Causes and consequences of subduction initiation

Mike Gurnis

Caltech

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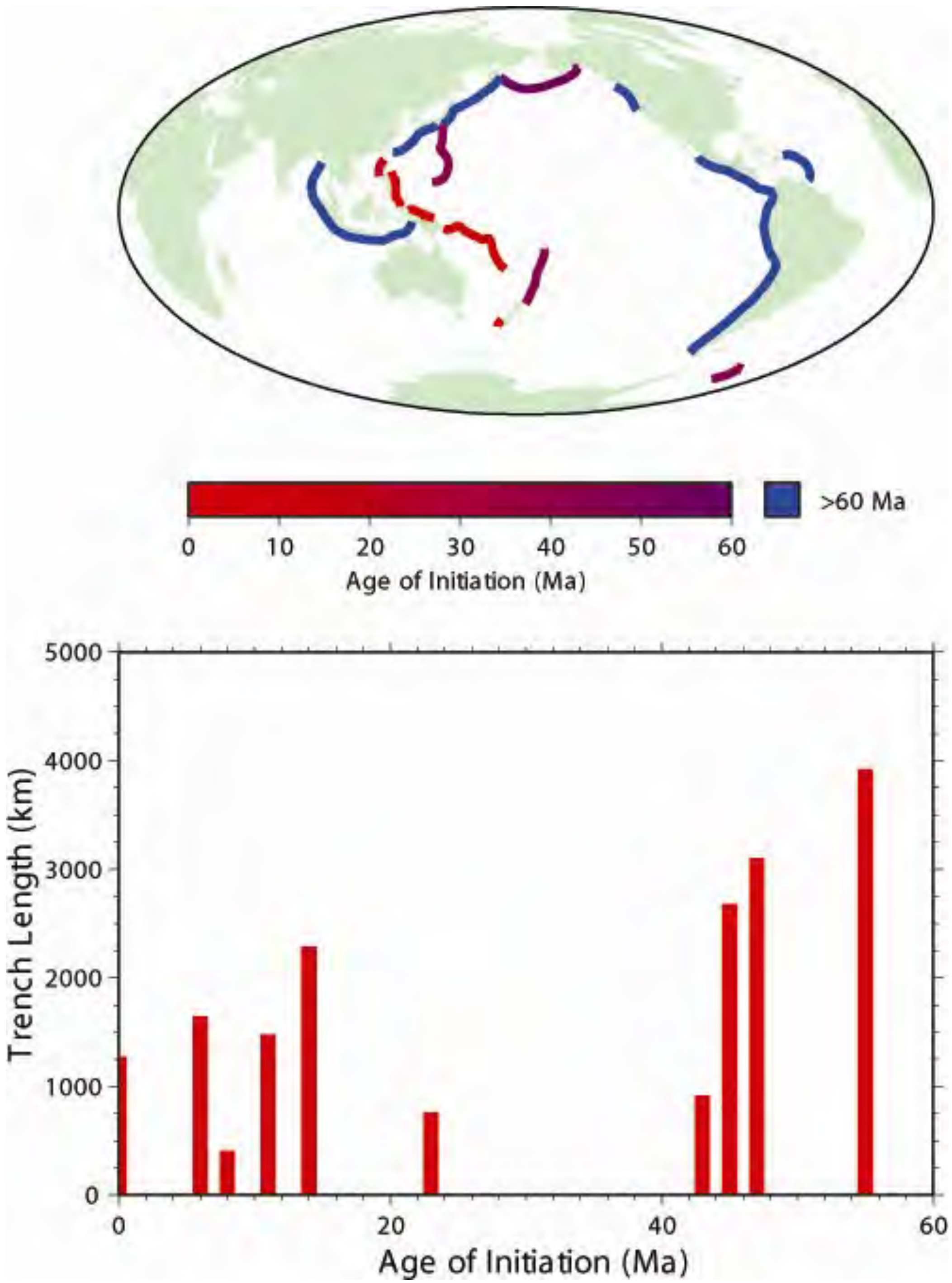
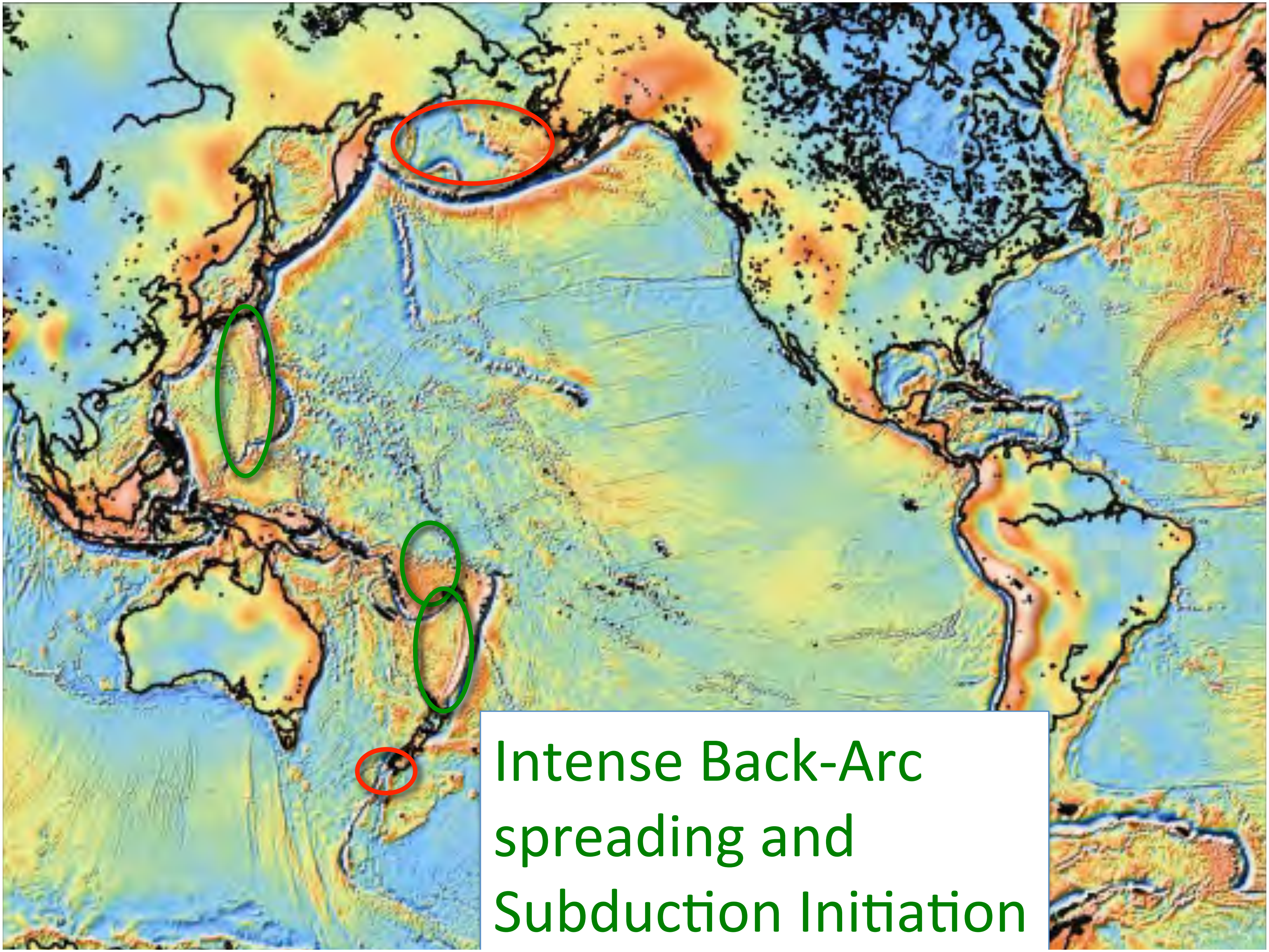
Outline

- Aspects of the history of Subduction Initiation in the Pacific
  - Examples of recent SI in the Pacific
  - Association of SI & back-arc spreading
  - New details of IBM formation
- Mechanical models of subduction initiation
  - Elasticity and faults
  - Long-wavelength state of compression
  - Association with back-arc spreading
  - Dependence on plate strength of far-field forces
  - Speculative match to IBM and Aleutian SZ formation
  - Connection to melting history
- Key geodynamical parameters can be measured in New Zealand
  - Puysegur SZ is making transition from forced to self-sustaining subduction
  - Regional compression associated with the formation of Tonga-Kermadec



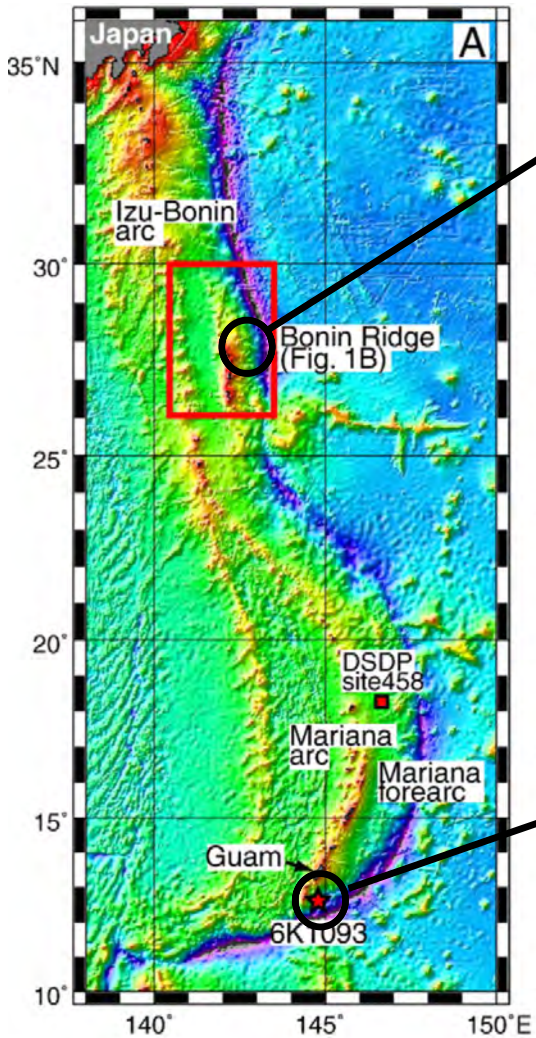
Many Subduction Zones are very 'Young'

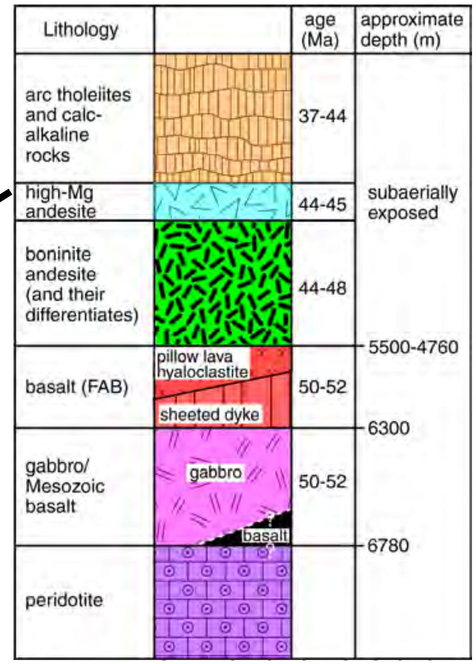
Gurnis, Hall & Lavier[2004]



