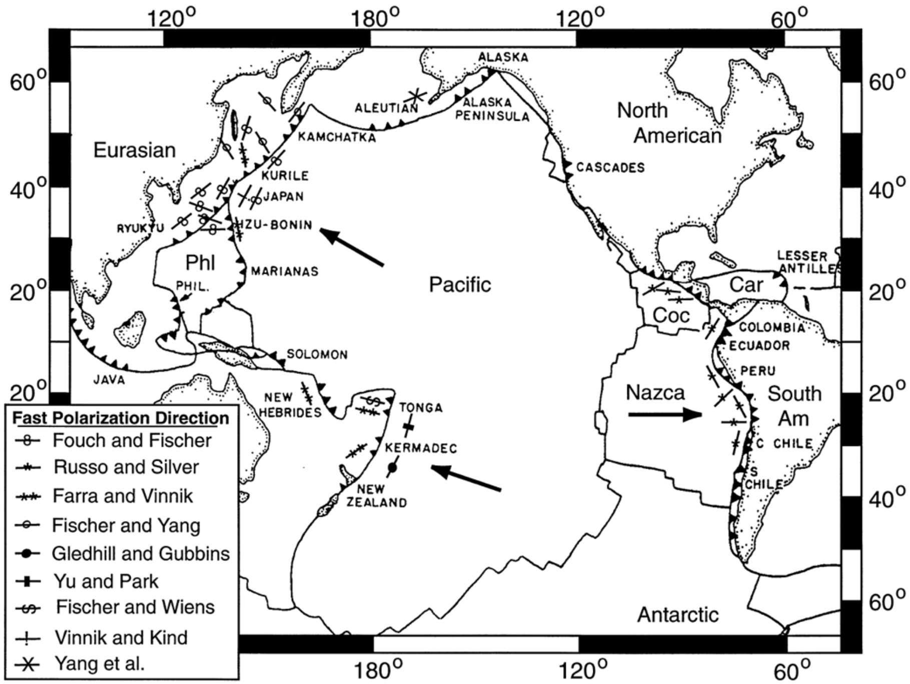
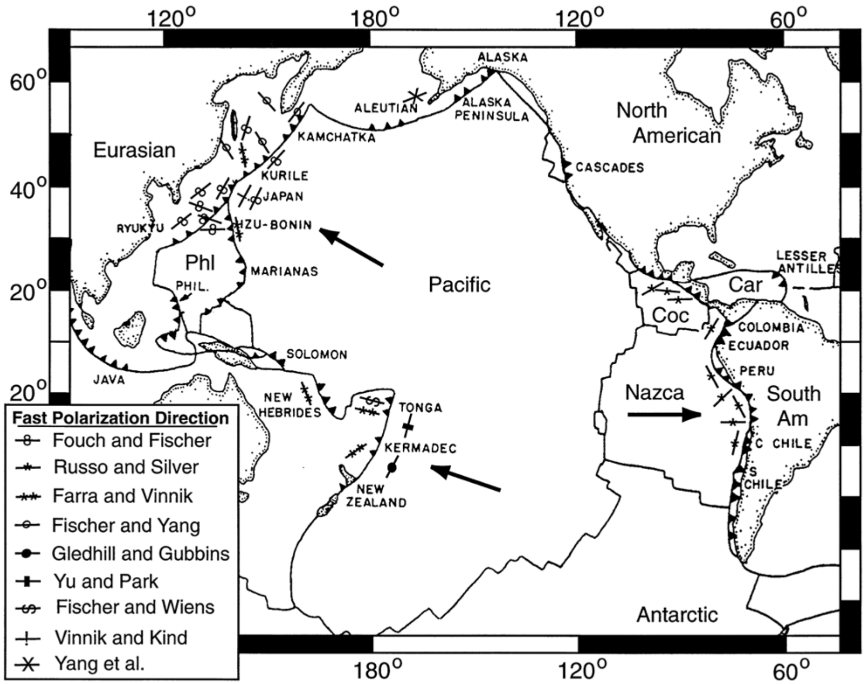
# Subduction-induced mantle flow

