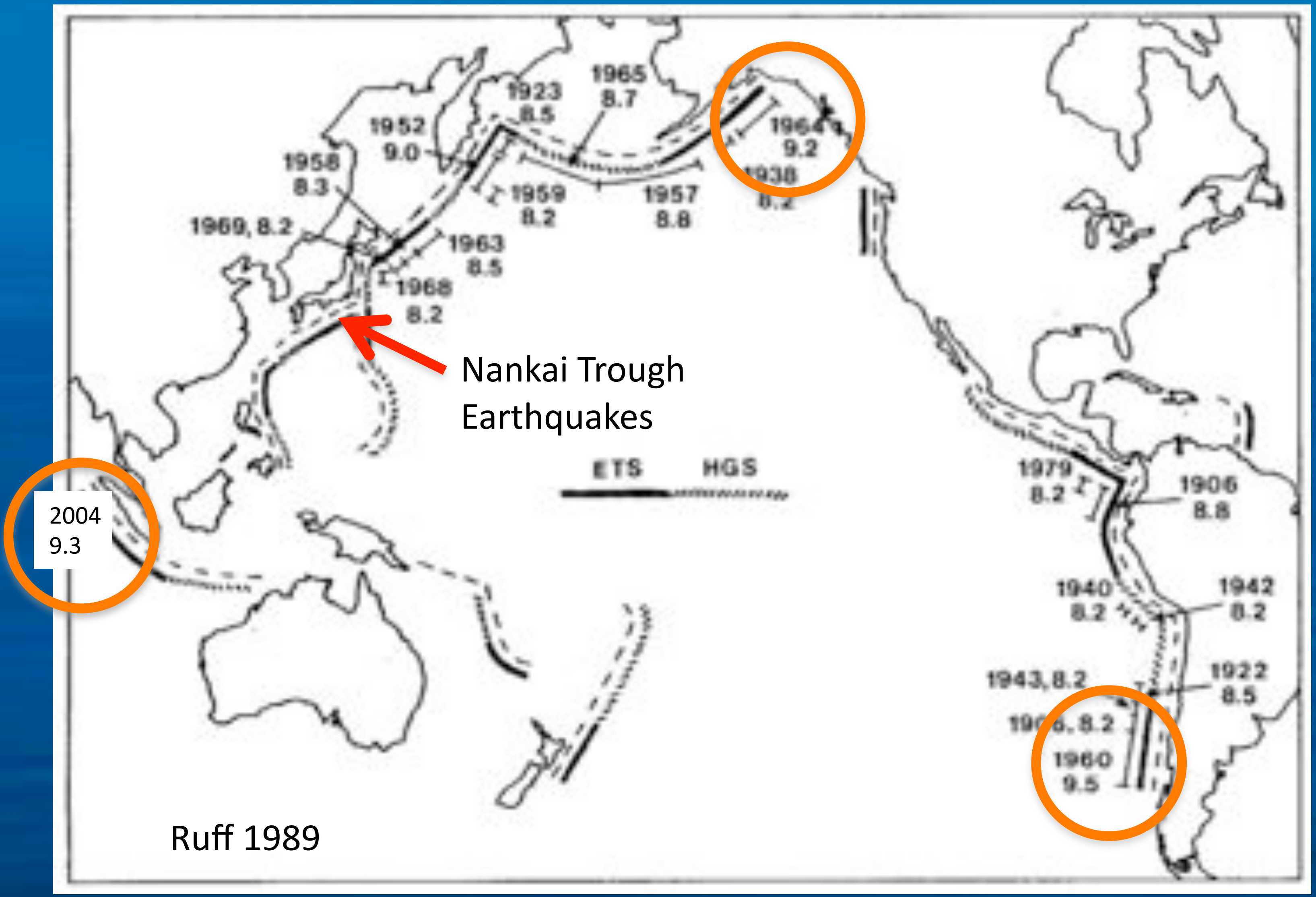
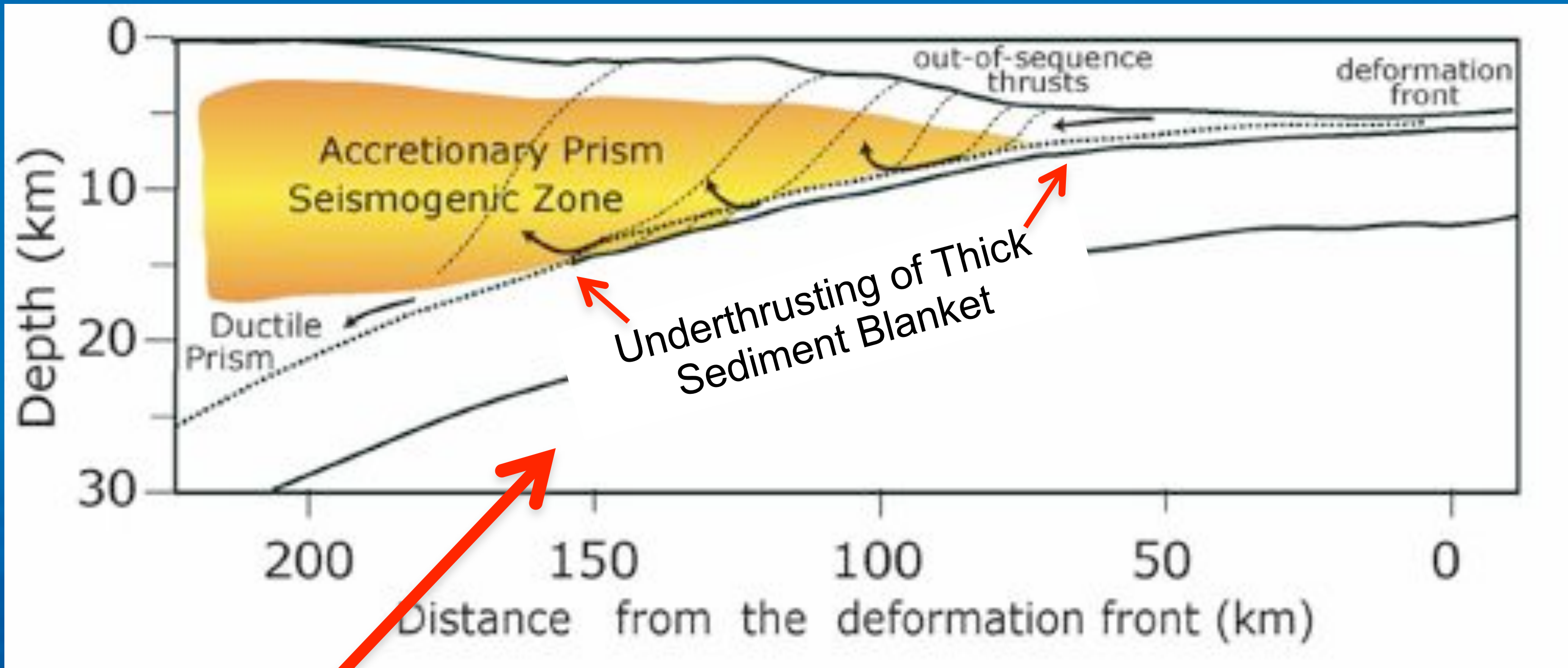
Geologic Context of the Biggest Earthquakes

By Casey Moore and Christie Rowe
UC Santa Cruz

- Sediment Influx and Biggest Earthquakes
- Consequent Accretionary Prisms
- Thermal Structure of Kumano Prism, Japan
- Probable Deformation Mechanisms
- Role of Solution Creep in Traditional Locked Zone
- Silica Mobility Hypothesis
- Quartz in Faults
- Porosity, Rigidity and Development of the Hanging Wall
- Anisotropy of Rock Strength
- Large Area of Seismogenic Zone

