What does modeling mean for my community?
Geodynamics/GeoPRISMS/CIG/CIDER

Peter van Keken (University of Michigan)

GeoPRISMS Geodynamic Processes at Rifting and Subducting Margins

NSF

Earthcube modeling
Boulder, CO
April 2013

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photo by Ikuko Wada

GeoPRISMS — Geodynamic Processes at Rifting and Subducting Margins

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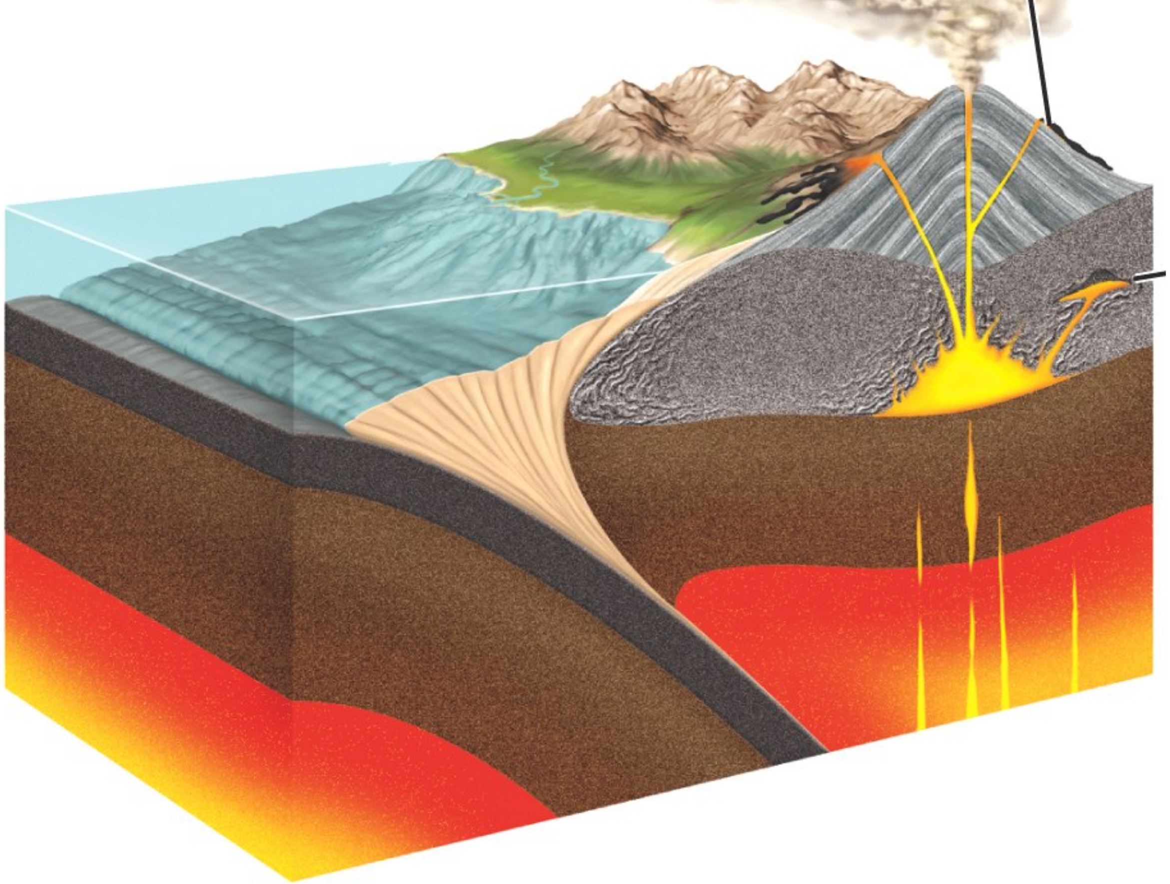

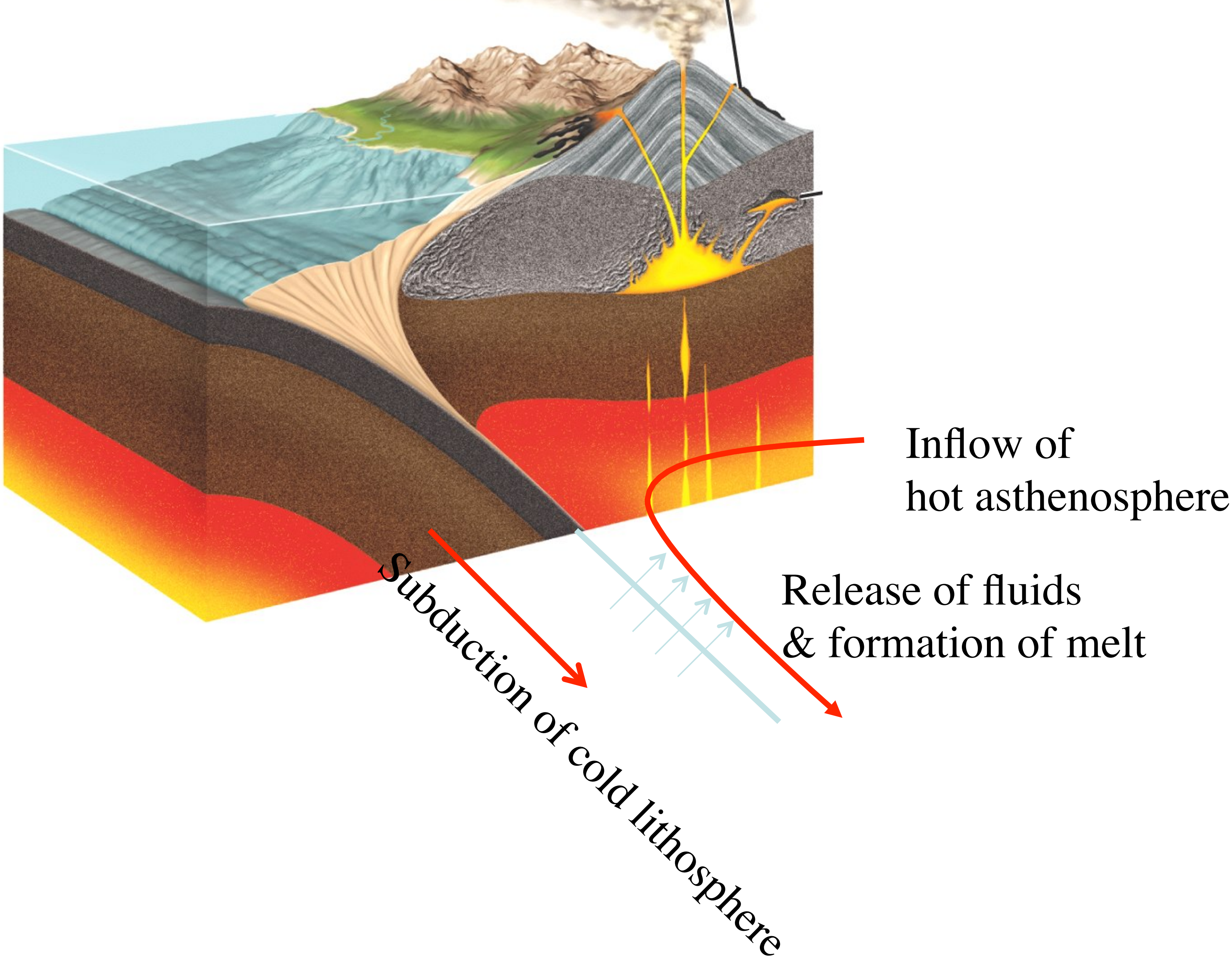
Inflow of
hot asthenosphere
Release of fluids
& formation of melt
Subduction of cold lithosphere

OCE
EAR
ODP

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GeoPRISMS

Geodynamic Processes at Rifting and Subducting Margins

info@geoprisms.org

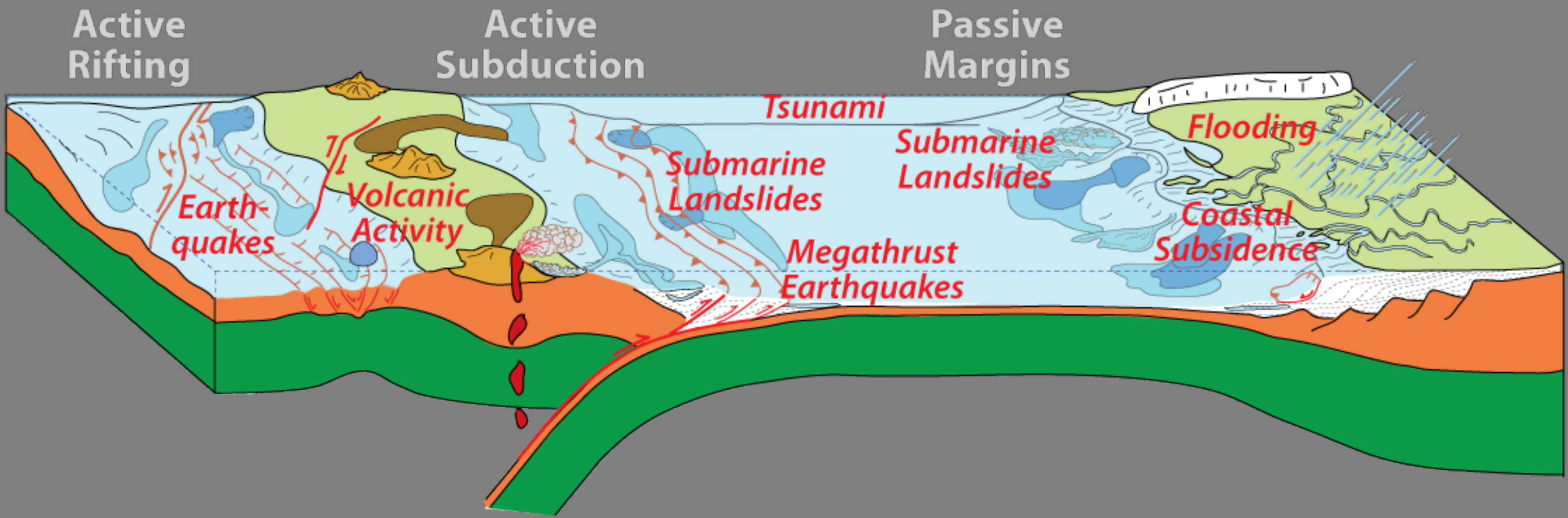
www.geoprisms.org

GeoPRISMS Office

2010-2013 Rice (Juli Morgan)

2013-2016 Michigan (van Keken)

GeoPRISMS Tectonic Settings

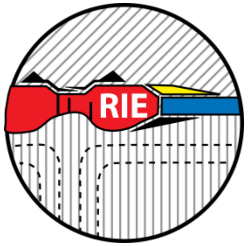


GeoPRISMS investigates the coupled geodynamics, earth surface processes, and climate interactions that build and modify continental margins *over a wide range of timescales (from s to My), and cross the shoreline, with applications to margin evolution & dynamics, construction of stratigraphic architecture, accumulation of economic resources, and associated geologic hazards and environmental management.*

GeoPRISMS Structure & Implementation

Two broadly integrated initiatives

Subduction Cycles & Deformation



Rift Initiation & Evolution

Research at Primary Sites & Thematic Studies

Five Primary Sites, three are North American margins

Leveraging and building new opportunities:

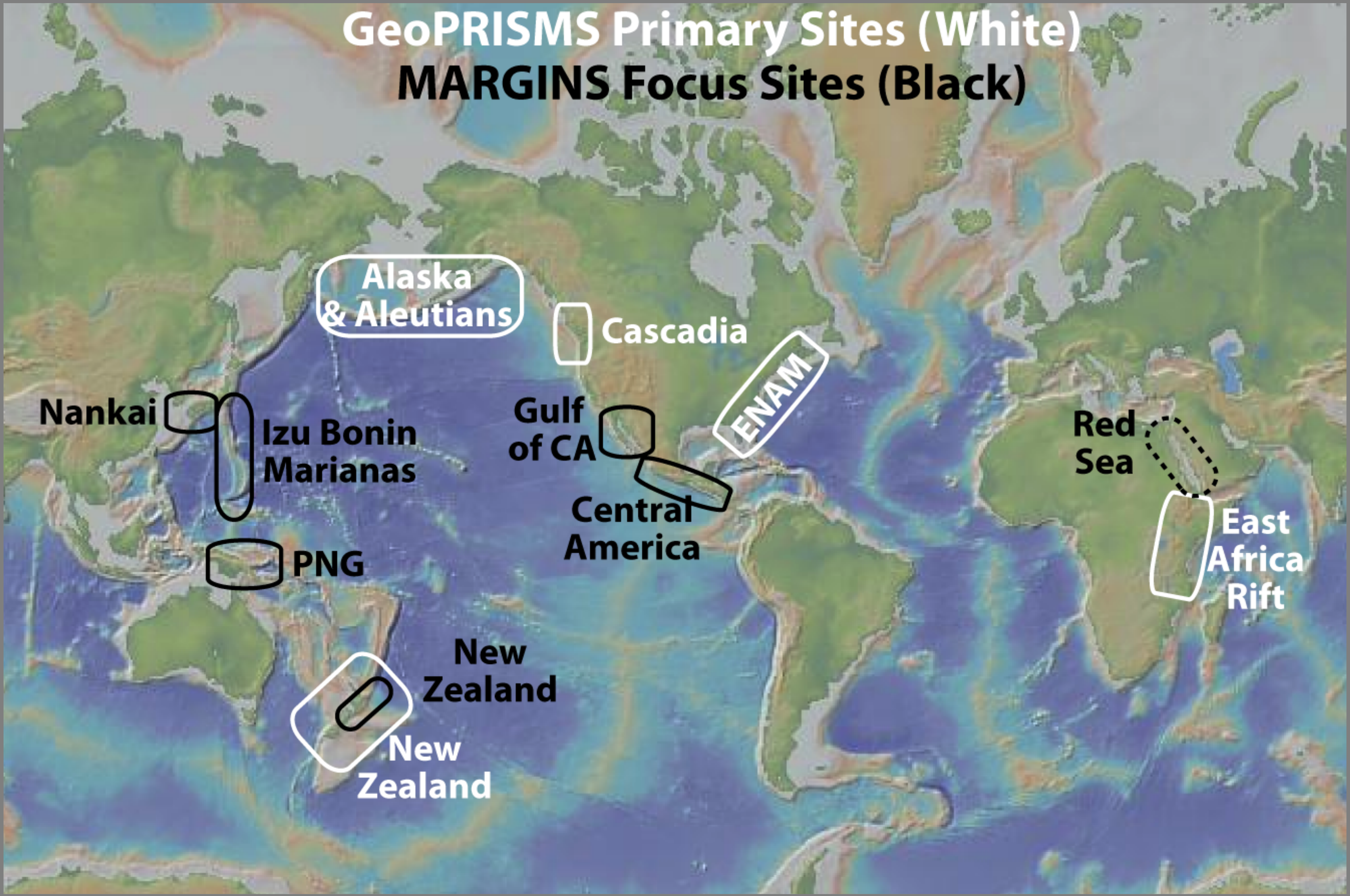
New facilities, e.g., EarthScope, Amphibious Array