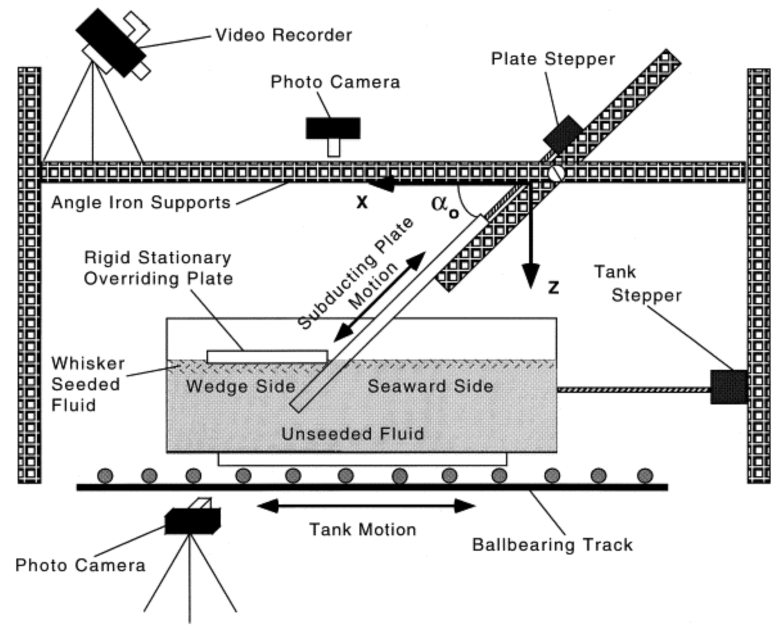
# Old analog models




Buttles & Olson, 1998

# Old analog models




Buttles & Olson, 1998