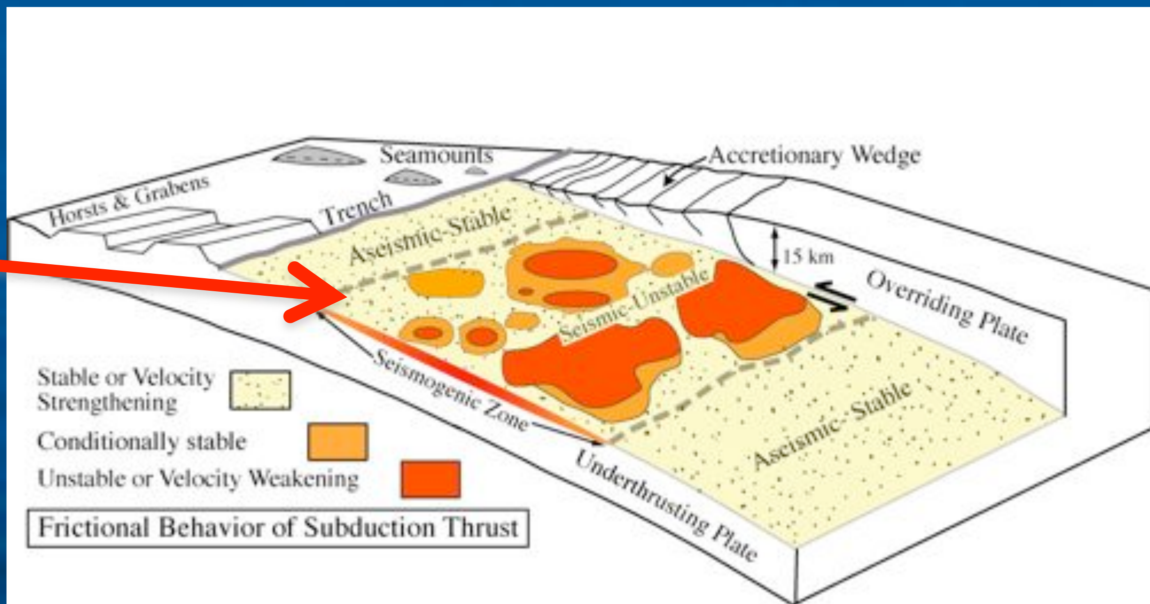
Biggest Earthquakes and Sediment Influx





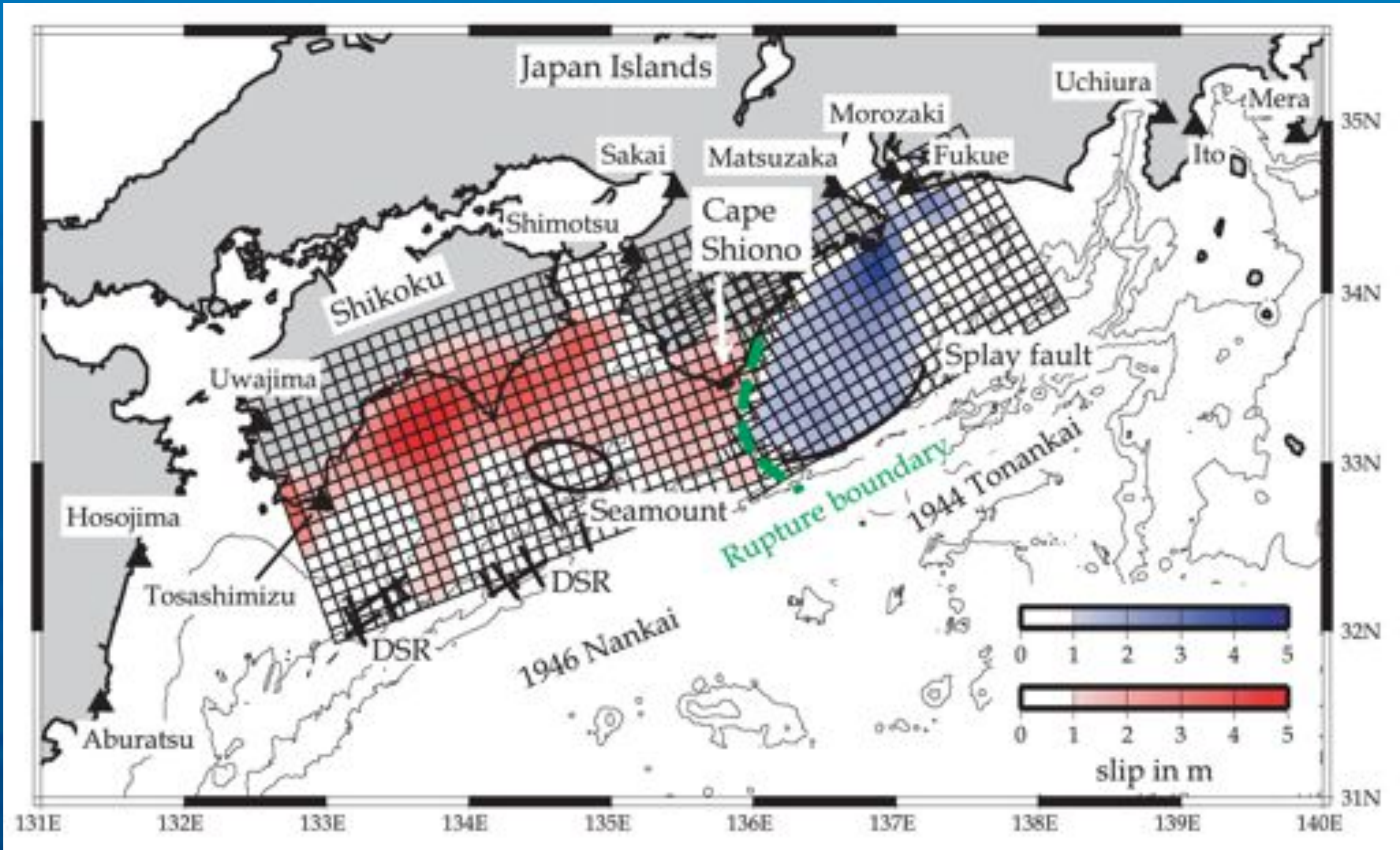
This

Not This

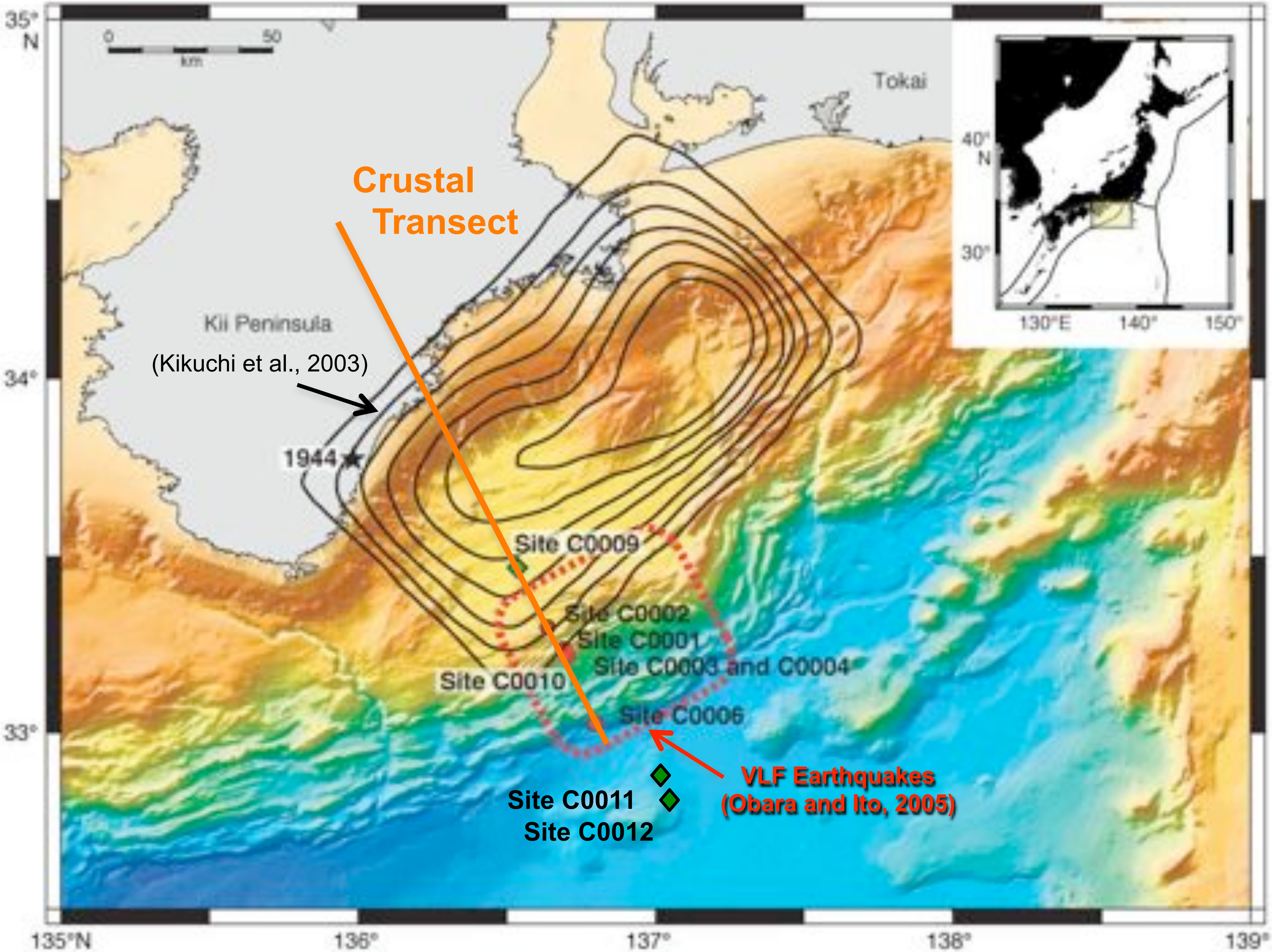


(After Lay, Schwartz, Bilek…..)

1944 M 8.1 Earthquake

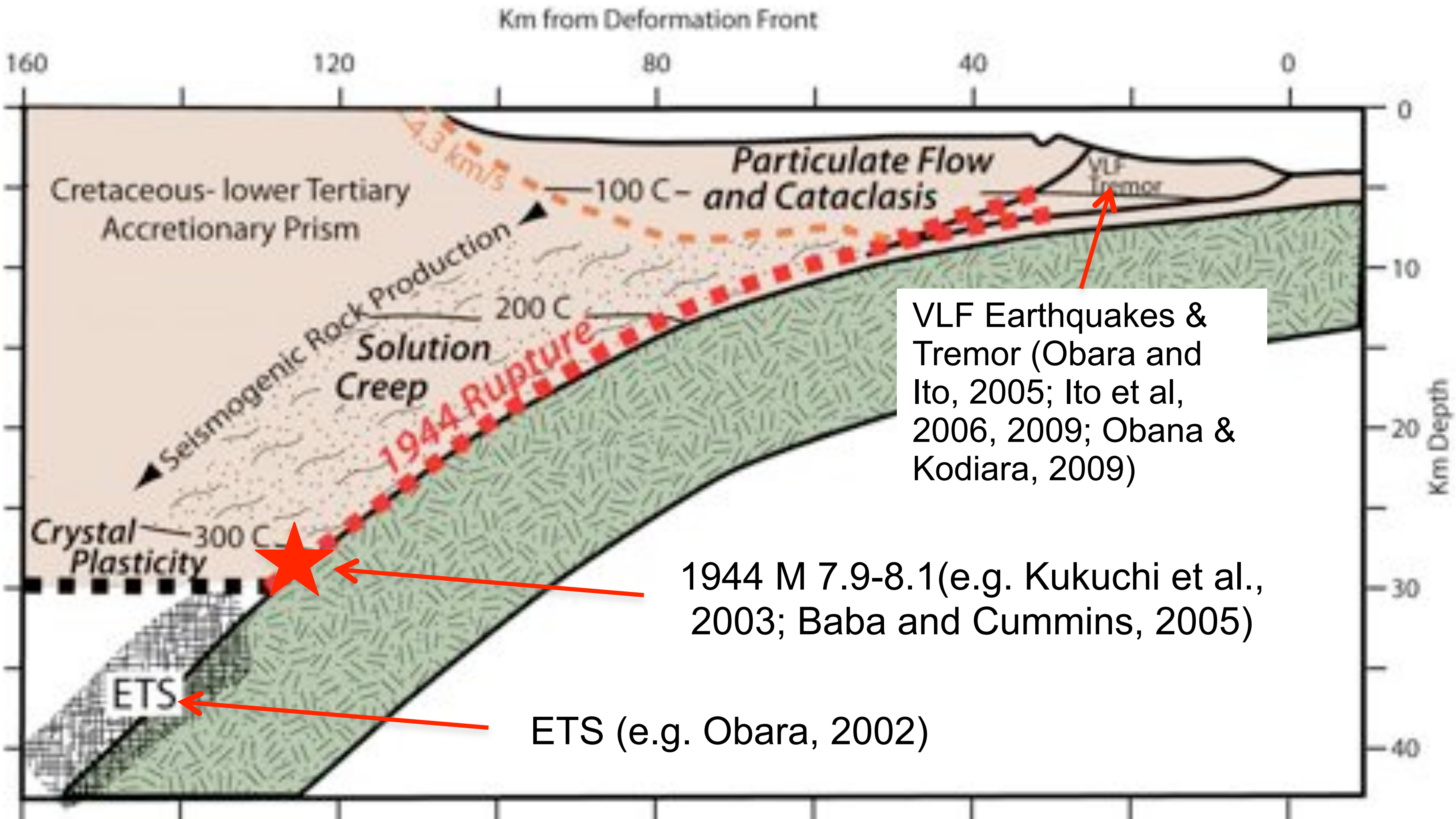


Baba and Cummins (GRL 2005)

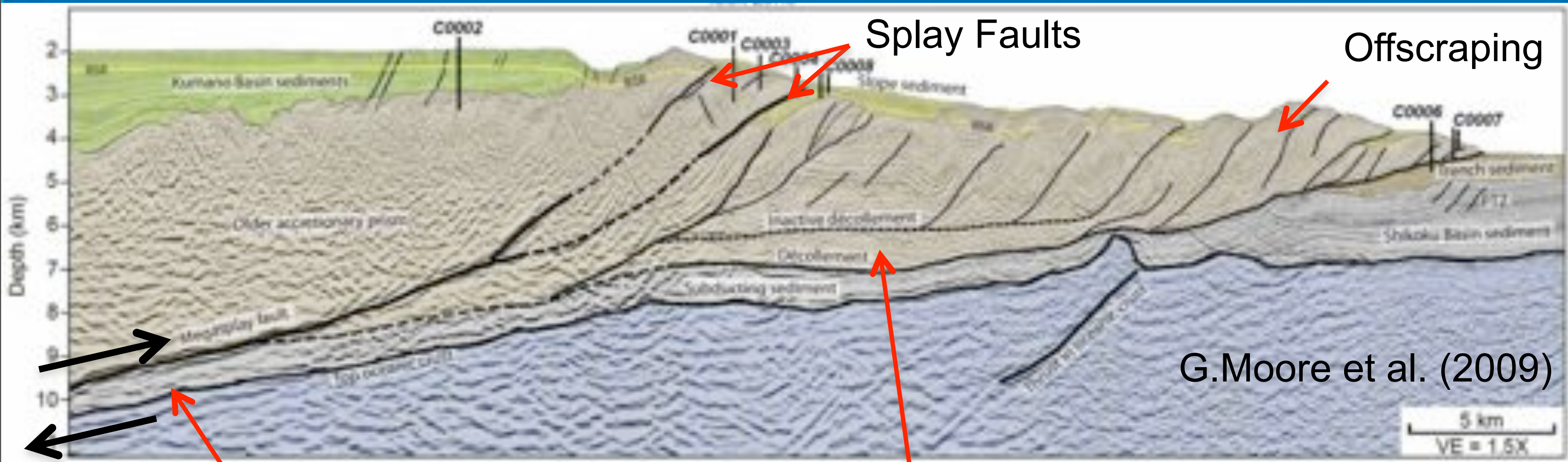


Crustal
Transect
Kii Peninsula
(Kikuchi et al., 2003)
1944
Tokai
Site C0009
Site C0002
Site C0001
Site C0003 and C0004
Site C0010
Site C0006
Site C0011
Site C0012
VLF Earthquakes
(Obara and Ito, 2005)
0
50
km
35°
N
34°
33°
135°N
136°
137°
138°
139°
40°
N
30°
130°E
140°
150°

Where is the Fault Slip?