Strong international & agency collaborations

Expanded societal relevance, linkages to industry

Broadened education & outreach programs

Where GeoPRISMS Works



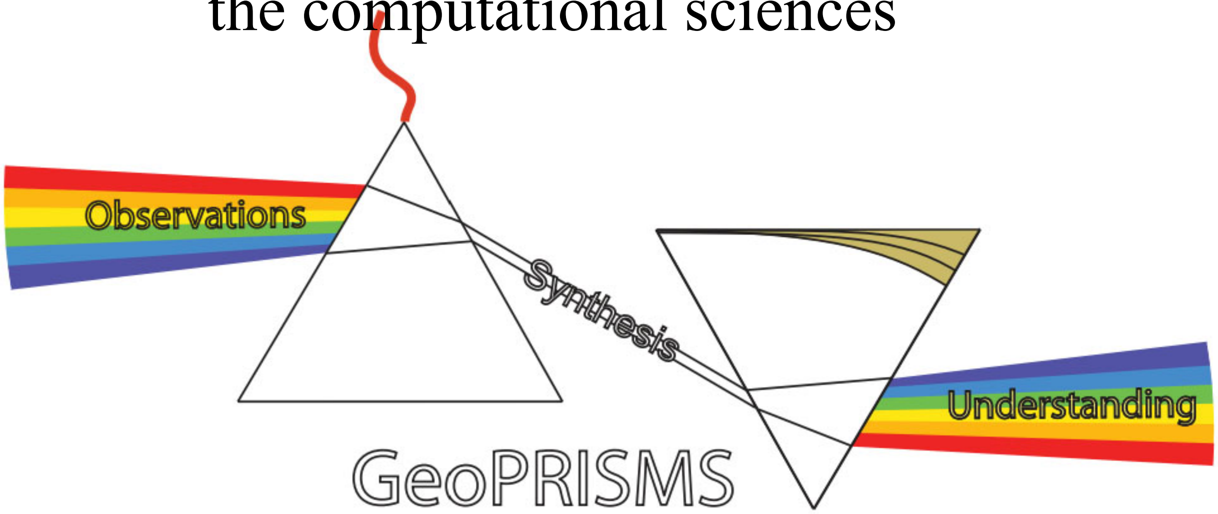
Modeling….

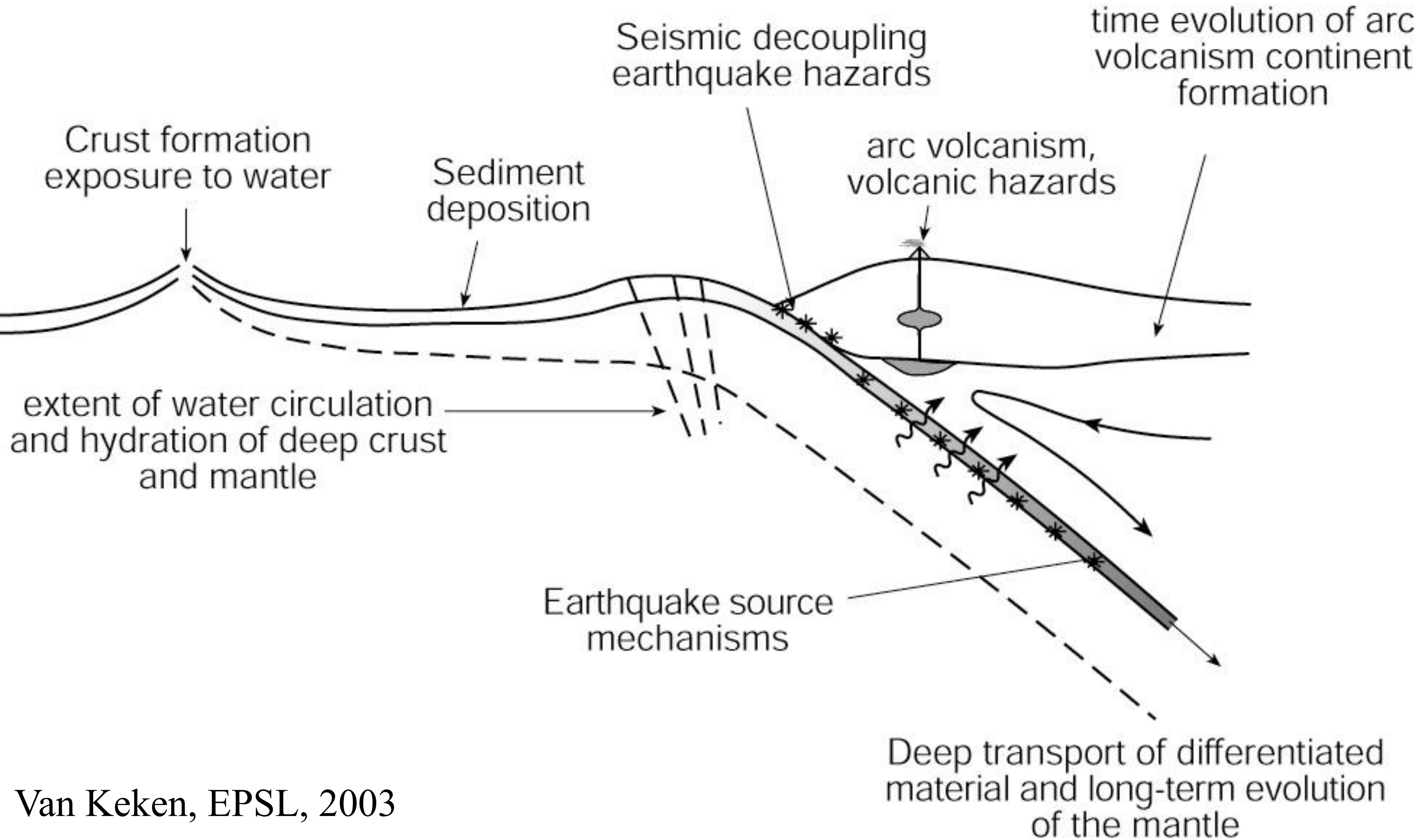
Is a tool in hypothesis development and testing

Requires verification, validation, benchmarking

Aids in synthesis & development of understanding of complex physical & chemical processes

Needs to (try to) keep up with advances in the computational sciences





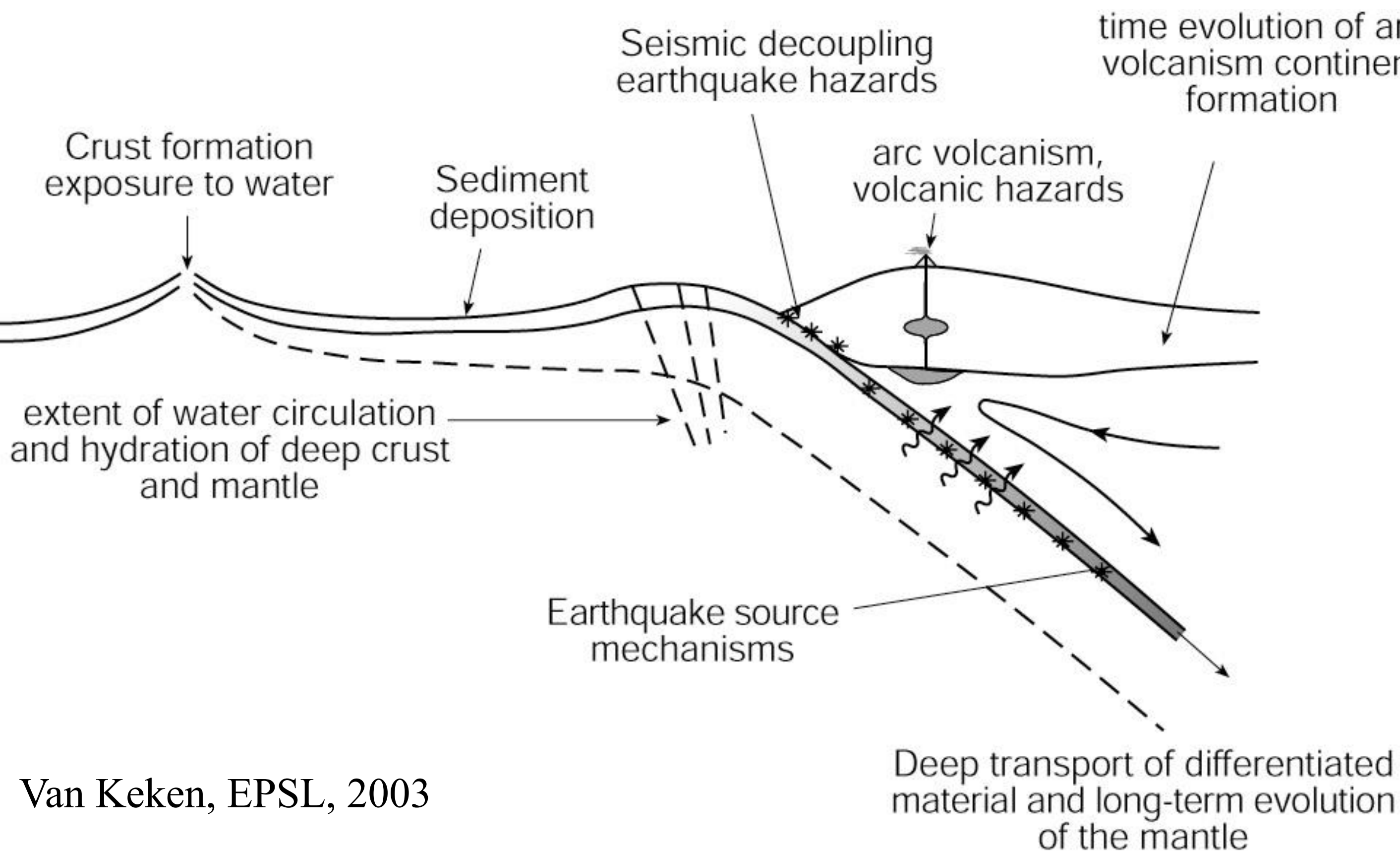
Van Keken, EPSL, 2003

Three mini case studies of subduction zone modeling:

Deformation before and during major thrust EQs

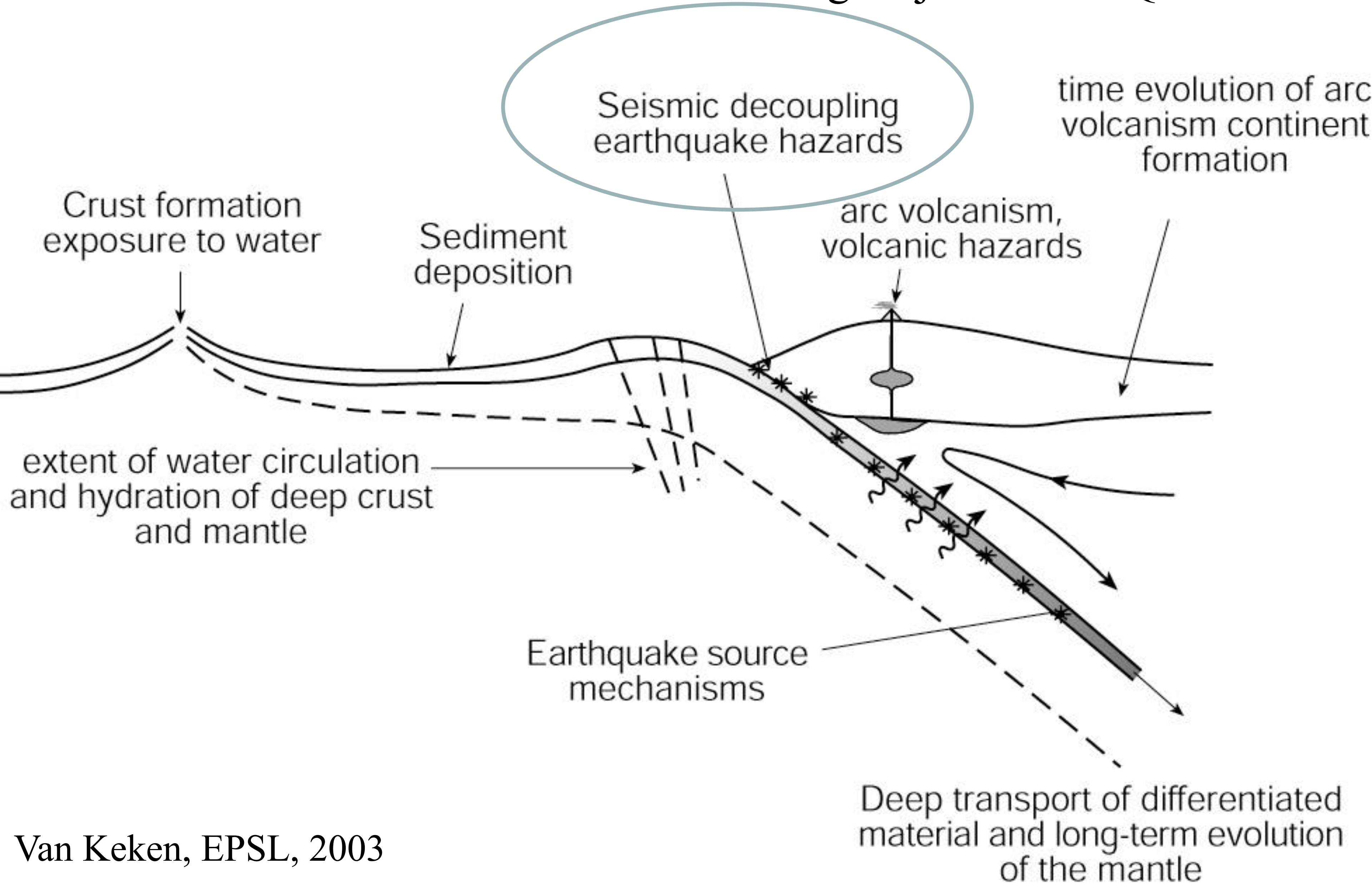
Thermal state and dehydration in subduction crust