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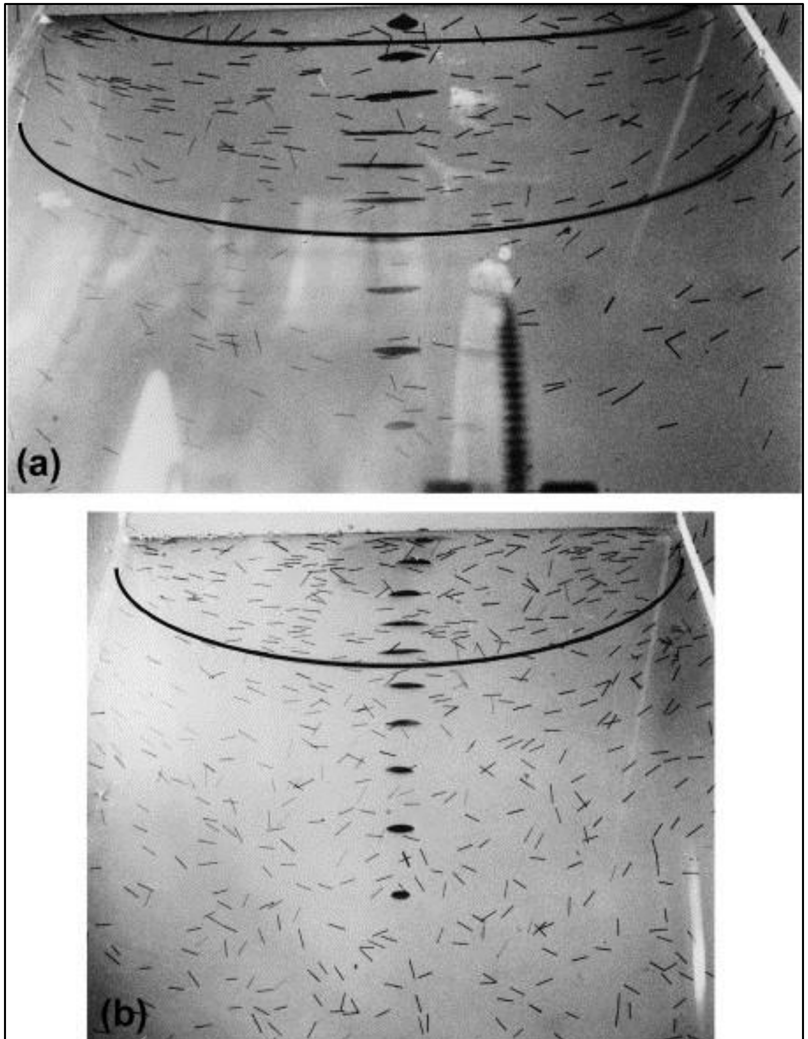
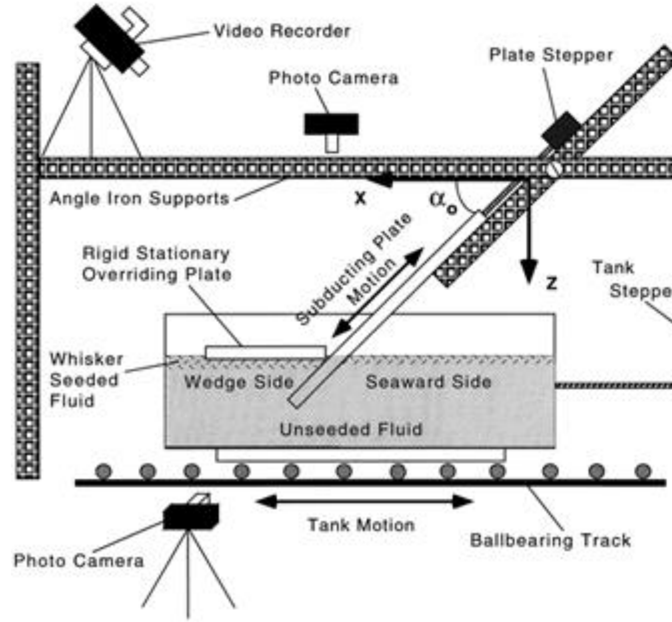
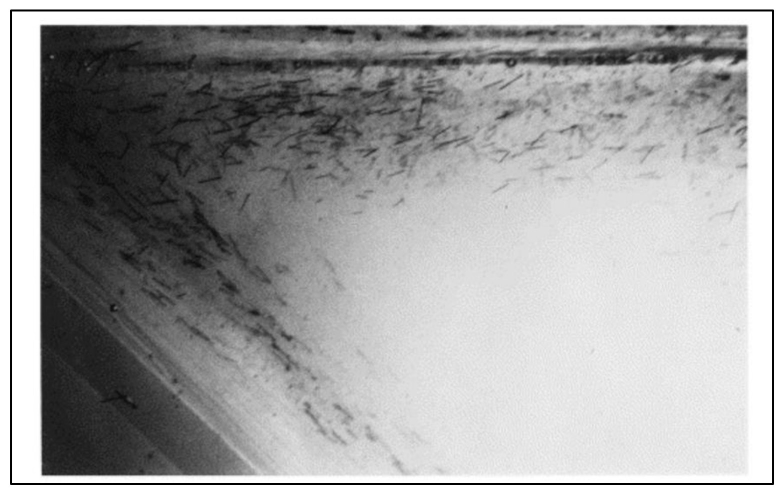