Large Sediment Influx Grows Prisms



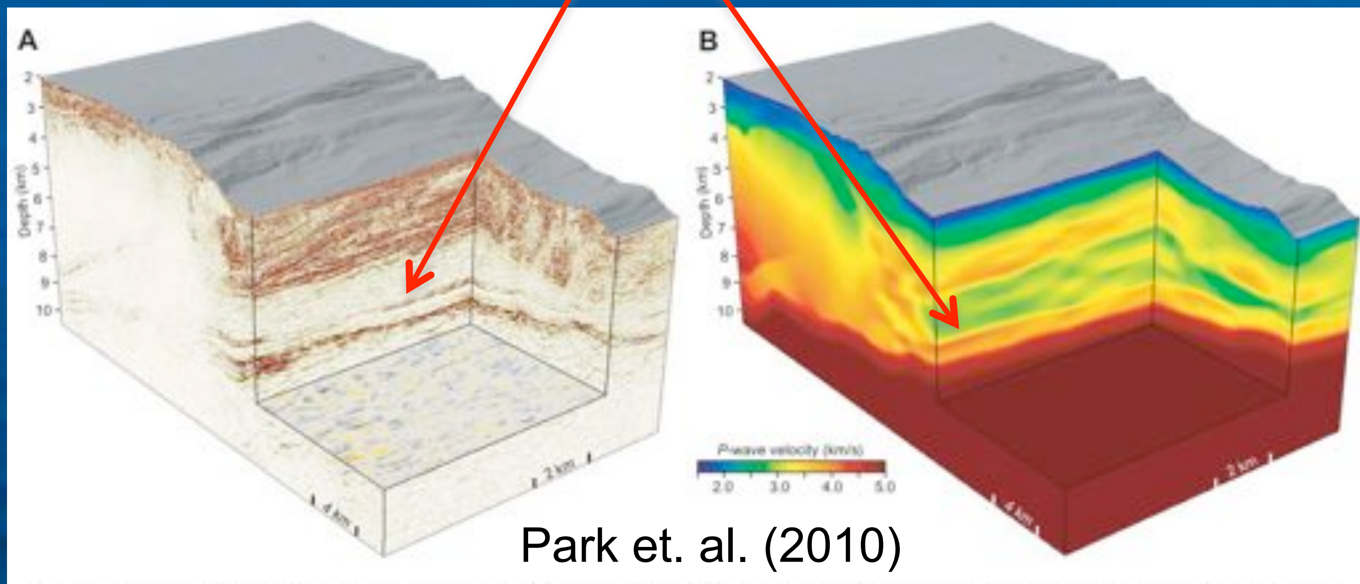
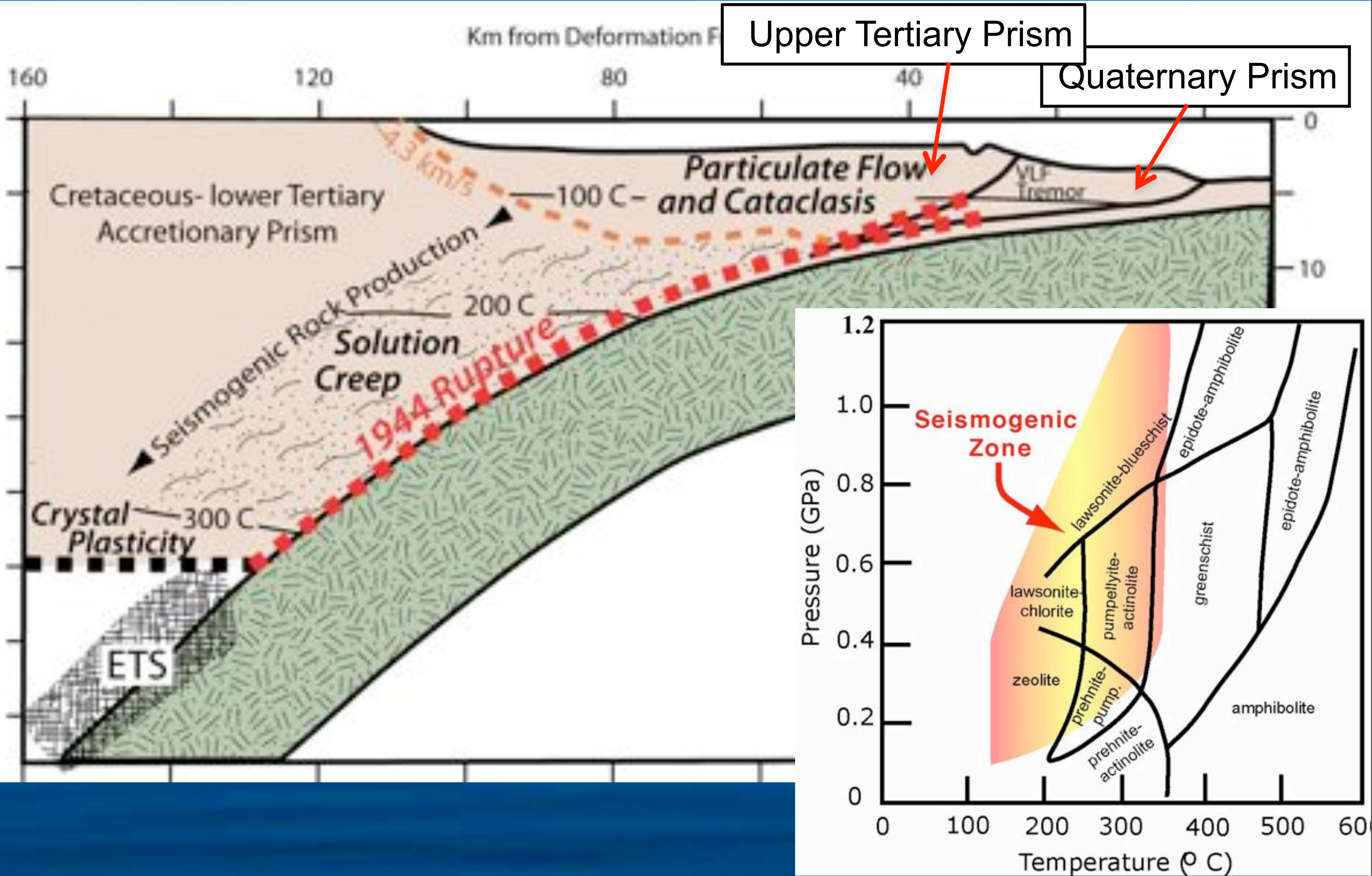
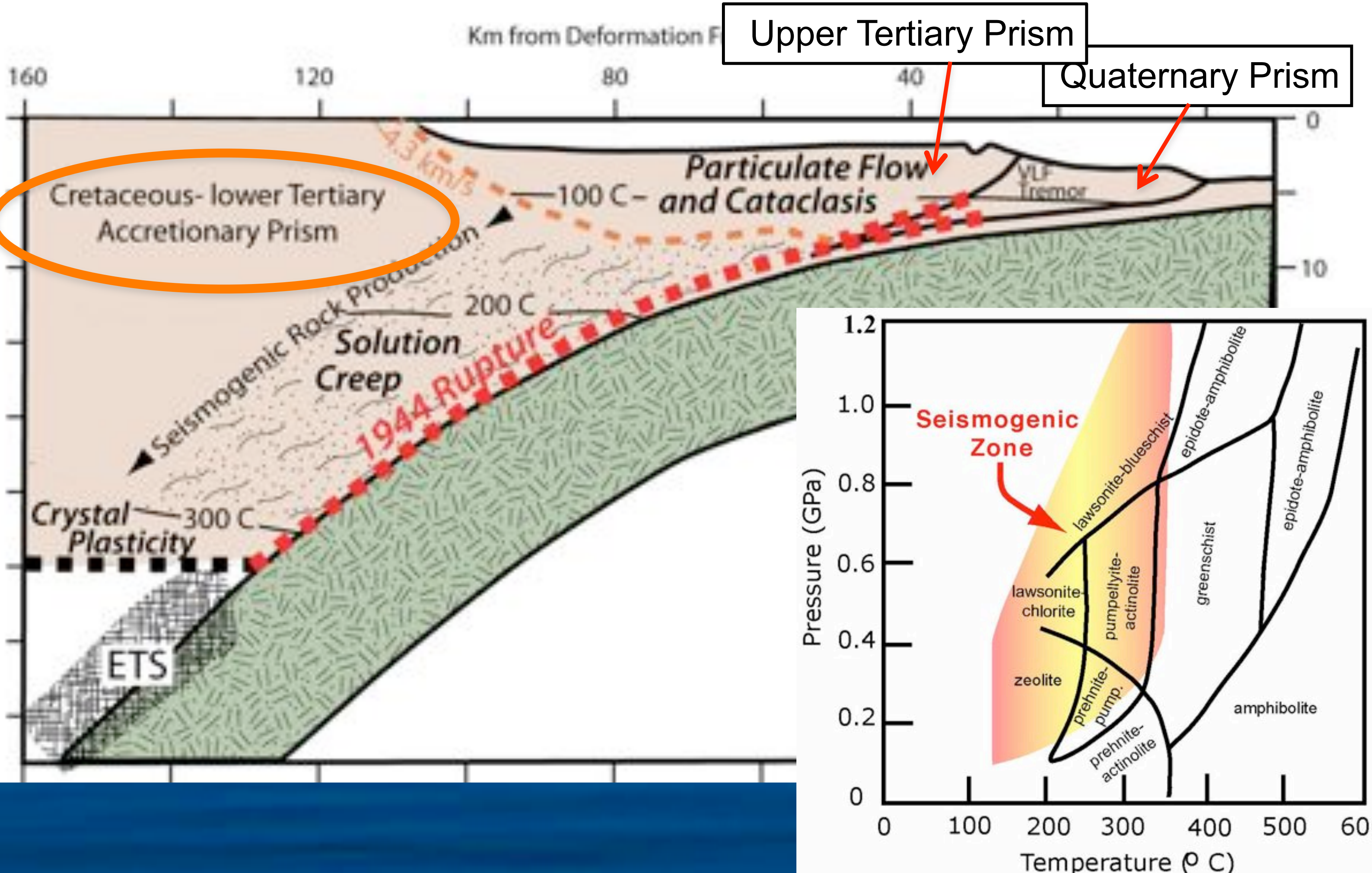


Figure 2. Final 3-D prestack depth migration (PSDM) results. A: 3-D view of seismic reflection image. B: P-wave velocity model derived from the 3-D PSDM. We used a

Materials at Depth



Materials at Depth



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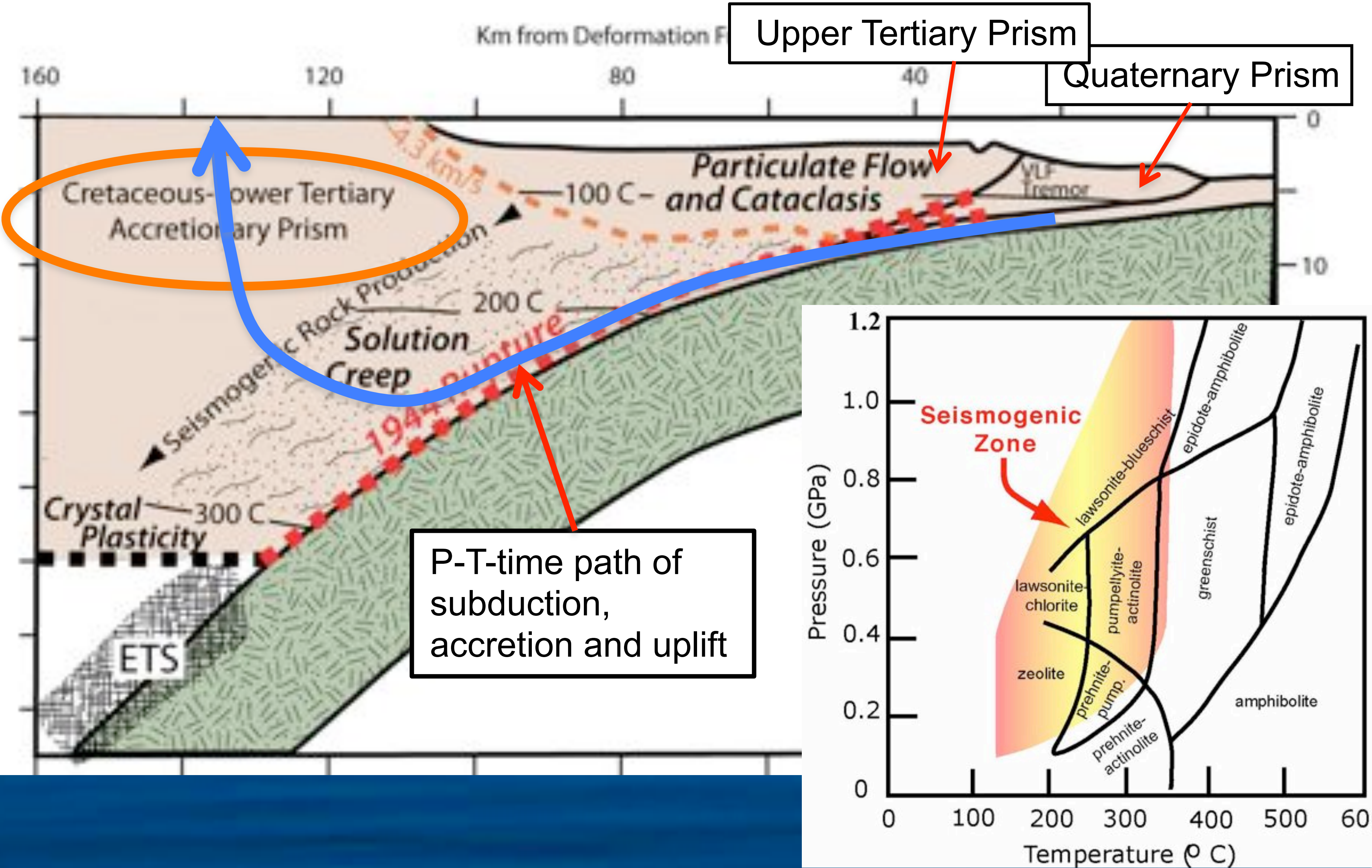
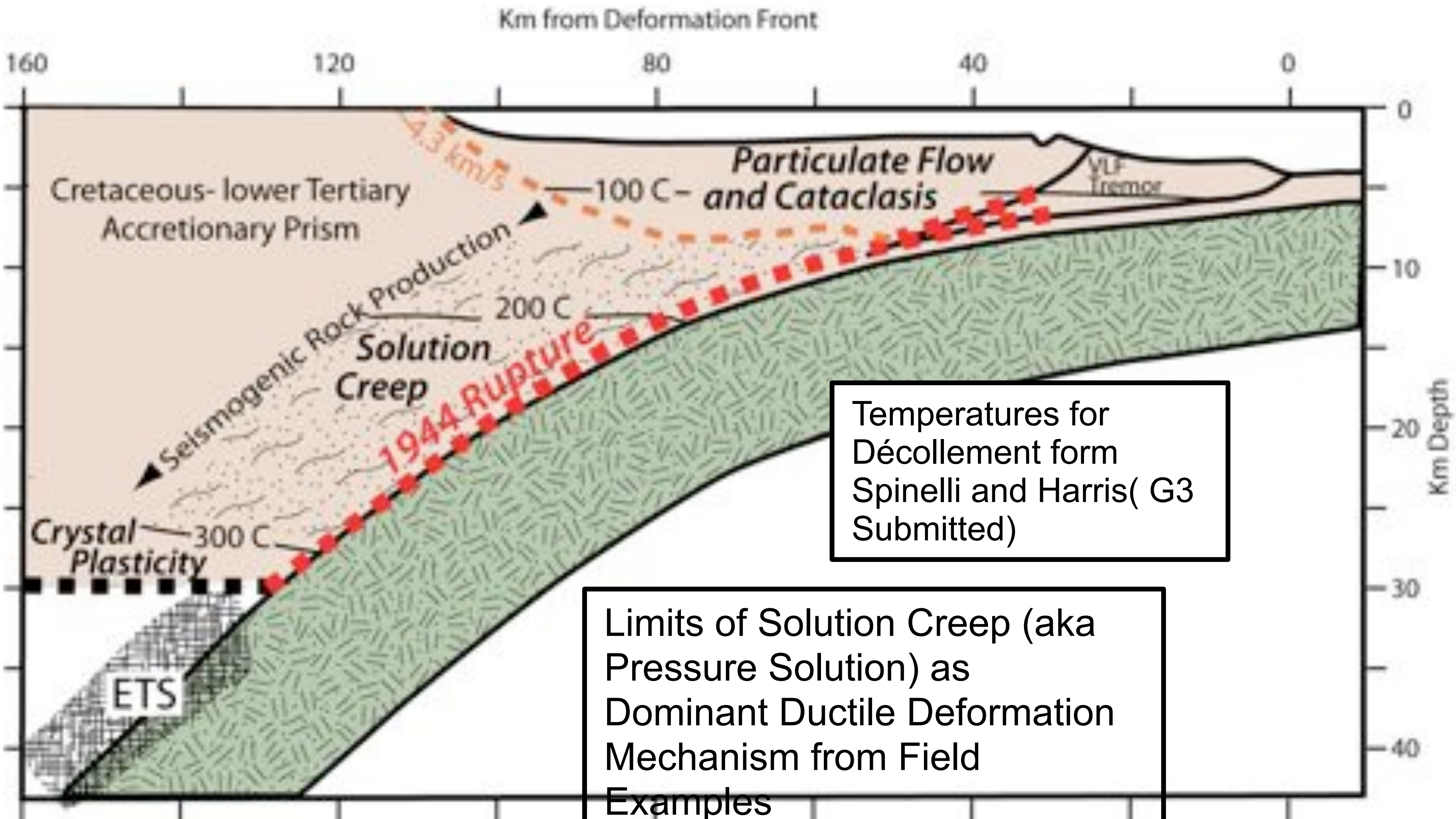


