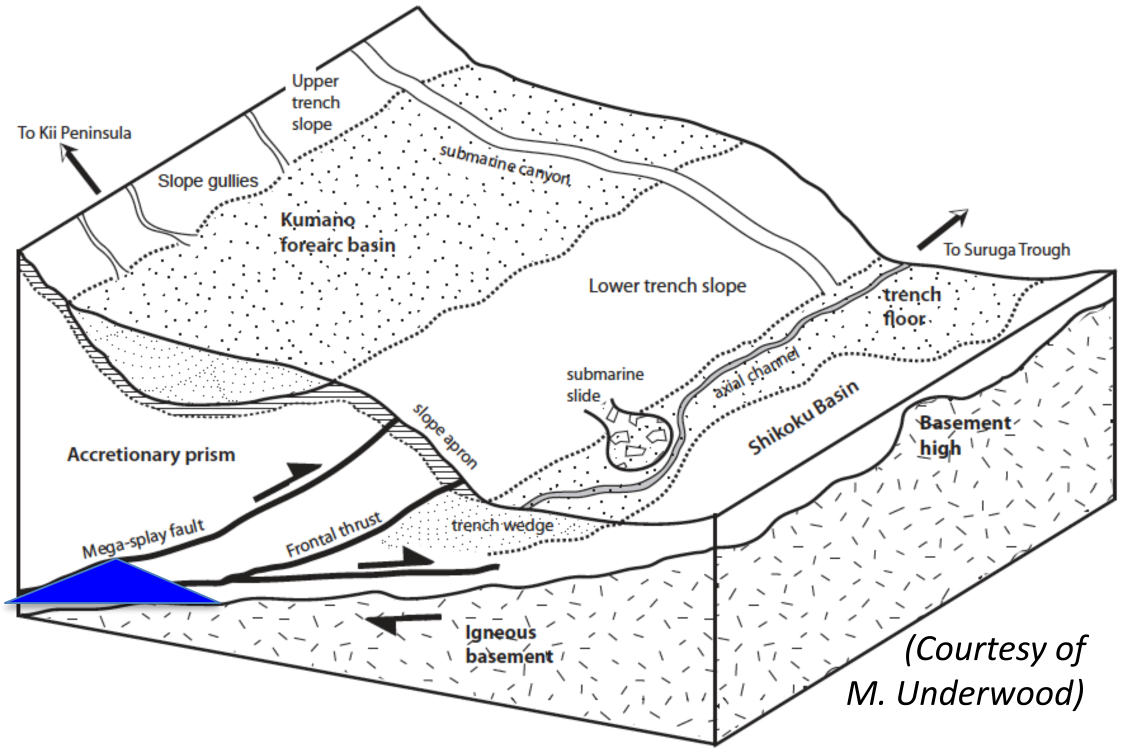
What are the critical feedbacks between surface processes, fluid flow, and subduction zone mechanics and dynamics? *(Summary by Juli Morgan)*



(Courtesy of M. Underwood)

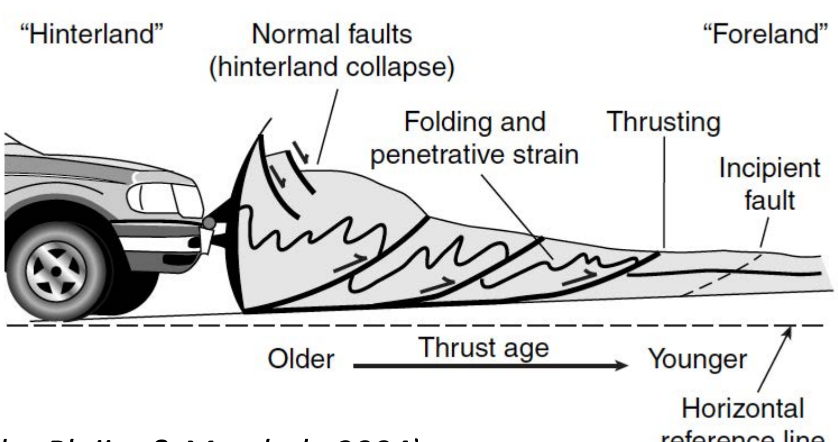
GeoPRISMS Science Plan

- Tectonic & magmatic processes build up margins
- Erosive & sediment dispersal processes tear them down
- Determines distributions, geometries, & mechanisms of deformation & fault slip across the margin
- Which influence rates of uplift & exhumation

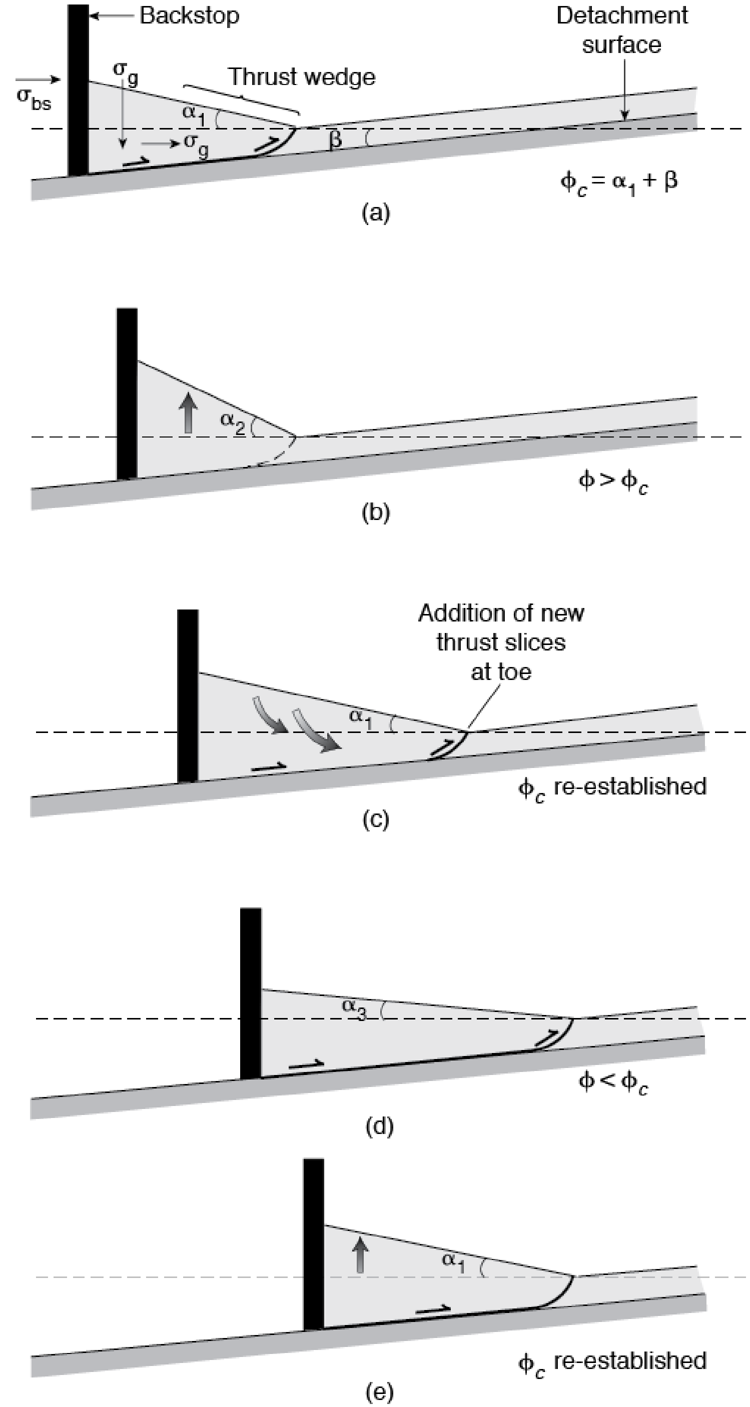
- **How do erosion, sediment transfer, and deposition, interact with deformation and subduction geometry during plate boundary evolution?**
- **How do sediment dispersal patterns influence forearc evolution?**
- **How do processes change over time & space? Role of subducting topography?**

What controls accretionary wedge geometry & deformation?

- **Critical Coulomb Wedge (CCW) Theory (Davis et al., 1983)**
  - Balance of driving and resisting forces
  - Controlling properties (traditional)
    - Internal and basal strengths (μ, μ_b)
    - Internal and basal pore fluid ratios (λ, λ_b) and
    - Sediment input and distribution
  - Assumes **steady-state**, **homogeneous**, **non-cohesive** contractional wedge, potentially **at failure** at all times throughout.
  - Simple, can assess properties, and effects of changes in those properties.



(van der Pluijm & Marshak, 2004)