Migration of fluids and melt below the arc



Van Keken, EPSL, 2003

I Deformation before and during major thrust EQs



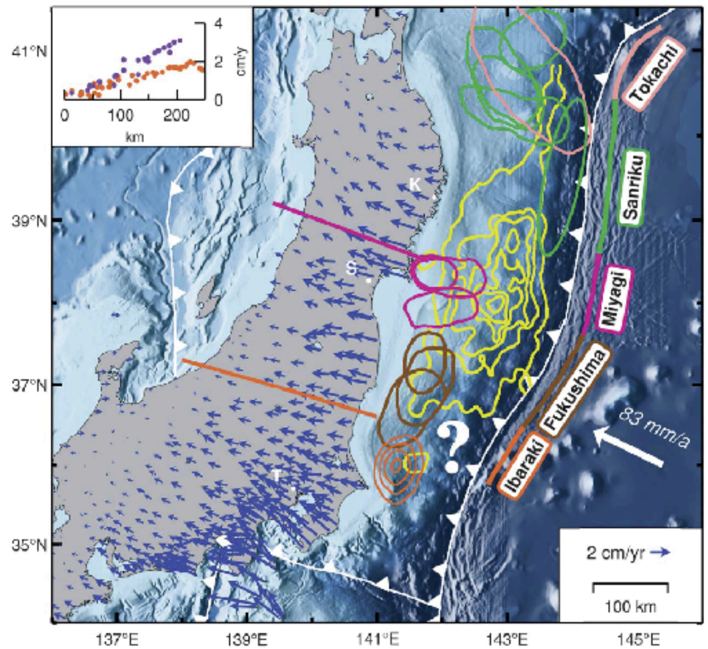
Van Keken, EPSL, 2003

Seismic cycle on subduction thrusts

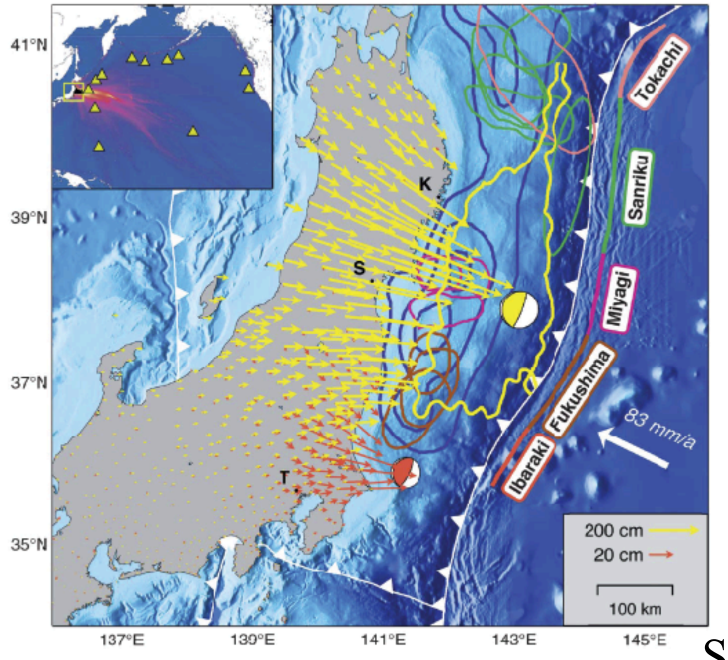
2004 M9.2 Sumatra

2010 M8.8 Maule

2011 M9.0 Tohoku



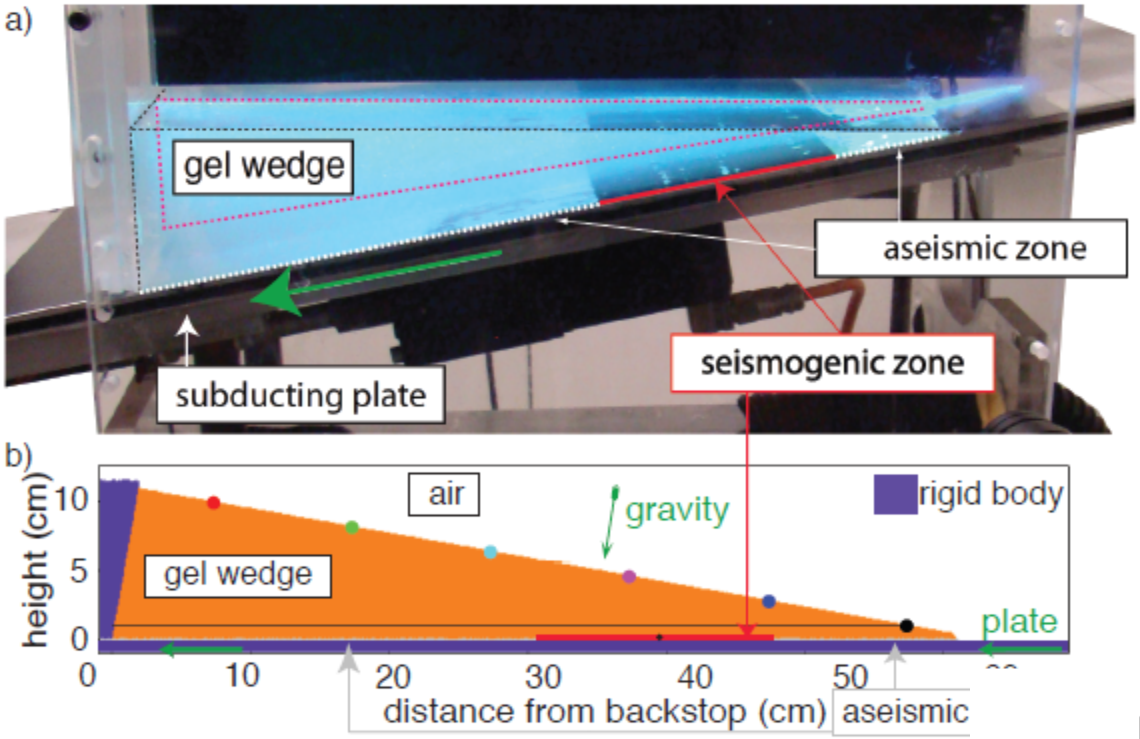
interseismic



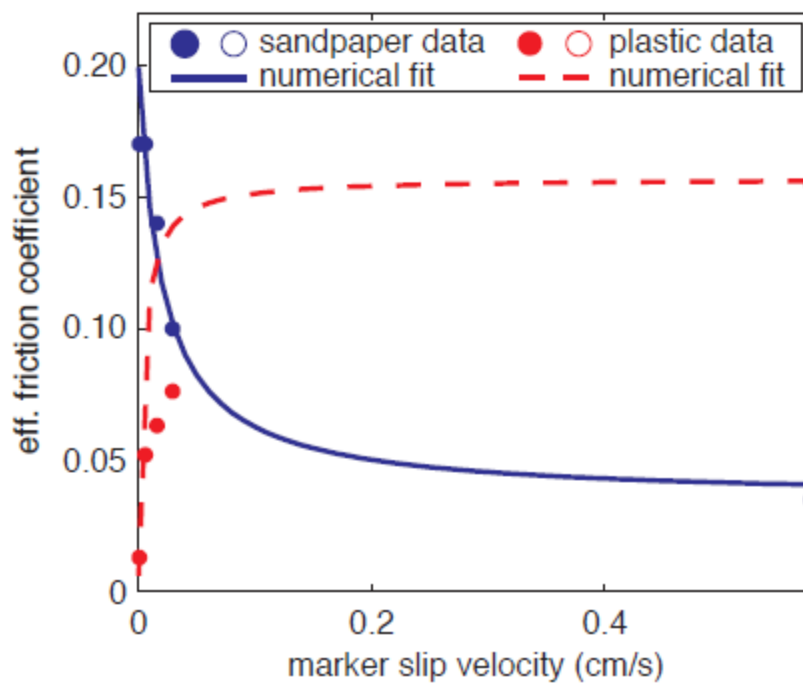
coseismic

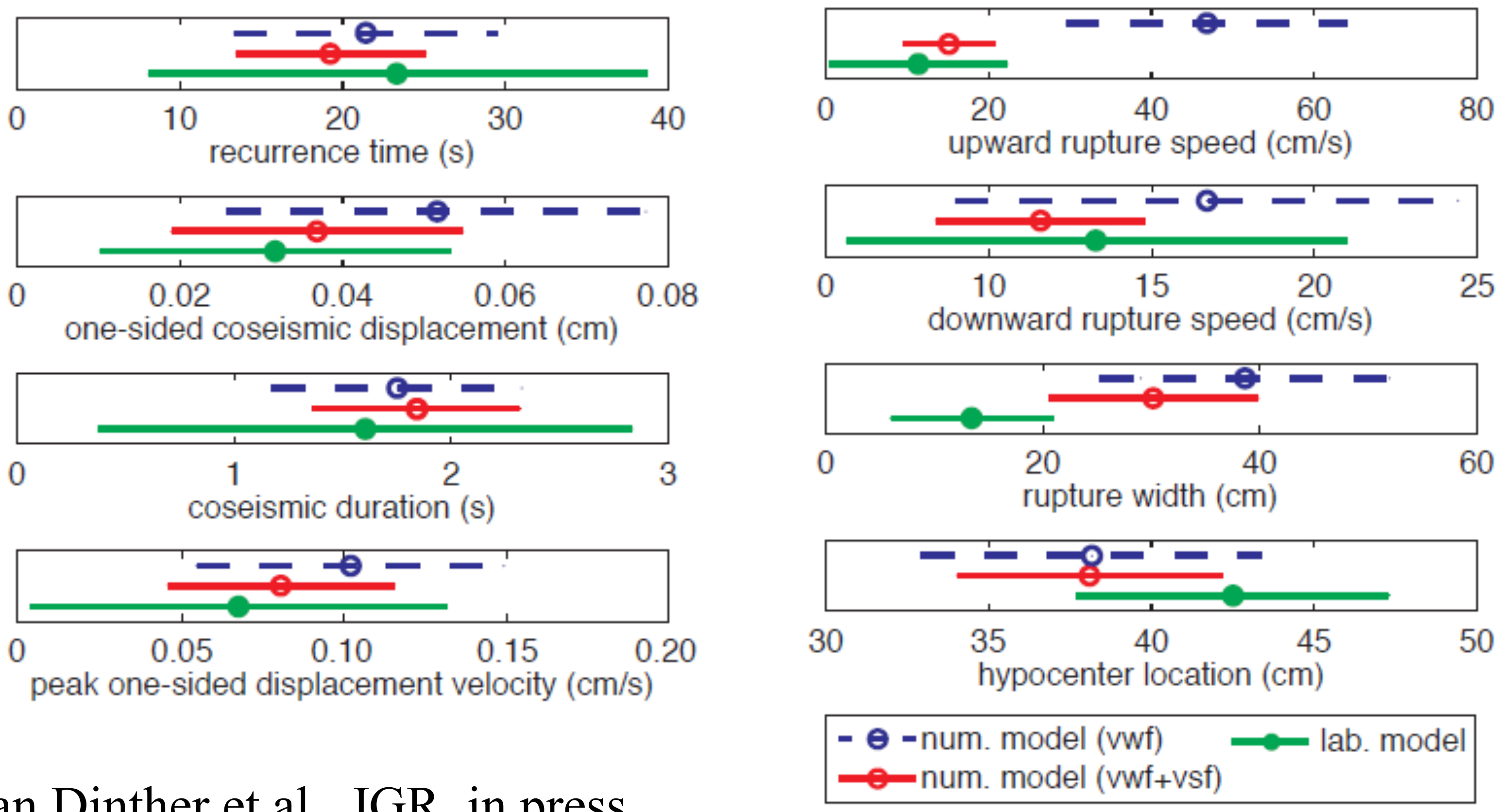
Simons et al. [2011]

Slide provided by Ylona Van Dinther (ETH)