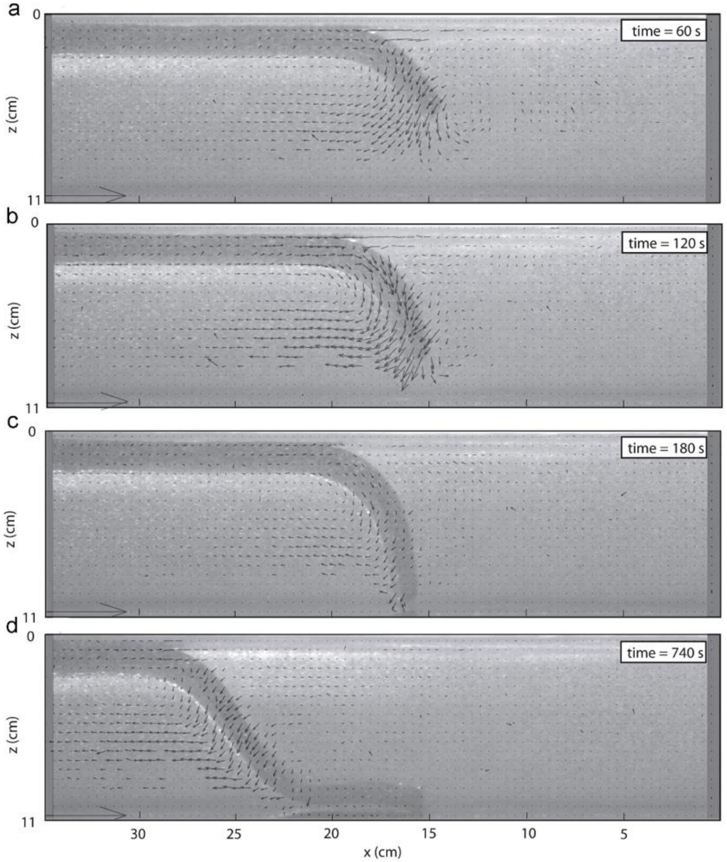



Buttles & Olson, 1998

# Funiciello's analog models

Cross-section

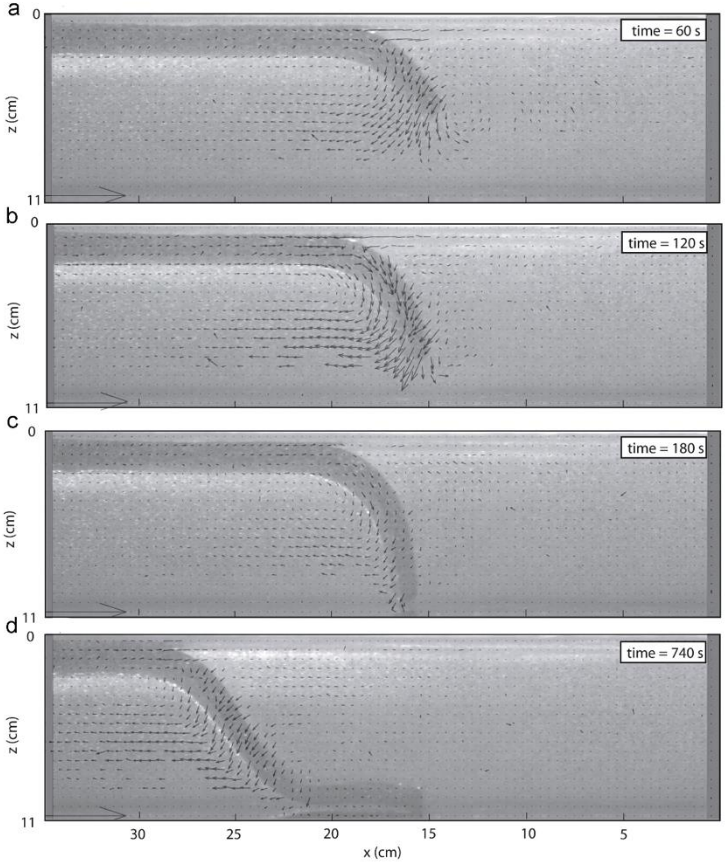



Funiciello et al., 2006

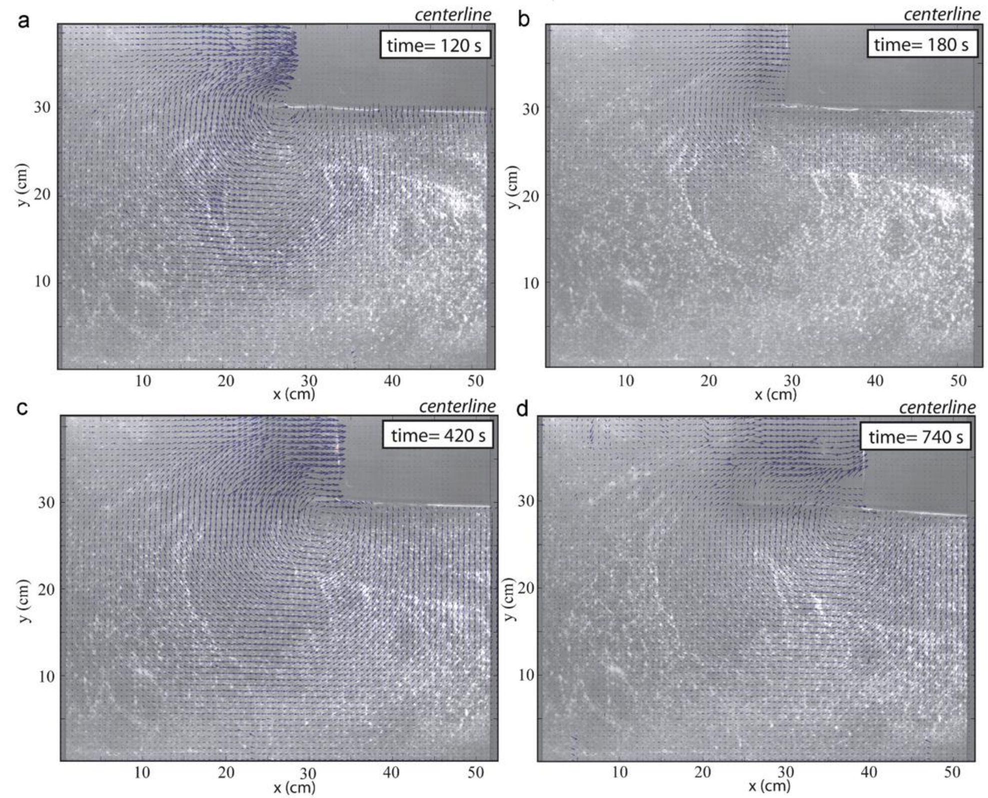
Cf. Funiciello et al., 2003; 2004

# Funiciello's analog models

Cross-section




Plan view

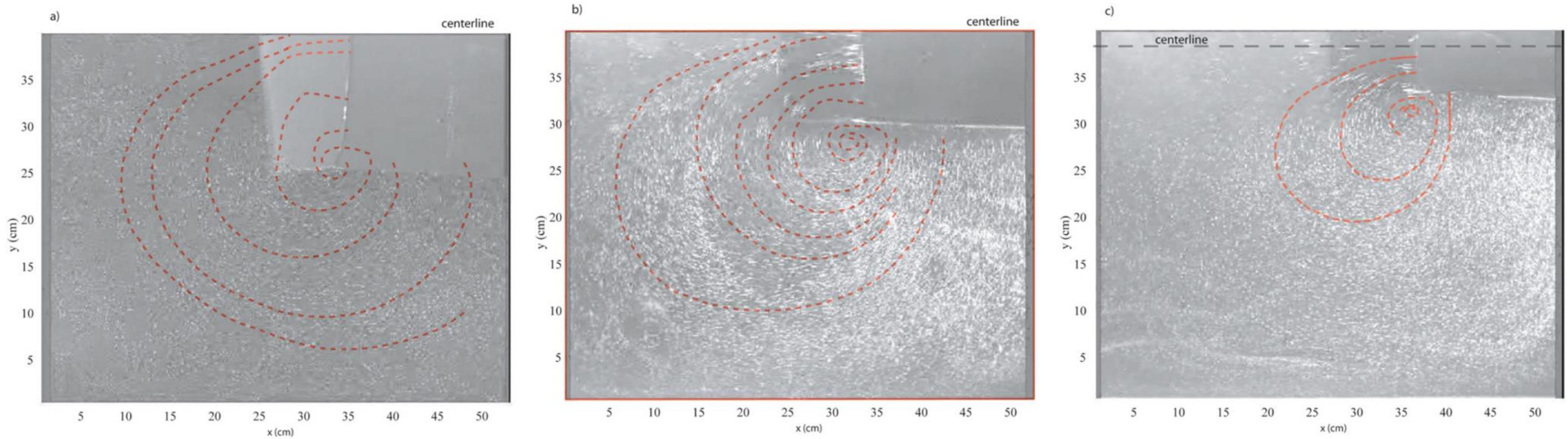



Funiciello et al., 2006

Cf. Funiciello et al., 2003; 2004

# Funiciello's analog models

Variable plate widths




Funiciello's conclusions:

(1) poloidal and toroidal mantle circulation both active since the start of subduction;
(2) mantle circulation is intermittent;
(3) plate width affects the velocity and the dimension of subduction induced mantle circulation area;
(4) mantle flow in subduction zones cannot be correctly described by models assuming a 2-D steady state process.

