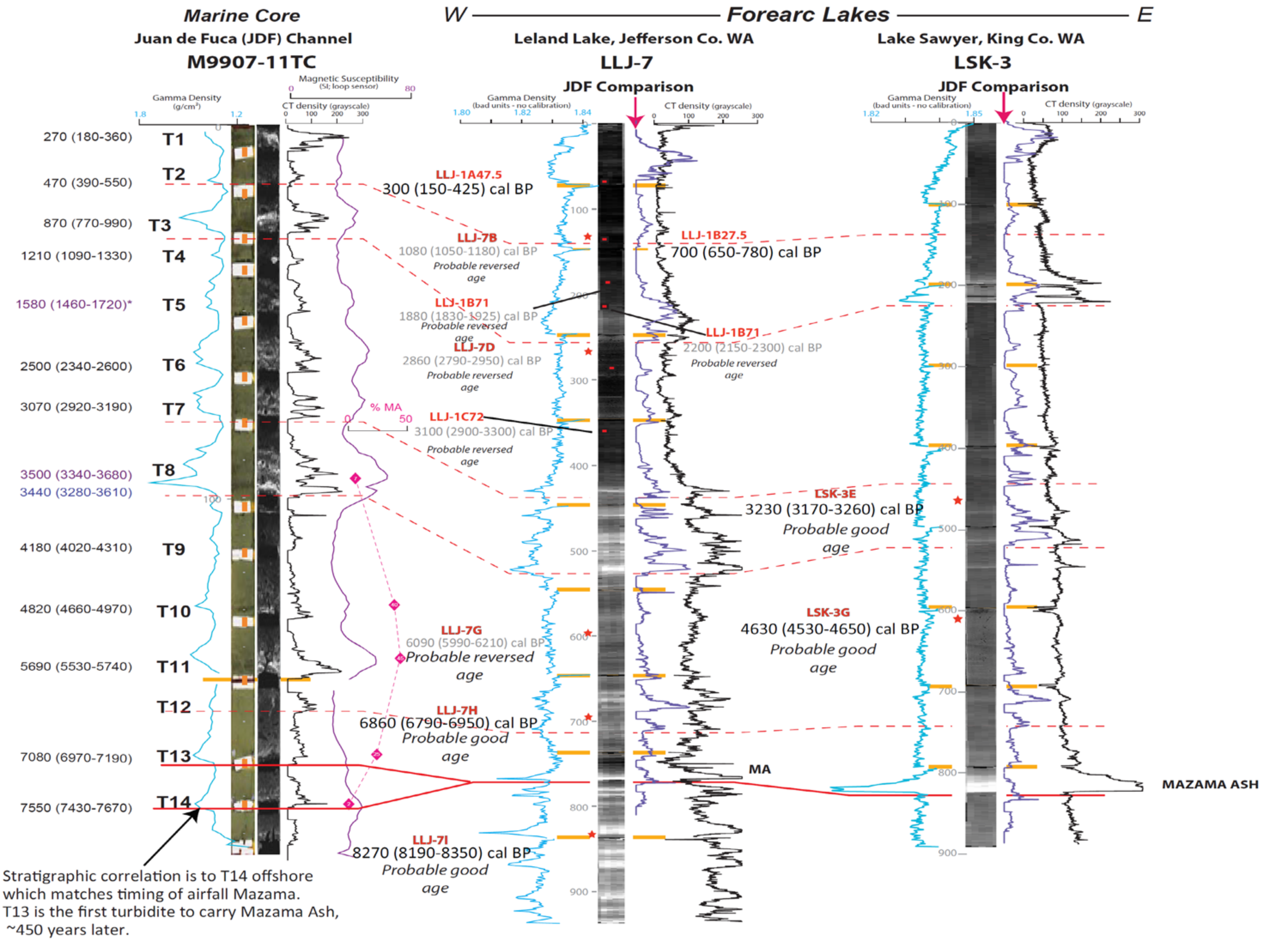

0 65 130 260 390 520
0 65 130 260 390 520


TRCIDX
70 209 348 487 626 765 904 1043 1182 1321 1460 1599 1738 1877 2016
TRCIDX
0
10
20
30
40


TRCIDX
70 209 348 487 626 765 904 1043 1182 1321 1460 1599 1738 1877 2016 2155 2294 2433
TRCIDX
10
20
30

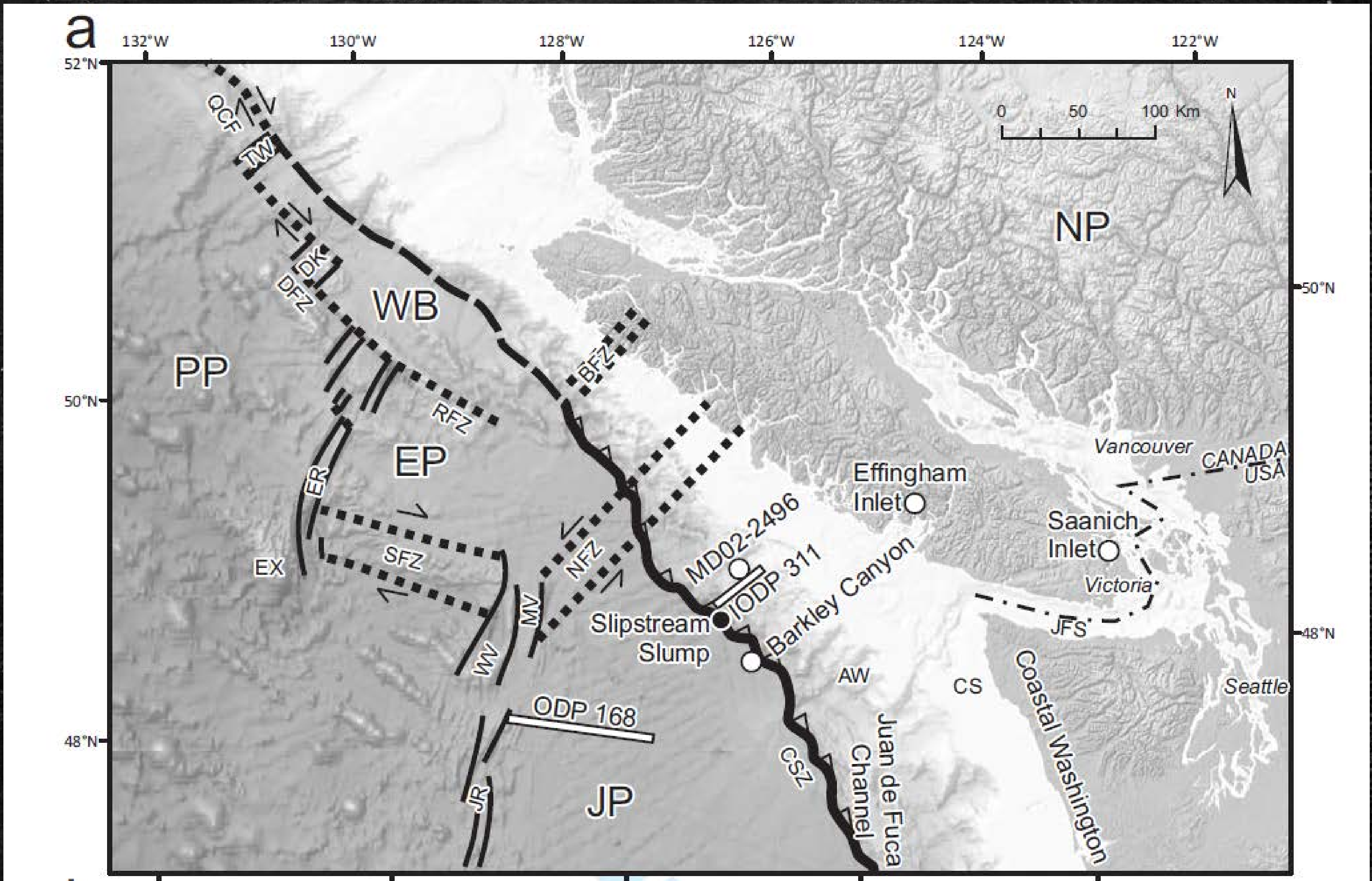

TRCIDX
70 209 348 487
TRCIDX
10
20
30


CIDX
70 209 348 487
10
20
30

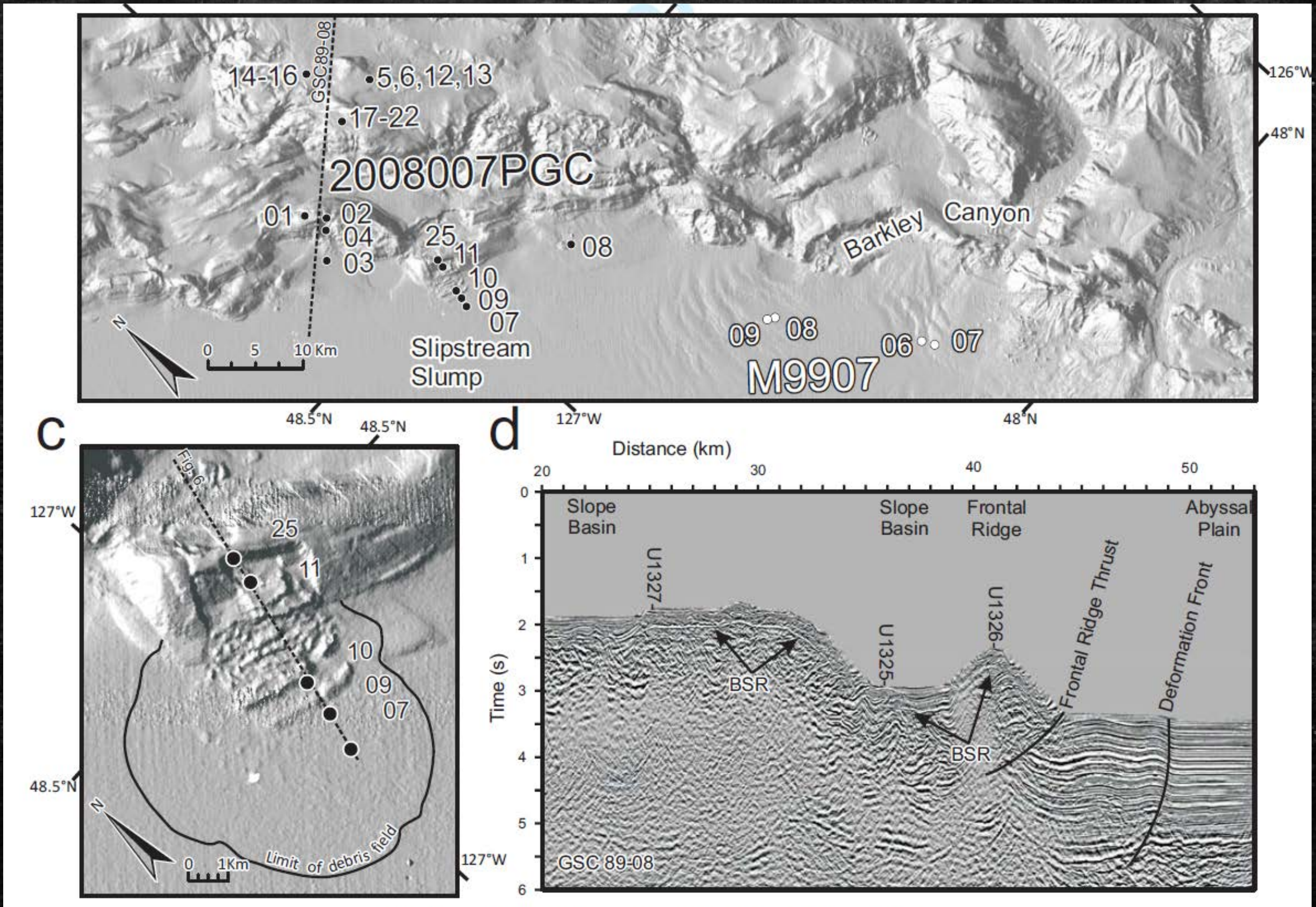


Marine Core
Juan de Fuca (JDF) Channel
M9907-11TC
W — Forearc Lakes — E
Leland Lake, Jefferson Co. WA
LLJ-7
JDF Comparison
Lake Sawyer, King Co. WA
LSK-3
JDF Comparison
Gamma Density (g/cm³)
Magnetic Susceptibility (SI; loop sensor)
CT density (grayscale)
Gamma Density (bad units - no calibration)
270 (180-360) T1
T2
470 (390-550)
870 (770-990) T3
1210 (1090-1330) T4
1580 (1460-1720)* T5
2500 (2340-2600) T6
3070 (2920-3190) T7
3500 (3340-3680) T8
3440 (3280-3610)
4180 (4020-4310) T9
4820 (4660-4970) T10
5690 (5530-5740) T11
T12
7080 (6970-7190) T13
7550 (7430-7670) T14
% MA
LLJ-1A47.5
300 (150-425) cal BP
LLJ-7B
1080 (1050-1180) cal BP
Probable reversed age
LLJ-1B27.5
700 (650-780) cal BP
LLJ-1B71
1880 (1830-1925) cal BP
Probable reversed age
LLJ-7D
2860 (2790-2950) cal BP
Probable reversed age
LLJ-1B71
2200 (2150-2300) cal BP
Probable reversed age
LLJ-1C72
3100 (2900-3300) cal BP
Probable reversed age
LSK-3E
3230 (3170-3260) cal BP
Probable good age
LSK-3G
4630 (4530-4650) cal BP
Probable good age
LLJ-7G
6090 (5990-6210) cal BP
Probable reversed age
LLJ-7H
6860 (6790-6950) cal BP
Probable good age
MA
MAZAMA ASH
LLJ-7I
8270 (8190-8350) cal BP
Probable good age
Stratigraphic correlation is to T14 offshore which matches timing of airfall Mazama.
T13 is the first turbidite to carry Mazama Ash, ~450 years later.

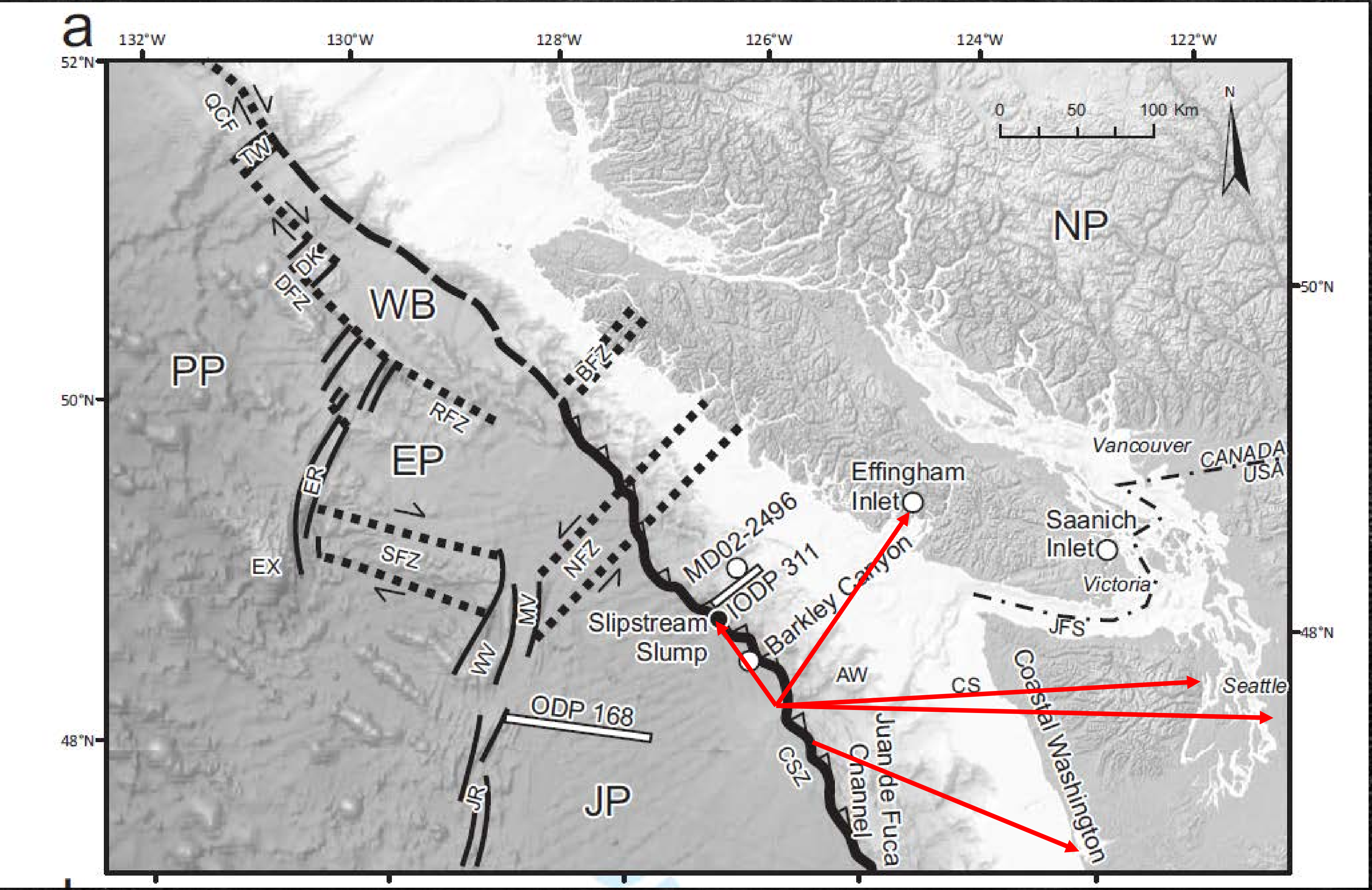
Another independent site investigated by Hamilton et al. (2014)



Slipstream slide: Hamilton et al. 2014



http://mc06.manuscriptcentral.com/cjes-pubs

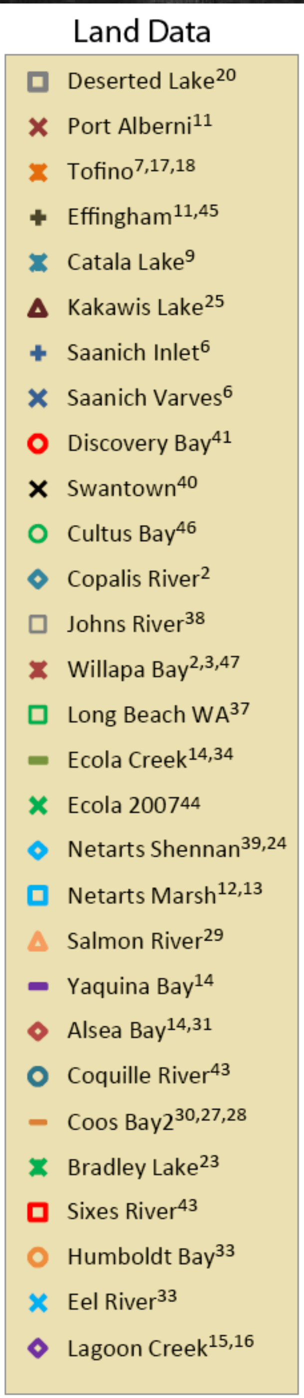


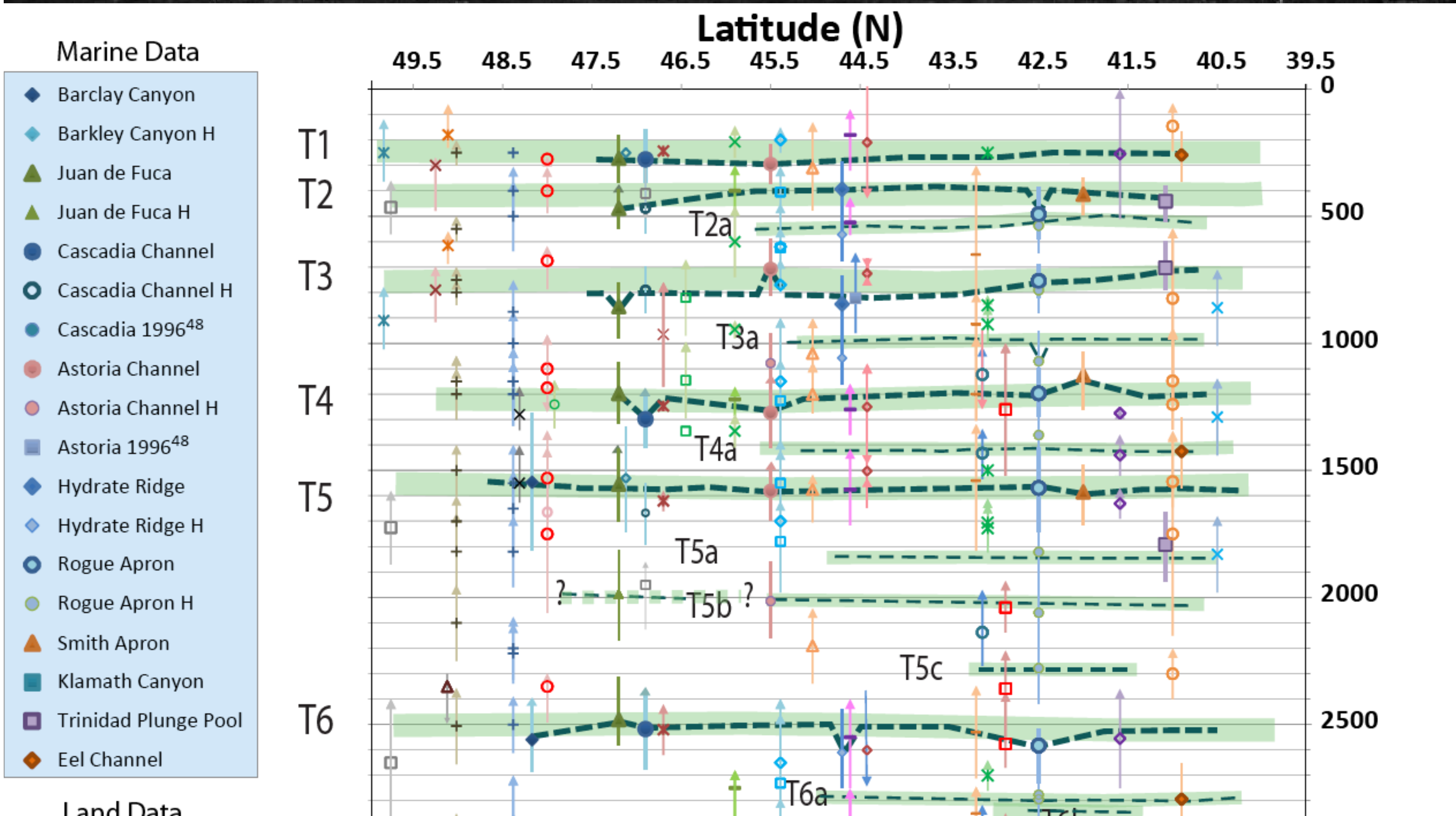
a
132°W
130°W
128°W
126°W
124°W
122°W
52°N
50°N
48°N
0
50
100 Km
N
NP
WB
PP
EP
JP
QCF
TW
DK
DFZ
RFZ
BFZ
ER
EX
SFZ
NFZ
MV
WV
JR
ODP 168
CSZ
MD02-2496
ODP 311
Slipstream
Slump
Barkley Canyon
AW
CS
Effingham
Inlet
Saanich
Inlet
Vancouver
Victoria
CANADA
USA
JFS
Seattle
Juan de Fuca
Channel
Coastal Washington

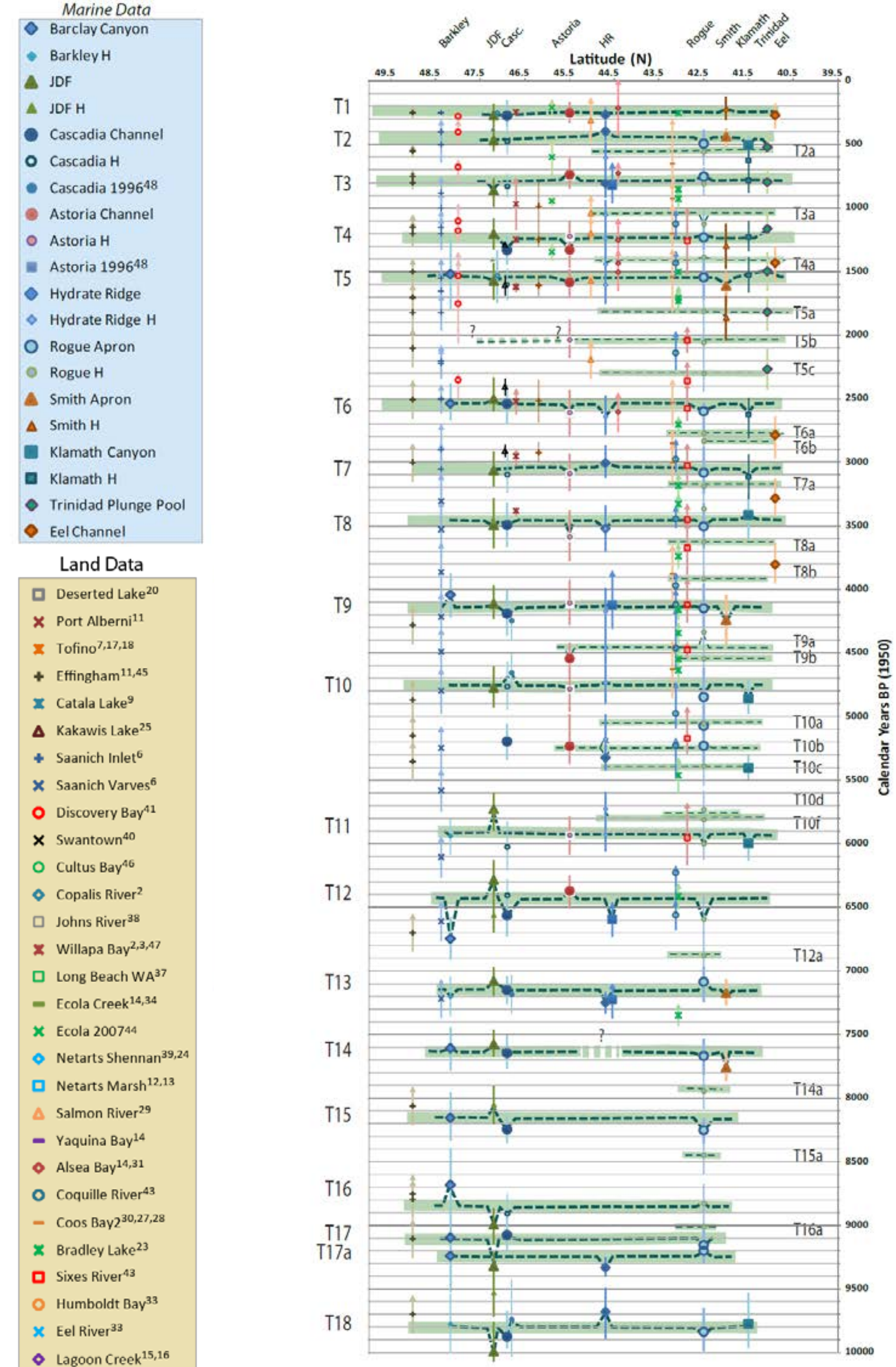
Onshore-Offshore space-time diagram for the most recent ~ 2800 years.