Van Dinther et al., JGR, in press





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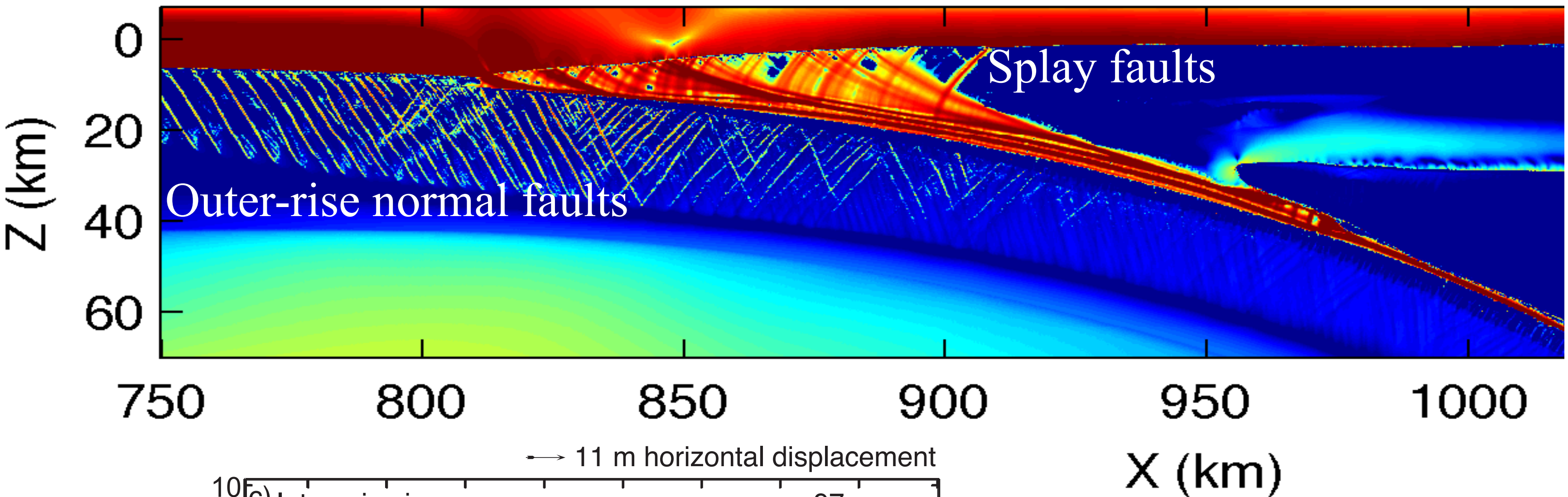
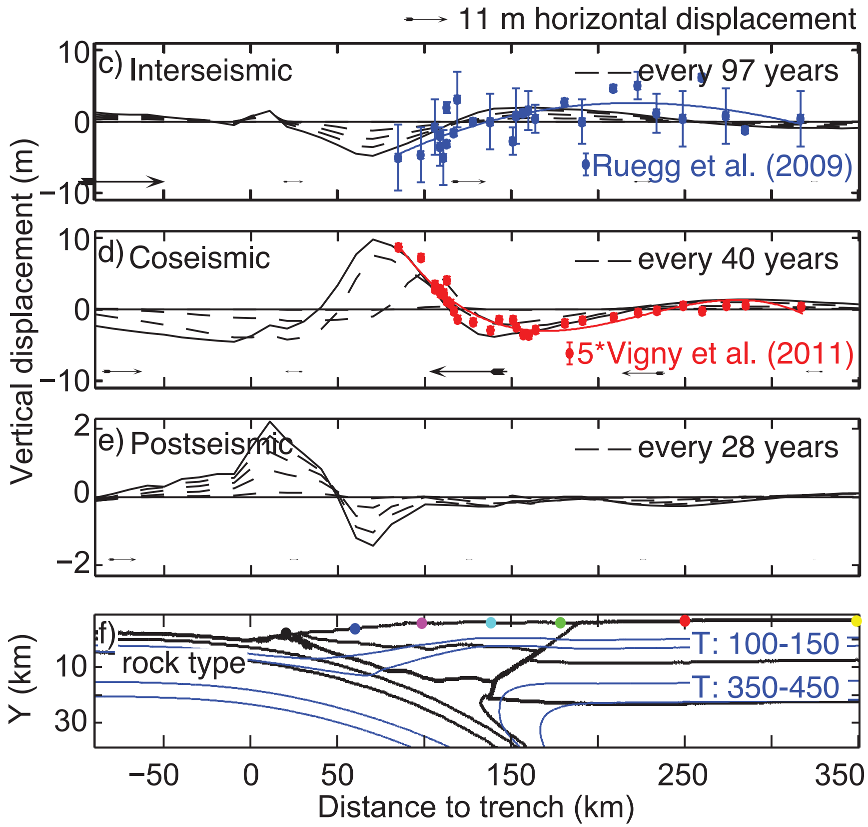
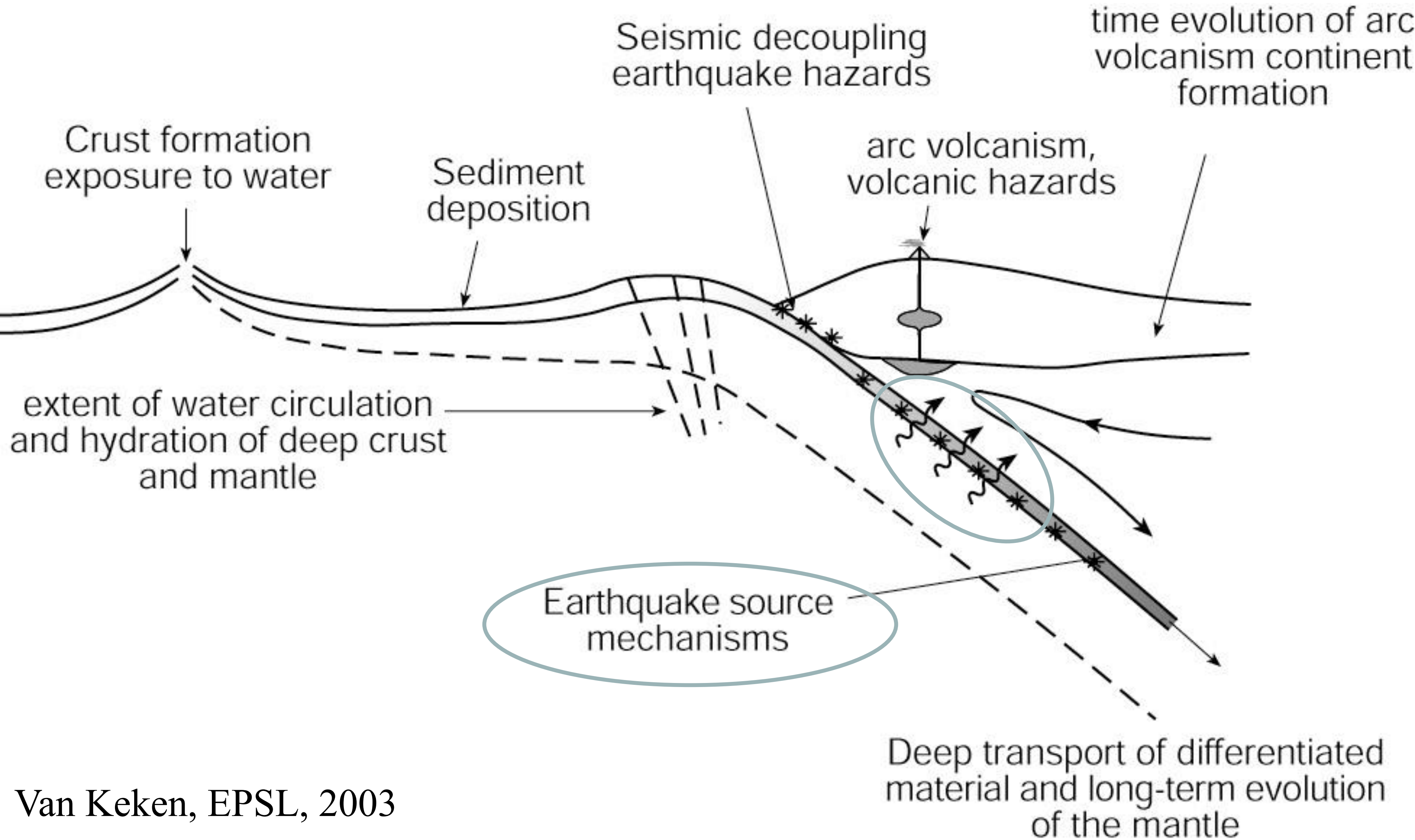




van Dinther et al. (in prep.)

