Long-Term Paleoseismology in Cascadia: Updated Probabilities, and Impacts to Oregon

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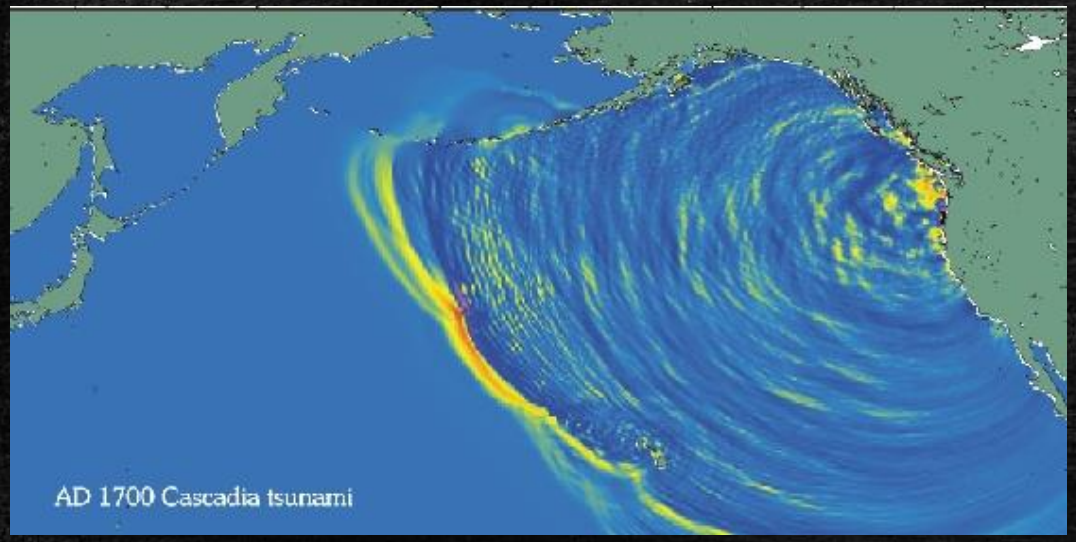
C. Hans Nelson†, Joel E. Johnson*, Steve Galer, Jeffrey Beeson, Bran Black, Ann E. Morey*, Julia Gutiérrez-Pastor†, Eugene Karabanov**, Andrew T. Eriksson*°, Rob Witter and George Priest ᵟ, Eulàlia Gràcia****, Kelin Wang***, Joseph Zhang ᵡ, Gita Dunhill††, Jason Patton*, Randy Enkin***, Audrey Dallimore*** , Tracy Valliersʃ, and the Shipboard Scientific Parties (52 students, colleagues, technicians)

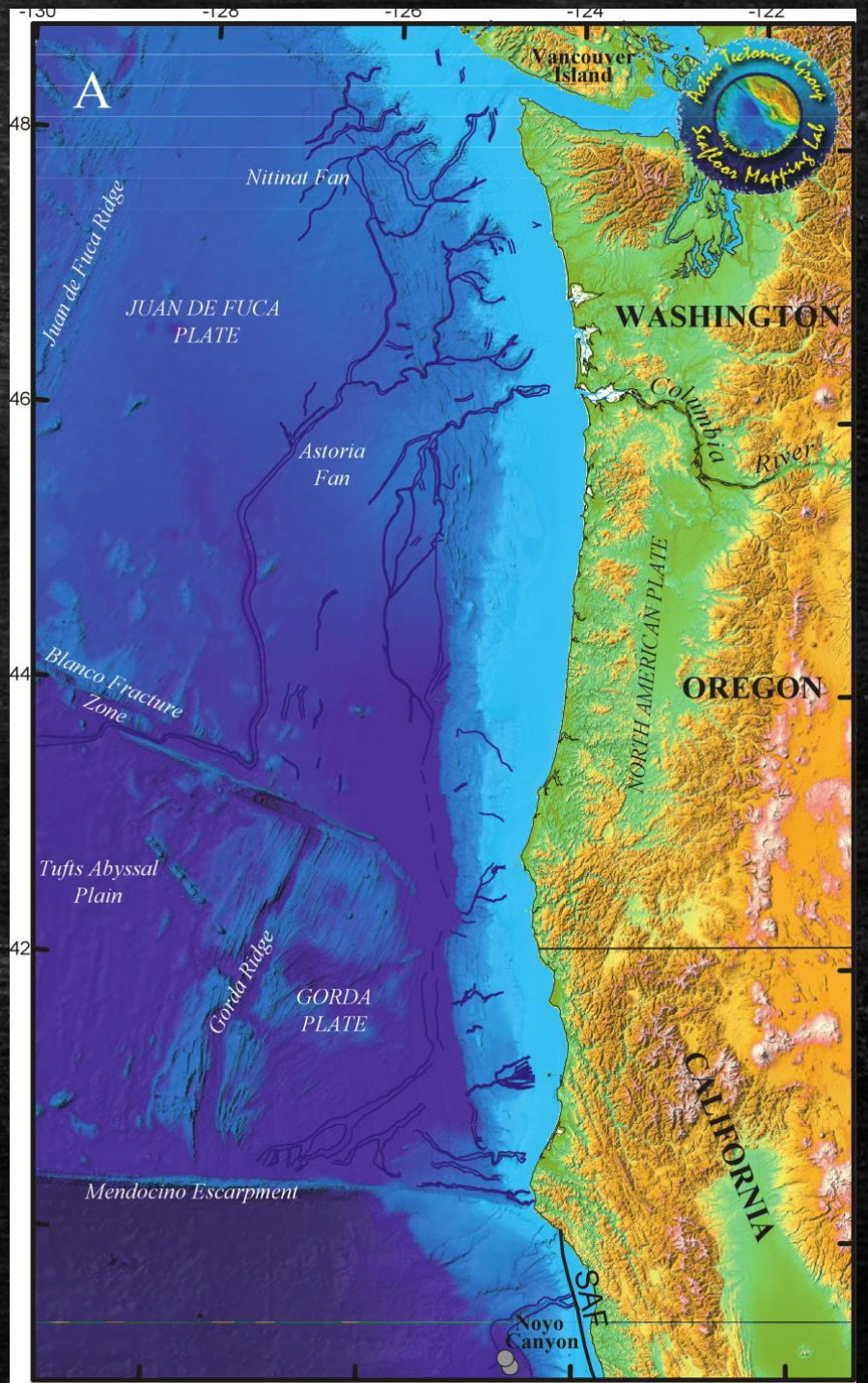
Goldfinger, C., et al., 2012, *Turbidite Event History: Methods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone*, USGS Professional Paper 1661-F, Reston, VA, U.S. Geological Survey, p. 184 p, 64 Figures. http://pubs.usgs.gov/pp/pp1661f/

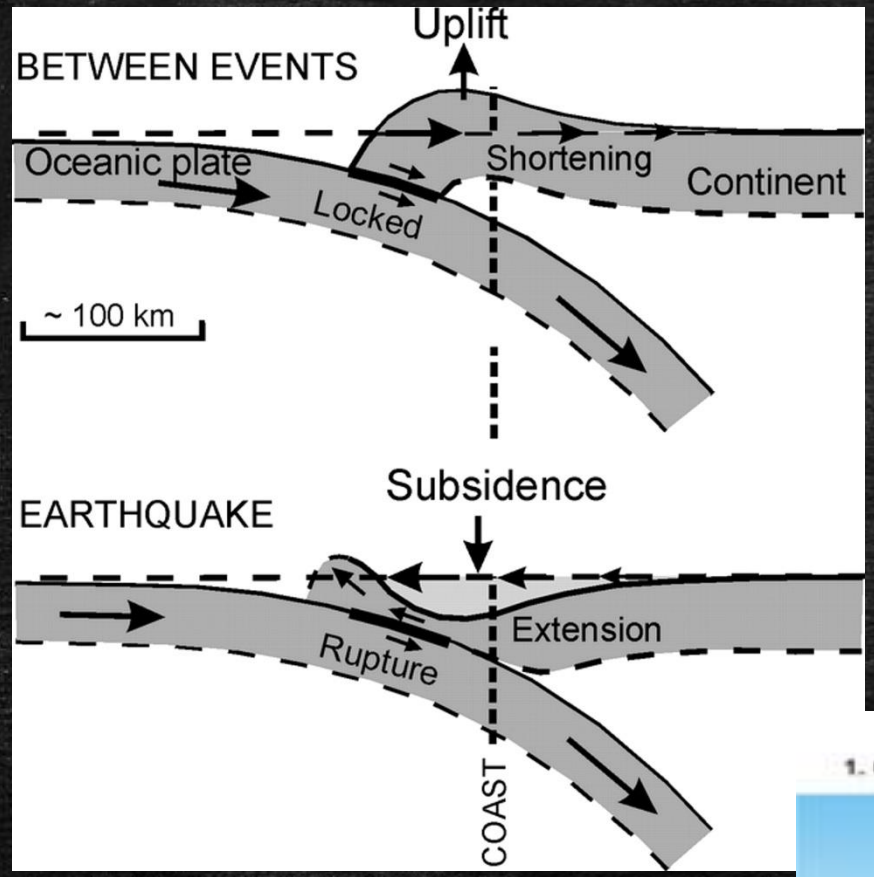
Goldfinger, C., Galer, S., Beeson, J.W., Hamilton, T.S, Black, B., Romsos, C., Patton, J., Nelson, C.H., Hausmann, R., Morey, A., 2016, The Importance of Site Selection, Sediment Supply, and Hydrodynamics: A Case Study of Submarine Paleoseismology on the Northern Cascadia margin, Washington USA, Marine Geology in press/online.

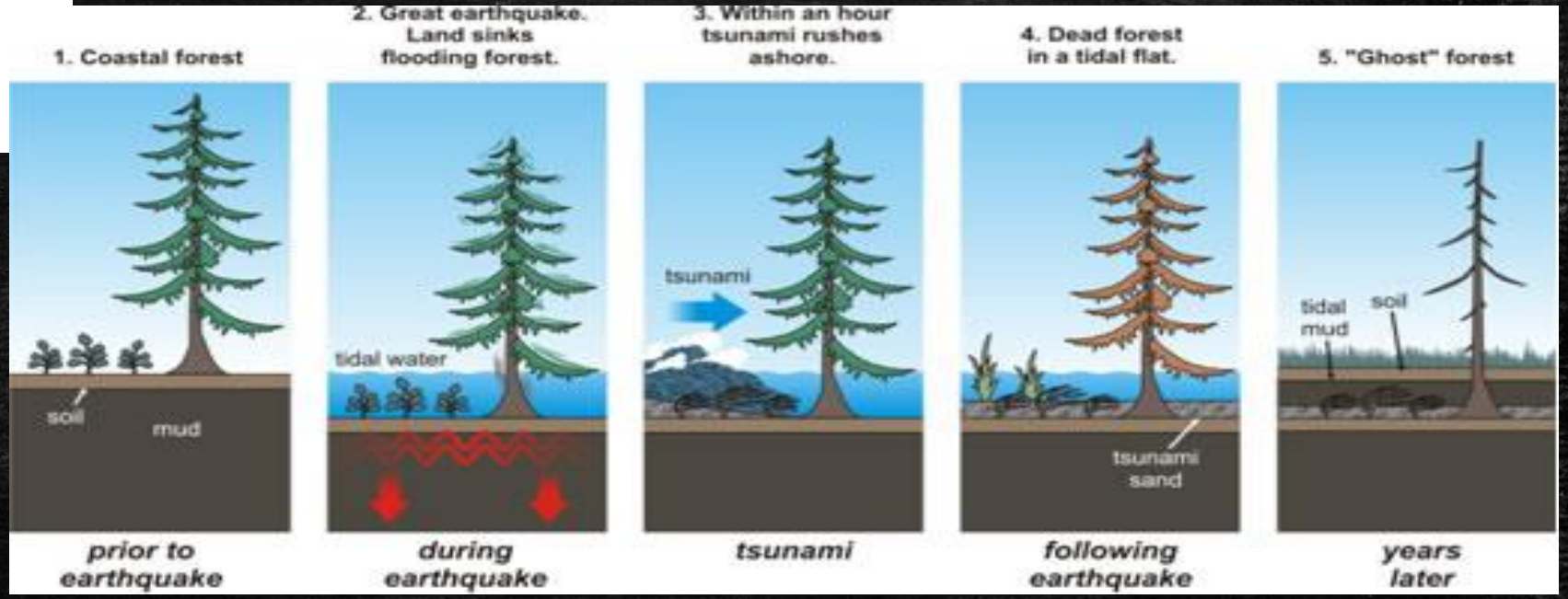
The National Academies of SCIENCES · ENGINEERING · MEDICINE

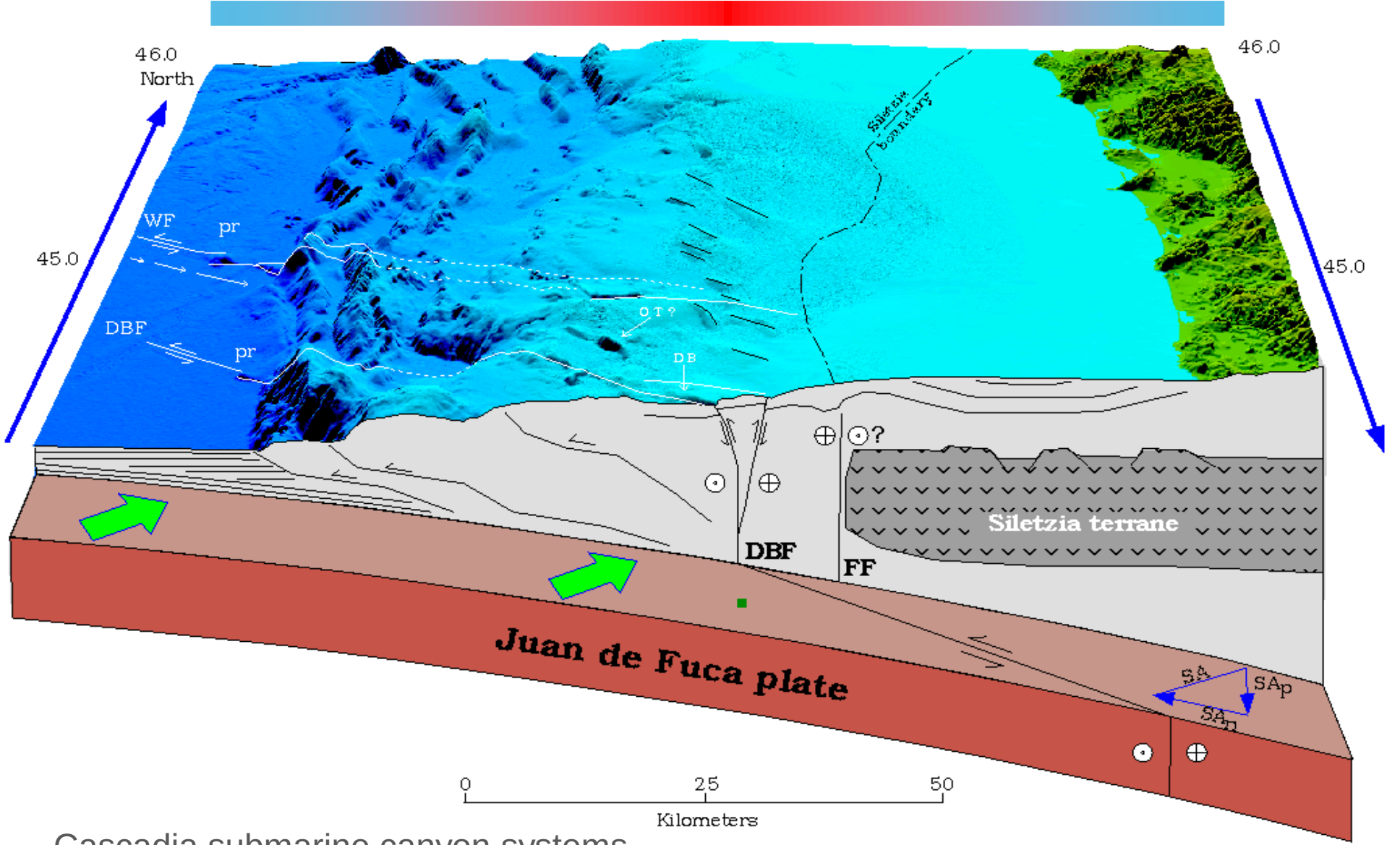
Discovery of the 1700 AD earthquake is a triumph of sleuthing!






BETWEEN EVENTS
Uplift
Oceanic plate
Locked
Shortening
Continent
~ 100 km
EARTHQUAKE
Subsidence
Rupture
Extension
COAST


1. Coastal forest
2. Great earthquake. Land sinks flooding forest.
3. Within an hour tsunami rushes ashore.
4. Dead forest in a tidal flat.
5. "Ghost" forest
soil
mud
tidal water
tsunami
tsunami sand
tidal mud
soil
prior to earthquake
during earthquake
tsunami
following earthquake
years later

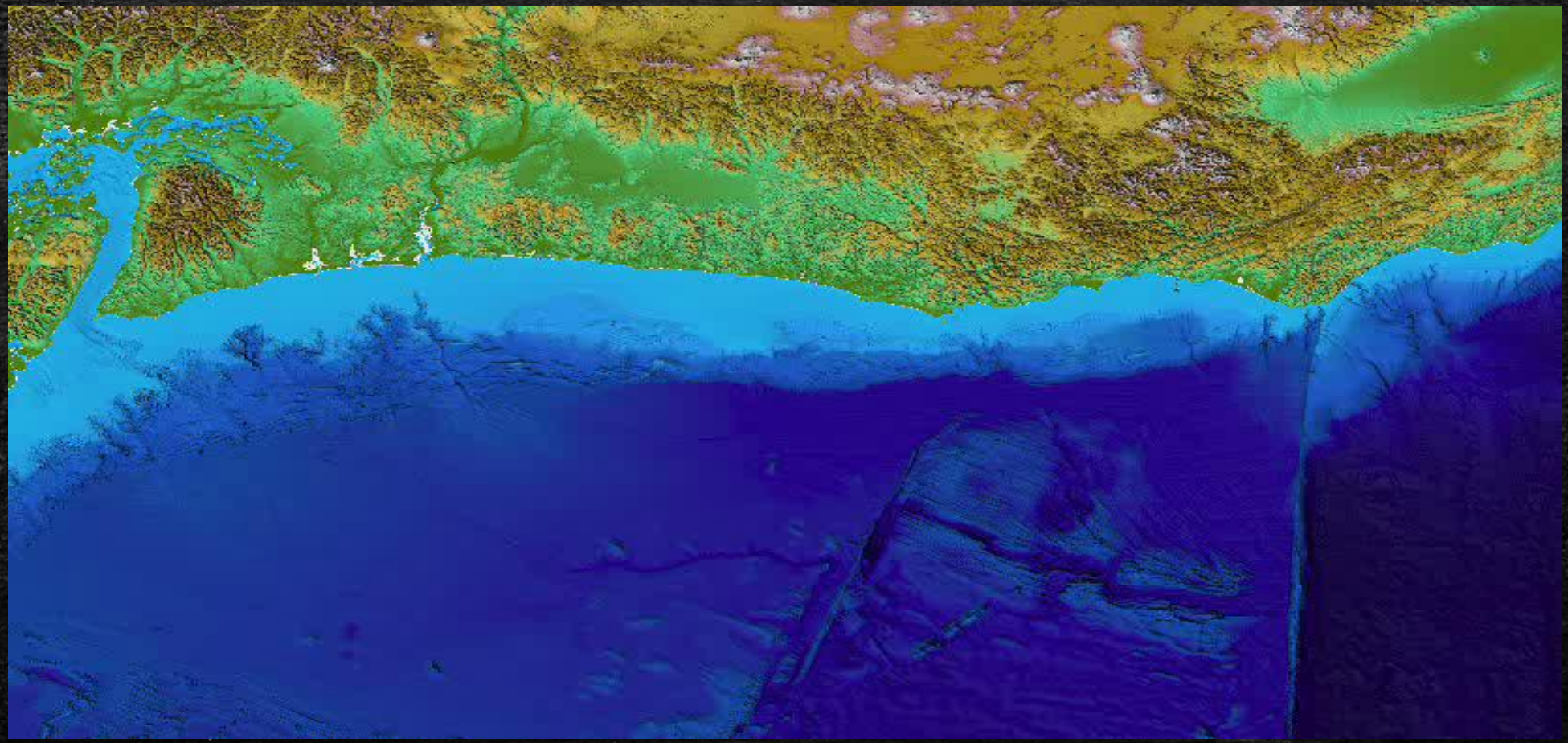


Cascadia submarine canyon systems traverse the locked zone, making them sensitive to ground shaking. They are, for the most part, isolated from river systems during high-stand conditions

From Goldfinger et al., 1997 JGR

What actually happens during the earthquake?

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



So our primary criteria for distinguishing earthquakes are

1) Aerial extent

2) Synchroneity, and

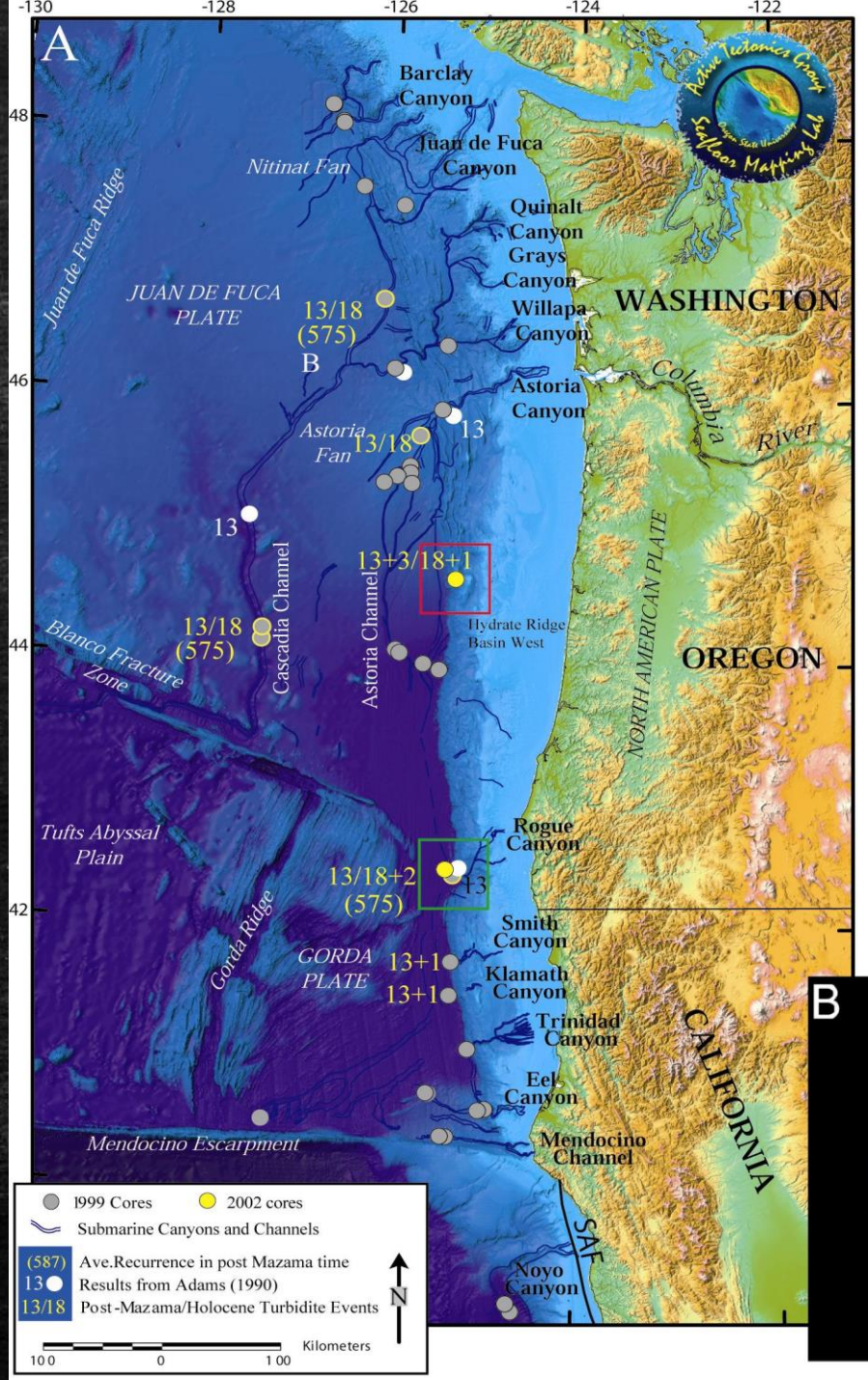
3) Sedimentology.

Synchronous means within a few minutes to hours at most…

^{14}C dating gets us only to within a few decades at best, usually not that good.

So how do we constrain relative timing to within a few hours?

Cheat!



Turbidite Paleoseismology:

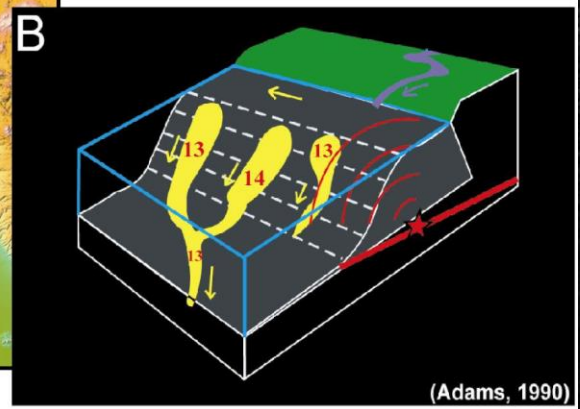
Extending the earthquake record

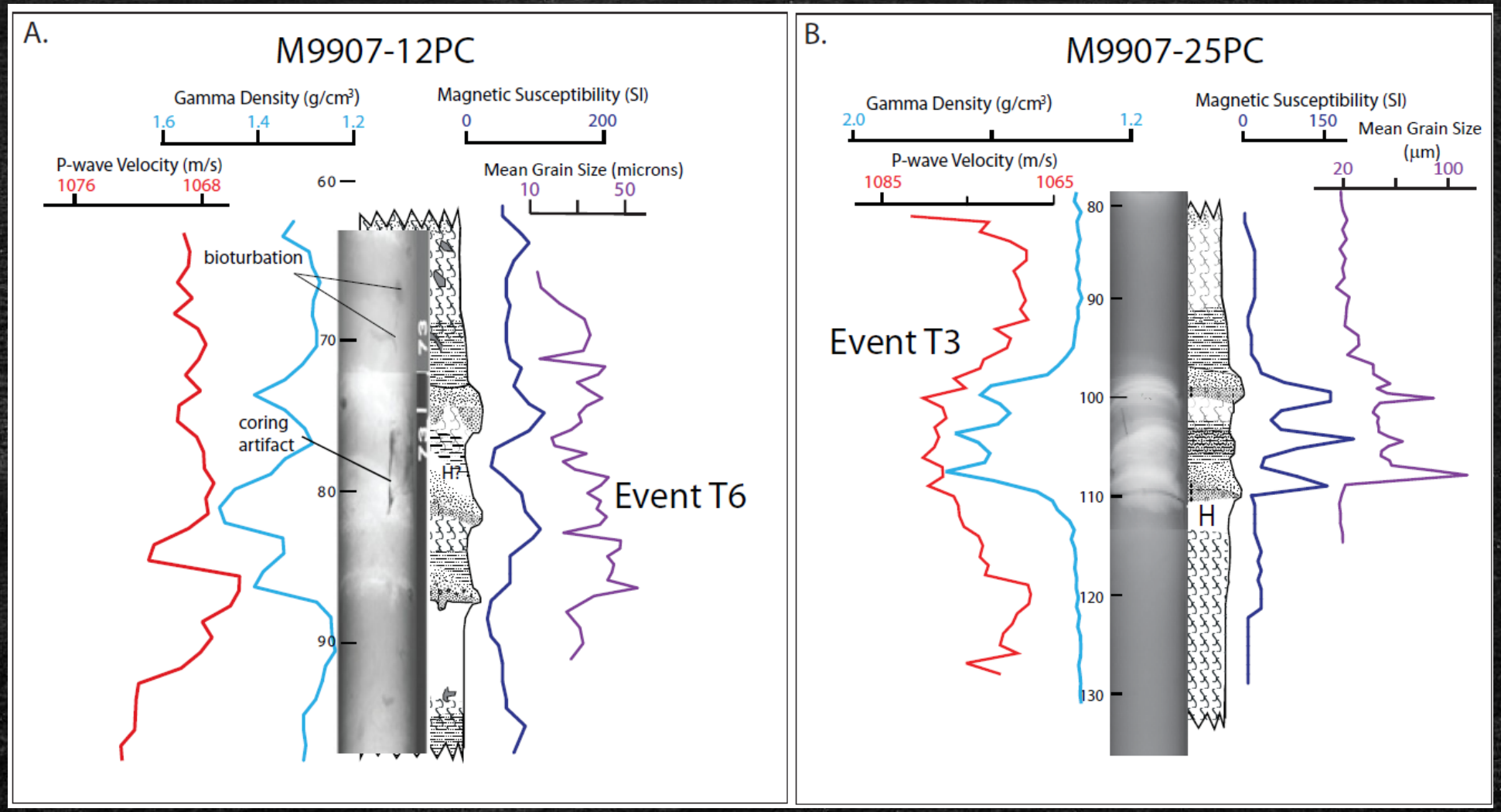
Cascadia Core Sites:

1999 = gray, 2002 = yellow

Older existing cores = white

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





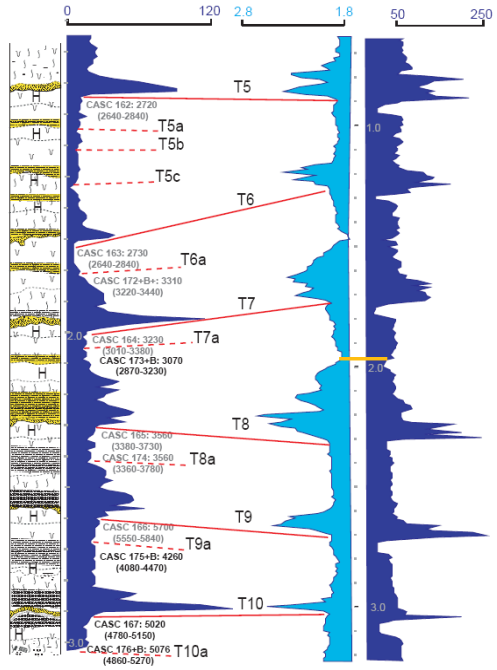
In addition to the confluence test, we correlate turbidites between remote sites to establish continuity, and test for synchronous triggering.