Funiciello et al., 2006

Cf. Funiciello et al., 2003; 2004

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L08304, doi:10.1029/2005GL025390, 2006

# Three-dimensional instantaneous mantle flow induced by subduction

C. Piromallo,[1] T. W. Becker,[2] F. Funiciello,[3] and C. Faccenna[3]

Received 2 December 2005; revised 16 February 2006; accepted 16 March 2006; published 19 April 2006.

[1] We conduct three-dimensional subduction experiments by a finite element approach to study flow around slabs, which are prescribed based on a transient stage of upper mantle subduction from a laboratory model. Instantaneous velocity field solutions are examined, focusing on the toroidal *vs*. poloidal components as a function of boundary conditions, plate width, and viscosity contrast between slab and mantle. We show how the slab-to-mantle viscosity ratio determines the strength of toroidal flow, and find that the toroidal flow component peaks for slab/mantle viscosity ratios ~100, independent of slab width or geometry.

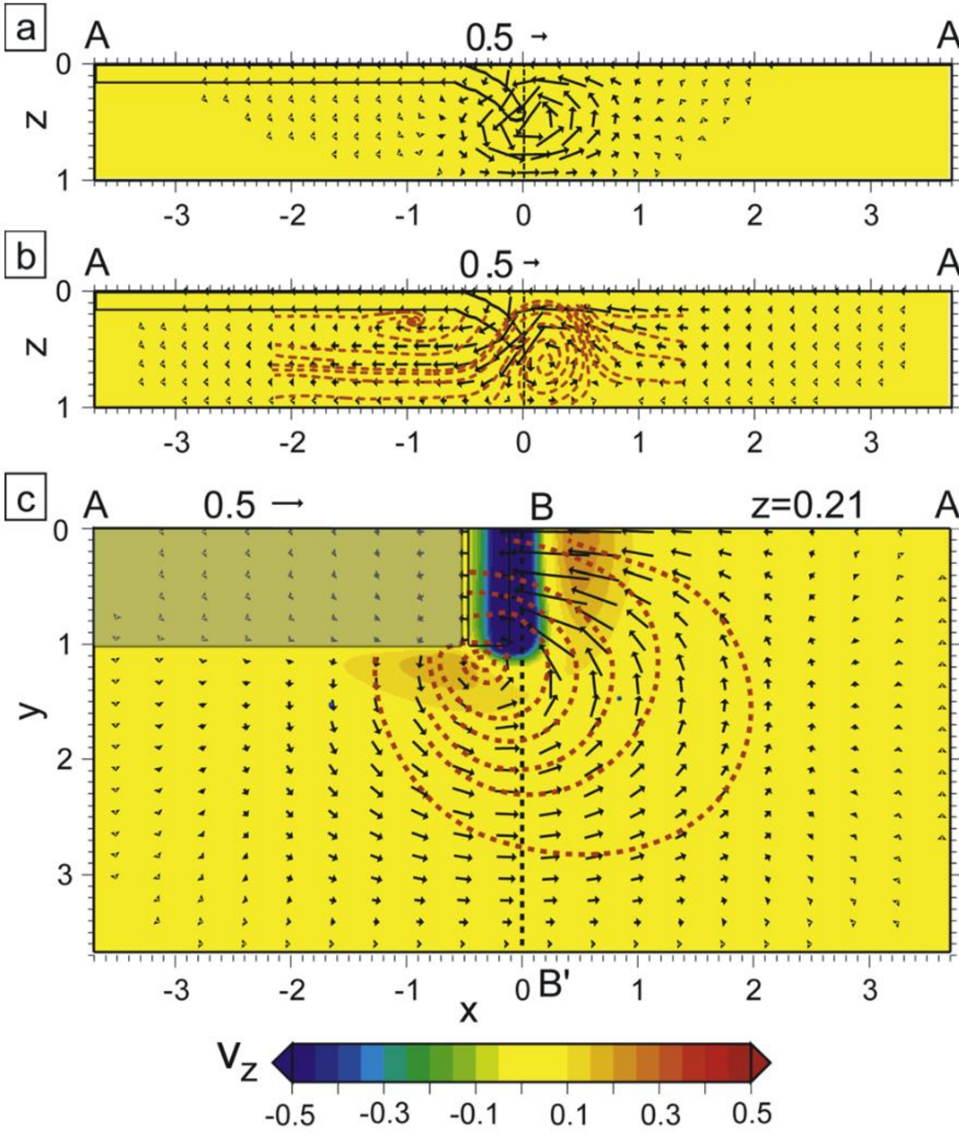
**Citation:** Piromallo, C., T. W. Becker, F. Funiciello, and C. Faccenna (2006), Three-dimensional instantaneous mantle flow induced by subduction, *Geophys. Res. Lett.*, *33*, L08304, doi:10.1029/2005GL025390.