Interval of Solution Creep Lies in 1944 Slip Zone



Temperatures for Décollement form Spinelli and Harris(G3 Submitted)

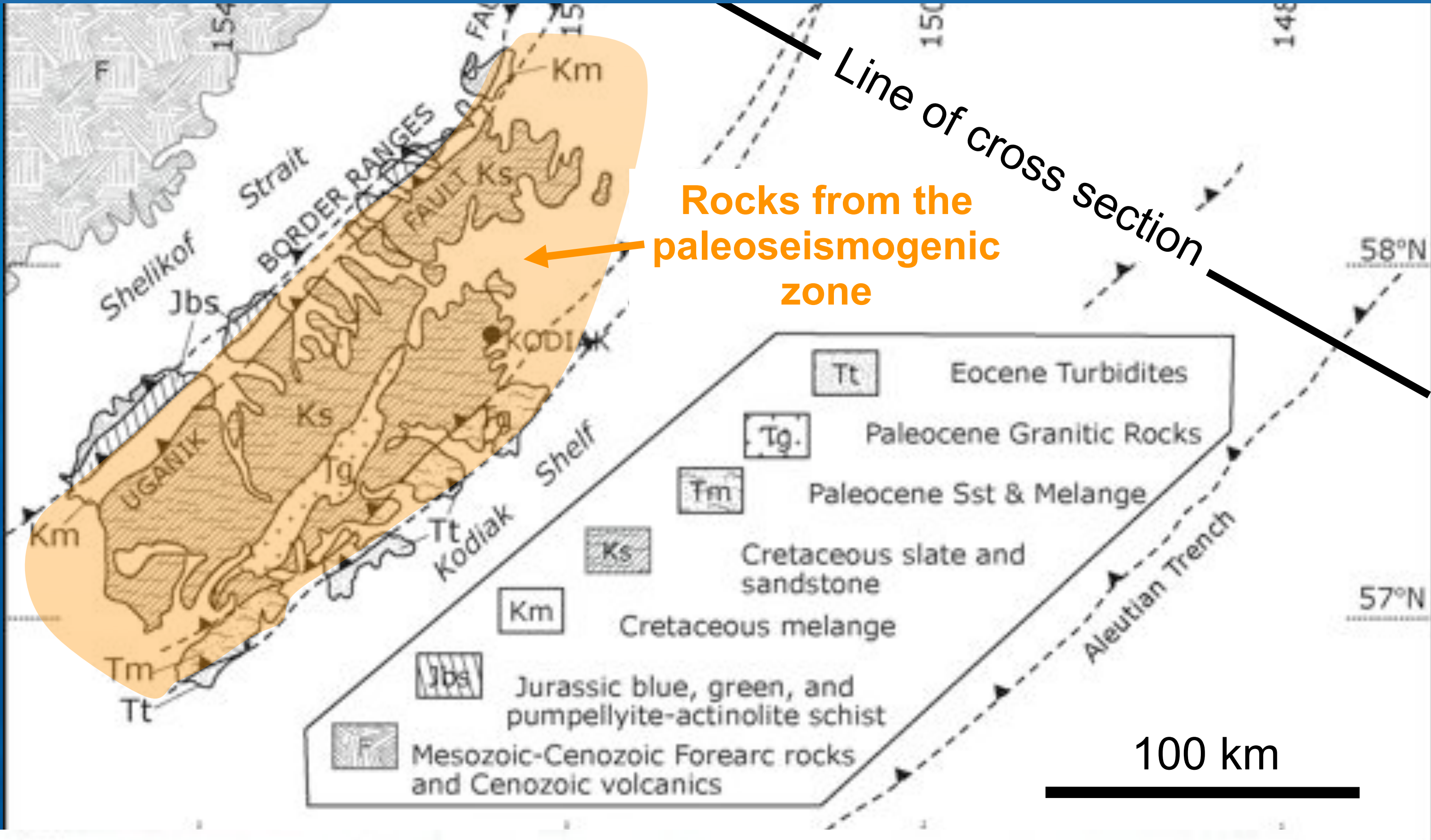
Limits of Solution Creep (aka Pressure Solution) as Dominant Ductile Deformation Mechanism from Field Examples

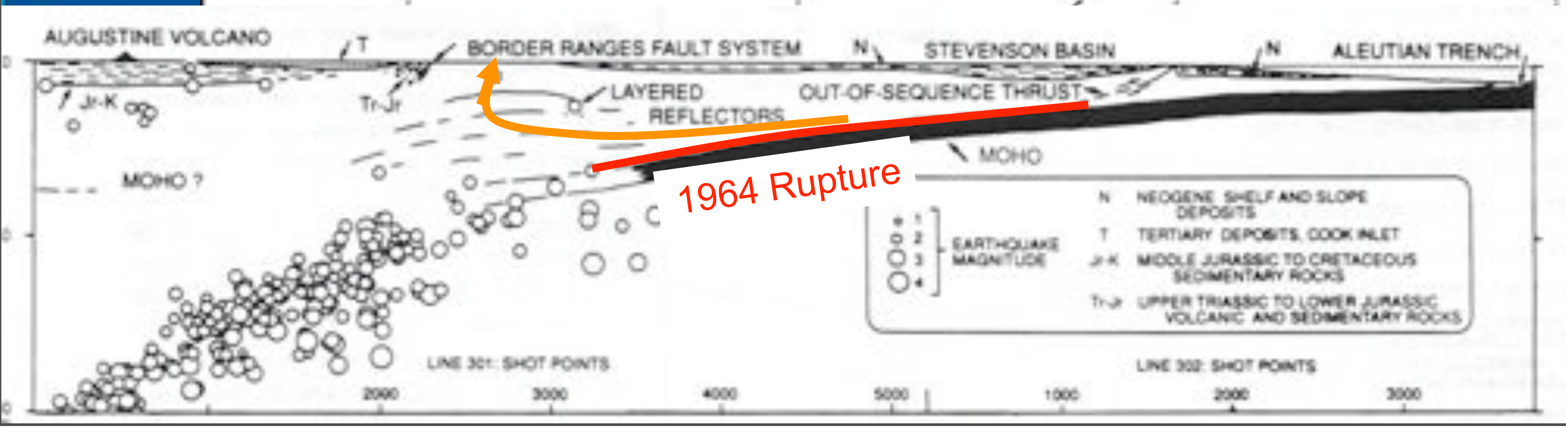
Does Solution Creep Affect the Seismogenic Behavior of Rocks?

1) Examples of Solution Creep
2) Quartz in Fault Zones
3) Increasing Shear Modulus

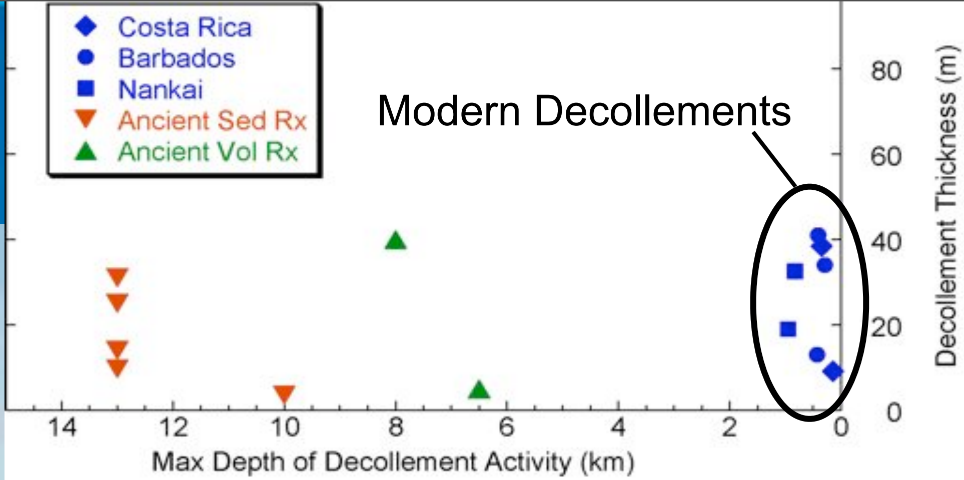
Progressively Veined Fault Zone from the Kodiak Accretionary Complex, SW Alaska

Kodiak Accretionary Complex, SW Alaska



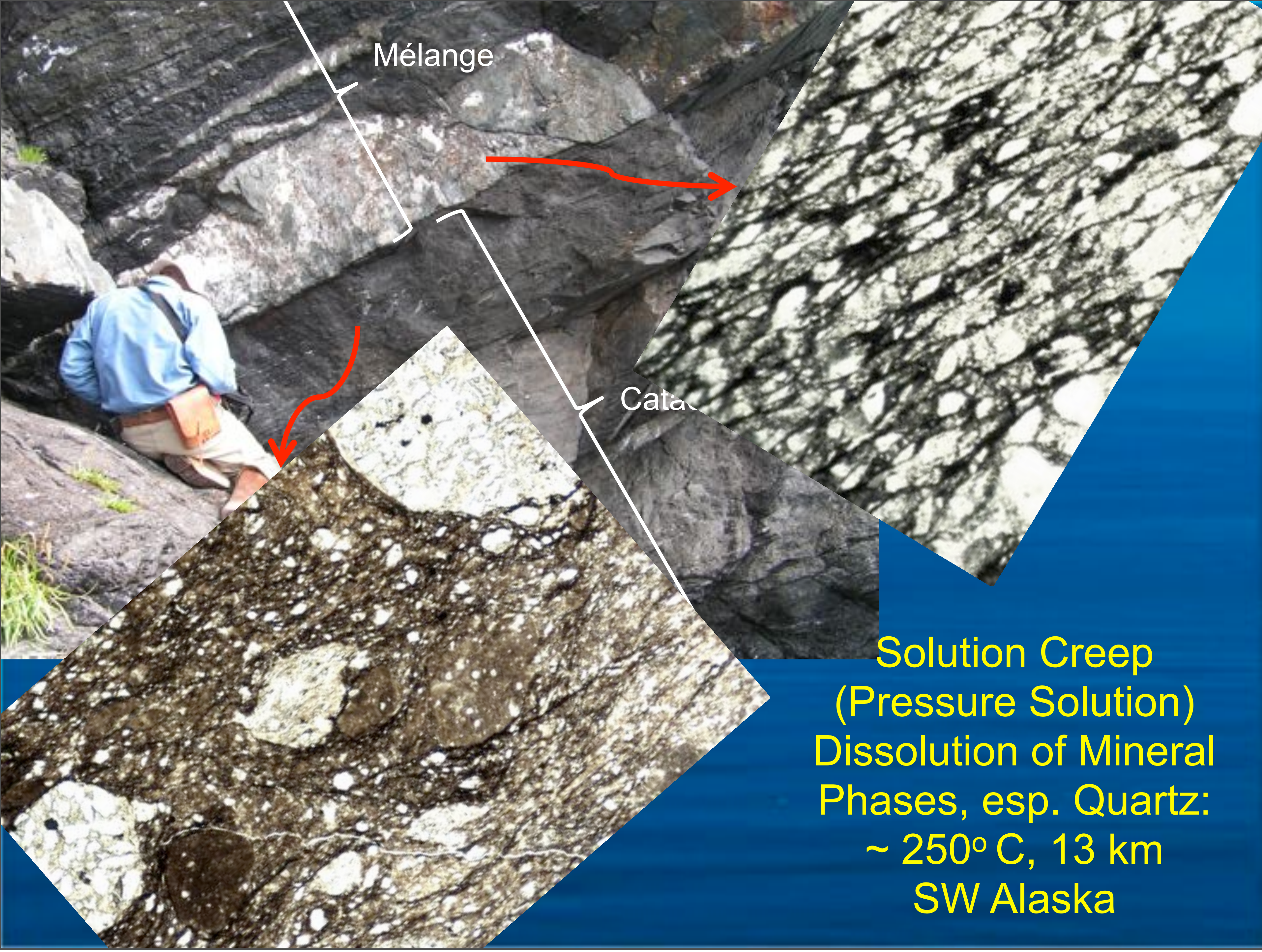


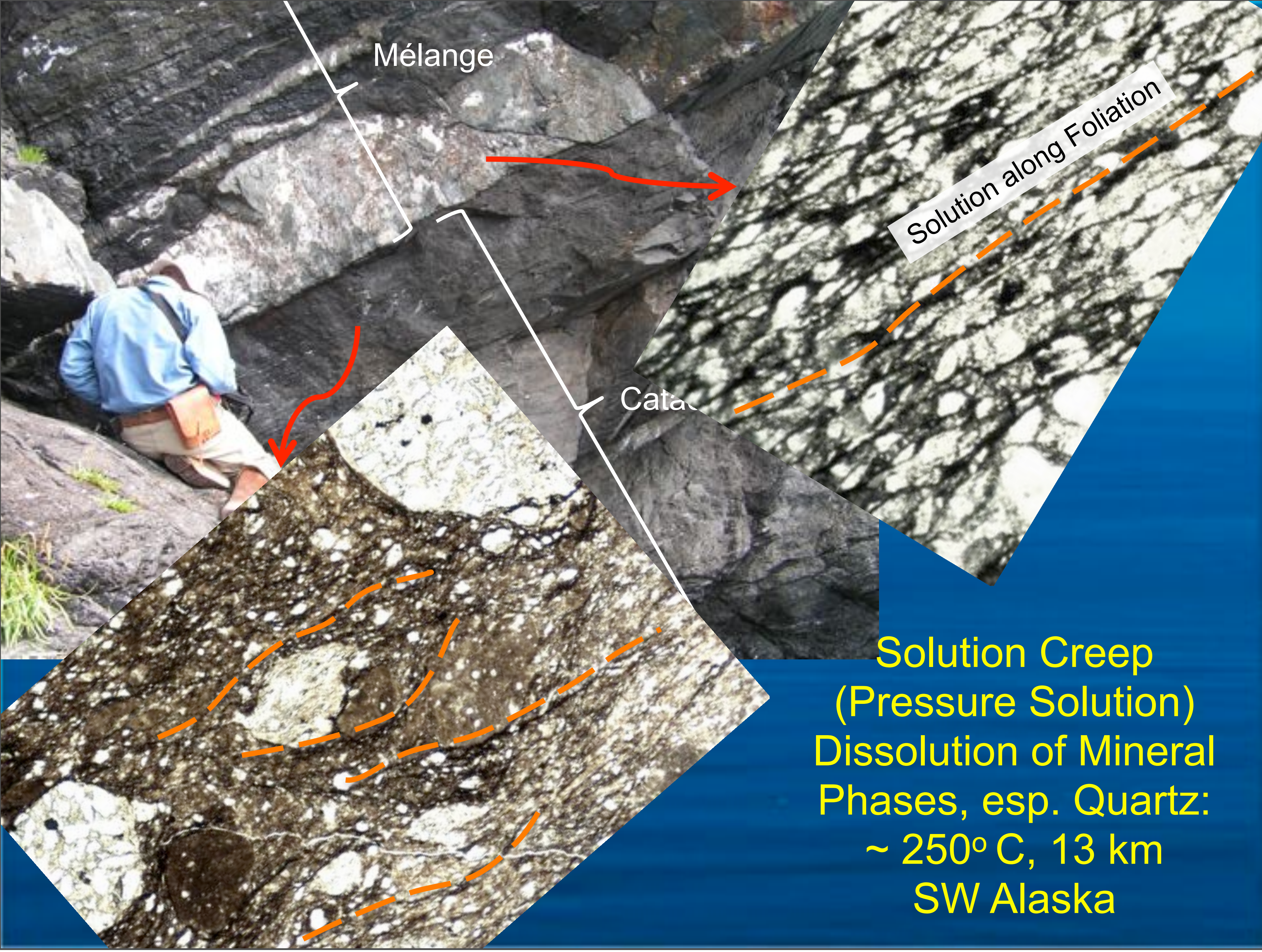
Kodiak Islands, Alaska



Probable Subduction Thrusts at Depth: 1) Similar in thickness to surface decollements, 2) finer grained material cross cutting mélange fabric