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

A. T5-T10

Rogue Channel Cascadia Channel

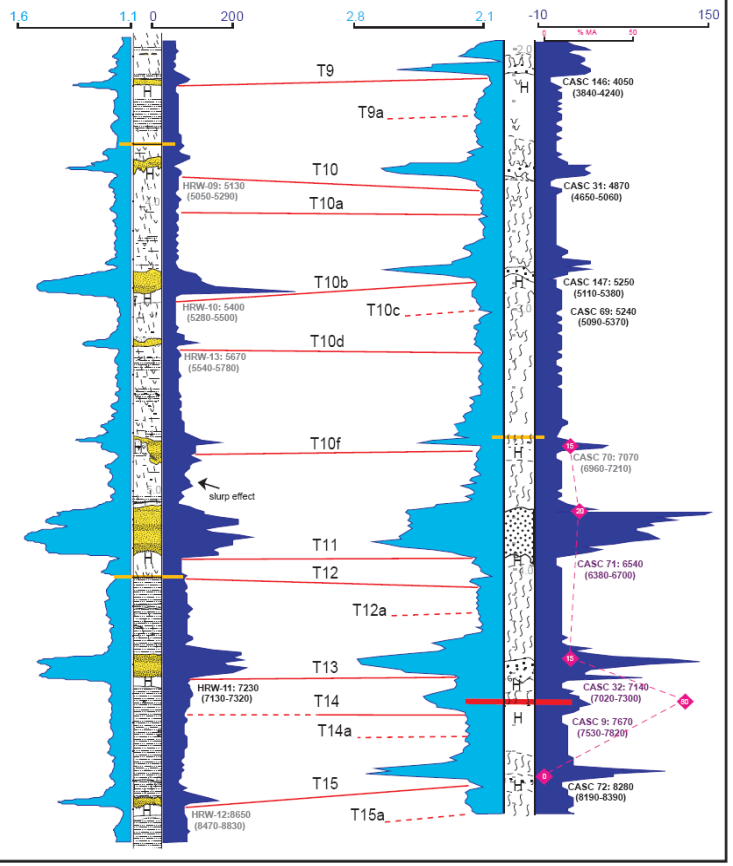
RR0207-55KC M9907-22PC



B. T9-T15

Hydrate Ridge Rogue Channel

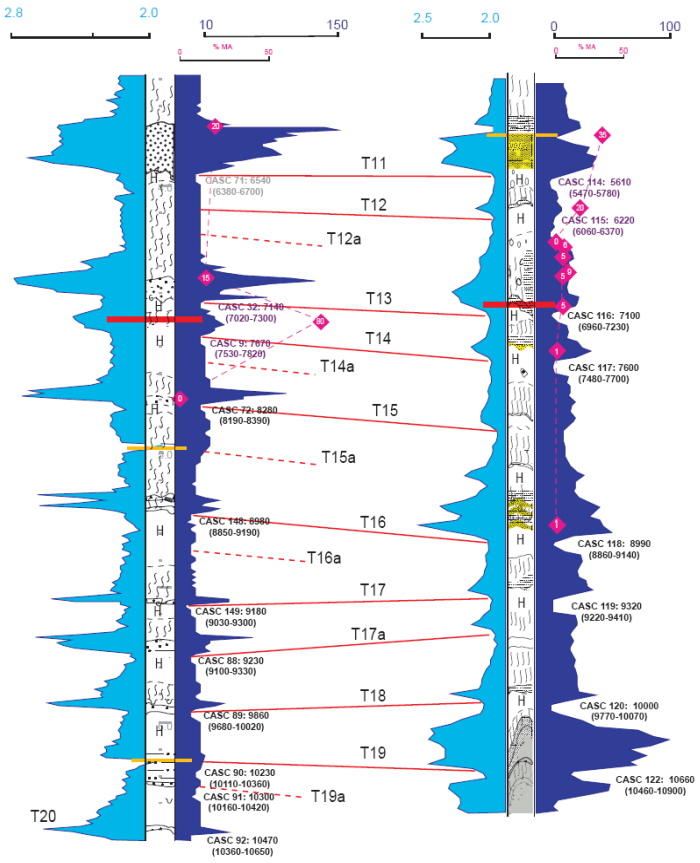
RR0207-56PC M9907-31 PC



C. T11-T20

Rogue Channel Juan de Fuca Channel

M9907-31 PC M9907-12PC



LEGEND

CASC-11: 7298 (7220-7377)
Sample # AMS ^{14}C age and 2σ range

CASC 11: 7298 (7220-7377)
Reversed AMS ^{14}C age and 2σ range

CASC 11: 7298 (7220-7377)
Erosion corrected AMS ^{14}C age and 2σ range

- 1st occurrence Mazama Ash
- Radiocarbon sample location
- Core break
- High-resolution point magnetics
- Density (g/cm^3)
- Mazama Ash: white text equals % ash
- Correlation Lines
- Events uncorrelated in paired core

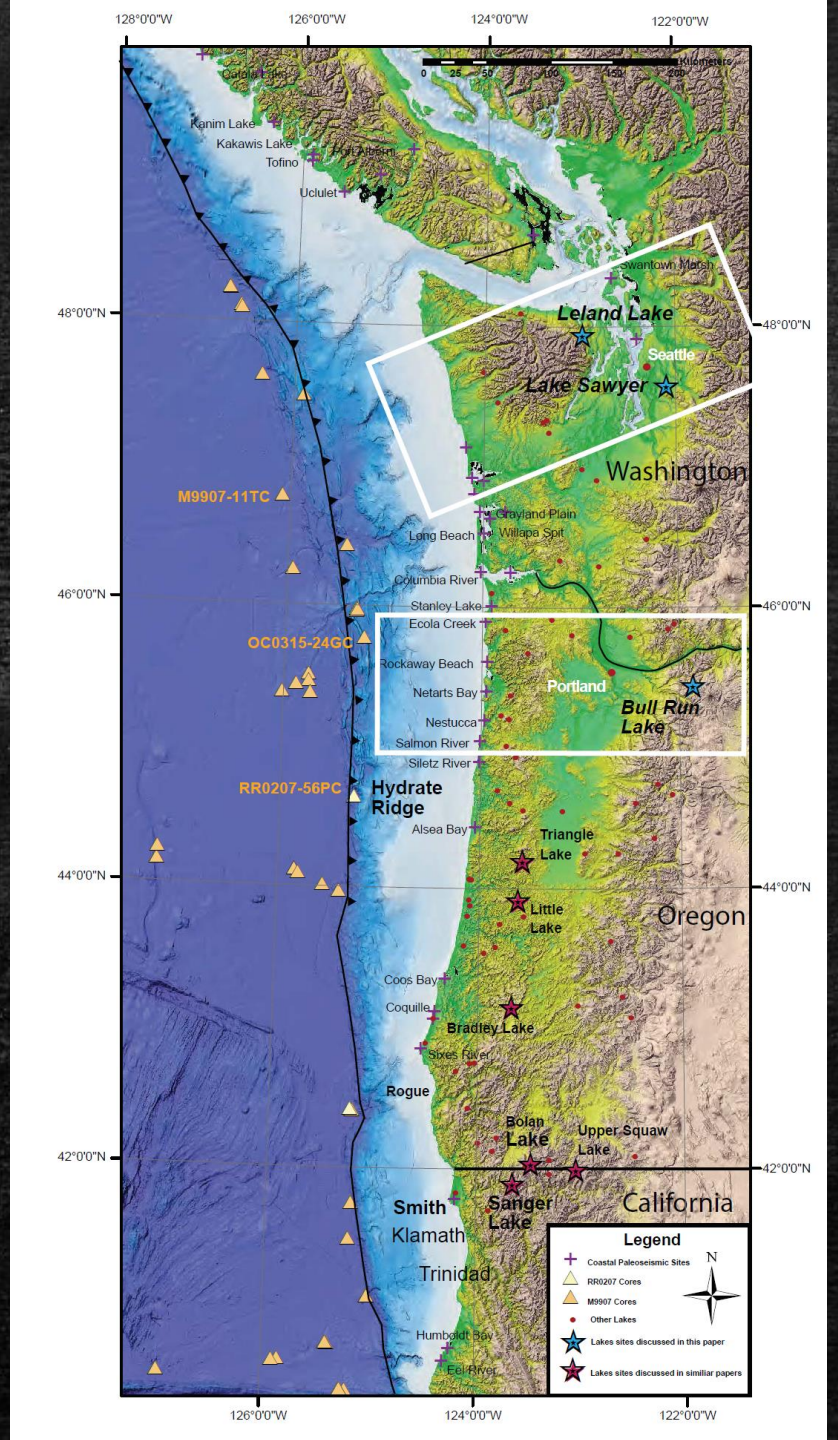
LITHOLOGY

- H Hemipelagic Clay
- Turbidite Silty Mud
- Silt
- Wood Fragment
- Shell
- Very Fine Sand
- Sand
- Mottled Clay
- Burrows

Correlation is done using oil industry techniques such as stretching and squeezing "ghost traces" to examine correlations, and flattening the correlation diagram to event horizons.

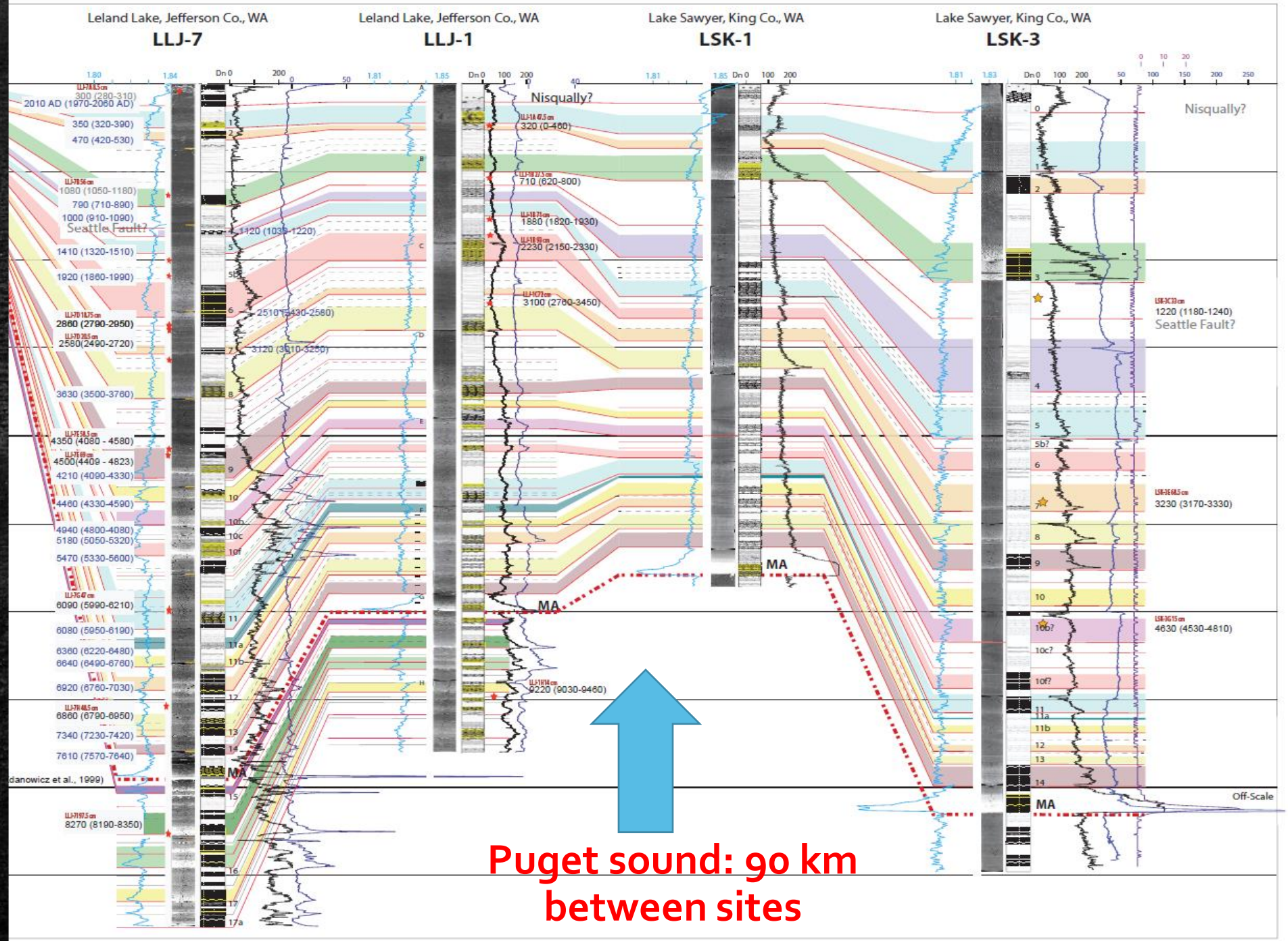
Correlations supported by numerous radiocarbon ages.

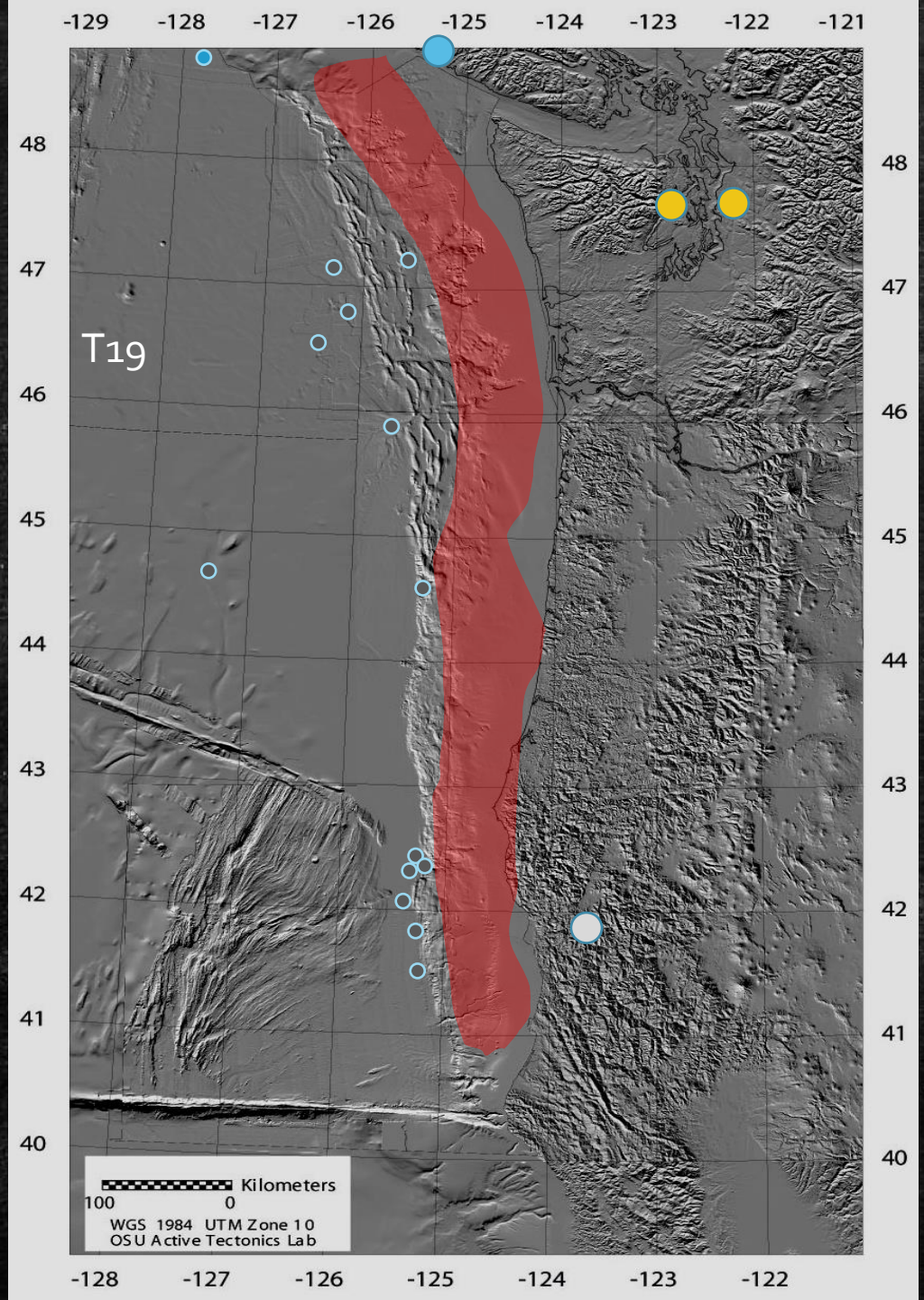

THOMAS G THOMPSON



Linking Onshore and Offshore:

Exploring inland turbidites and ground motions.


Leland Lake, Jefferson Co., WA
LLJ-7
Leland Lake, Jefferson Co., WA
LLJ-1
Lake Sawyer, King Co., WA
LSK-1
Lake Sawyer, King Co., WA
LSK-3
2010 AD (1970-2060 AD)
350 (320-390)
470 (420-530)
1080 (1050-1180)
790 (710-890)
1000 (910-1090)
Seattle Fault?
1410 (1320-1510)
1920 (1860-1990)
2860 (2790-2950)
2580(2490-2720)
3630 (3500-3760)
4350 (4080 - 4580)
4500(4409 - 4823)
4210 (4090-4330)
4460 (4330-4590)
4940 (4800-4080)
5180 (5050-5320)
5470 (5330-5600)
6090 (5990-6210)
6080 (5950-6190)
6360 (6220-6480)
6640 (6490-6760)
6920 (6760-7030)
6860 (6790-6950)
7340 (7230-7420)
7610 (7570-7640)
8270 (8190-8350)
danowicz et al., 1999)
MA
Nisqually?
320 (0-460)
710 (620-800)
1880 (1820-1930)
2230 (2150-2330)
3100 (2760-3450)
9220 (9030-9460)
MA
MA
Nisqually?
1220 (1180-1240)
Seattle Fault?
3230 (3170-3330)
4630 (4530-4810)
Off-Scale
MA
Puget sound: 90 km between sites