II Thermal state and dehydration in subduction crust



Van Keken, EPSL, 2003

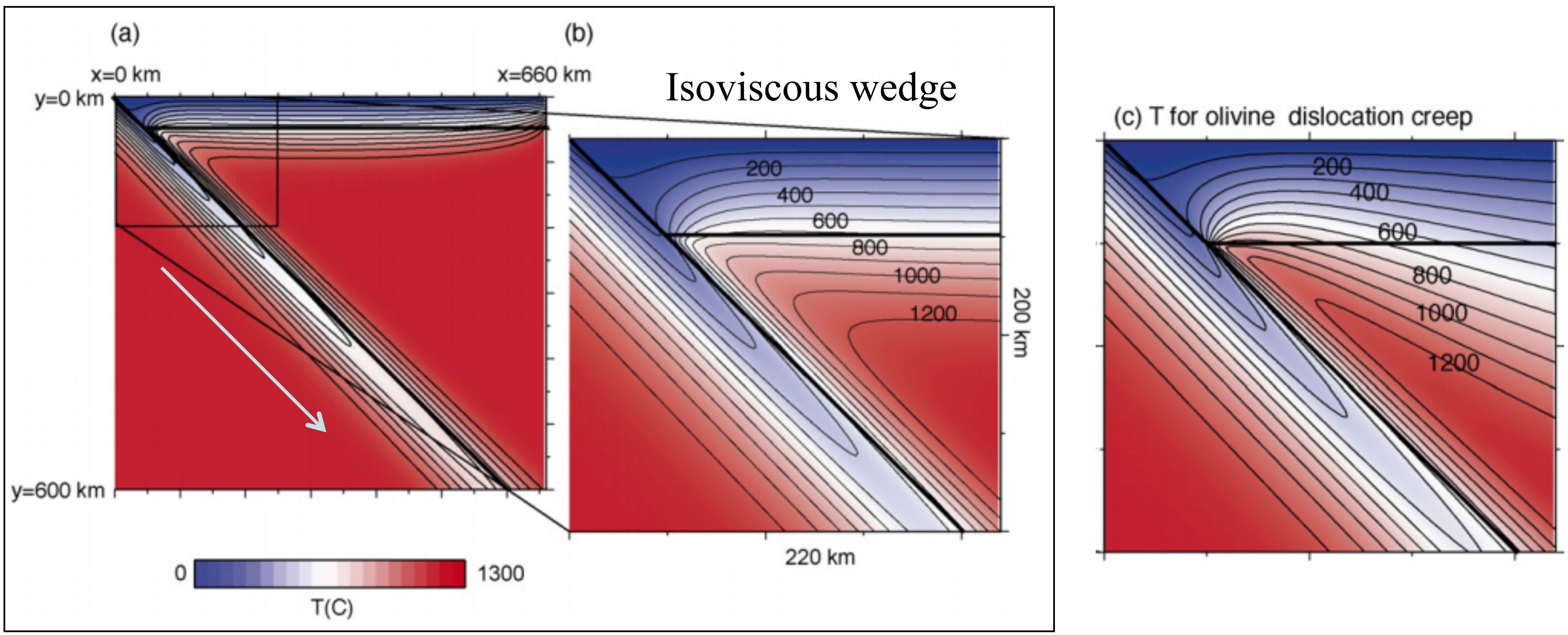
ELSEVIER

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

A community benchmark for subduction zone modeling

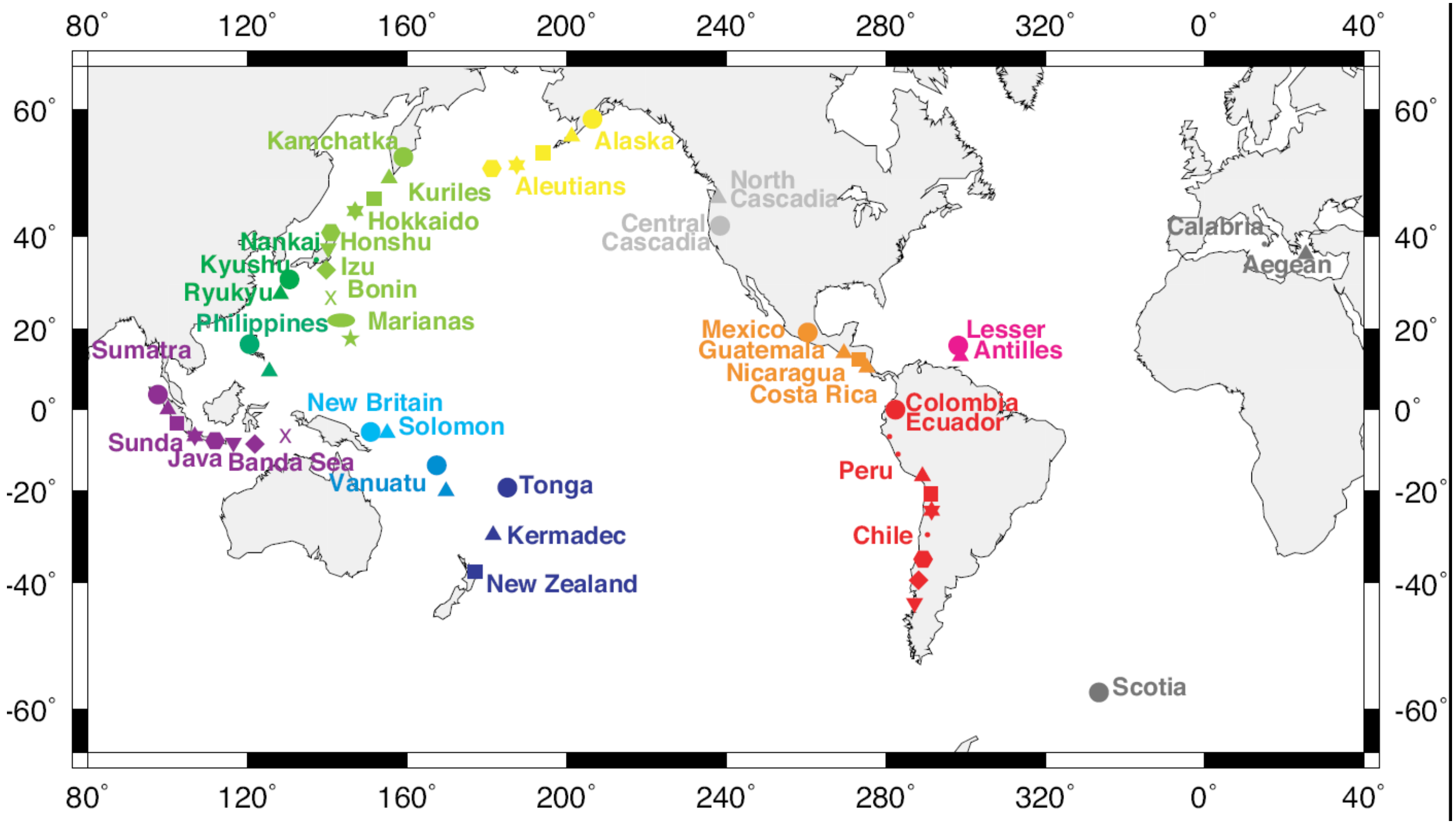
Peter E. van Keken[a,*], Claire Currie[b], Scott D. King[c], Mark D. Behn[d], Amandine Cagnioncle[h], Jiangheng He[e], Richard F. Katz[f,g], Shu-Chuan Lin[i], E. Marc Parmentier[h], Marc Spiegelman[f], Kelin Wang[e]

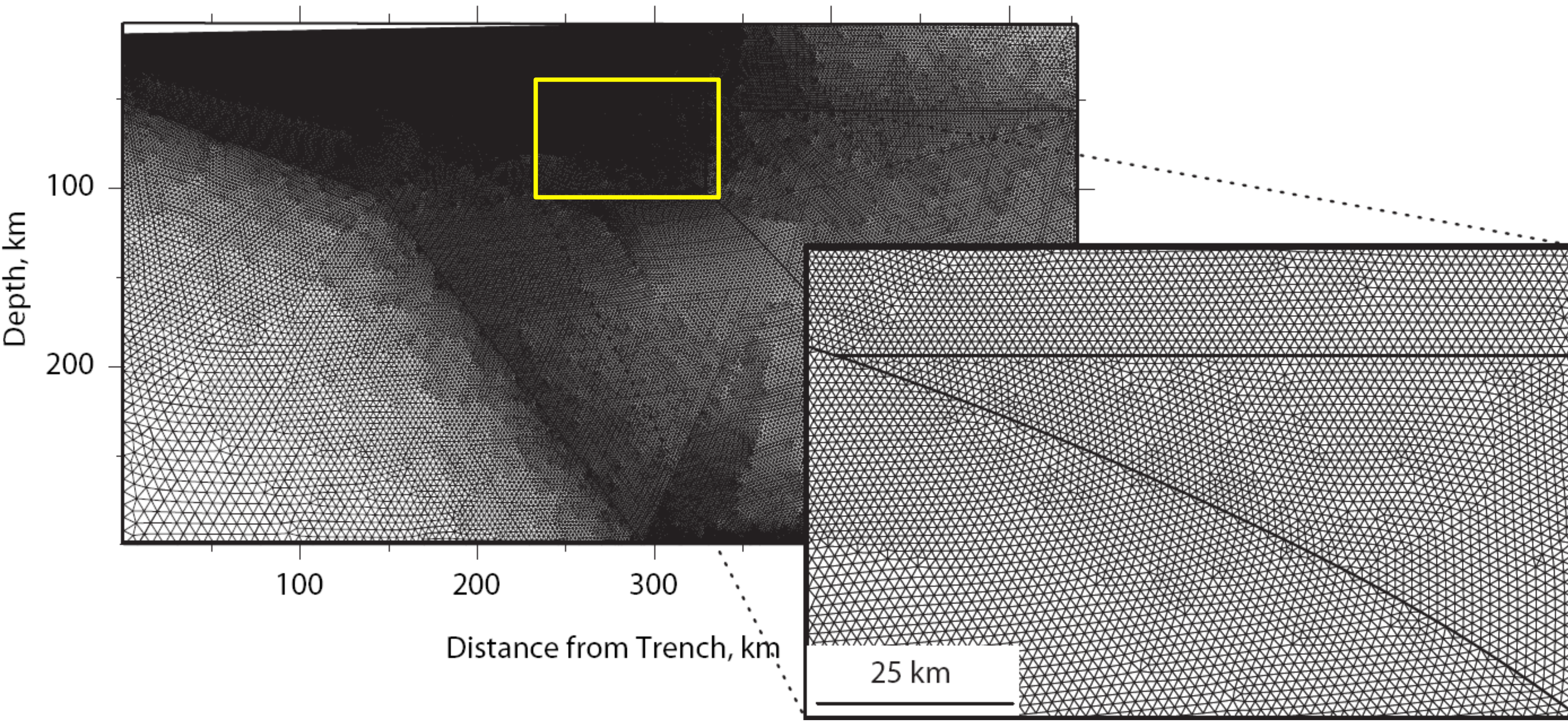


The global range of subduction zone thermal models

Ellen M. Syracuse[a,*], Peter E. van Keken[b], Geoffrey A. Abers[c]

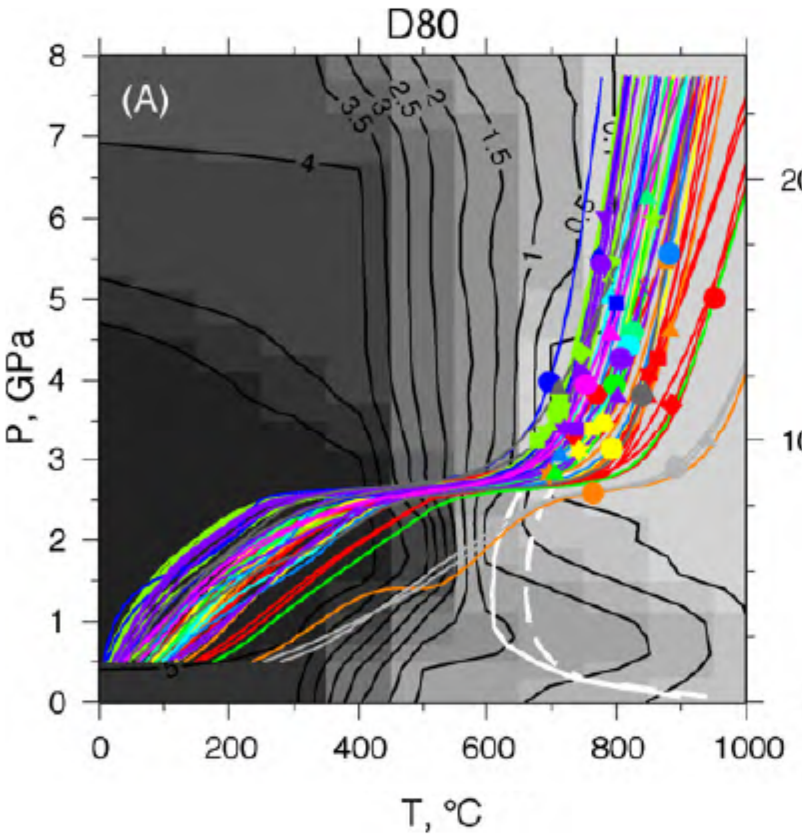
[a] Department of Geoscience, University of Wisconsin, 1215 W. Dayton St., Madison, WI 53706, USA
[b] Department of Geological Sciences, University of Michigan, 1100 North University Avenue, Ann Arbor, MI 48109-1005, USA
[c] Lamont-Doherty Earth Observatory, Columbia University, PO Box 1000, 61 Rte 9W, Palisades, NY 10964, USA



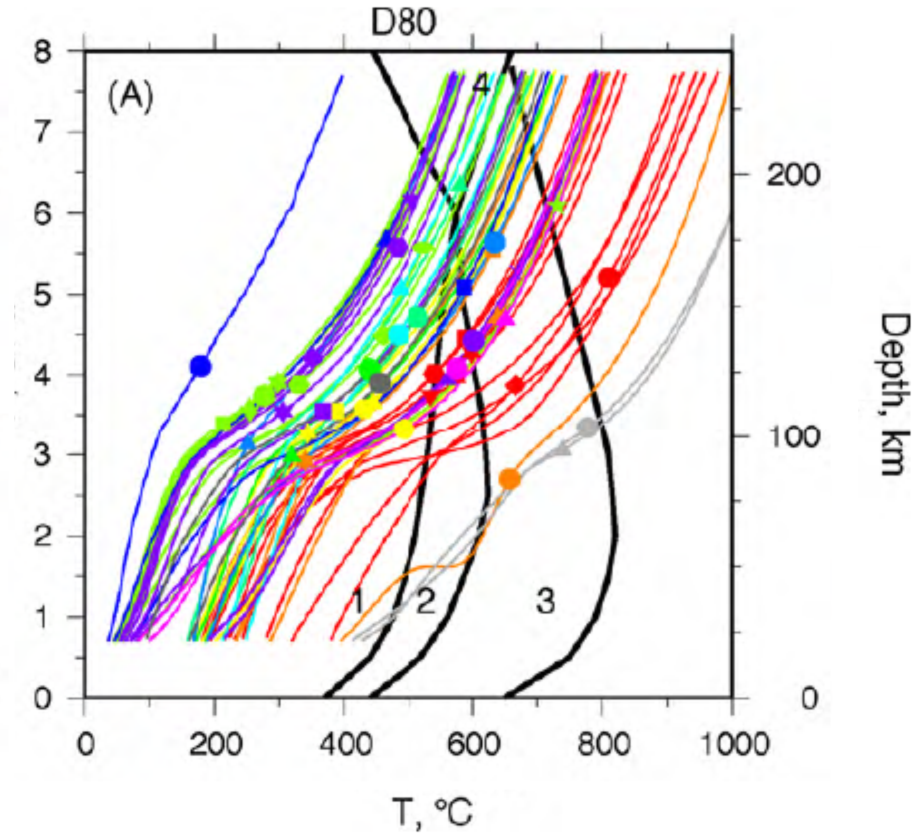


Syracuse et al., PEPI, 2010
Subduction zone benchmark in Van Keken et al., PEPI, 2008