(Filled symbols are marine data, open symbols land data; smaller open symbols are bulk peat ages, given lower weighting here.)

Stratigraphic correlation for offshore data shown in blue dashed lines.







Onshore-Offshore space-time diagram including only higher precision land ages

(Filled symbols are marine data, open symbols land data; smaller open symbols are bulk peat ages, given lower weighting here.)

Stratigraphic correlation for offshore data shown in blue dashed lines.

And finally, back to the model.

The inputs are quantified where possible according to this scheme:

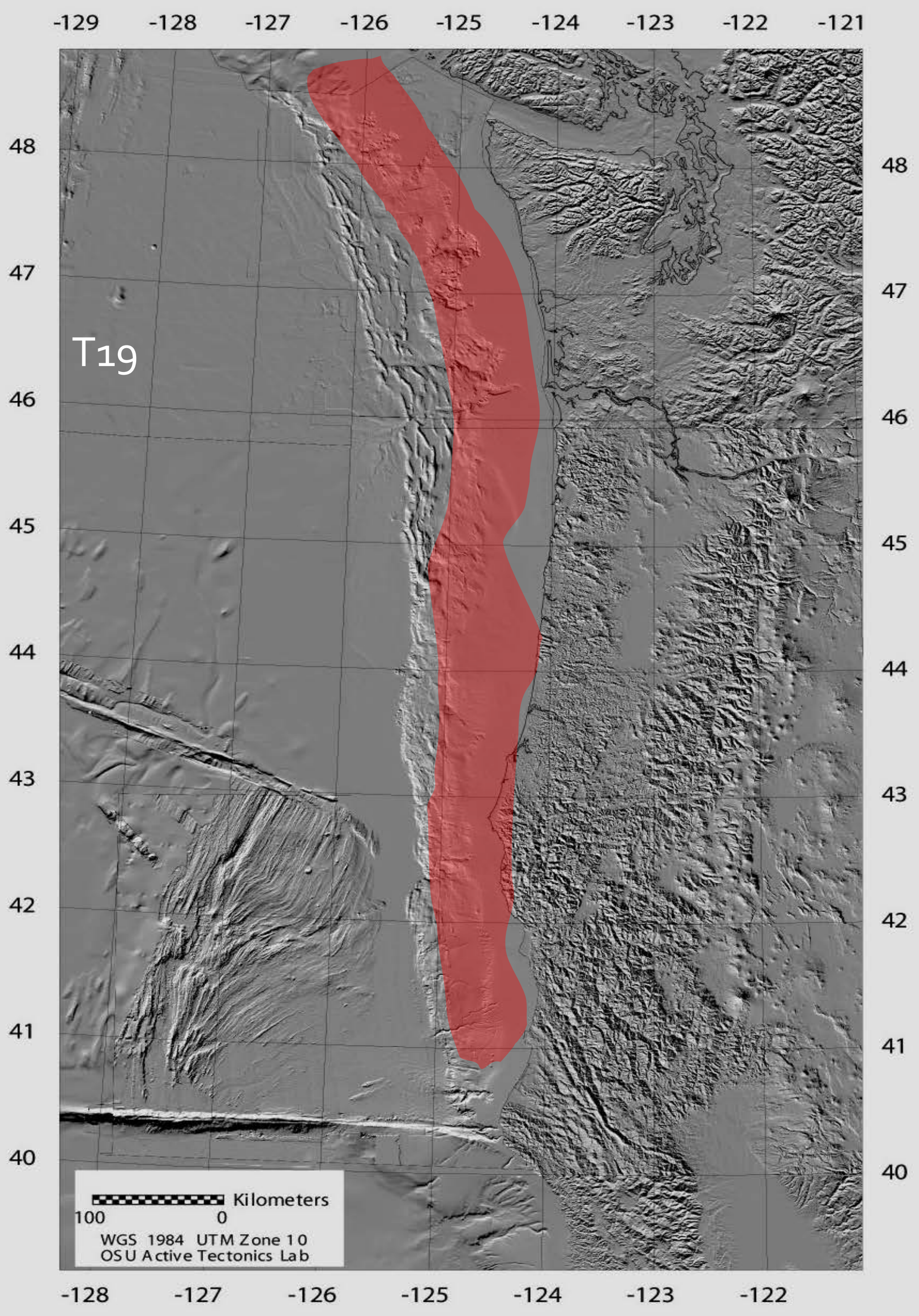
- OxCal chi^2 and agreement indices as measures of radiocarbon fit, land and marine data.
- Pearson correlation coeff. for downcore series.
- 85% probability assigned (+/- 15) for confluence and coincidence tests based on all relevant data.
- Boolean (yes/no) for turbidite filter criteria.
- Binning of strike length and number of sites observed.
- Seismic correlation criteria not applicable to northern margin (topography too rough).
- Hydrodynamic model fit RMS can be used with caution.
- The model is in development, and the following should be considered experimental.

Preliminary results: probability of correlation given the input data, T1-18 for (JDF, Cascadia, HR, Rogue) and high precision land sites.

Idnum	freq		probabilities of Correl	P(case)
1	1	*	(0.94 0.06)	4.17444e-008
2	1	*	(0.77 0.23)	4.17444e-008
3	1	*	(0.82 0.18)	4.30094e-008
4	1	*	(0.88 0.12)	4.17444e-008
5	1	*	(0.71 0.29)	4.43127e-008
6	1	*	(0.93 0.07)	4.17444e-008
7	1	*	(0.87 0.13)	4.30094e-008
8	1	*	(0.73 0.27)	4.30094e-008
9	1	*	(0.83 0.17)	4.17444e-008
10	1	*	(0.63 0.37)	4.30094e-008
11	1	*	(0.85 0.15)	4.17444e-008
12	1	*	(0.74 0.26)	4.17444e-008
13	1	*	(0.89 0.11)	4.17444e-008
14	1	*	(0.82 0.18)	4.30094e-008
15	1	*	(0.77 0.23)	4.30094e-008
16	1	*	(0.85 0.15)	4.17444e-008
17	1	*	(0.83 0.17)	4.17444e-008
17a	1	*	(0.81 0.19)	4.30094e-008
18	1	*	(0.79 0.21)	4.17444e-008

Average probability long ruptures= 81%, southern ruptures 64%

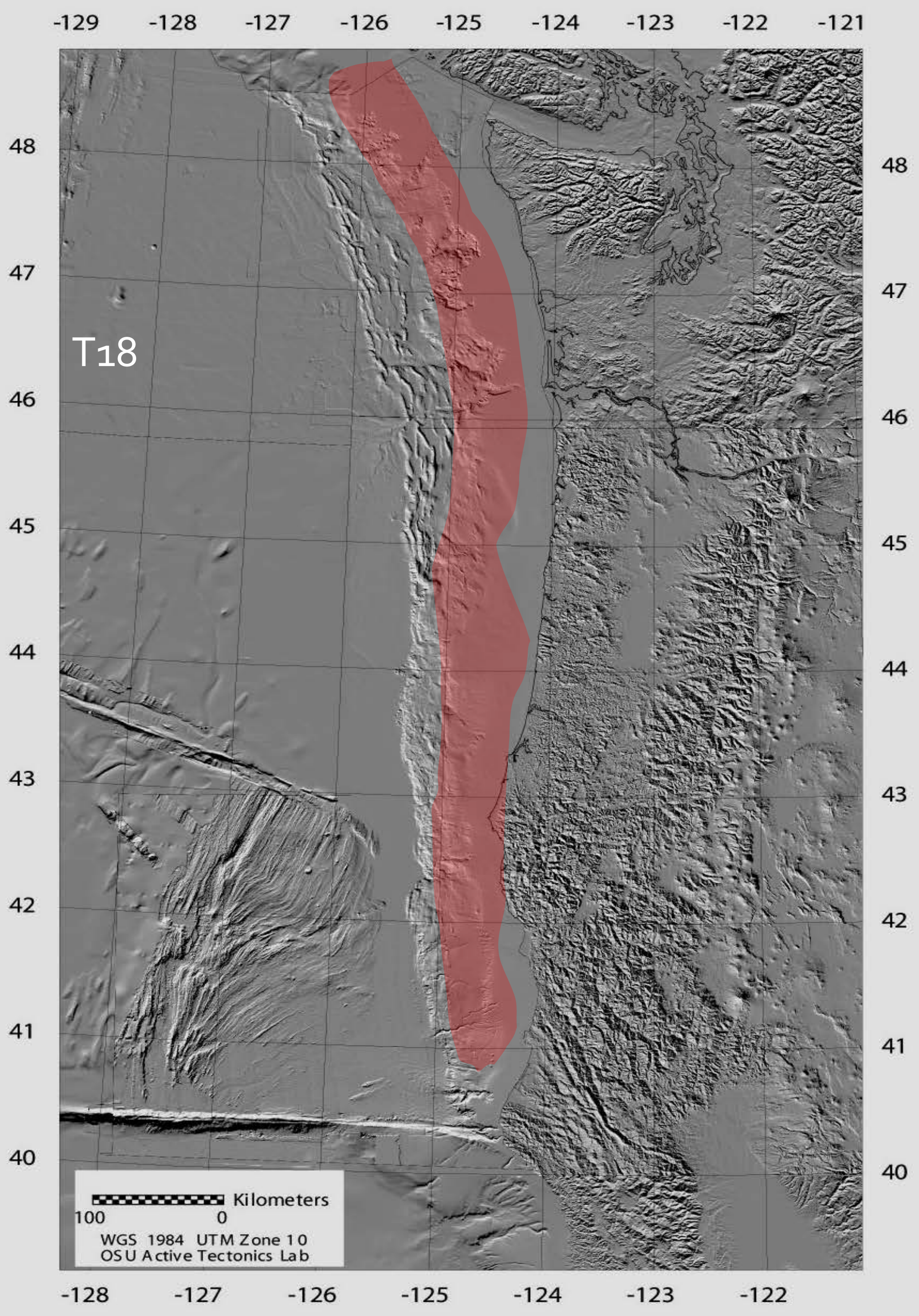
Cascadia: The Movie

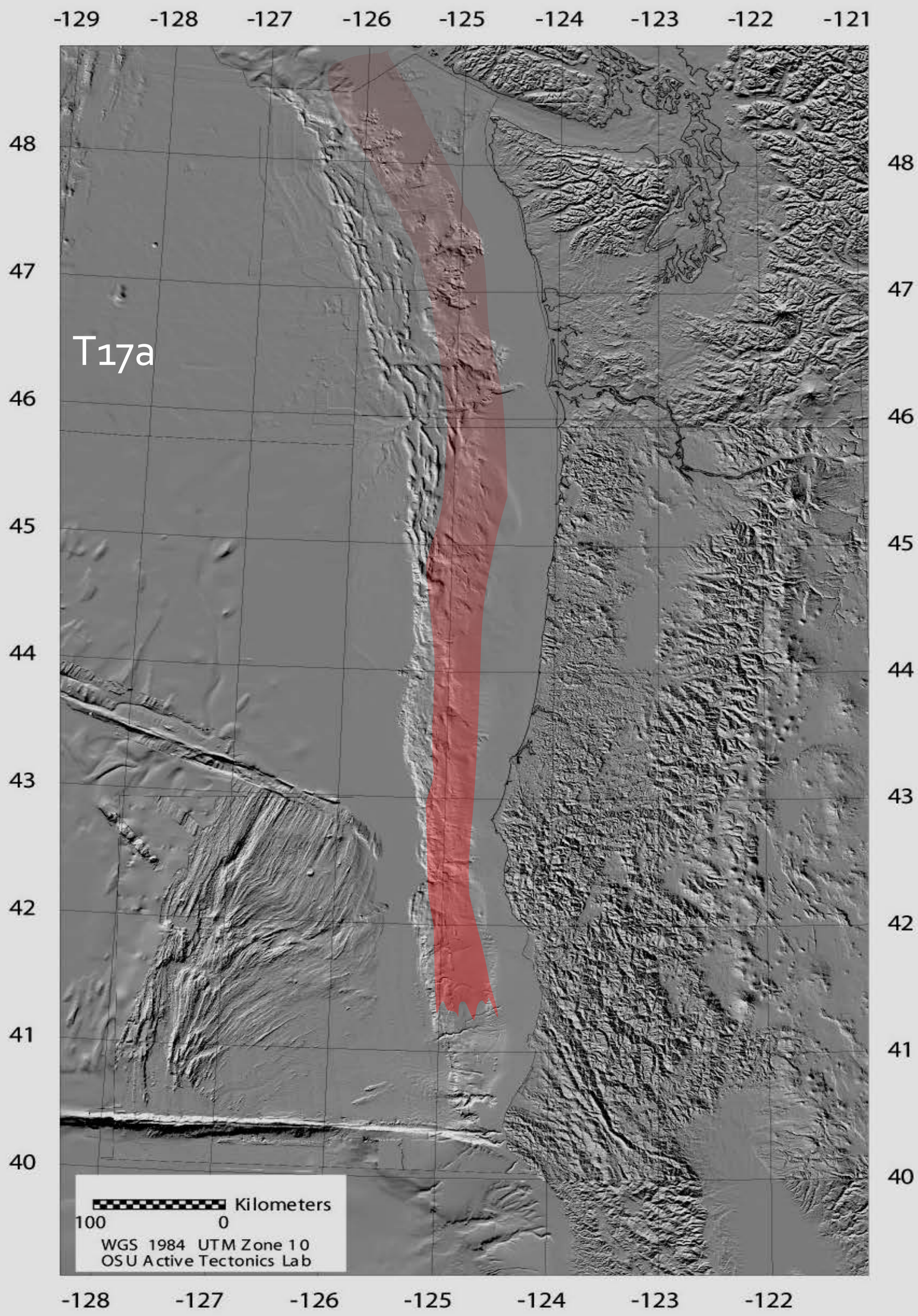


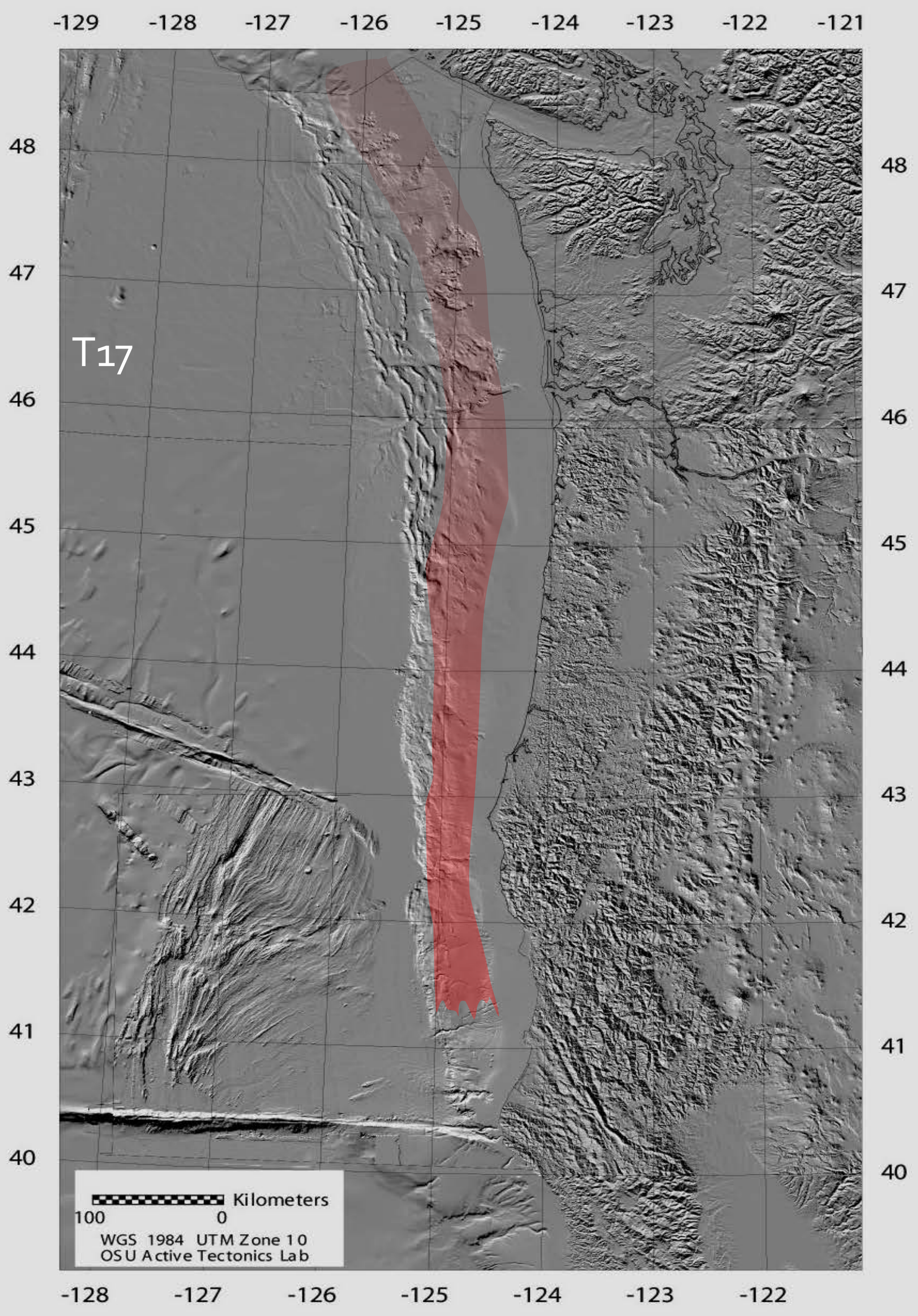
This sequence shows the Cascadia Holocene earthquake sequence.

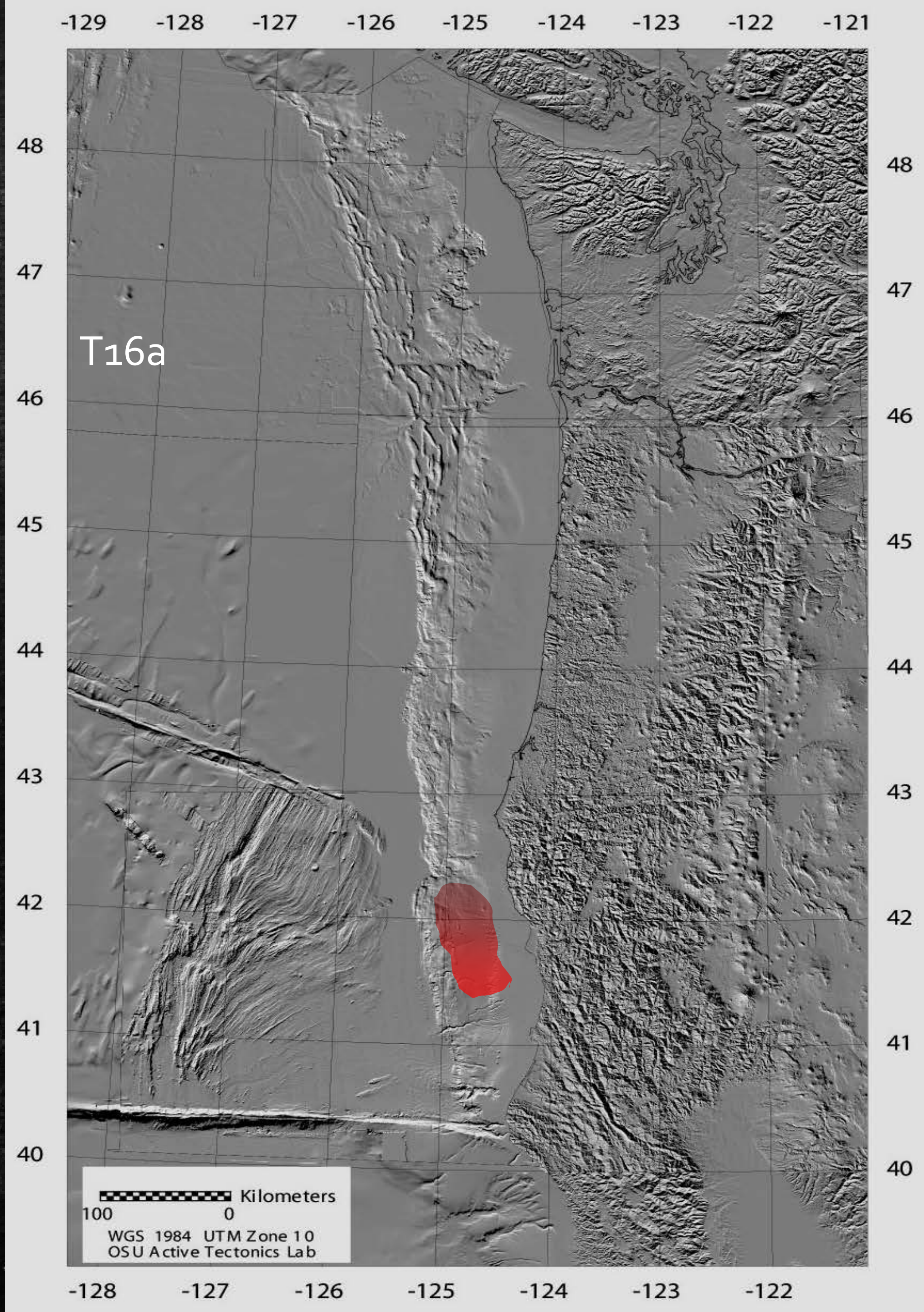
The slides are timed at 1 sec ~ 200 years.