Intense Back-Arc spreading and Subduction Initiation

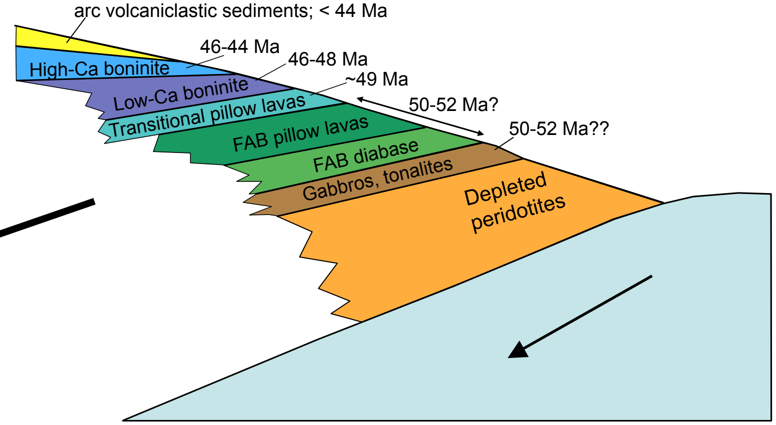
Initiation of the Izu-Bonin-Mariana (IBM) subduction zone





(not to scale)

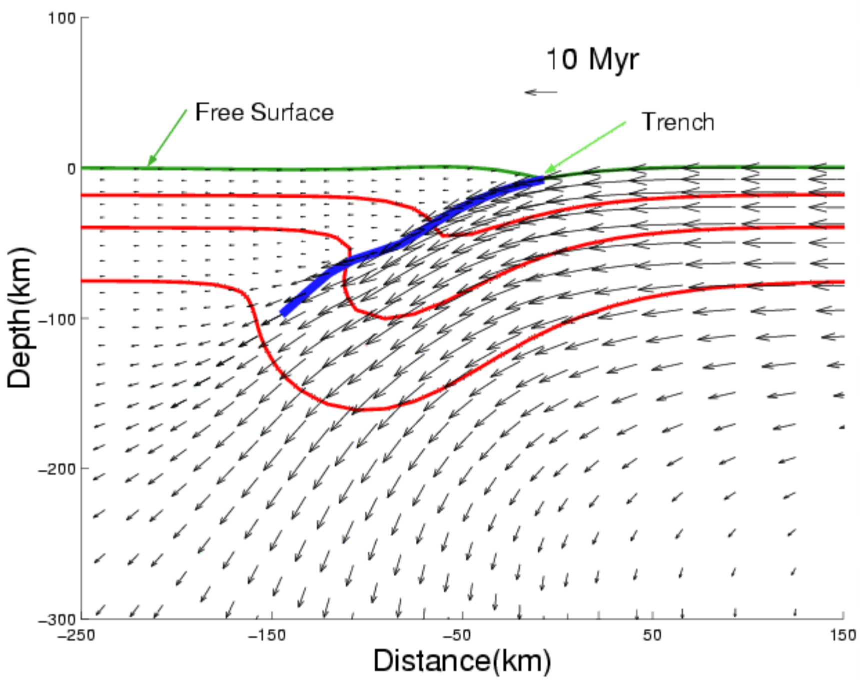
Ishizuka et al. [2011]



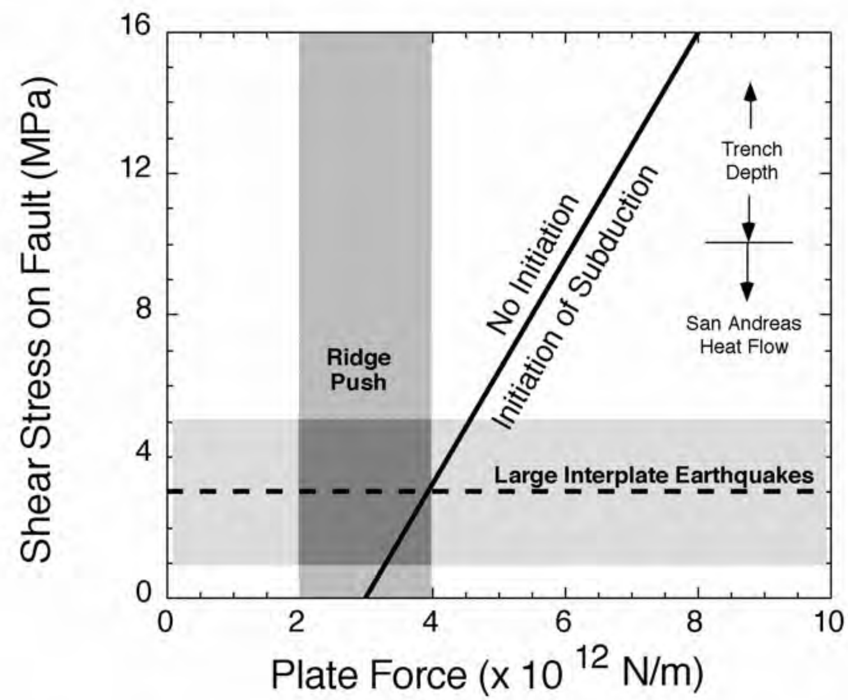
From Mark Reagan, U. Iowa, also G3-2010

Mechanical Models for the Initiation of Subduction

Elastic bending and fault friction dominate the initial stage of subduction initiation [McKenzie, 1977]



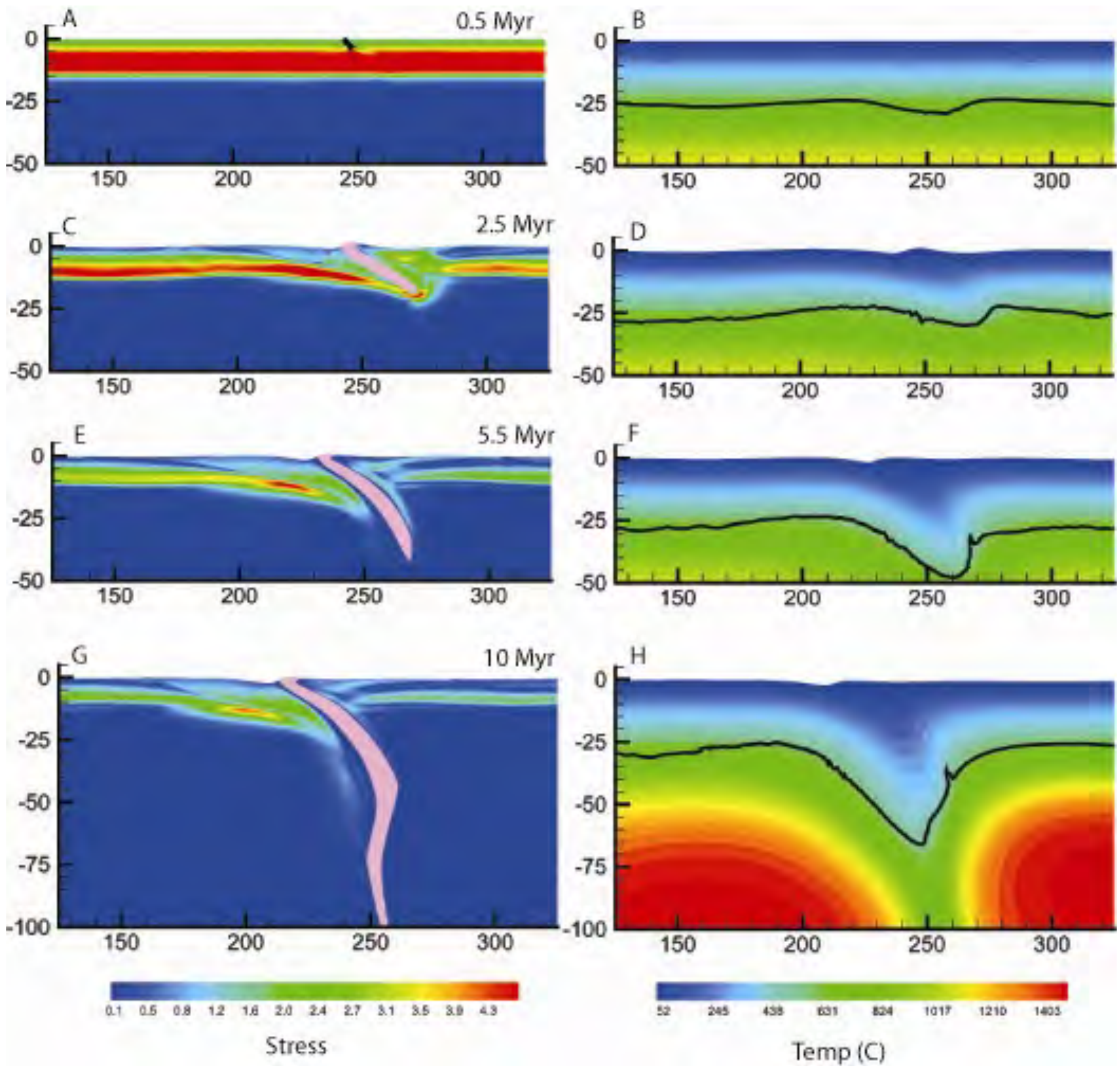
Visco-elastic plate with fault & convection

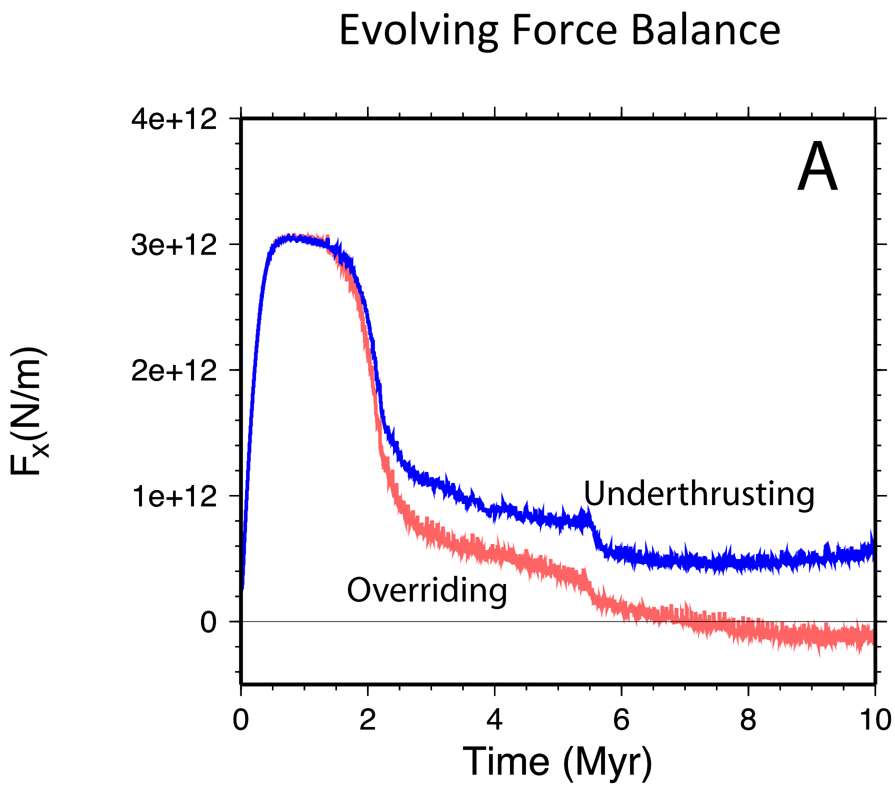


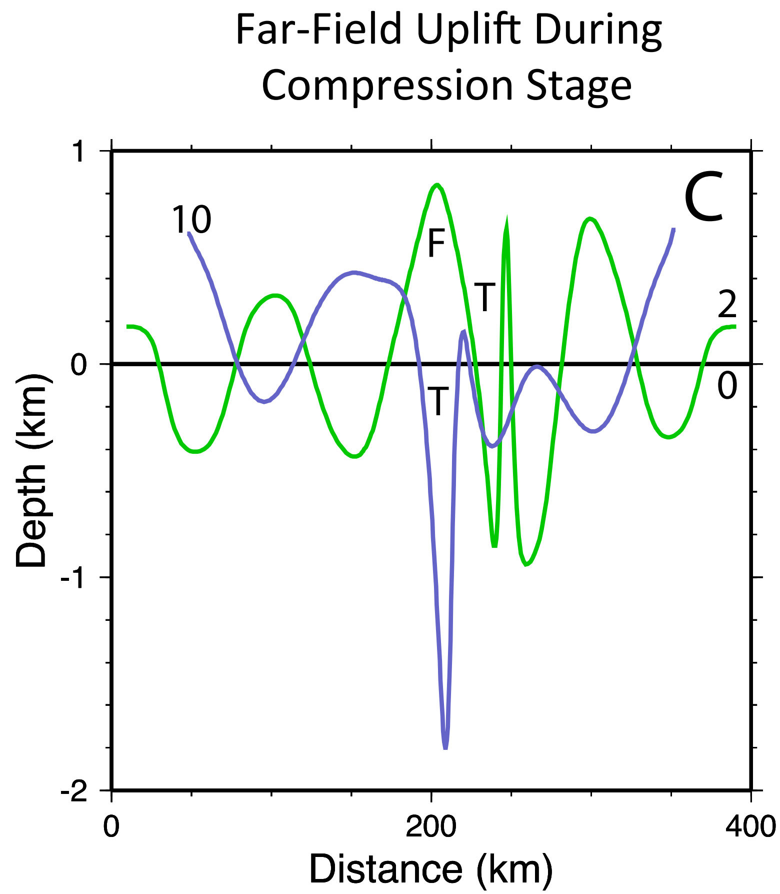
Toth & Gurnis [1998]