T at top of slab



T at oceanic Moho



Models assume constant coupling depth of 80 km

Syracuse et al., PEPI, 2010

increasing p,T → H_2O

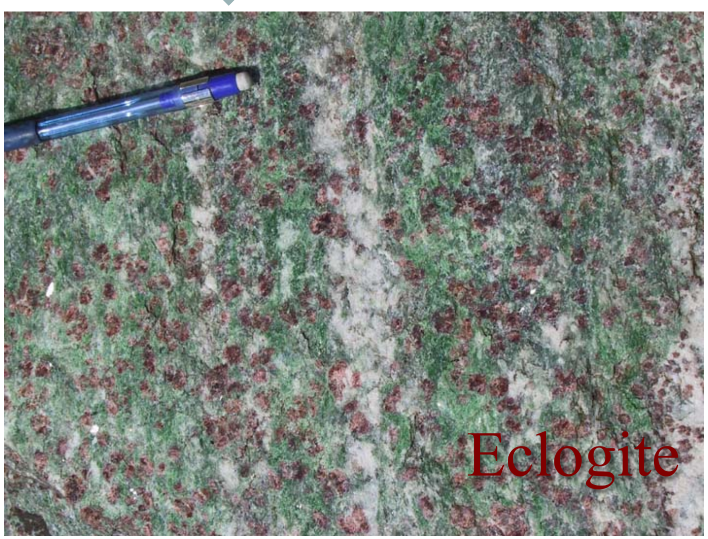
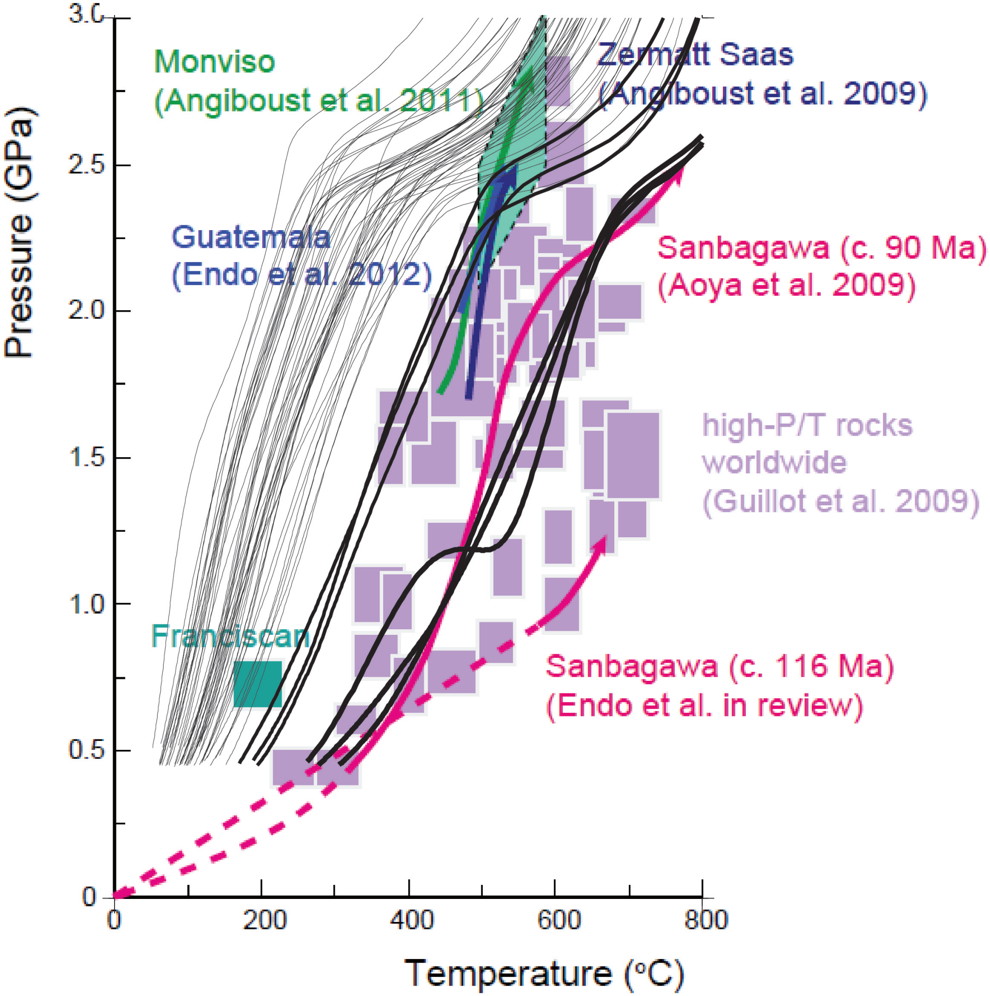
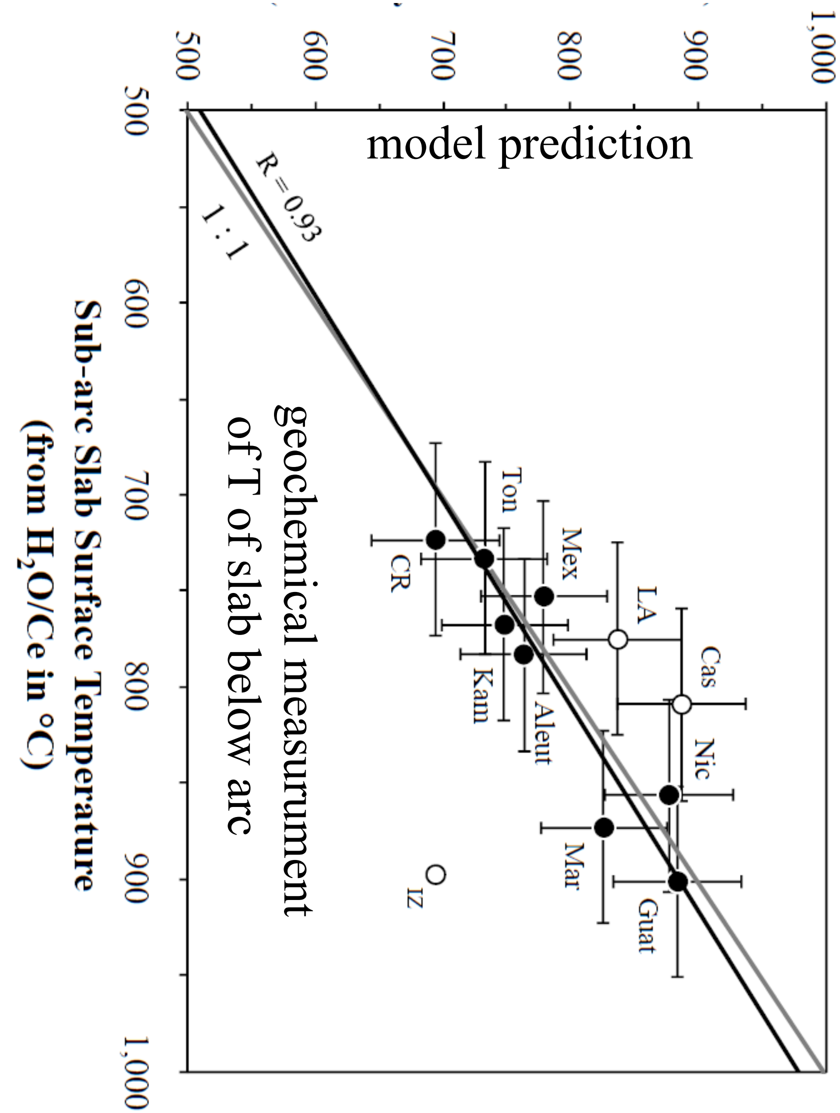


Photo by Brad Hacker

Models of warm SZ match petrological conditions in exhumed terranes

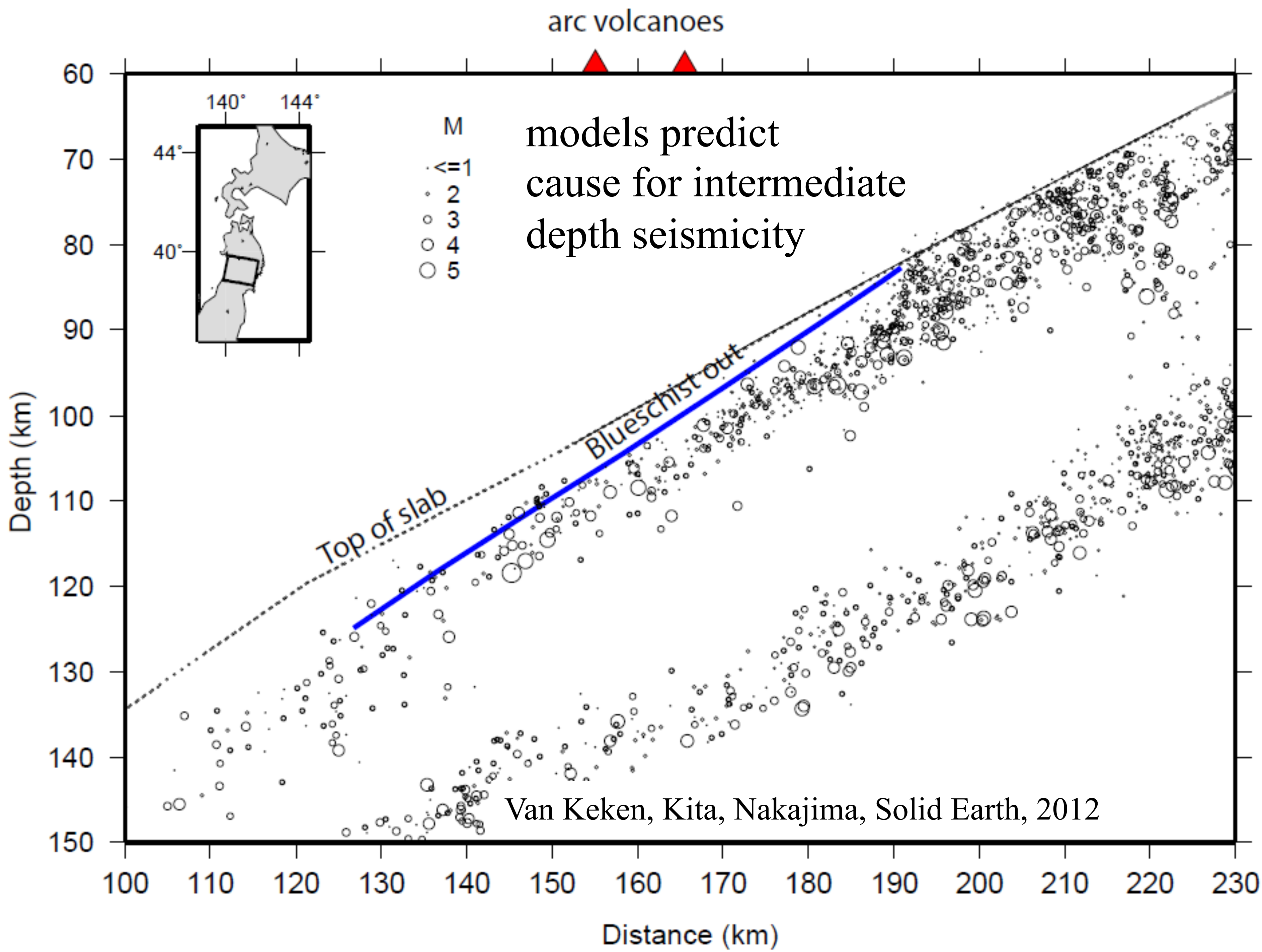


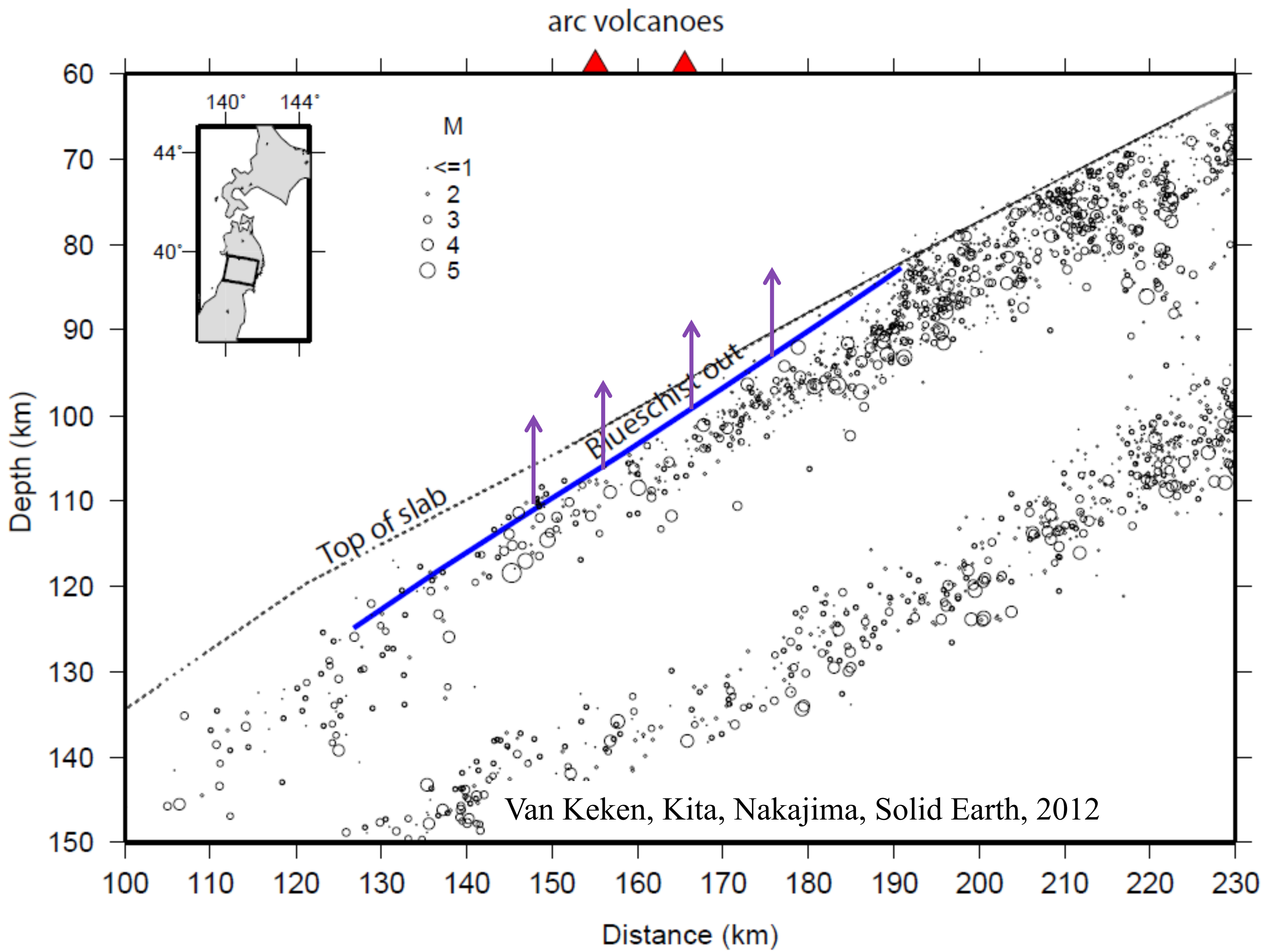
Models match geochemistry



Compilation by Simon Wallis (Nagoya)

Cooper et al., G3, 2012


arc volcanoes
models predict
cause for intermediate
depth seismicity
M
<=1
2
3
4
5
140°
144°
44°
40°
Top of slab
Blueschist out
Van Keken, Kita, Nakajima, Solid Earth, 2012
Depth (km)
Distance (km)
60
70
80
90
100
110
120
130
140
150
100
110
120
130
140
150
160
170
180
190
200
210
220
230