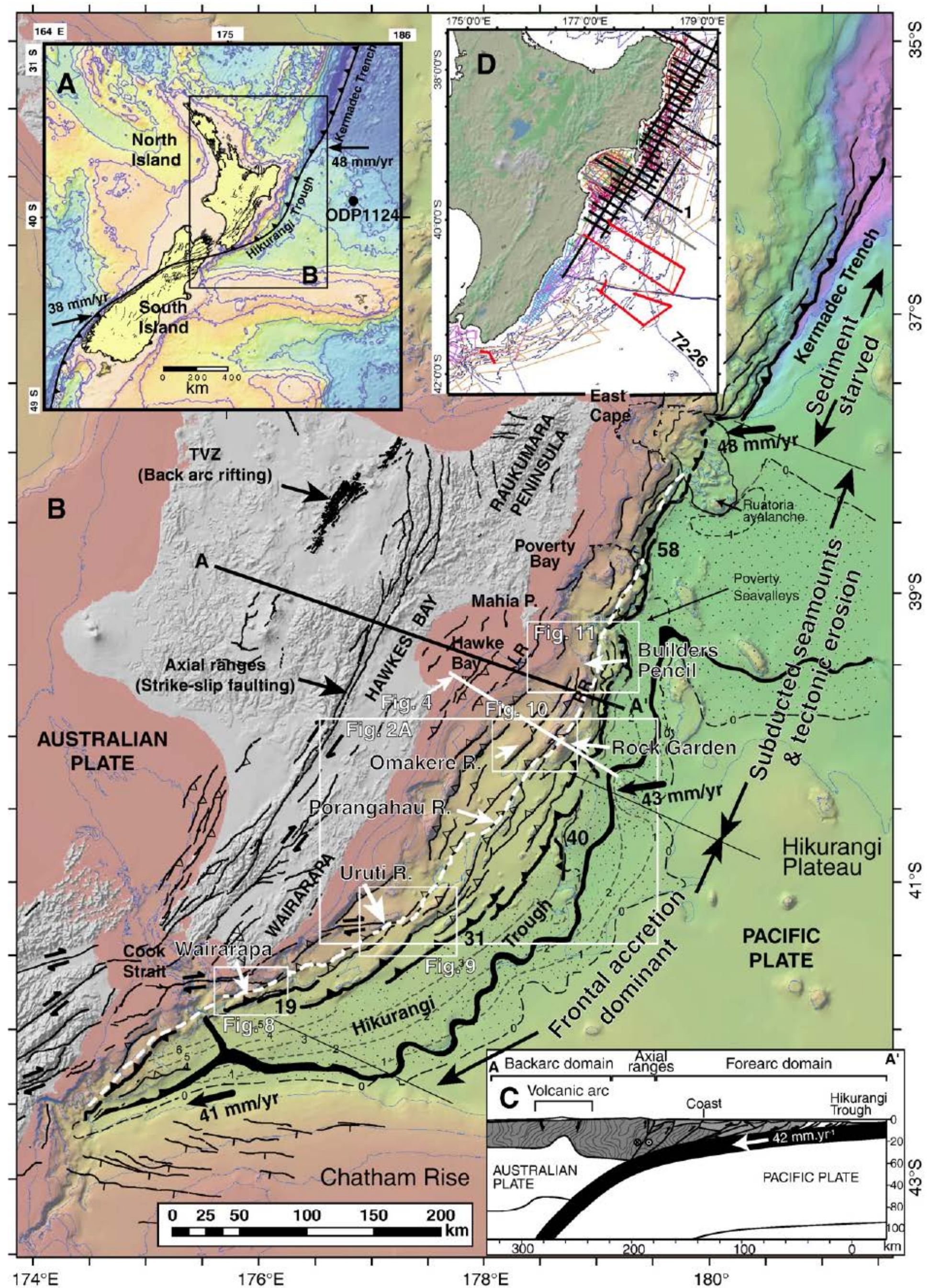


Example: Hikurangi Margin

(e.g., Wallace et al., 2004; Barker et al., 2009; Barnes et al., 2010; Fagereng, 2011; Bassett et al., 2014)

Significant along strike variations

- **Southern Margin**
  - Broad wedge, low surface slope (4°)
  - Thick incoming sediments, smooth seafloor
  - Subduction accretion & growth
- **Northern Margin**
  - Narrow wedge, steeper slope (10°)
  - Rough incoming seafloor, thin sediment cover
  - Subduction erosion, landsliding
- **To first order, differences can be explained by CCW Theory**
  - Low vs. high basal strength (effective)
- **What else controls wedge geometries and deformation?**

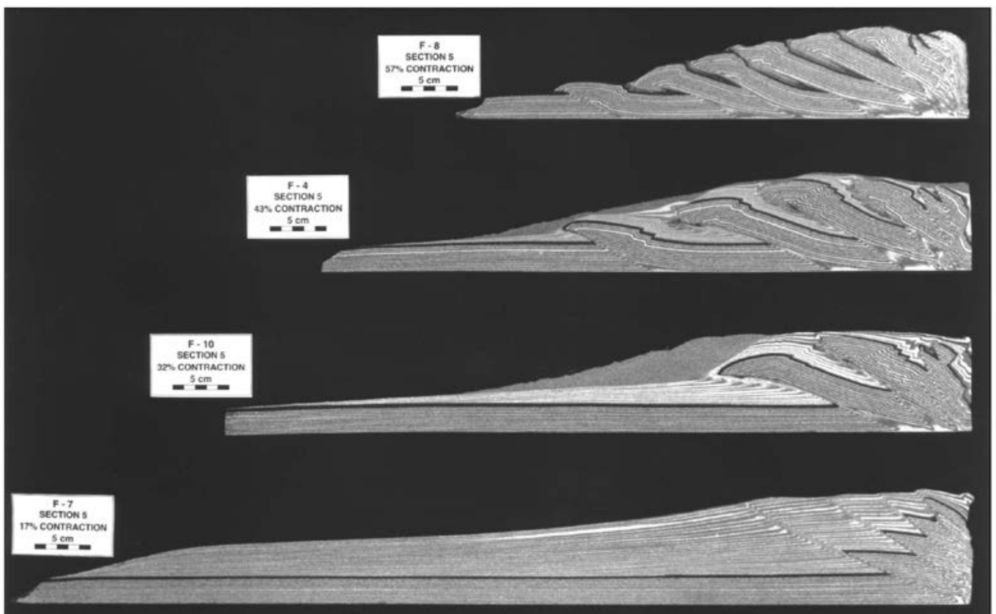


What controls wedge geometry and deformation?

Steady state factors

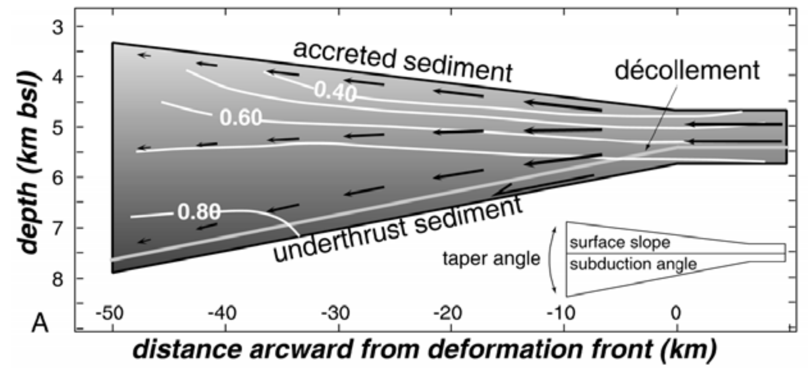
- Sedimentation rates
- Consolidation rates
- Permeability
- Strain (convergence) rates

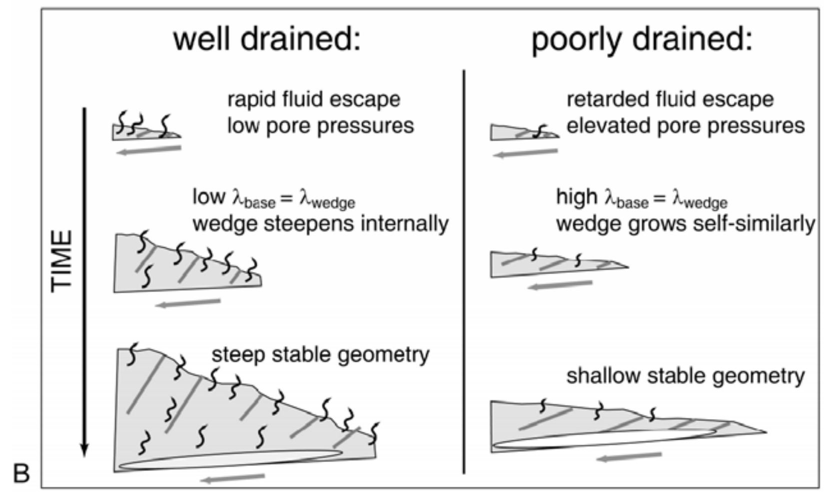
What is effect on megathrust slip behavior?

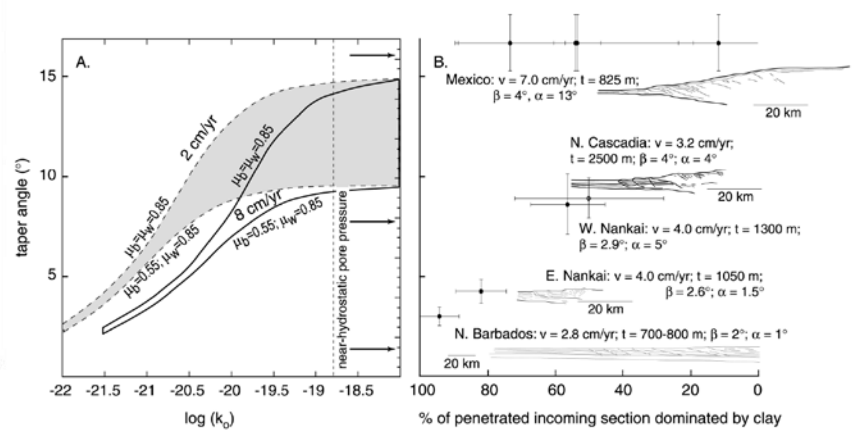


(Storti and McClay, 1995)

(Saffer and Bekins, 2002)