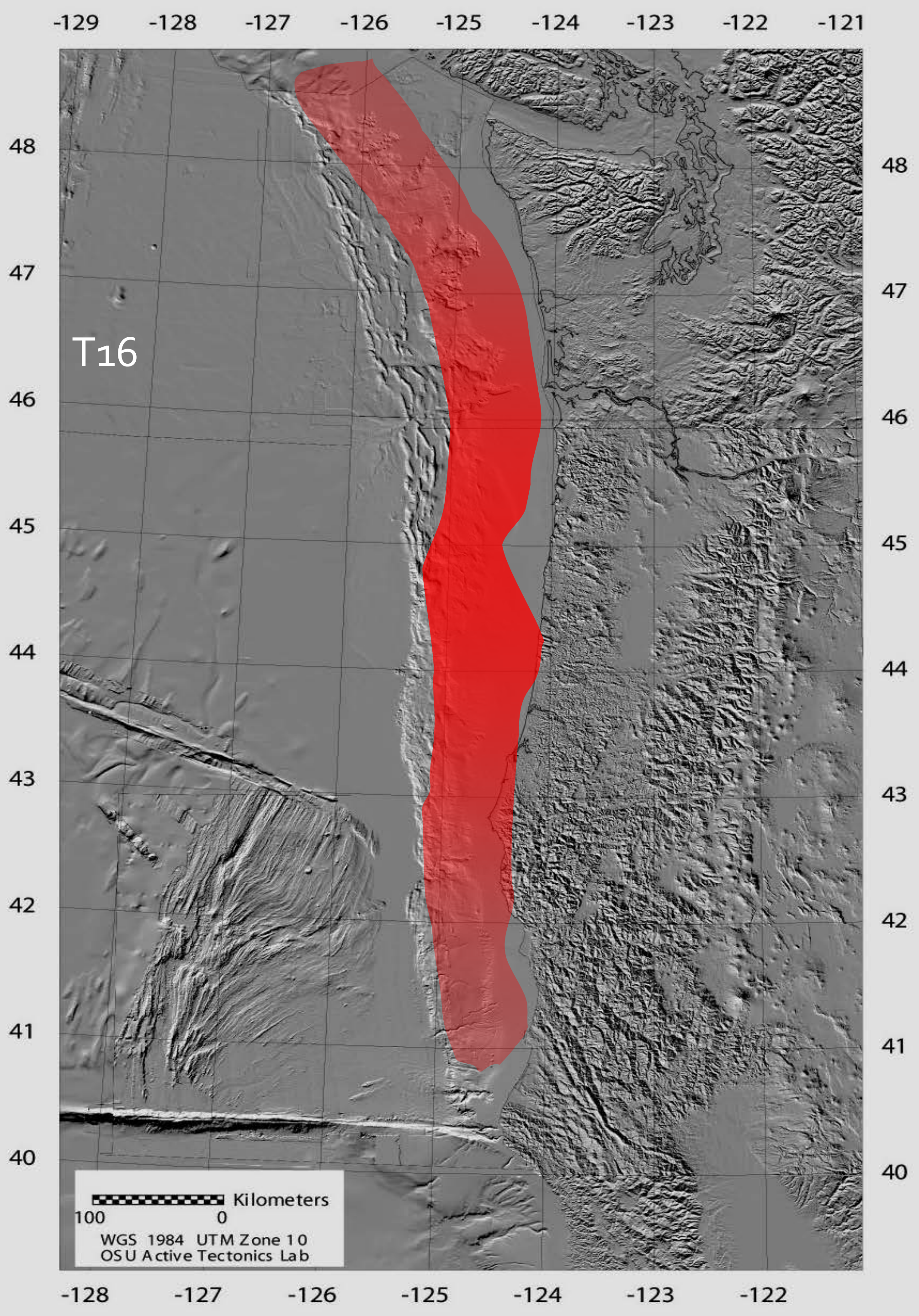
Event pulses that correlate at all sites are shown by flashes of the "locked zone" in red. Event "size" shown by intensity of red shading

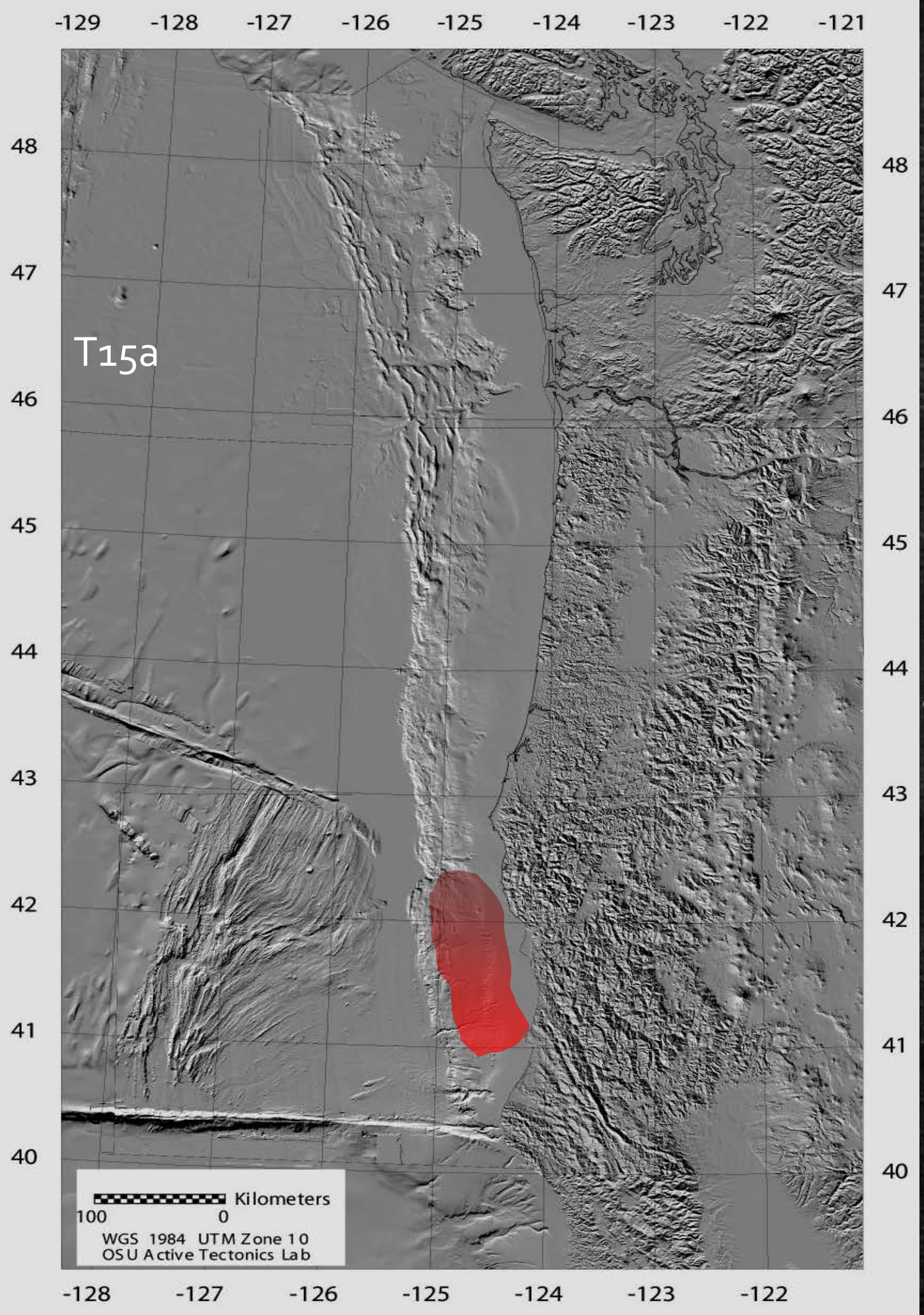

-129
-128
-127
-126
-125
-124
-123
-122
-121
48
47
46
45
44
43
42
41
40
T18
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128
-127
-126
-125
-124
-123
-122


T17a
-129
-128
-127
-126
-125
-124
-123
-122
-121
48
47
46
45
44
43
42
41
40
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128
-127
-126
-125
-124
-123
-122

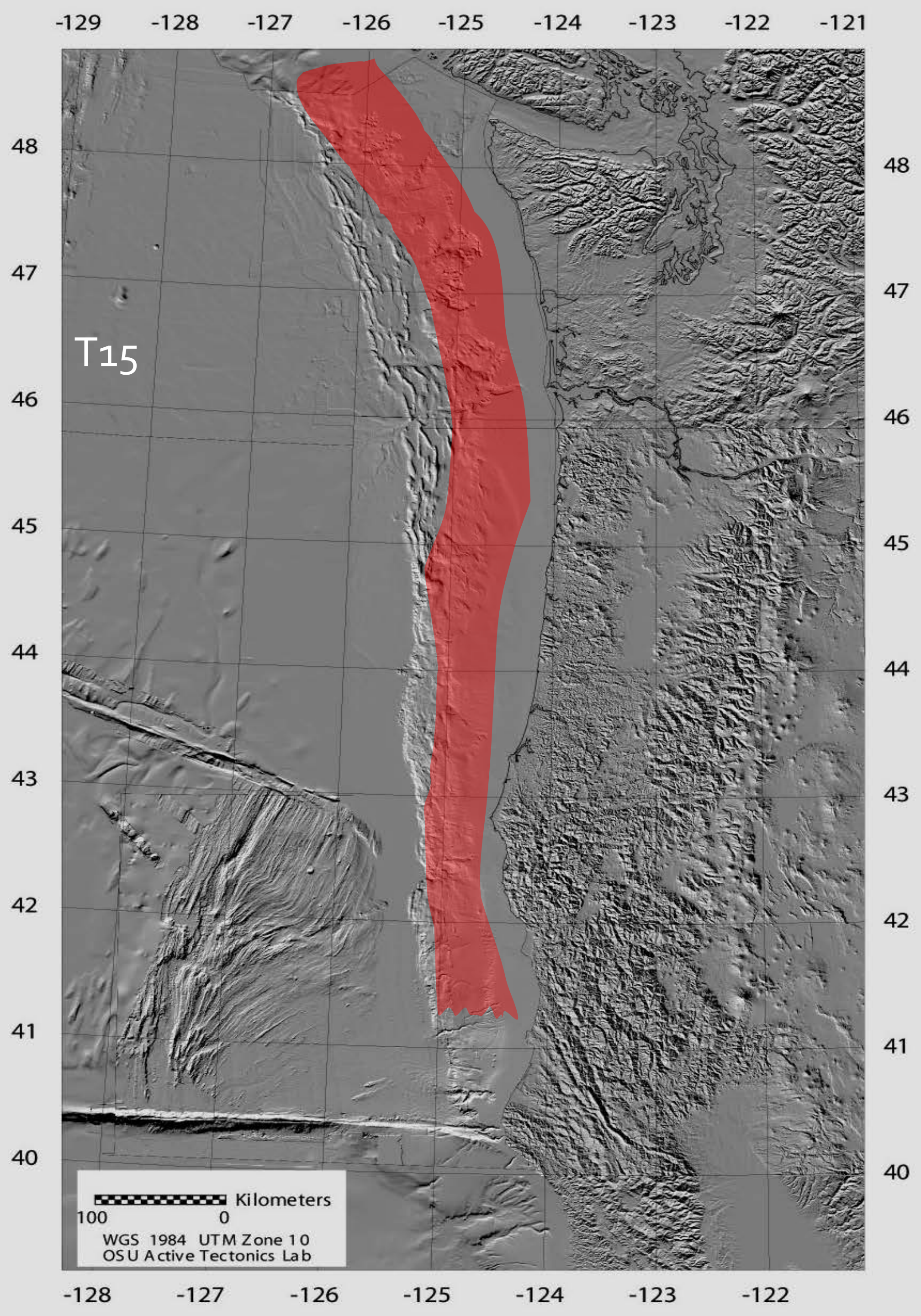

-129 -128 -127 -126 -125 -124 -123 -122 -121
48 47 46 45 44 43 42 41 40
T17
Kilometers
100 0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128 -127 -126 -125 -124 -123 -122


-129 -128 -127 -126 -125 -124 -123 -122 -121
48
47
46
45
44
43
42
41
40
T16a
Kilometers
100 0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128 -127 -126 -125 -124 -123 -122

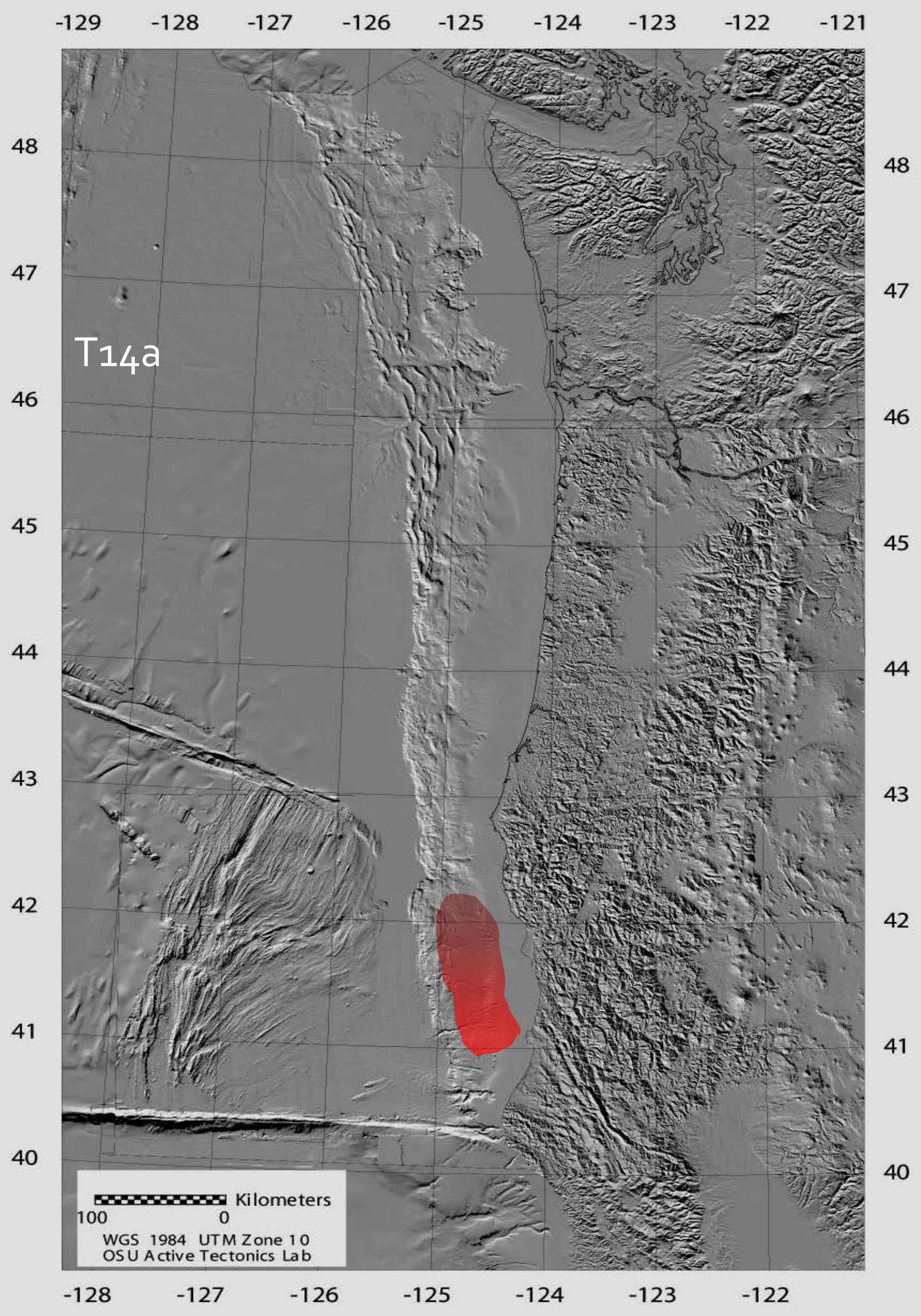

-129 -128 -127 -126 -125 -124 -123 -122 -121
48 47 46 45 44 43 42 41 40
T16
Kilometers
100 0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128 -127 -126 -125 -124 -123 -122



-129
-128
-127
-126
-125
-124
-123
-122
-121
48
47
46
45
44
43
42
41
40
T15a
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128
-127
-126
-125
-124
-123
-122



-129 -128 -127 -126 -125 -124 -123 -122 -121
48
47
46
45
44
43
42
41
40
T15
Kilometers
100 0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
-128 -127 -126 -125 -124 -123 -122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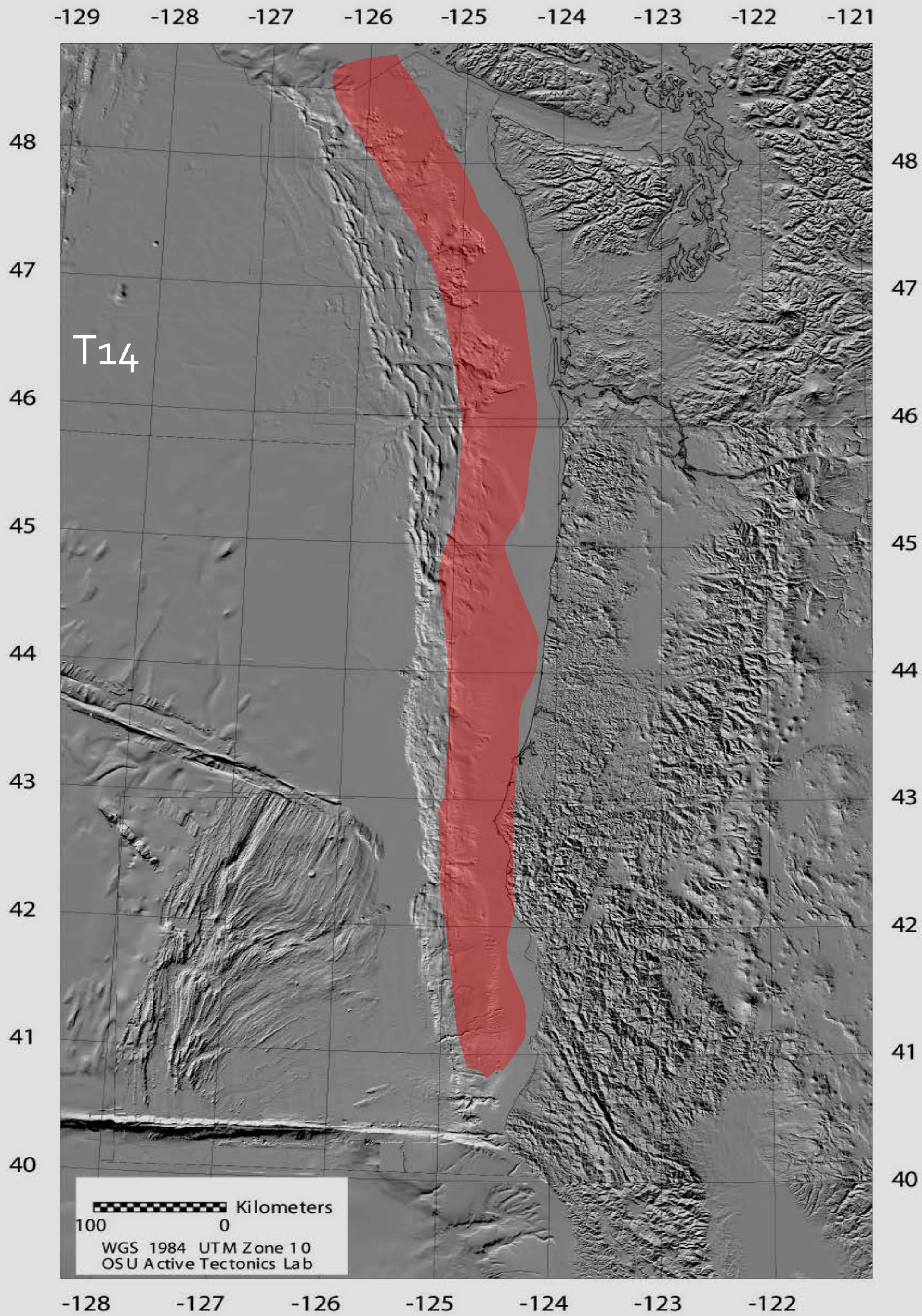
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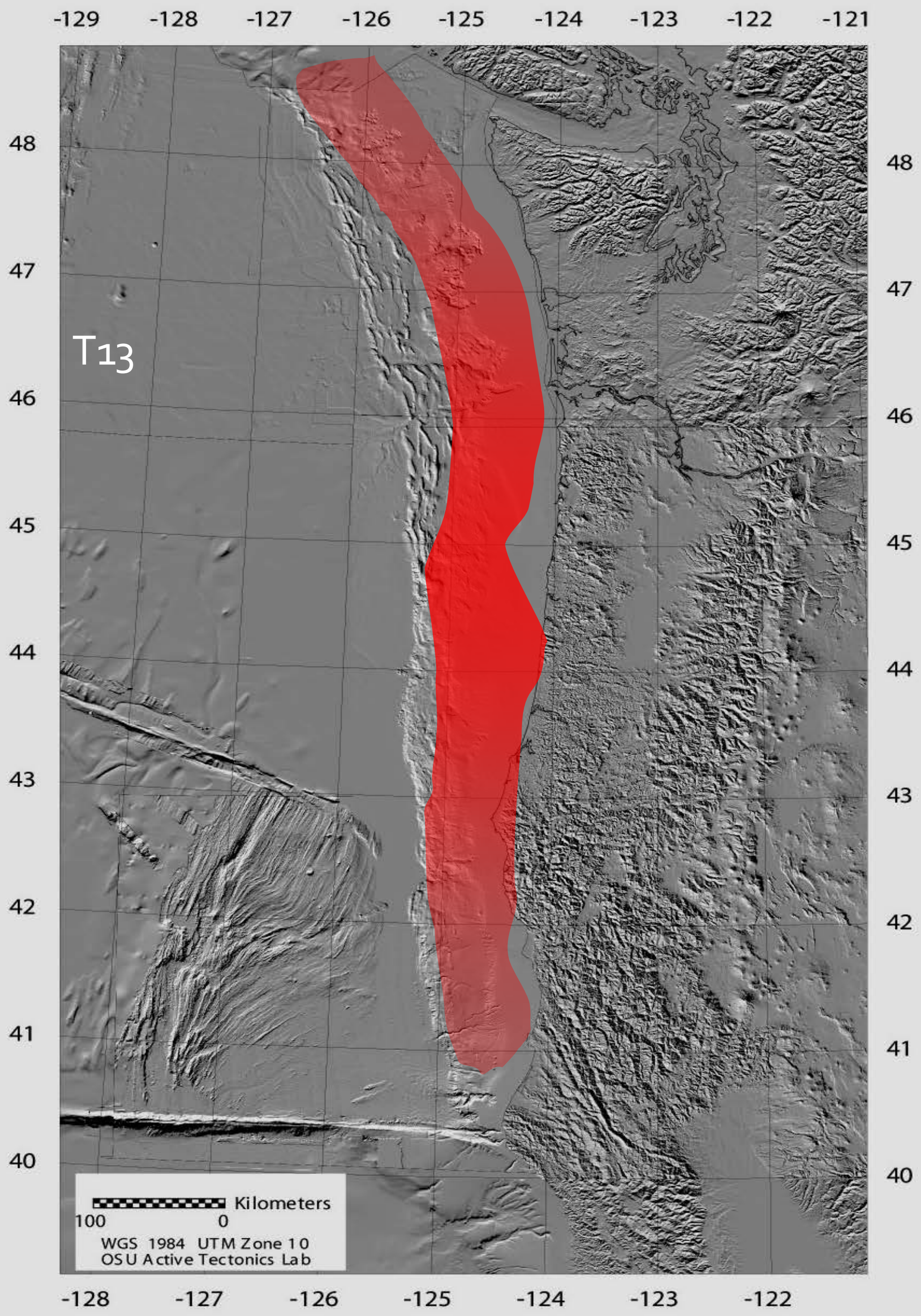
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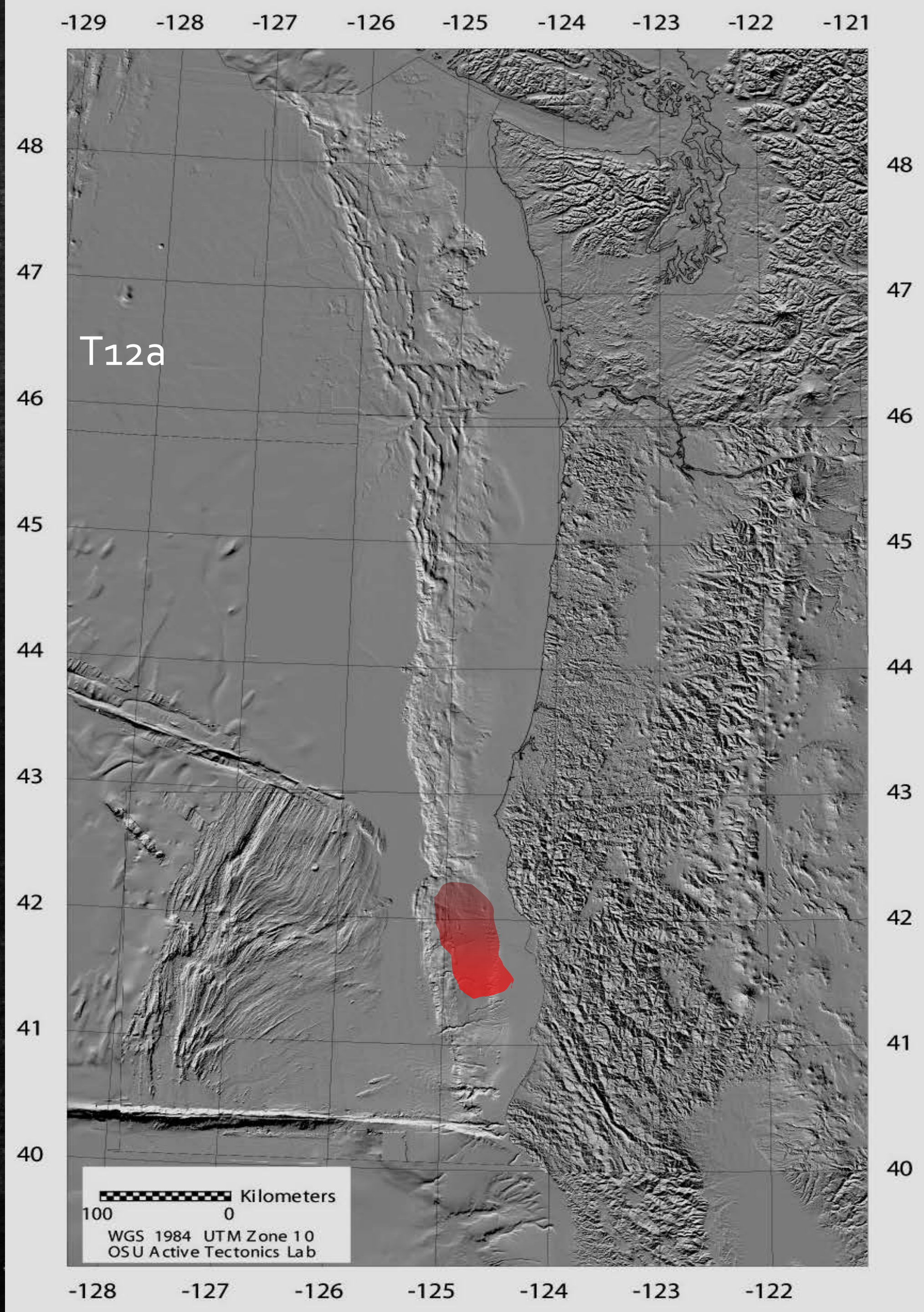