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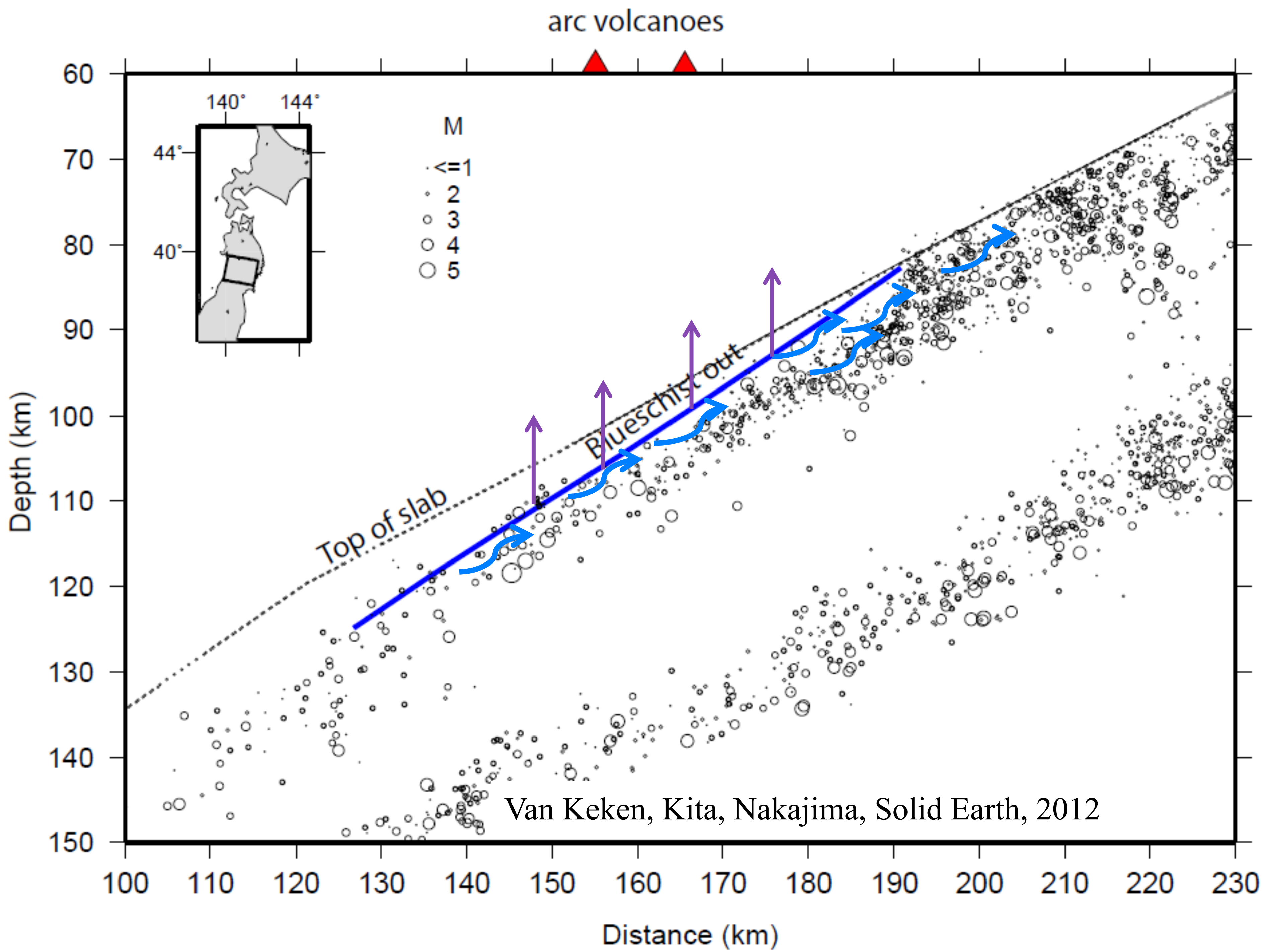

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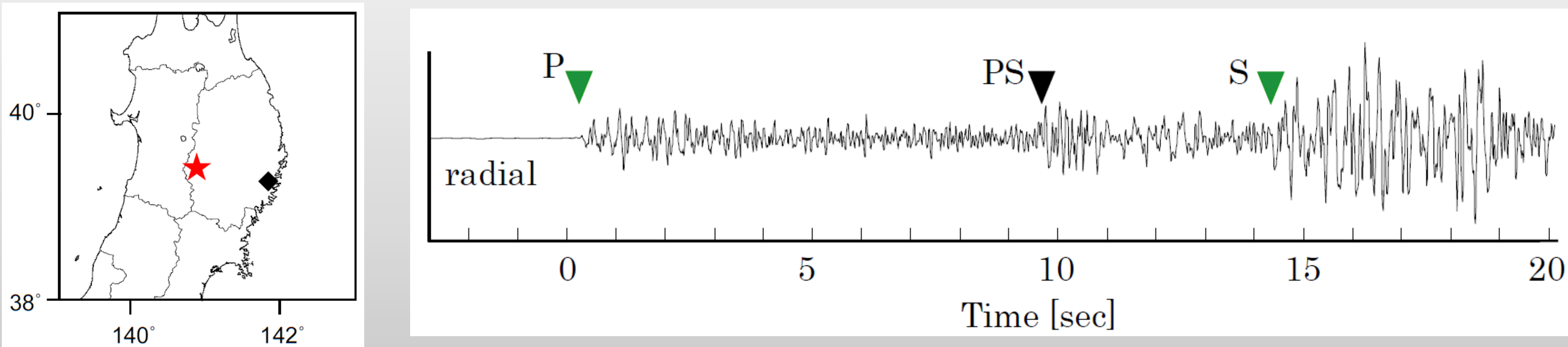
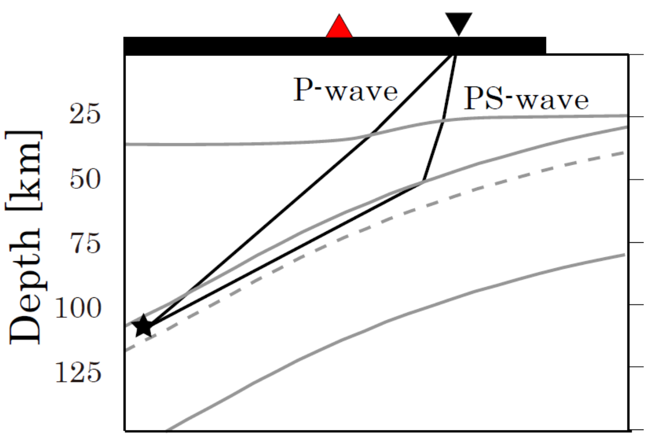
Van Keken, Kita, Nakajima, Solid Earth, 2012

Very low P-wave velocity in upper crust below Tohoku (Shiina, Nakajima and Matsuzawa)

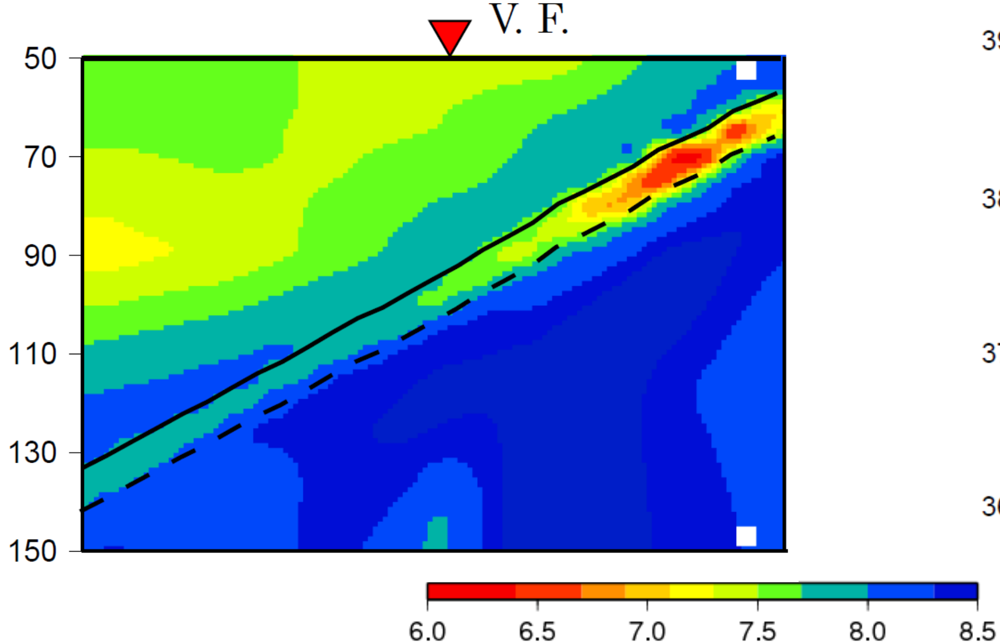




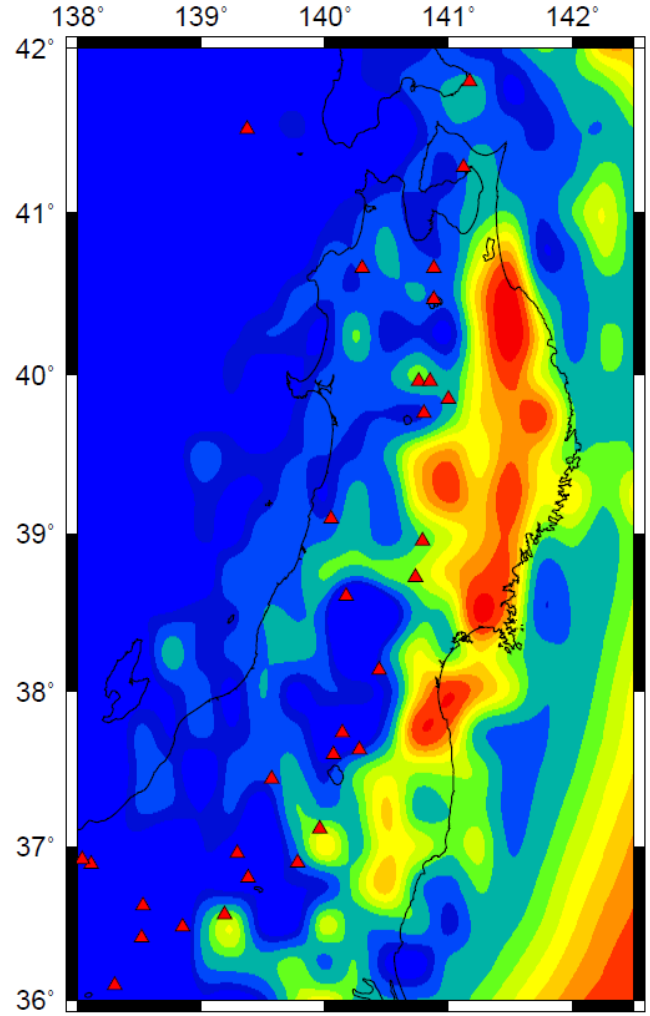
A schematic figure of a PS wave

P-wave velocity < 7.2 km/s suggest presence of free fluids

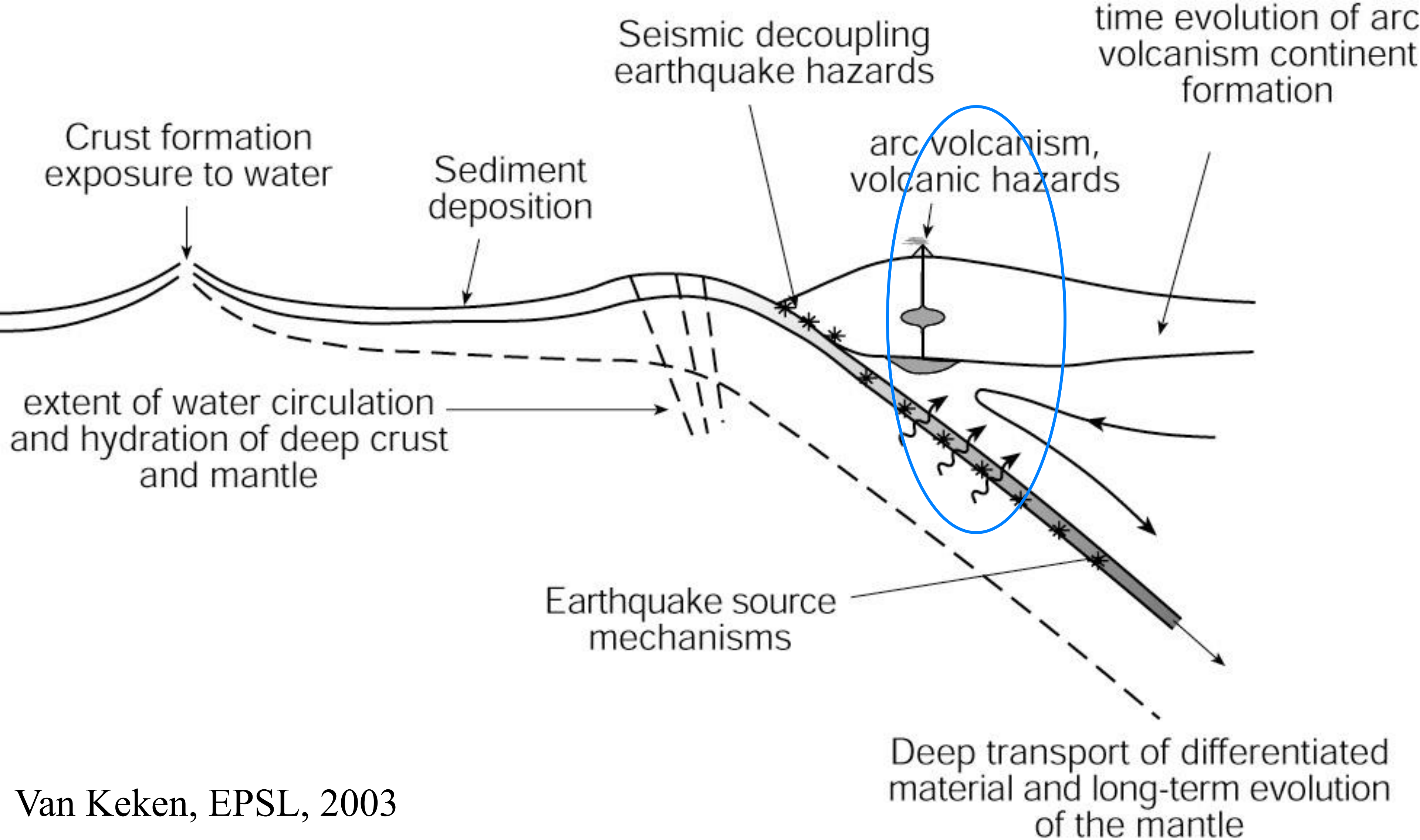
Shiina, Nakajima and Matsuzawa



Vp [km/s]