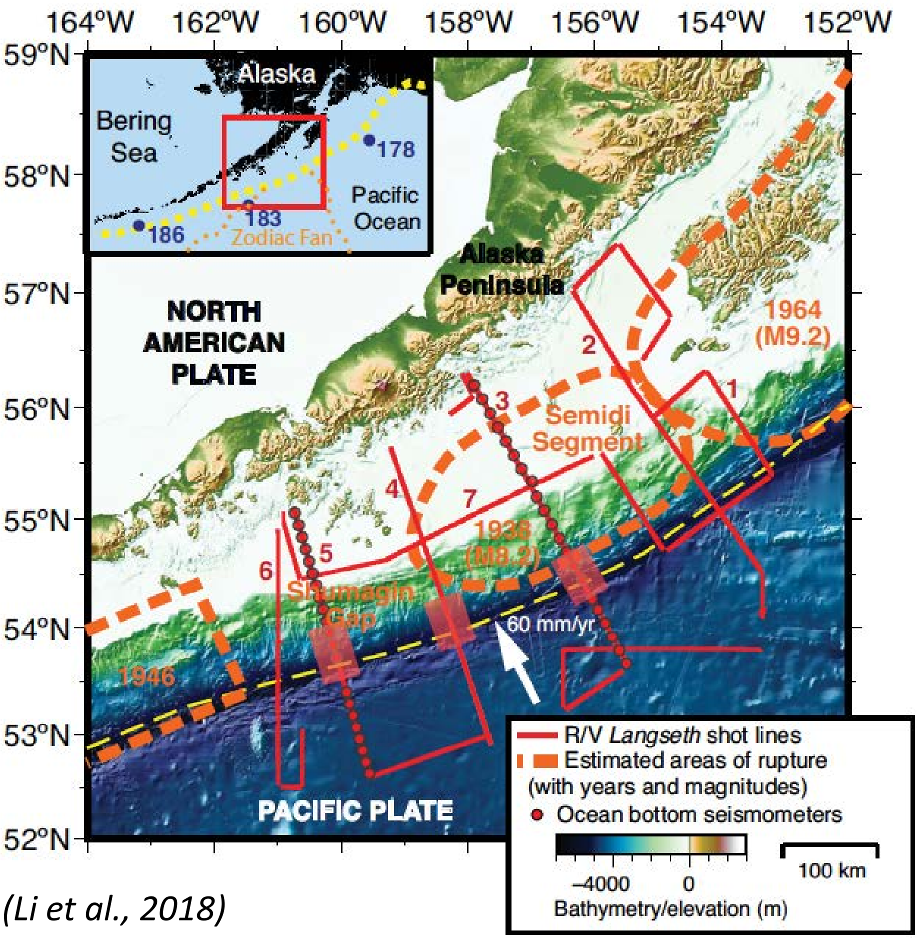


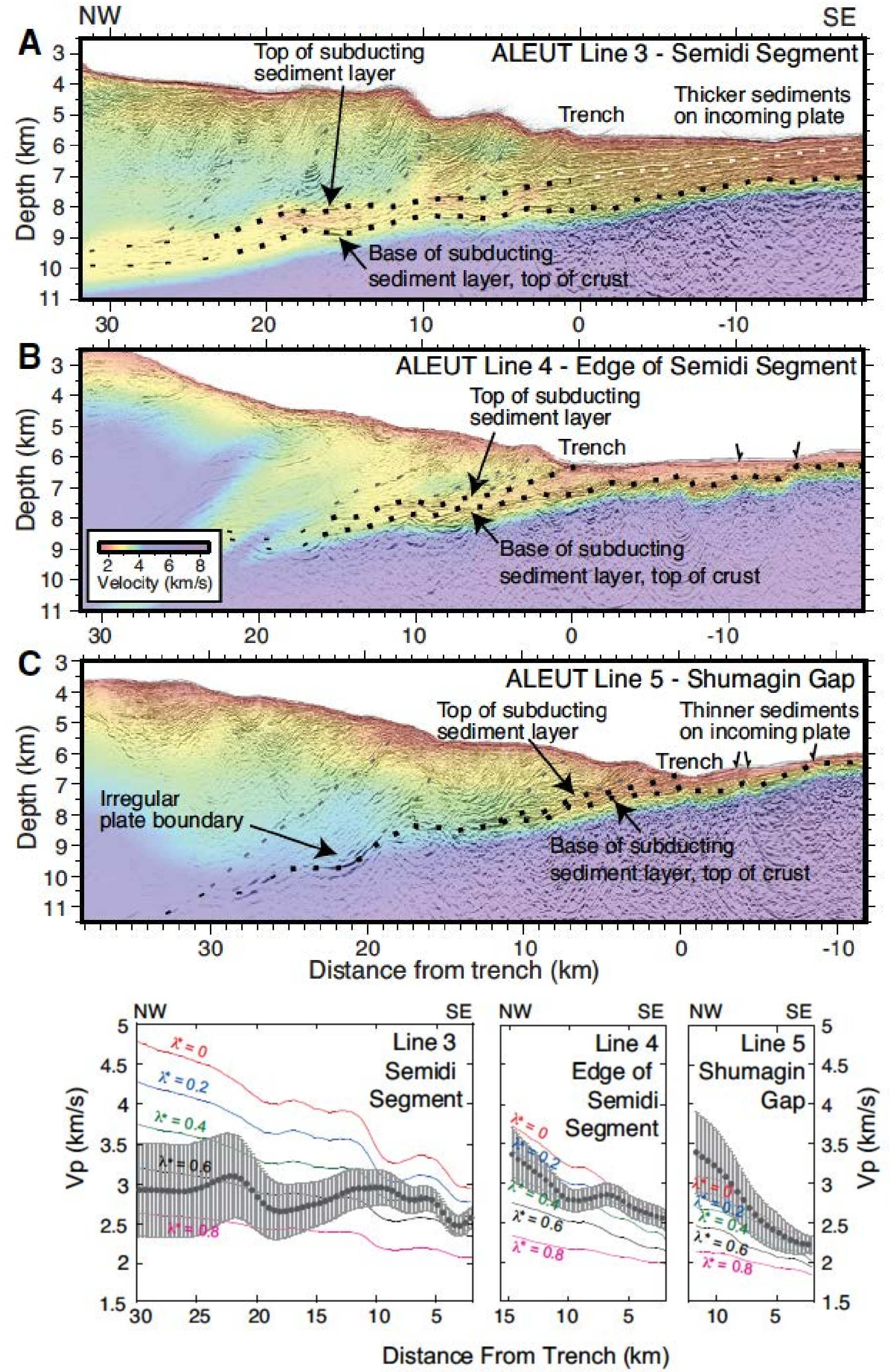


What controls megathrust fault strength and behavior?

- Sediment thickness
- Consolidation state
- Pore fluid pressure
- Seafloor rouchness

Correlate w seismicity, locking, and earthquake rupture history



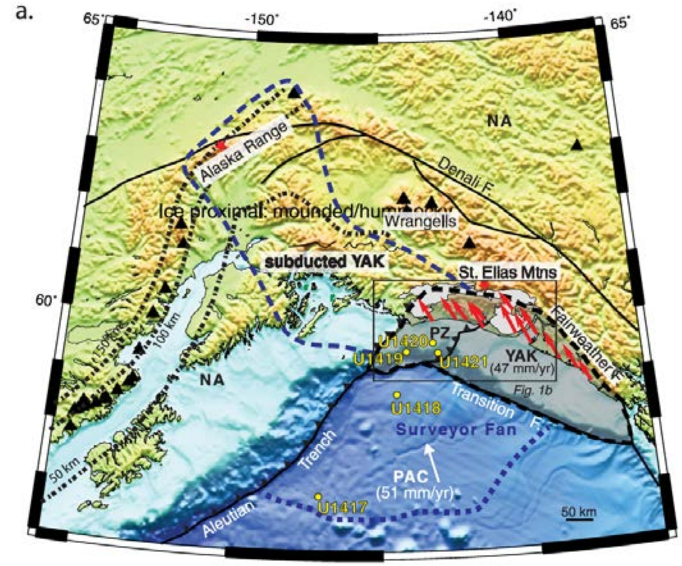


(Li et al., 2018)

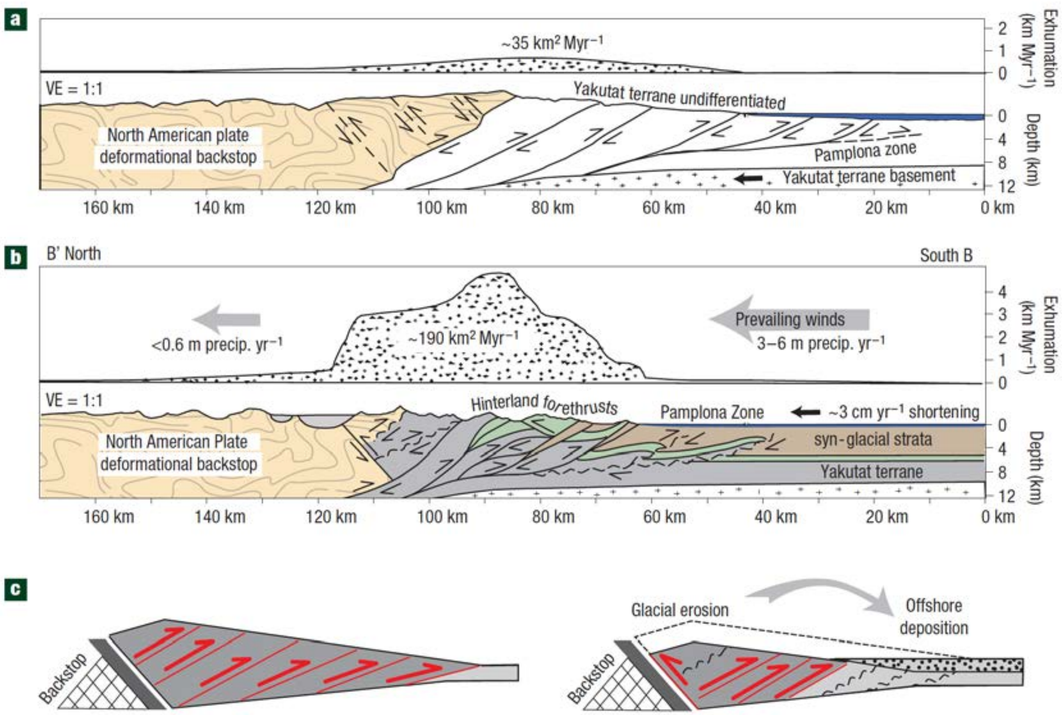
What controls wedge geometry and deformation?

Spatial and temporal variability, e.g.,

- Erosional patterns (climate, lithology)
- Sediment flux & dispersal



(Berger et al, 2008)