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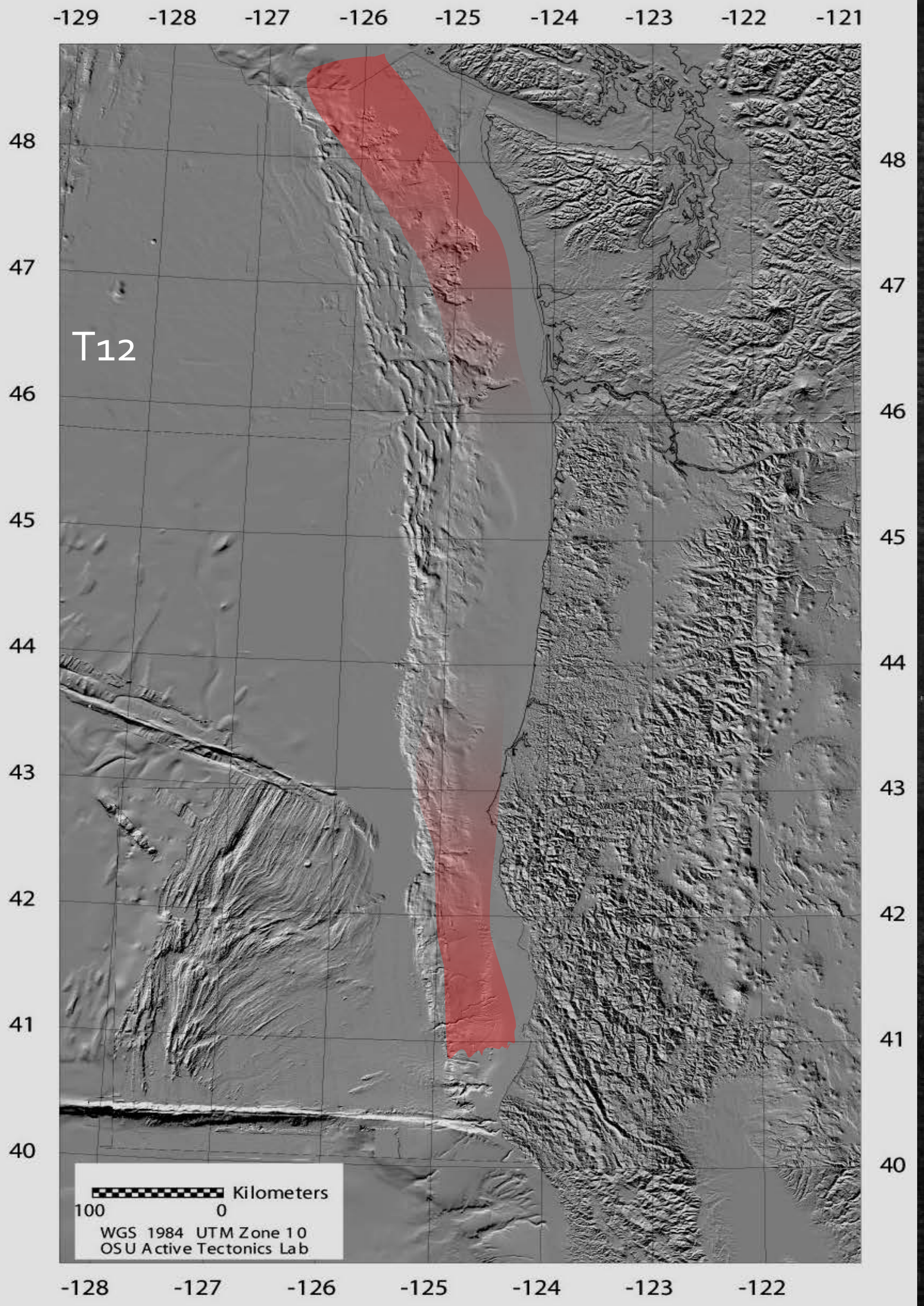

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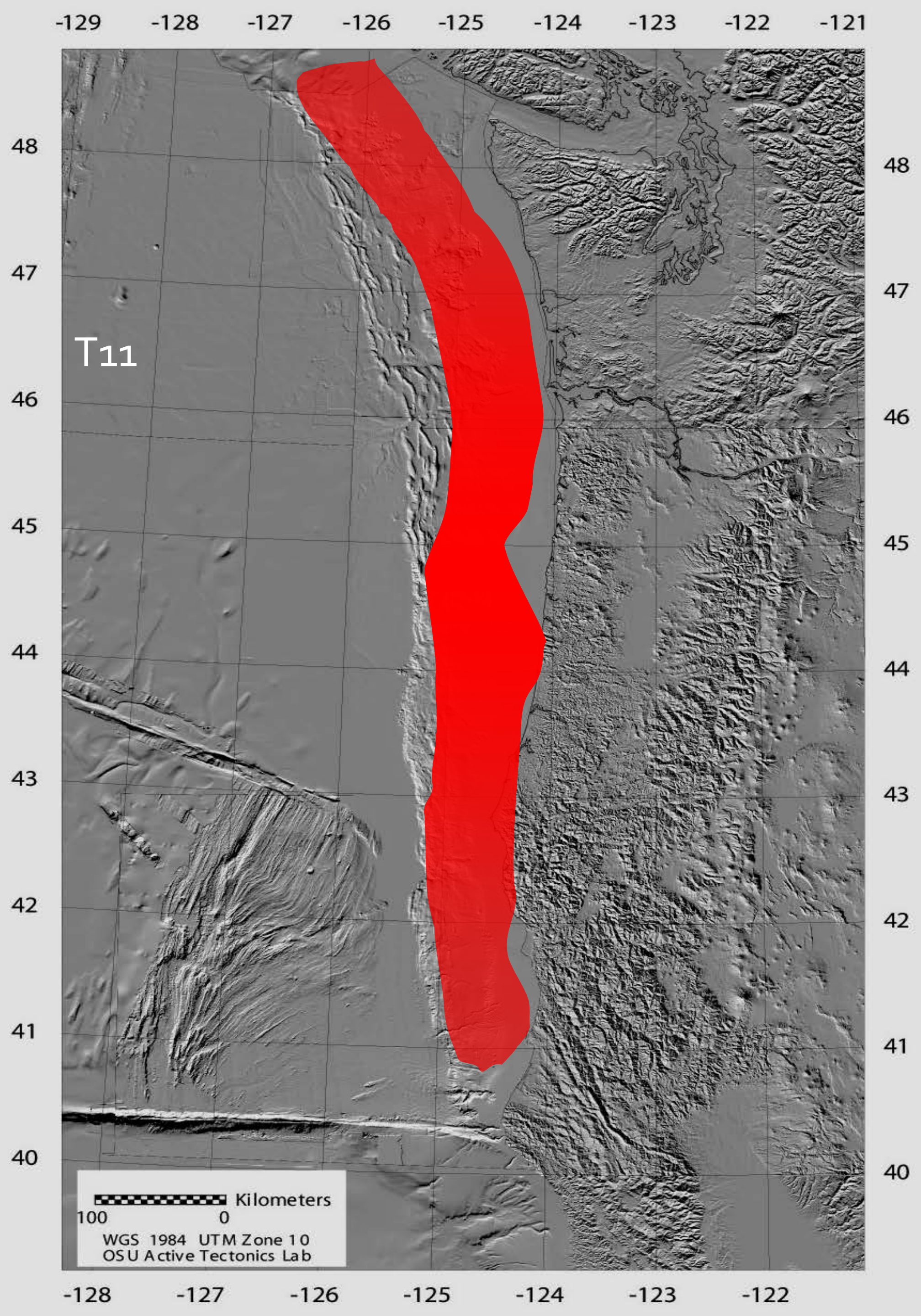
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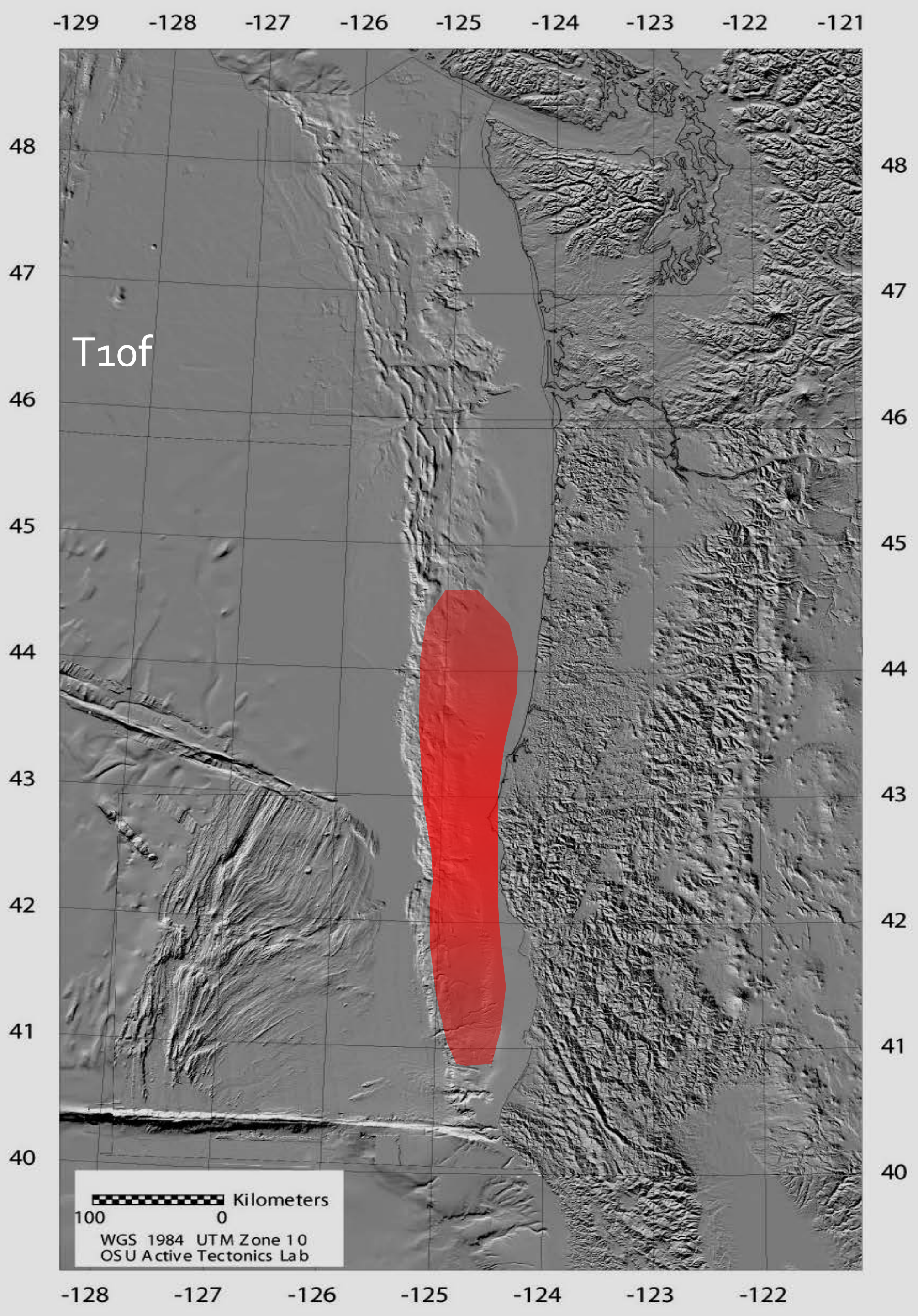

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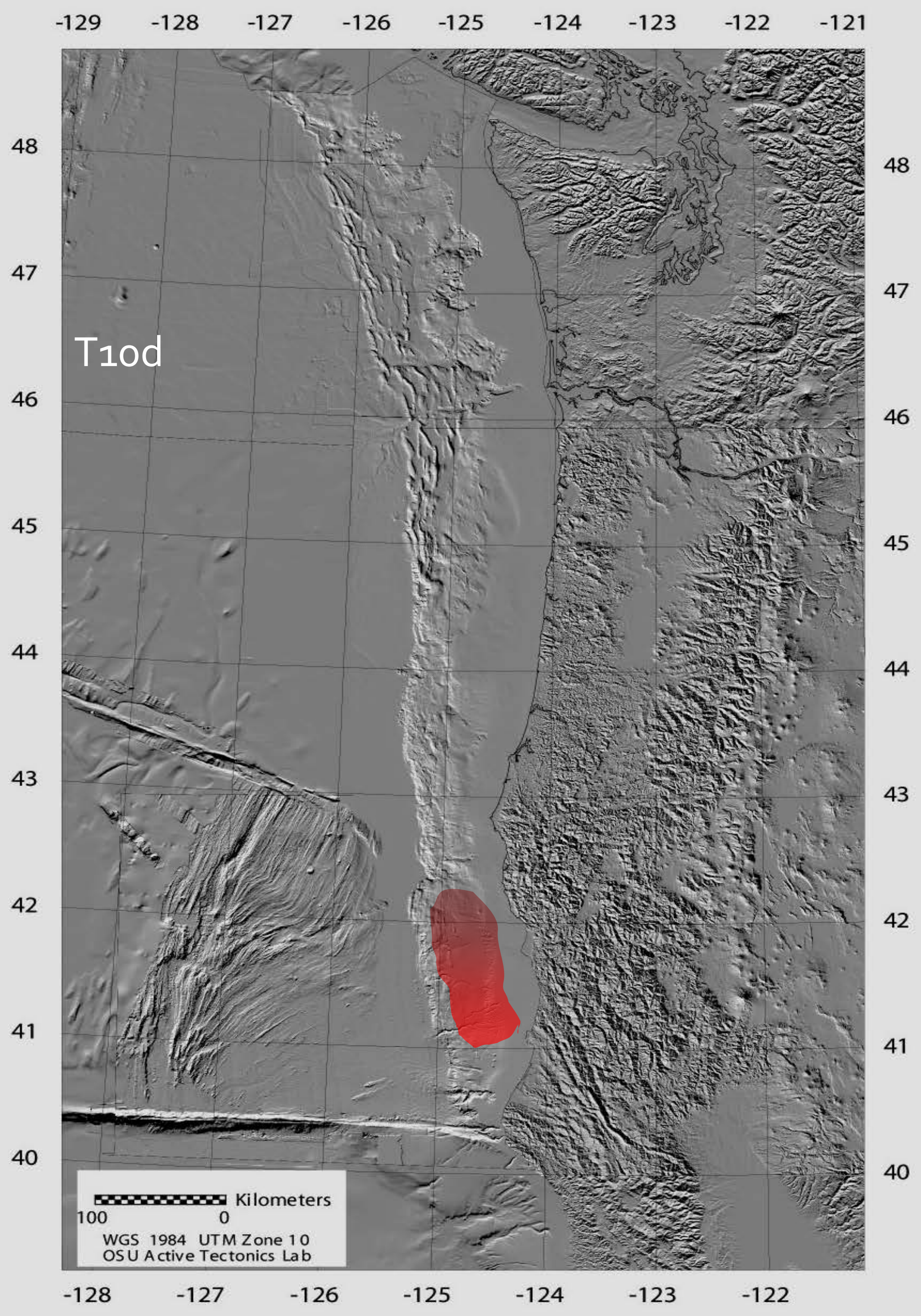

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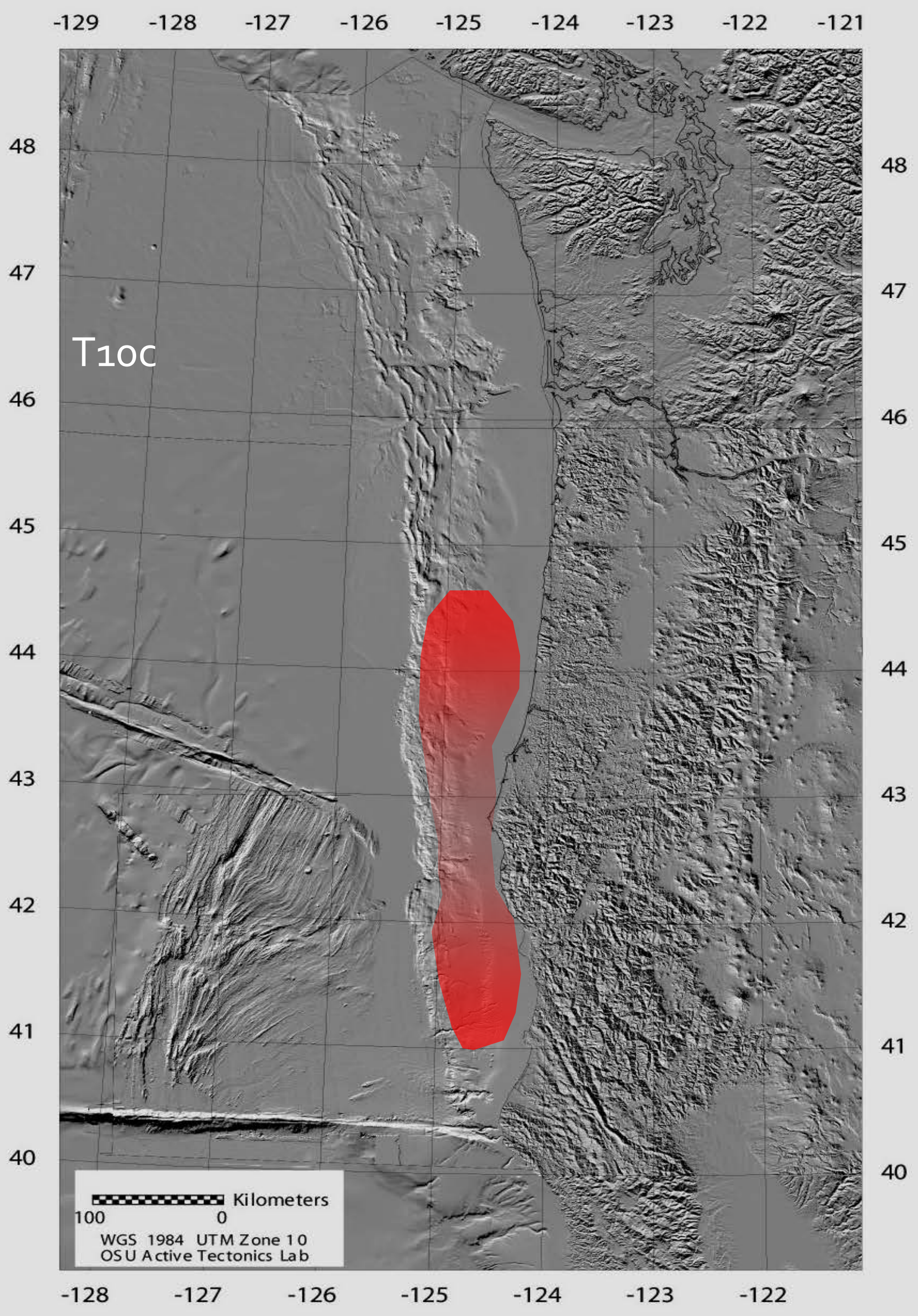

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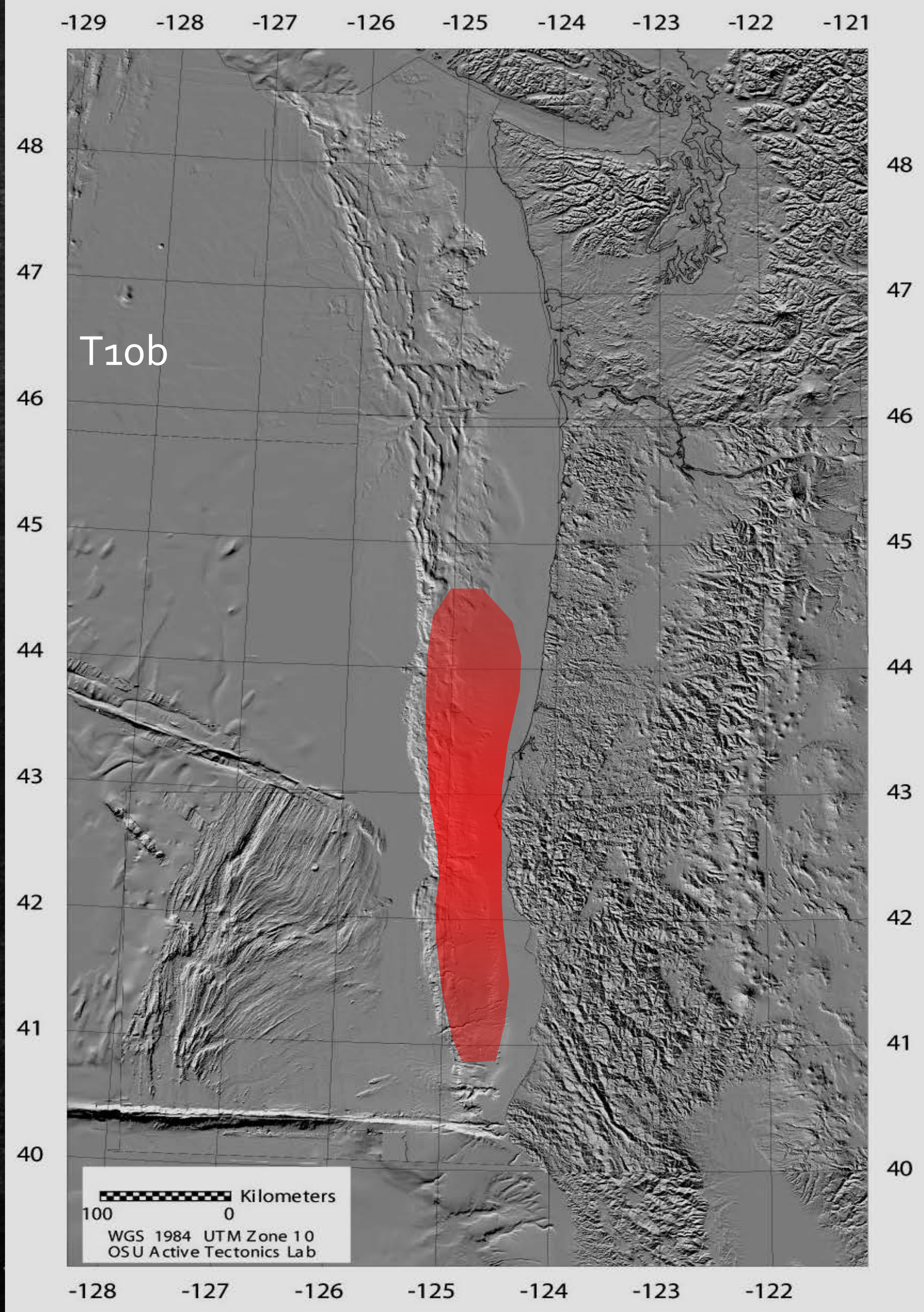