Far-field response to compression of a homogeneous plate

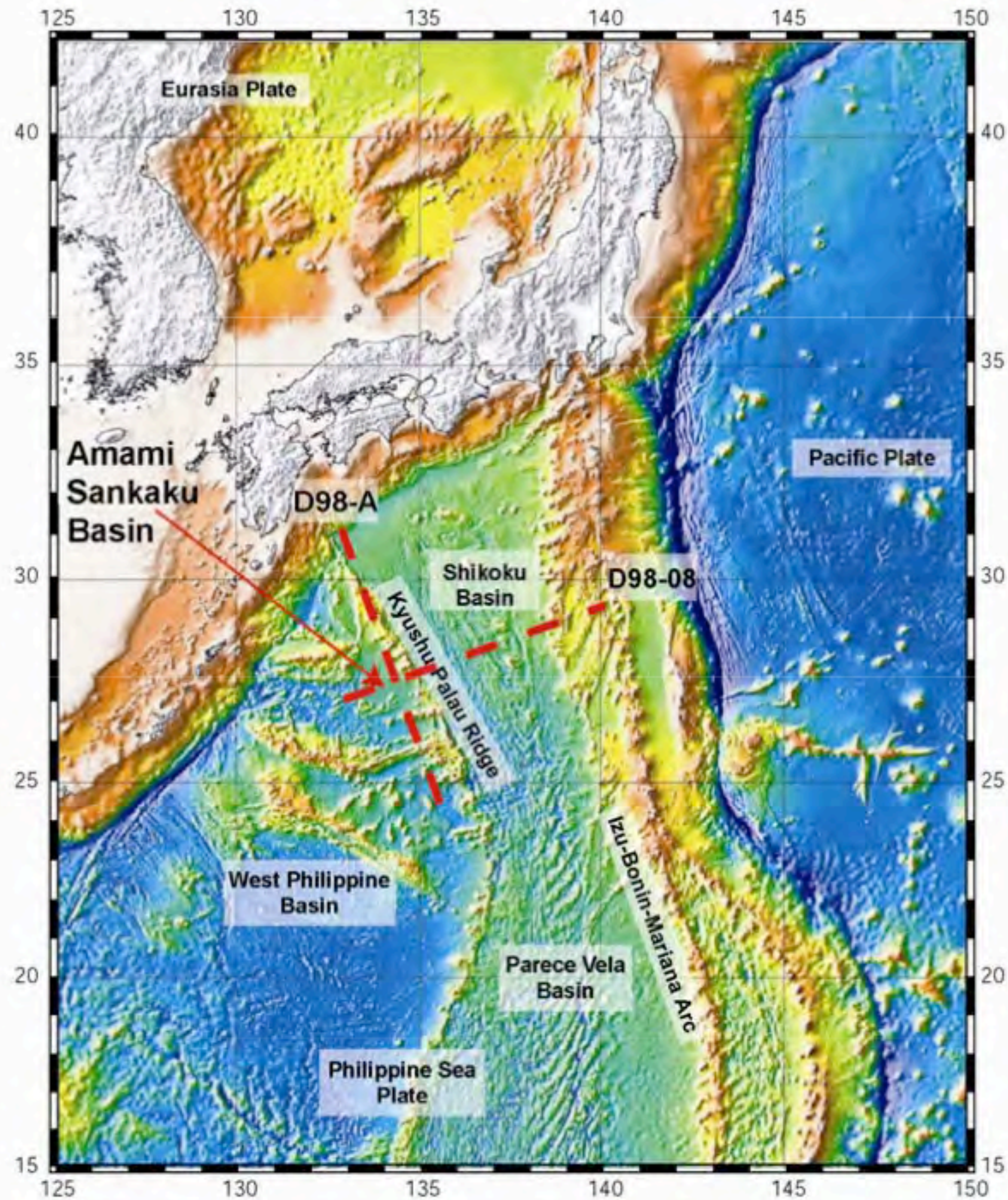
Homogeneous 30 Myr Plate



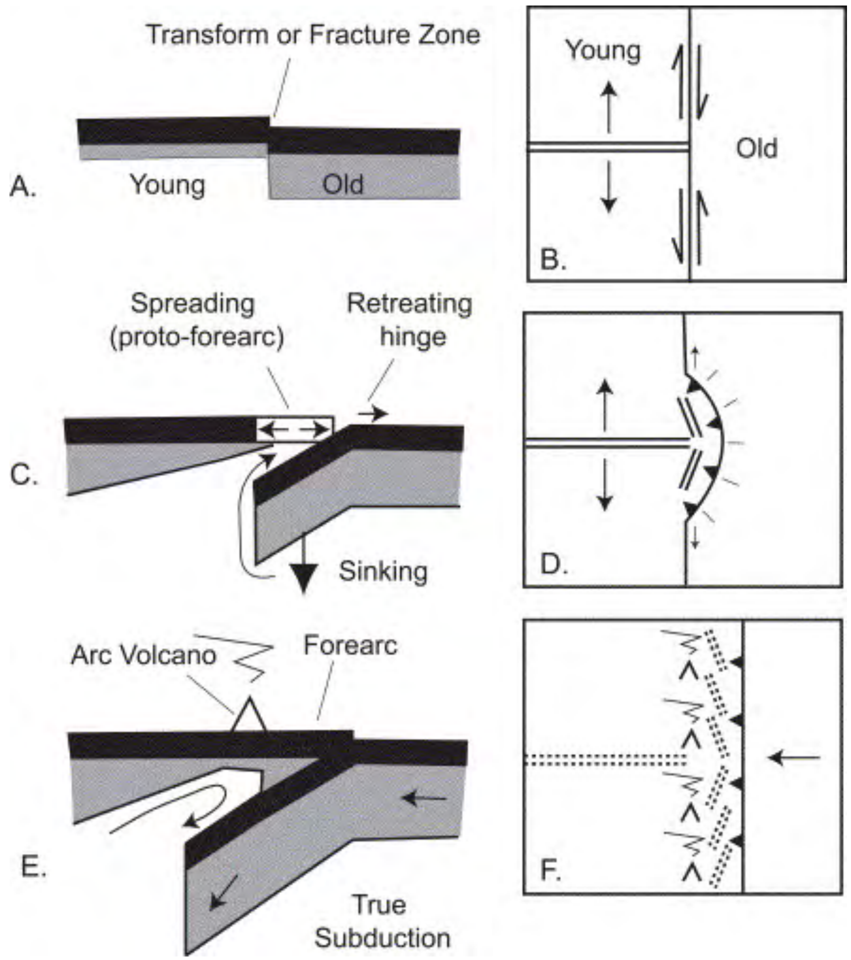

Evolving Force Balance
A
4e+12
3e+12
2e+12
1e+12
0
F_x(N/m)
Underthrusting
Overriding
0
2
4
6
8
10
Time (Myr)


Far-Field Uplift During
Compression Stage
C
1
0
-1
-2
Depth (km)
10
F
T
T
2
0
0
200
400
Distance (km)

Time-dependence of subduction, back-arc basin extension & volcanism

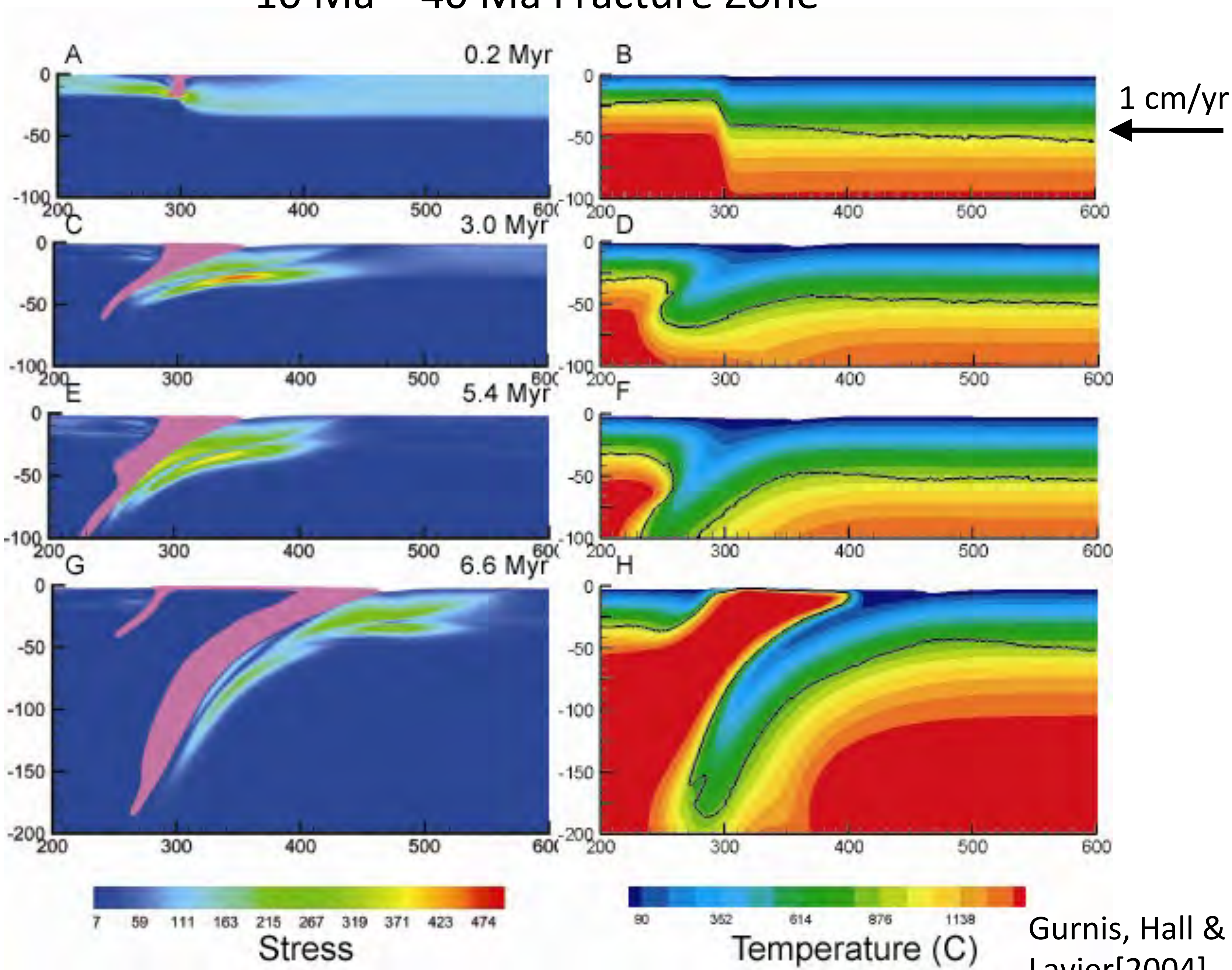


Eurasia Plate
Amami Sankaku Basin
D98-A
Shikoku Basin
D98-08
Kyushu-Palau Ridge
Pacific Plate
West Philippine Basin
Parece Vela Basin
Izu-Bonin-Mariana Arc
Philippine Sea Plate
125
130
135
140
145
150
40
35
30
25
20
15