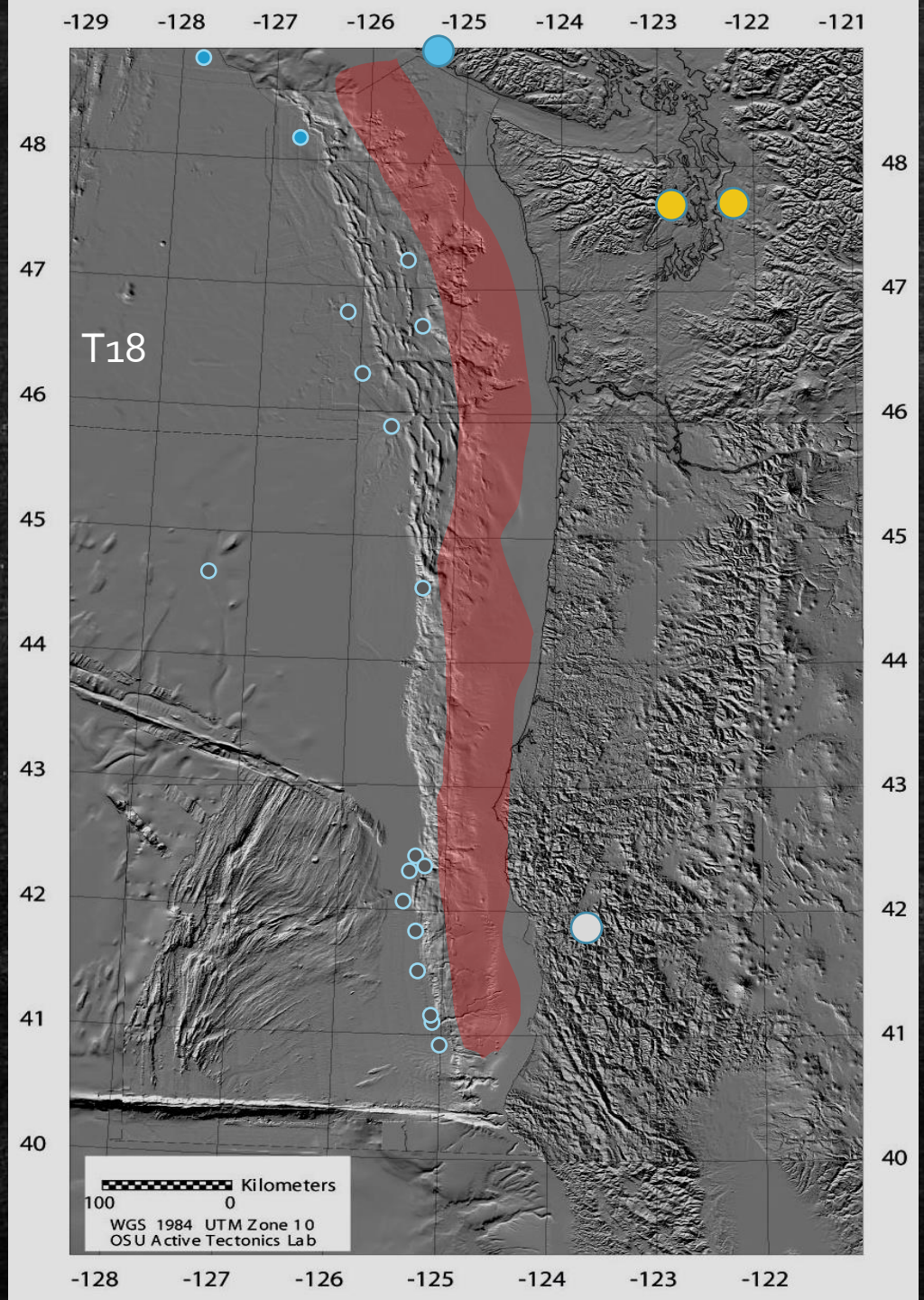


Cascadia: The Movie

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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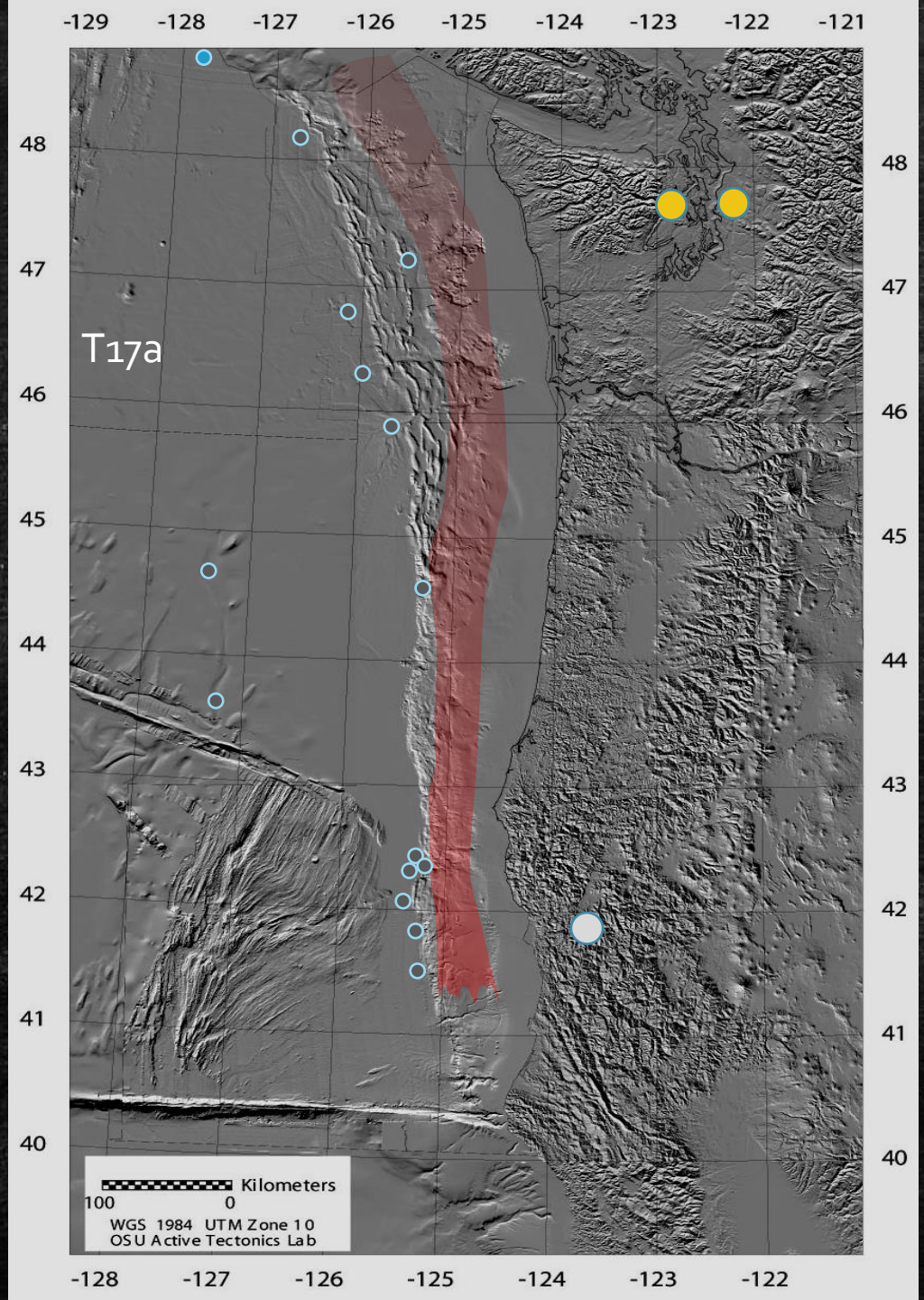
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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WGS 1984 UTM Zone 10
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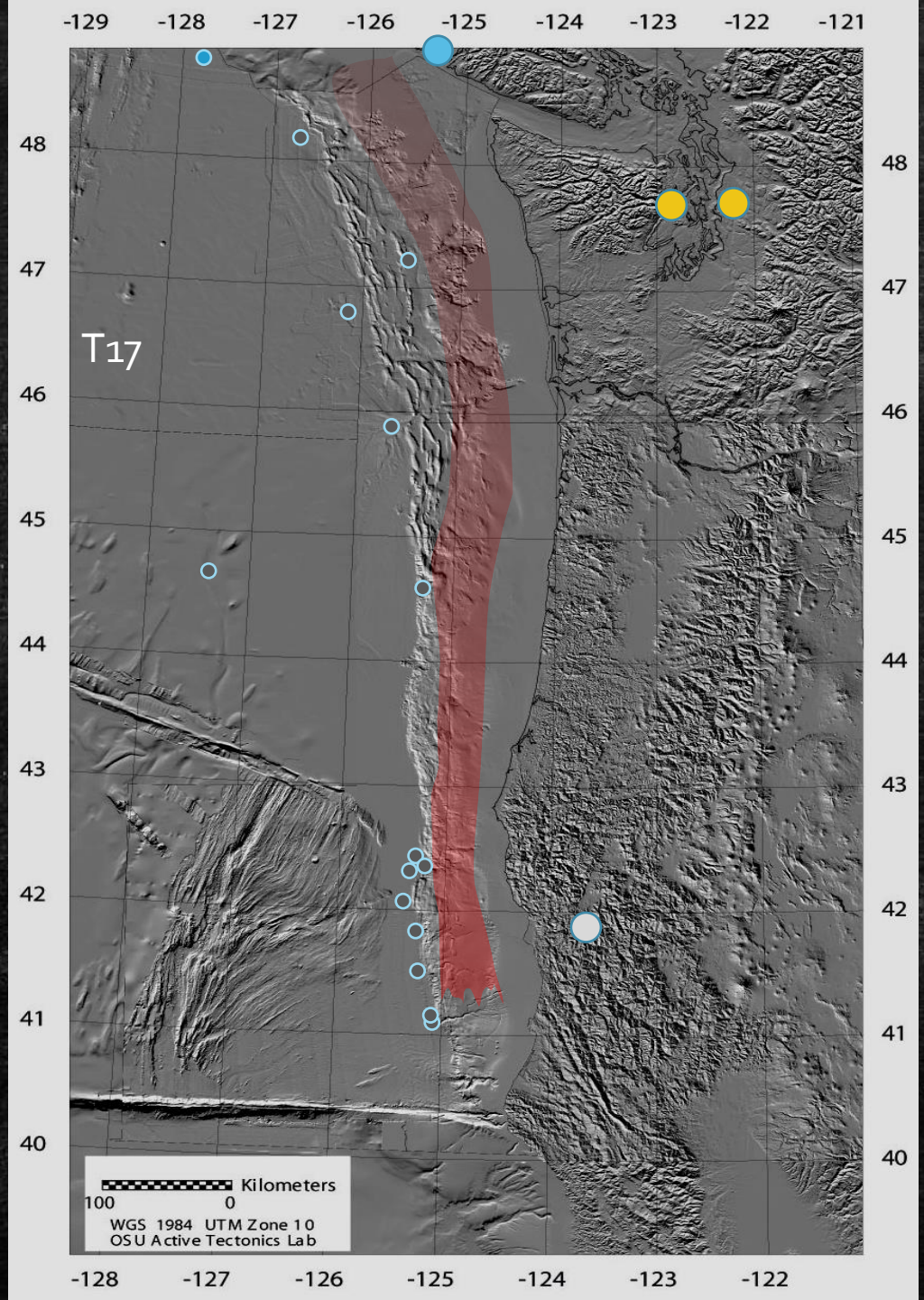
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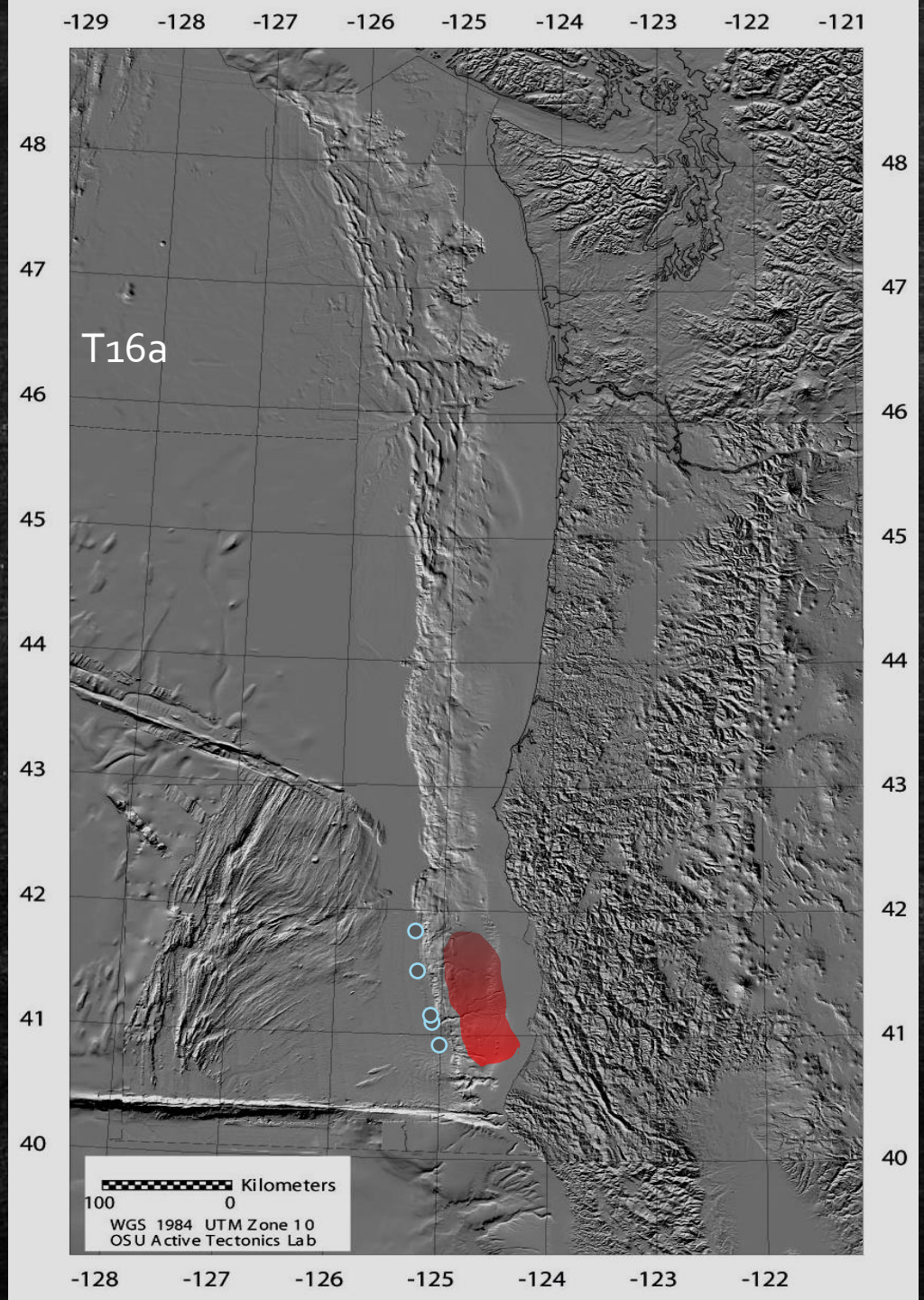
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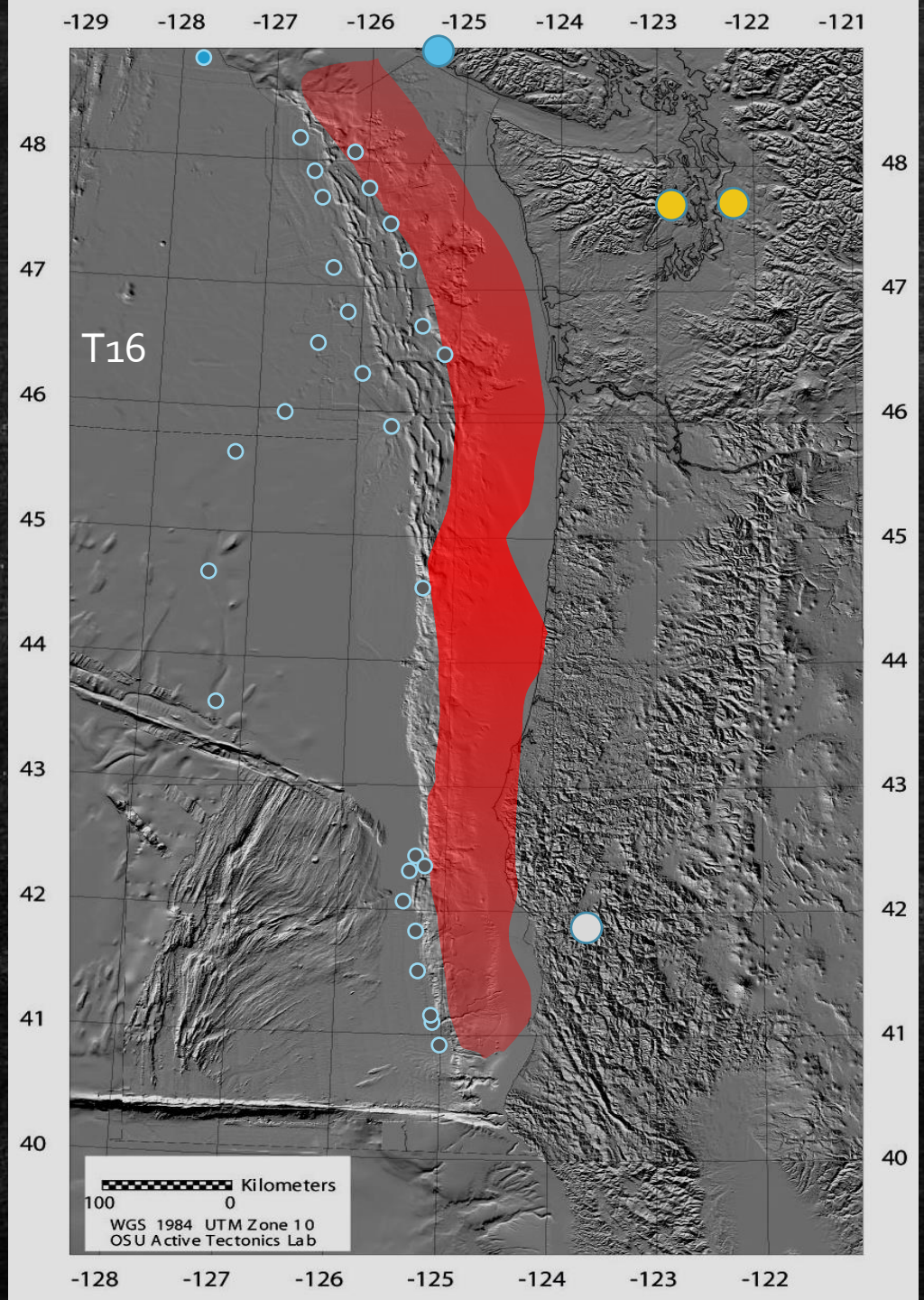
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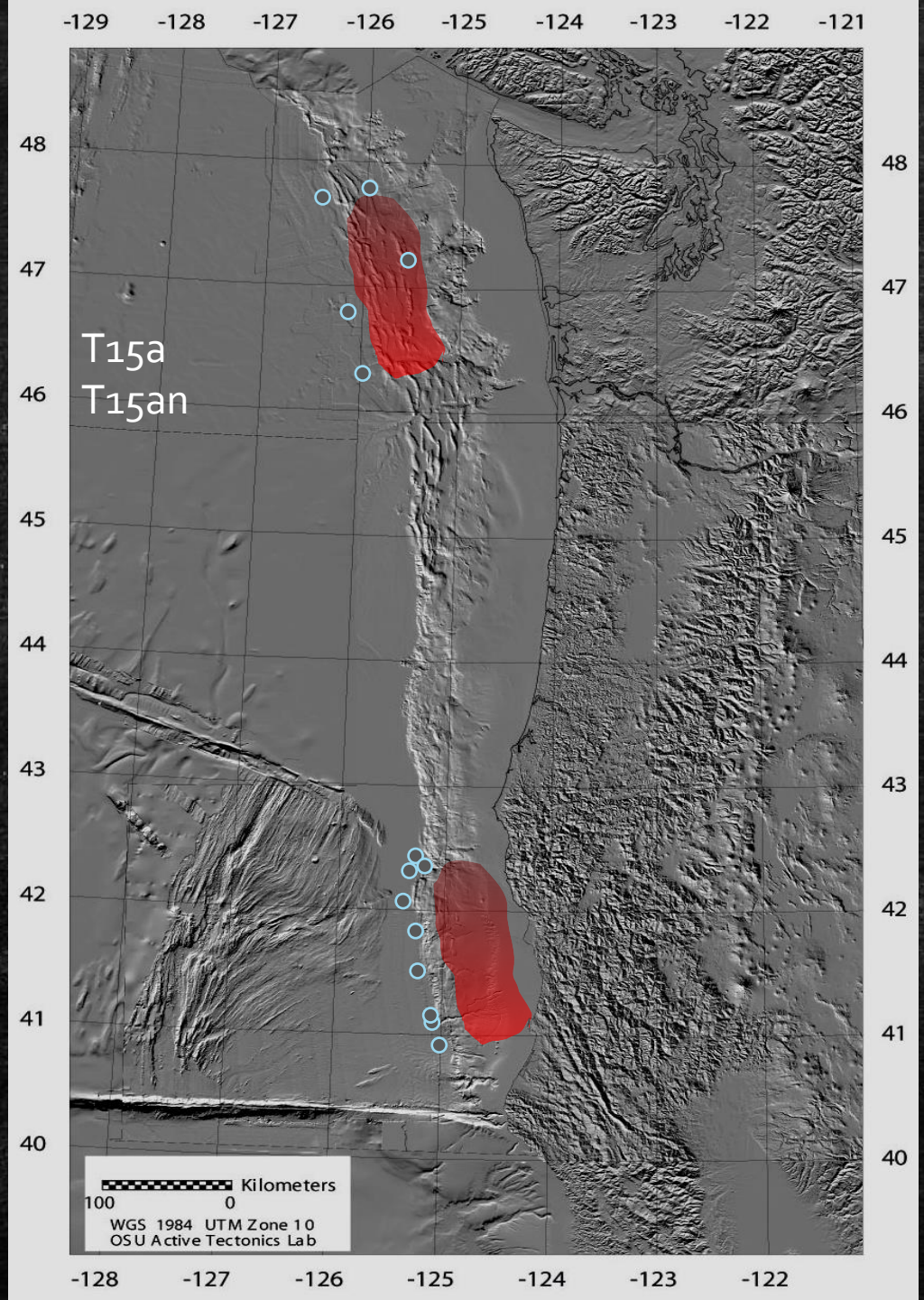
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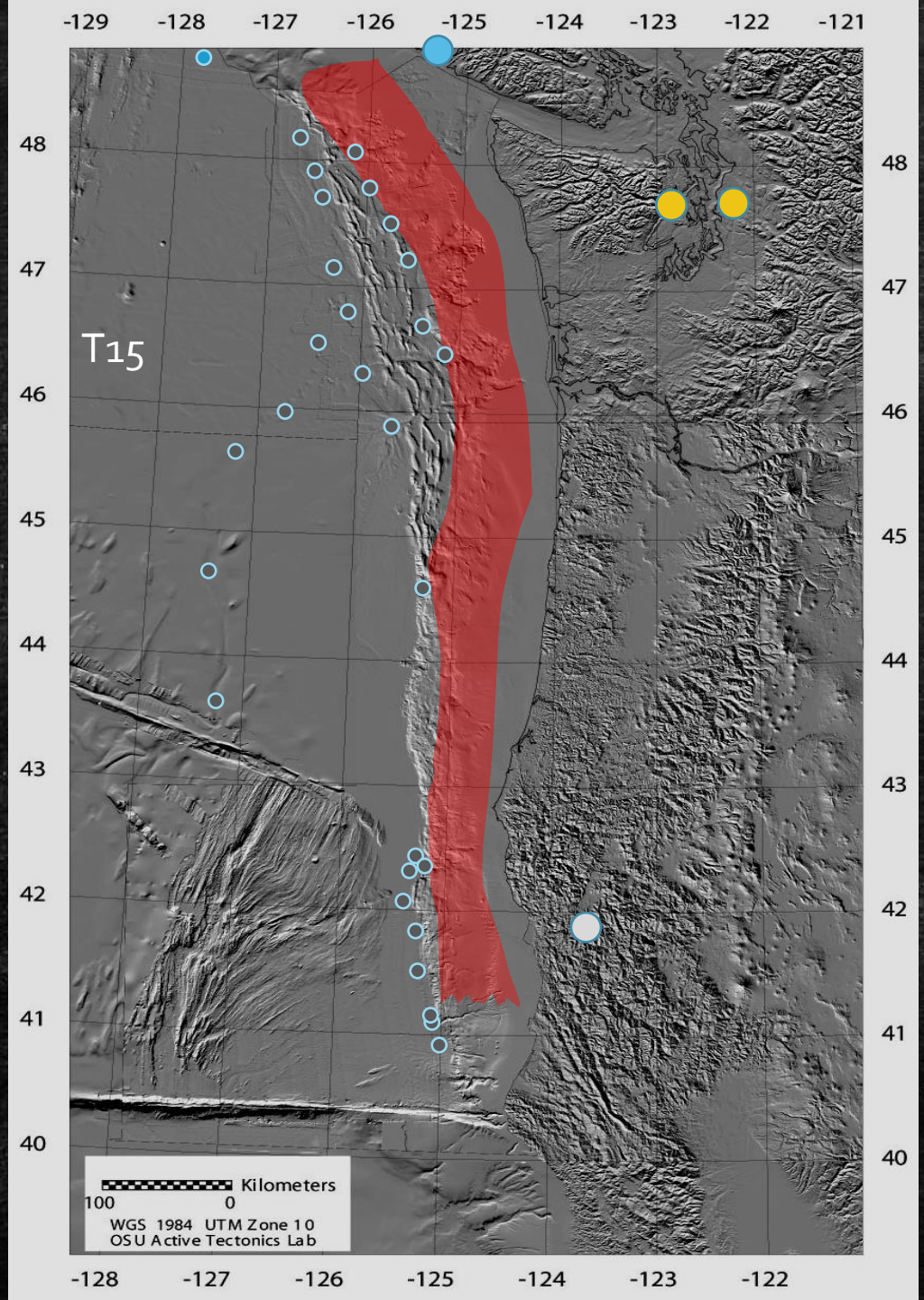
OSU Active Tectonics Lab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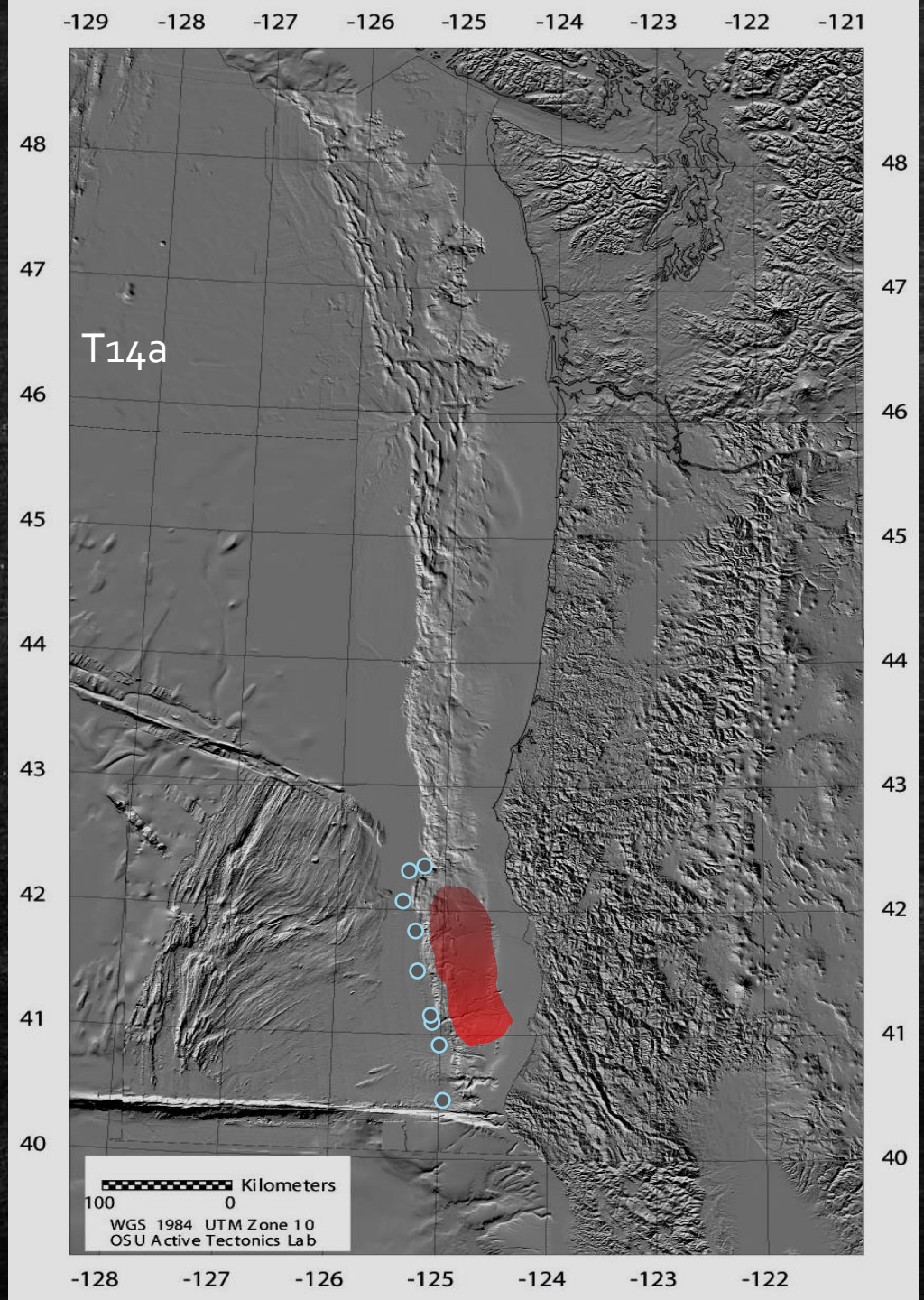
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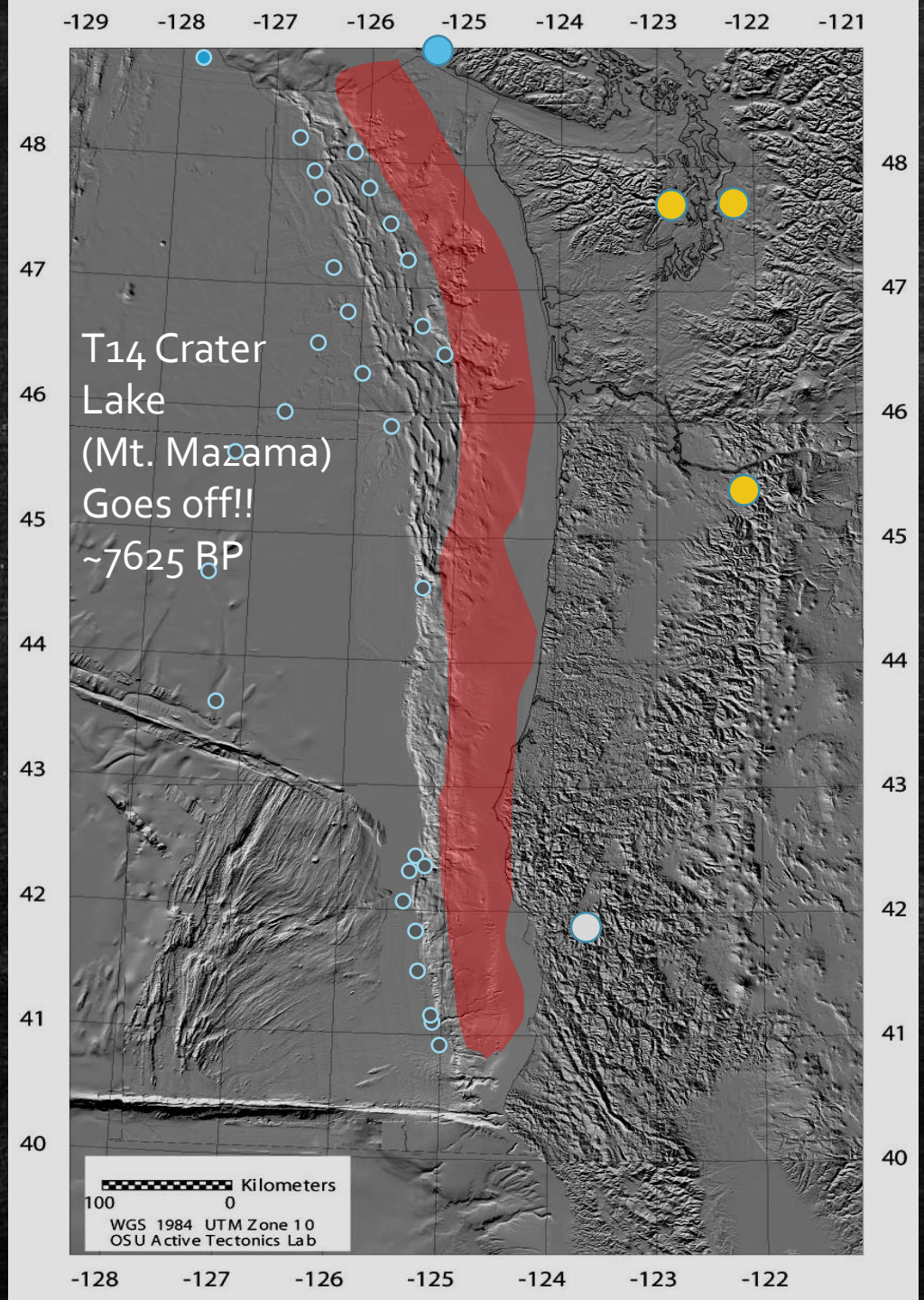
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T14 Crater Lake (Mt. Mazama) Goes off!!
~7625 BP
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WGS 1984 UTM Zone 10
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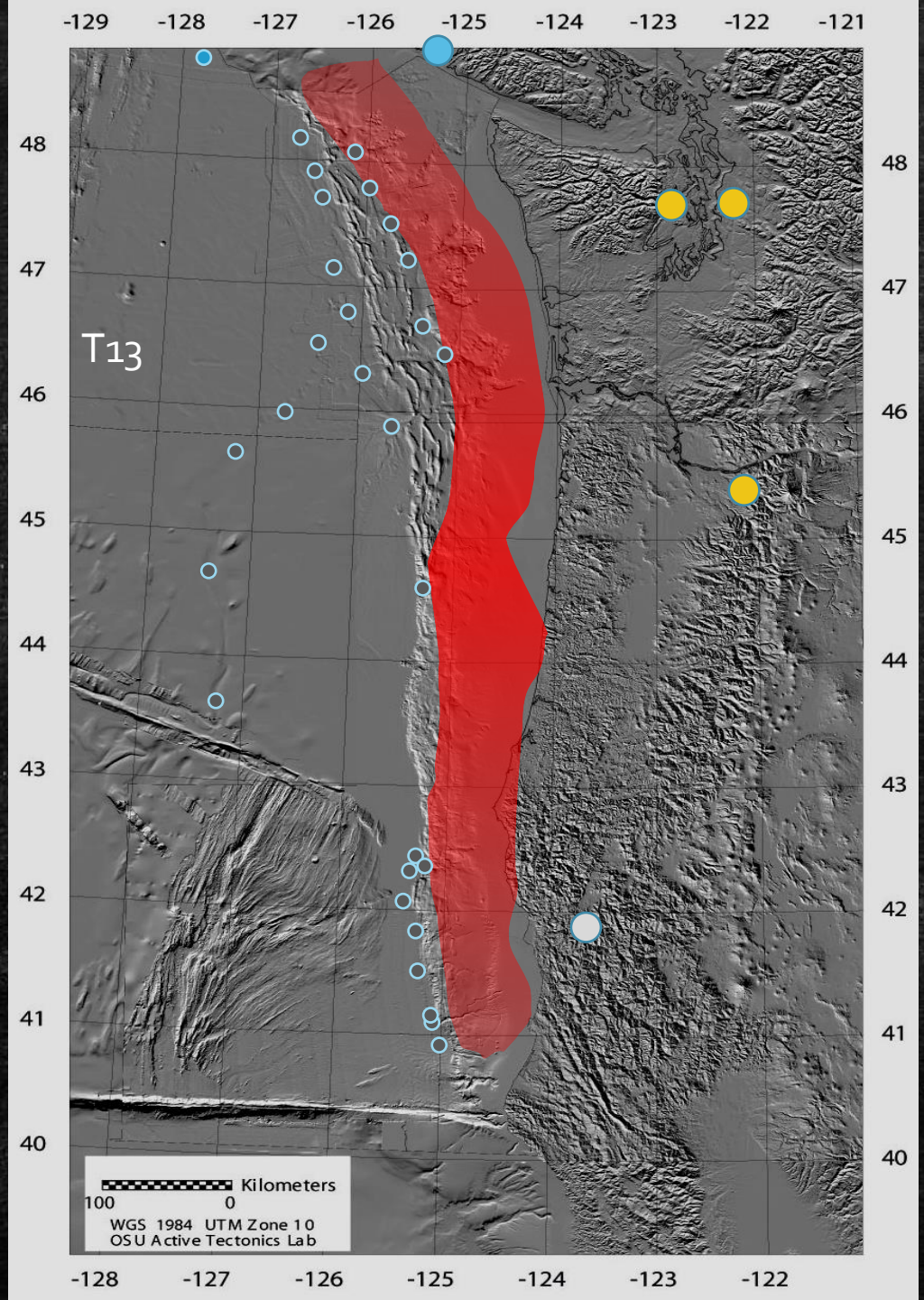
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WGS 1984 UTM Zone 10
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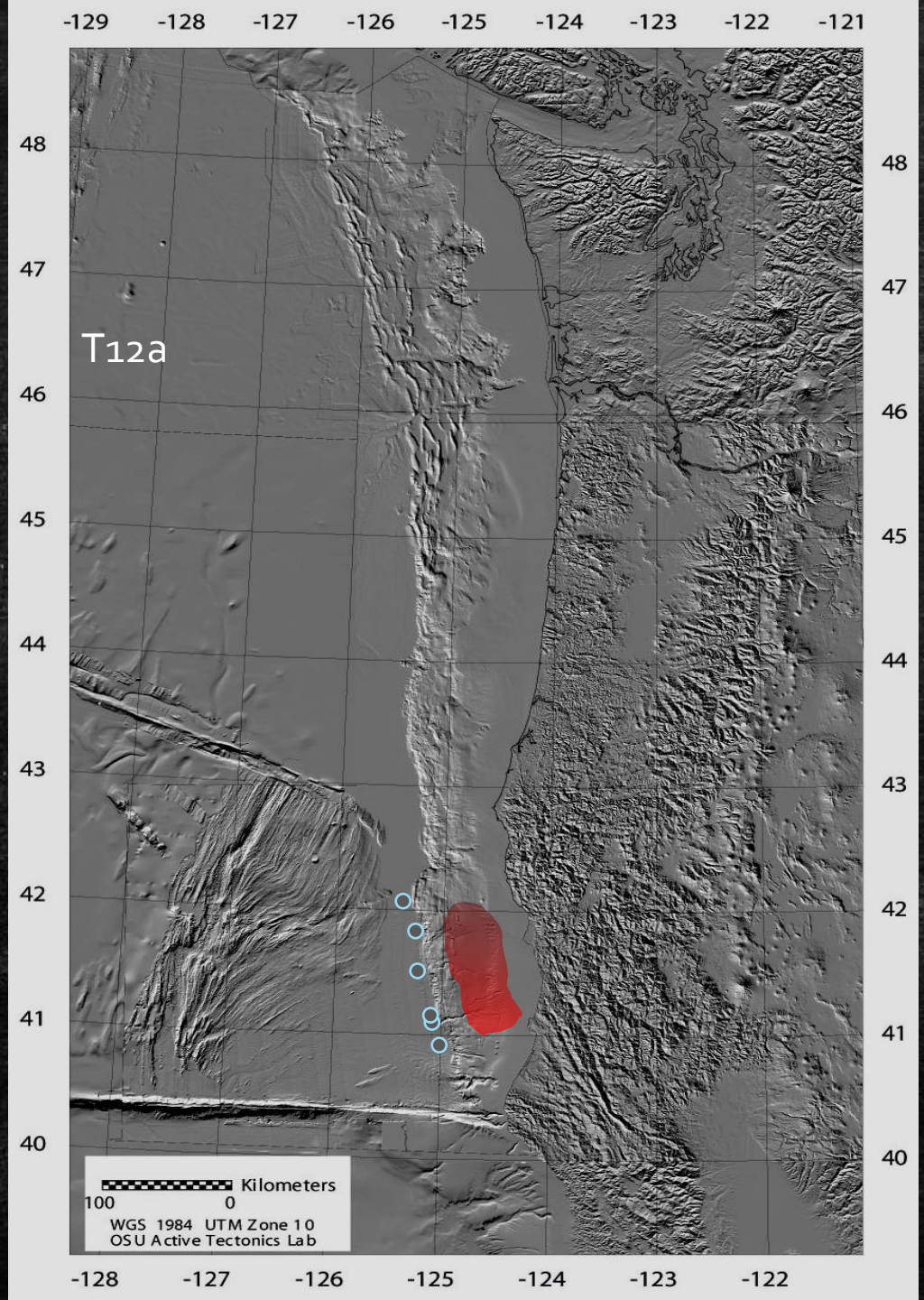
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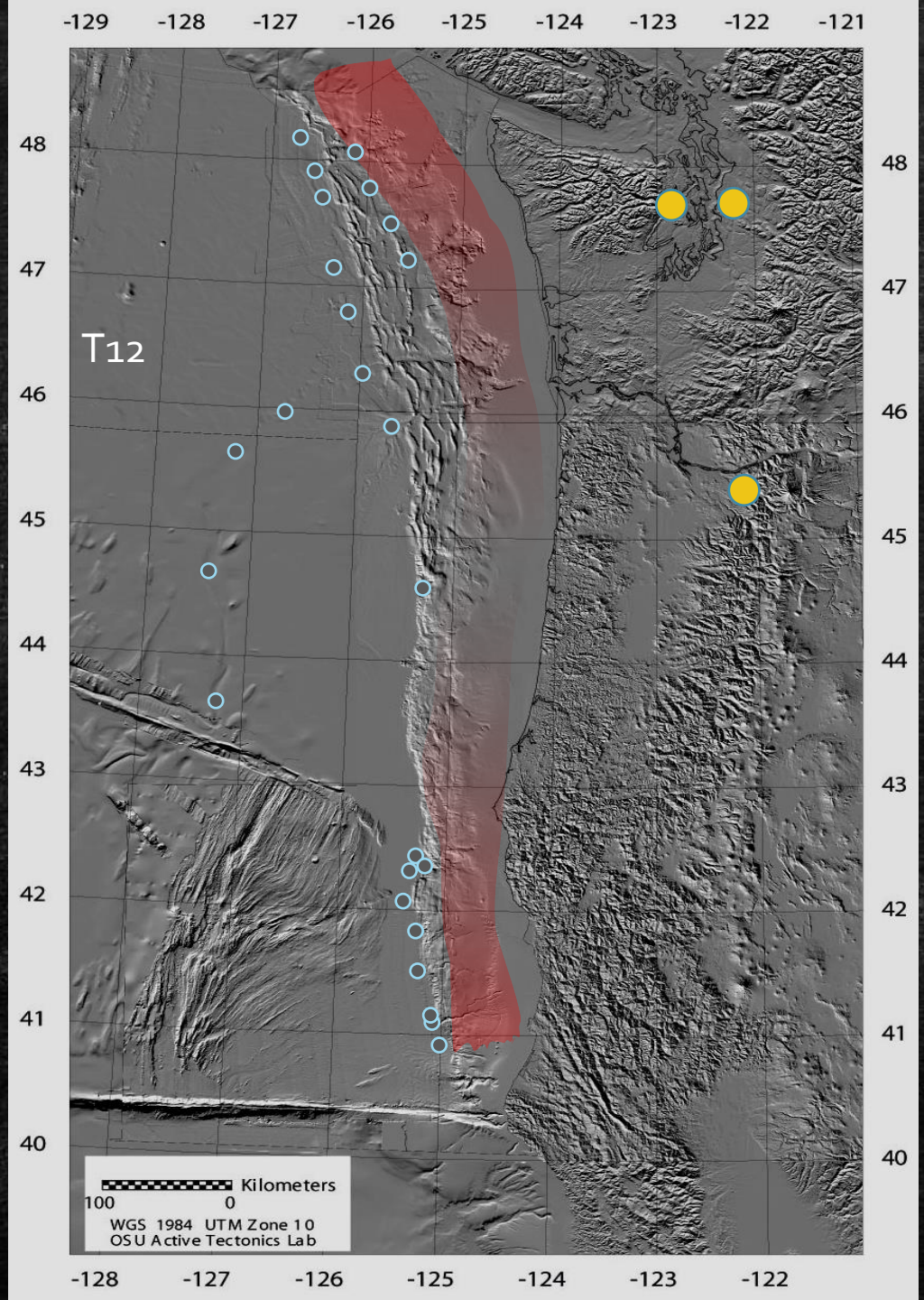