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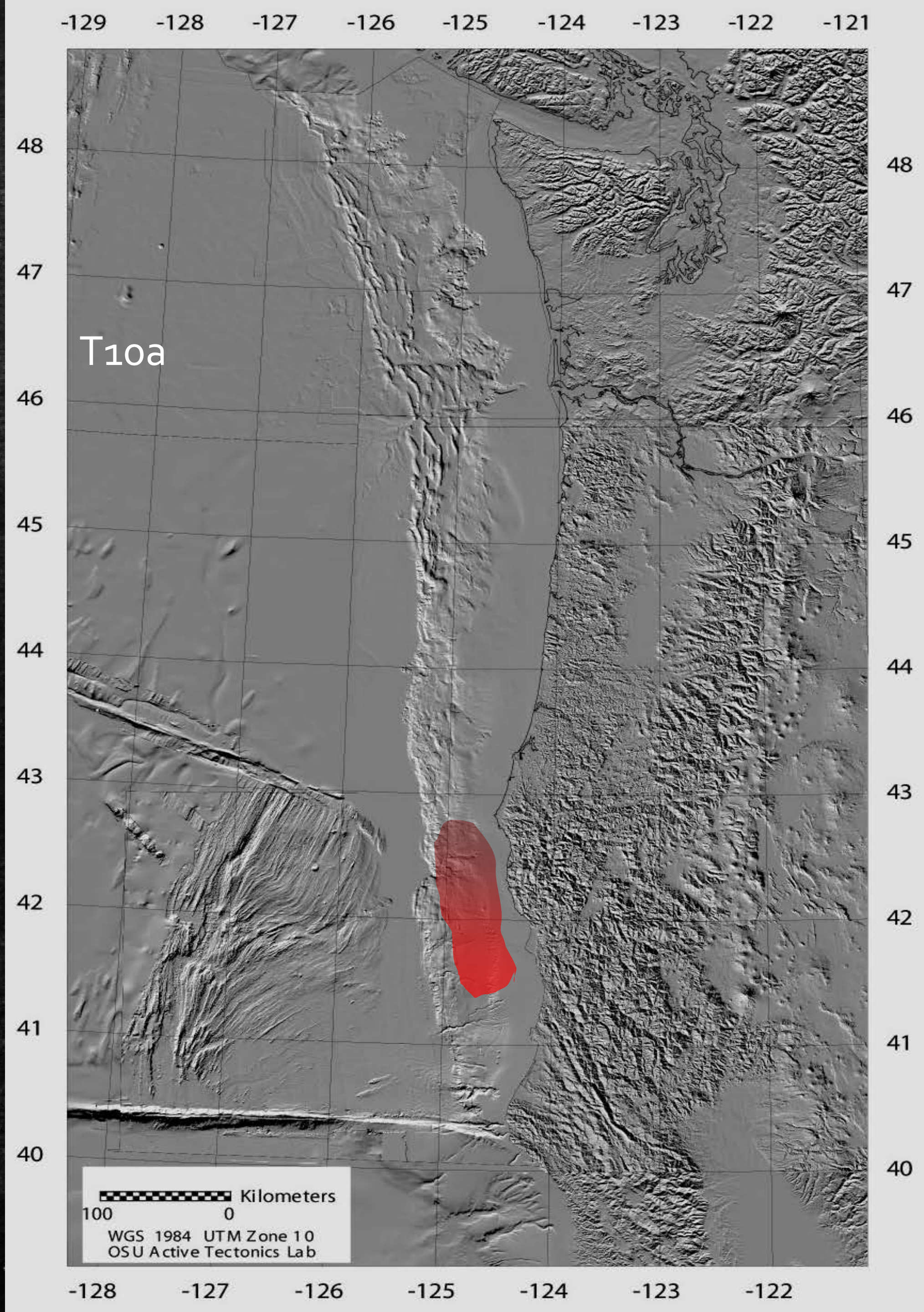

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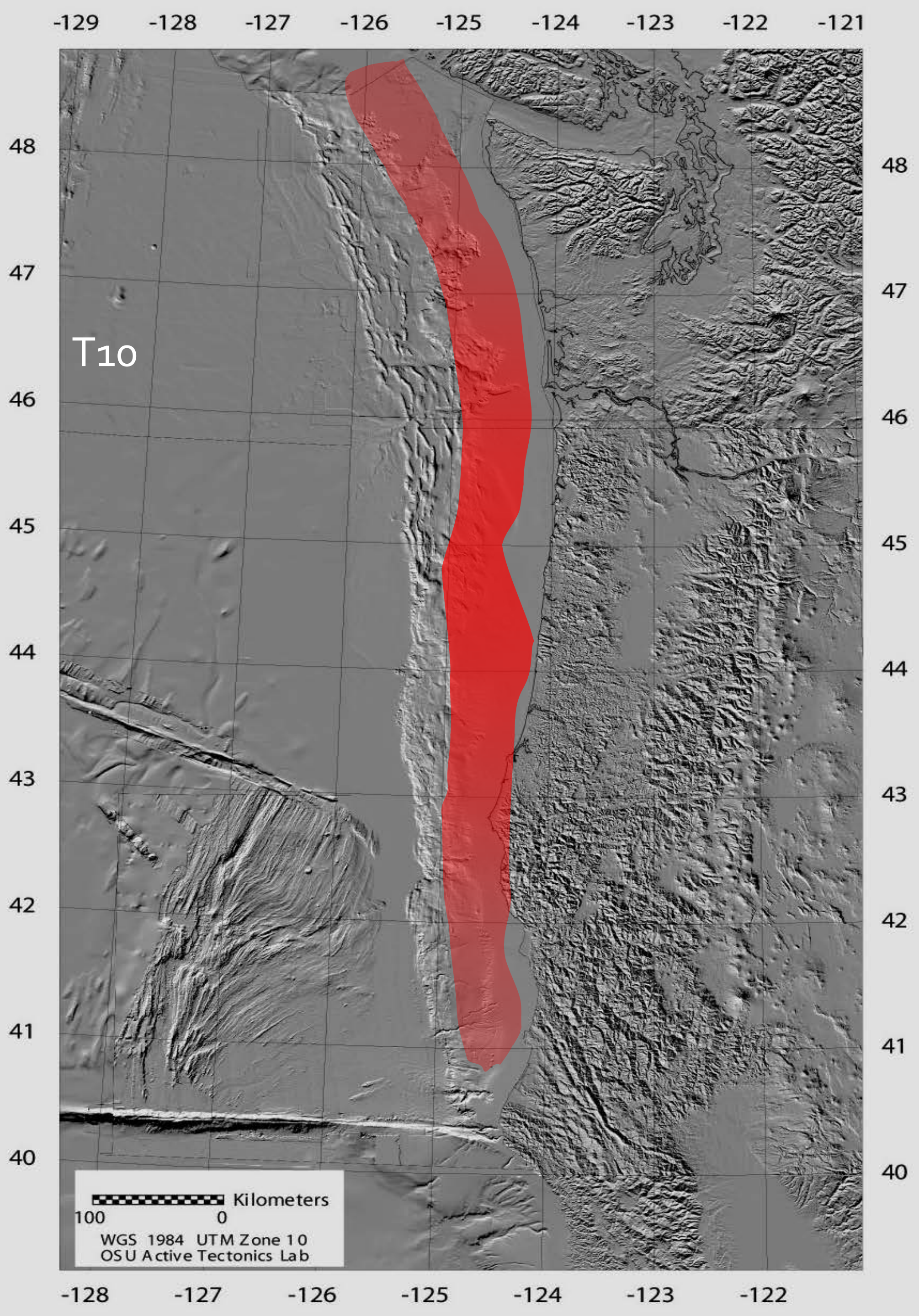
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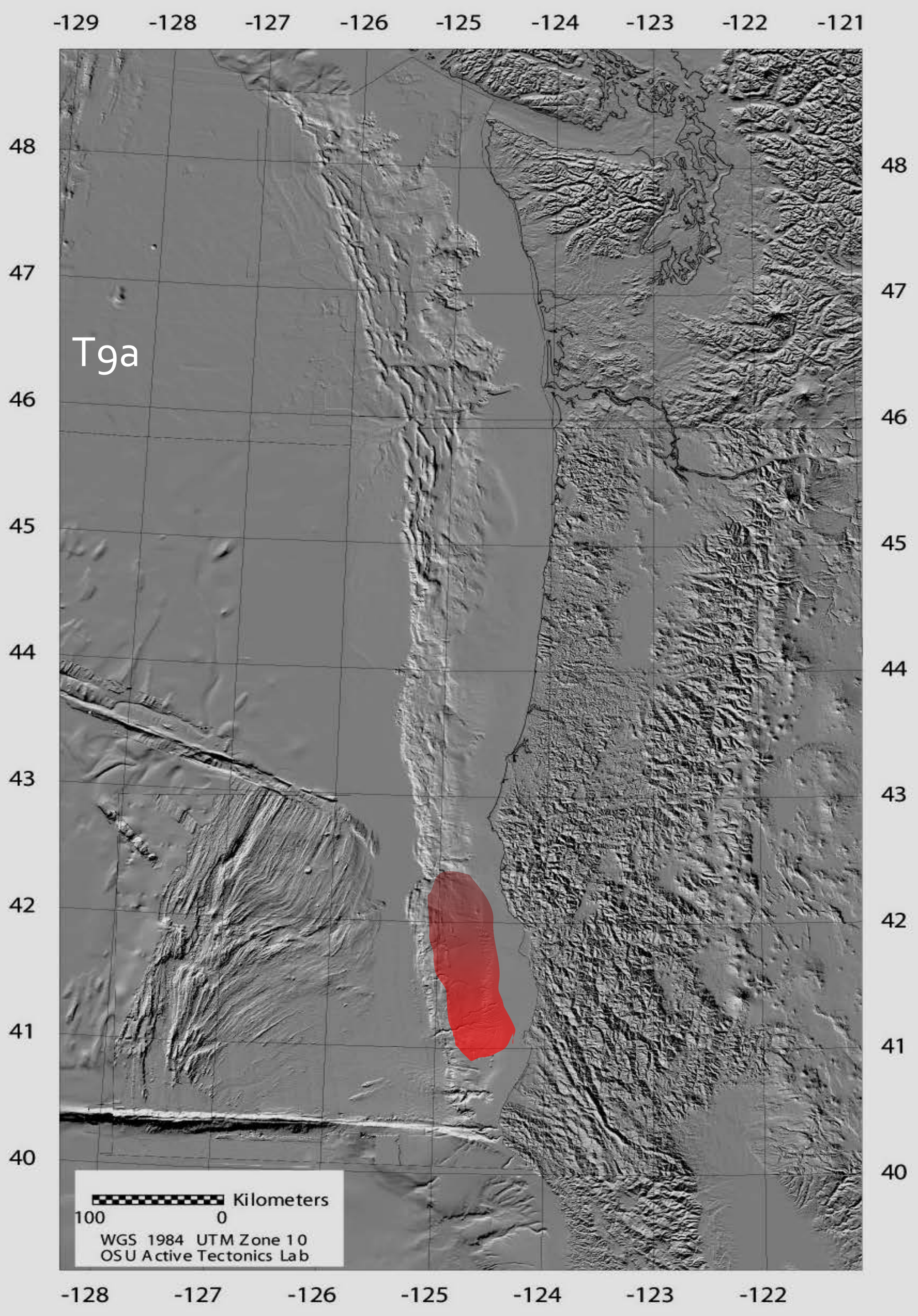

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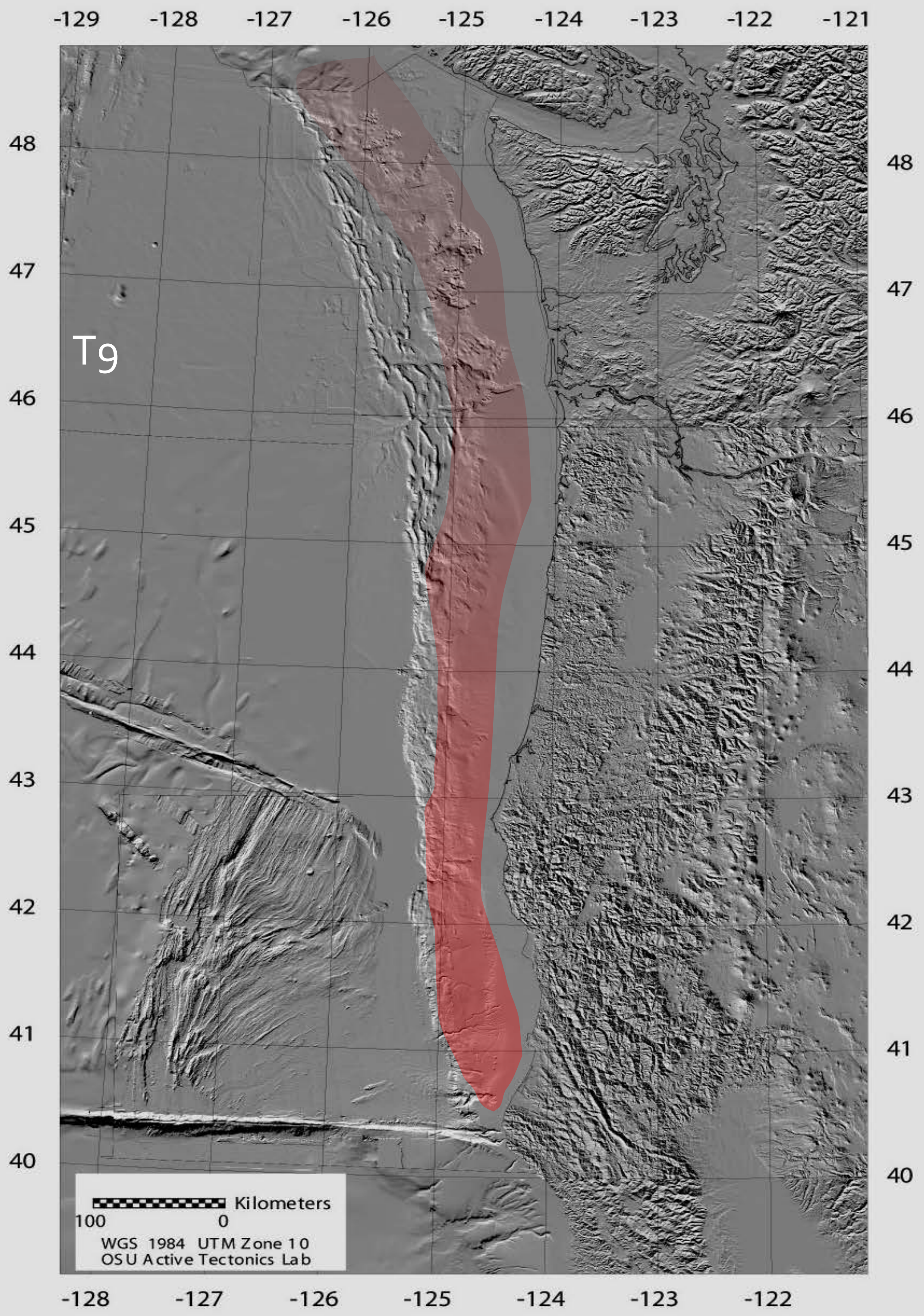

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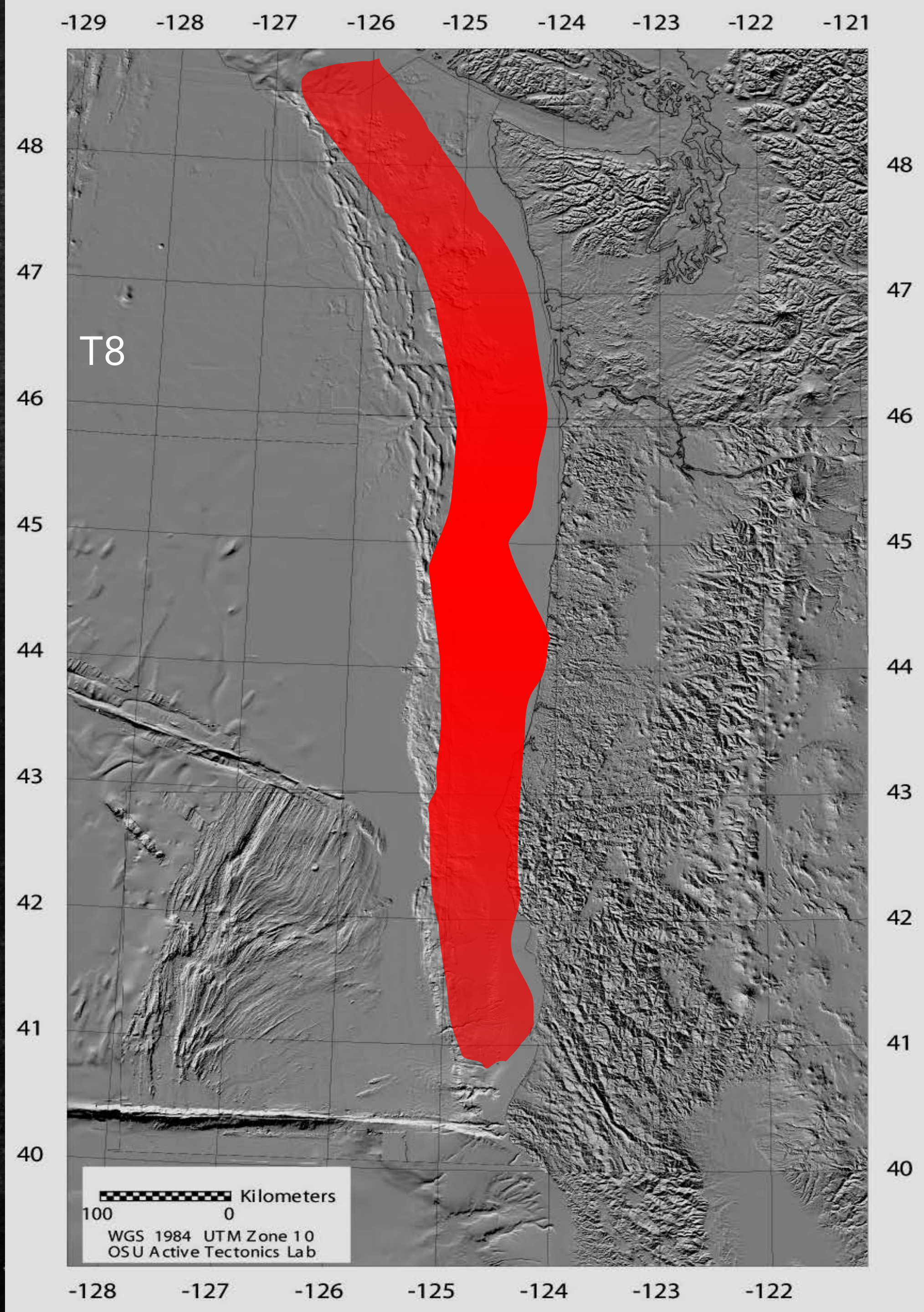
OSU Active Tectonics Lab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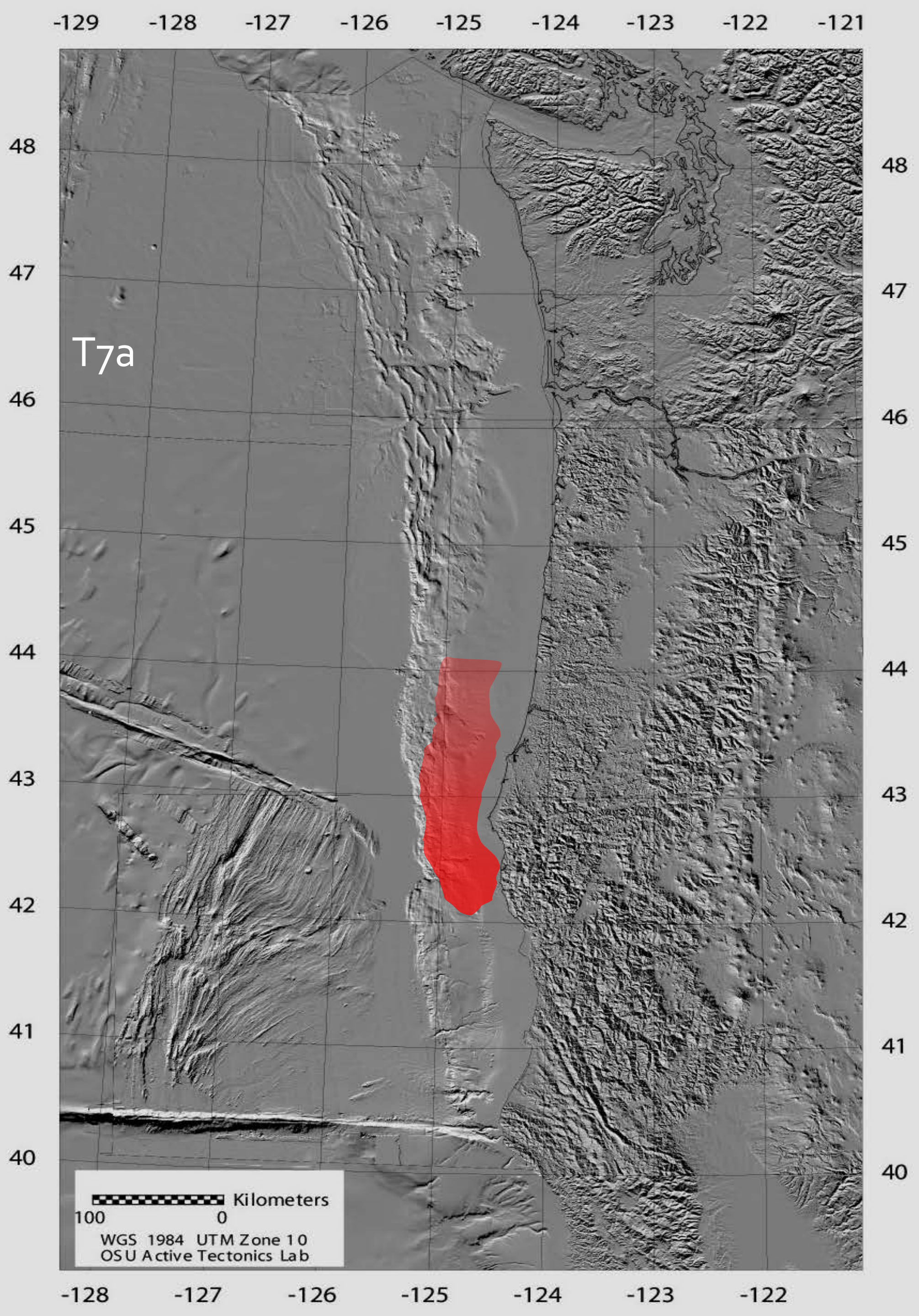
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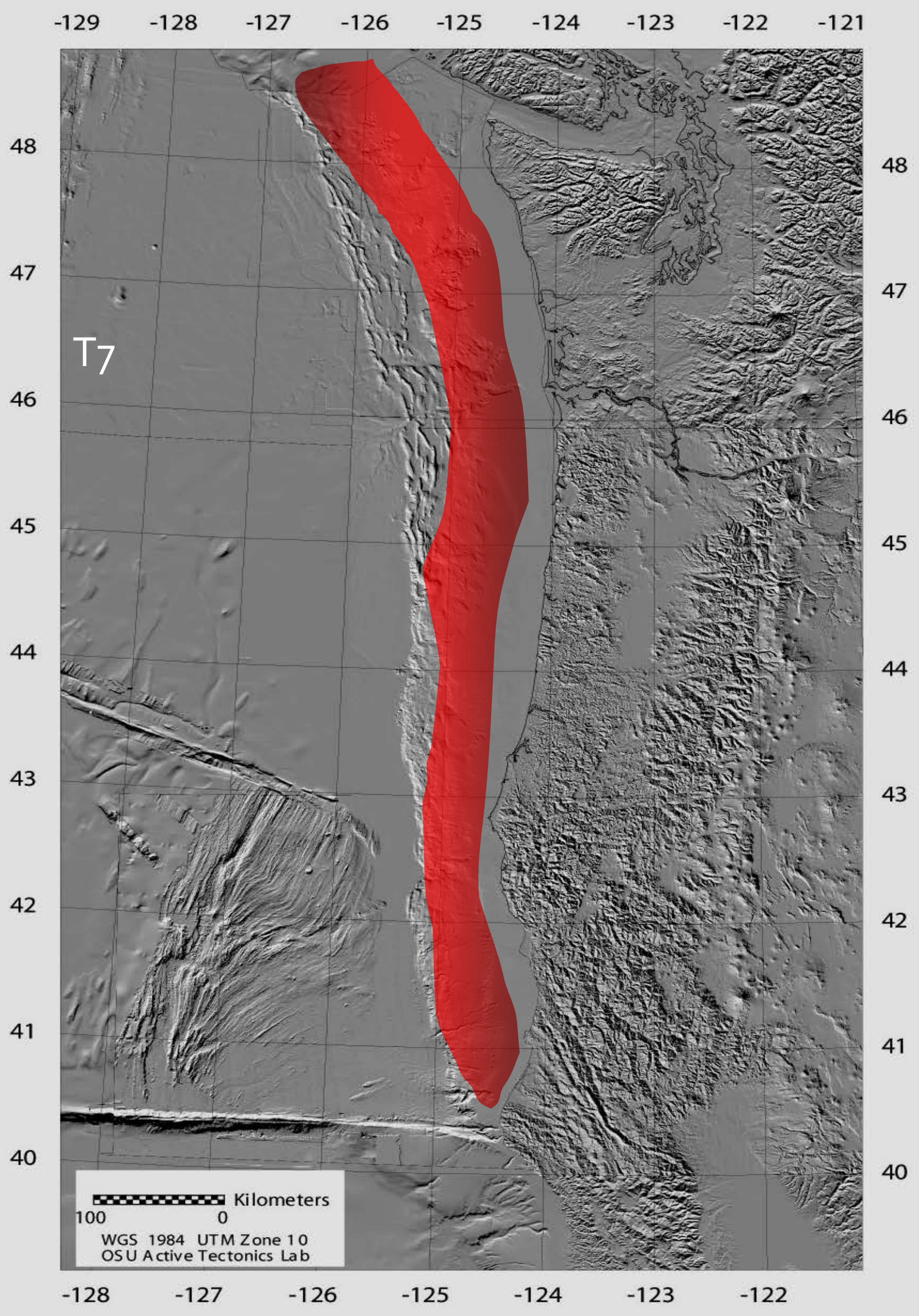
OSU Active Tectonics Lab