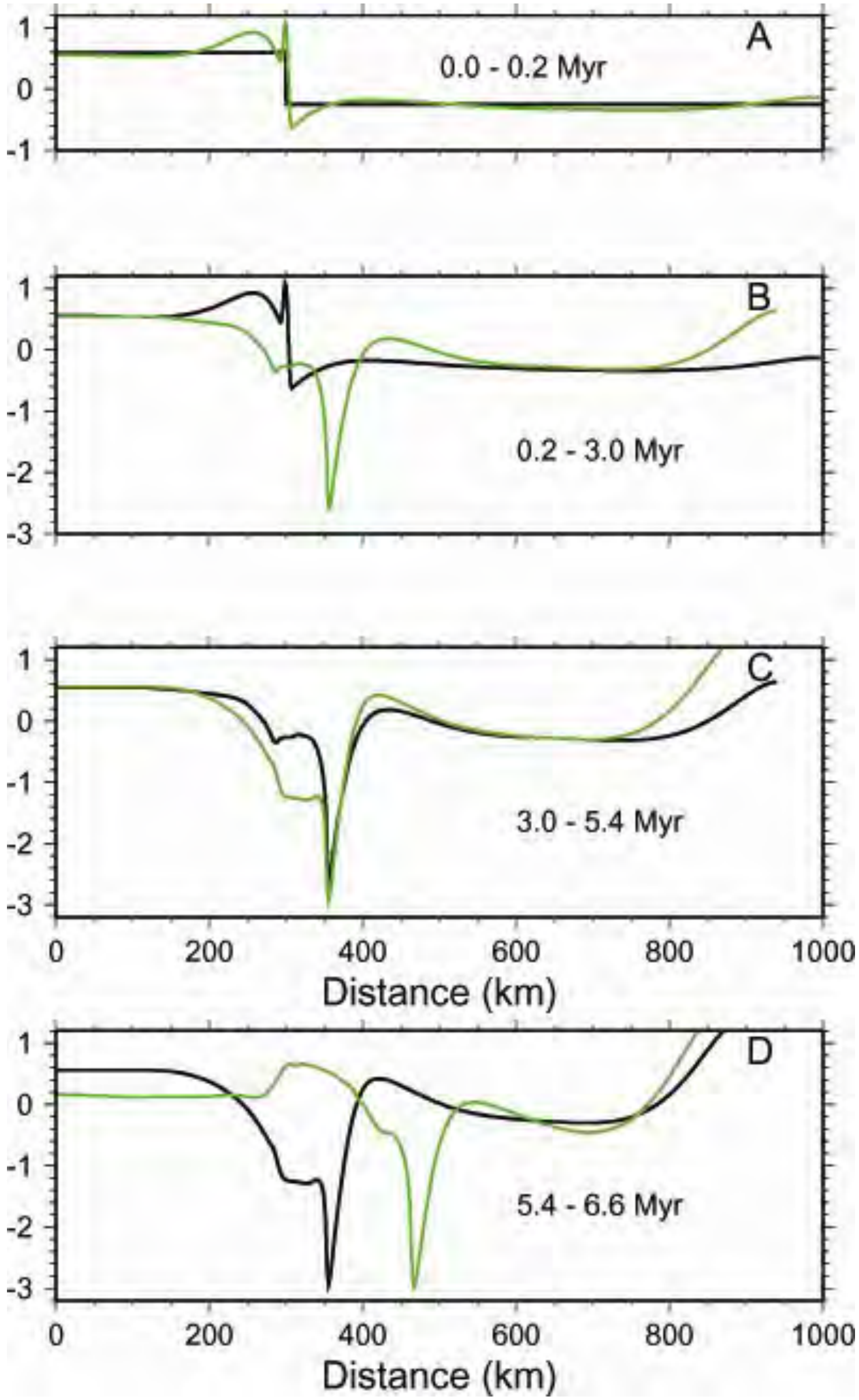

Transform or Fracture Zone
A.
Young
Old
Young
Old
B.
Spreading
(proto-forearc)
Retreating
hinge
C.
Sinking
D.
Arc Volcano
Forearc
E.
True
Subduction
F.

Stern [2004]

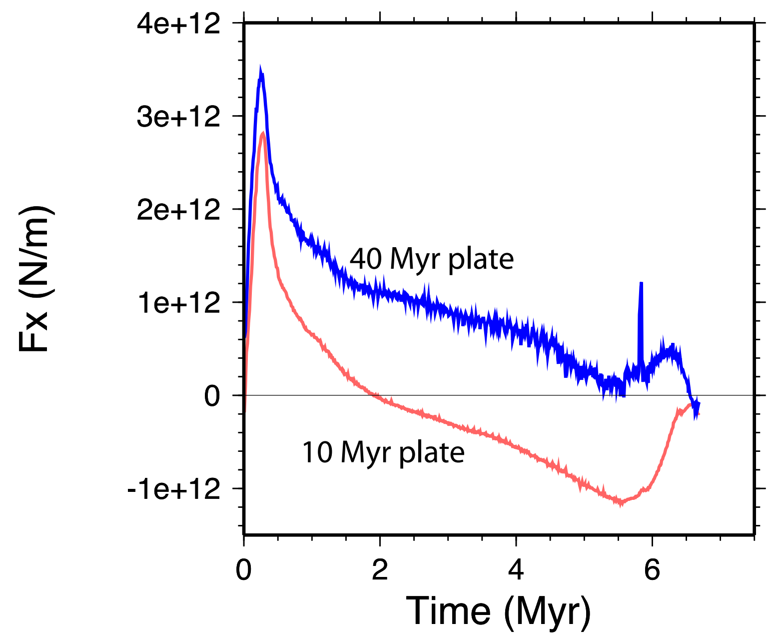
10 Ma – 40 Ma Fracture Zone



Gurnis, Hall & Lavier[2004]

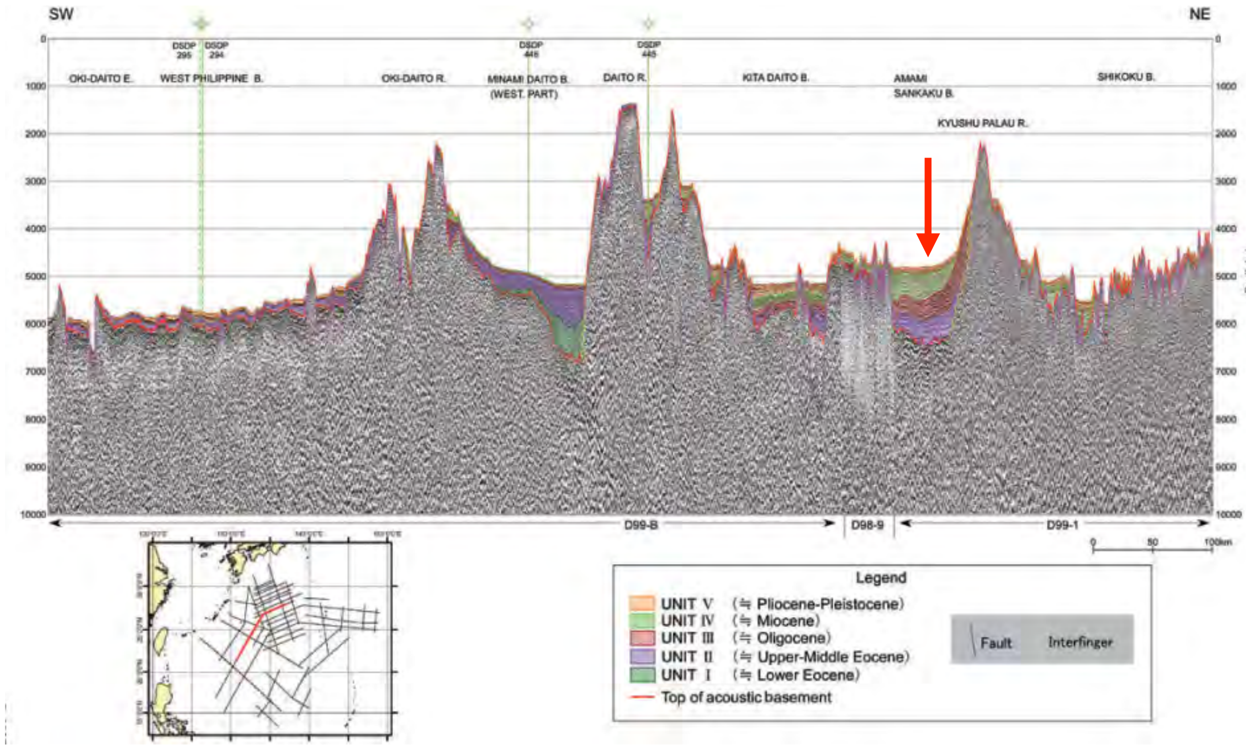


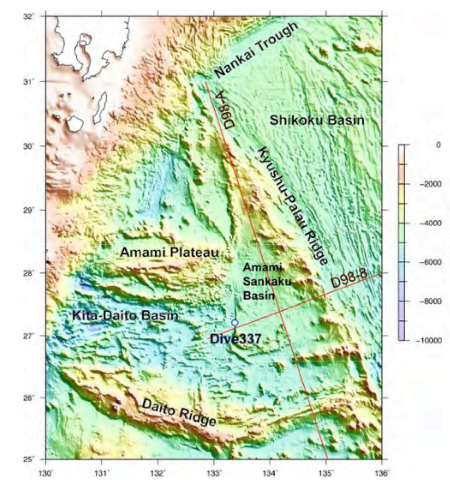
Evolution of topography for 10 Ma – 40 Ma Fracture Zone Model



Gurnis, Hall & Lavier[2004]

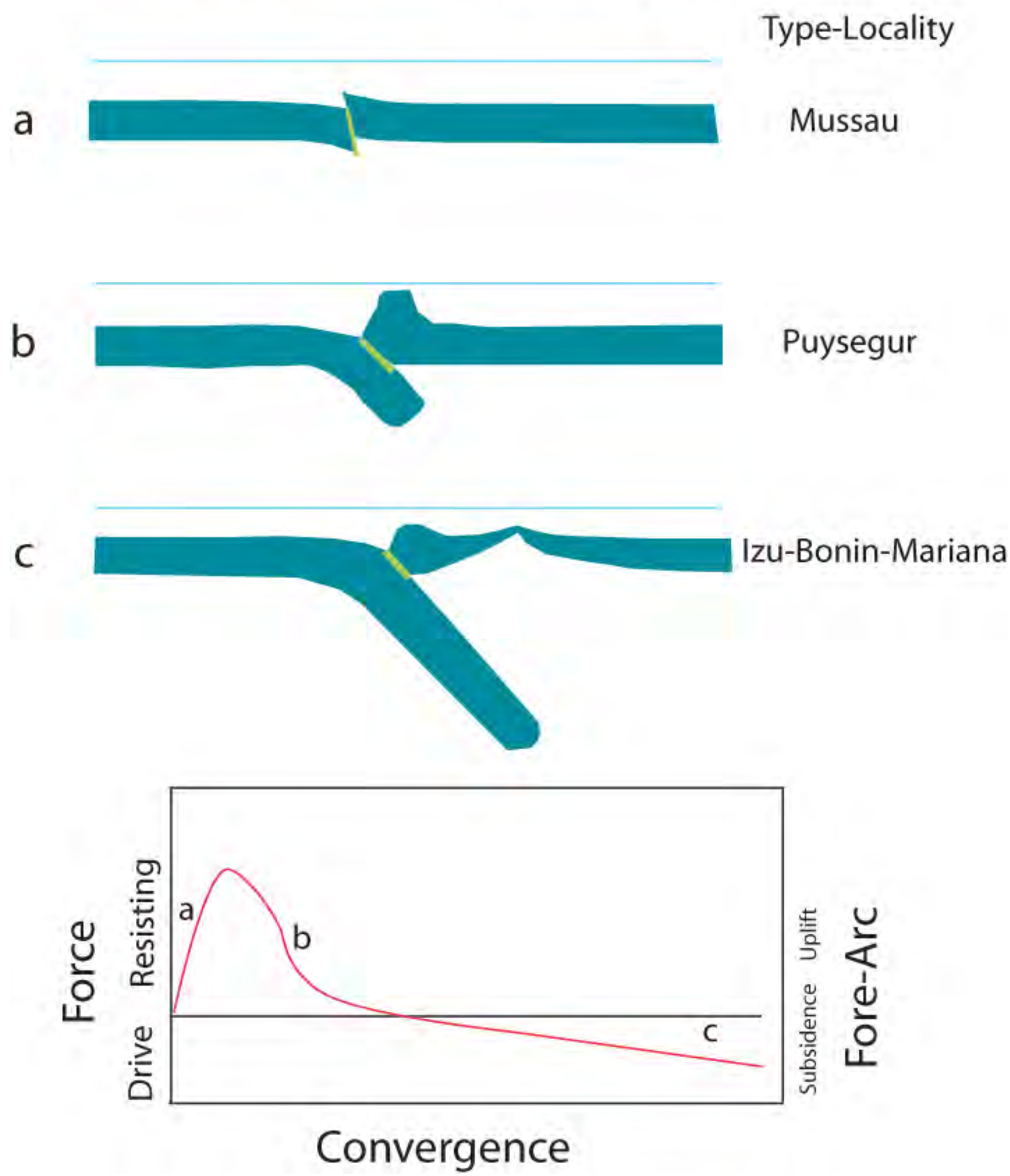
Expeditions 351 scheduled for the JOIDES Resolution in 2014