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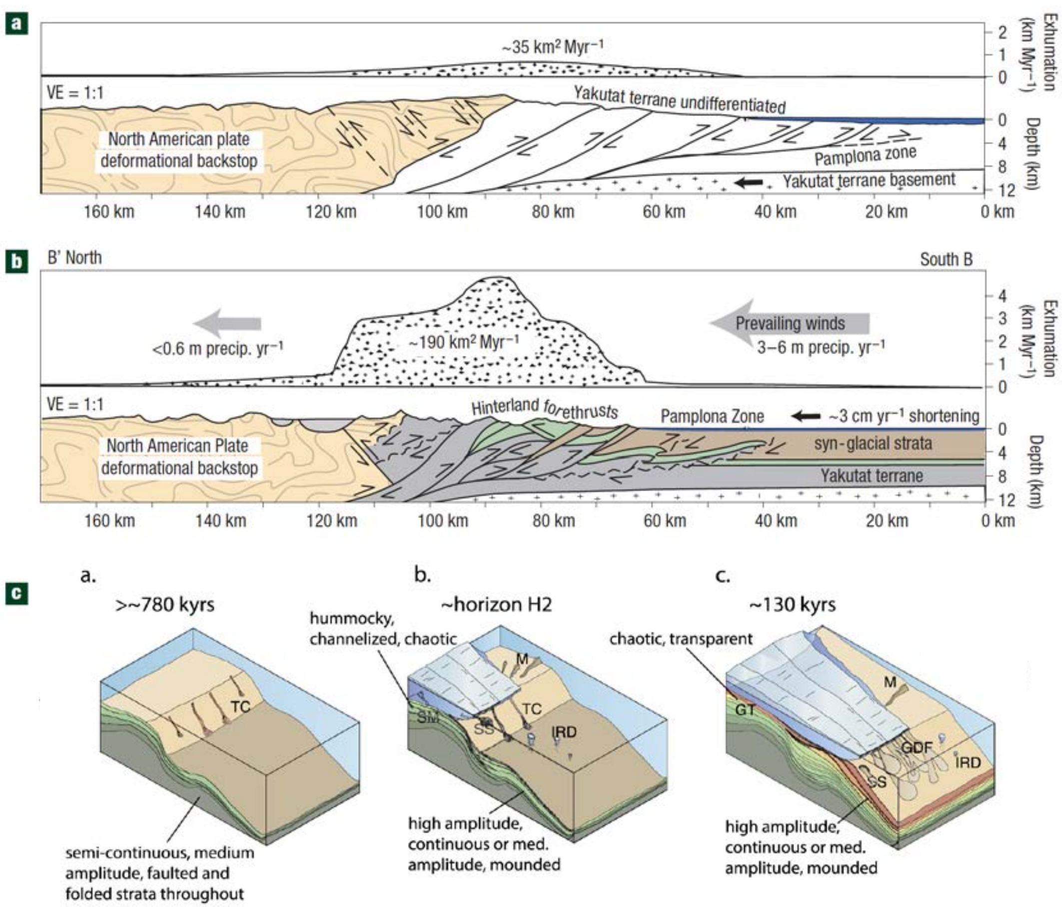
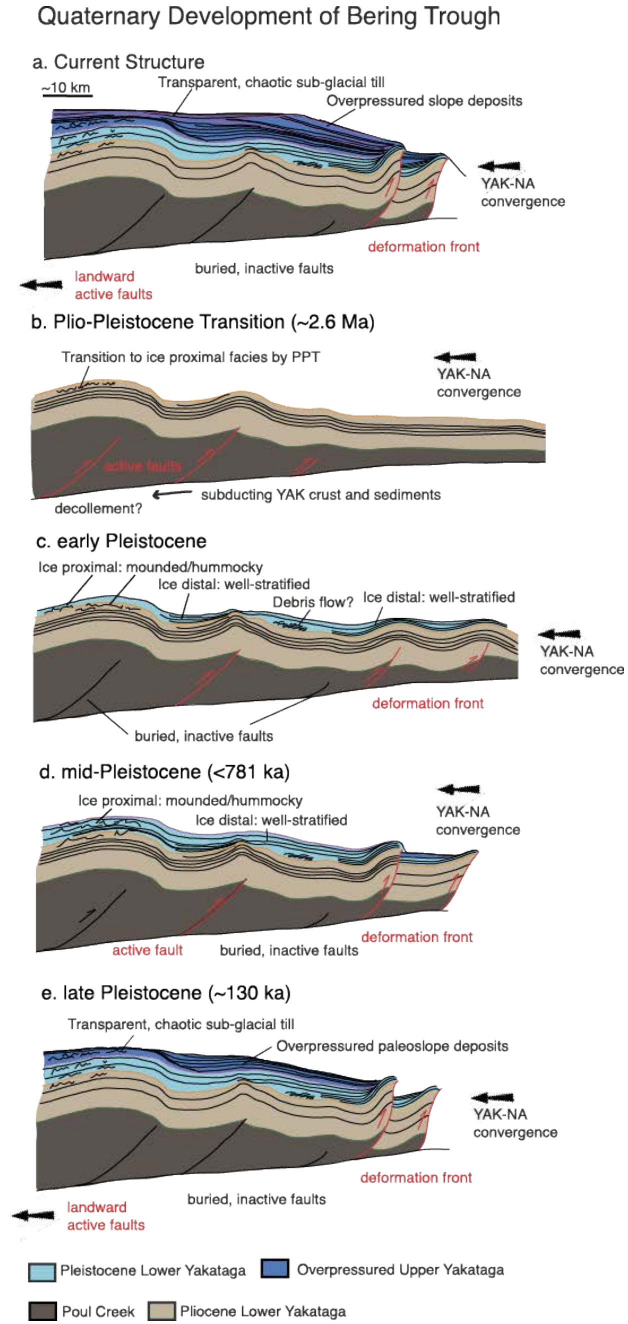
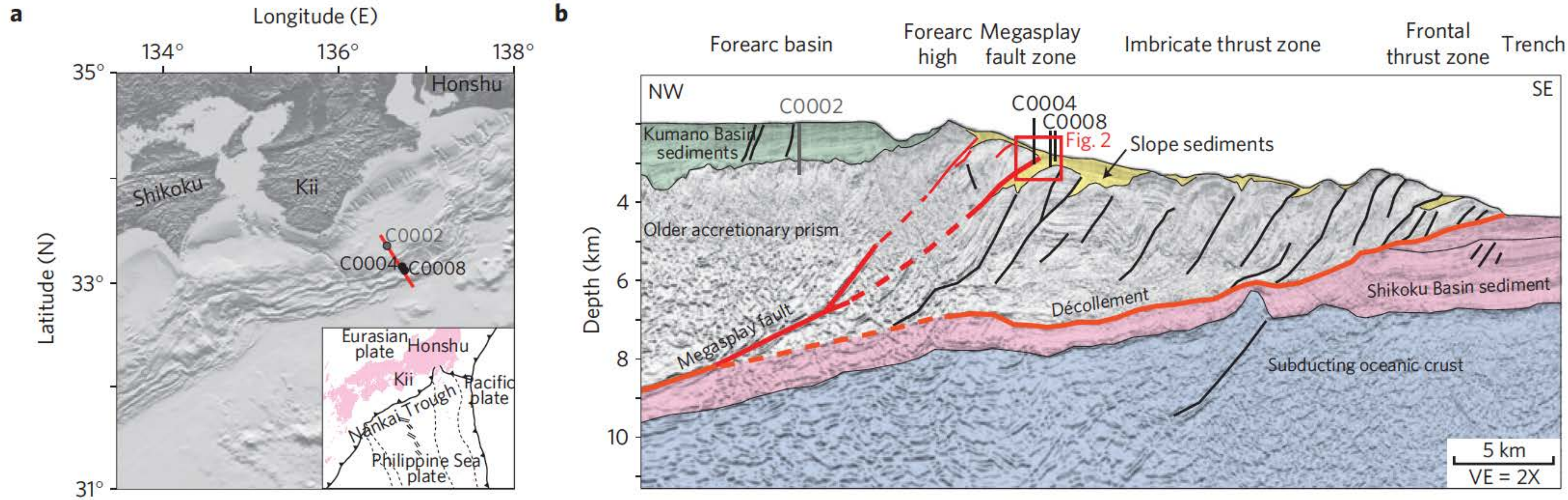


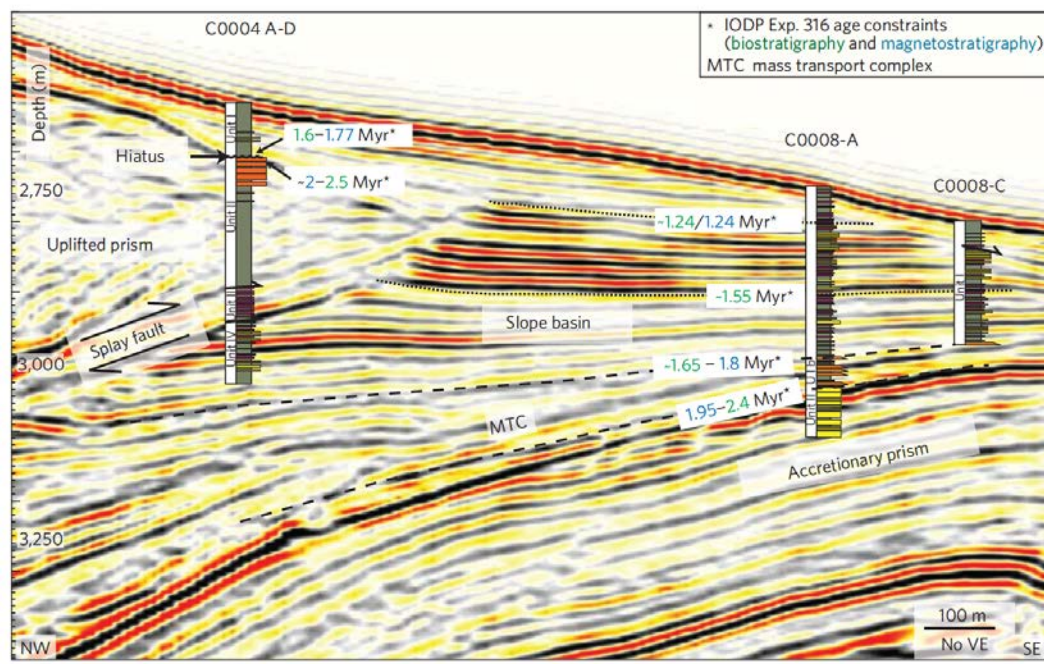


(Worthington et al, 2018)



(Underwood et al., 2003; Strasser et al., 2009, 2011; Gulick et al., 2011; Wells et al., 2003)