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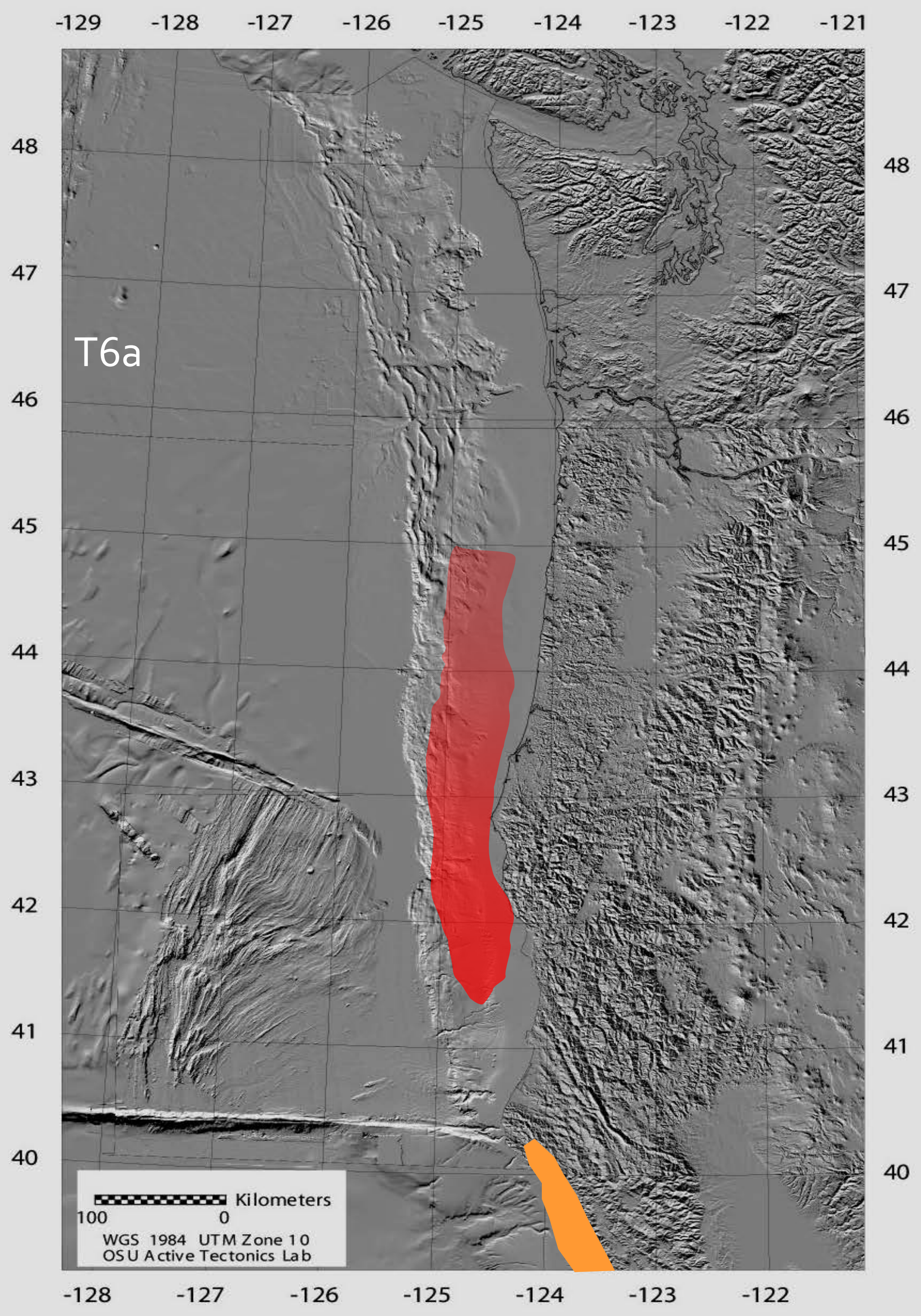
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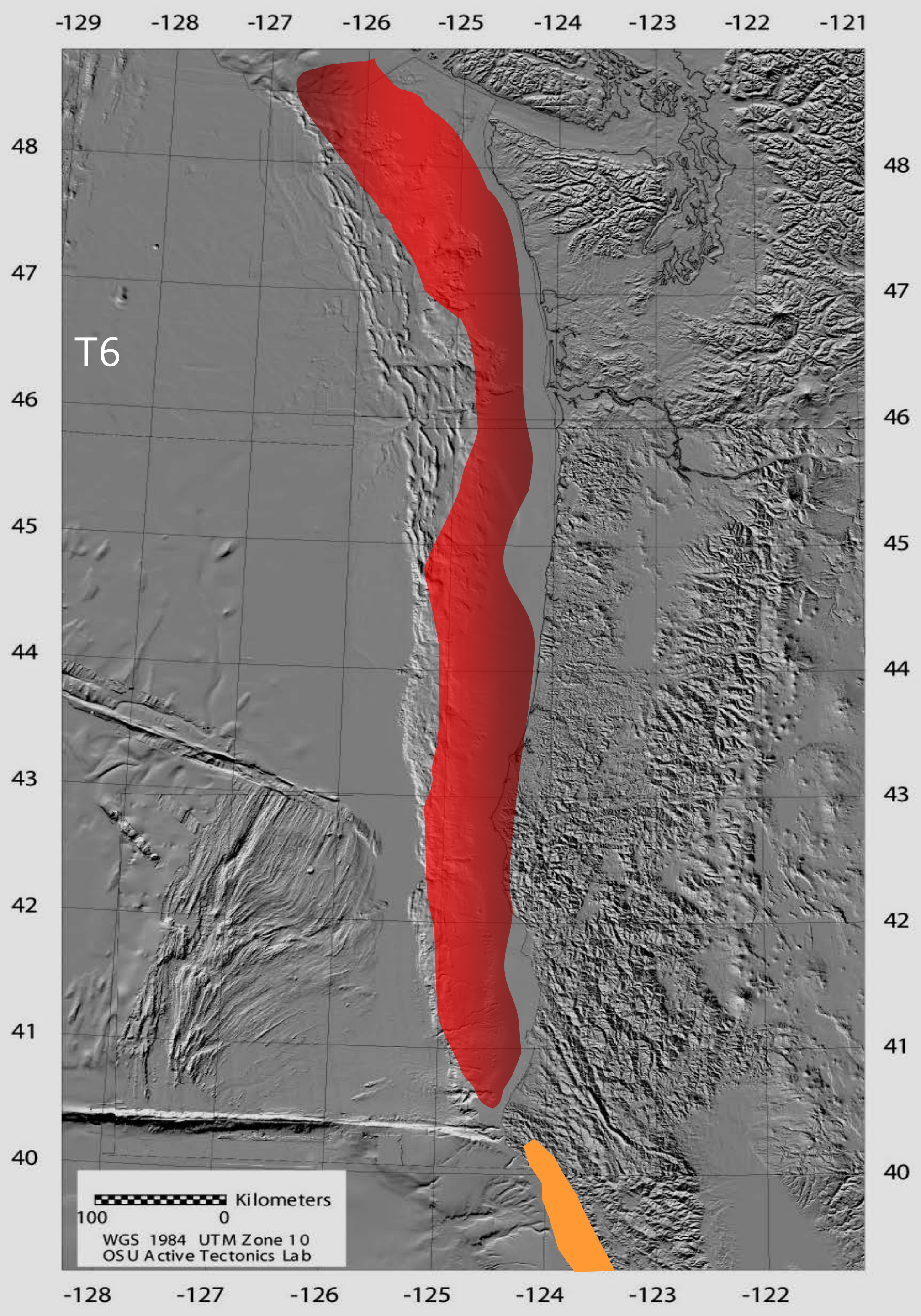

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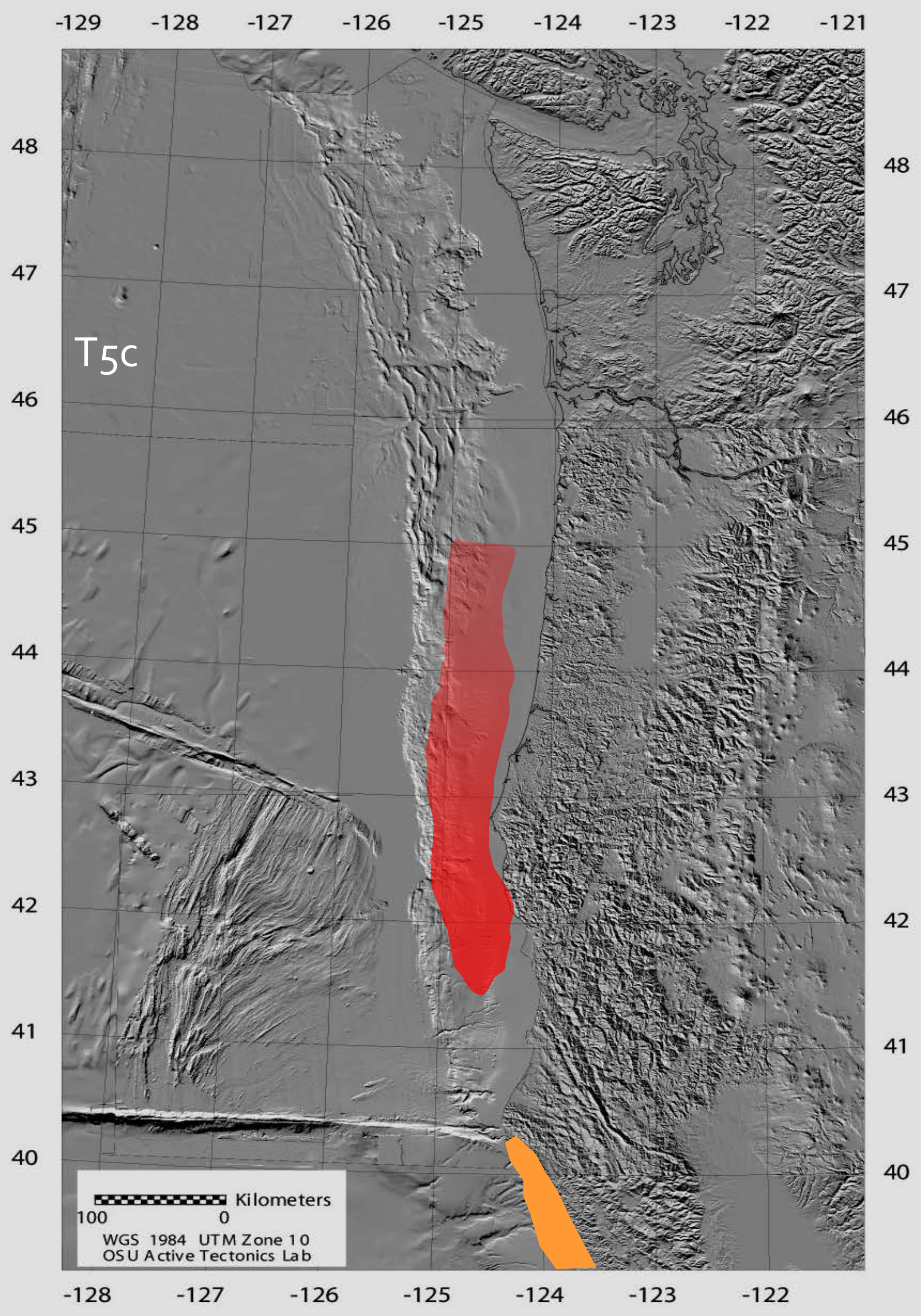
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T5c
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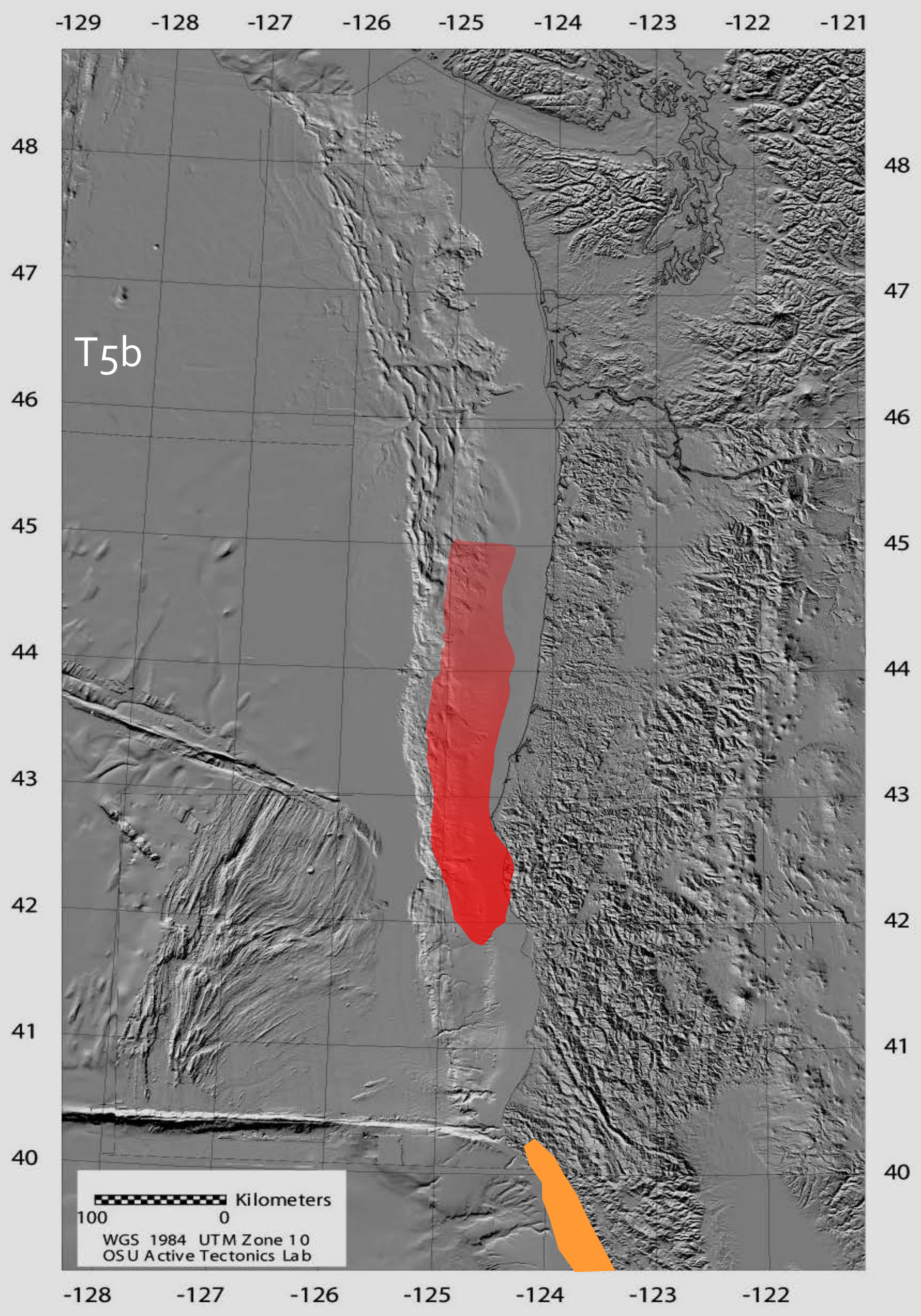
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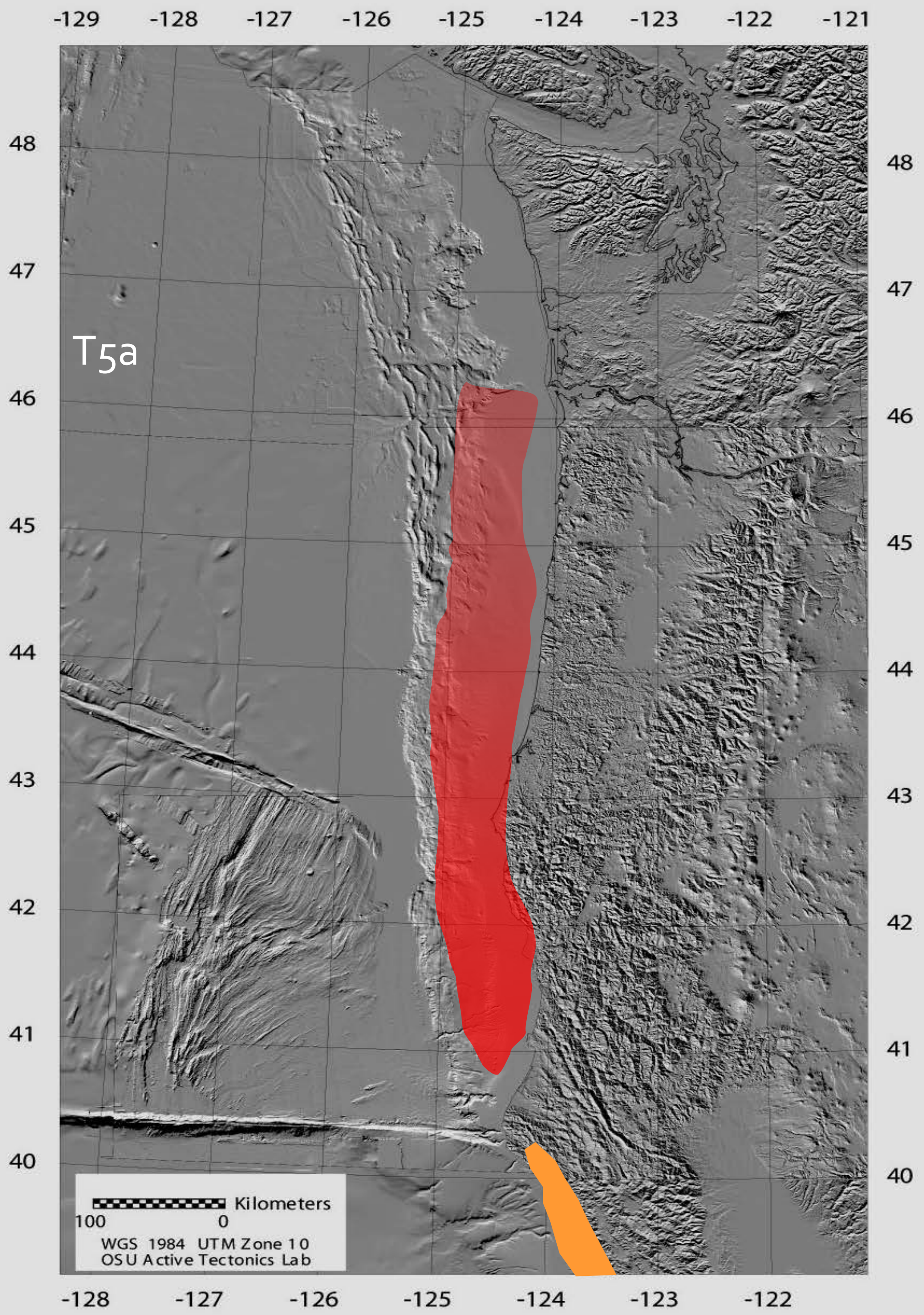
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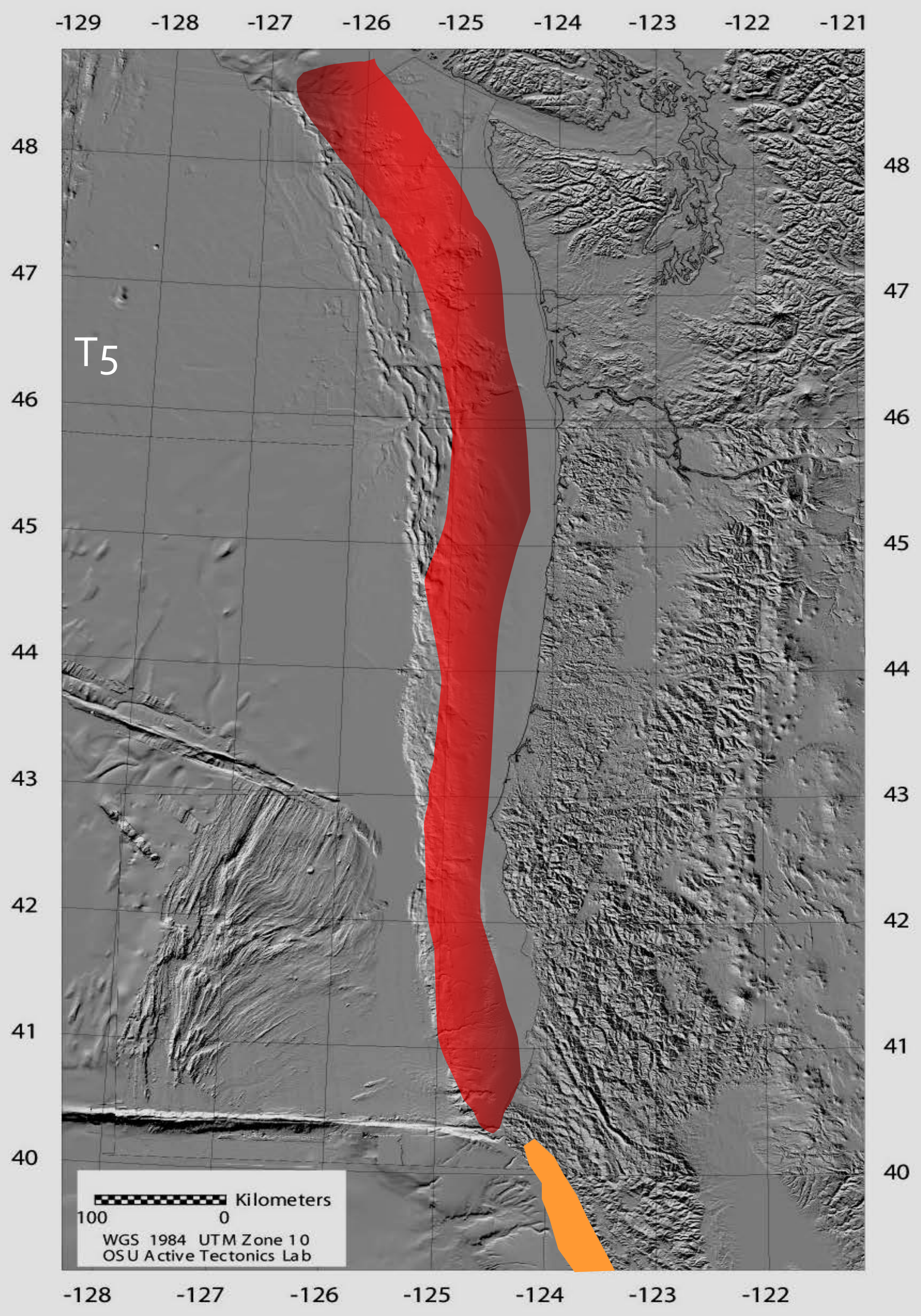

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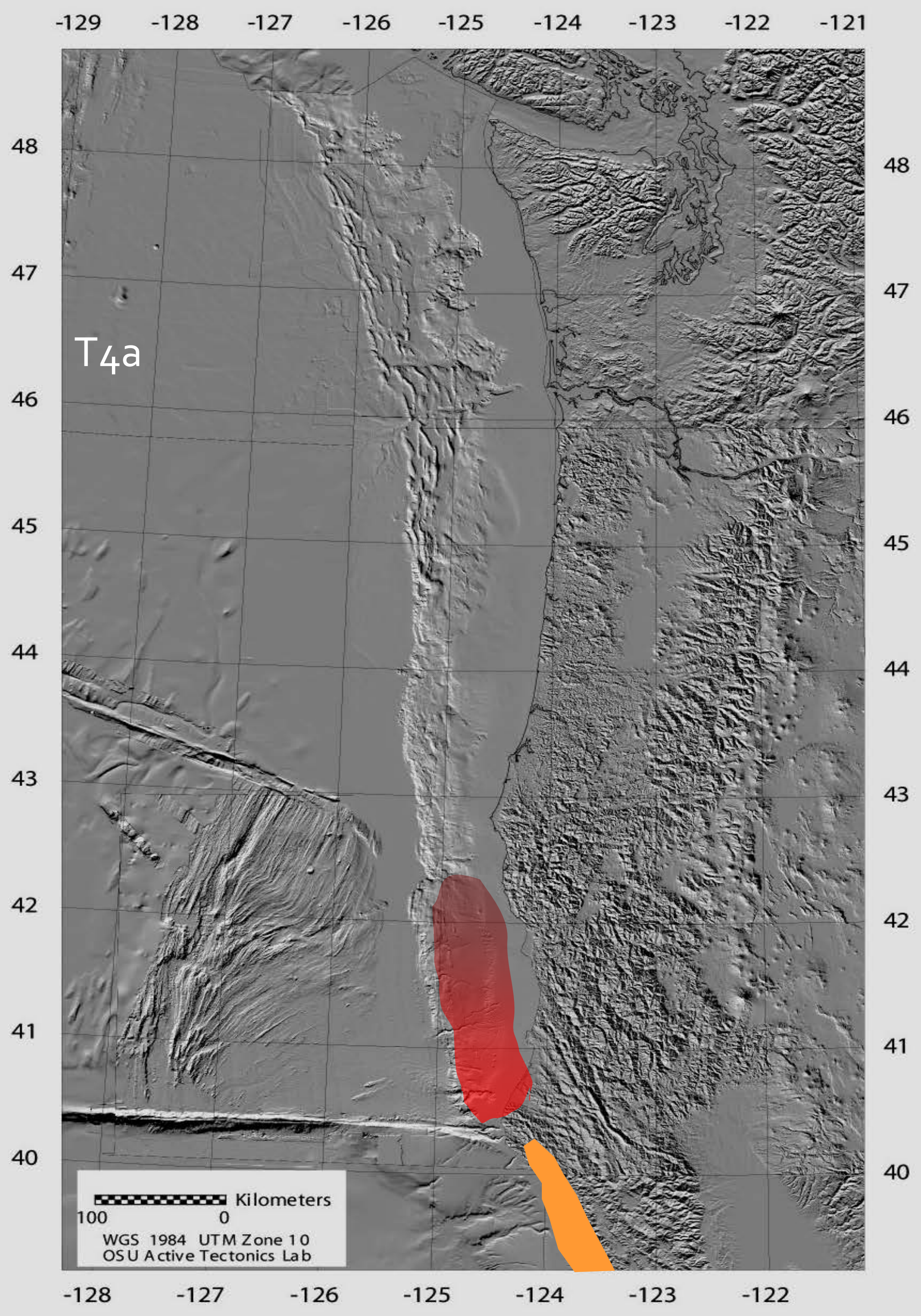