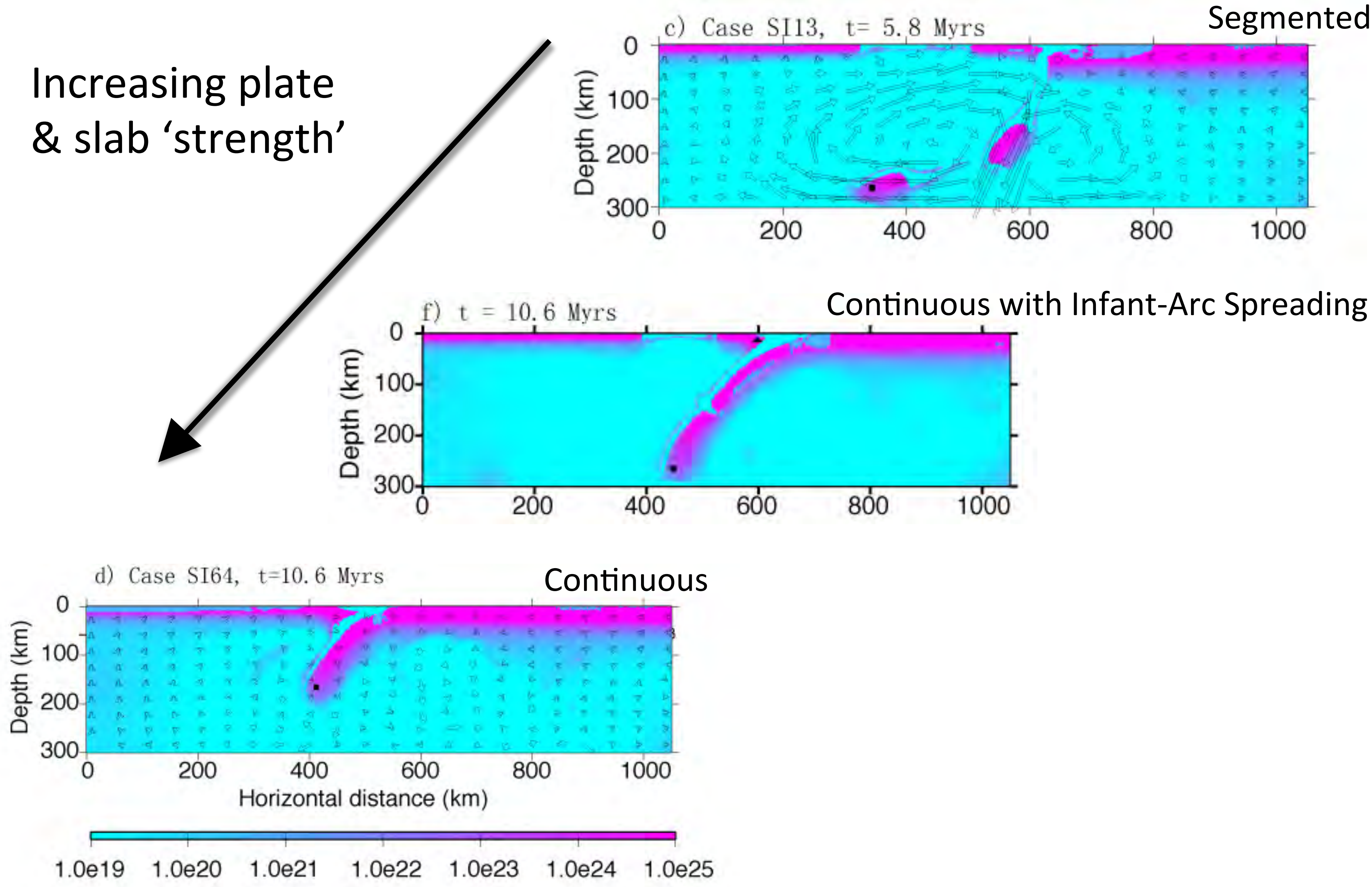


1300 meters of (Pliocene to Eocene) sediments and 150 m of basement

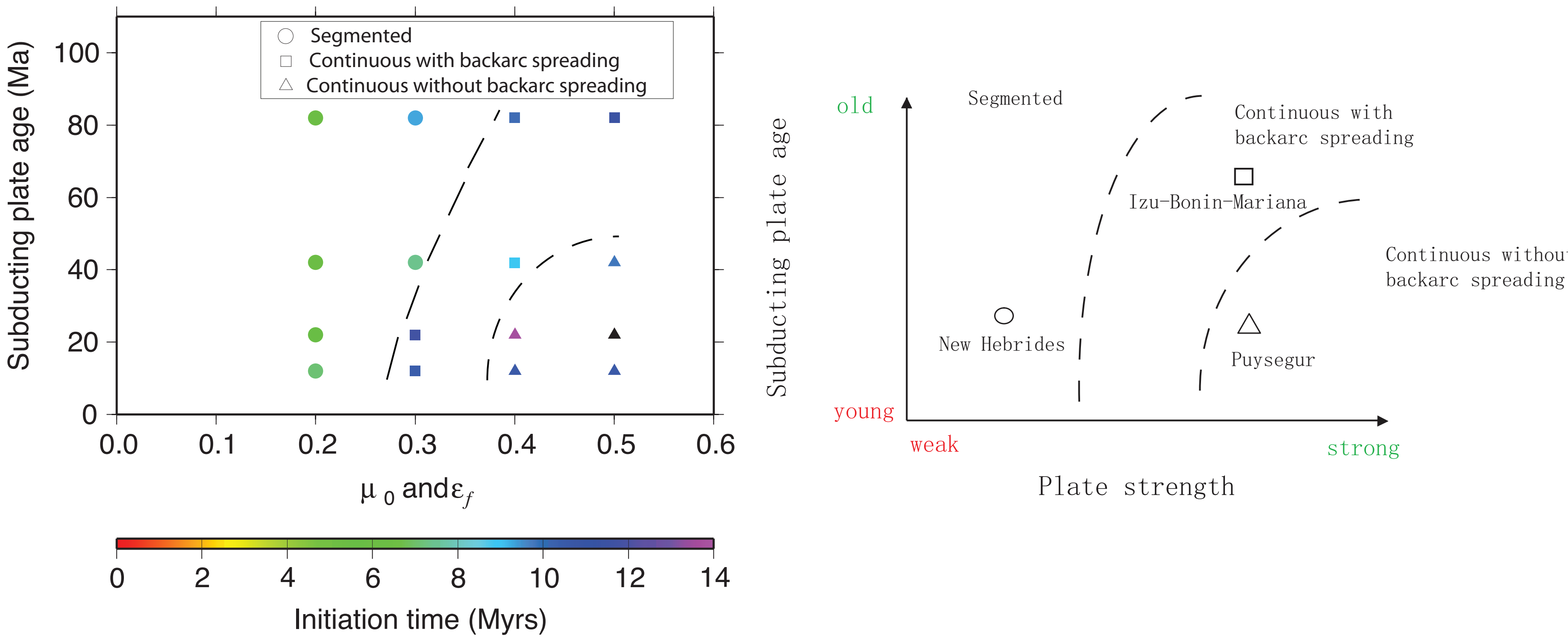
From Forced to Self-sustaining Subduction



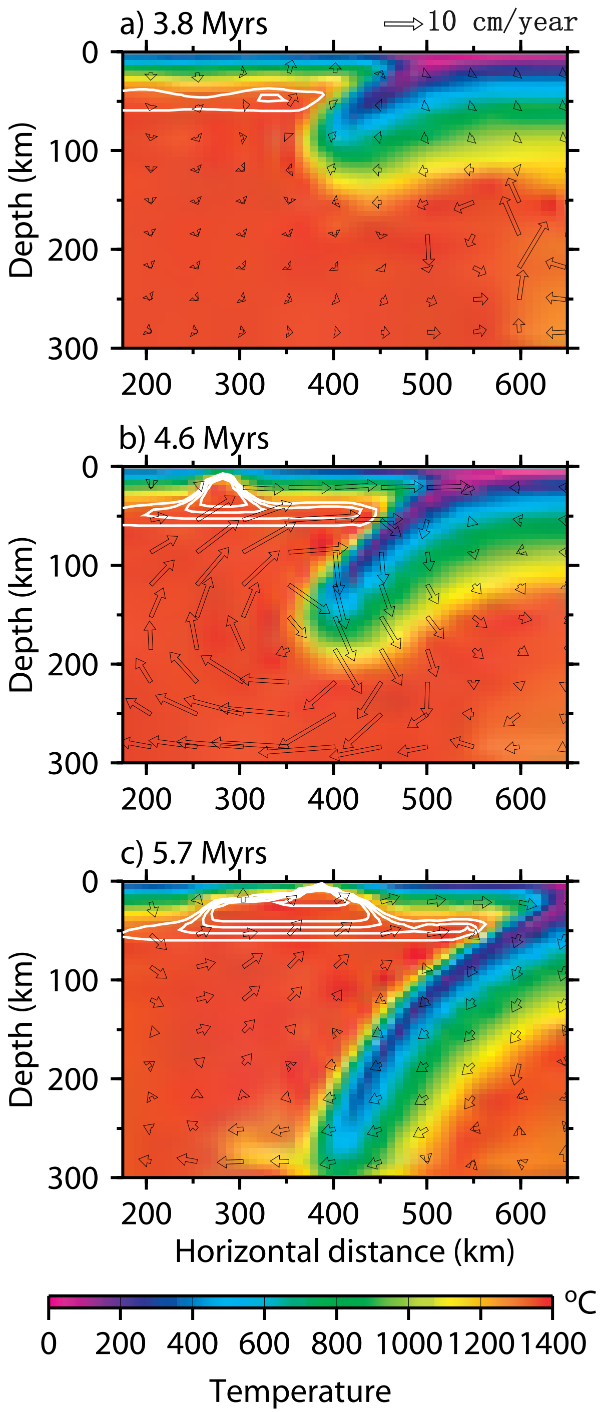
Strong dependence on plate strength & far field forces



Leng & Gurnis [2011]