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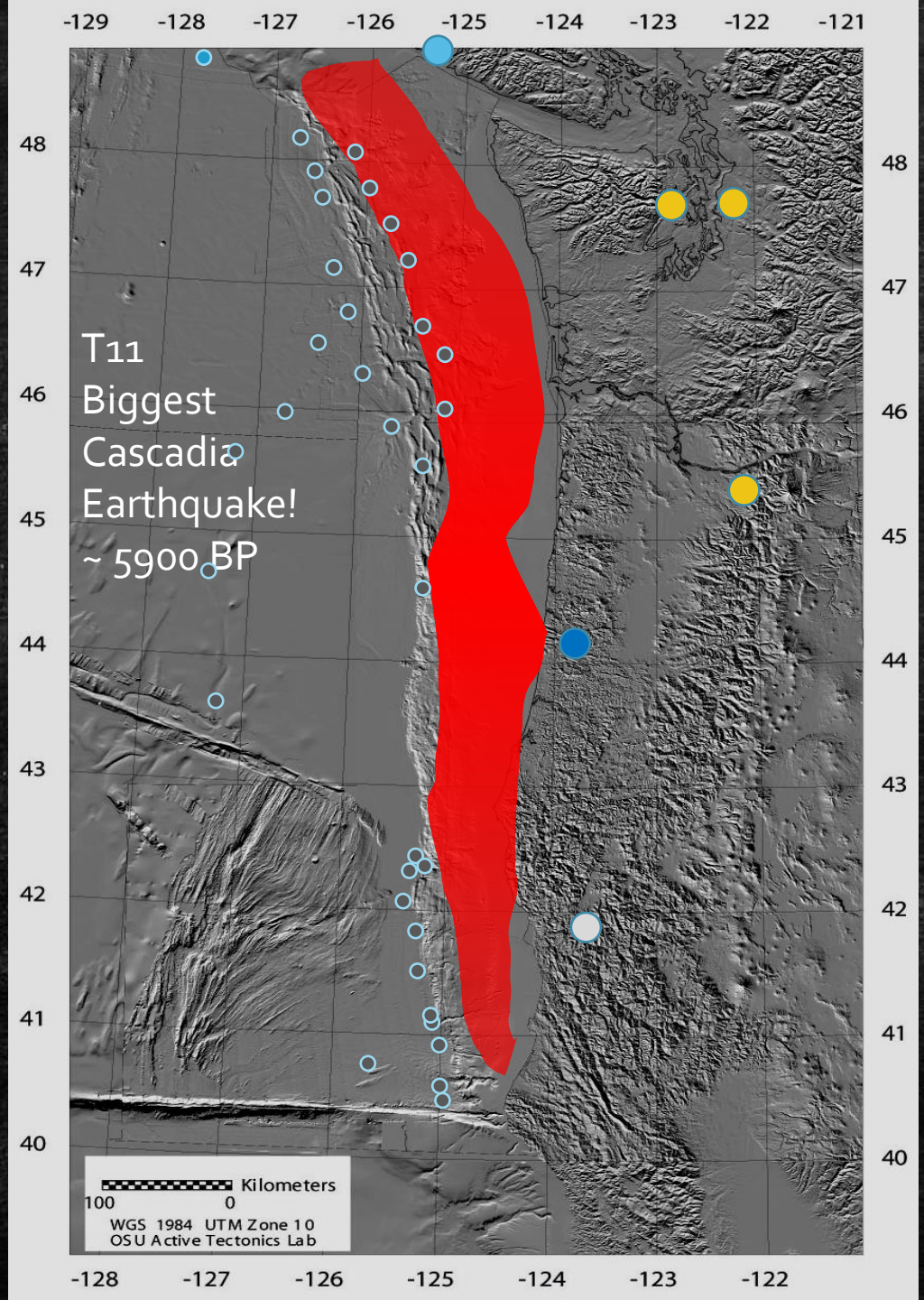
T11
Biggest
Cascadia
Earthquake!
~ 5900 BP
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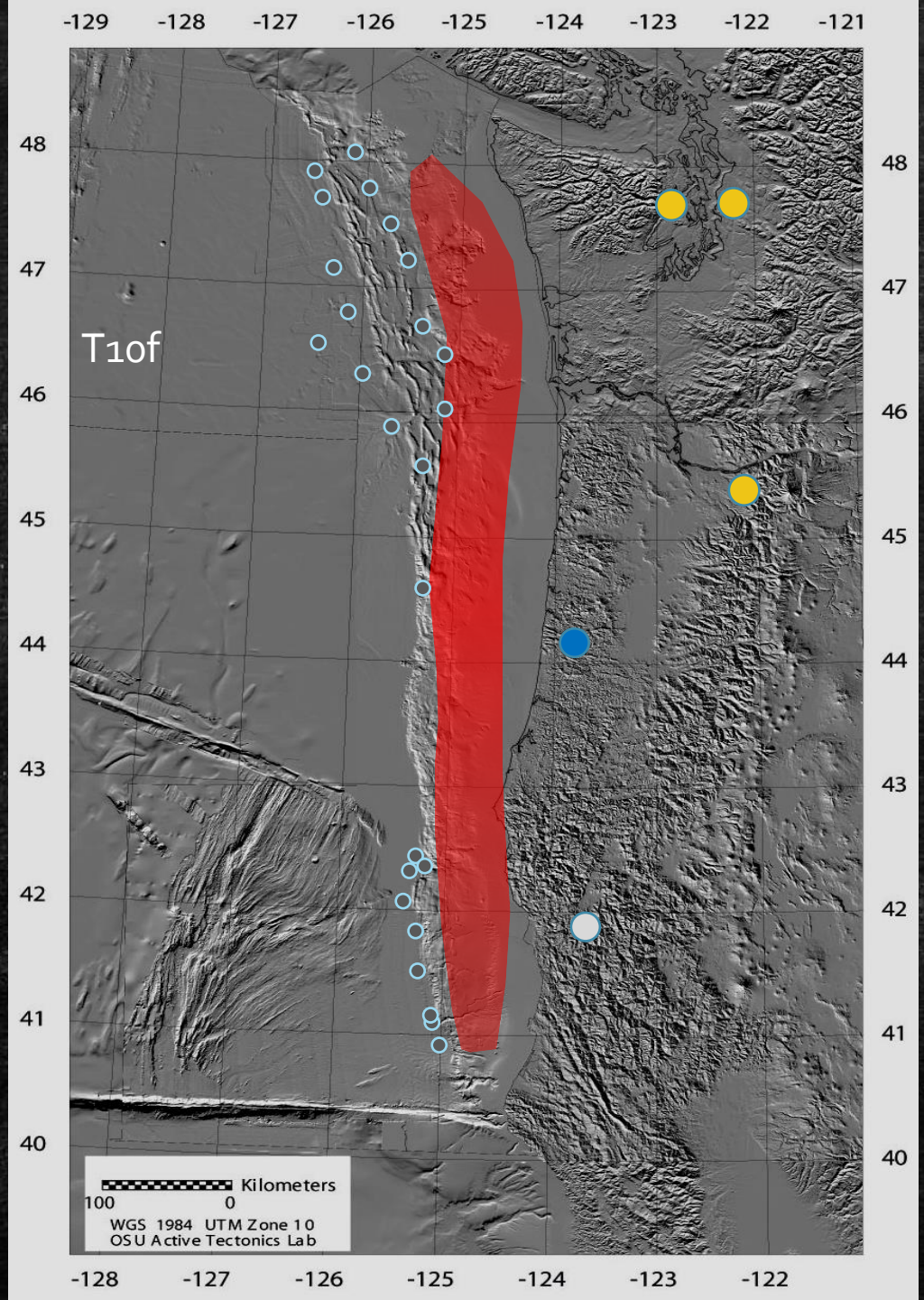
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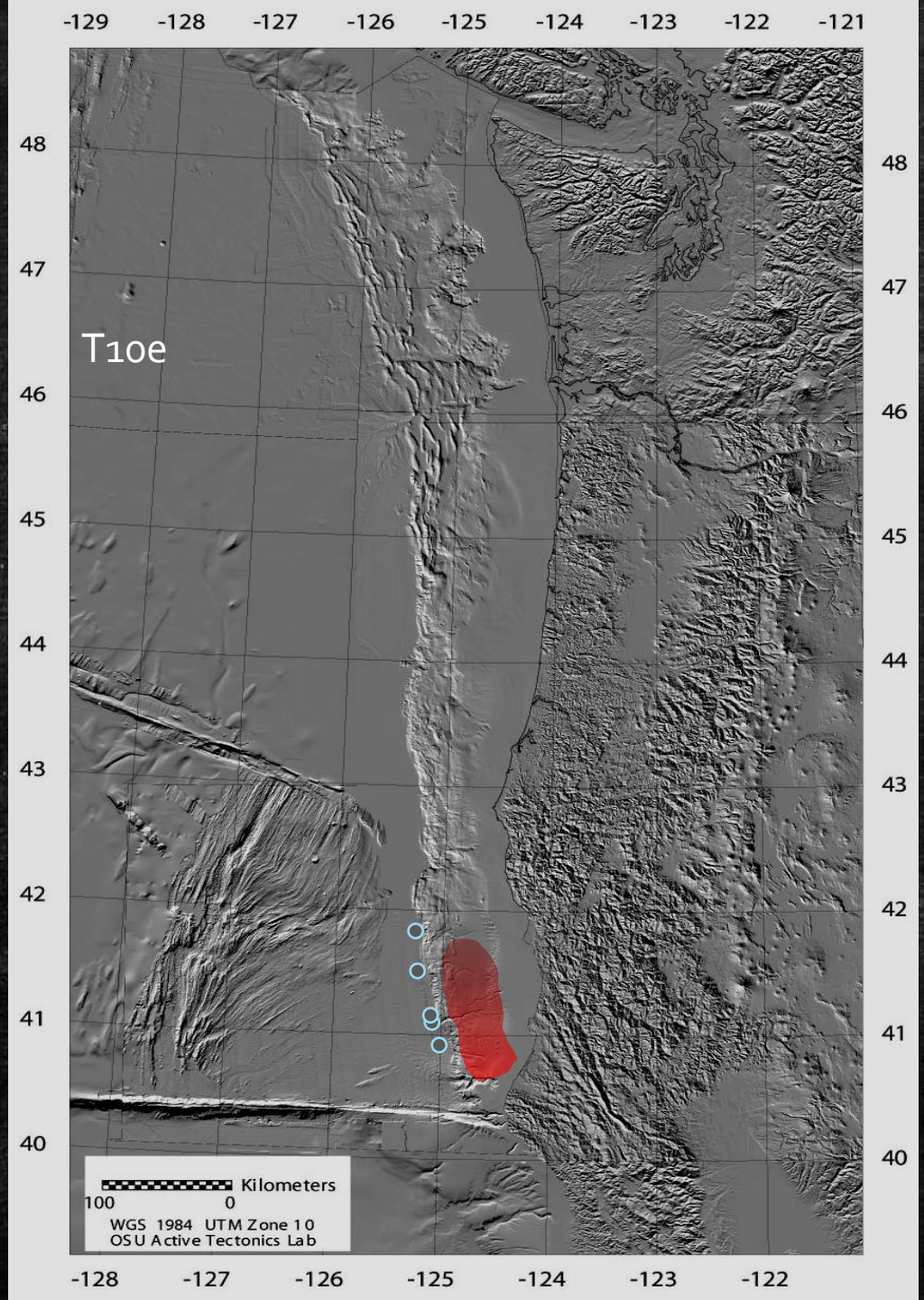
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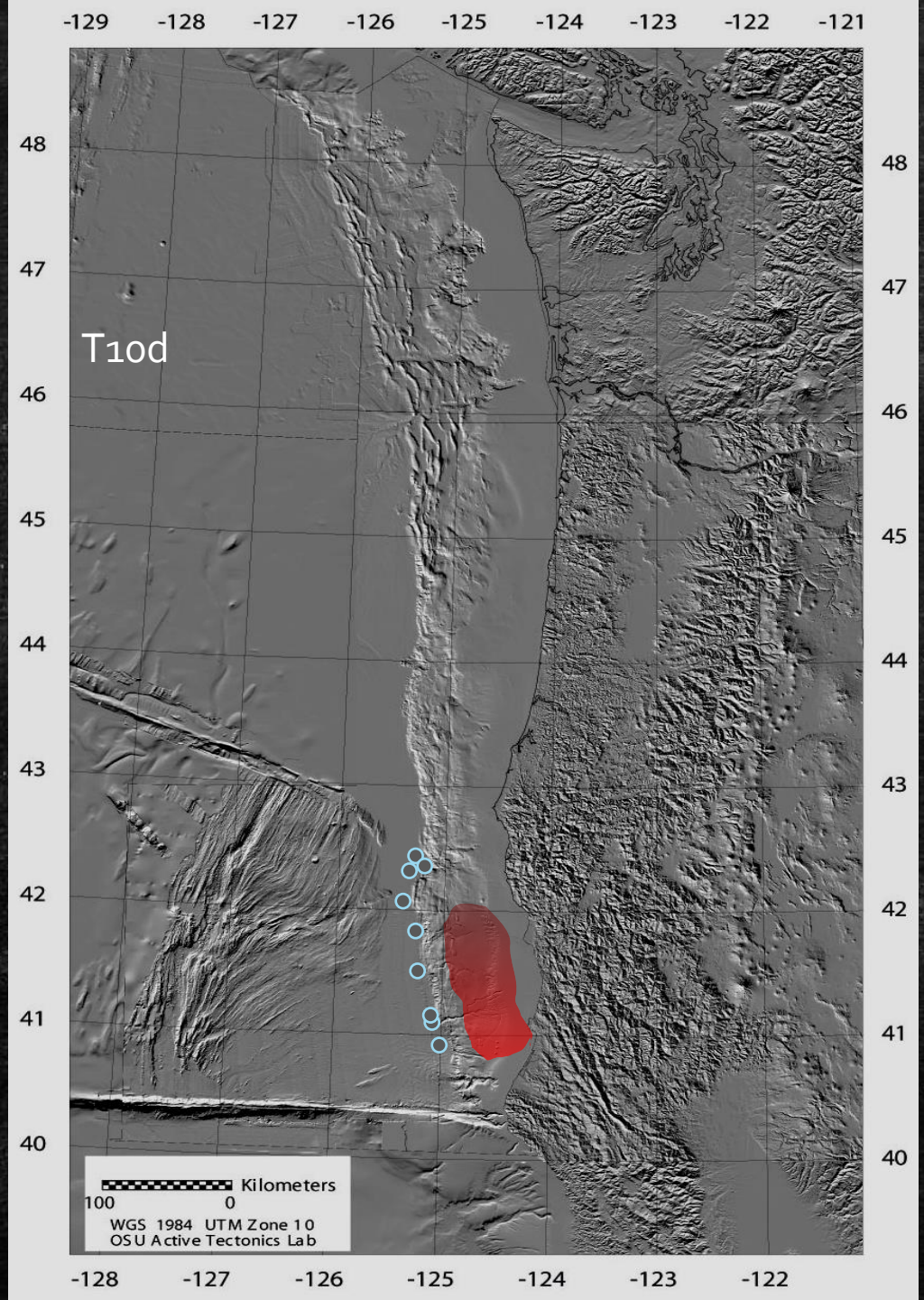
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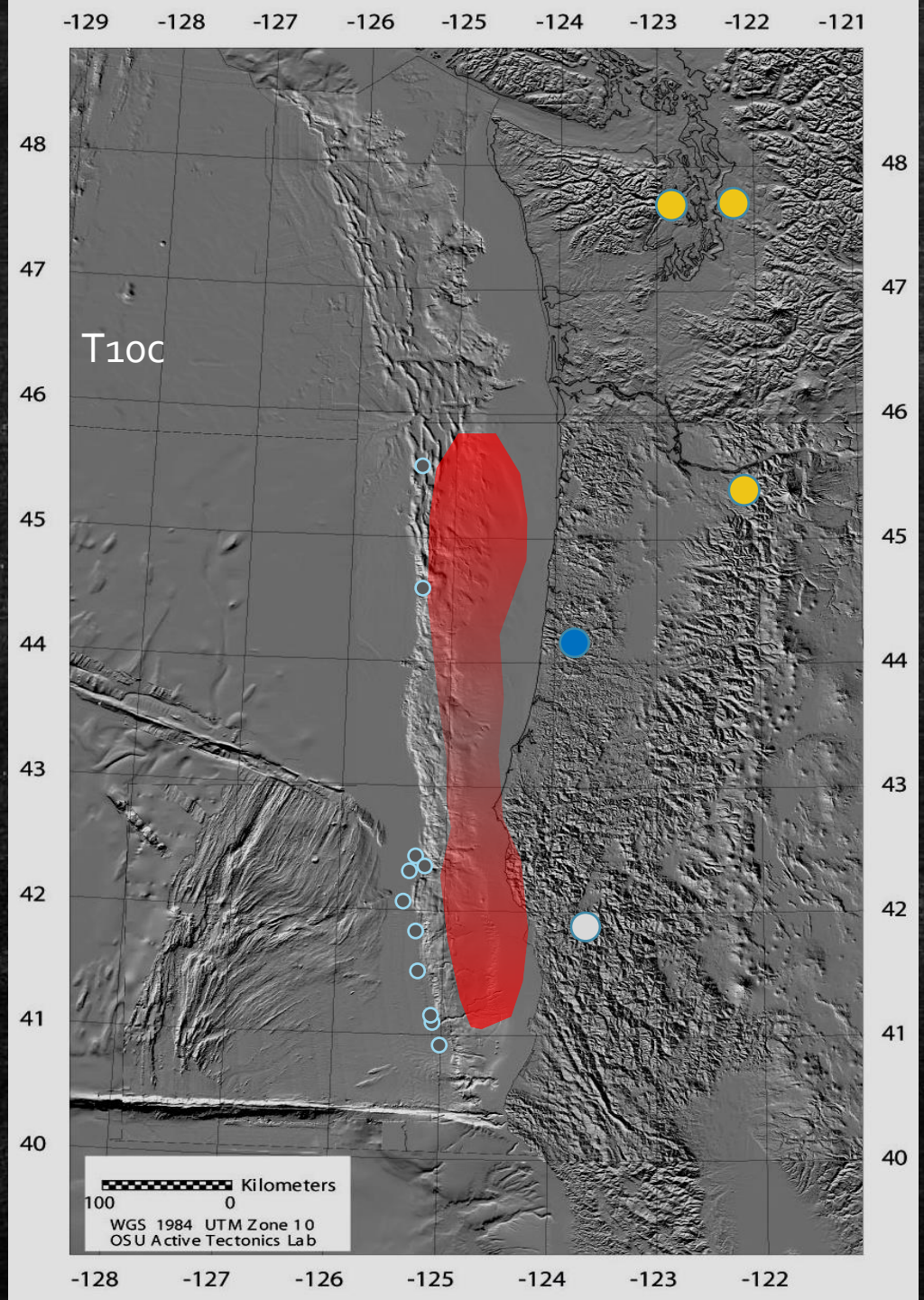
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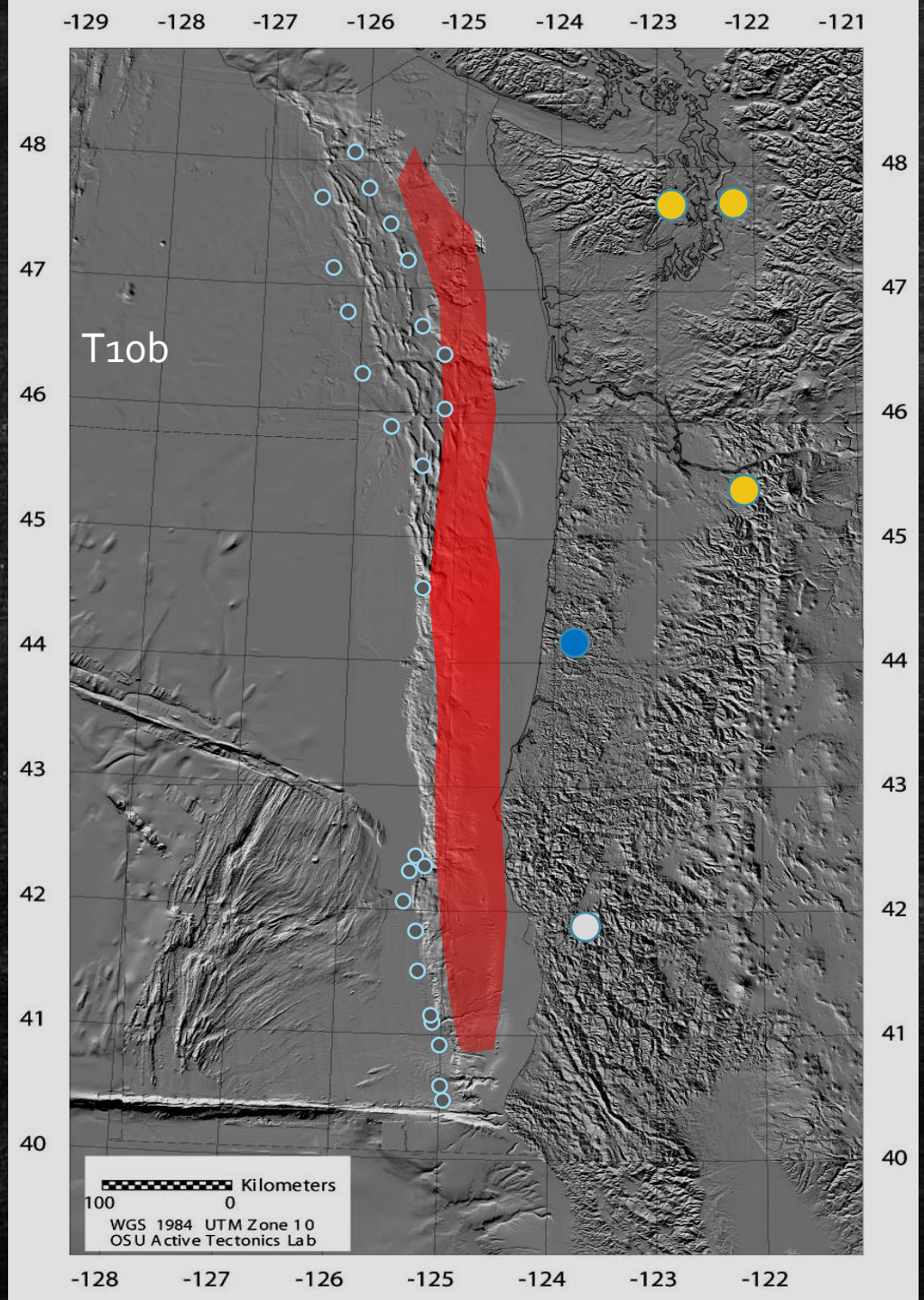
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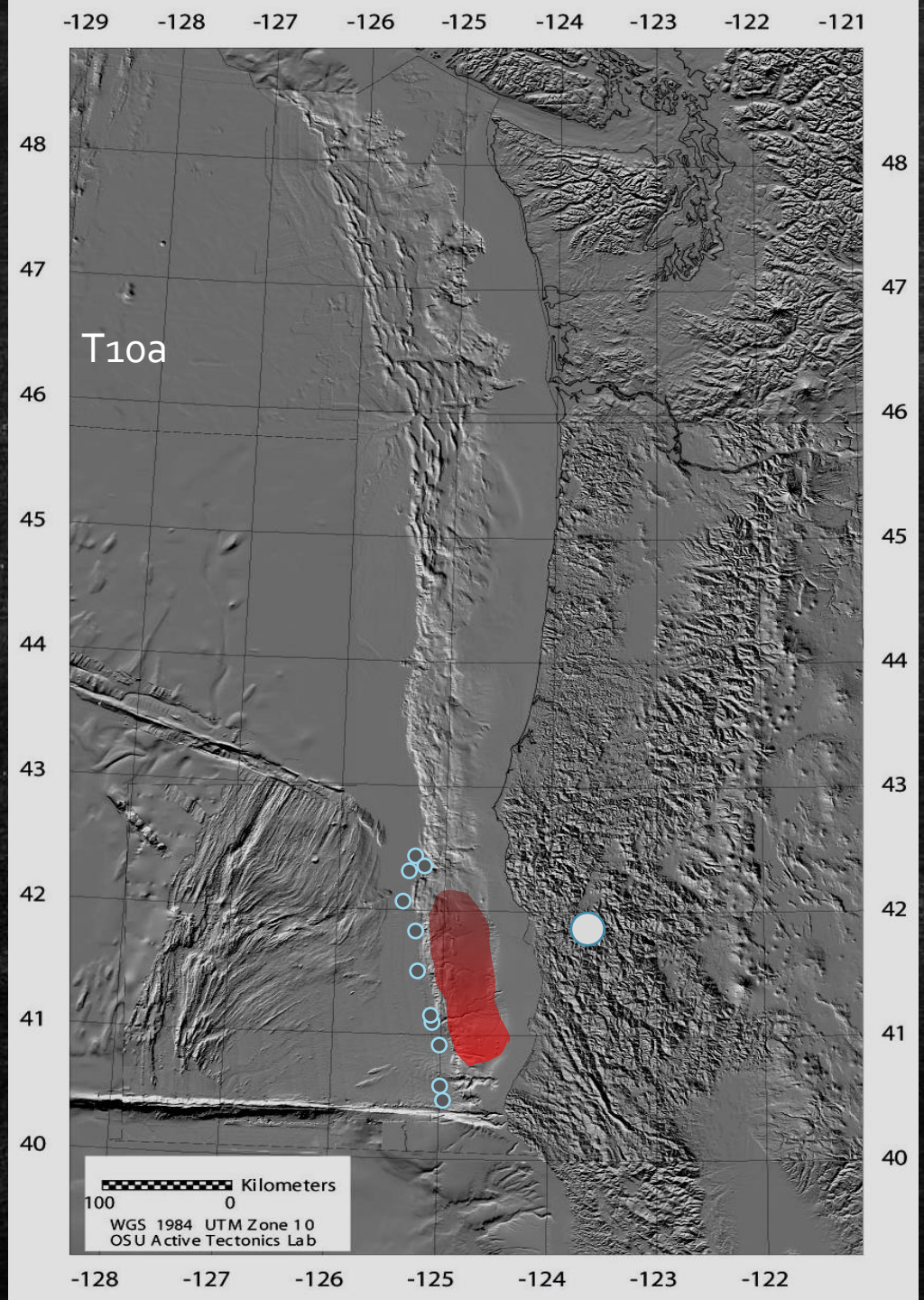
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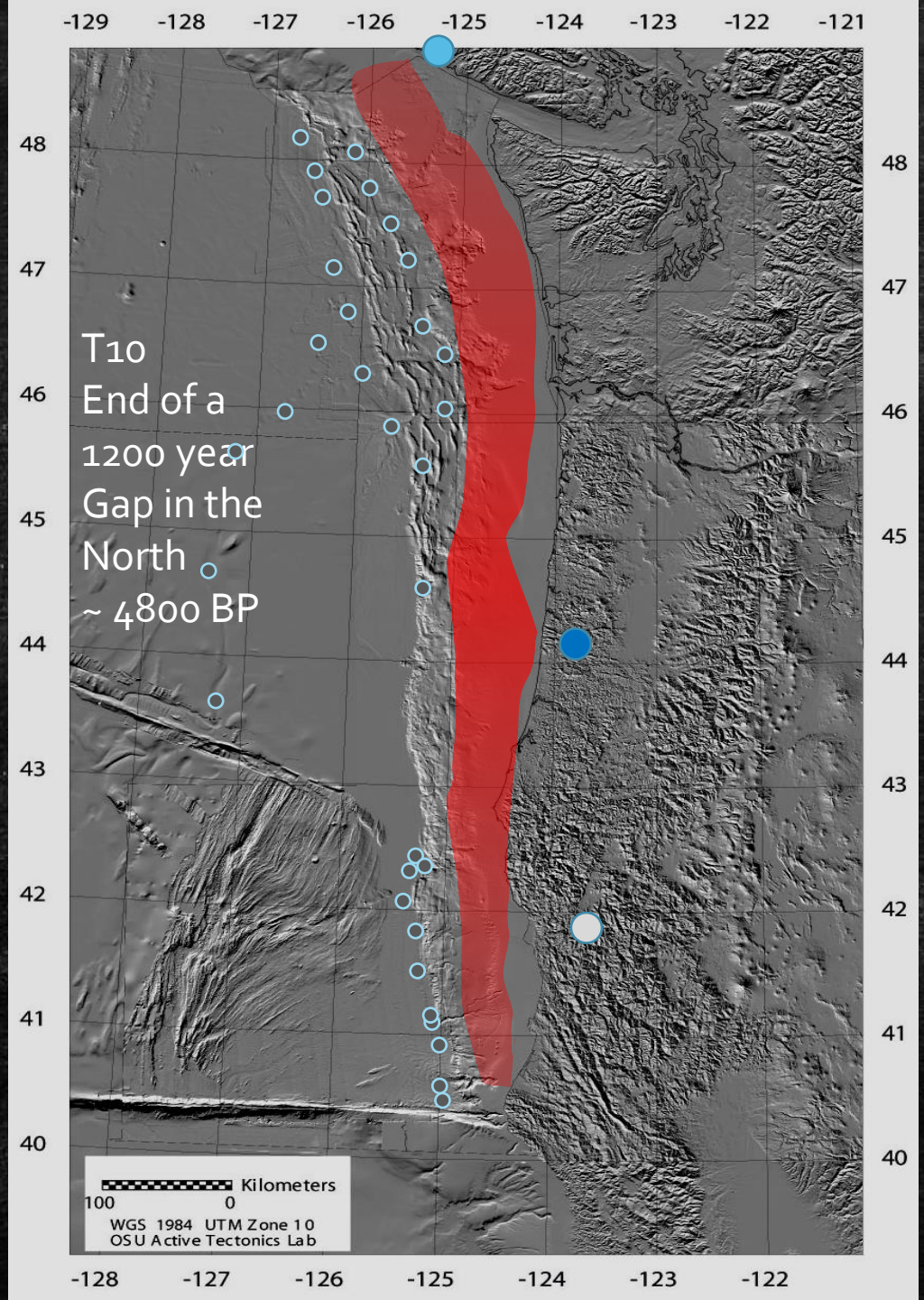
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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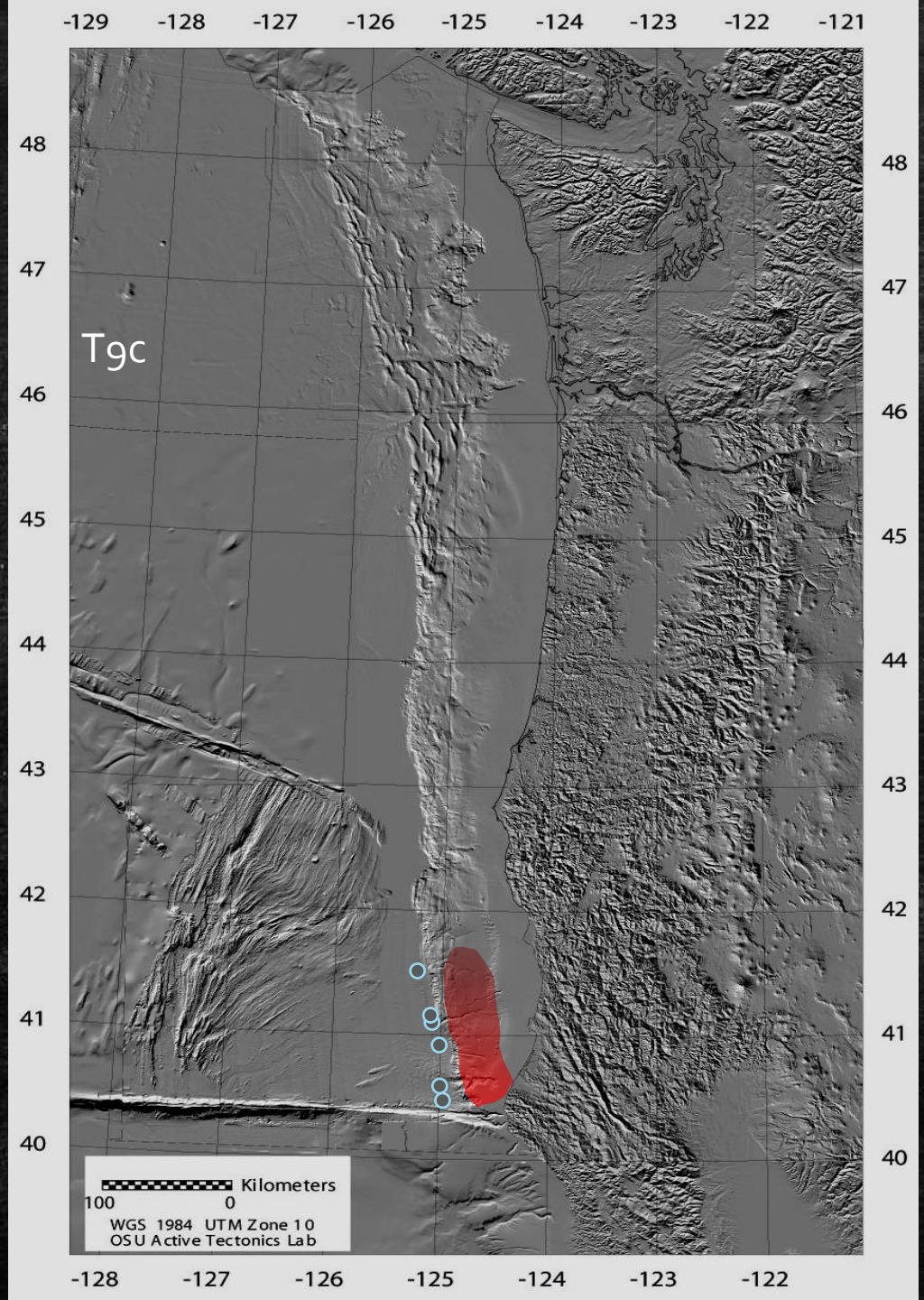
T10
End of a
1200 year
Gap in the
North
~ 4800 BP
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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T9c
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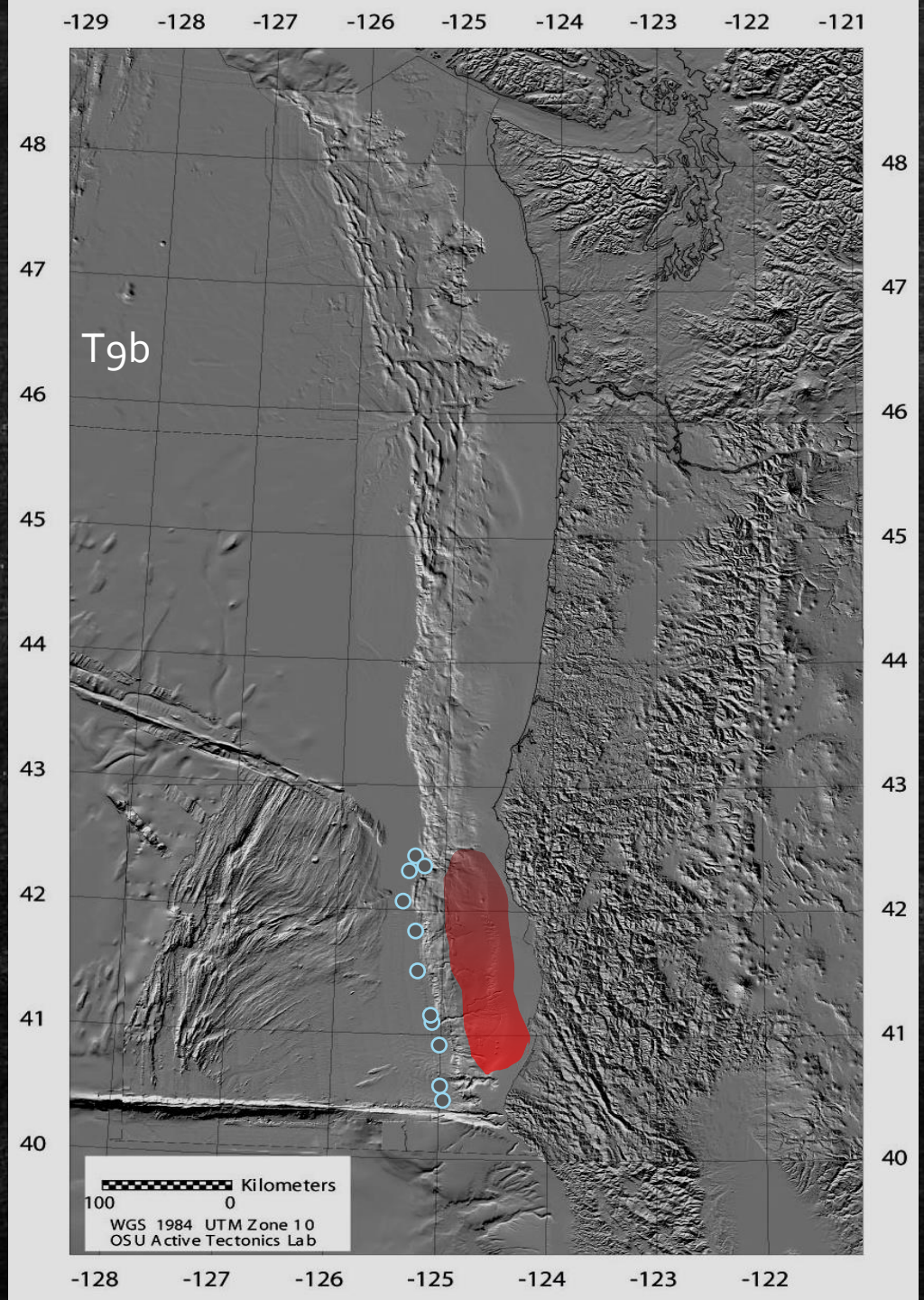
OSU Active Tectonics Lab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T9b
Kilometers
100
0
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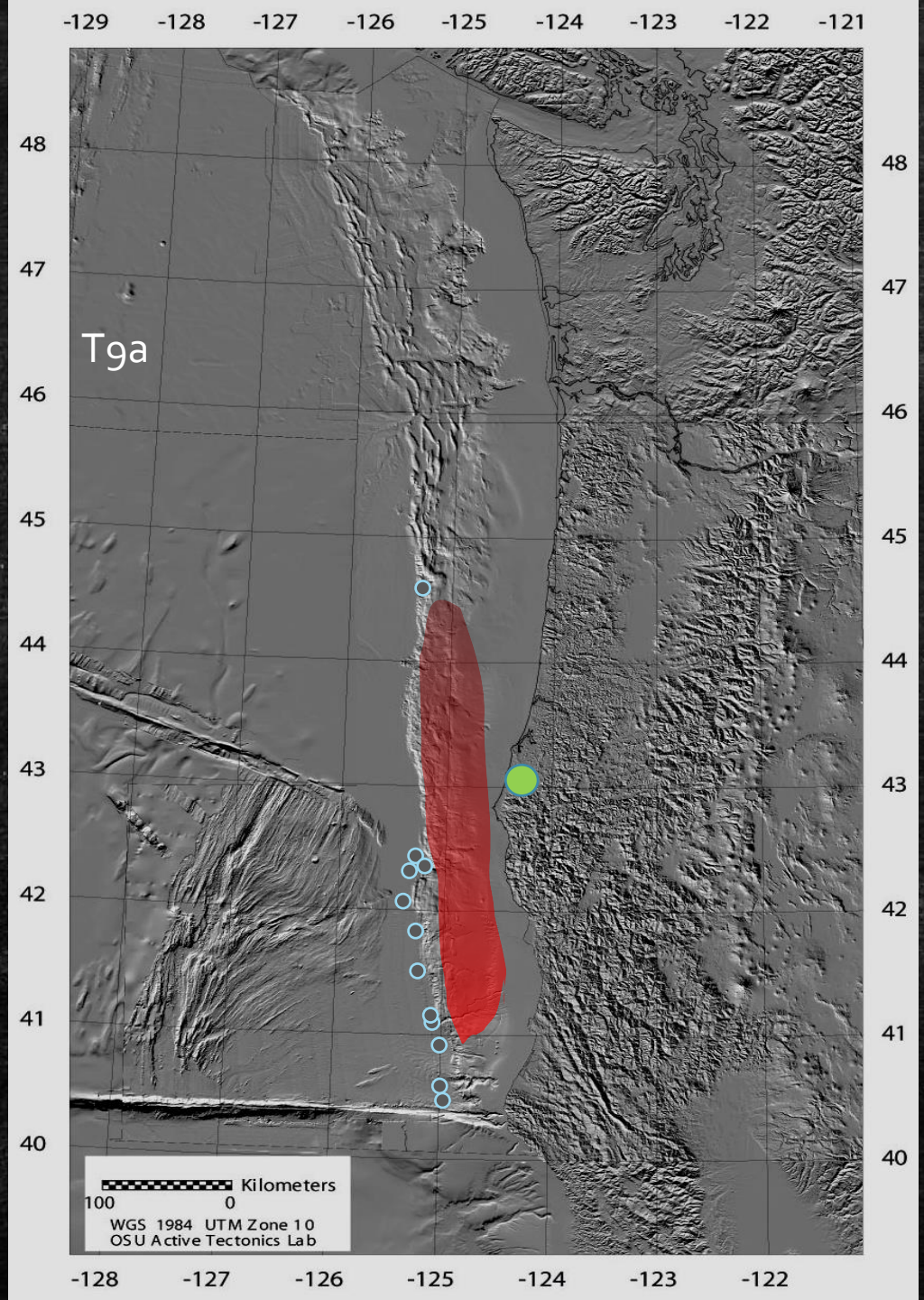
OSU Active Tectonics Lab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T9a