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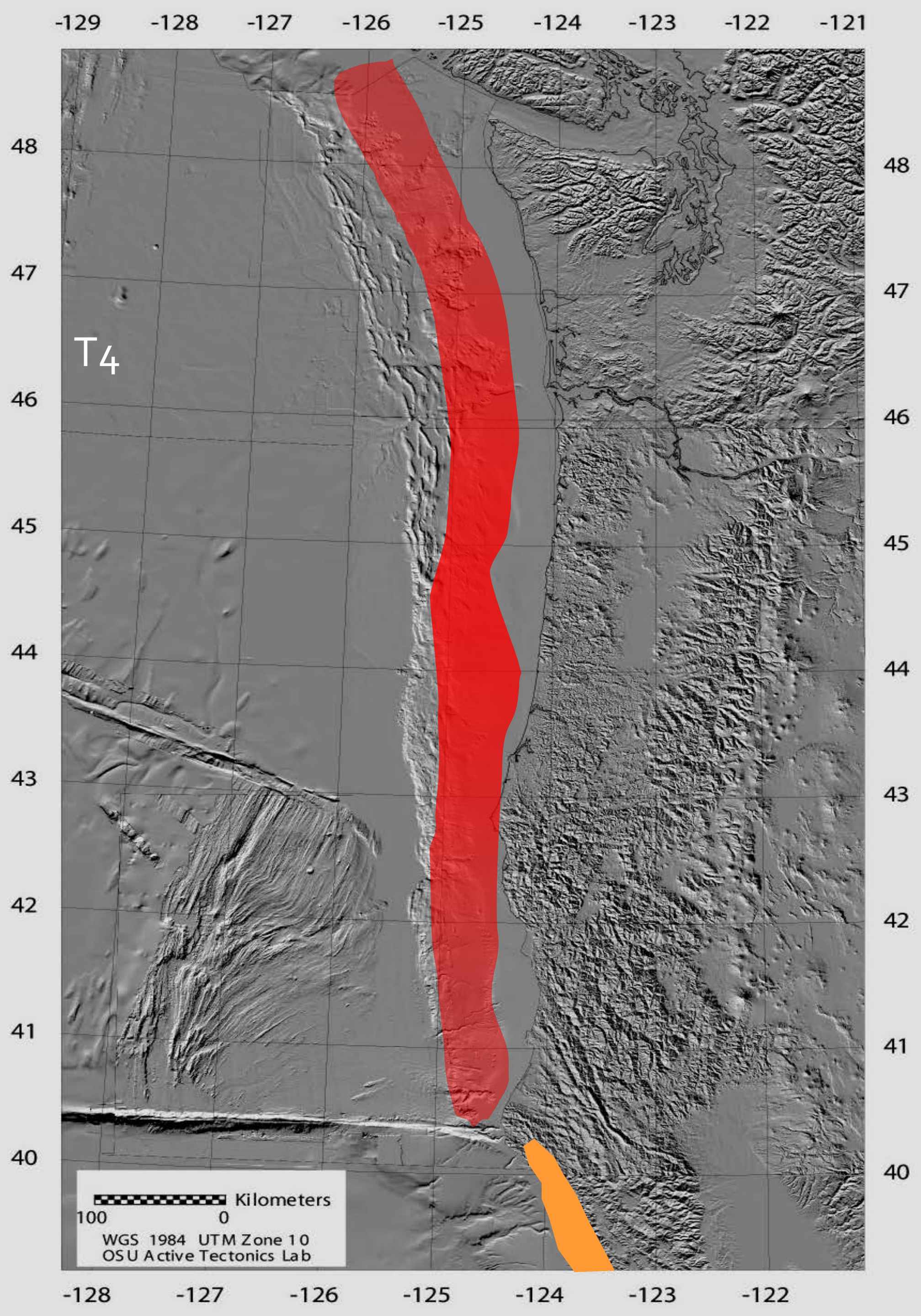

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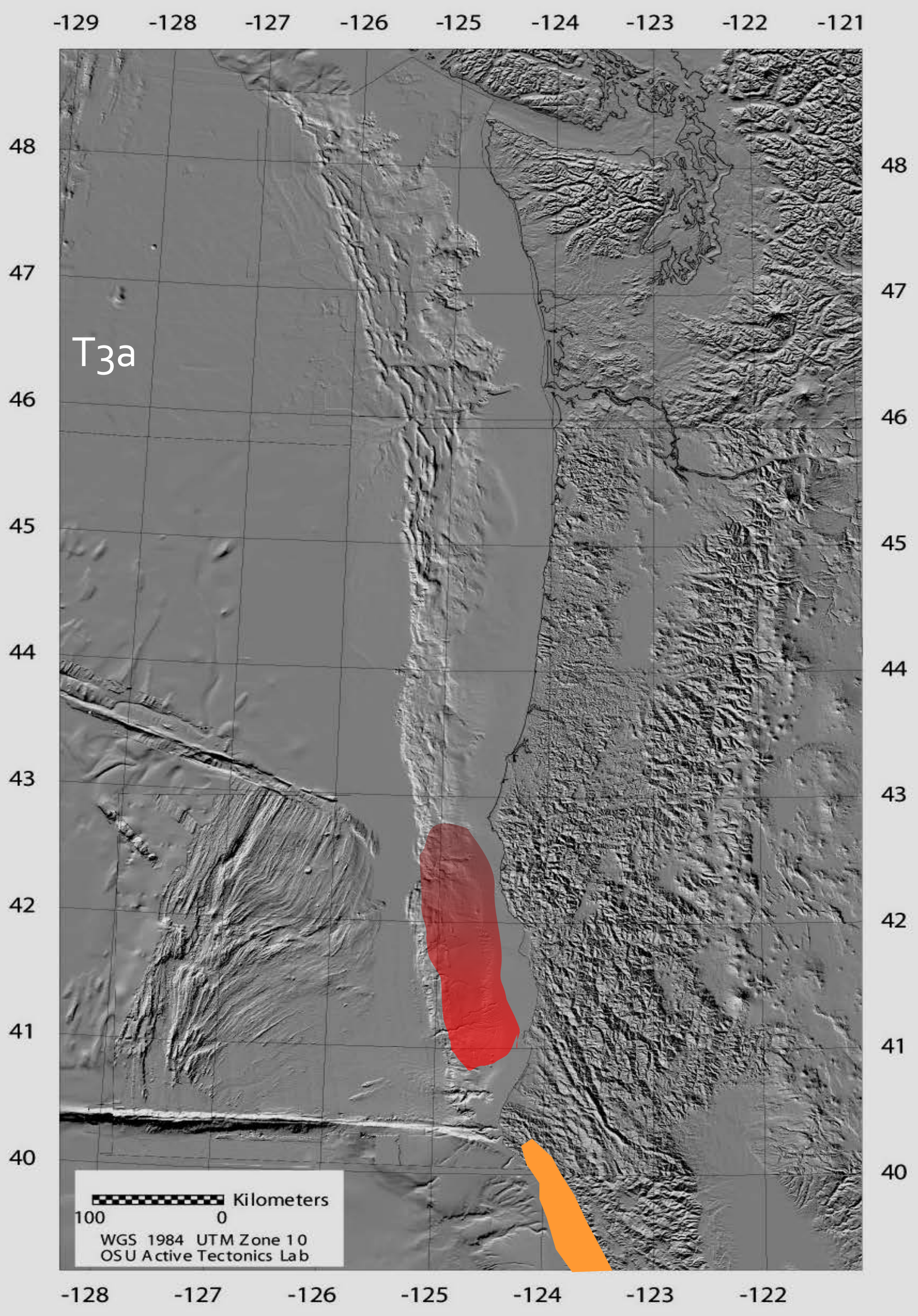
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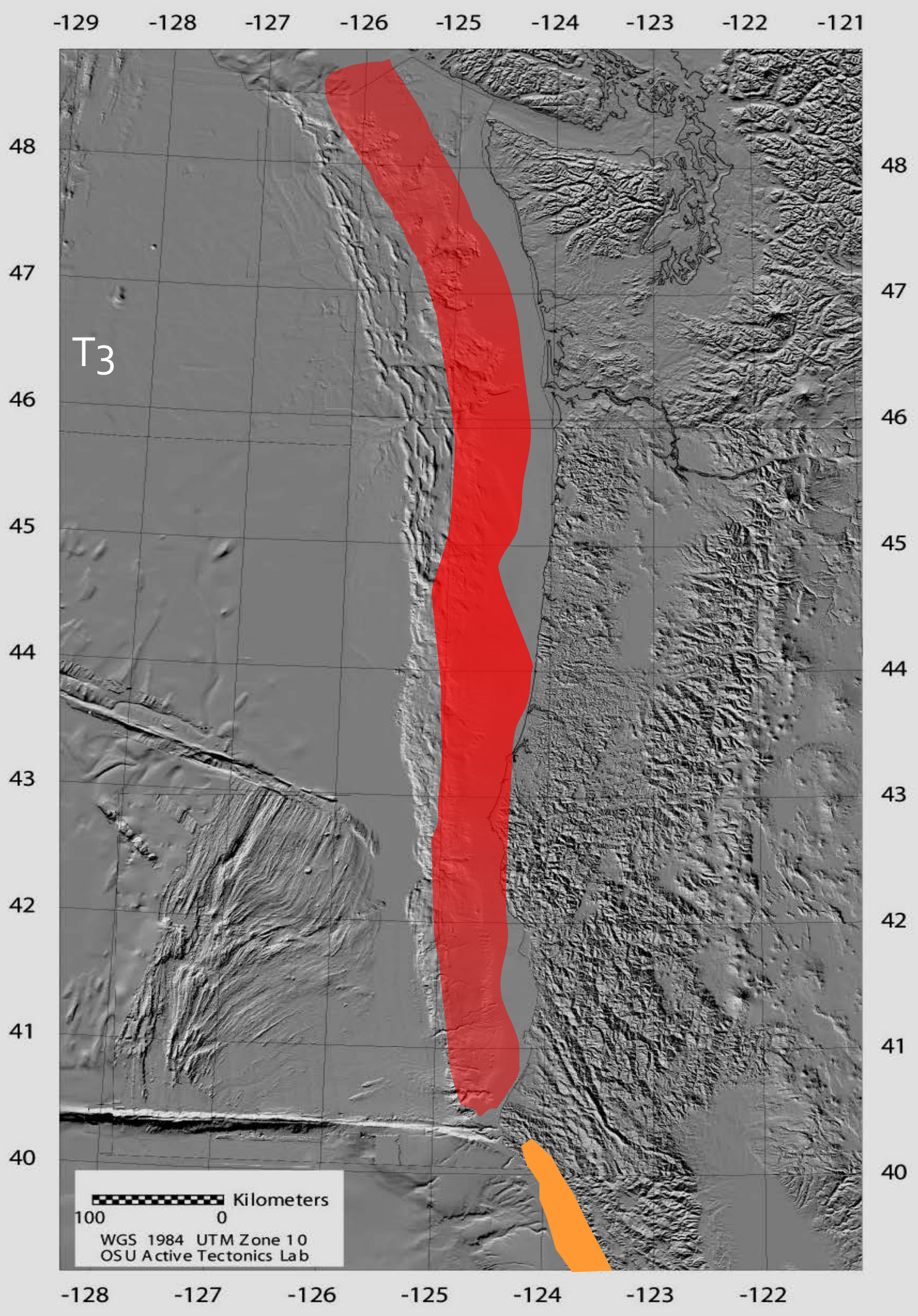
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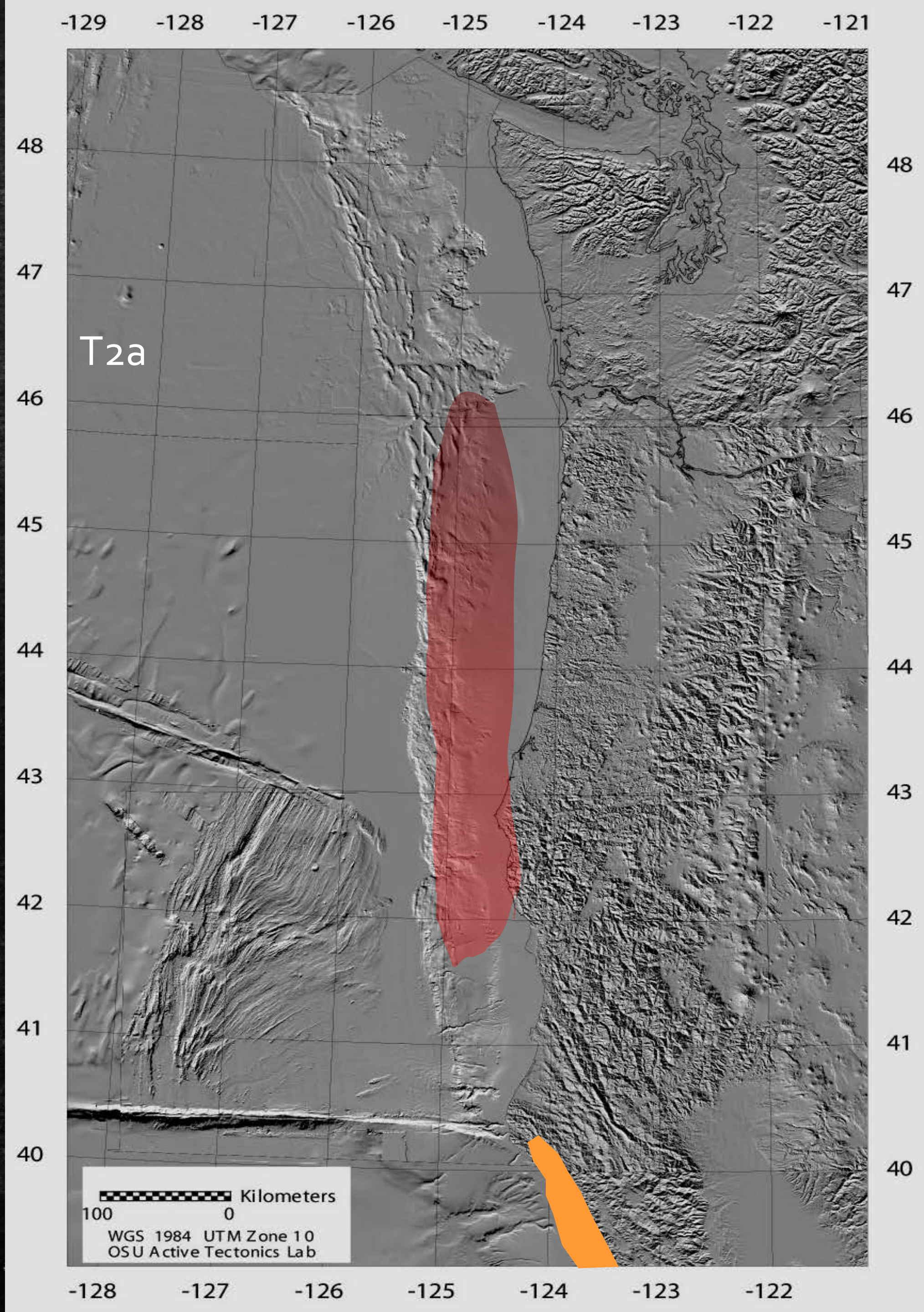
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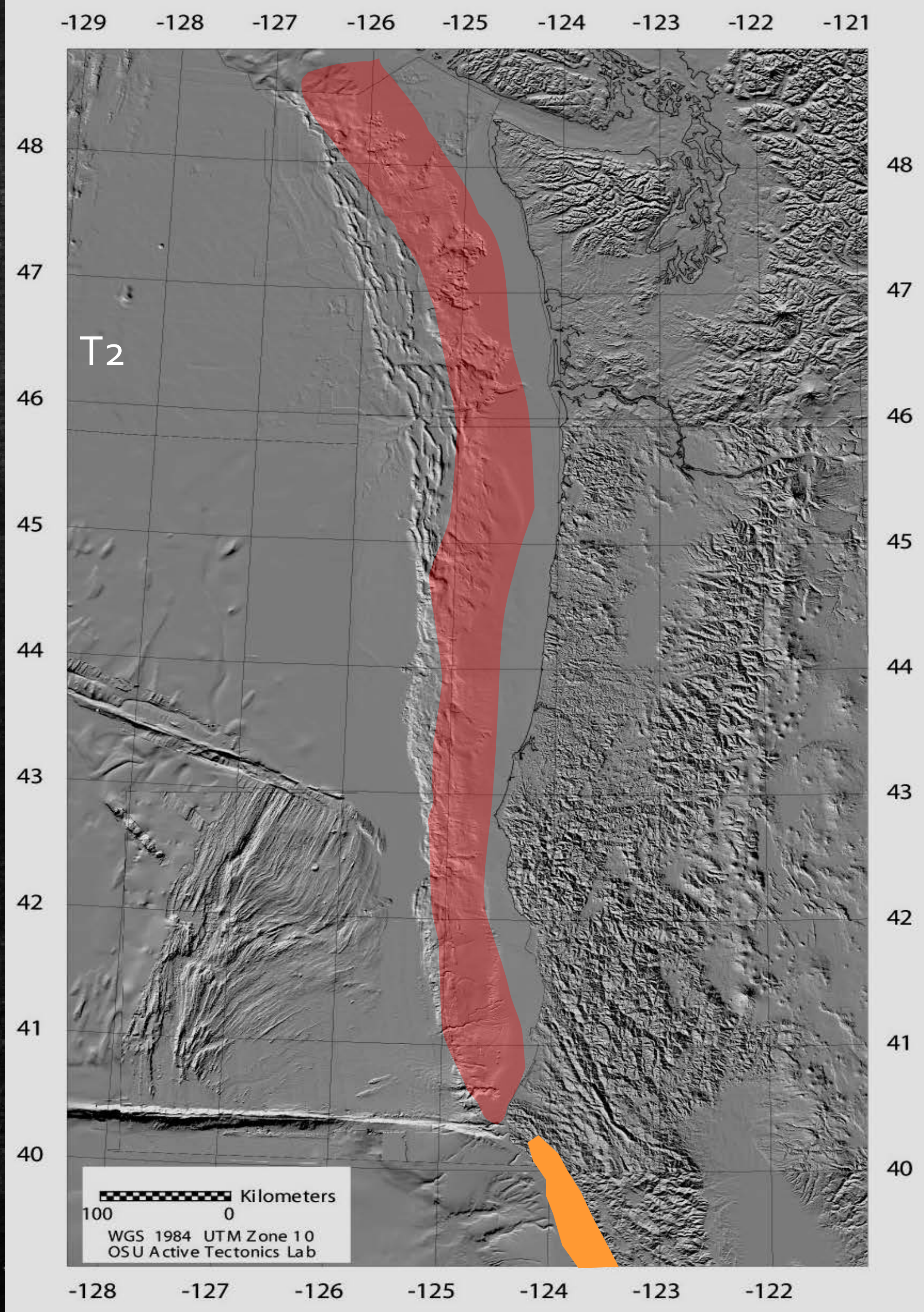
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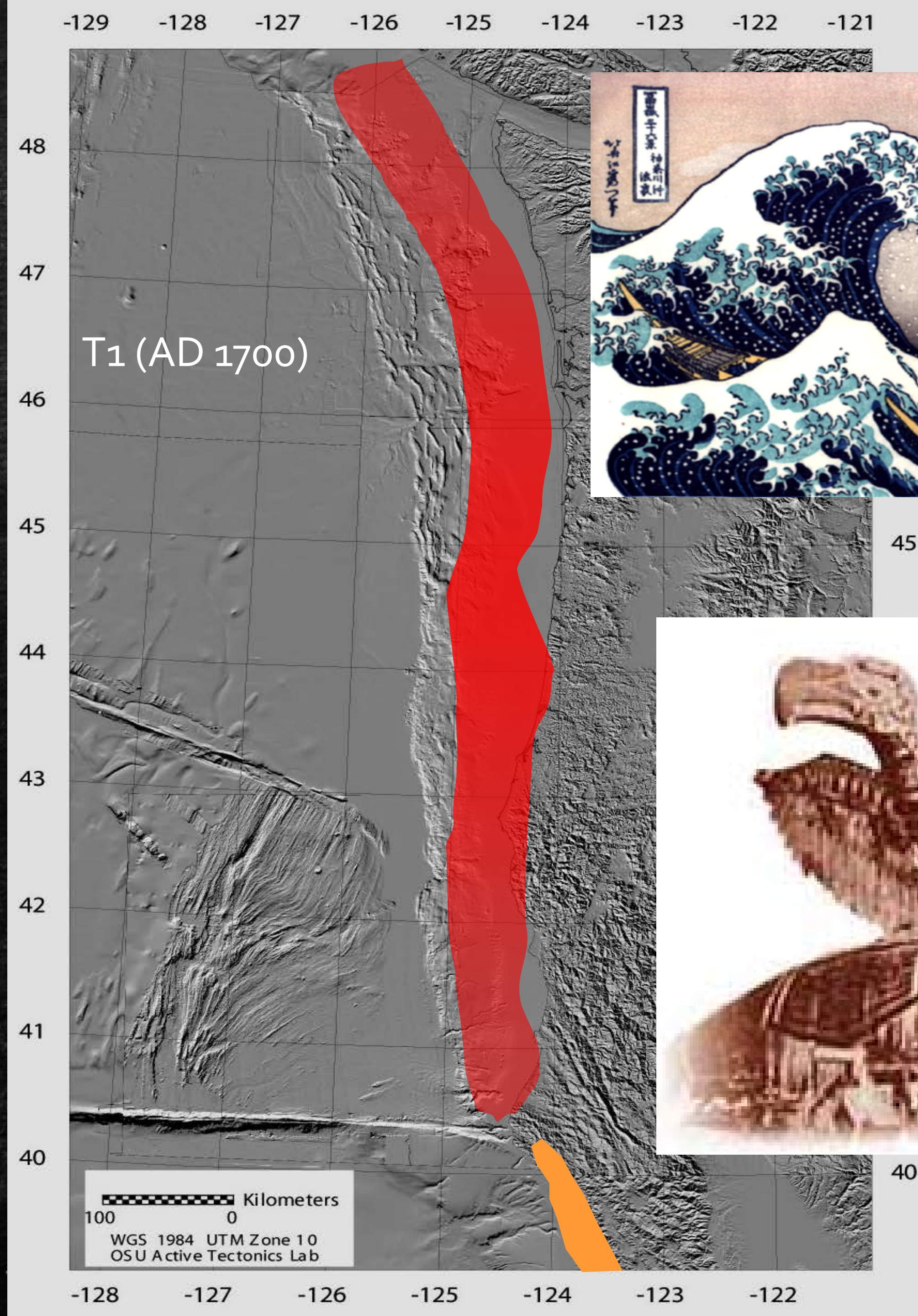
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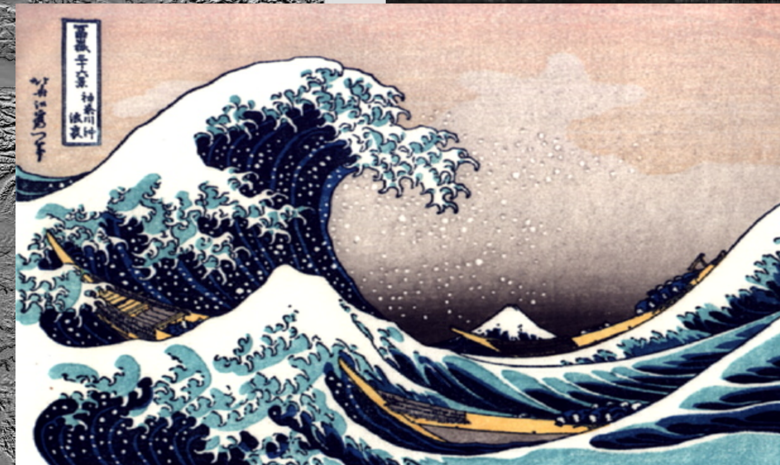
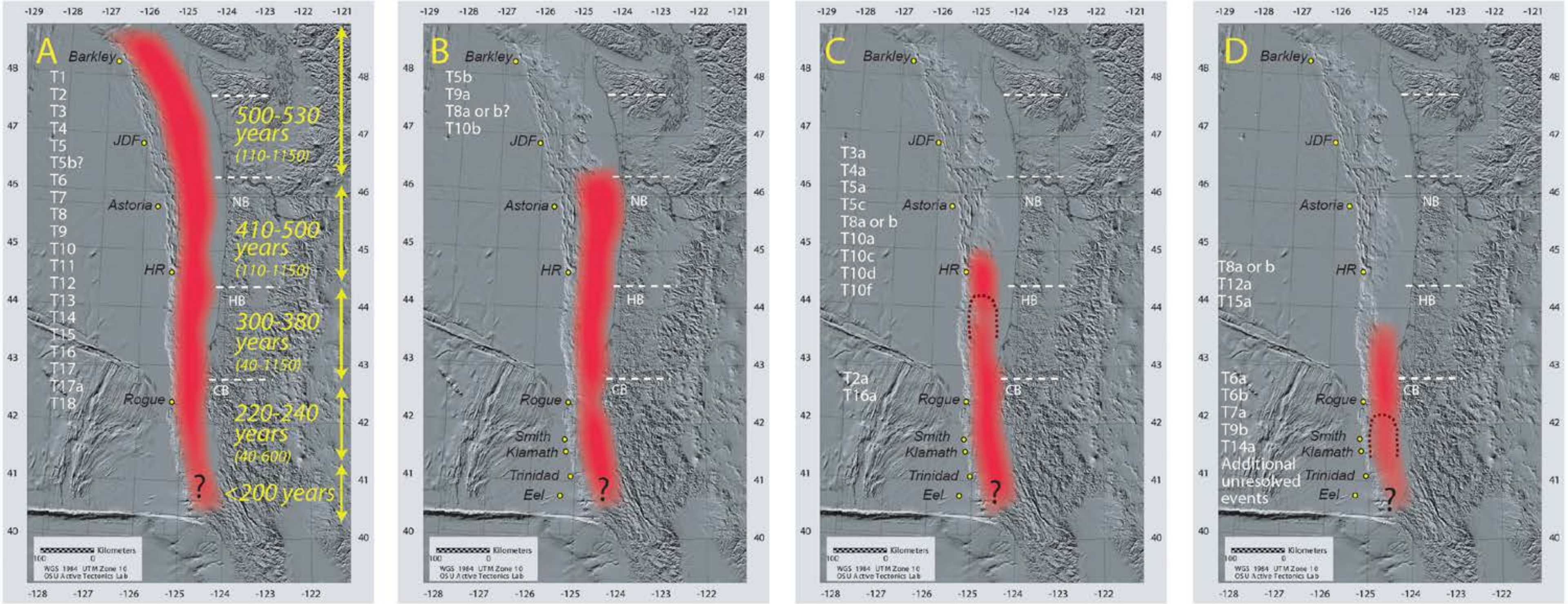
OSU Active Tectonics Lab





Rupture lengths from Holocene Offshore/Onshore paleoseismic record.