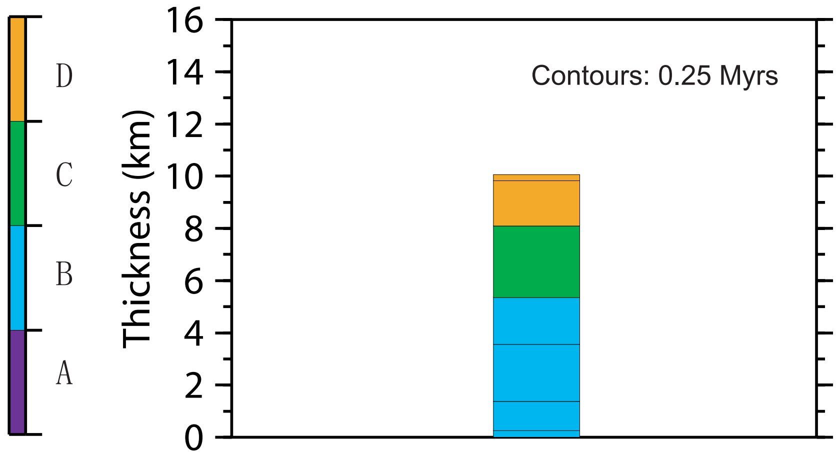
Segmented
Continuous with backarc spreading
Continuous without backarc spreading
Subducting plate age (Ma)
100
80
60
40
20
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
μ 0 andε f
0
2
4
6
8
10
12
14
Initiation time (Myrs)
Subducting plate age
old
young
weak
strong
Plate strength
Segmented
Continuous with
backarc spreading
Izu-Bonin-Mariana
Continuous without
backarc spreading
New Hebrides
Puysegur



Continuous Subduction initiation with Infant-arc Spreading

Leng, Gurnis, & Asimow [2012]

a) Compositional group



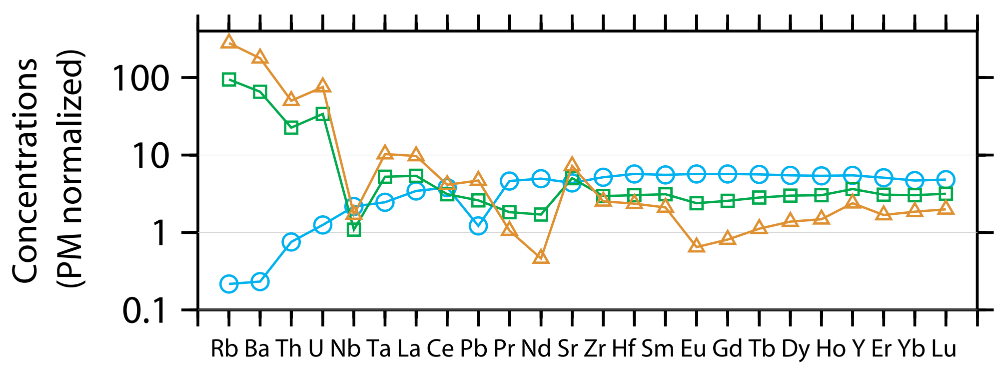
For a sample point between ridge in the infant-arc and the trench

Boninite eruption follows basalts

b) Major element

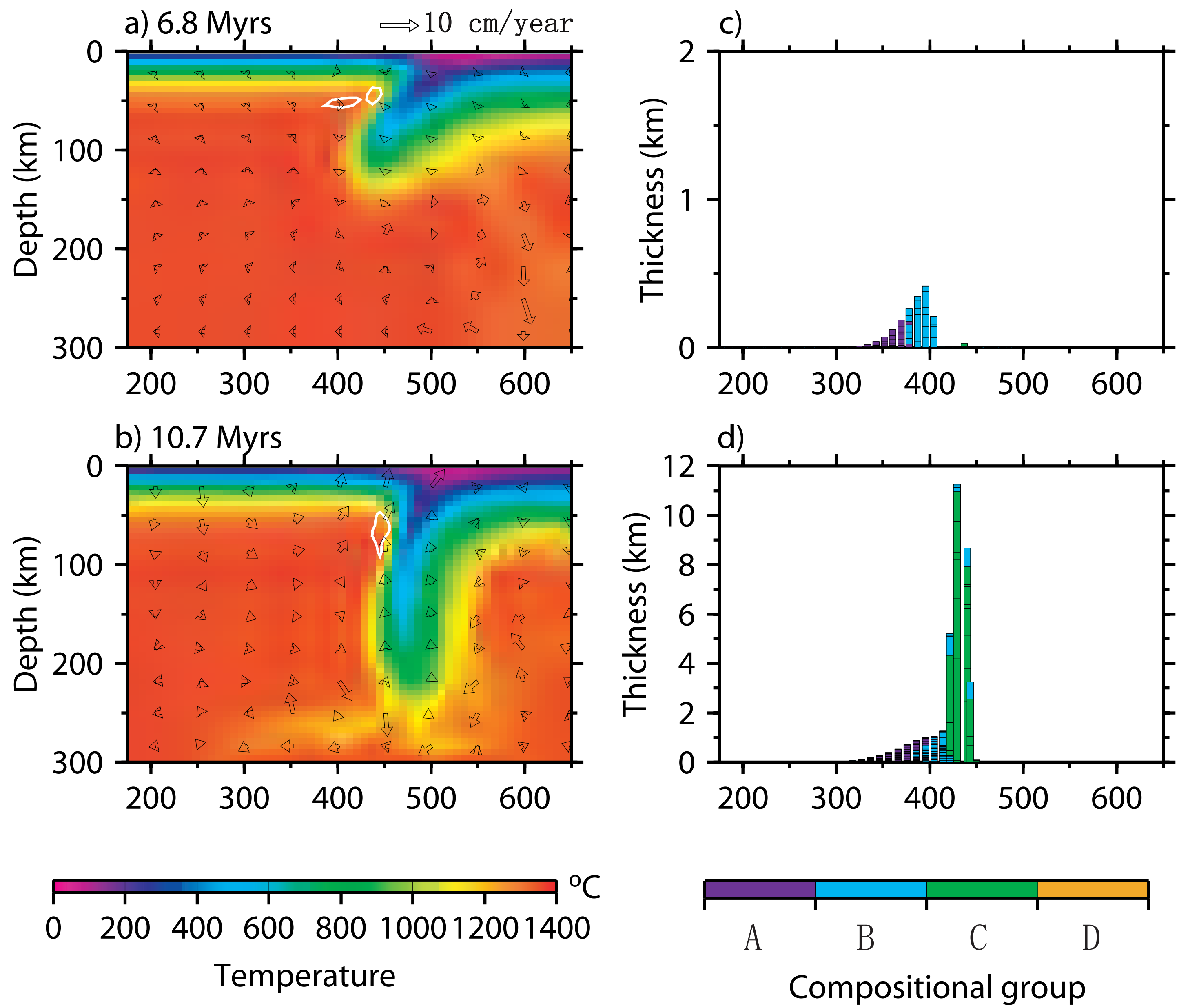
(in wt%)	SiO_2	Al_2O_3	MgO	FeO	TiO_2	Na_2O	K_2O	CaO	(Mg#)
Group A:	54.79	17.62	7.78	6.23	0.91	5.10	1.16	6.42	(69.2)
Group B:	49.35	17.28	11.06	8.46	0.82	3.04	0.05	9.95	(70.2)
Group C:	48.41	15.60	14.02	9.37	0.56	1.16	0.01	10.87	(72.9)
Group D:	52.57	12.16	16.17	8.94	0.27	0.18	0.00	9.70	(76.5)

c) Trace element

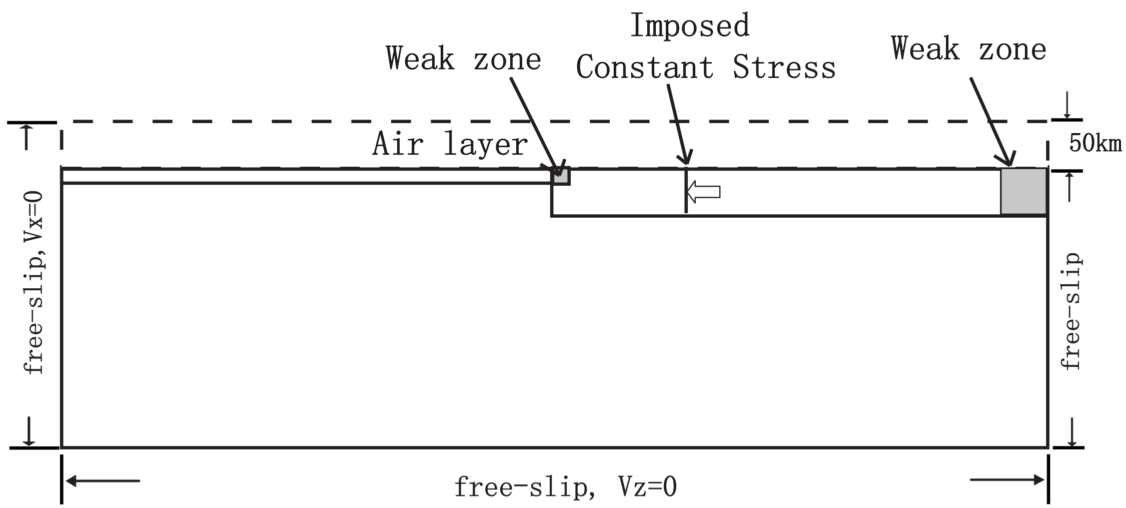


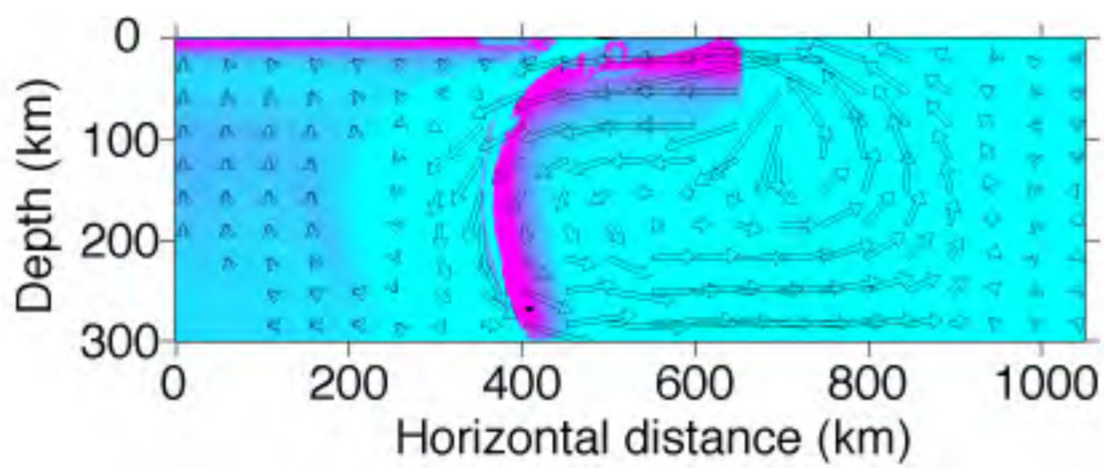
Leng, Gurnis, & Asimow [2012]

By increasing the parameters which govern the strength of the plate, the initiation switches to continuous without back-arc spreading: Boninites eruption disappears.



What happens if we change from a constant velocity to a constant stress 'far-field' force ?