Sediment-Rich Margins: Nankai



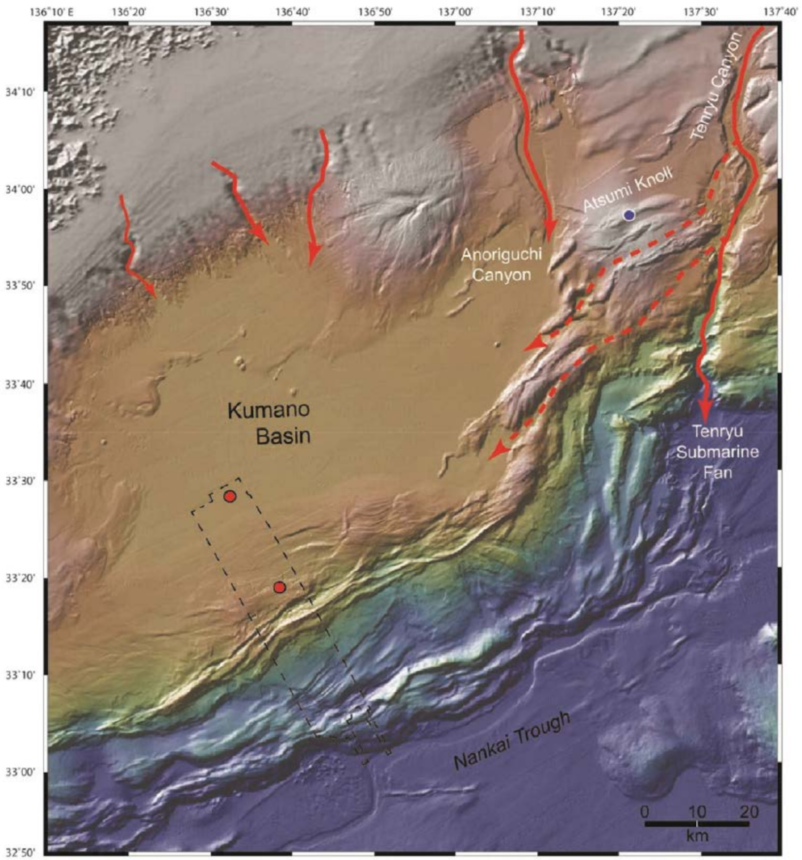
Forearc & Slope Basins

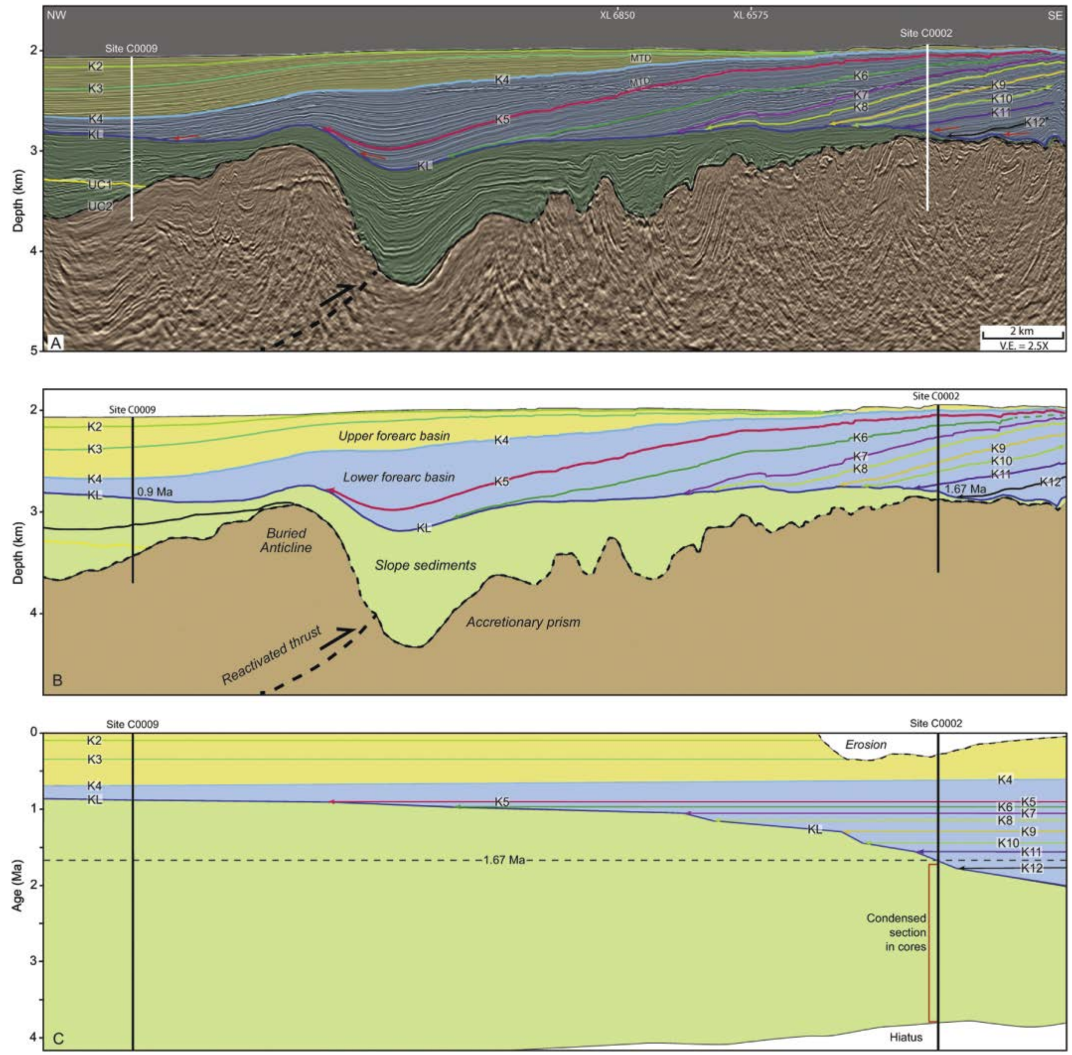
- Sediment accumulation
- Preserve a record of vertical motions and thrust slip
- Modulate wedge deformation

How, where, why do basins form?

Example: Kumano Basin

(Moore et al, 2007, 2015; Gulick et al., 2011)





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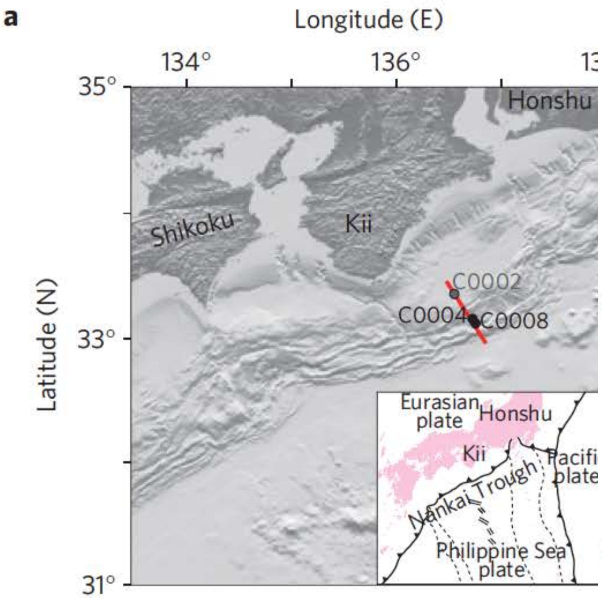
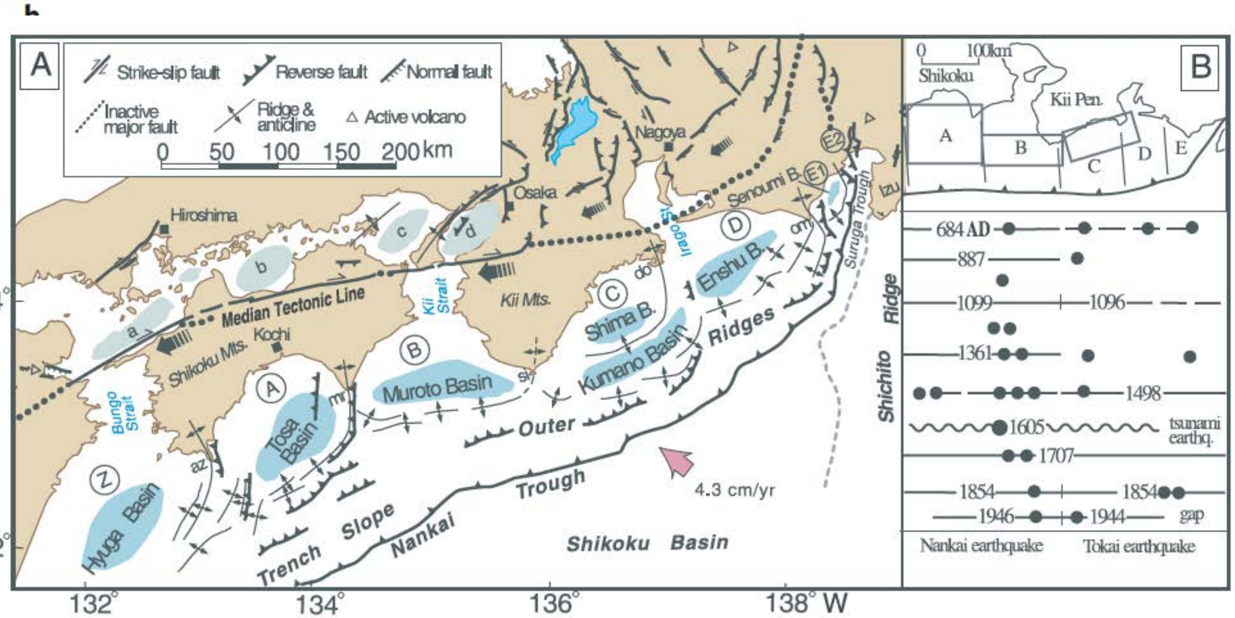
(Moore et al., 2015)

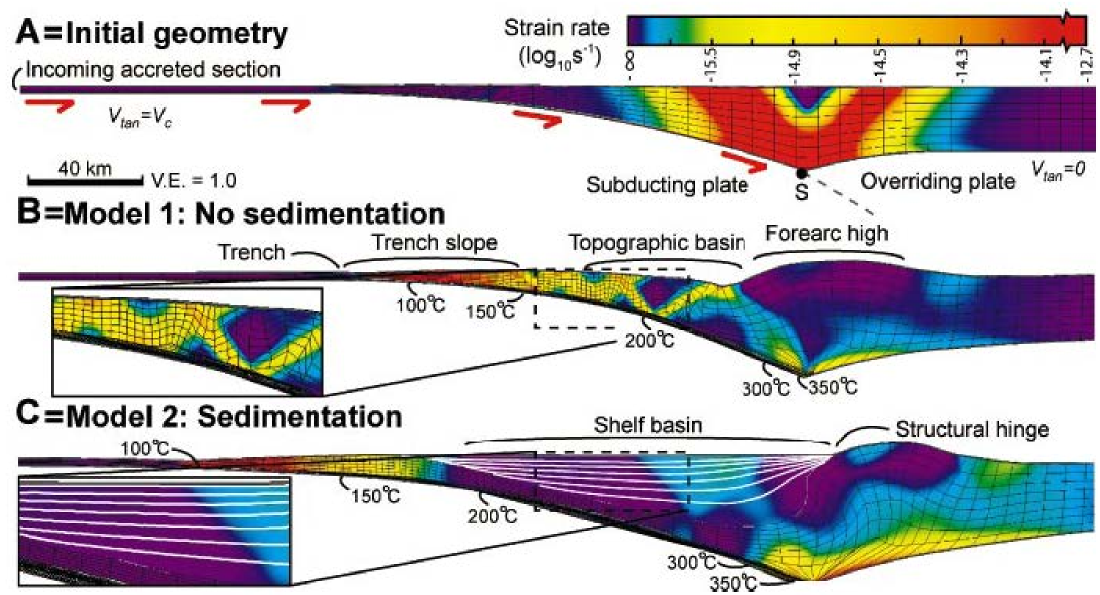




Forearc & Slope Basins

Nankai Margin *(Underwood et al., 2003; Strasser et al., 2009, 2011; Gulick et al, 2011; Moore et al, 2007)*