Kilometers
100
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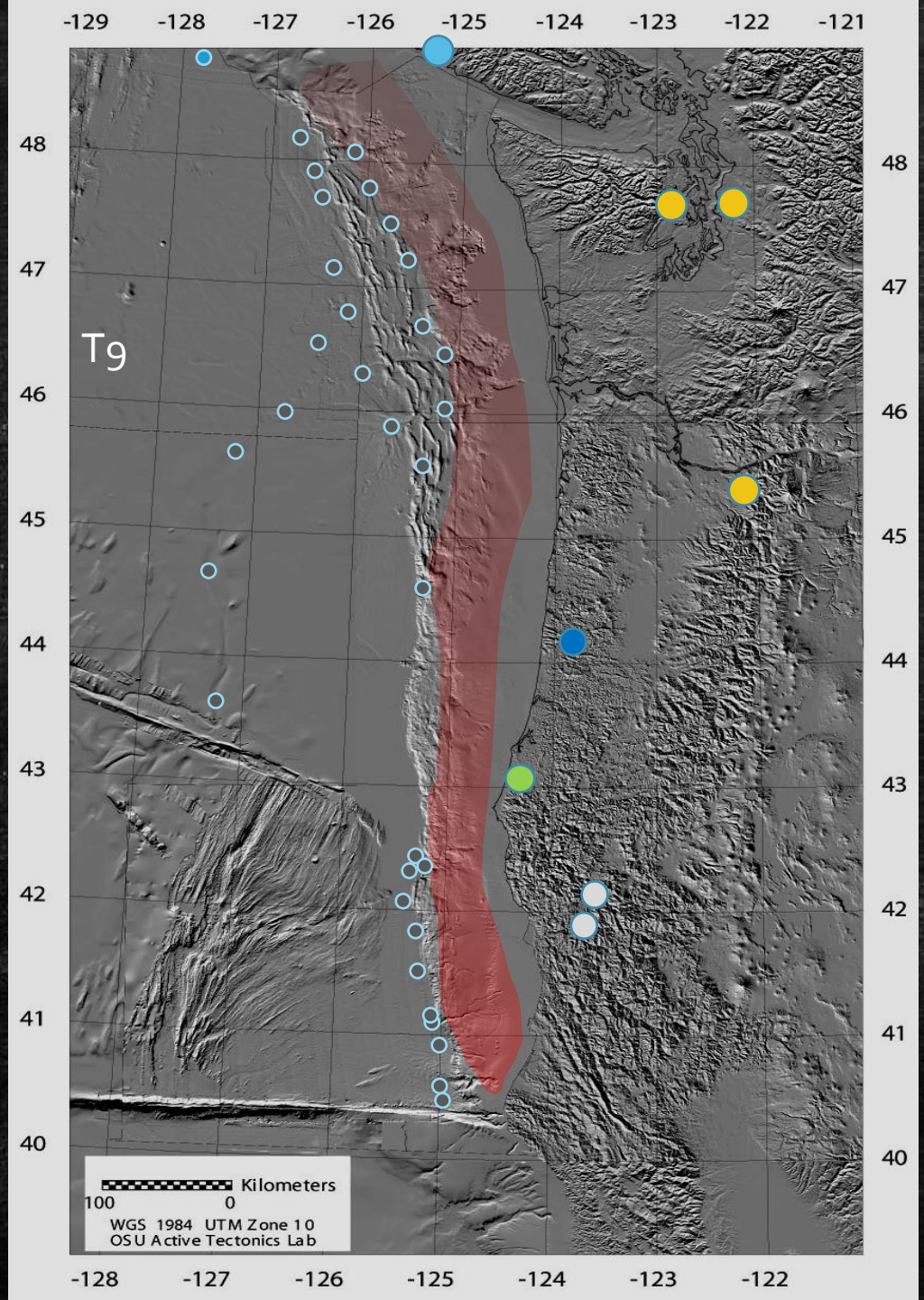
OSU Active Tectonics Lab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Kilometers
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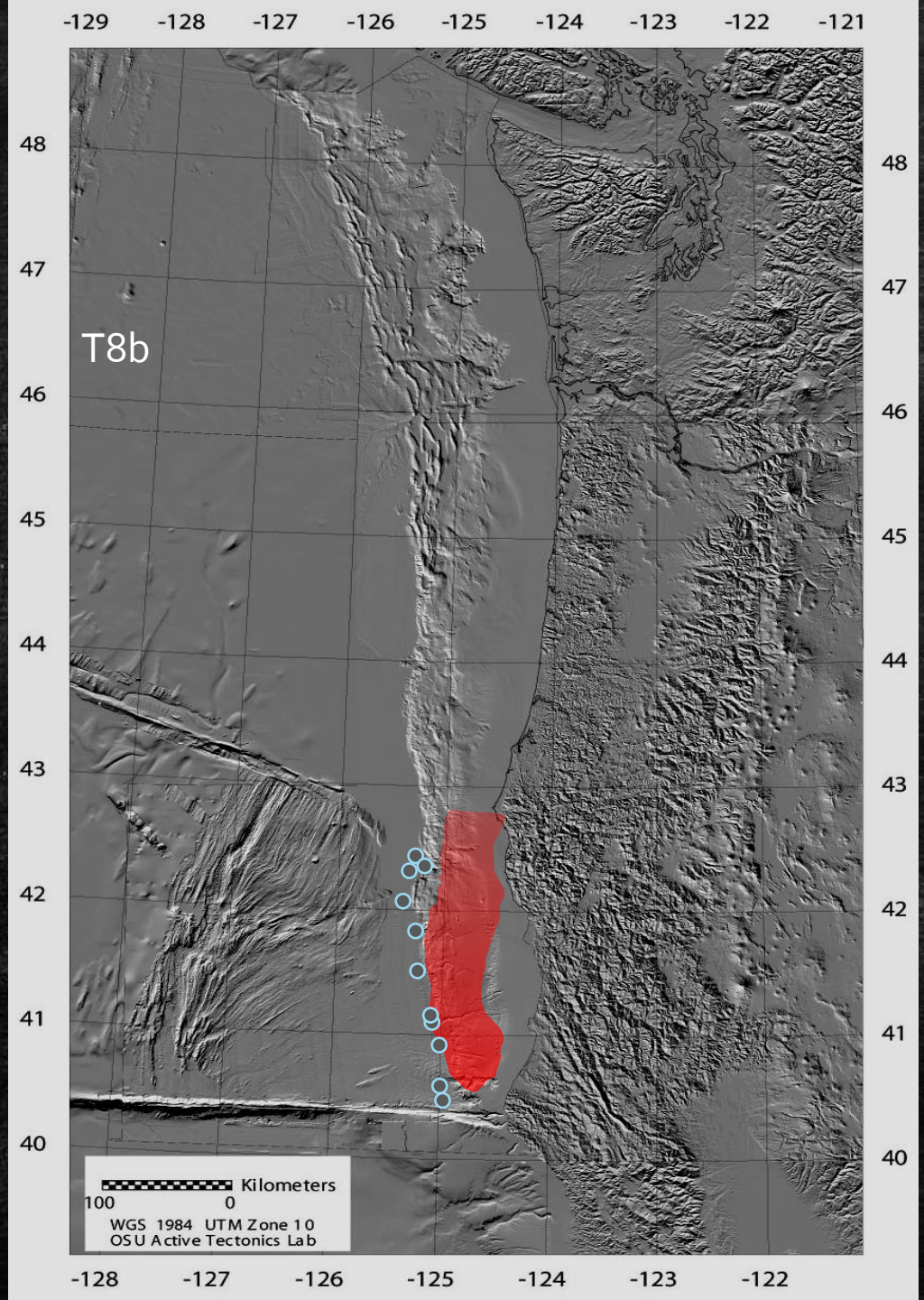
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Kilometers
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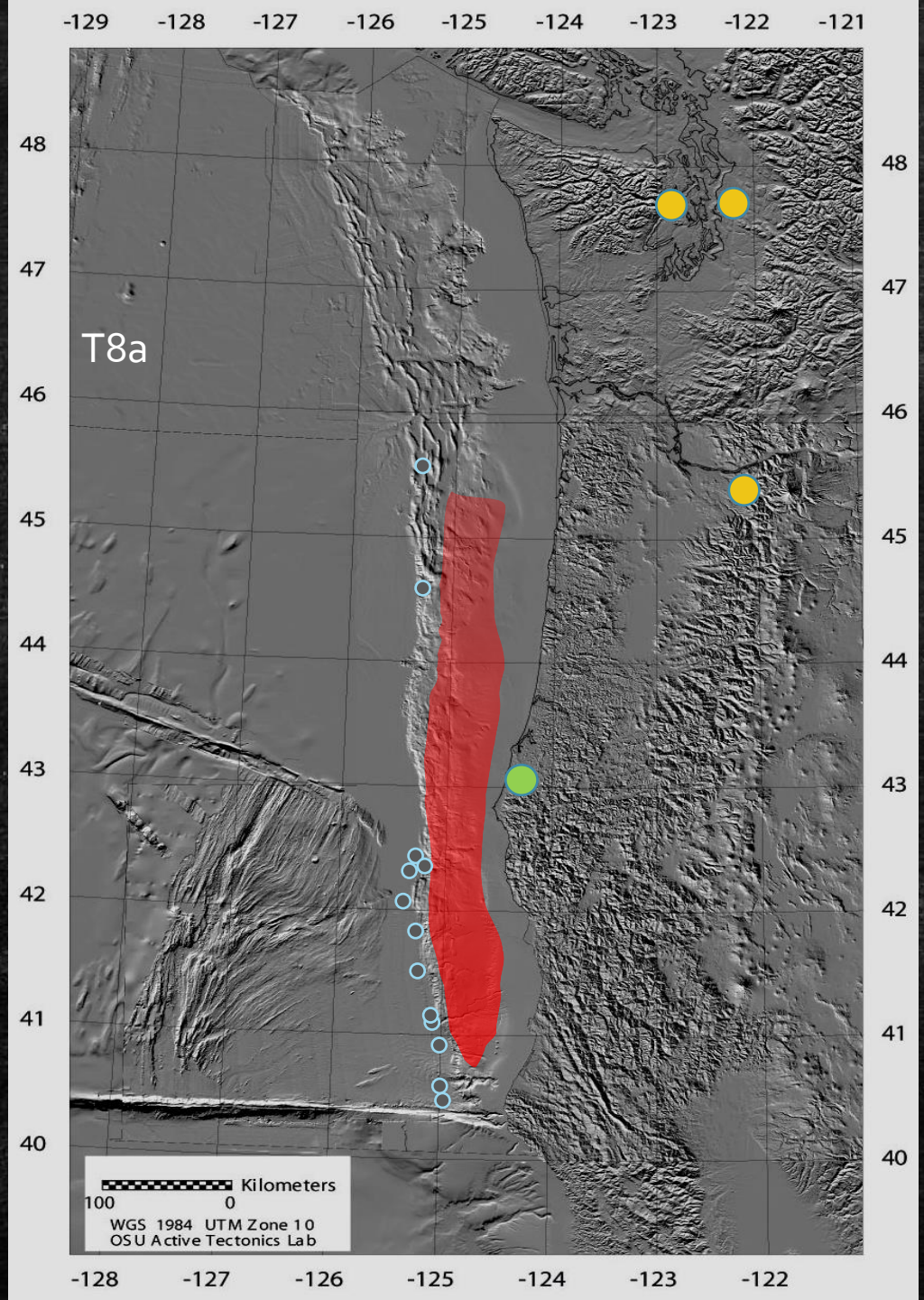
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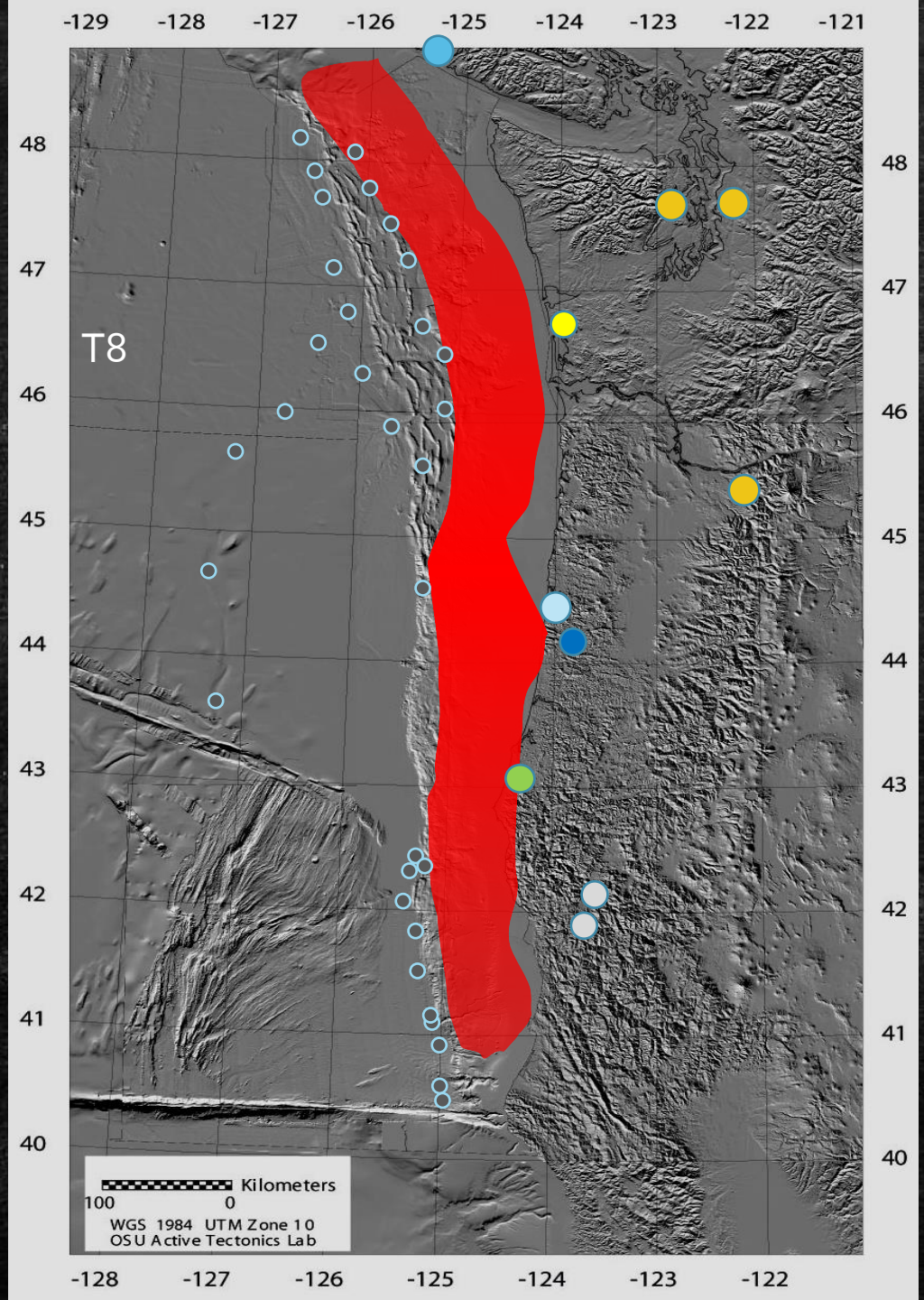
T8a
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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Kilometers
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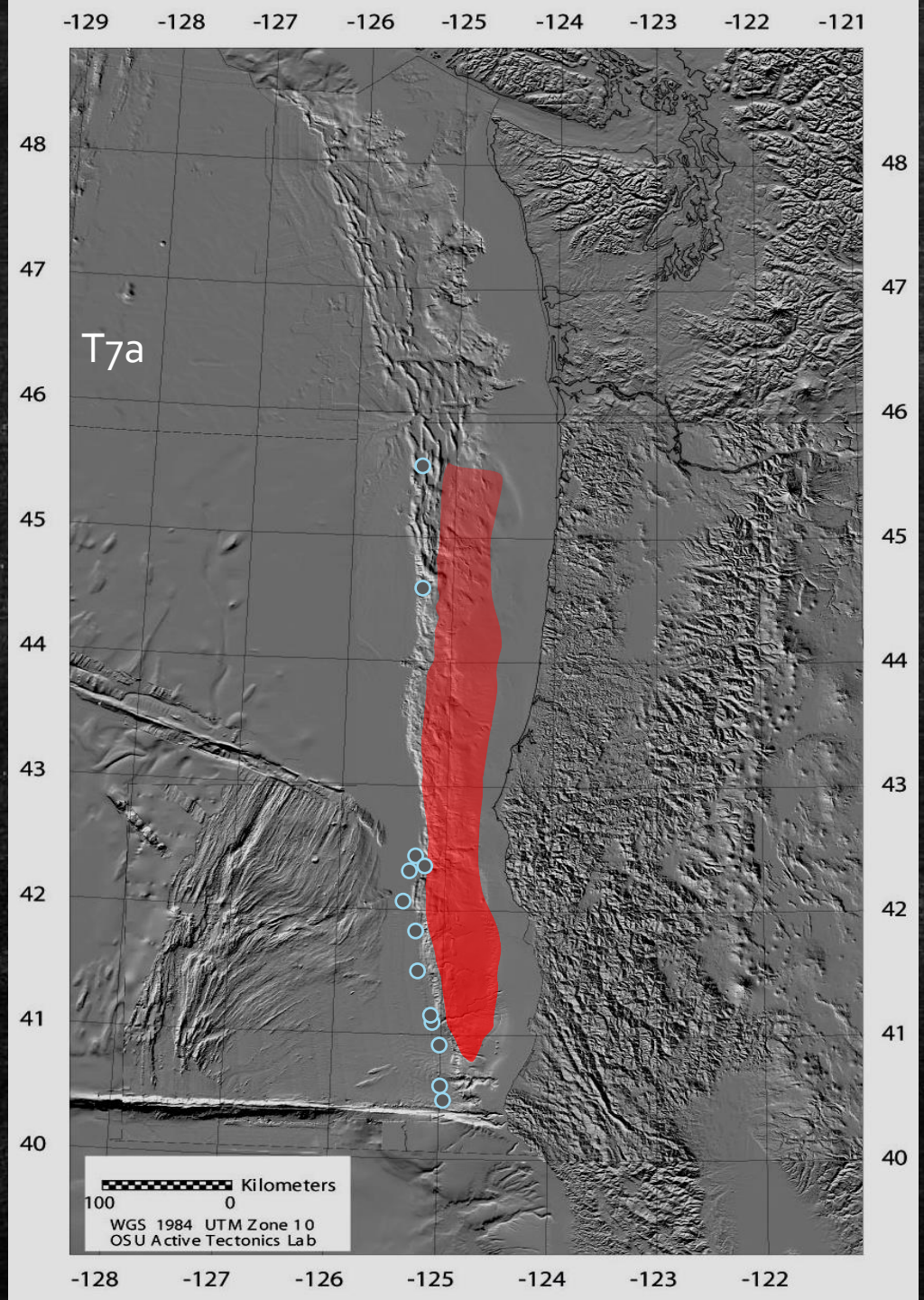
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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T7a
Kilometers
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0
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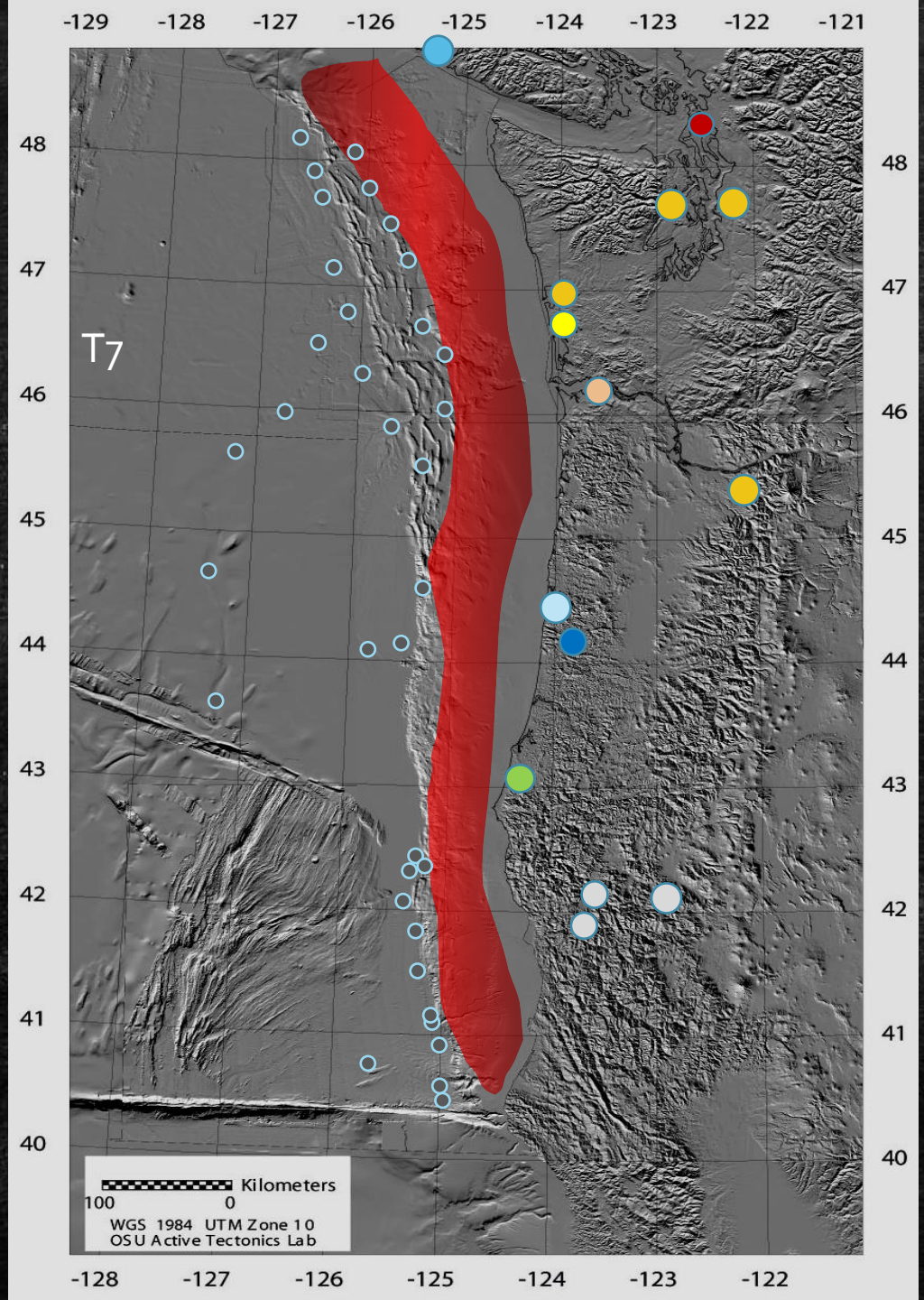
OSU Active Tectonics Lab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T7
Kilometers
100
0
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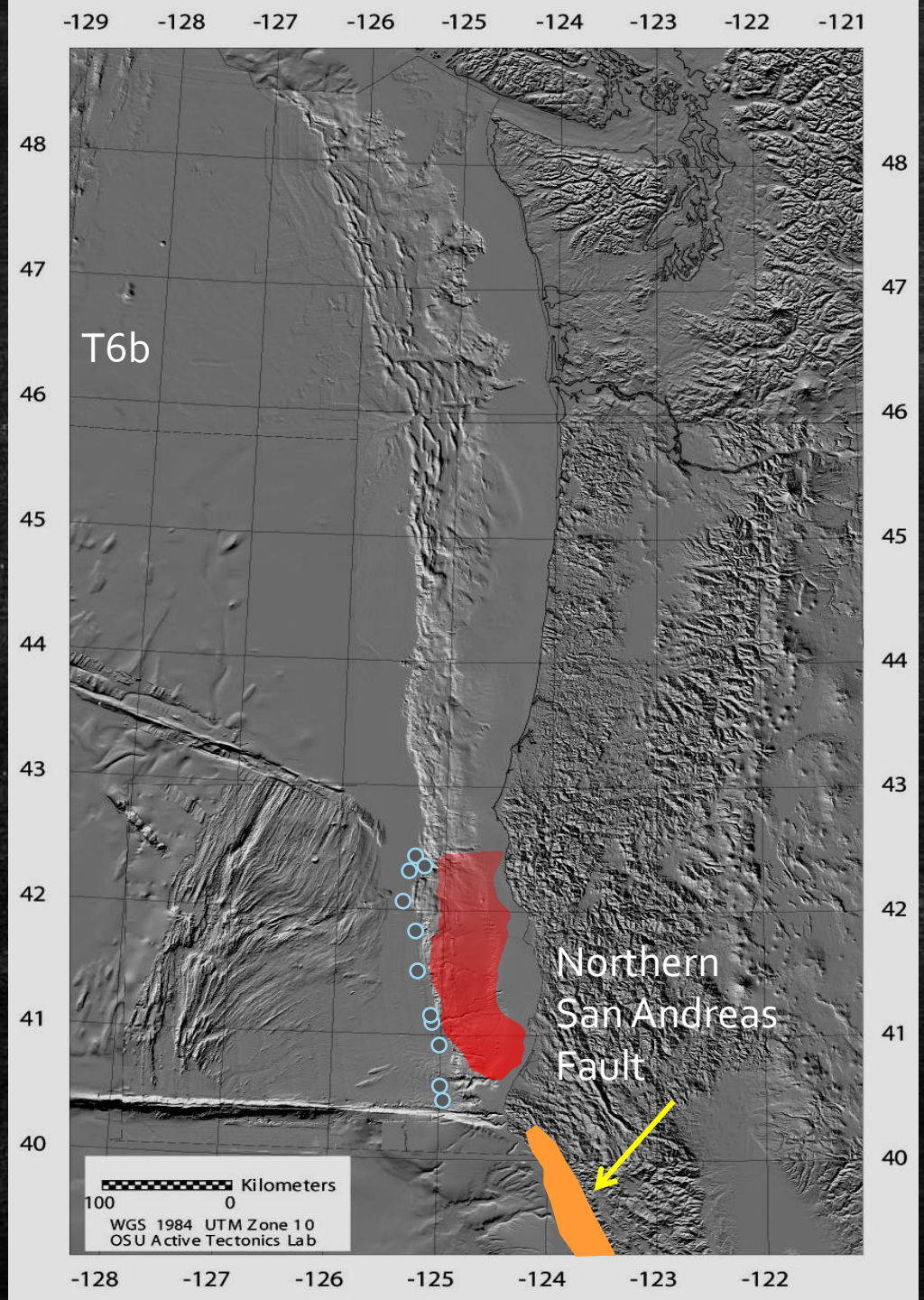
OSU Active Tectonics Lab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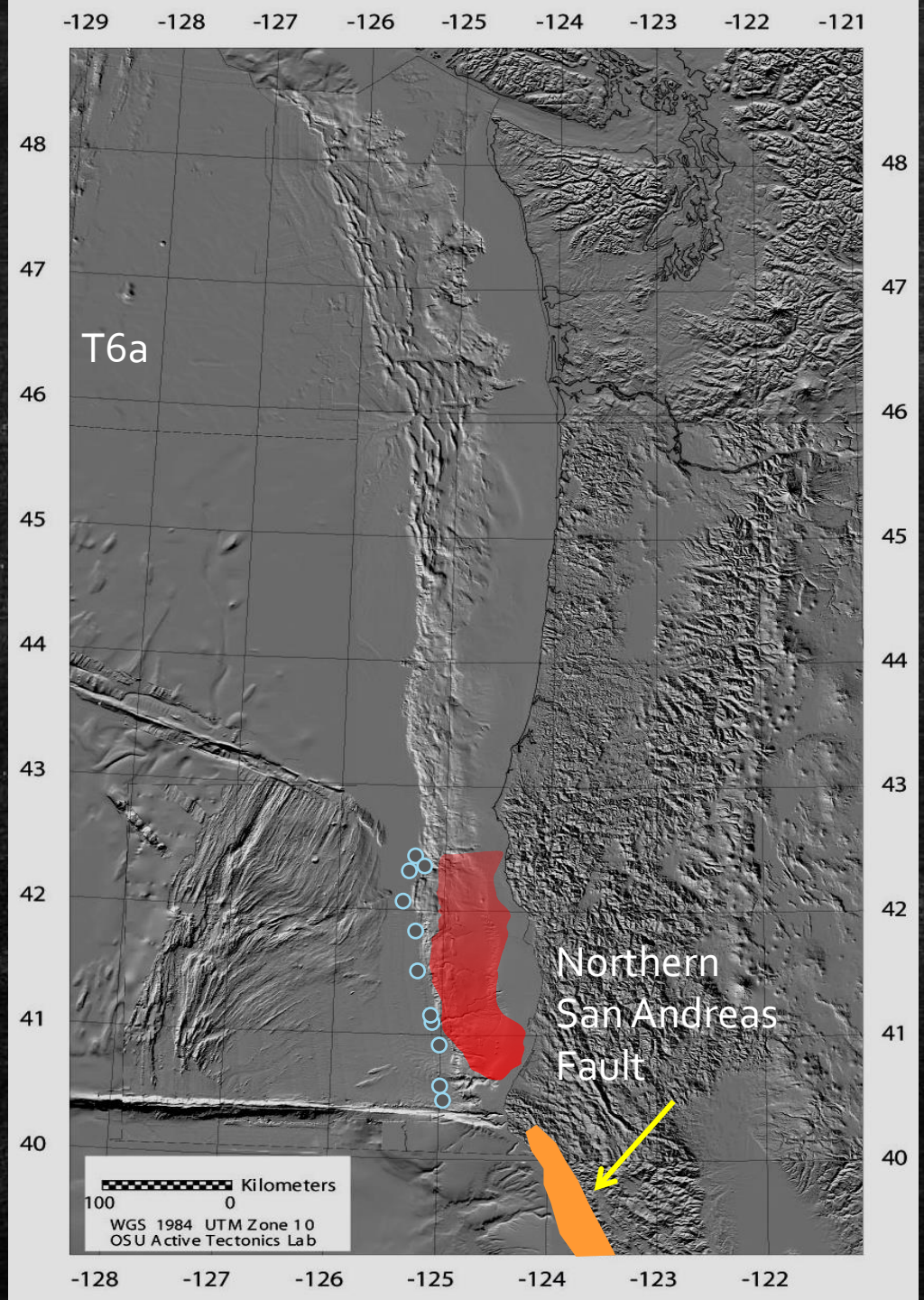
T6b
Northern
San Andreas
Fault
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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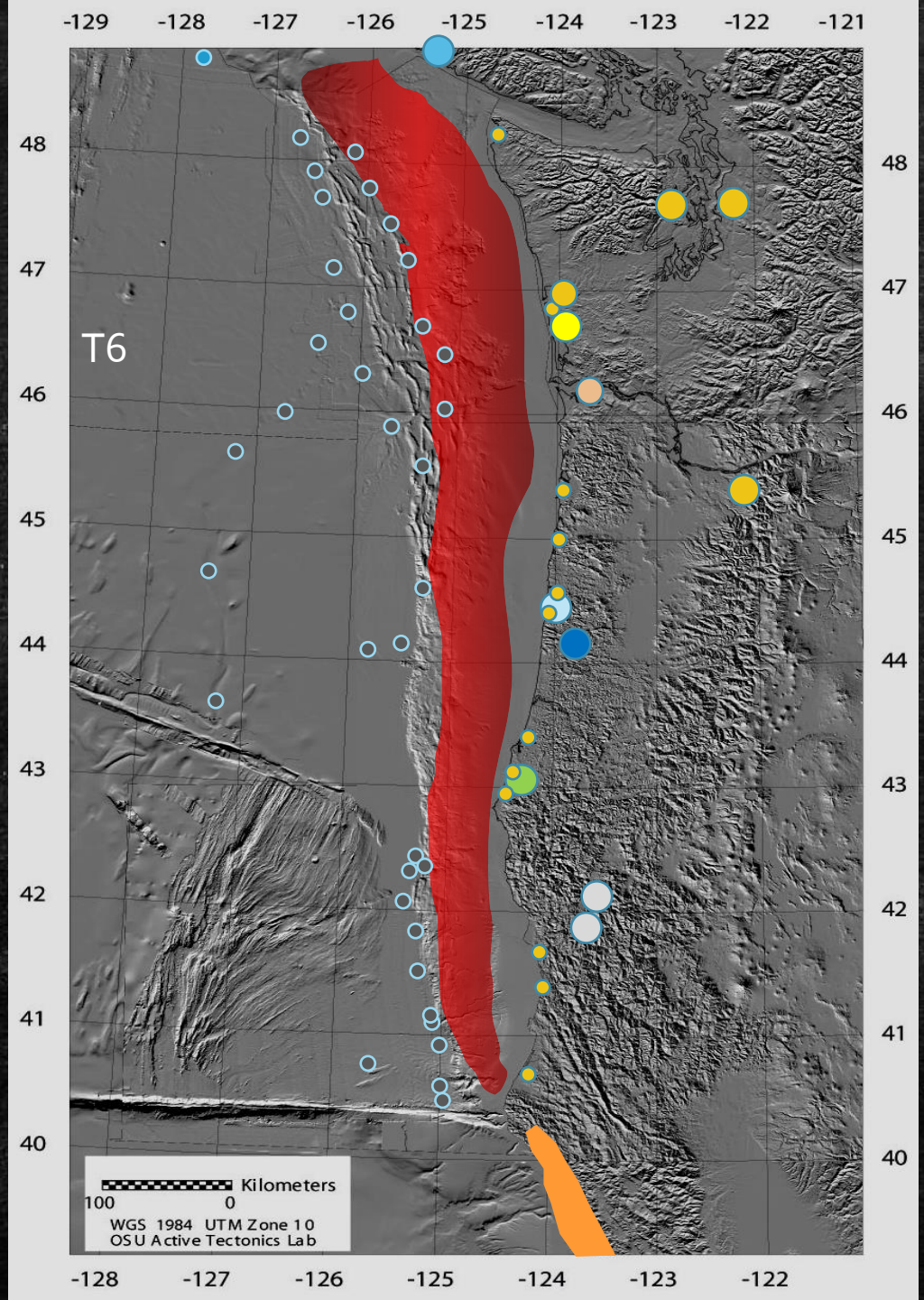