Mélange
Cataclasite


Mélange
Solution Creep
(Pressure Solution)
Dissolution of Mineral
Phases, esp. Quartz:
~ 250° C, 13 km
SW Alaska


Mélange
Solution along Foliation
Solution Creep
(Pressure Solution)
Dissolution of Mineral
Phases, esp. Quartz:
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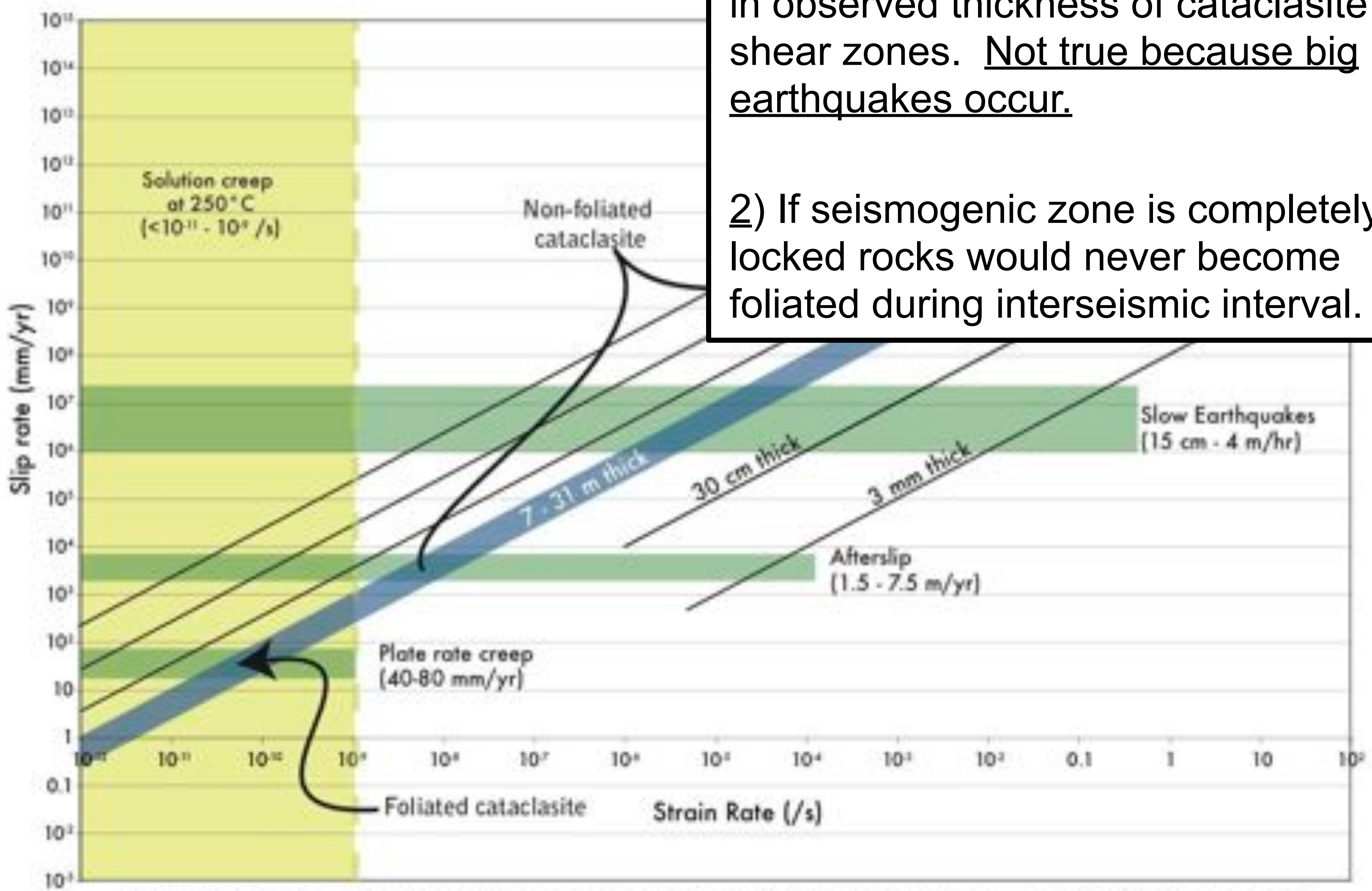
SW Alaska

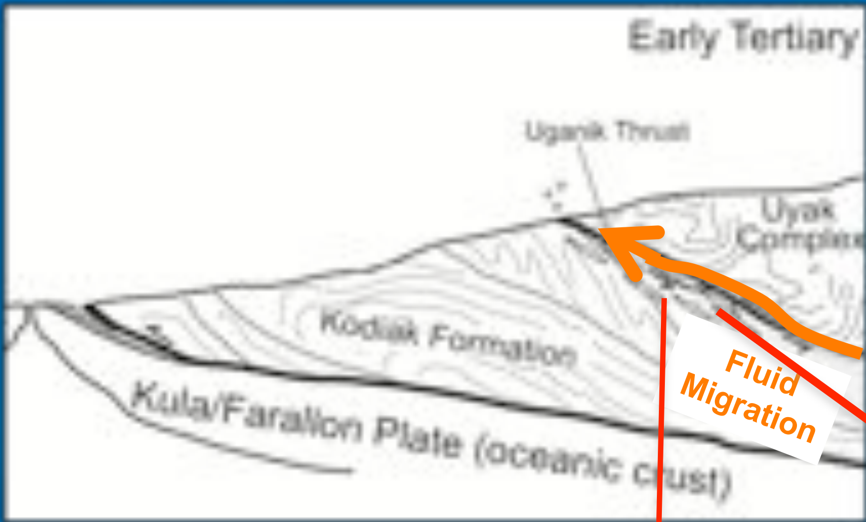
Slip Rages Verses Solution Creep Strain Rates

1) Estimates of solution creep rates would accommodate plate convergence in observed thickness of cataclasite shear zones. Not true because big earthquakes occur.

2) If seismogenic zone is completely locked rocks would never become foliated during interseismic interval.

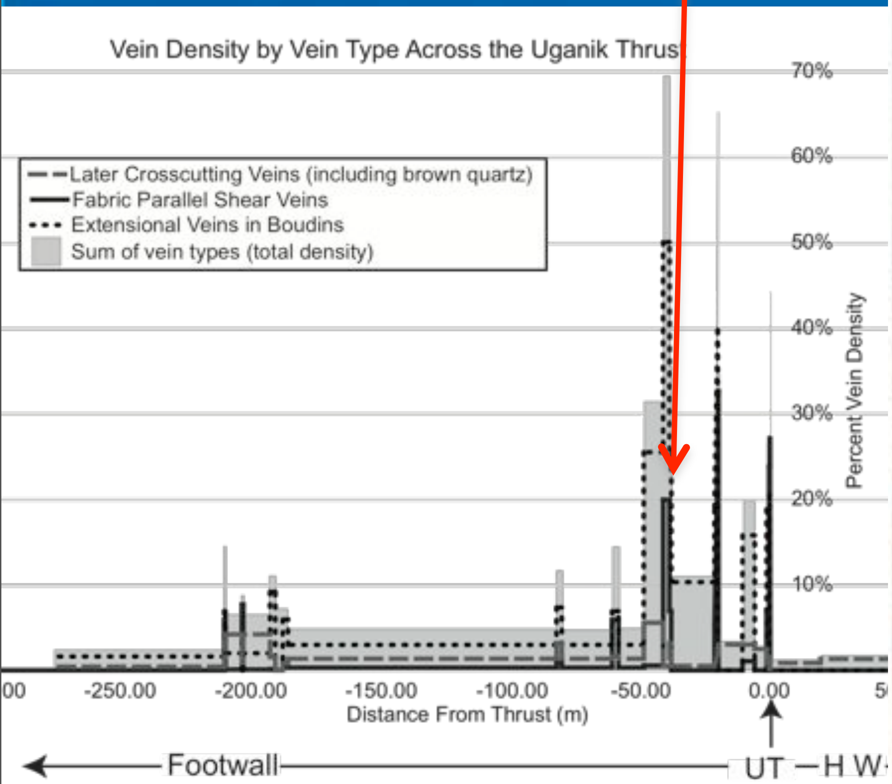


Slip rates from: Gahalaut et al. 2010, Linde and Sacks 2002, Oleskevich et al. 1999, Singh et al. 2006
Solution creep rates from : Shimizu 1995, Renard et al. 2000

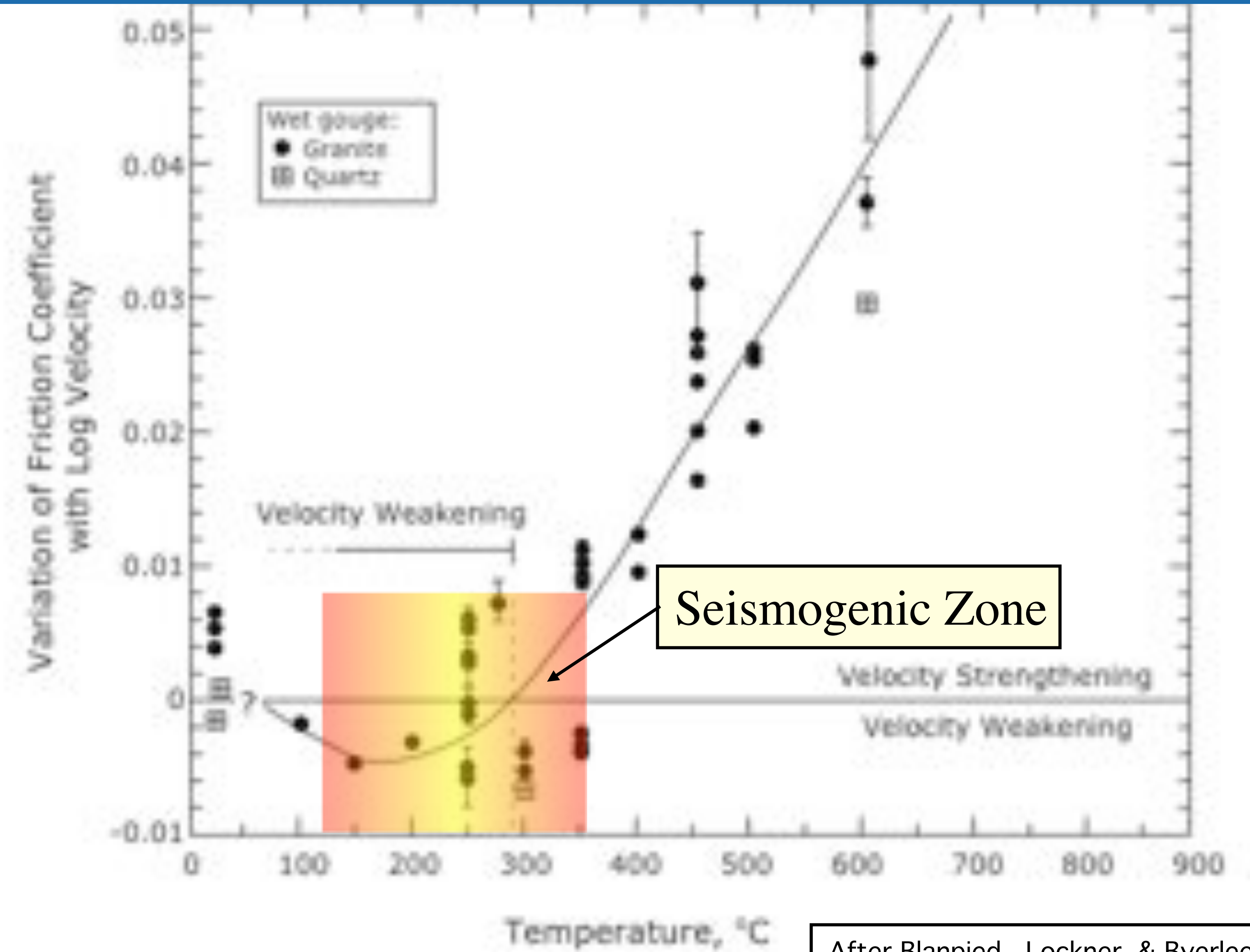


Fluid Migration Up Splay Fault:

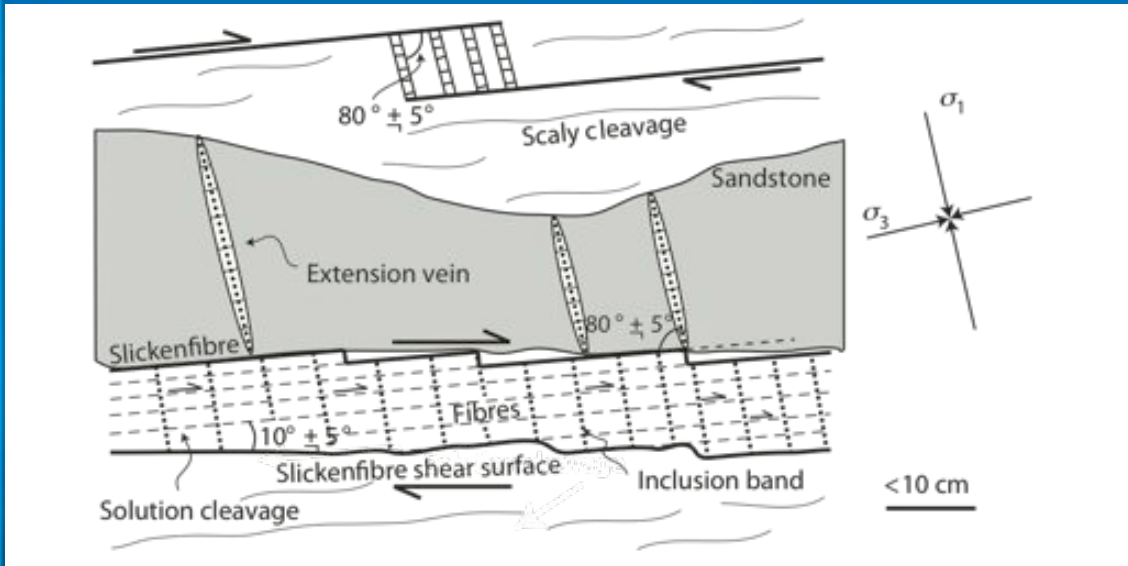
Shear Zones in Footwall with Abundant Quartz Veins (Rowe et al., 2009)



Velocity Weakening of Quartz and other Framework Silicates (Granite)



After Blanpied, Lockner, & Byerlee, 1995



Quartz Precipitation in linked Extensional and Shear Veins Chrystalls Beach Accretionary Complex, New Zealand (Fagereng, Remitti, and Sibson, 2010)


Mélange
Cataclasite


Mélange
Frictional Melt (Pseudotachylyte)
Cataclasite

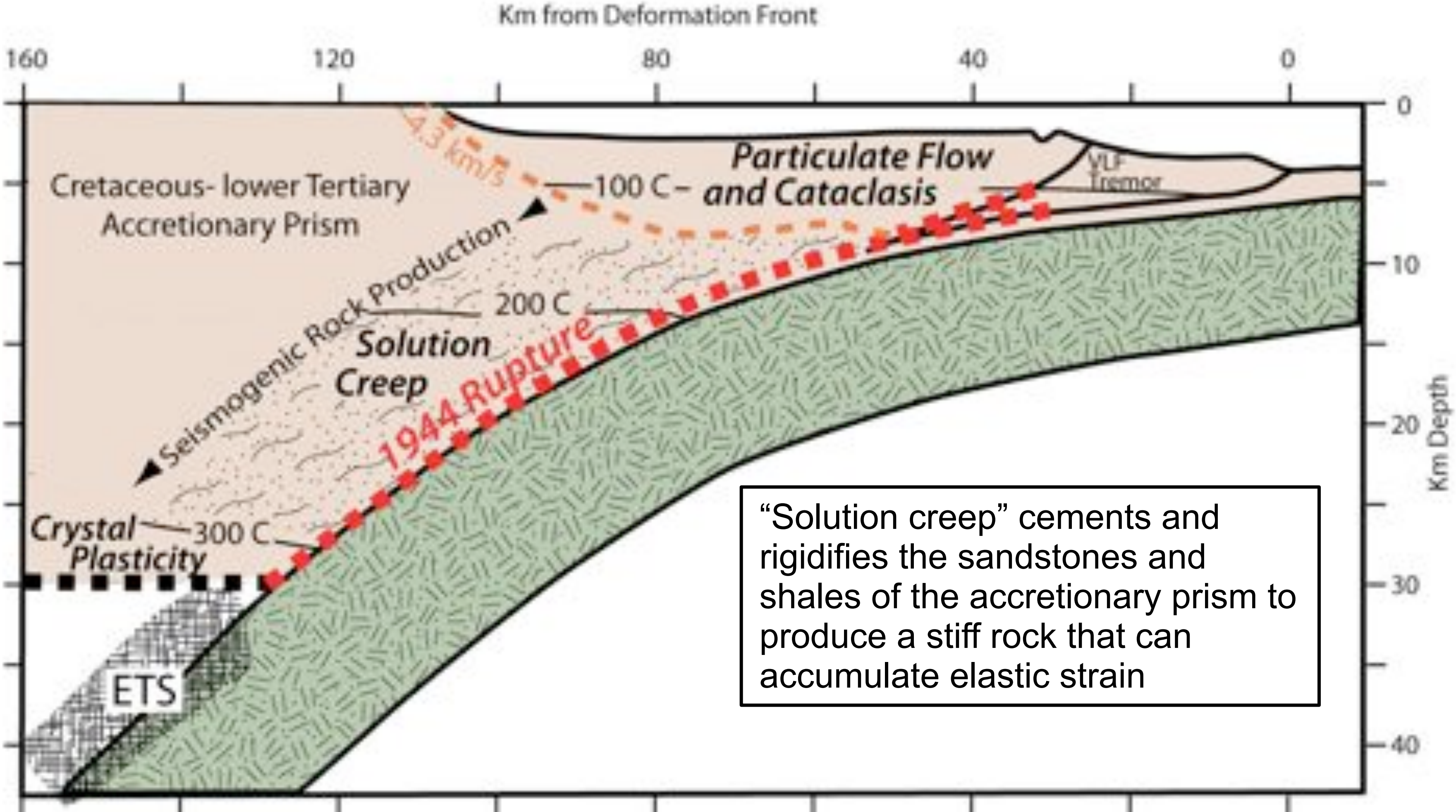

Mélange
Frictional Melt (Pseudotachylyte)
Cataclasite


solution fabric

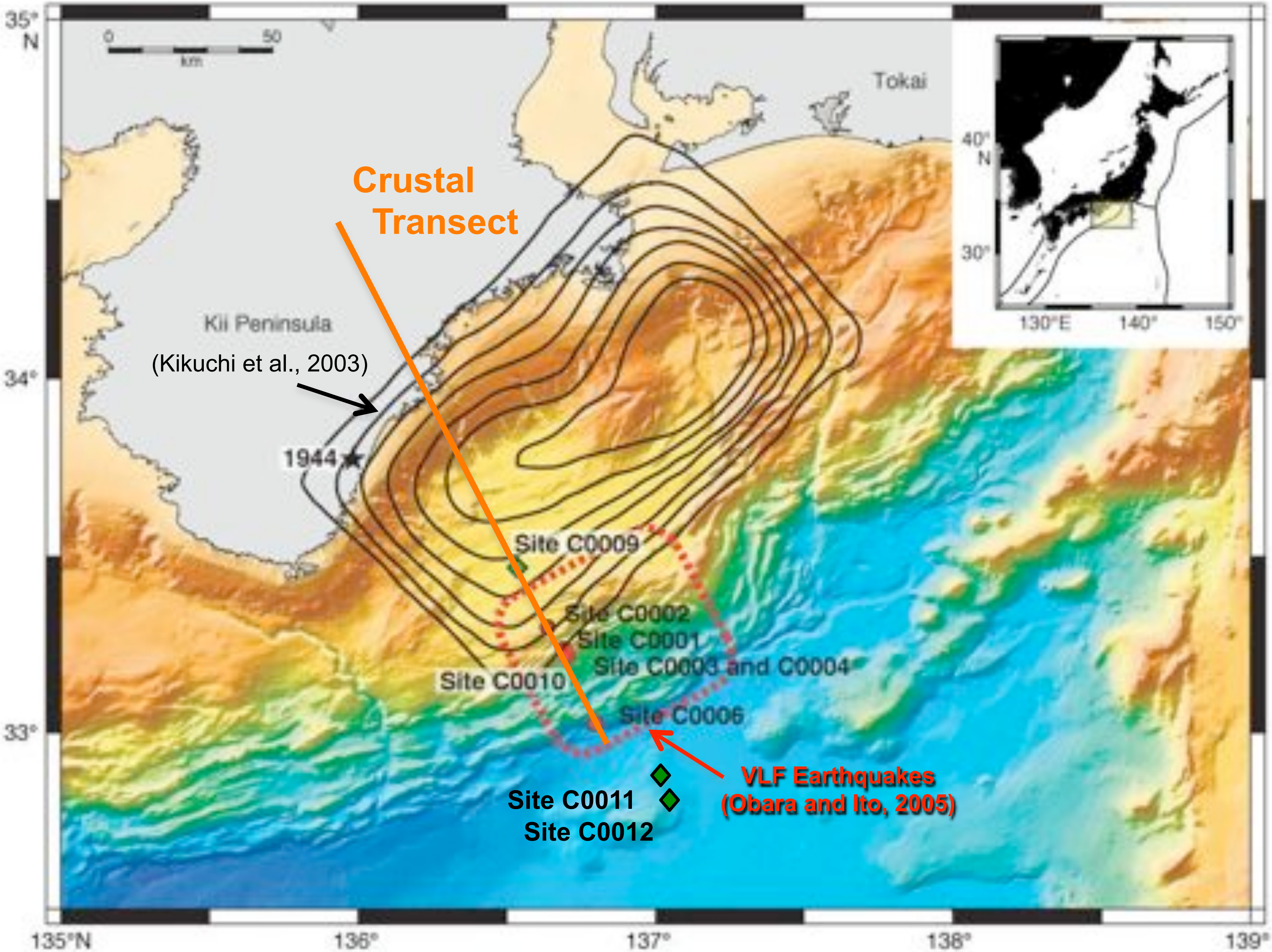
Frictional Melt = High Velocity Slip

But, absence of major quartz shear veins along failure surface

Some other aspect of rock also fosters stick-slip



"Solution creep" cements and rigidifies the sandstones and shales of the accretionary prism to produce a stiff rock that can accumulate elastic strain