- Sediment accumulation
- Preserve a record of vertical motions and thrust slip
- **Areas of high coseismic slip** *(Wells et al., 2003; Fuller et al., 2006).*
  - Thinned underlying crust, thick sediments, subsidence.
  - Stablizes wedge locally



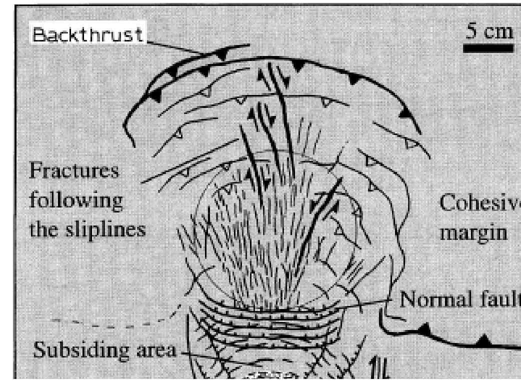
How do basins affect basal slip?

Sediment-Poor Margins: Costa Rica

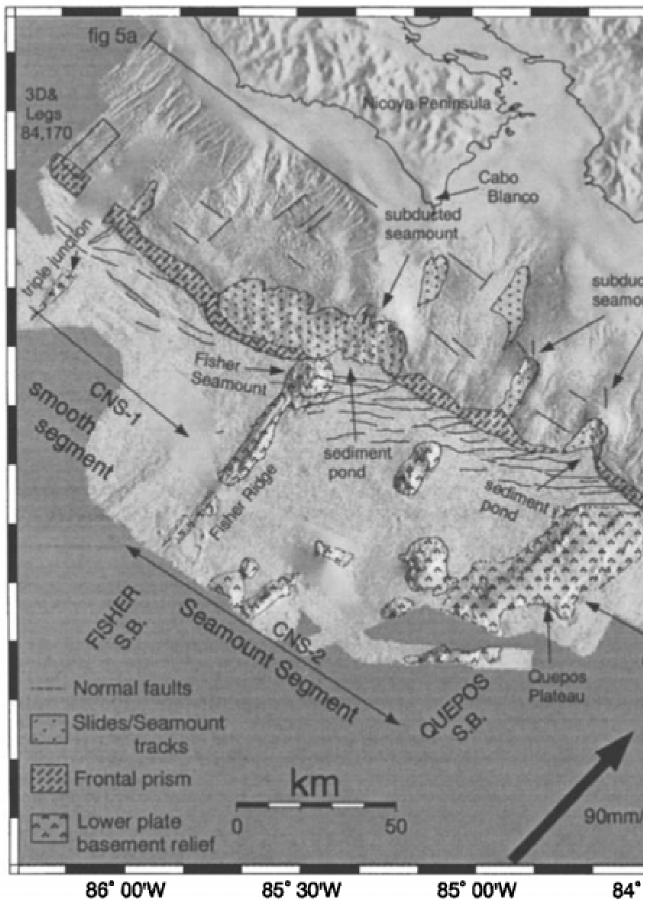
Subduction Erosion

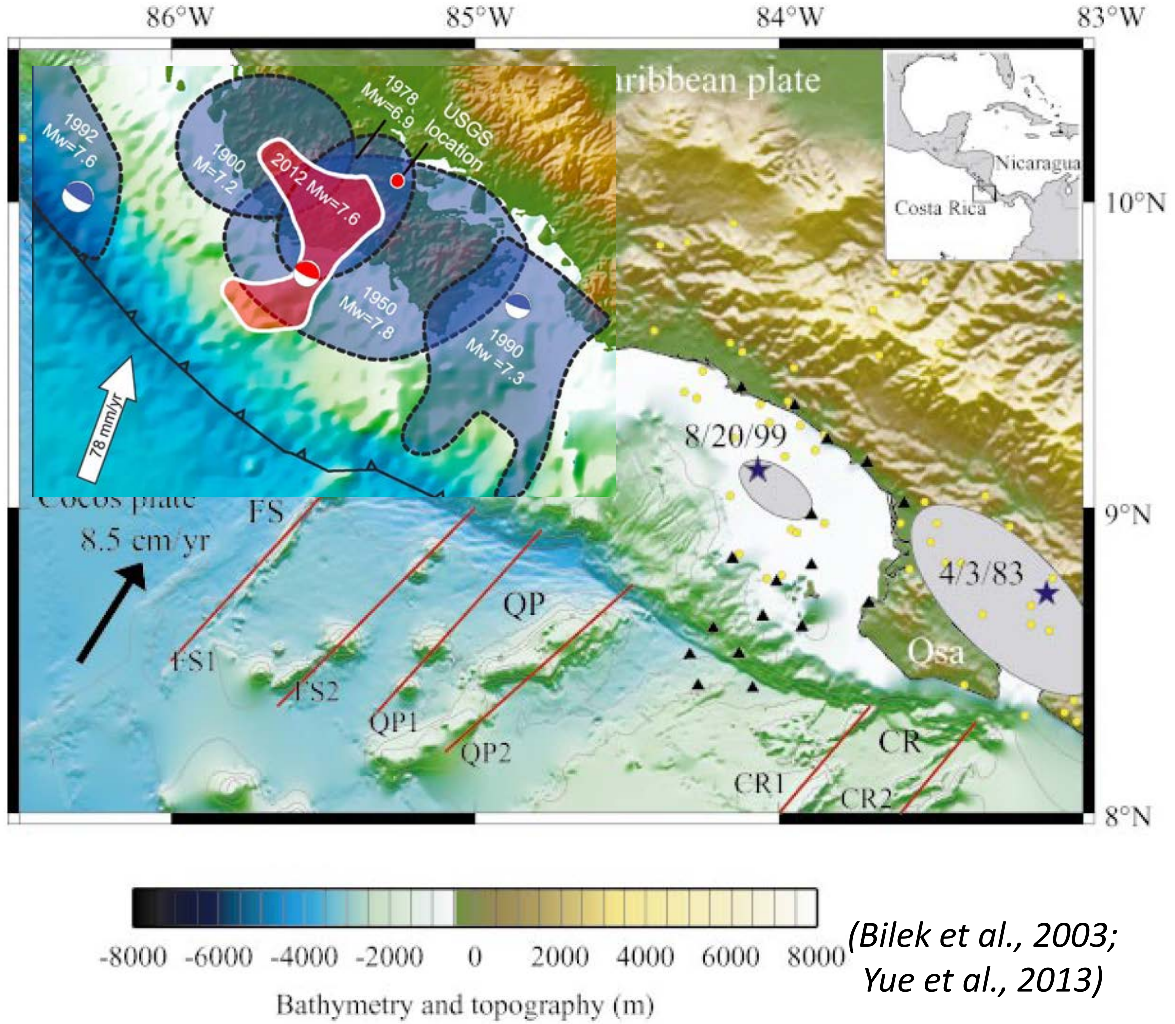
- Seamount subduction, erosion, material transfer to depth
- History of uplift and subsidence
- Modest megathrust earthquakes

(Dominguez et al., 1998)



(von Huene et al., 2000)



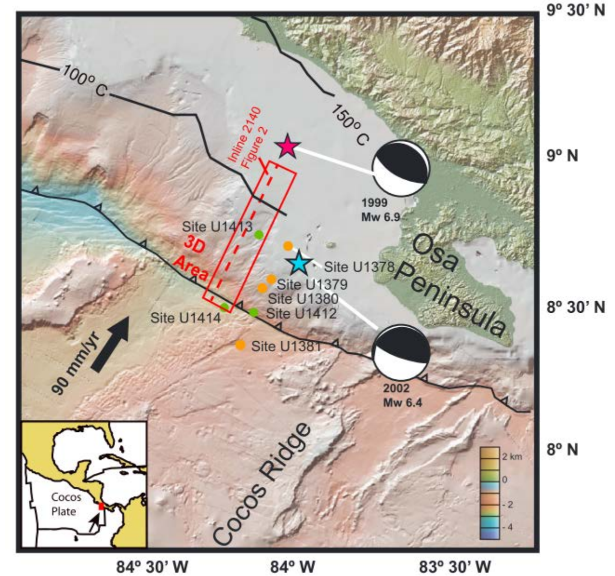


(Bilek et al., 2003; Yue et al., 2013)

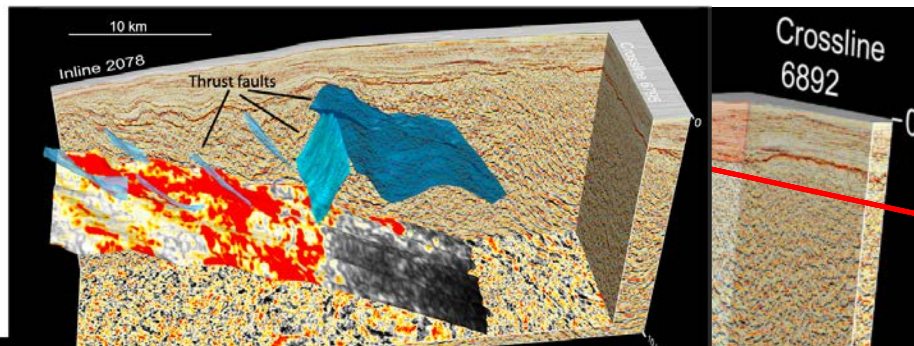
Costa Rica: 3D Seismic Survey

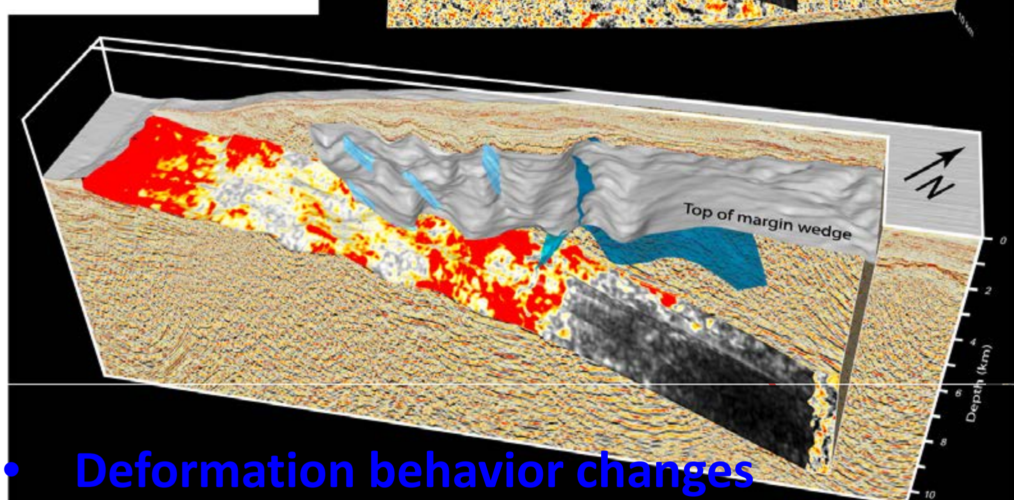
Surprising observations raise new questions