# Example mantle flow field

2-D

3-D

3-D

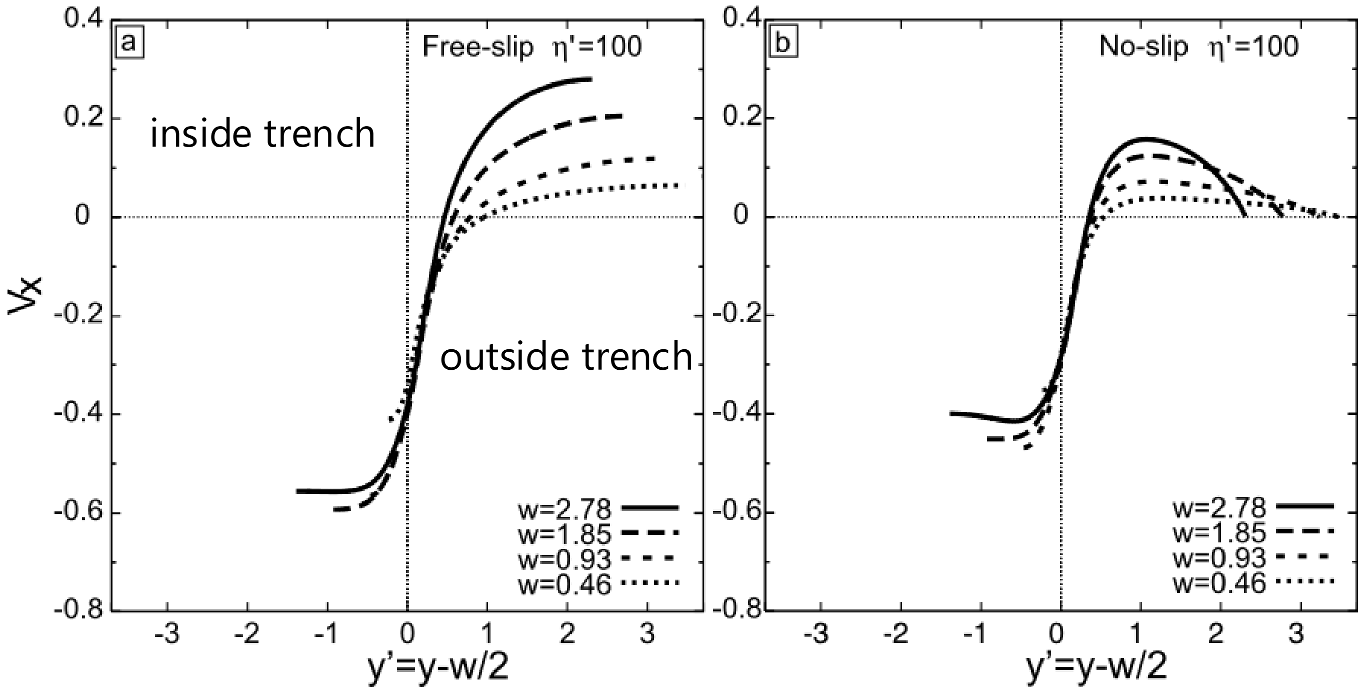



Funiciello et al., 2006

Piromallo et al., 2006

# Role of plate width and boundary conditions

Trench-perpendicular mantle flow velocities just in-front of the slab




- More vigorous around-slab horizontal flow for wider trenches.
- No slip BCs have damping effect on around-slab mantle flow