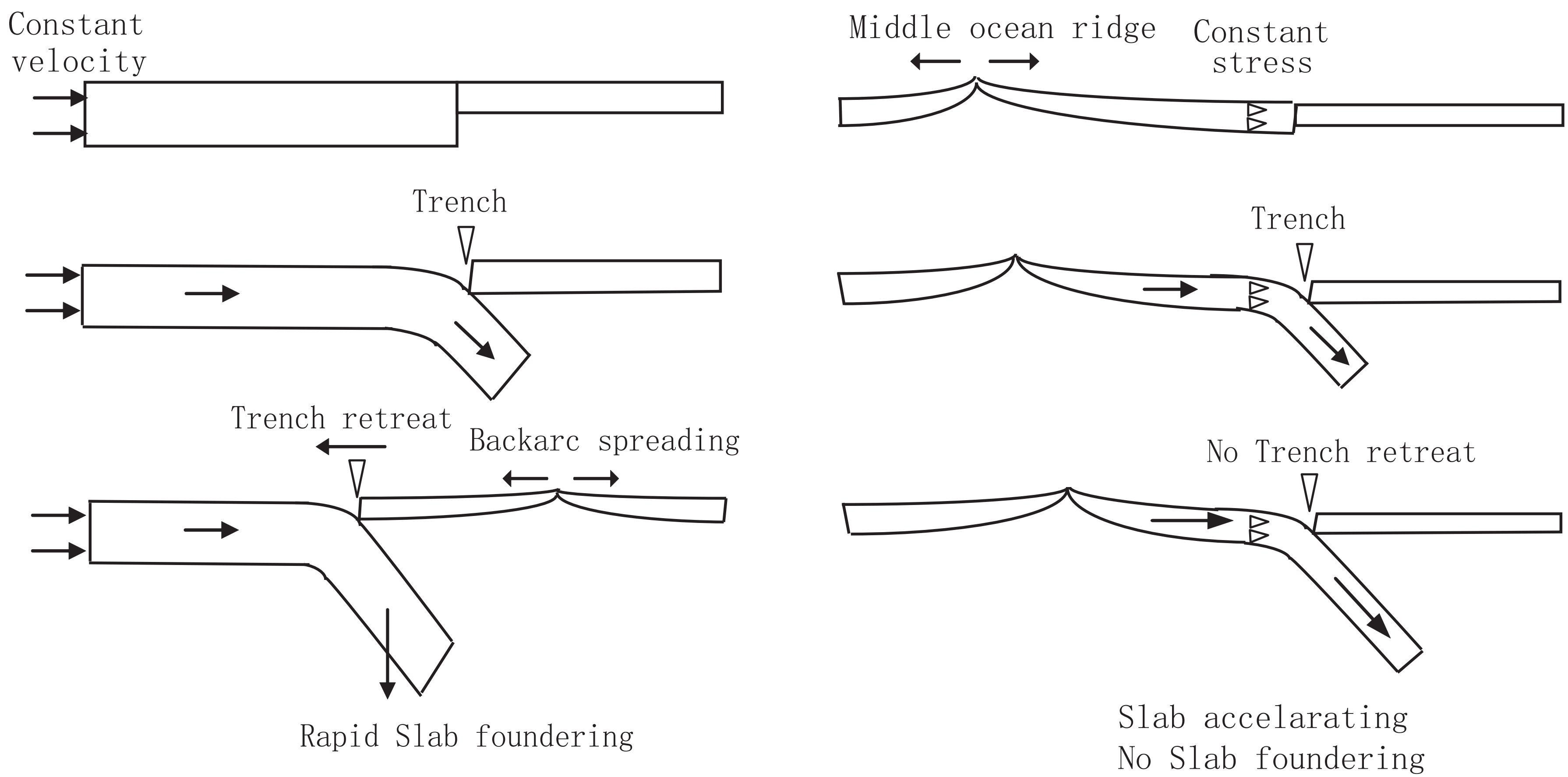




Leng & Gurnis [2011]

Constant Velocity BC

Constant Stress BC



Leng & Gurnis [2011]

At ~ 52 Ma, Different Force Balance on the Pacific & Kula Plates

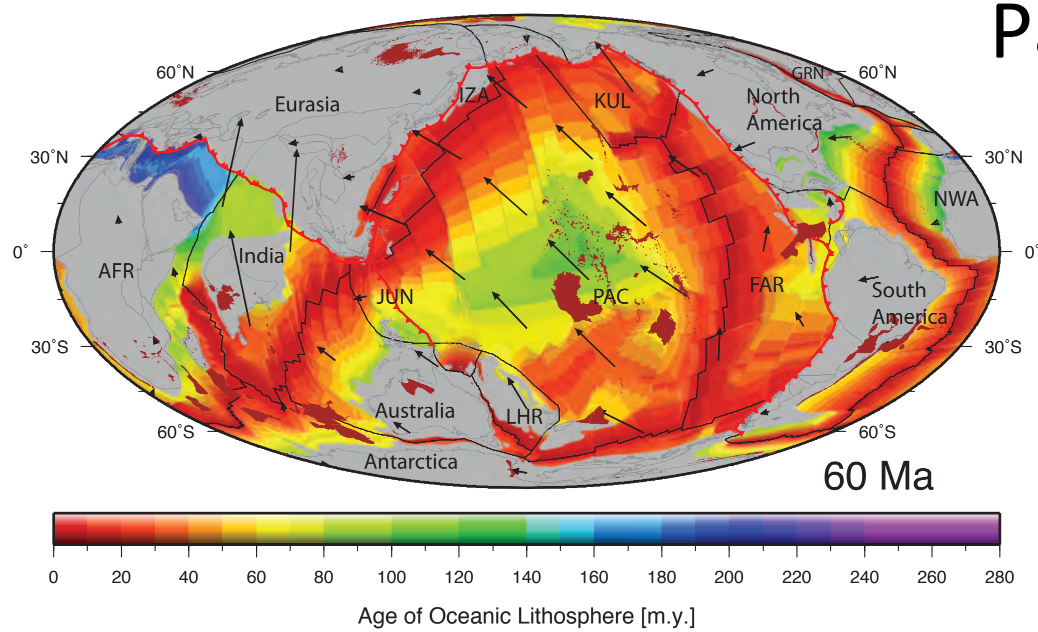
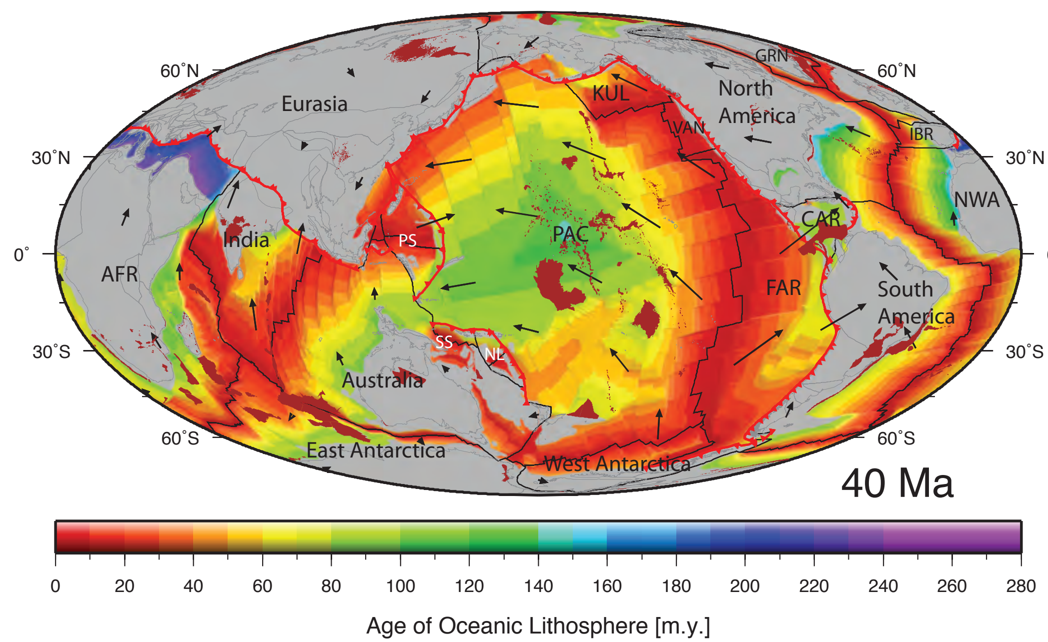
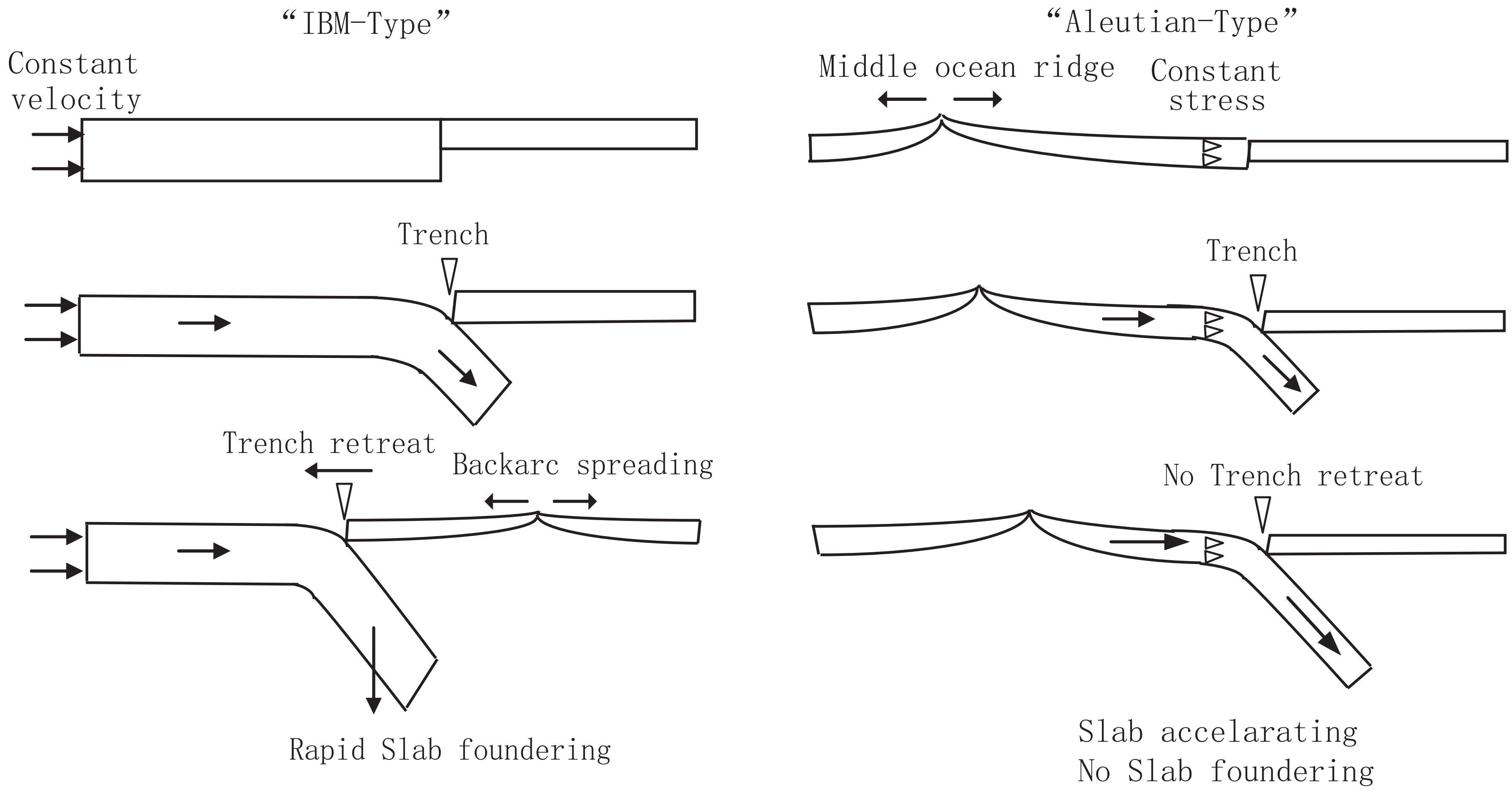


Figure 3h: Seton et. al.