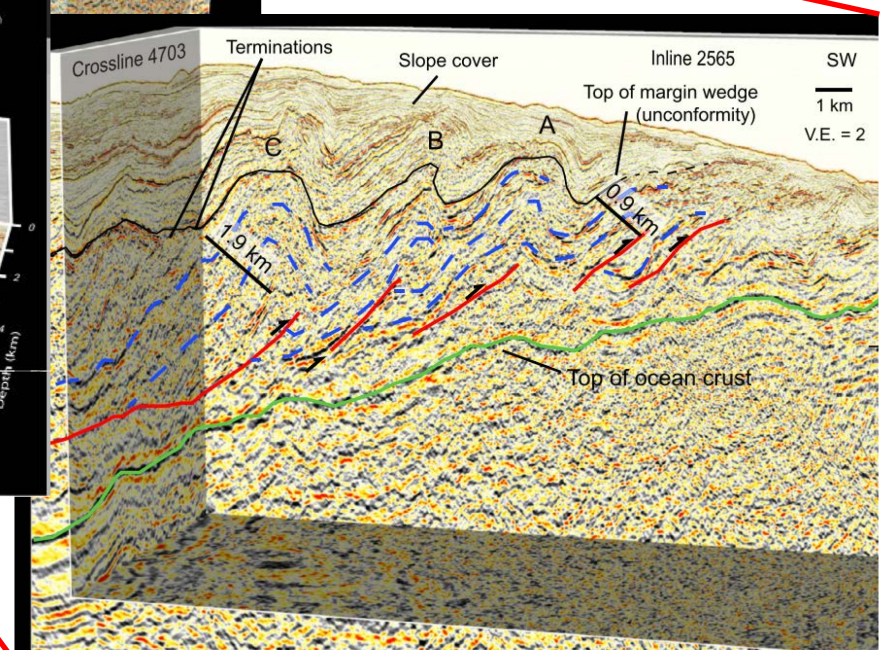
- Lineated basement topography
- Superimposed thrust and normal faults
- Broad, imbricated accretionary complex



(Bangs et al., 2015, 2016)







- **Deformation behavior changes significantly over time. Why?**
- **How affects megathrust slip behavior?**

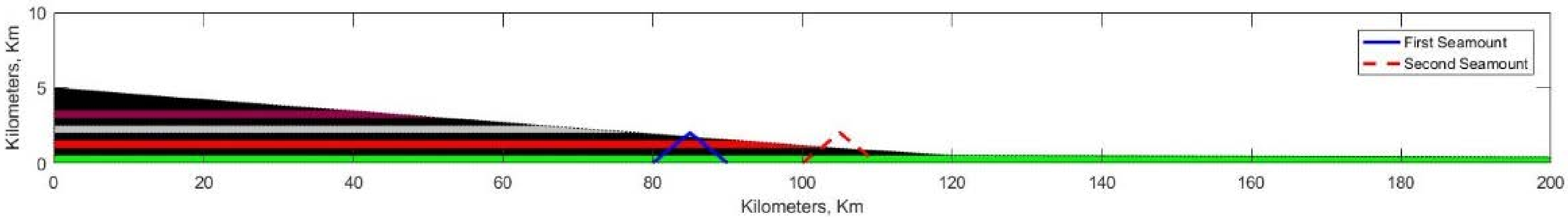
What is manifestation of seamount-wedge interactions over time? And how do these affect margin behavior?

(Morgan and Bangs, 2017; Foo, Morgan & Bangs, in prep)

- **How do seamount interactions influence wedge deformation?**
- **Can seamounts drive alternating episodes of accretion and erosion?**
- **How do seamounts transfer sediments and fluids? Where are they released?**
- **What are the implications for megathrust slip behavior?**

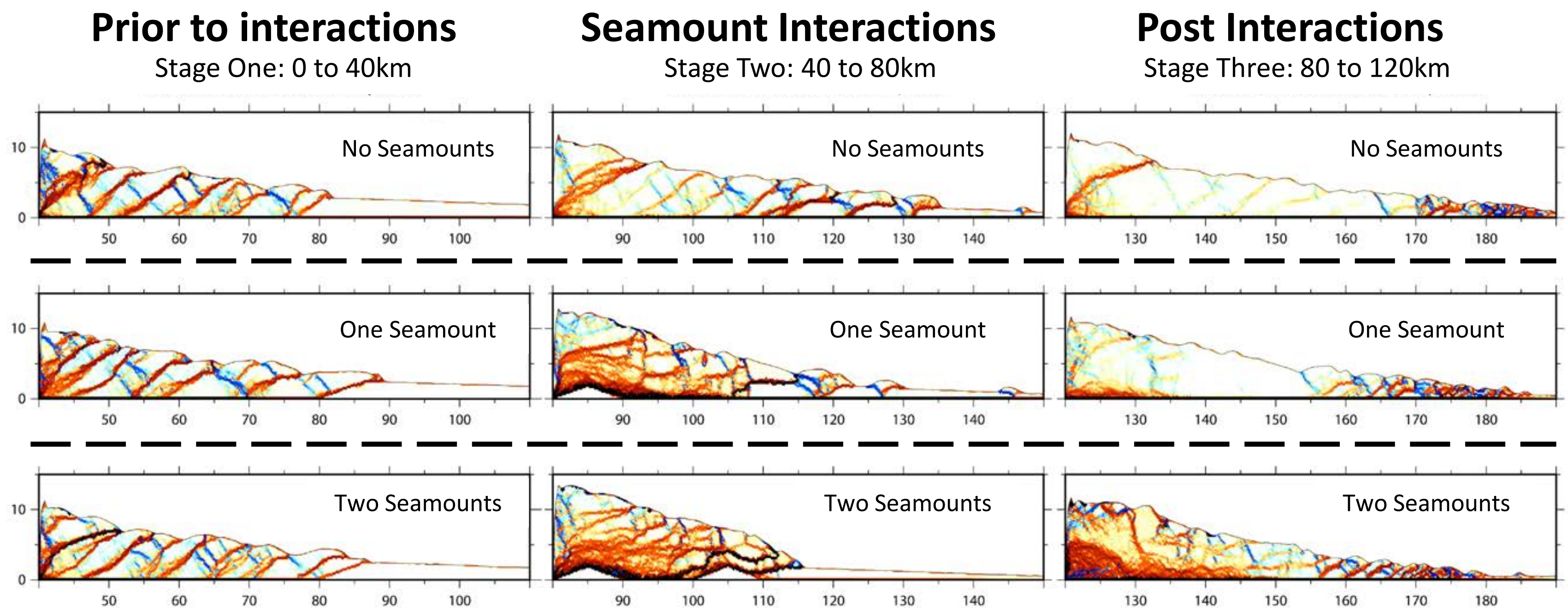
- **Discrete Element Simulations** *(Foo, Morgan & Bangs, in prep)*
  - Tapered wedge of sediments
  - Zero, one, or two seamounts
  - Constant back wall displacement
  - Monitor decollement position, active wedge volume, slip evolution

Experimental Set-up



Seamount Interactions & Stages of Deformation

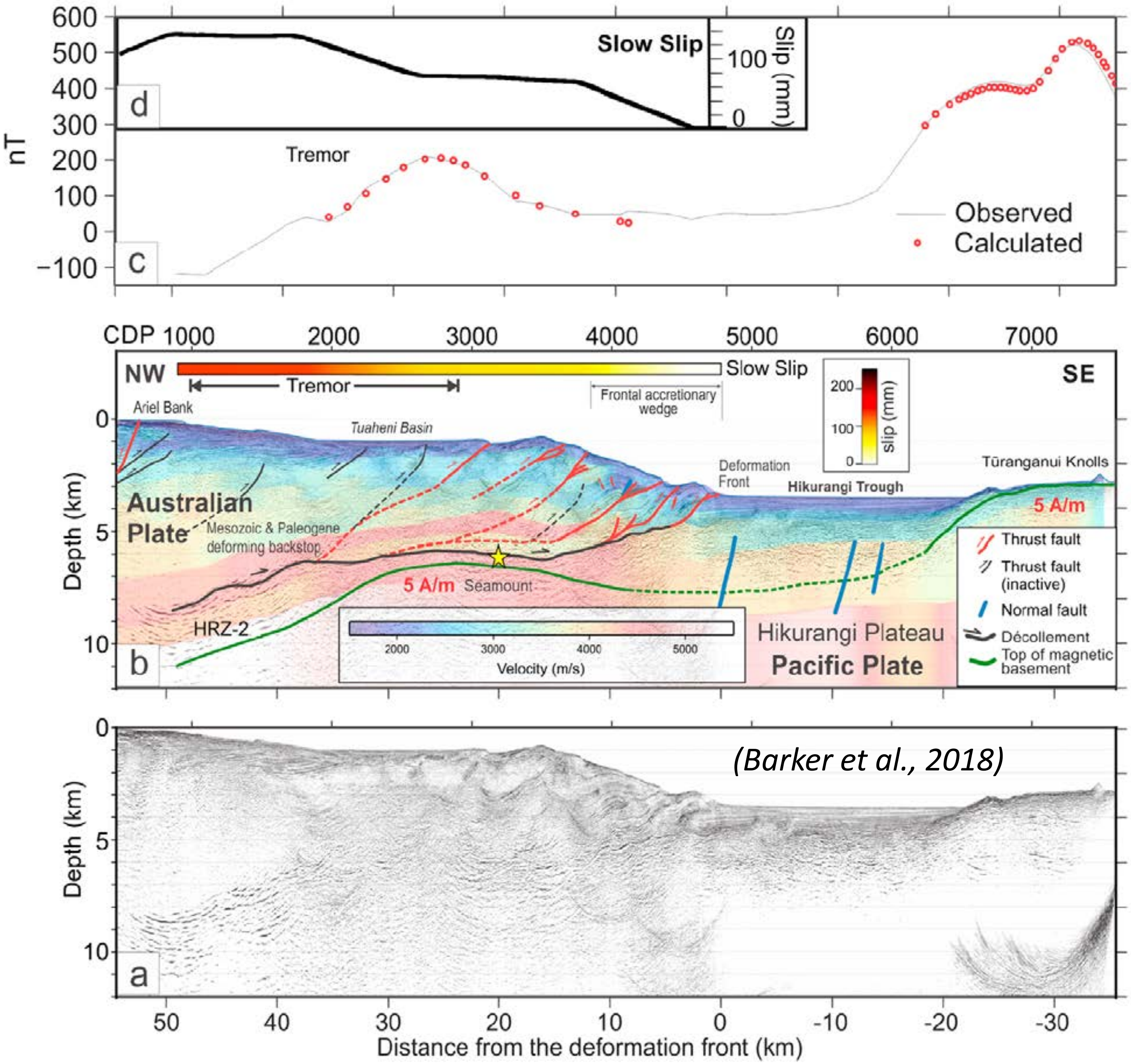
(Foo, Morgan, and Bangs, in prep)