Crustal Transect
Tokai
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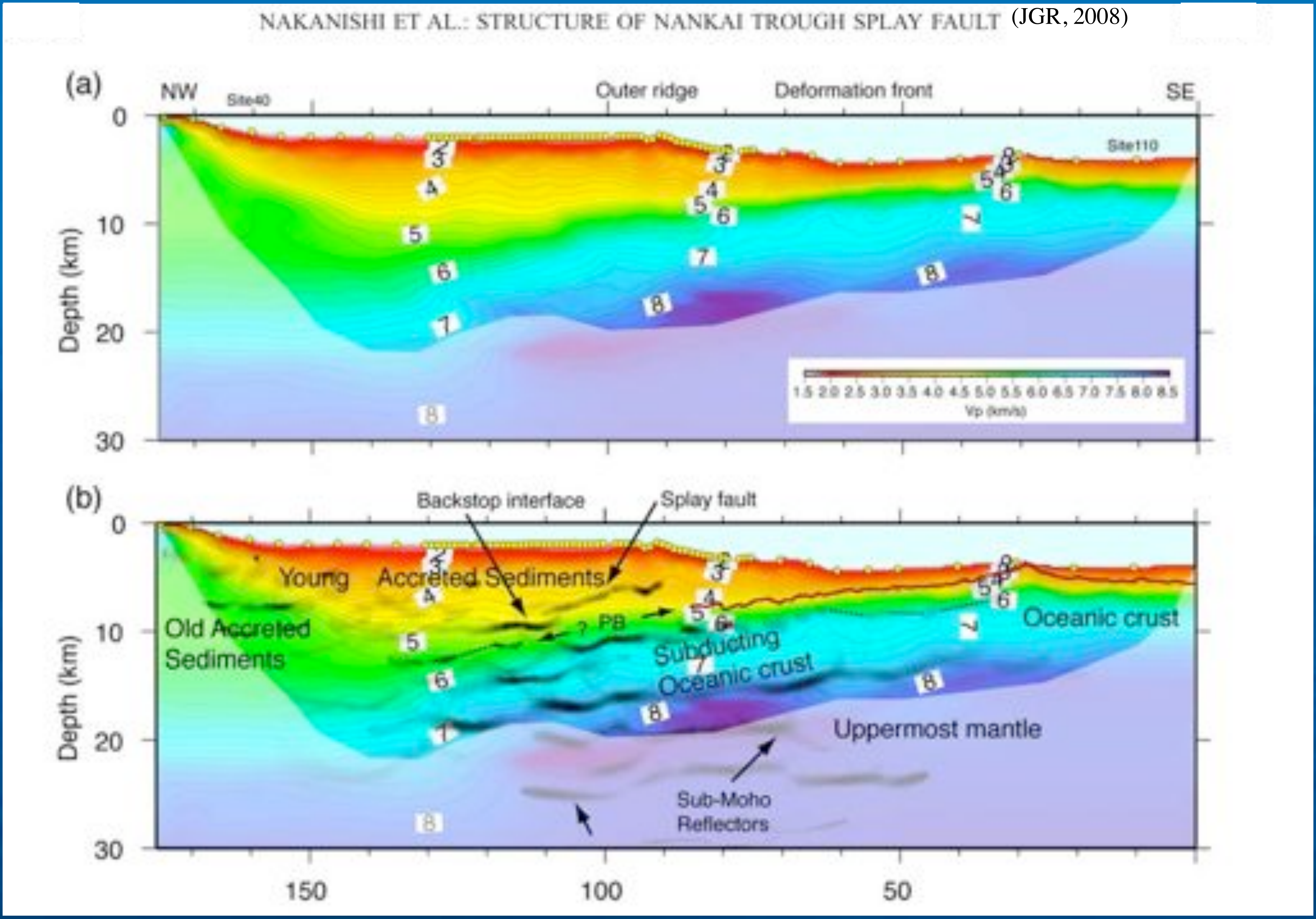
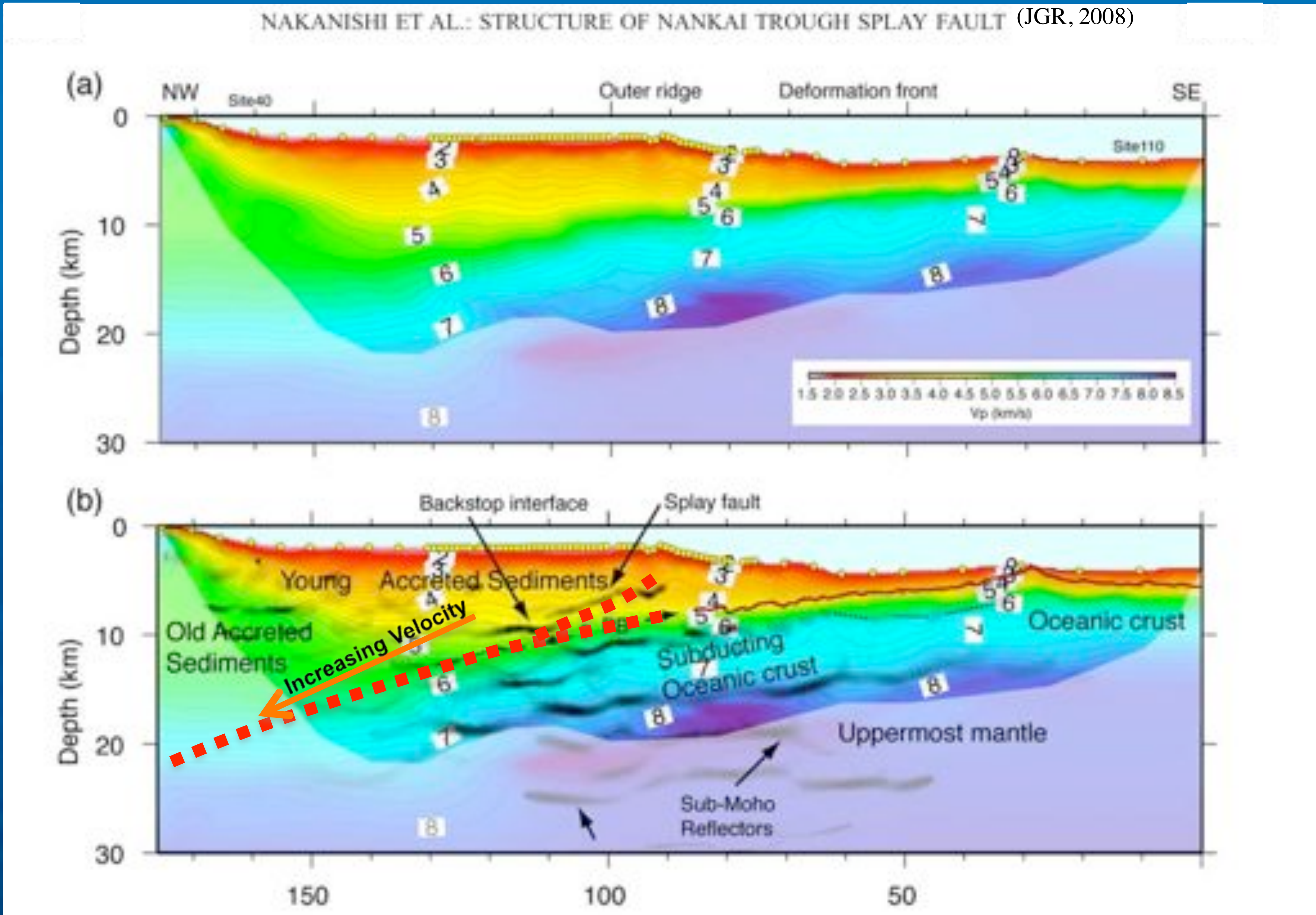
35° N
34°
33°
135°N
136°
137°
138°
139°
0
50
km
40° N
30°
130°E
140°
150°

Increasing Velocity of Upper Plate Indicates Increasing Rigidity and Density

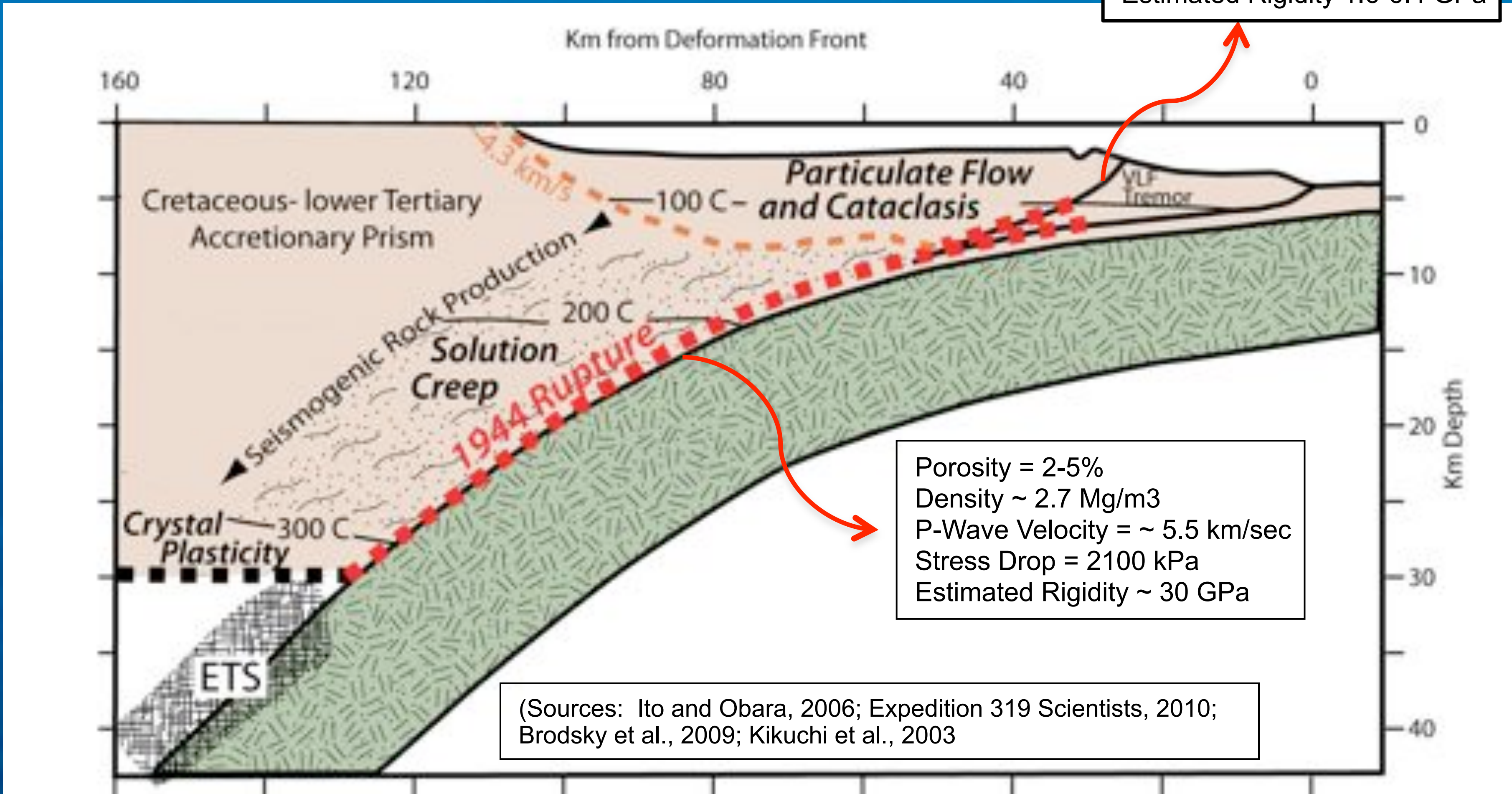


Increasing Velocity of Upper Plate Indicates Increasing Rigidity and Density



Rigidity and Stress Drop Rise Dramatically with Prism Consolidation and Cementation

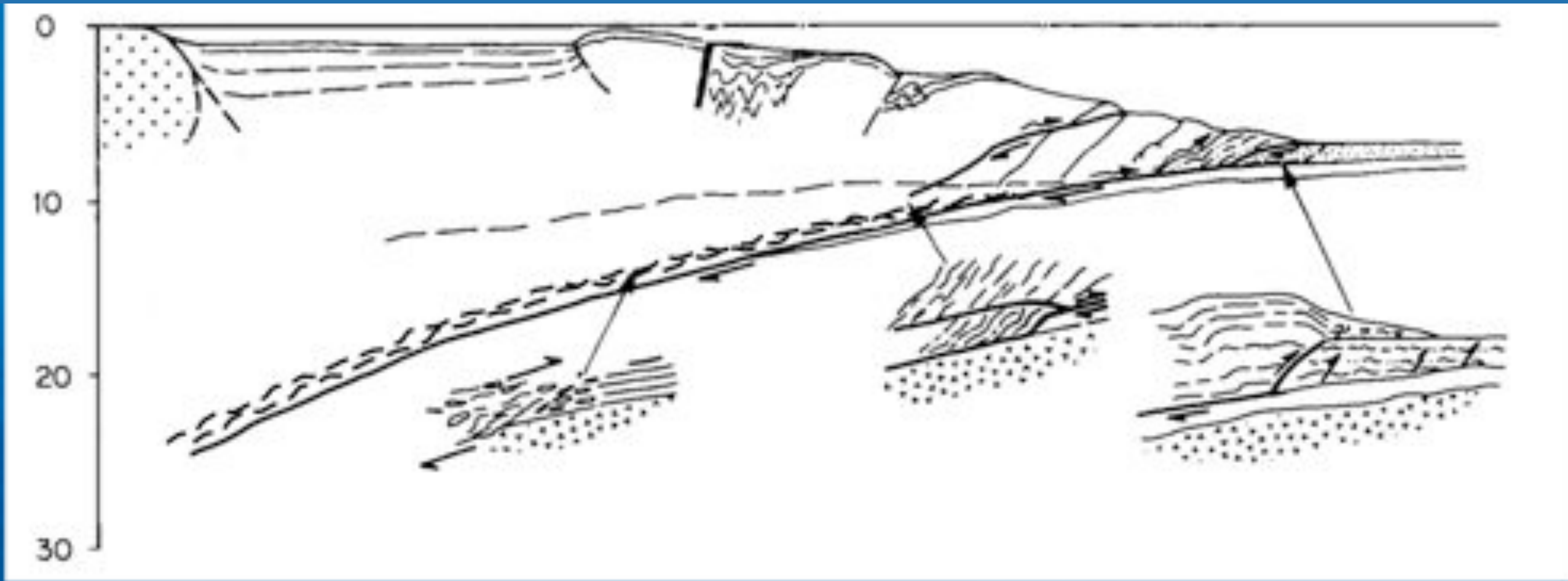
Porosity ~ 30%
Density ~ 2.2 Mg/m3
P-Wave Velocity ~ 3 km/sec
Stress Drop < 10 kPa
Estimated Rigidity 1.6-6.4 GPa



Porosity = 2-5%
Density ~ 2.7 Mg/m3
P-Wave Velocity = ~ 5.5 km/sec
Stress Drop = 2100 kPa
Estimated Rigidity ~ 30 GPa

(Sources: Ito and Obara, 2006; Expedition 319 Scientists, 2010; Brodsky et al., 2009; Kikuchi et al., 2003

Progressive Shear Through Solution Creep and Higher Velocity Slip Progressively Rotates Planar Fabric Parallel to Subduction Thrust



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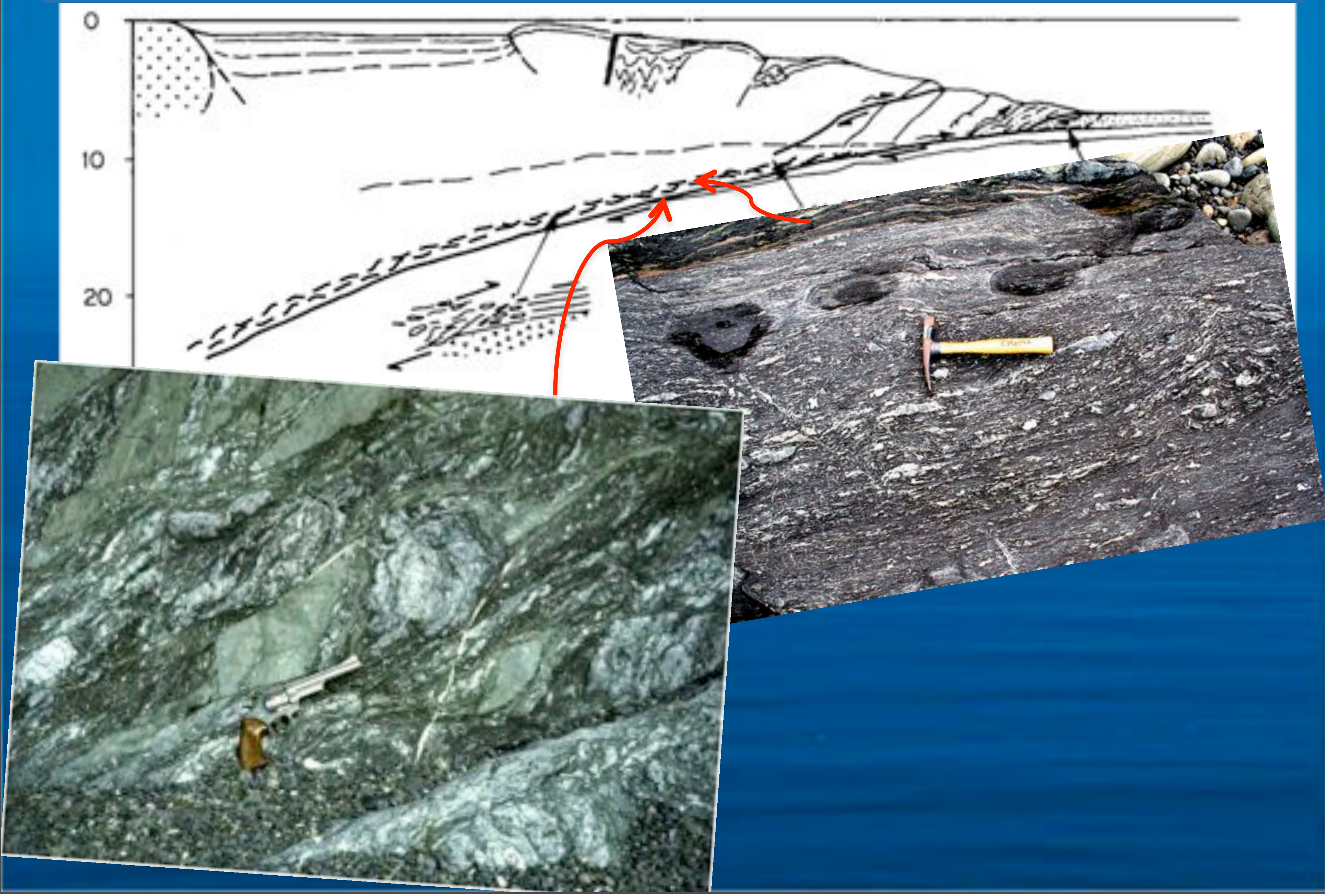