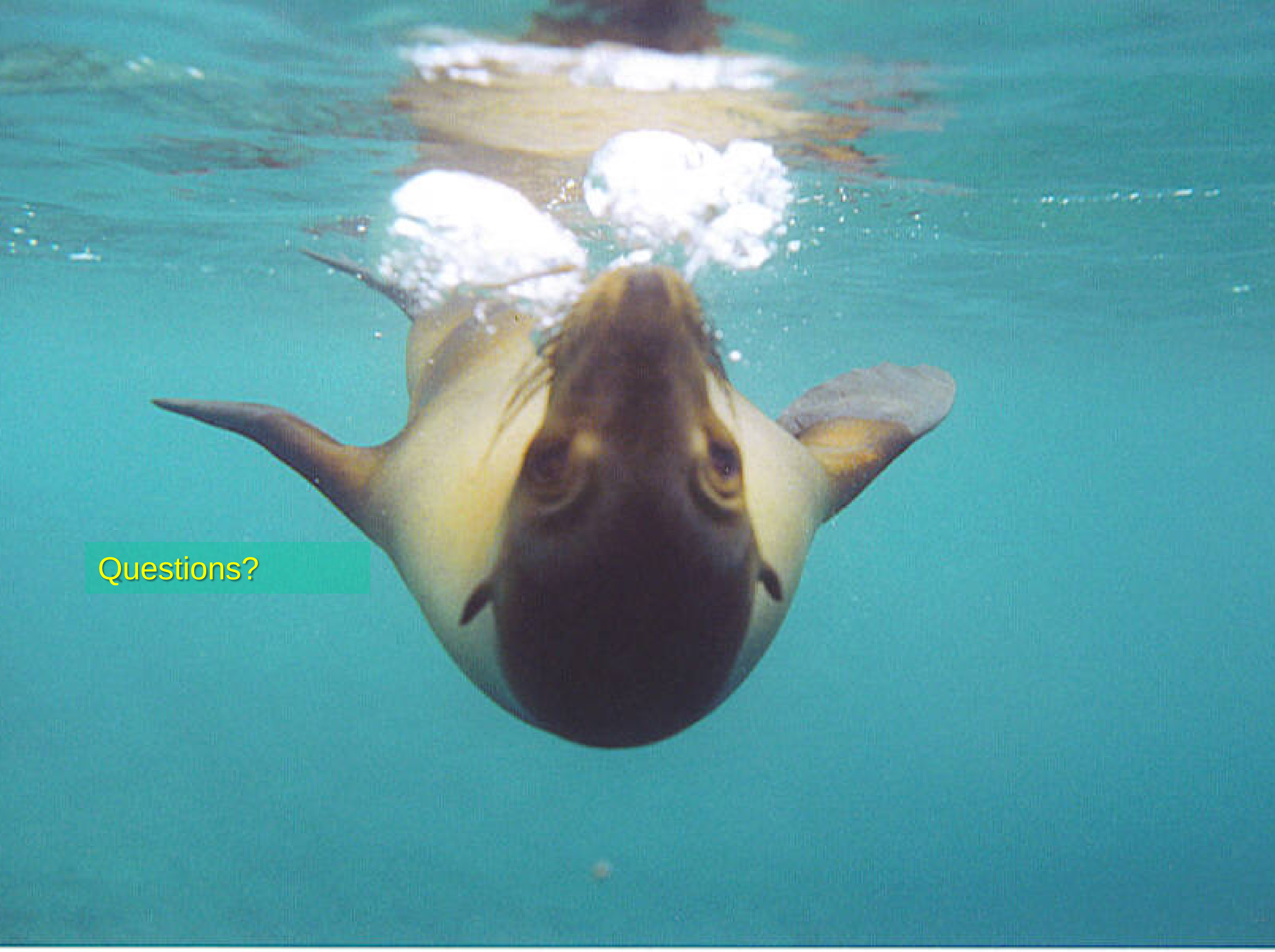
While mean recurrence interval is ~ 500 years in northern Cascadia, it is only 240 years in the south. The NSAF recurrence during this time is similar, ~200 years. Smaller Cascadia events correlate with shorter rupture length and Bradley Lake tsunami deposits.

Segment boundaries are roughly compatible with ETS segment boundaries proposed by Brudzinski et al., 2007, though both sets of boundaries are quite crude.

Conclusions

- Understanding of channel pathways and their history and dynamics is critically important. Erroneous conclusions may be drawn from inappropriate sampling strategies.
- Many cores are required to unravel the unknowns. We may not be smarter than mud on the first try!
- Alternative pathways and turbidite counts are not supported by data or physics.
- Using appropriate cores from active channel/canyon systems, the turbidite stratigraphy is remarkably consistent. Linkages to Effingham Inlet, the Slipstream Slide, onshore lakes and marsh sites suggest consistent record of ~ 19-20 significant events in the Holocene.
- Bayesian models can help quantify and evaluate the numerous inputs to paleoseismic models (19 in this case).   Improvements in the data result in improvements to the model.

Thanks for your attention!

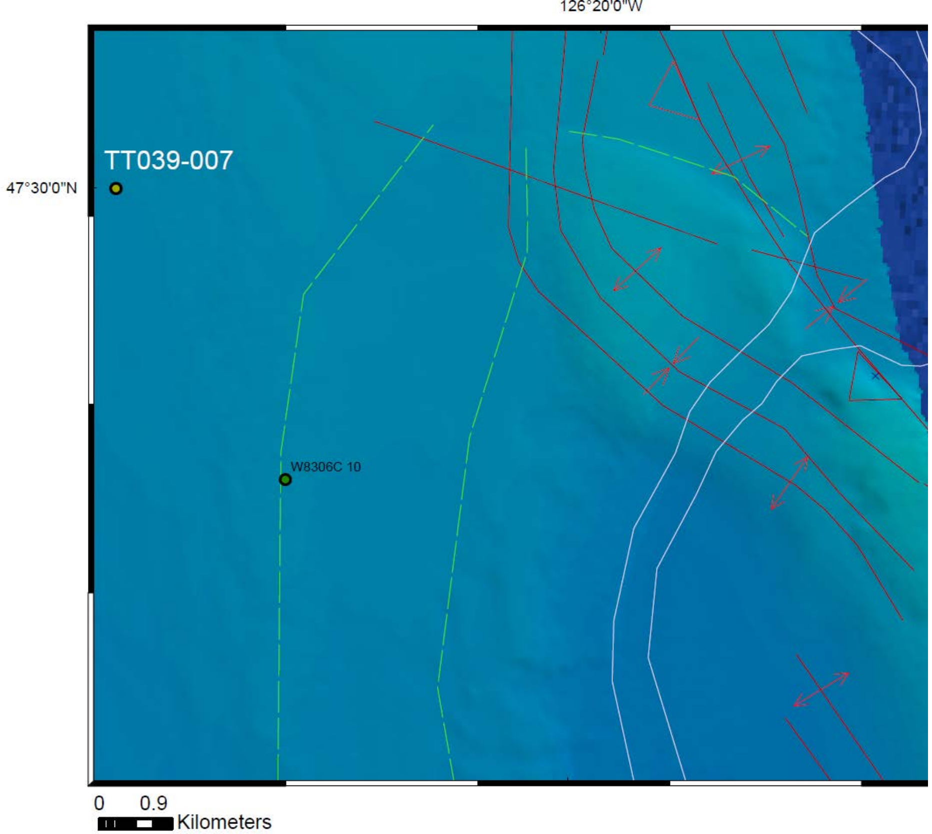

Questions?

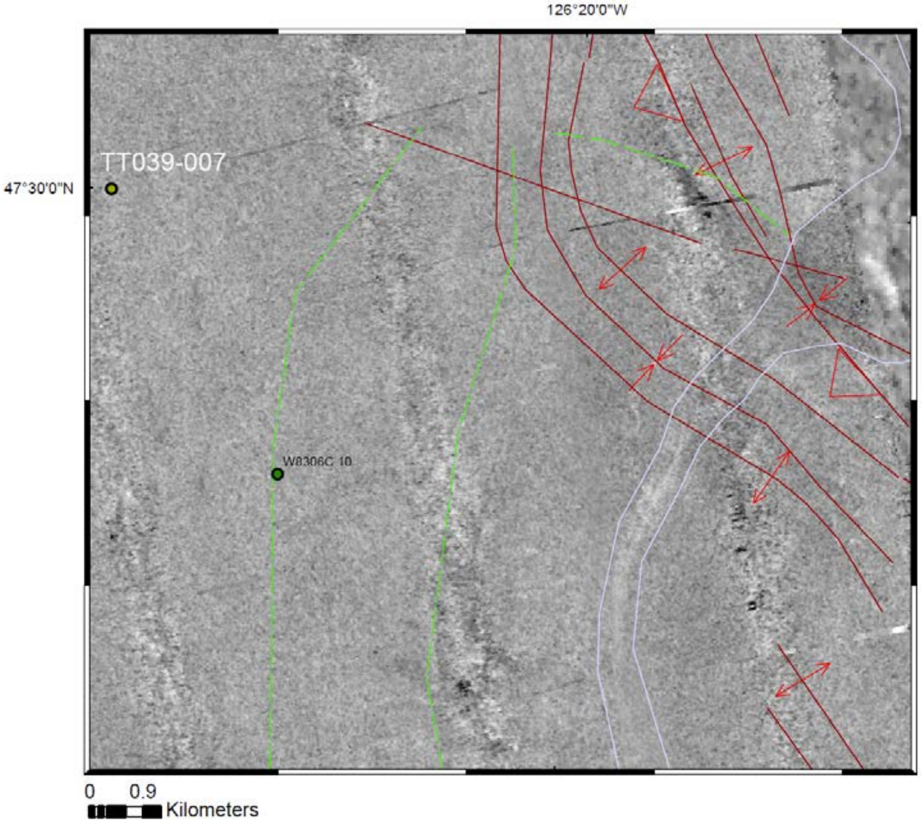
Willapa Wave field

JDF Channel

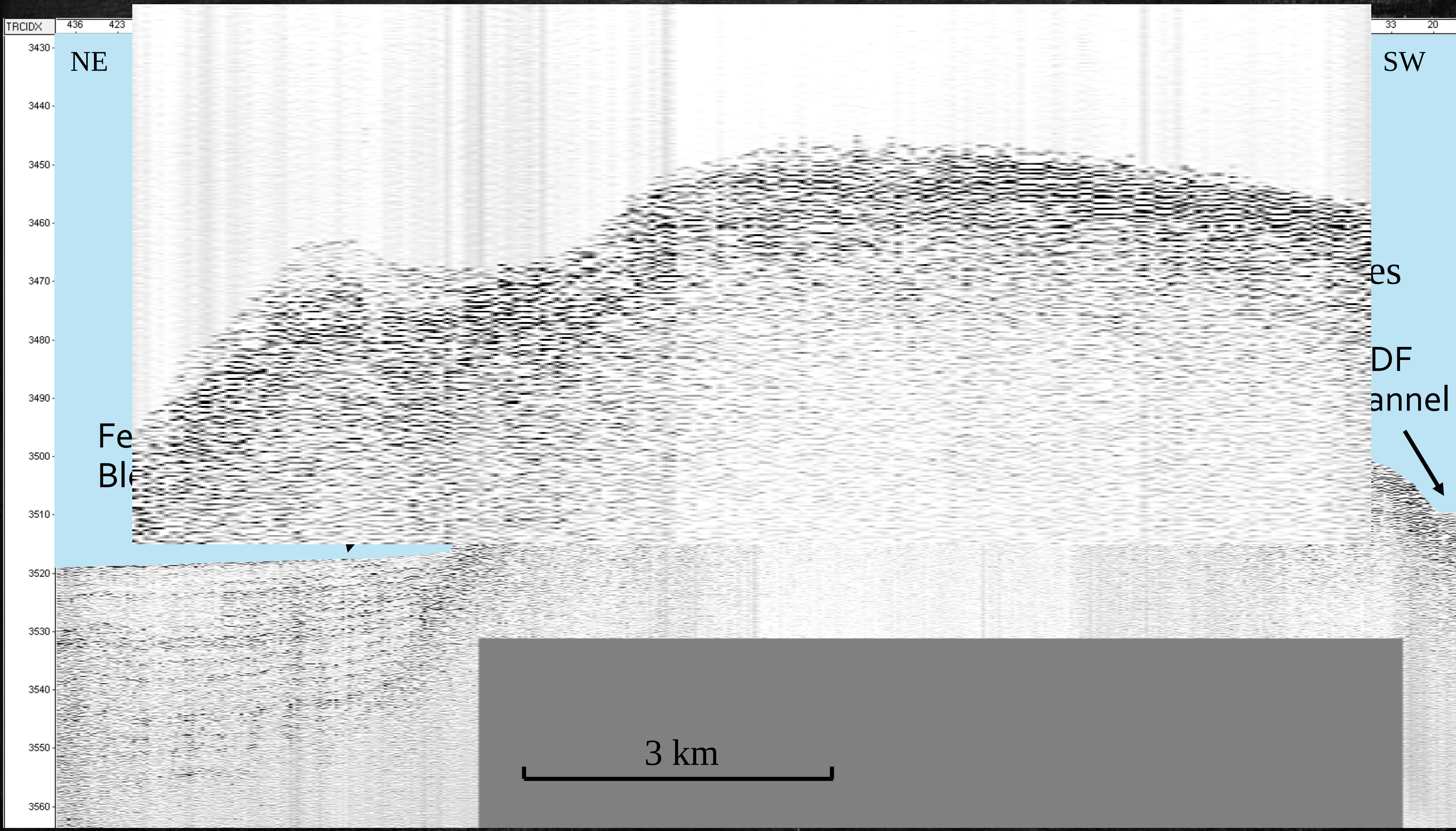
Willapa Channel

The Holocene record in this core consists of ~ 50% hemipelagic mud, and 50% mud turbidites at a range of 12.5 km from the main Willapa bend. This area should be affected by the blowout events, but lack of Holocene record supports and older time frame.





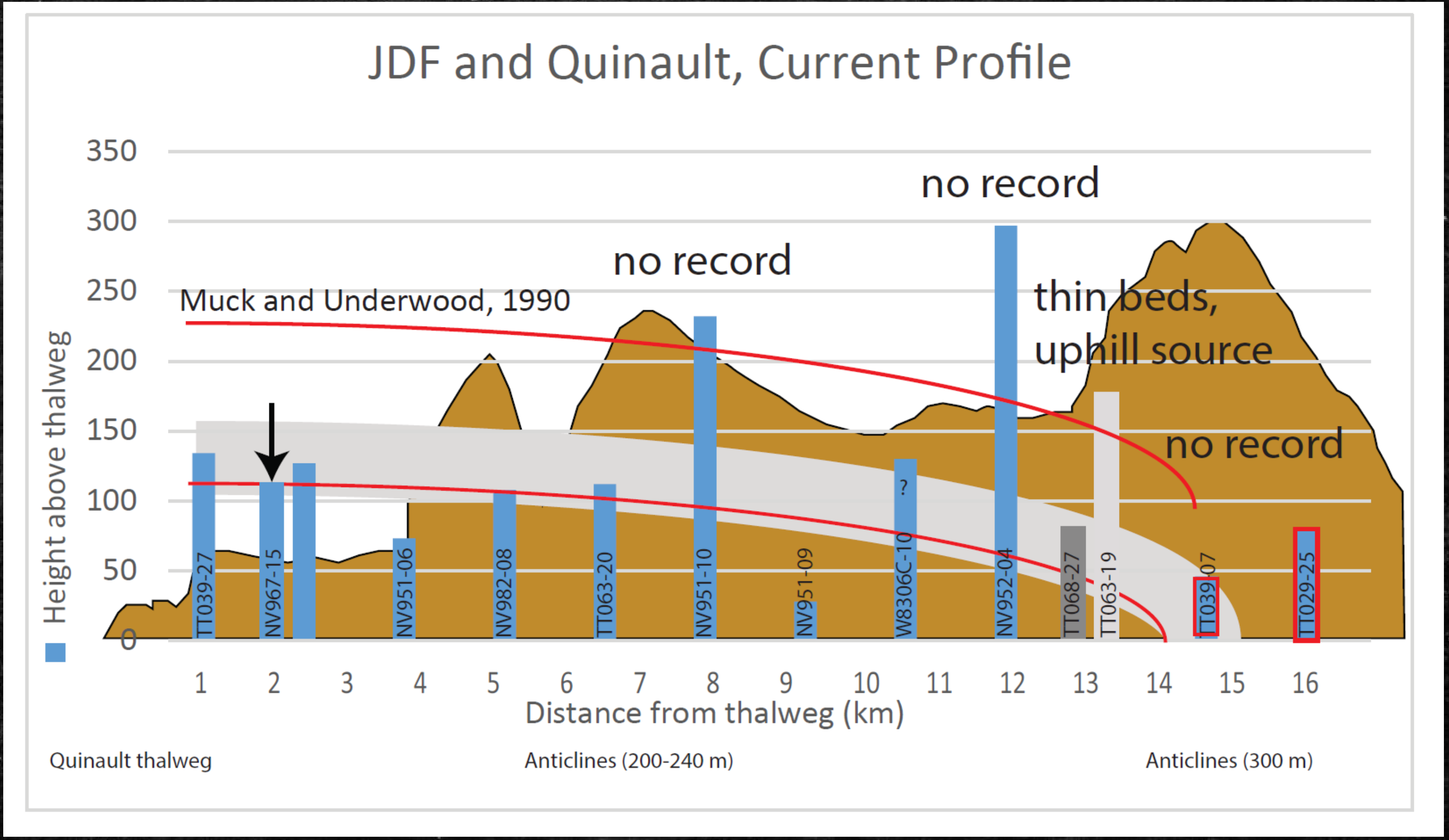
The frontal thrust blocks both JDF and Quillayute, forcing JDF to go over the ridge, and redirecting Quillayute several km north where it joins JDF. A fine grained sediment pool results here as well. Walls of a paleo Quillayute Channel are visible, as is the sand tongue exiting this second bottleneck.

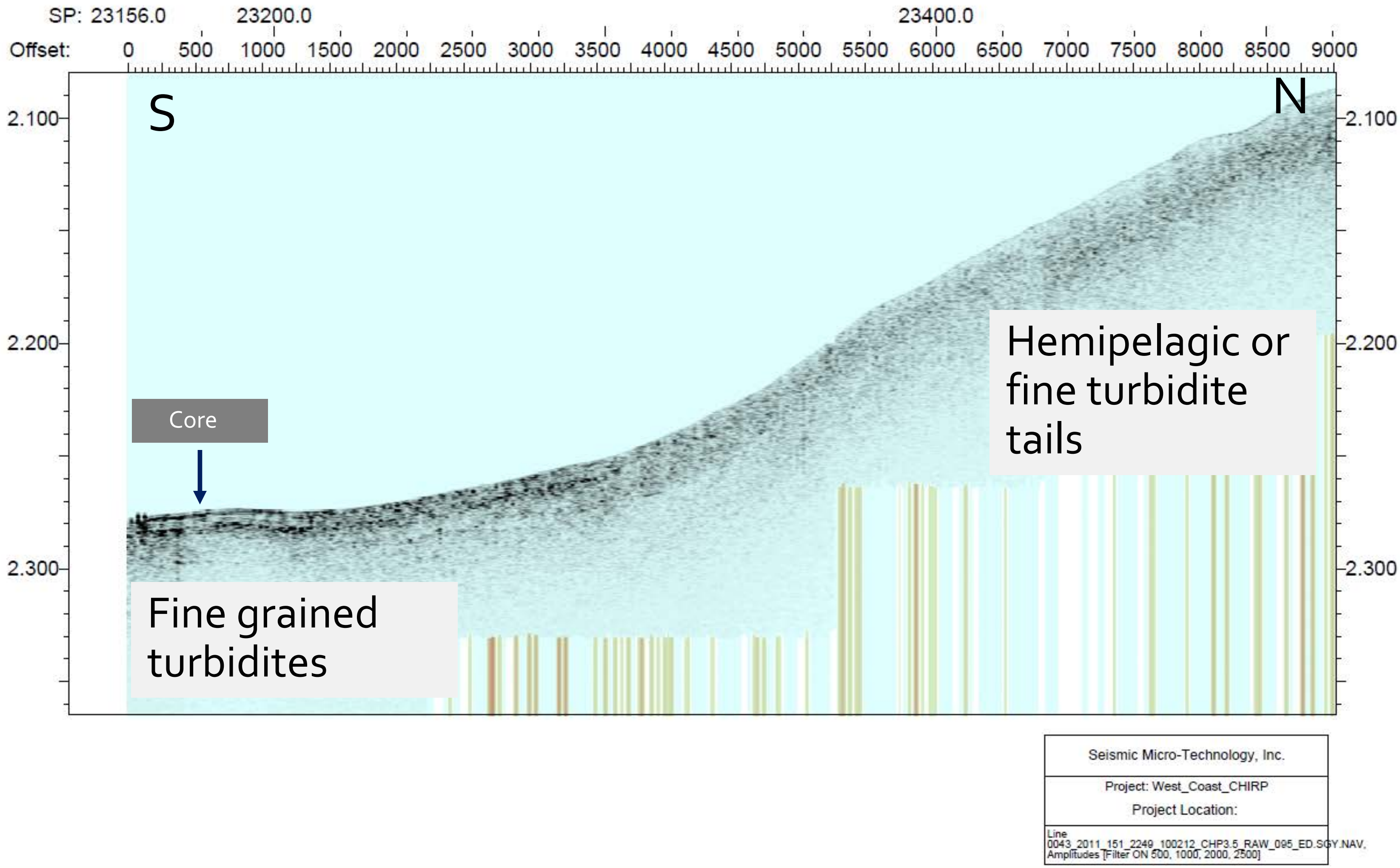


High-resolution chirp profile across the Feature A Blowout Basin to JDF Channel. Sandy turbidites sourced from JFD give way eastward to nearly transparent Holocene fill in the basin, consistent with backscatter data.

- A common misconception is that with evidence of M9 earthquakes, it should be simple to examine cores for this evidence which should be widespread.
- Surprisingly though, there are not as many sites with good paleoseismic records as one might think.
- Moreover, Cascadia is characterized by fine grained turbidite systems for the most part, particularly in the northern relict canyons. This means that techniques used must be capable of reliably detecting and characterizing fine grained deposits in detail.
- Lets look first at the aerial distribution of Holocene turbidite stratigraphy.

Model and empirical considerations

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Core
Hemipelagic or fine turbidite tails
Fine grained turbidites
Seismic Micro-Technology, Inc.
Project: West_Coast_CHIRP
Project Location:
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