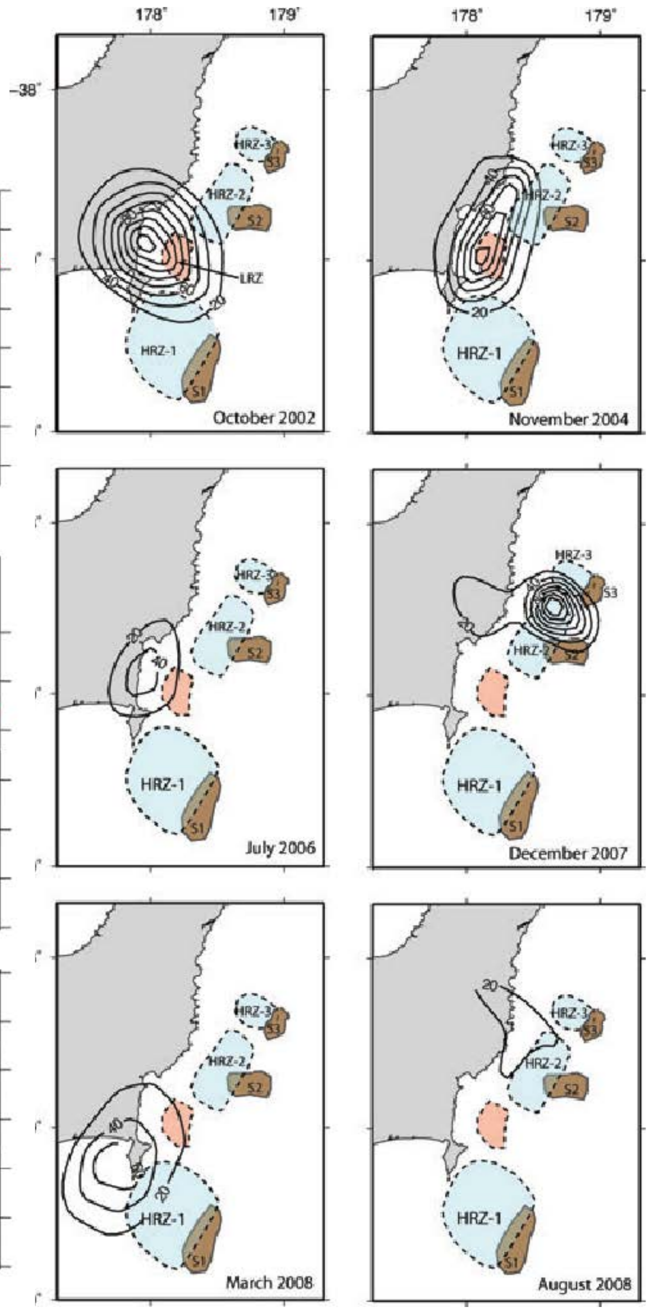
- **Deformation evolves over time**
  - No seamount: frontal accretion, stabilizing hinterland, constant taper
  - 1 seamount: advanced accretion, decollement stepping, then frontal accretion
  - 2 seamounts: advanced accretion, decollement stepping, intense internal deformation
  - Seamount interactions cause local uplift, subcretion, and basal erosion
- **Wide range of fault slip behaviors**
  - Culminating in late-stage landsliding, continuous basal sliding > large earthquakes!

Seamounts & Slow Slip: Hikurangi

(Bell et al, 2010; Barker et al., 2018, Wallace et al., 2012)



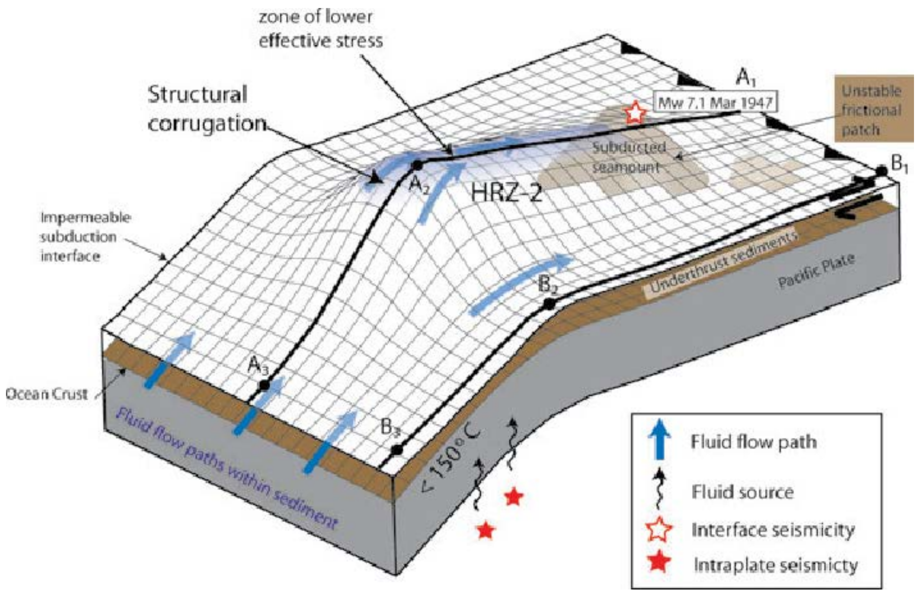
(Wallace et al., 2012)

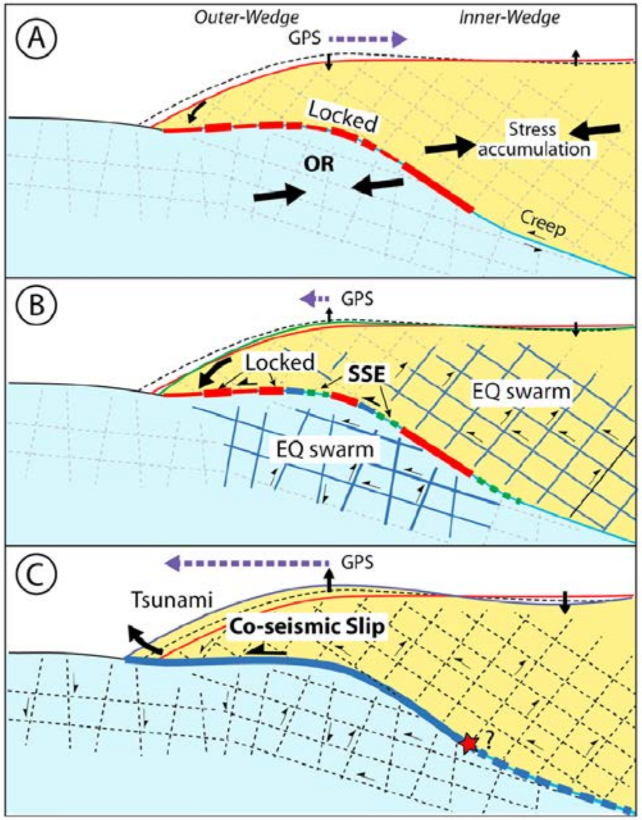


(Bell et al., 2010)

Mechanics of Seamount Slip

(Bell et al., 2010,2014; Wang & Bilek, 2011; Collot et al, 2017)





- **Stress heterogeneity**
  - Compression on leading flank; protected trailing
  - Reduced consolidation in flanking sediments
  - Enhanced pore pressures, channeled
  - Unique lithologies, e.g., altered volcaniclastics
- **How do stress, buttressing, lithology, pore pressure, and dilatancy affect slip behavior?**
- **Barrier to decollement slip, shear stress builds at asperity.**
  - Loading phase is dilatant, negative pore pressures, arresting slip *(Segall et al., 2010; Blank et al, in press)*
  - Is slow slip arrested fast slip?
  - When barrier overcome, other factors control behavior
- **Is slow slip a time-limited process, favored near seamounts?**

Science Questions – Feedbacks

Original Questions (GeoPRISMS Science Plan)

- How do erosion, sediment transfer, and deposition, interact with deformation and subduction geometry during plate boundary evolution?
- How do sediment dispersal patterns influence forearc evolution?

Additional Questions

- **How do processes change over time & space? Role of subducting topography?**
- What are the relative contributions of megathrust properties, topography, and upper plate deformation in controlling megathrust slip behavior? How and why do these change over time? And what are the records of these?
- How are sediments and fluids transported to depth. How and where are they released? And what are the temporal and spatial consequences?
- What explains the relationship between seamounts and slow slip?

Gaps and Needs (GeoPRISMS Science Plan)

- **Integrated onshore and offshore studies** to clarify these relationships
- **Comparative studies at margins** to discern the relative importance of factors
- **Detailed 3-D seismic data** with direct sampling and in-situ measurement
- **Coupled numerical models** (especially 3-D) to test these dynamic feedbacks

GeoPRISMS Synthesis & Integration