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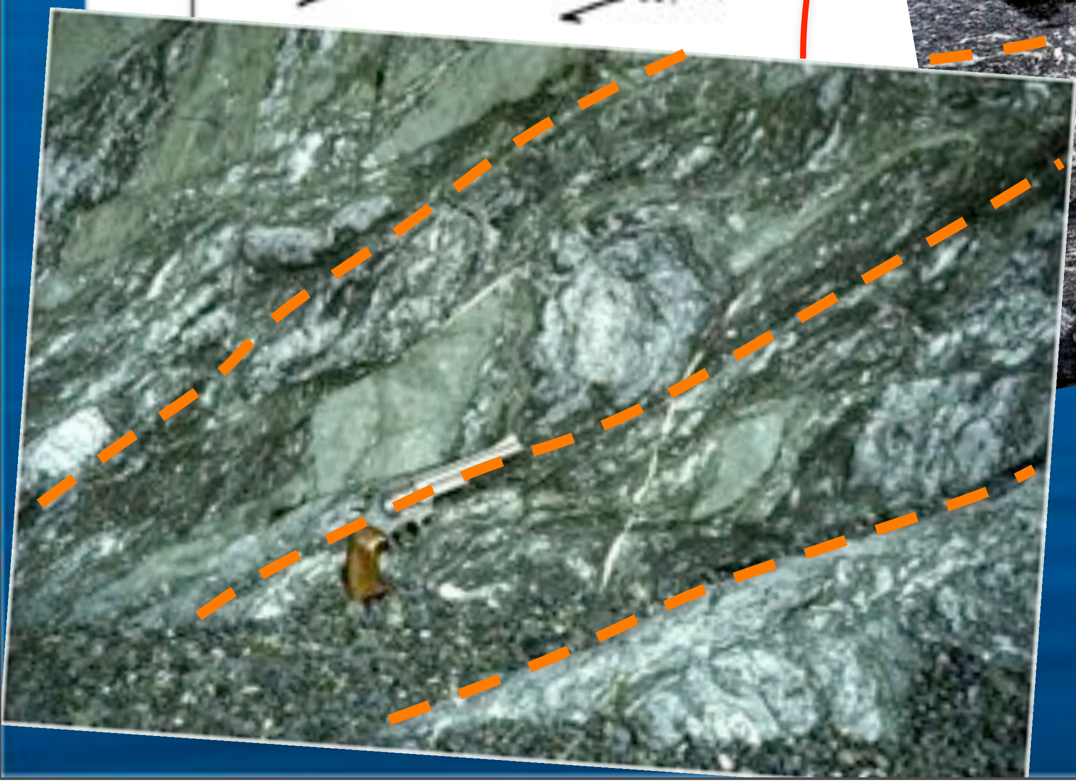
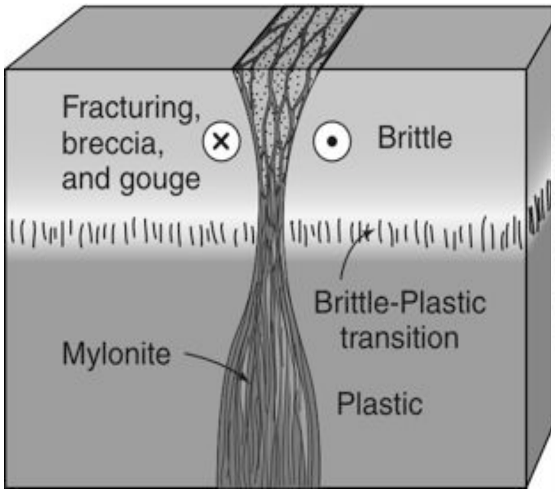
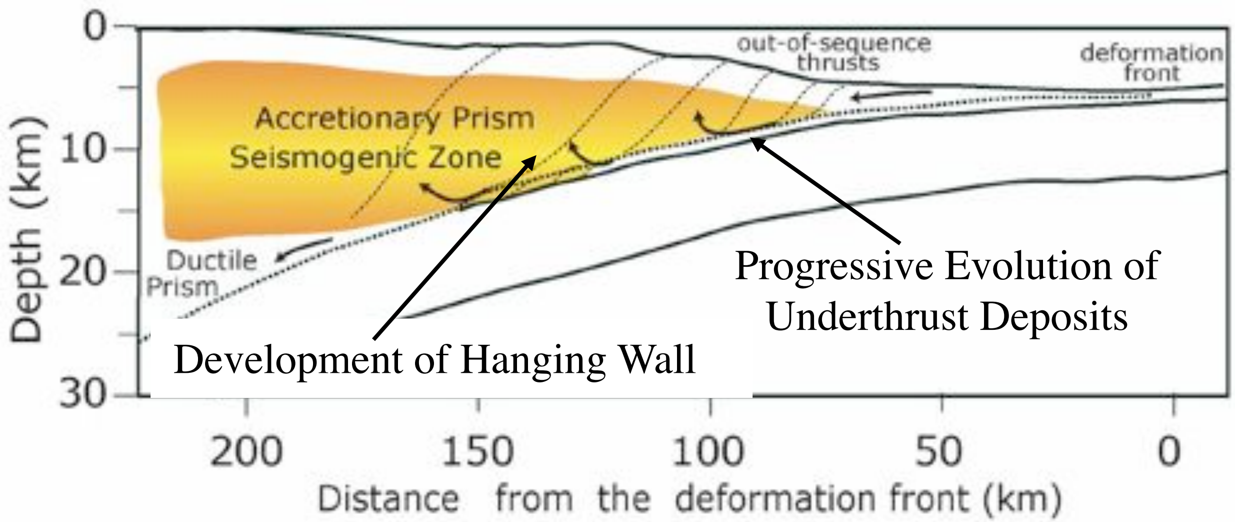


Through-going Planes of Weakness Encourage Slip Propagation

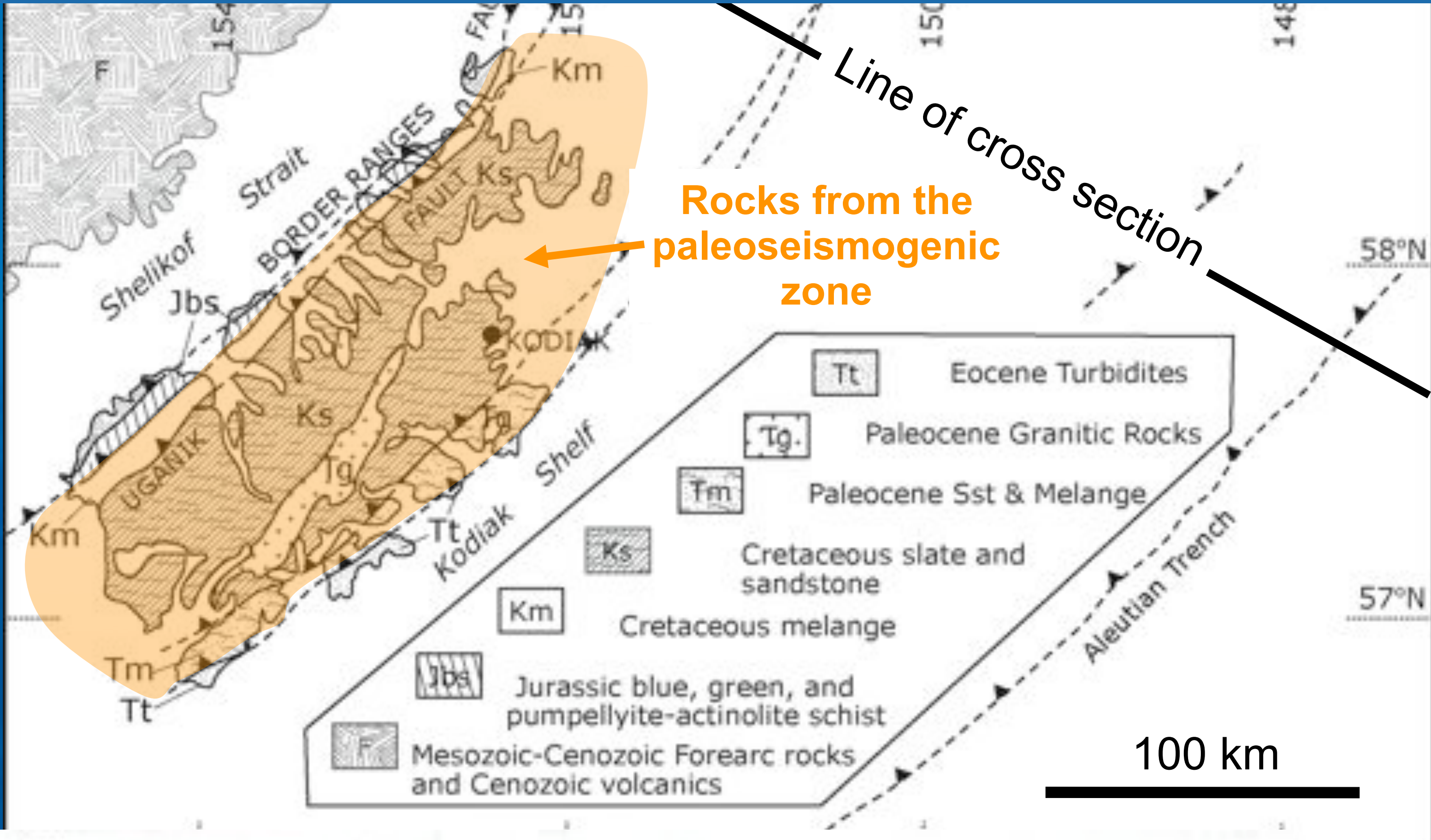
Low Dip of Subduction Thrust Increases Area in Seismogenic Zone Therefore Increases Potential Size of Earthquakes

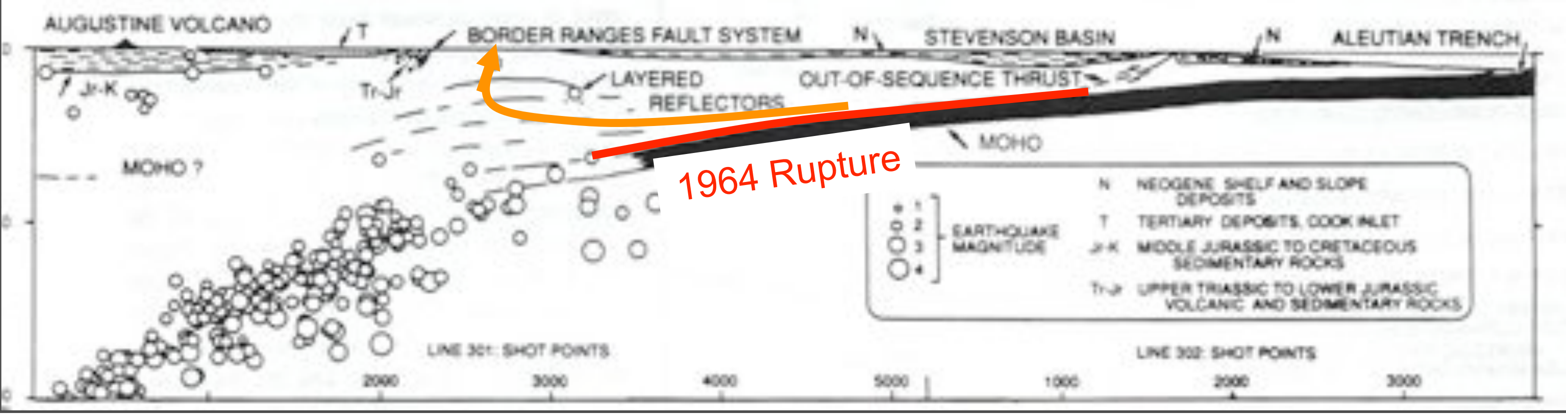


crustal
strike-slip fault
e.g. San Andreas



Very Shallow Subduction Thrust in SW Alaska: Large Sediment Supply, Broadens the Prism





Summary

- Limits of solution creep matches much of the rupture zone of large thrust earthquakes
- Deposition of quartz in faults can foster velocity-weakening slip
- Consolidation and cementation by solution creep substantially increases the rigidity of upper plate and creates a volume of rock prone to stick-slip failure
- Planar fabrics due to creep and high velocity shear along the plate boundary form an anisotropy favoring slip propagation
- Accretionary prism growth lengthens the potential seismogenic zone of subduction thrusts, leading to large earthquakes.