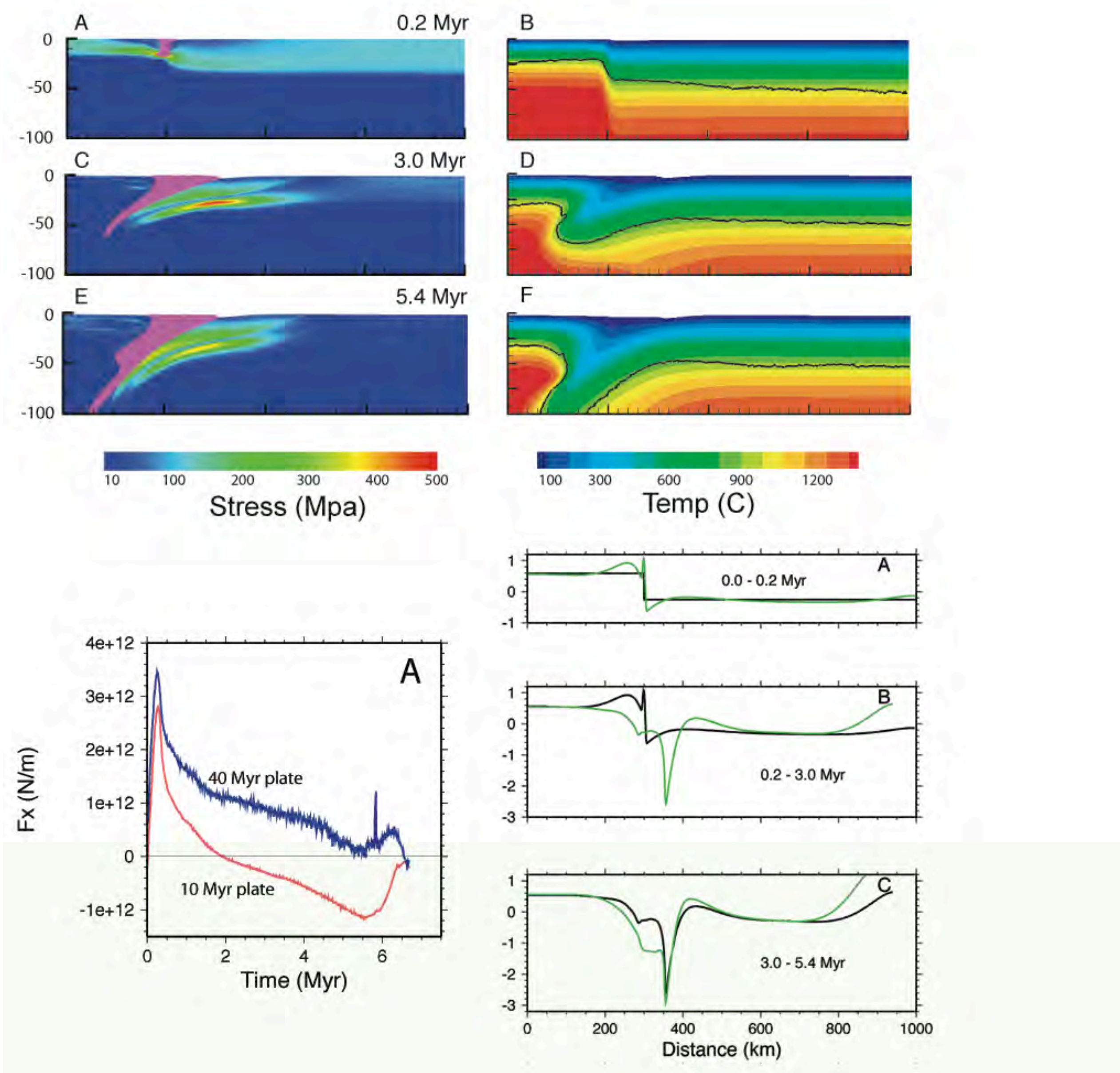


Seton et al. [2012]

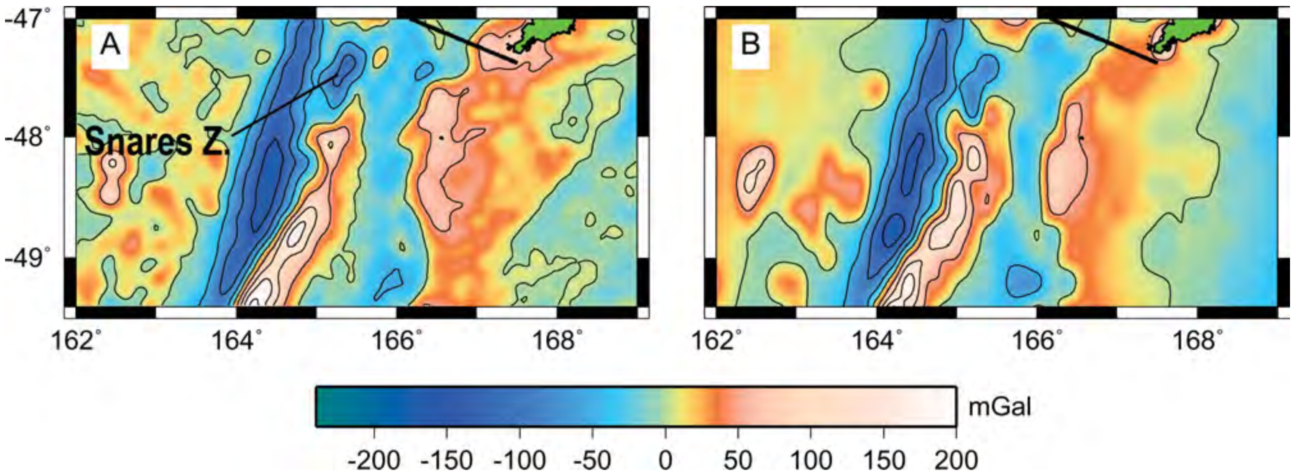


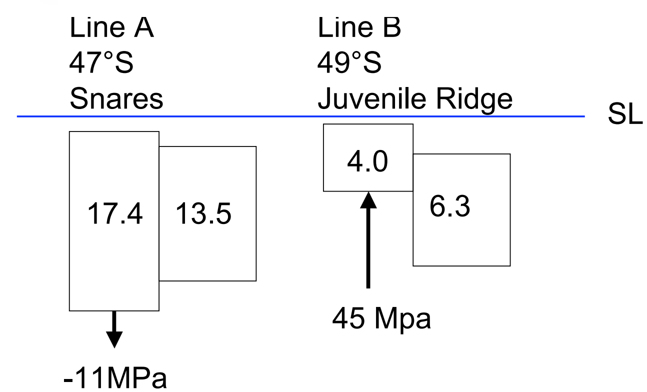
Leng & Gurnis [2011]

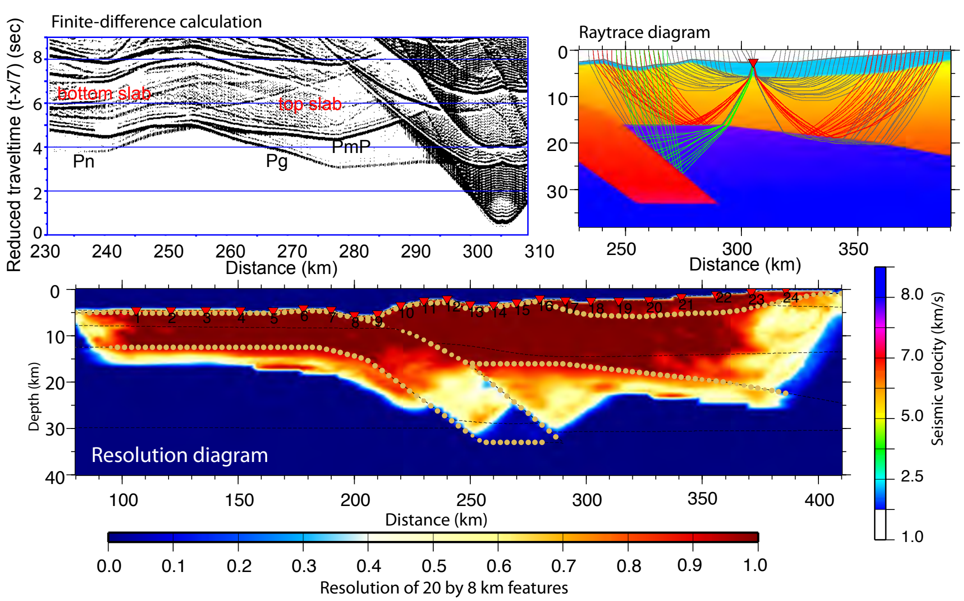
Can we measure key properties of a nascent subduction zones making the transition from forced to self-sustaining ?



The gravity, bathymetry and geomorphology strongly suggests that the Puysegur Region is making this key transition from forces to self sustaining

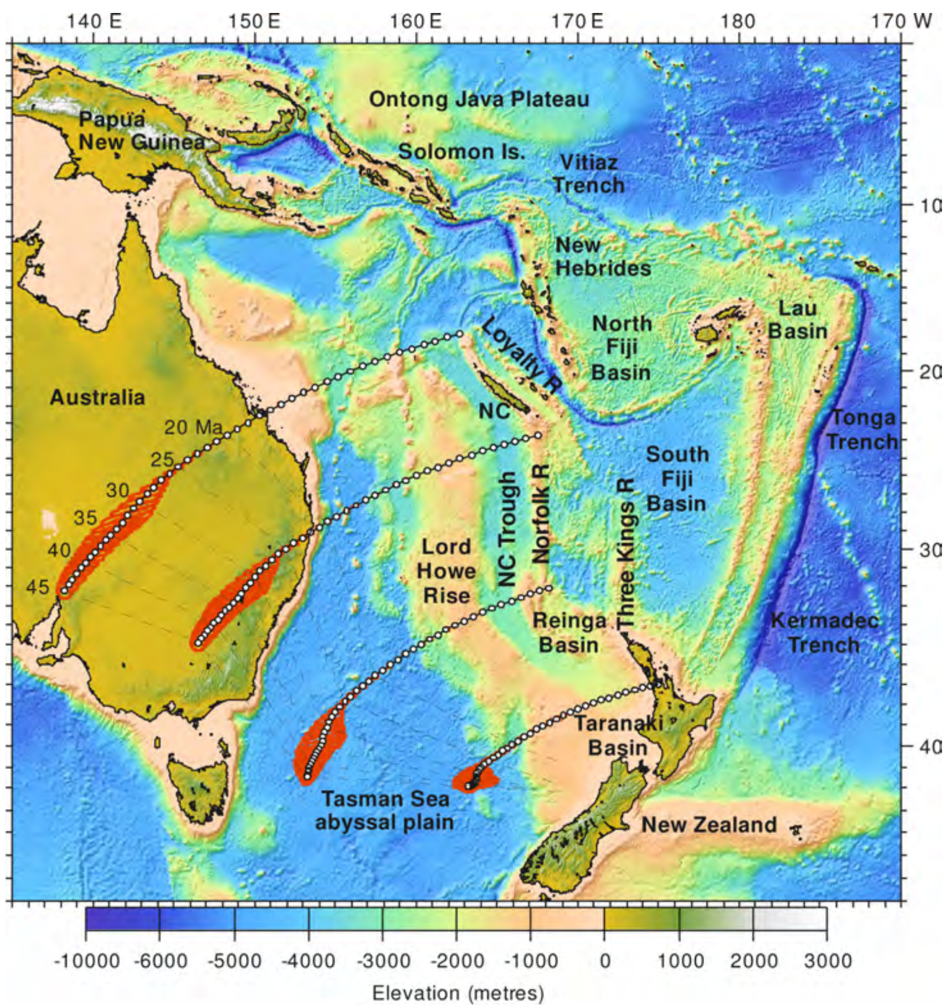






The Key quantities can be measured with an active source seismic experiment

Given the result that the onset of subduction initiation is controlled by the cumulative amount of convergence, we predict at N-S patter in the ages of initiatioin – earlier in the North



Outlook

- In the New Zealand region, we can test hypotheses and mechanical models of:
  - how the oceanic lithosphere behaves during the earlier phase of initiation by detailed studies of the Puysegur segment
  - the motion of the entire Pacific region through detailed study of the ~Eocene Lord Howe Rise compressional event and the volcanic stratigraphy of the Tonga-Kermadec fore arc