T6a
Northern
San Andreas
Fault
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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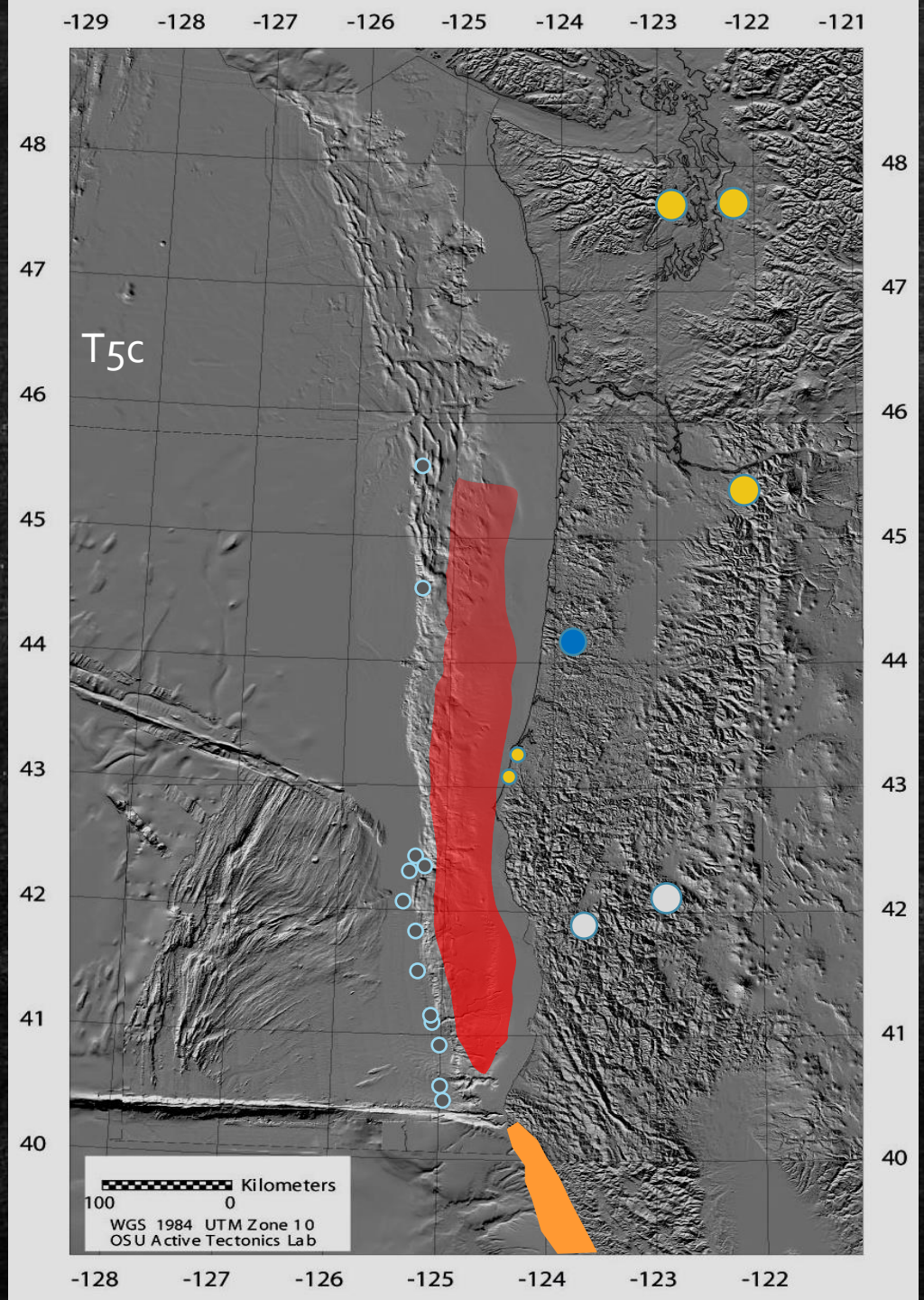
T6
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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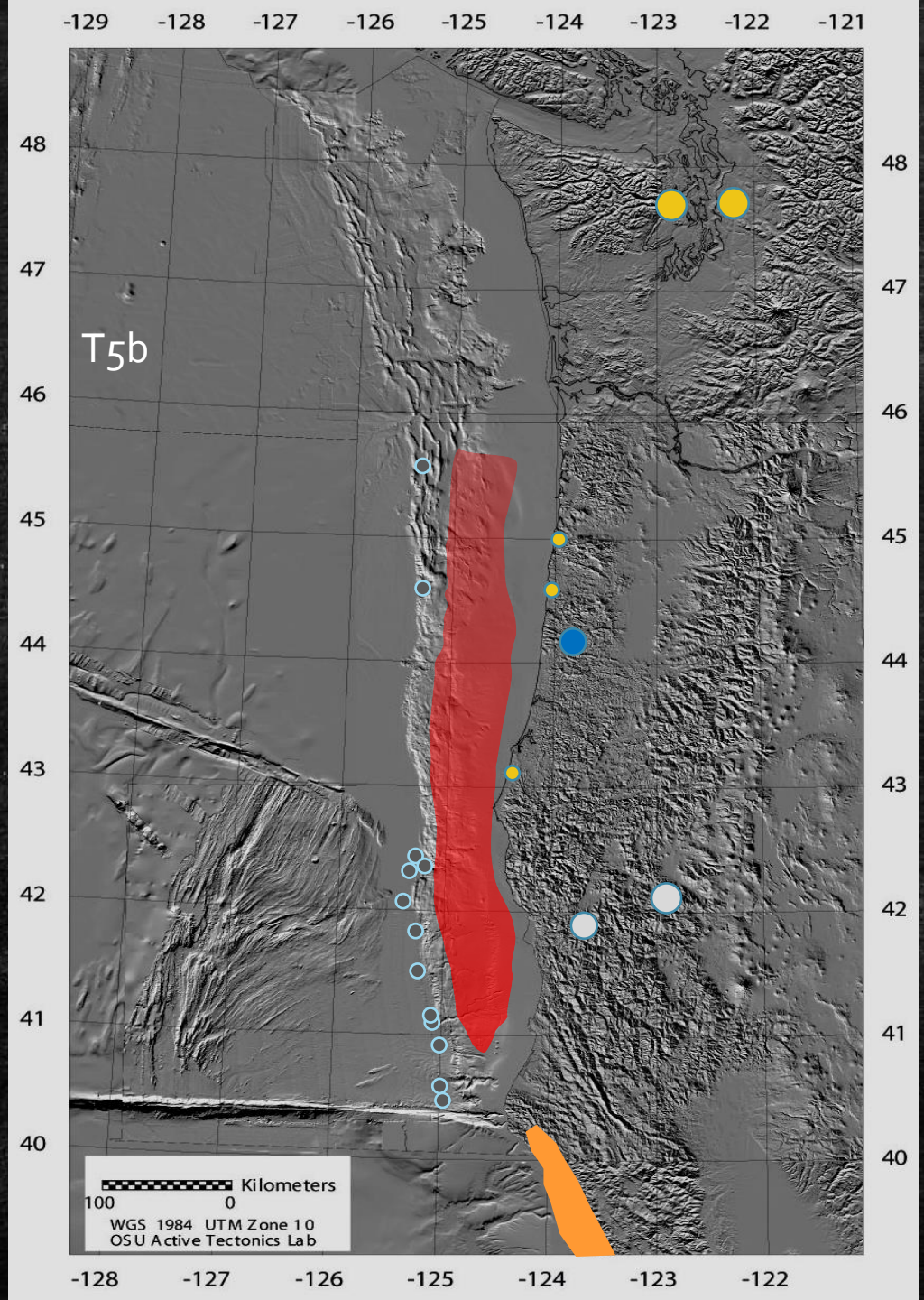
T5c
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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T5b
Kilometers
100
0
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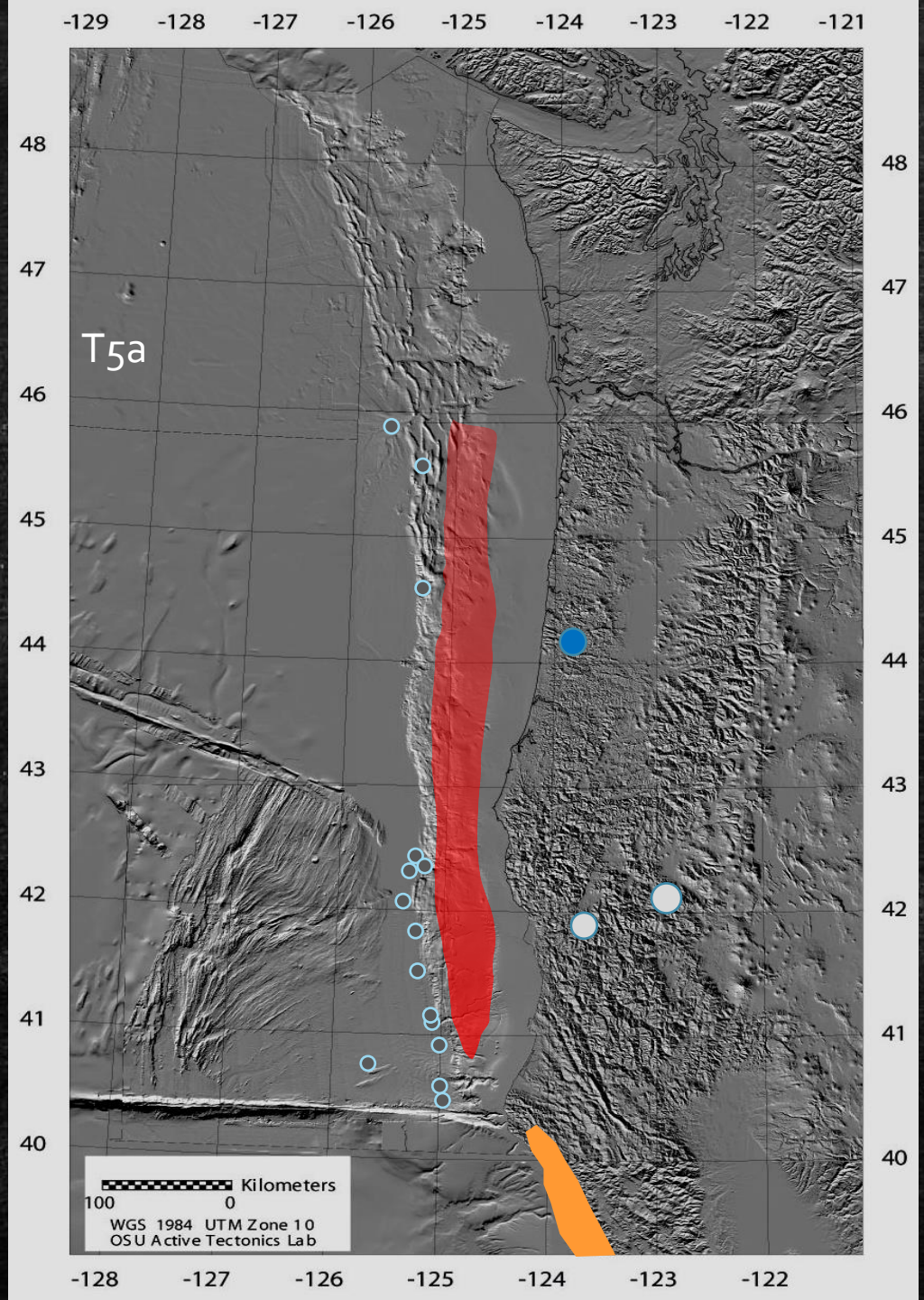
OSU Active Tectonics Lab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T5a
Kilometers
100
0
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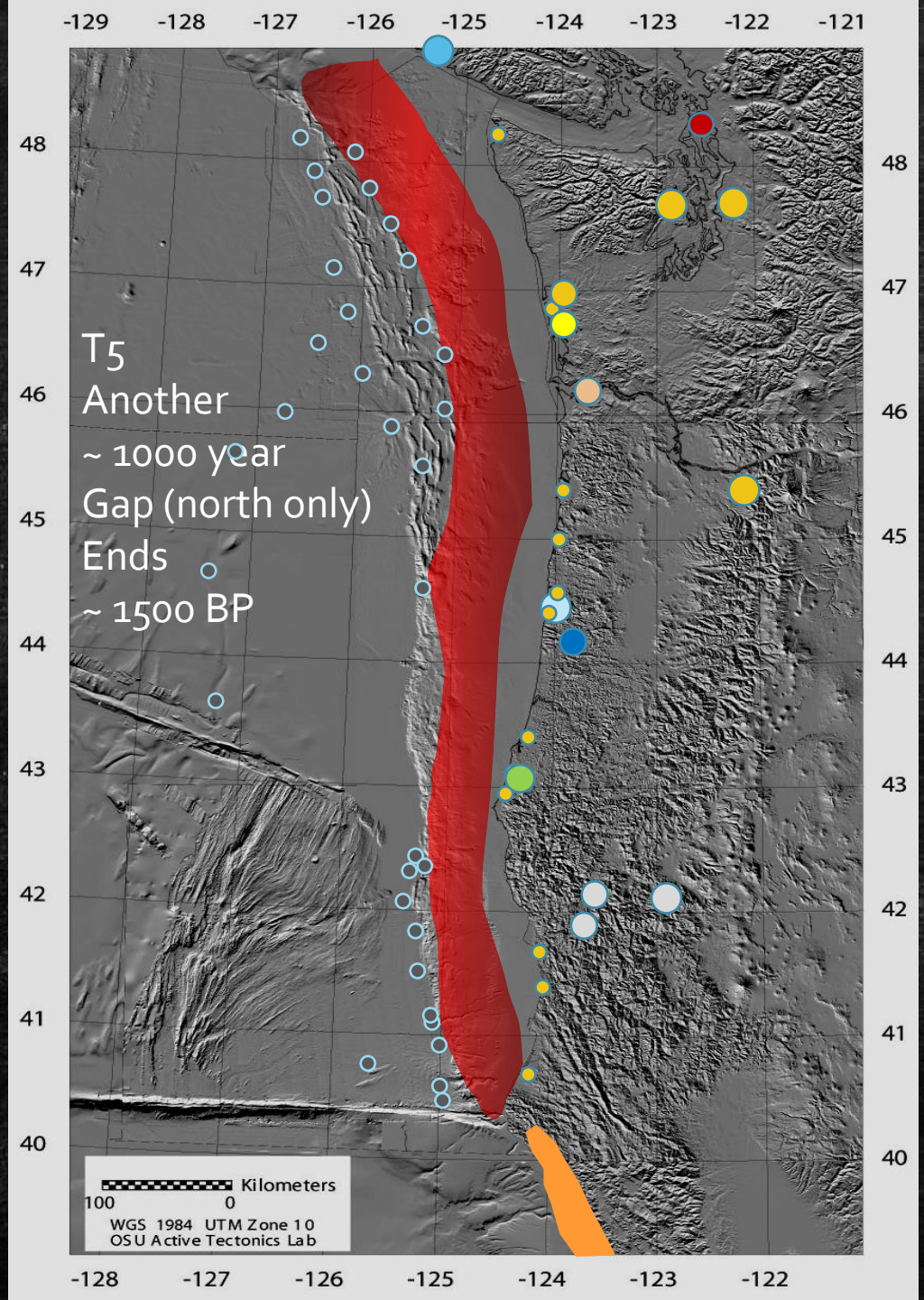
OSU Active Tectonics Lab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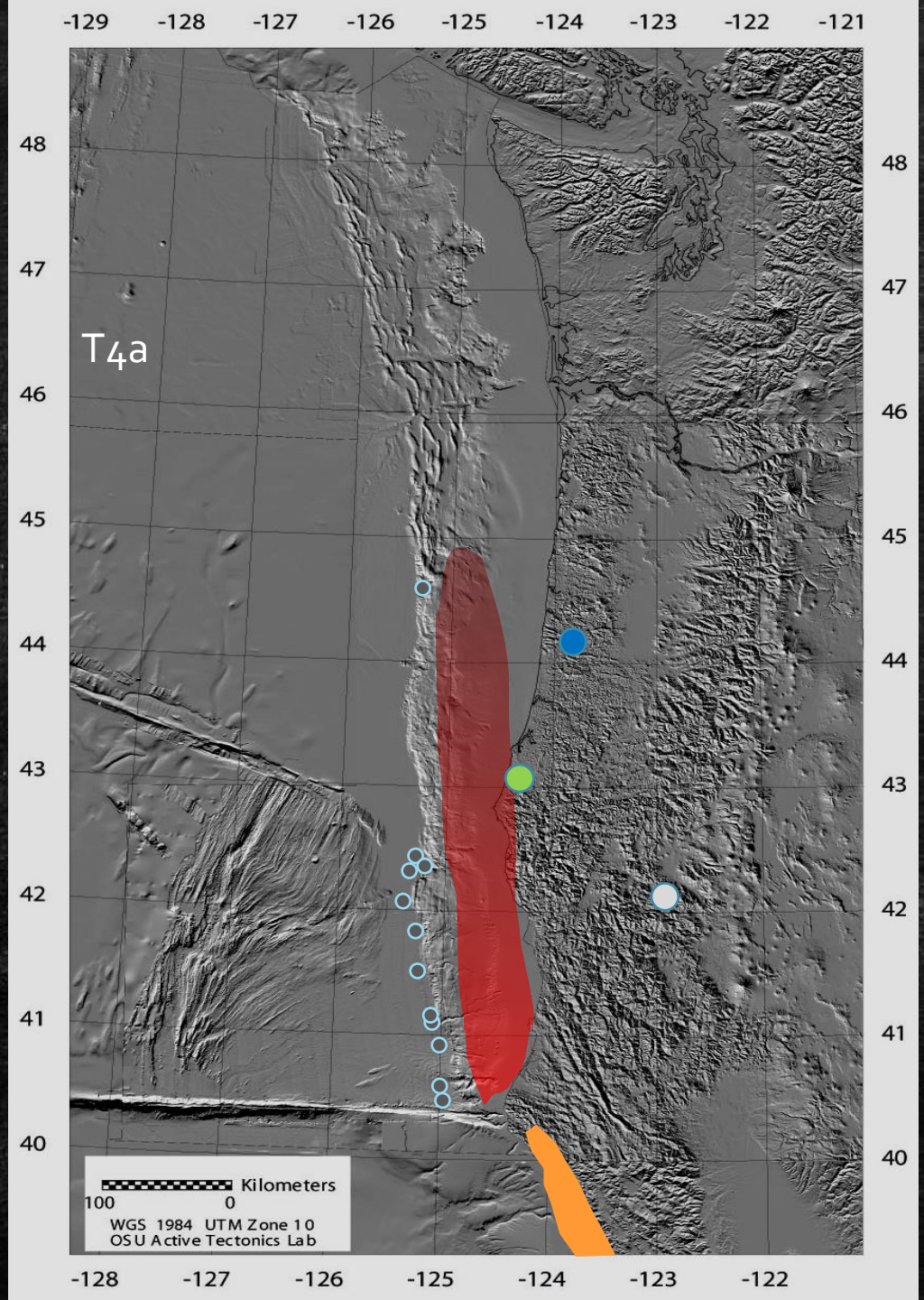
T5
Another
~ 1000 year
Gap (north only)
Ends
~ 1500 BP
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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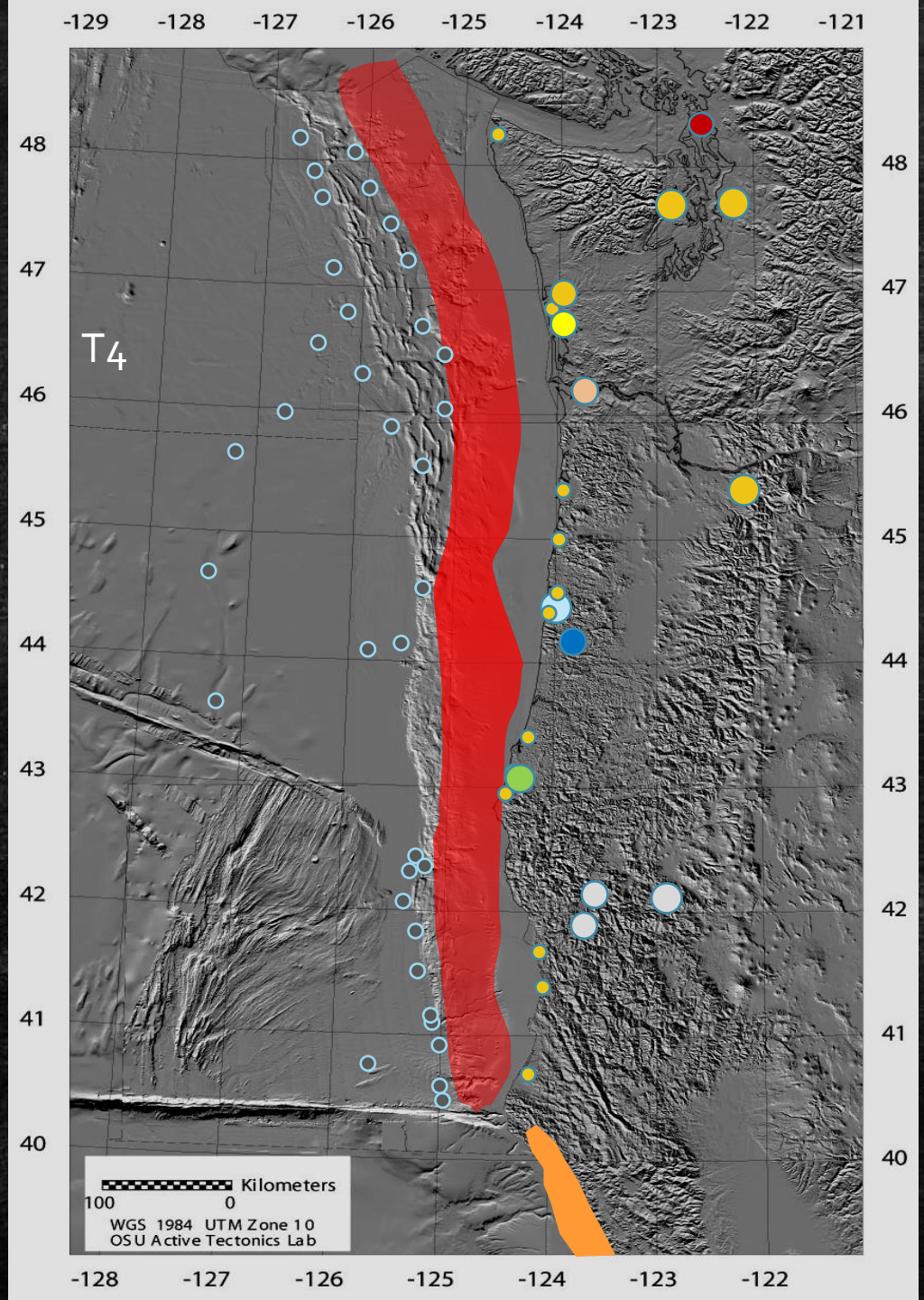
T4a
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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-128
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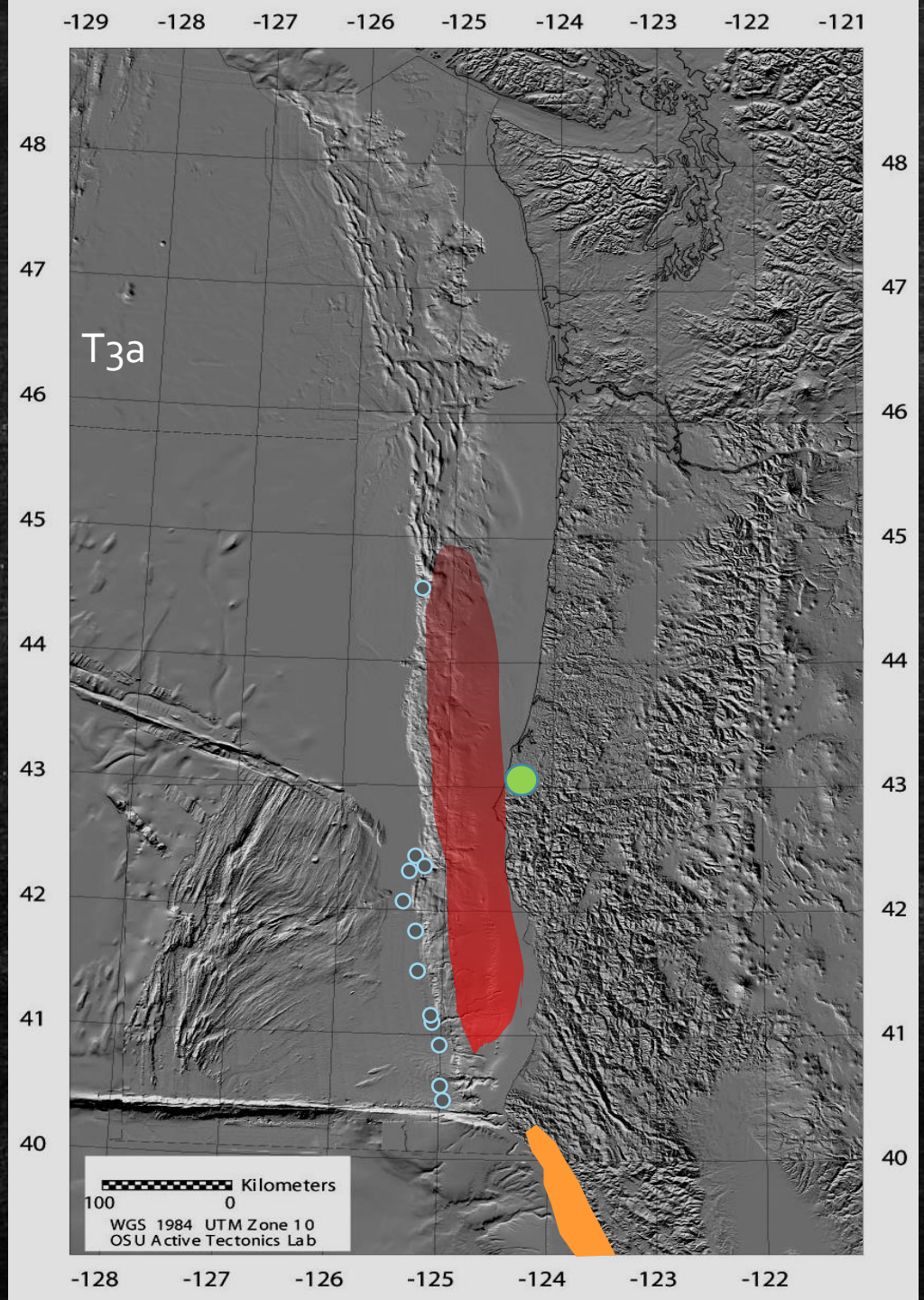
T4
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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-128
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T3a
Kilometers
100
0