Migration of fluids and melt below the arc



Van Keken, EPSL, 2003

From Slab to Arc: Modeling the migration of fluids in subduction zones

Cian R. Wilson[1]

Marc Spiegelman[1,2], Peter E. Van Keken[3]

FEniCS:
fenicsproject.org

Logg et al. (2012)

PETSc:
www.mcs.anl.gov/petsc

PETSc

Balay et al. (2012)

SPuD:
amcg.ese.ic.ac.uk/Spud

Ham et al. (2009)

Magma Dynamics

(e.g. McKenzie, 1984, Spiegelman, 1993, Bercovici et al., 2003, Katz et al, 2007,Simpson et al, 2010

Conservation Equations

Mass: Fluid Phase

$$\frac{\partial \rho_f \phi}{\partial t} + \nabla \cdot [\rho_f \phi \mathbf{v}] = \Gamma$$

Mass: Solid Phase

$$\frac{\partial \rho_s (1-\phi)}{\partial t} + \nabla \cdot [\rho_s (1-\phi) \mathbf{V}] = -\Gamma$$

Momentum: Fluid Phase

$$\phi(\mathbf{v} - \mathbf{V}) = -\frac{k_\phi}{\mu} [\nabla P - \rho_f \mathbf{g}]$$

Momentum: Solid Phase

$$\nabla P = \nabla \cdot \left(\eta \left[\nabla \mathbf{V} + \nabla \mathbf{V}^T \right] \right) + \nabla \left[\left(\zeta - \frac{2}{3}\eta \right) \nabla \cdot \mathbf{V} \right] + \bar{\rho} \mathbf{g}$$

Basic physics of fluid flow

General rule of thumb for melt motion

$$\mathbf{v} = \mathbf{V} + \frac{w_0}{U_0}\nabla P$$

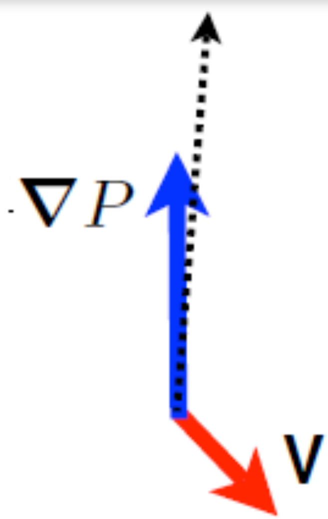
where in general

Buoyancy — Dynamic Pressure — Comp. Pressure

$$\nabla P = \Delta\rho\mathbf{g} + \nabla\cdot\eta(\nabla\mathbf{V} + \nabla\mathbf{V}^T) + \nabla\zeta\nabla\cdot\mathbf{V}$$

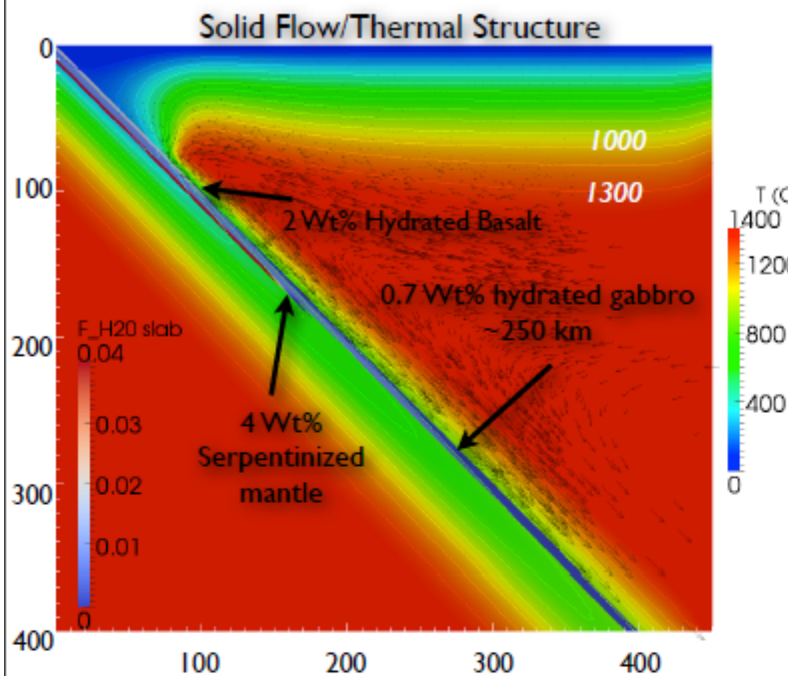
Separation Velocity

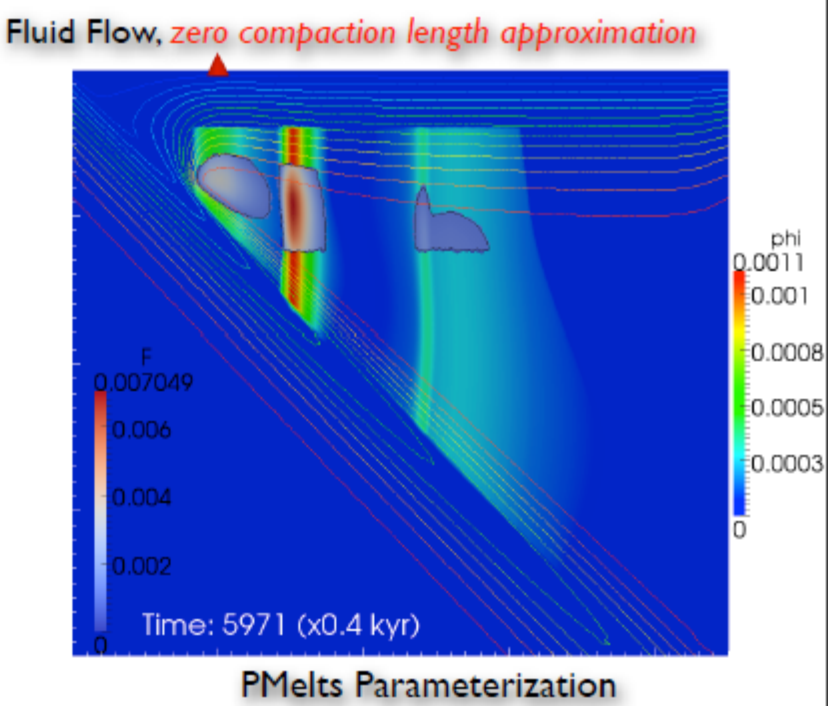
$$w_0 = \frac{K(\phi)\Delta\rho g}{\phi\mu}$$

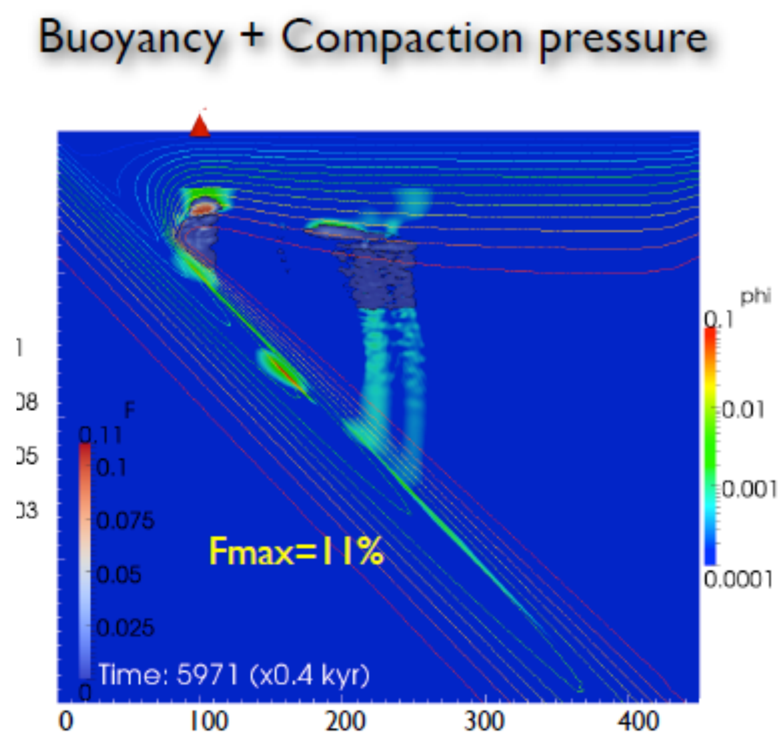


$$\frac{w_0}{U_0} >> 1$$

fluid flow with ‘more’ realistic physics leads to focusing of melt & more realistic magmatic conditions

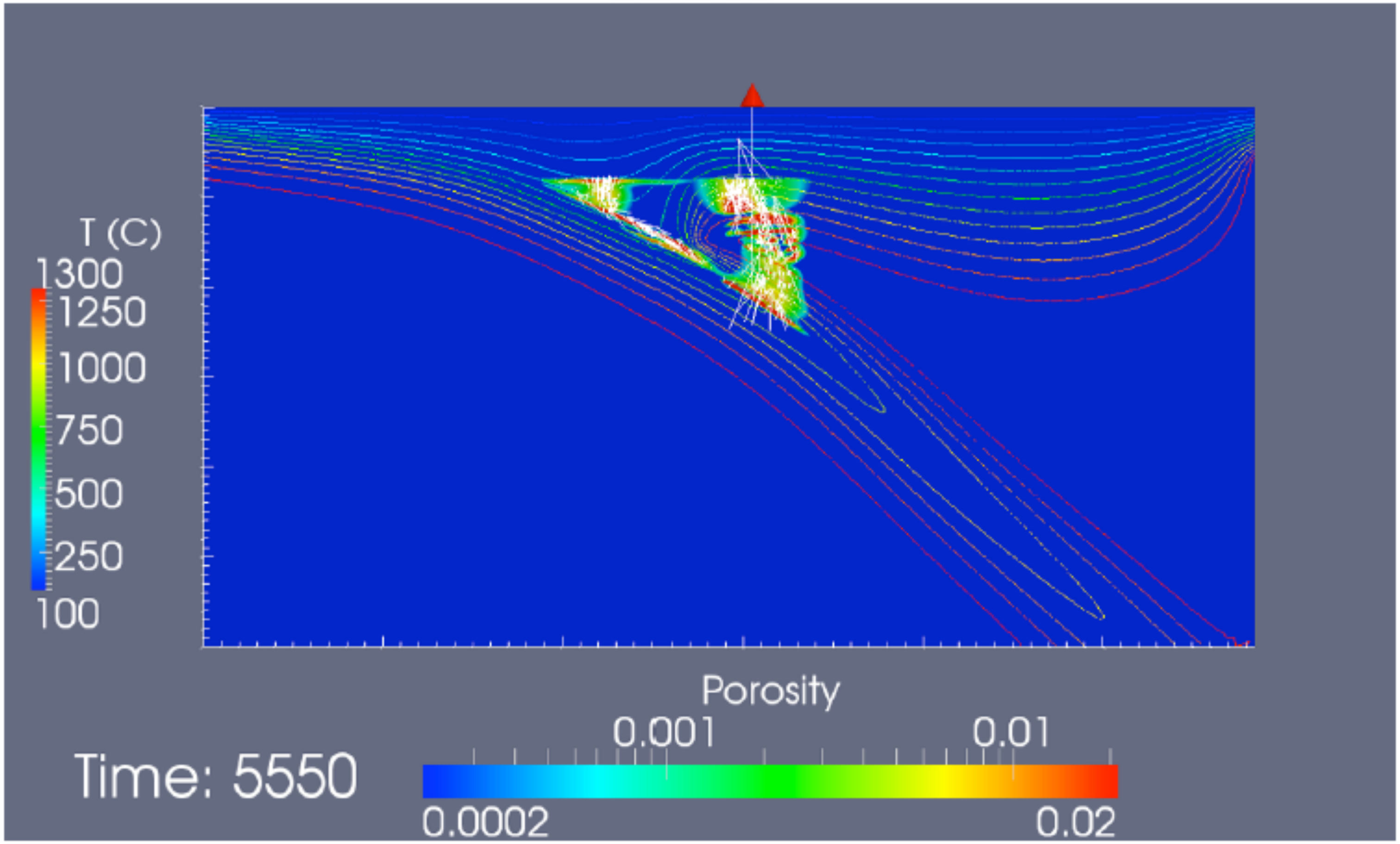






More realistic geometries

Cascadia



Prediction for Cascadia:
melt is sourced from serpentinized mantle

Modeling….

Is a tool in hypothesis development and testing
Requires verification, validation, benchmarking
Aids in synthesis & development of understanding of complex physical & chemical processes
Needs to (try to) keep up with advances in the computational sciences
Is an essential part of GeoPRISMS science

GeoPRISMS
Geodynamic Processes at Rifting and Subducting Margins
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with thanks to Cian Wilson, Marc Spiegelman, Ellen Syracuse, Brad Hacker, Geoff Abers, Ylona van Dinther, Juli Morgan, Simon Wallis