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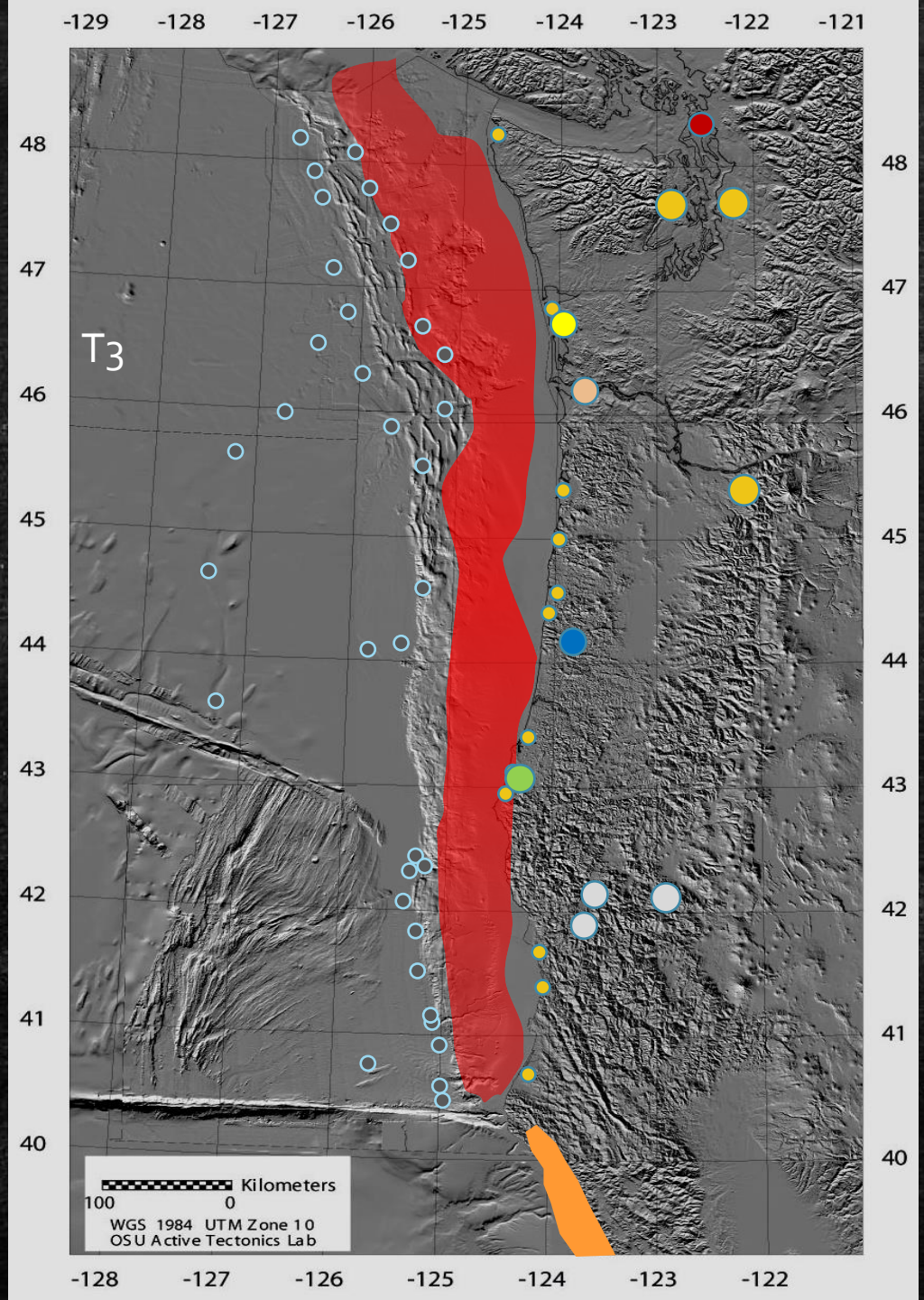
OSU Active Tectonics Lab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T3
Kilometers
100
0
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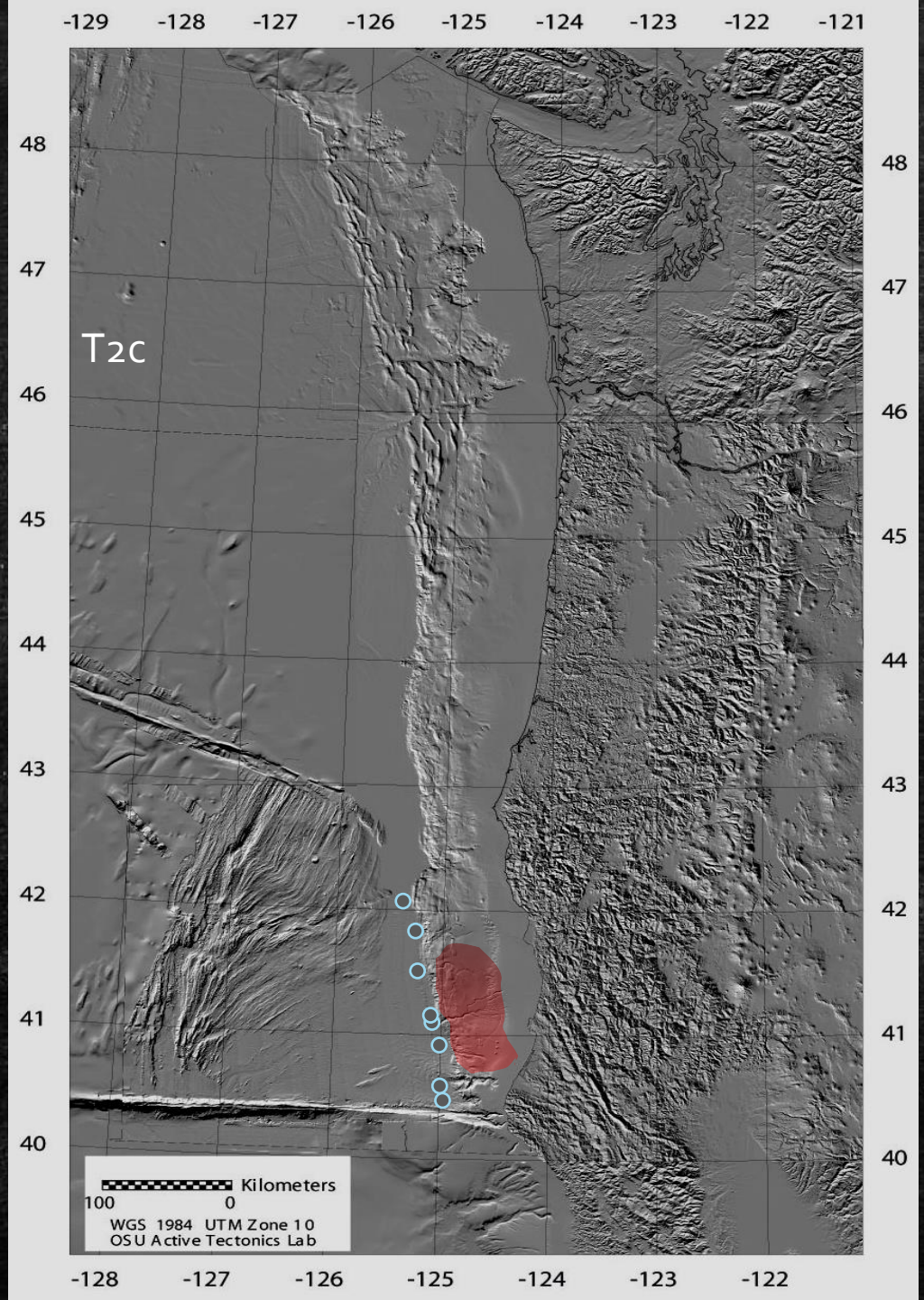
OSU Active Tectonics Lab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T2c
Kilometers
100
0
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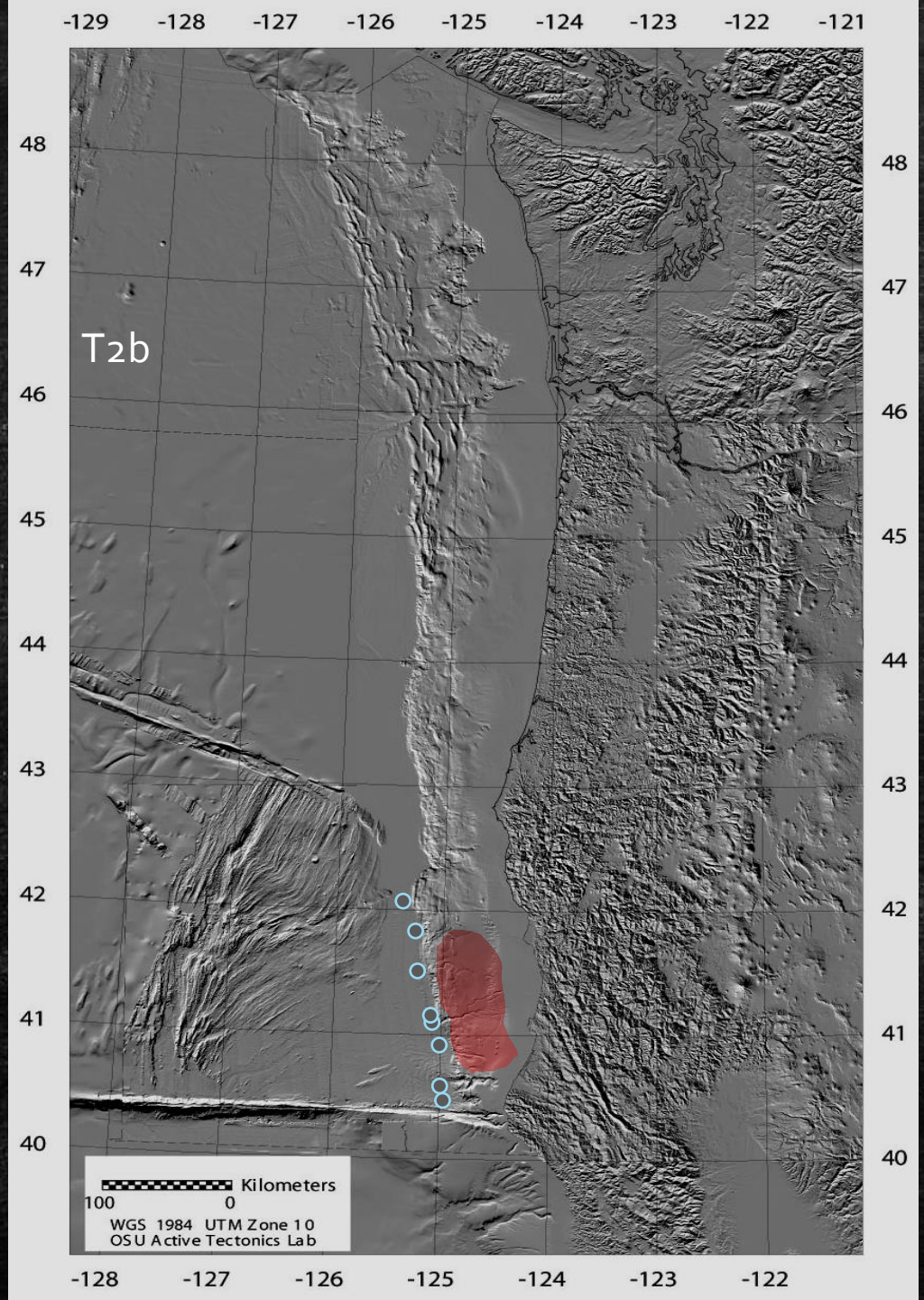
OSU Active Tectonics Lab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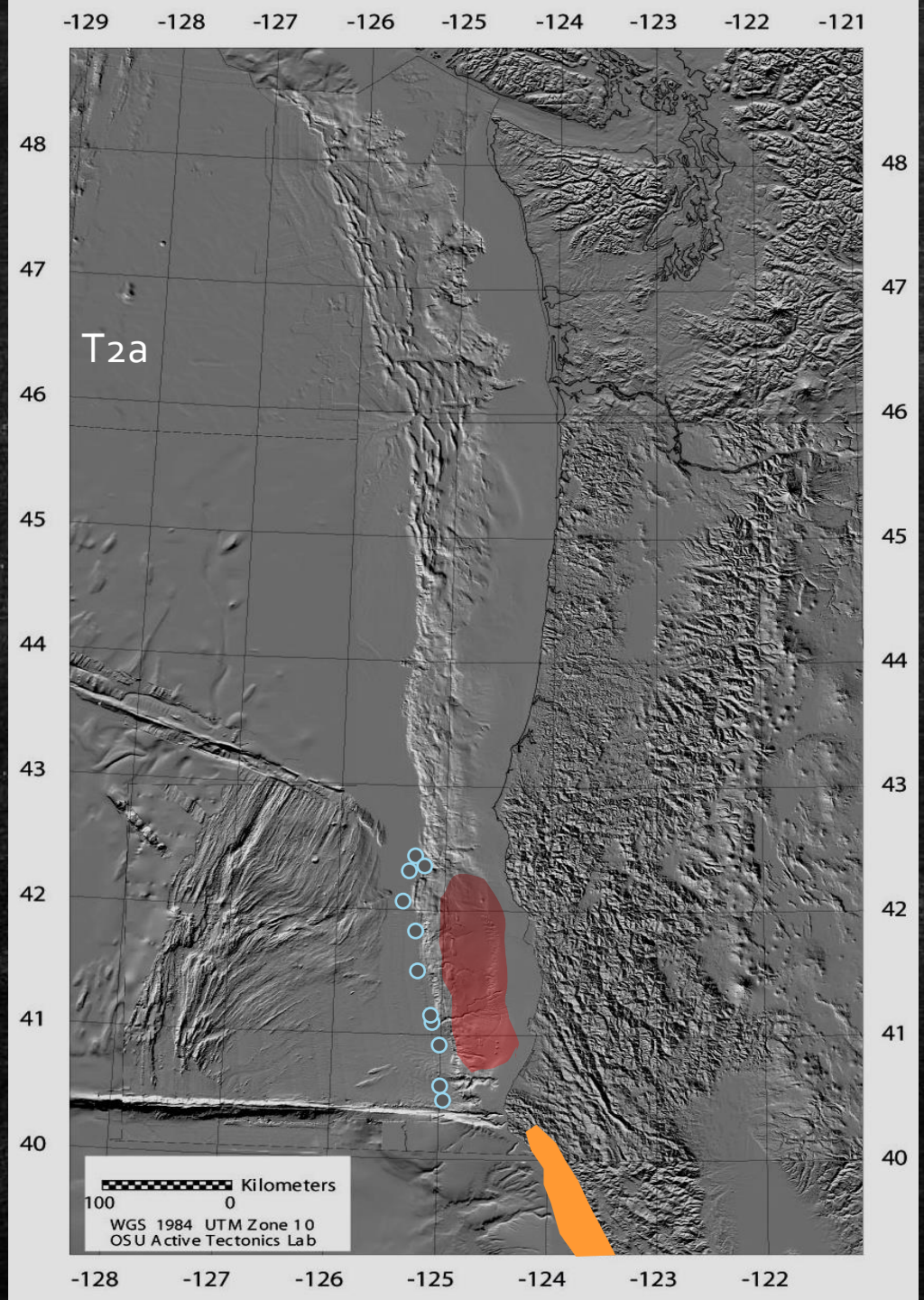
T2b
Kilometers
100
0
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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T2a
Kilometers
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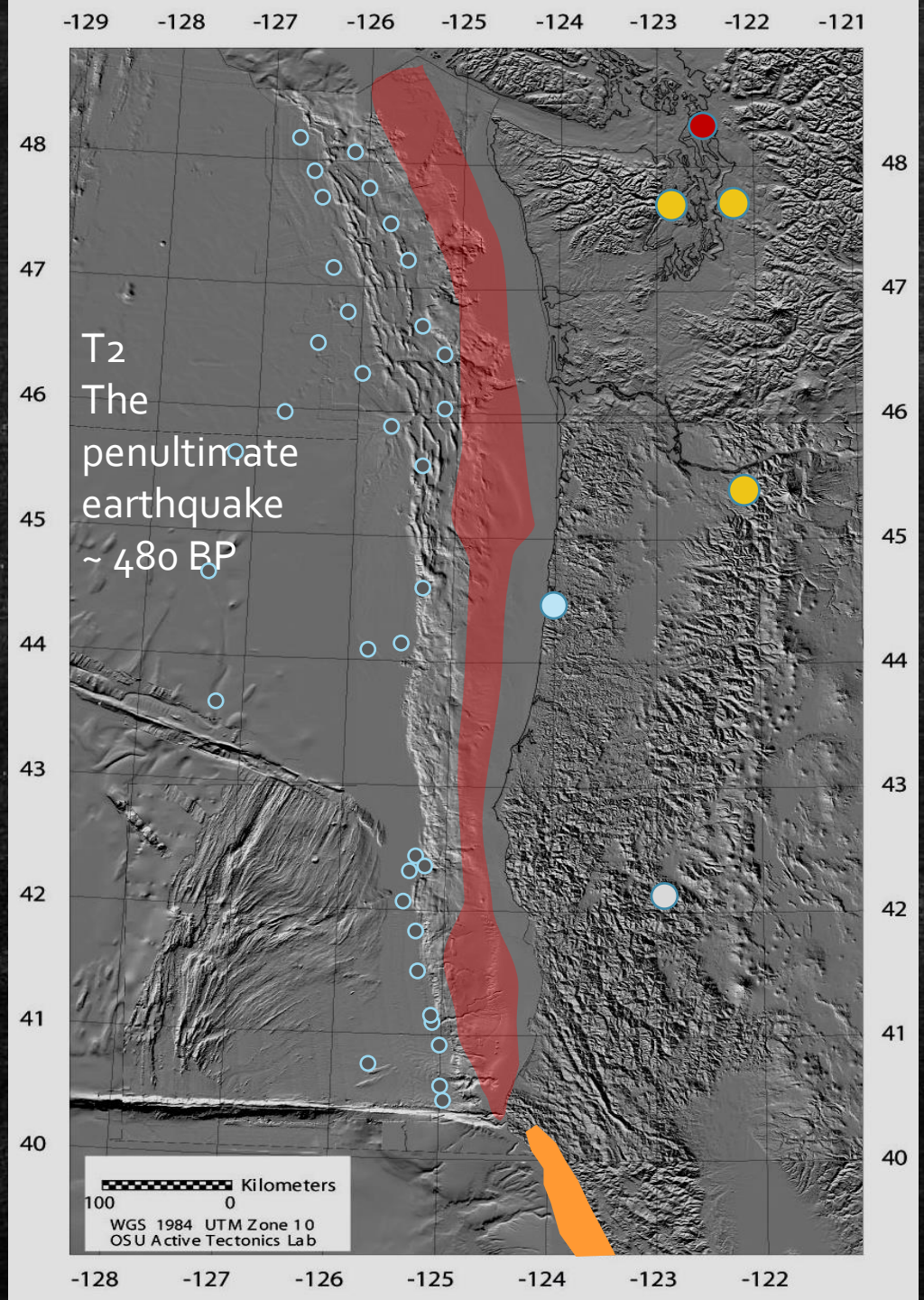
WGS 1984 UTM Zone 10
OSU Active Tectonics Lab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T2
The
penultimate
earthquake
~ 480 BP
Kilometers
100
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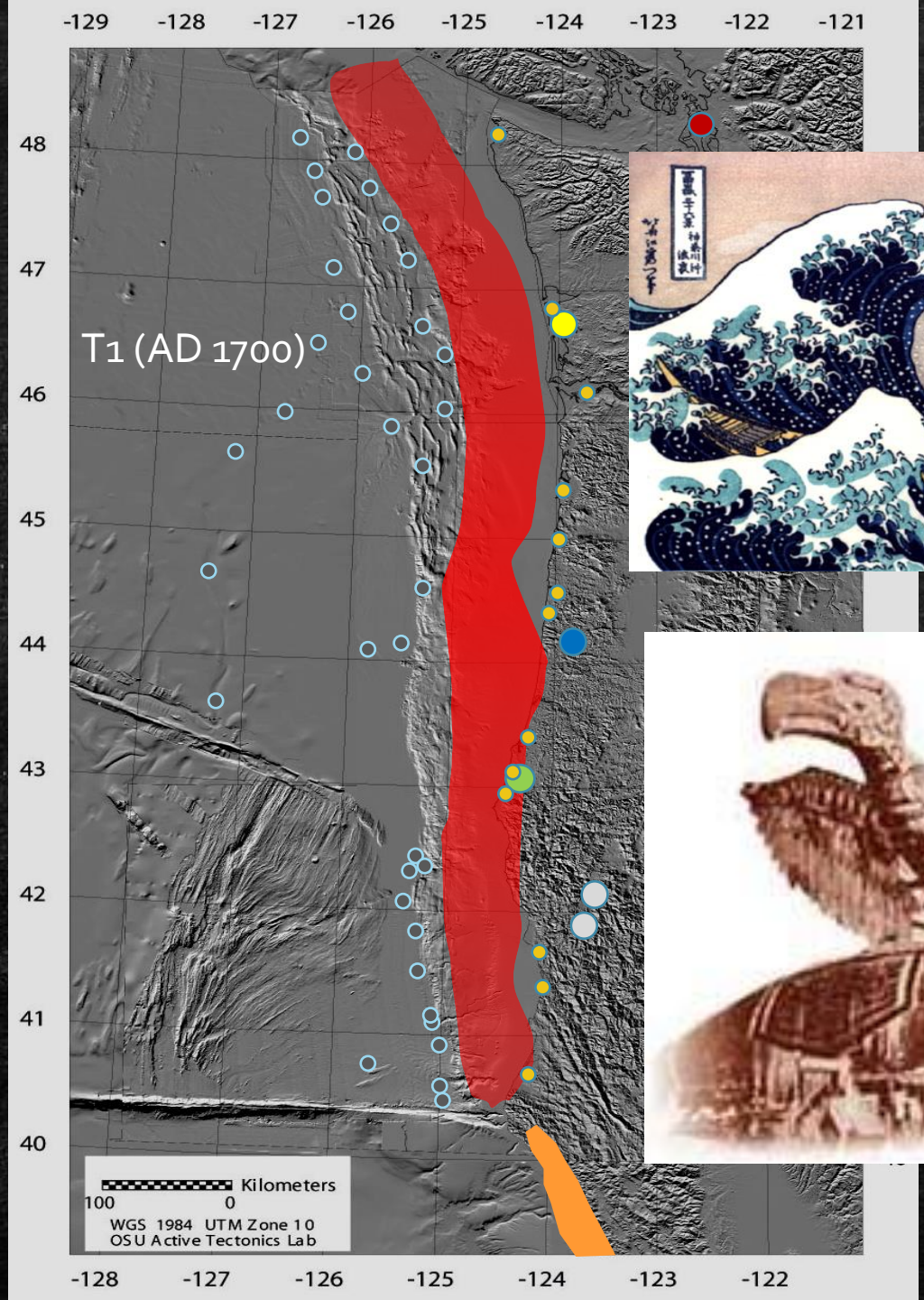
OSU Active Tectonics Lab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T1 (AD 1700)
Kilometers
100
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WGS 1984 UTM Zone 10
OSU Active Tectonics Lab
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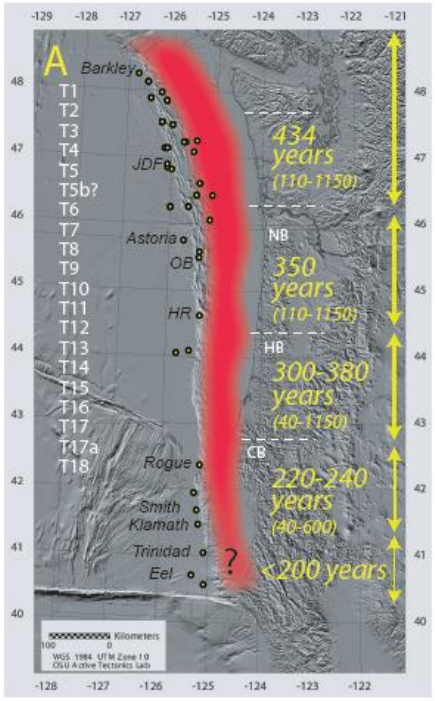
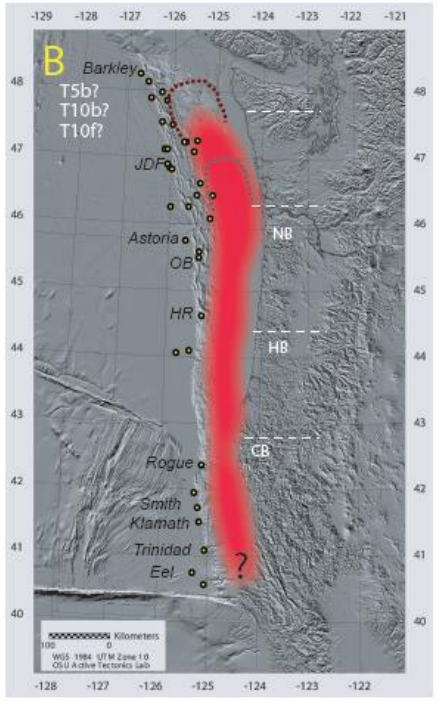
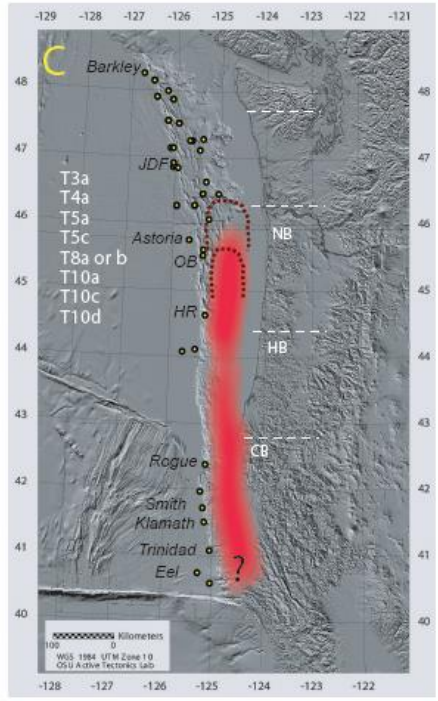
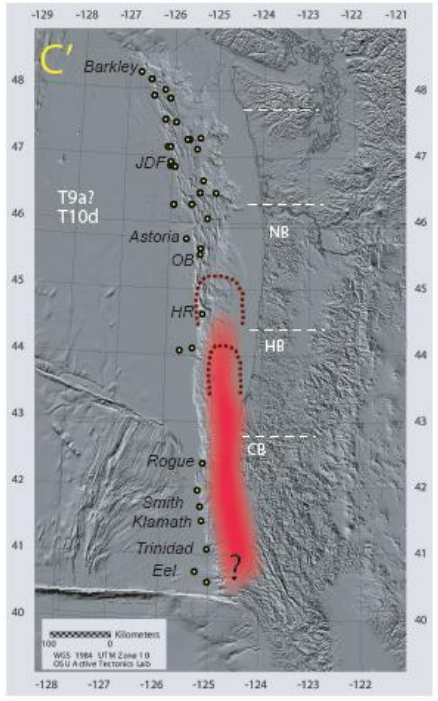
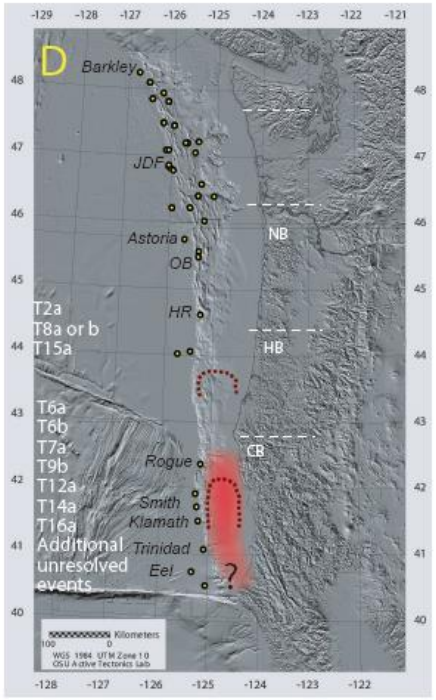
-122

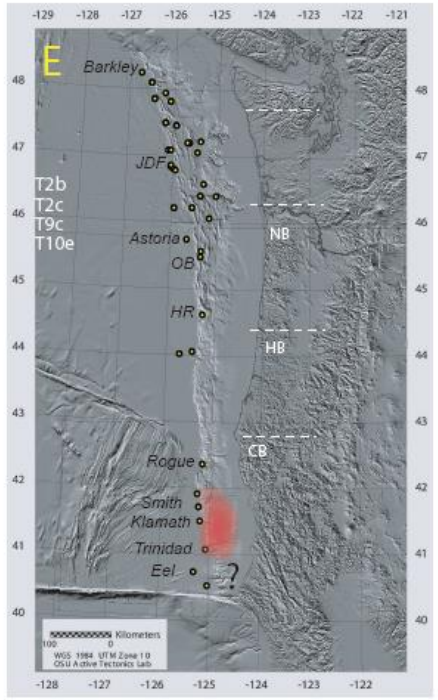


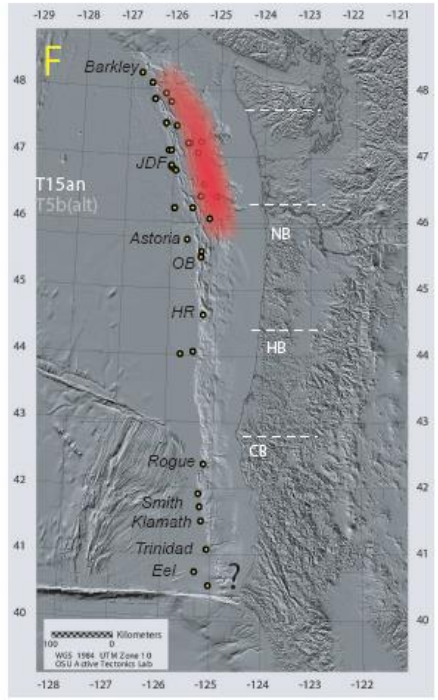










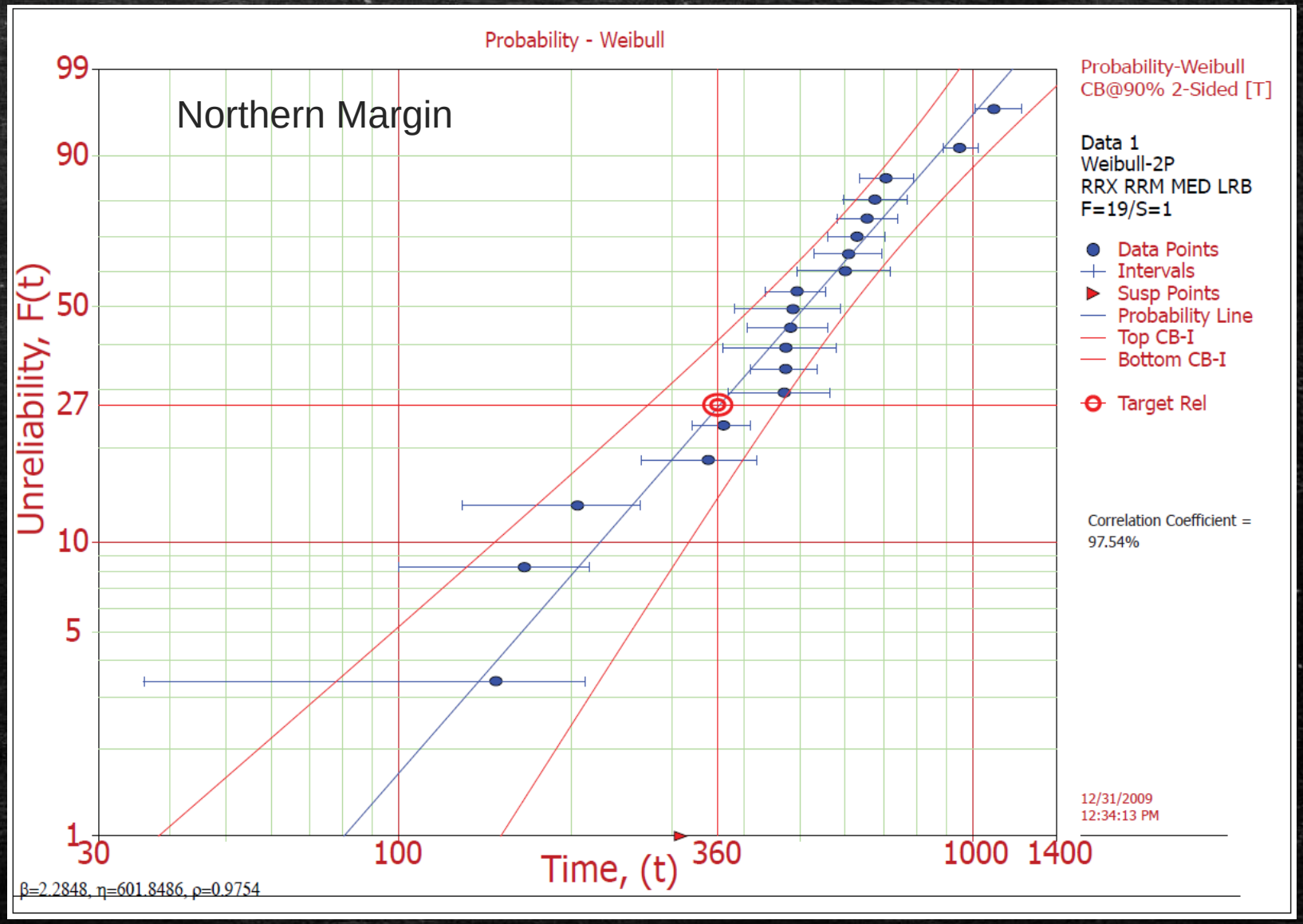


Rupture lengths from paleoseismic data, past 10,000 years. Segment boundaries are roughly compatible with ETS segment boundaries proposed by Brudzinski et al., 2007, though both sets of boundaries are quite crude.

For the northern margin, probabilities are relatively low, many intervals longer than 360 years are in the paleoseismic record.

The reliability analysis suggests at 360 years, 25% of repeat times will have been exceeded.
Conditional probability in 50 years is 14% (12-17%).

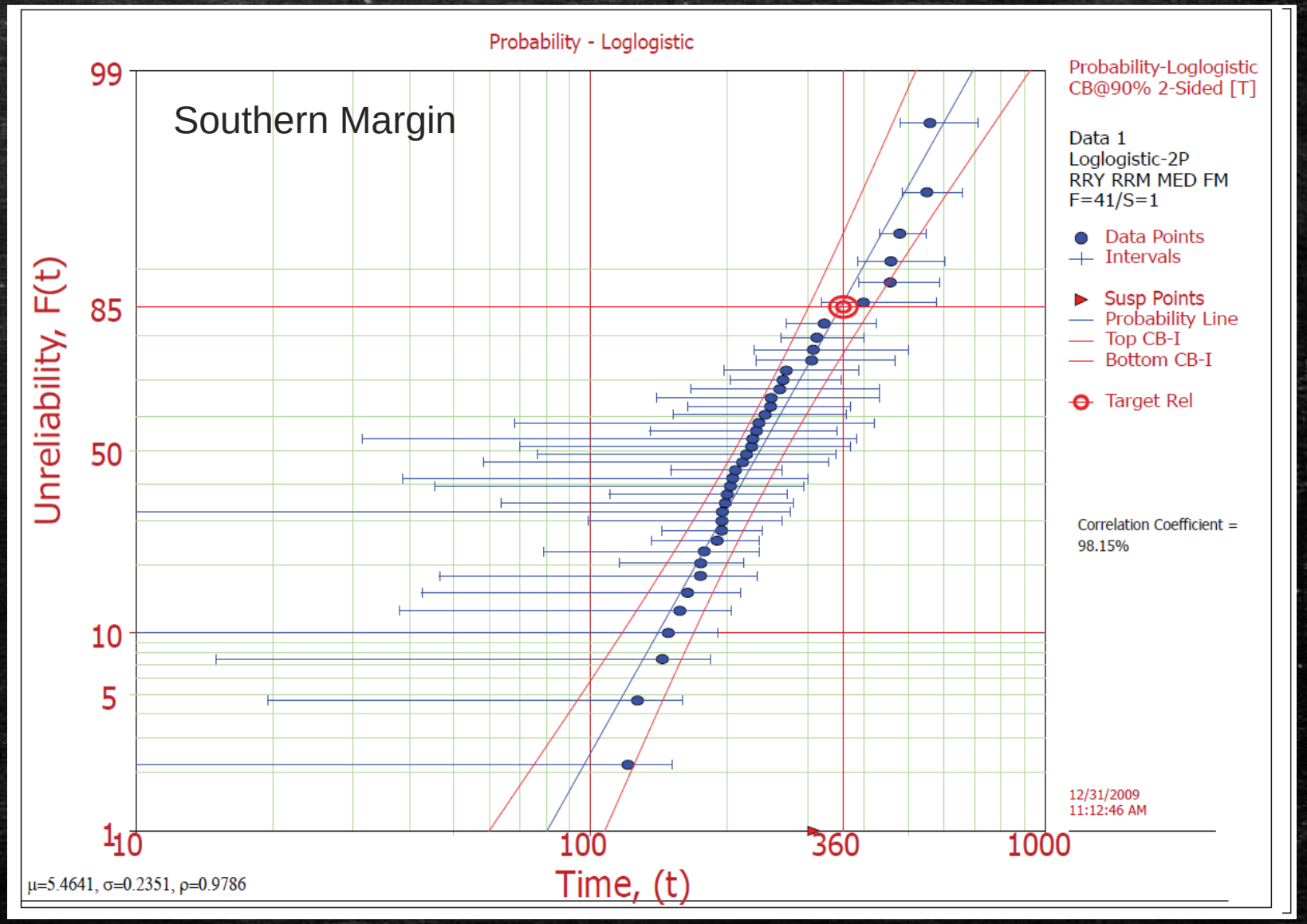
(slight revision of repeat times and probabilities, in 2016 Marine Geology paper).

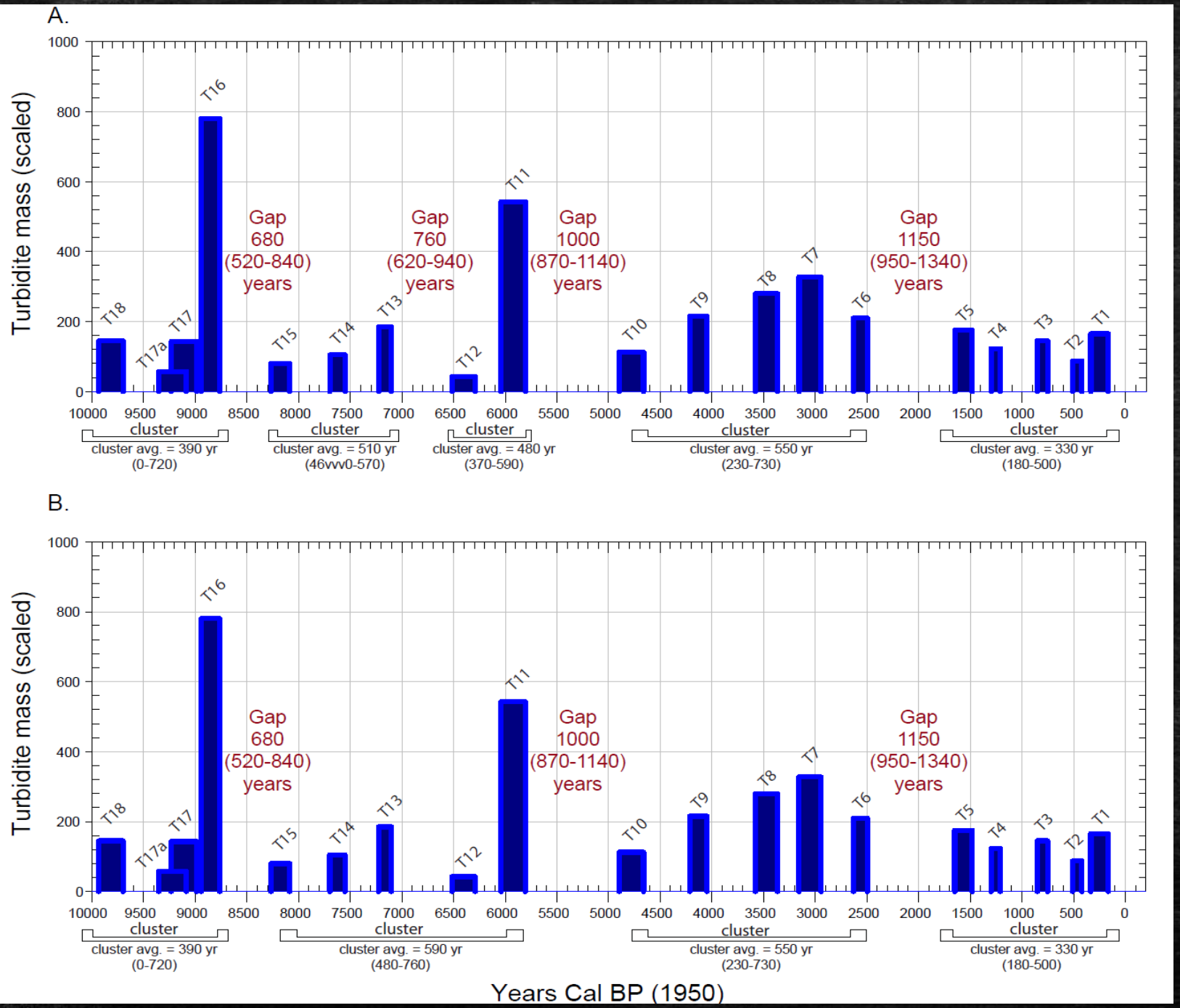


For the southern margin, if our interpretation is correct, 70-93% of repeat times will have been exceeded.

Conditional probability in 50 years is 37% (32-42%).

Portland is in between these extremes, with a recurrence of ~ 340 years, and **50 year probability of ~ 20%.** (This is a slight increase, 2016 Marine Geology paper)





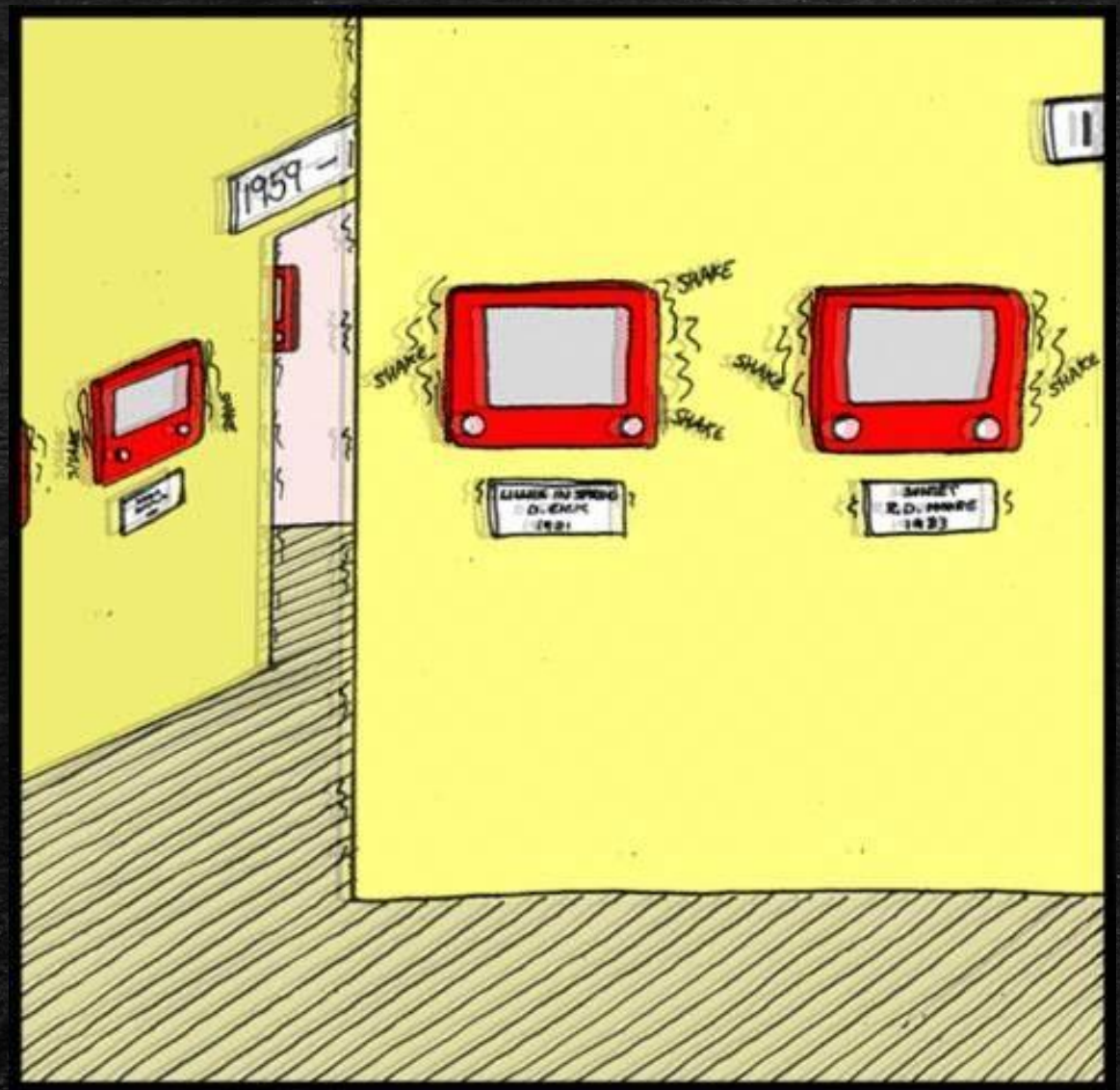
What about clustering?

There seems to be a poorly developed clustering, suggested here.

It certainly makes a difference whether the next expected event is part of a cluster or not, if clusters exist, and if the next event reflects a repeat of recent behavior.

In cluster 50 year probabilities are ~ 25%, not in a cluster, ~ 2%.

Clustering seems better developed in the latter half of the Holocene. If a repeat were to occur, a gap may be next.



IT WAS ONLY A MINOR EARTHQUAKE, BUT THE ETCH-A-SKETCH GALLERY WAS RUINED

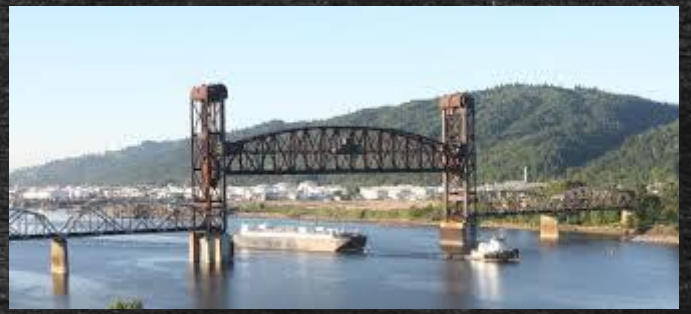
This is what success looks like in a Great Earthquake. Japan lost ~ 20,000.

It could have been 230,000 as in Sumatra.

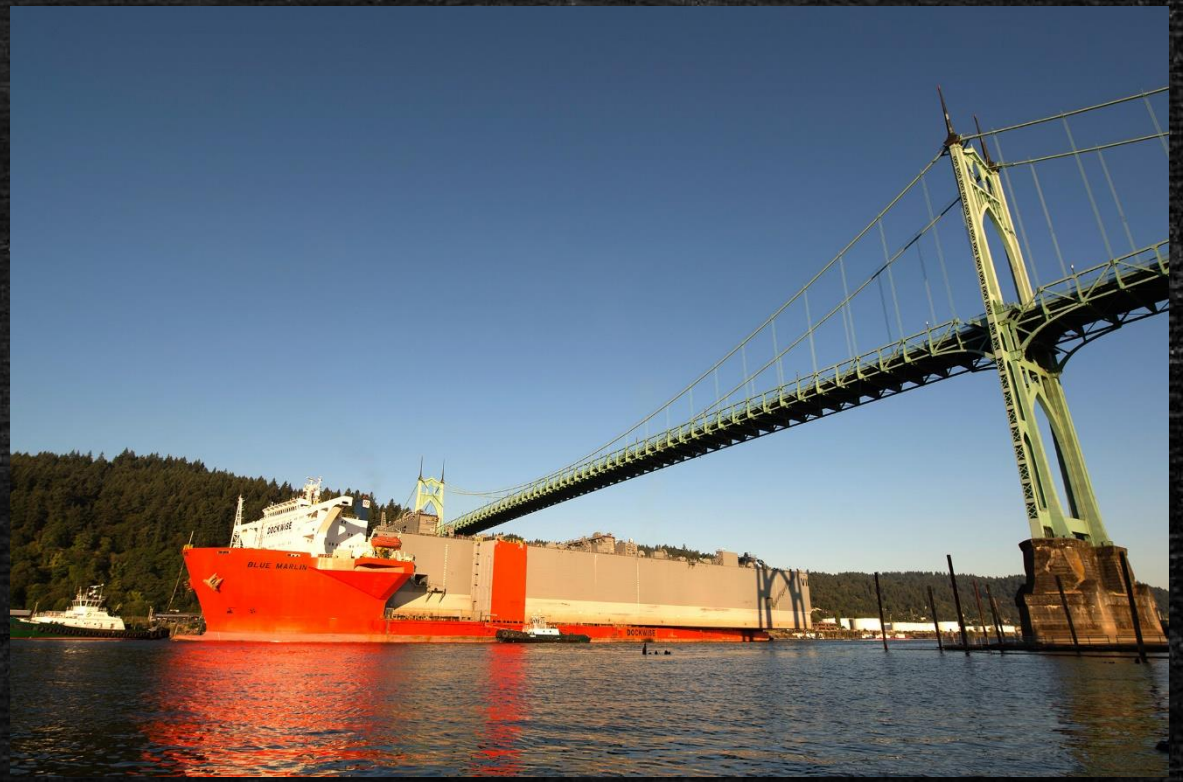
In Oregon, we have hundreds of these URM buildings, along with bridges, hospitals, and ~ 1000 schools that need to be retrofitted.

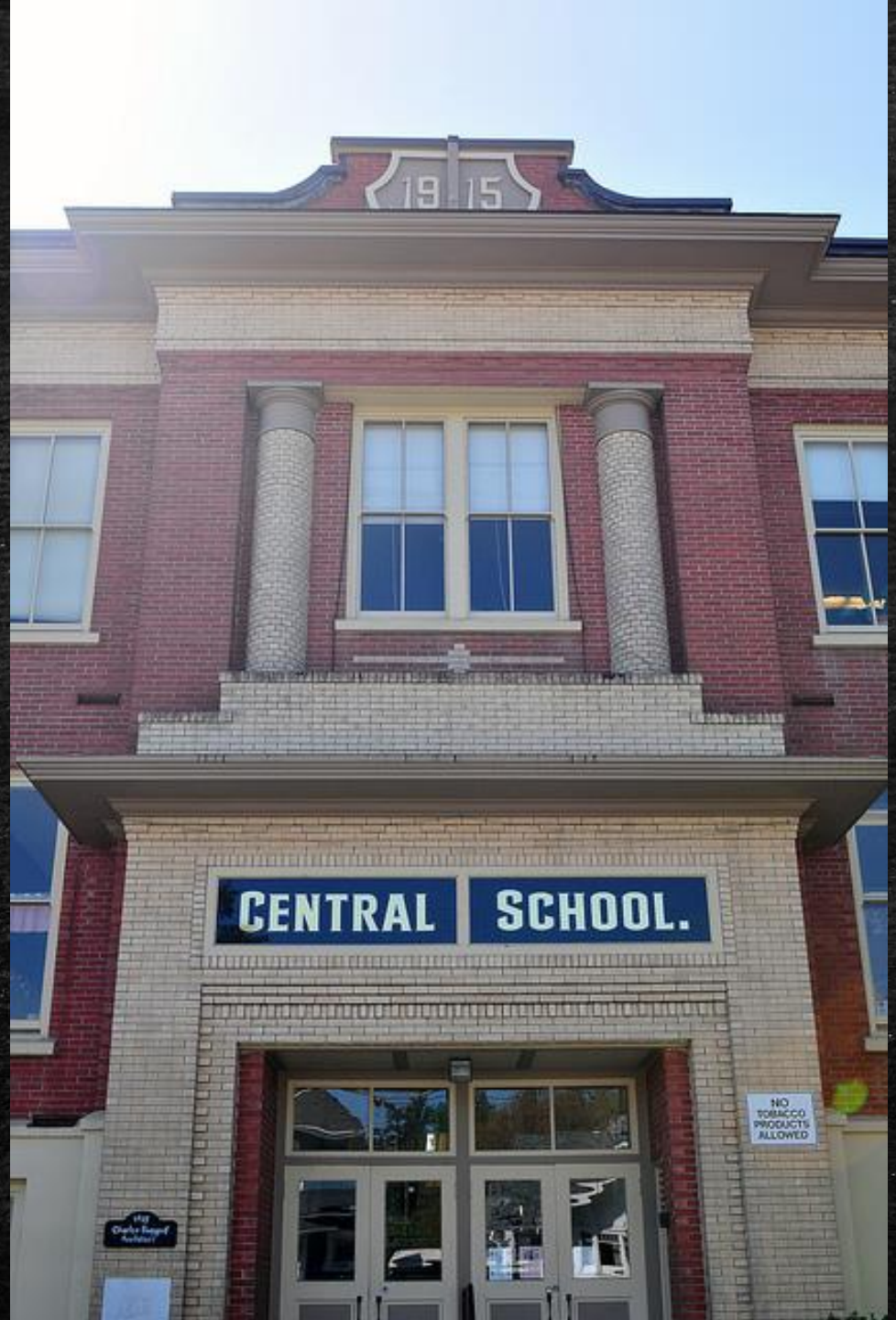
The cost? Very high obviously, in the billions. The cost of not doing it? Much higher.

Even small earthquakes of M4-5 can cause absurd amounts of damage to unreinforced masonry buildings.



In Oregon alone, we have about 300 of these

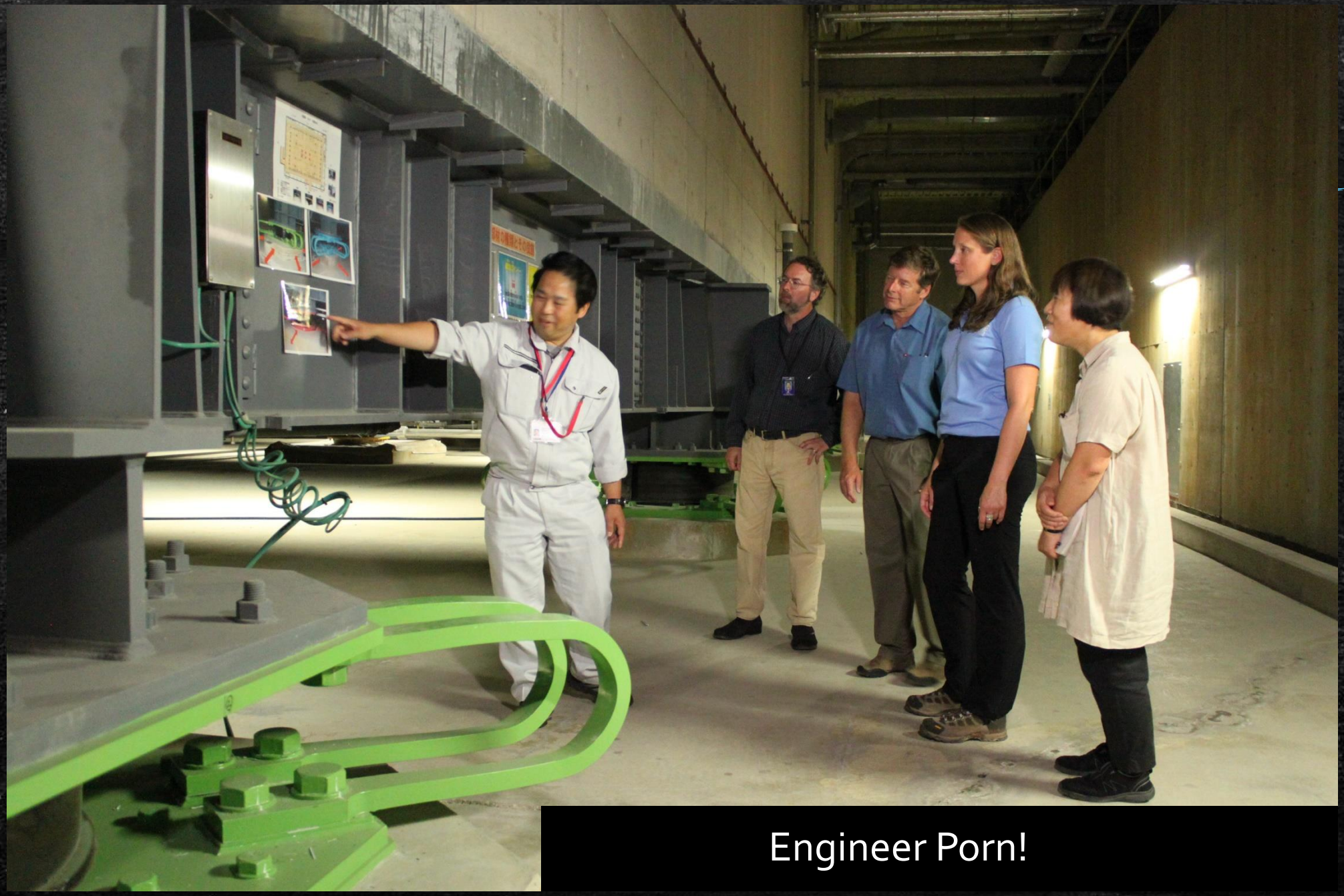




And 1000 of these


Stand Up! 門脇
新たな
門脇が
動き出す。
街に、ルネッサンス
石巻市
Ishinomaki City
UR
UR都市機構
一日も早い復興へ 全力で取り組んでいます
〈完成イメージ〉イメージは事業の段階で変わる場合があります。
石巻市新門脇地区被災市街地復興土地区画整理事業


道路計画高さ
高さはここまで ▼
造成計画高さ
高さはここまで ▼
竹中JV



Engineer Porn!


防災対策庁舎

100 year time-dependent probability:
31% (Gaussian); 37% (log-normal)

During the ~ 100 year lifespan of the proposed OSU building at Hatfield, there is a 30-40% chance of a great earthquake and tsunami at the site. If it is a L, XL, or XXL, much of what is there today will be gone. Choosing to build a school on this site given what we know is a moral error, not an engineering problem.

What would Mayor Sato do?

Questions?


Thanks for your attention!