Piromallo et al., 2006

# Flow decomposition

2-D velocities on each layer expressed as a sum of an irrotational and a divergence-free field:

$$\underline{v}_h \equiv \underline{v}_{h,\mathrm{pol}} + \underline{v}_{h,\mathrm{tor}} \equiv \underline{\nabla}_h \varphi + \underline{\nabla} \times (\psi \hat{z})$$

Taking the horizontal divergence of this yields Poisson equation for the poloidal velocity potential, and taking the vertical vorticity yields a Poisson equation for the toroidal velocity scalar:

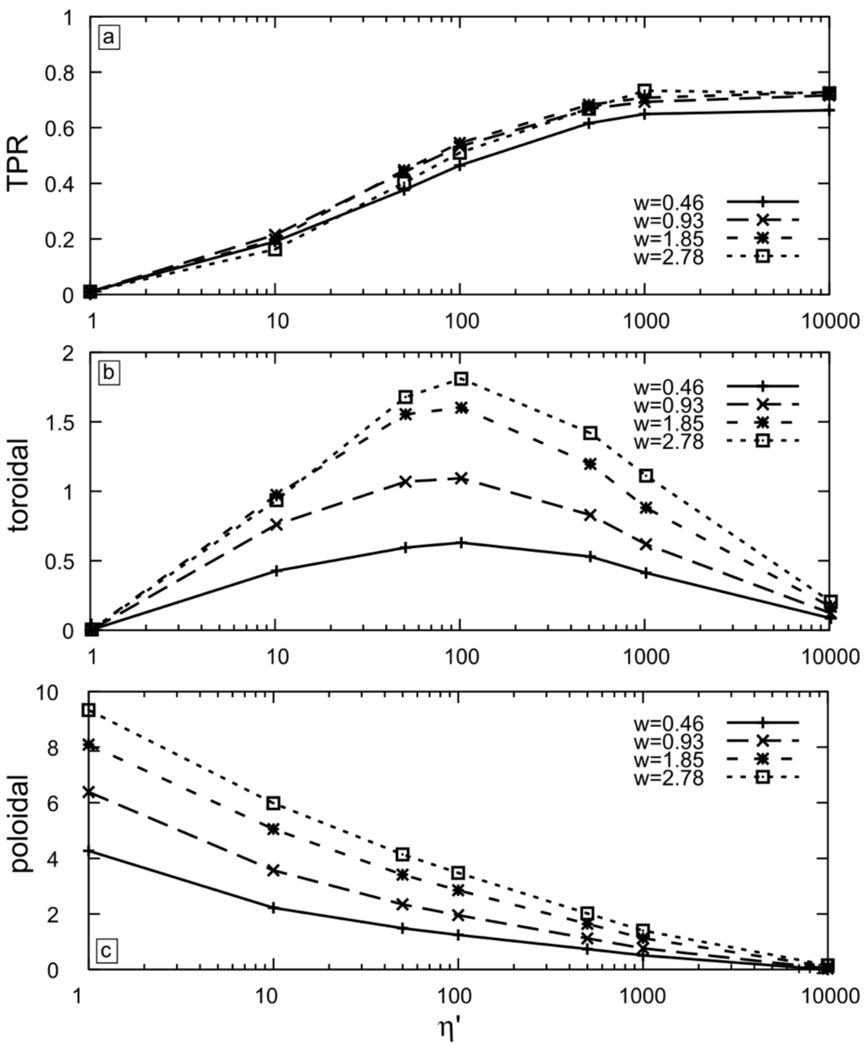
$$\nabla^2 \varphi = \underline{\nabla}_h \bullet \underline{v}_h ; \nabla^2 \psi = \mathbf{vort}_z(\underline{v}_h)$$

Can solve either of these according to free or no slip boundary, and then reconstruct the toroidal and poloidal velocity components. In Piromallo et al., they then calculate the Toroidal to Poloidal Ratio (TPR) as follows:

$$TPR = {\sum_{i=1}^{N} RMSv_{tor}} \Big/ {\sum_{i=1}^{N} RMSv_{pol}}$$

Tackley (2000)

# Flow decomposition

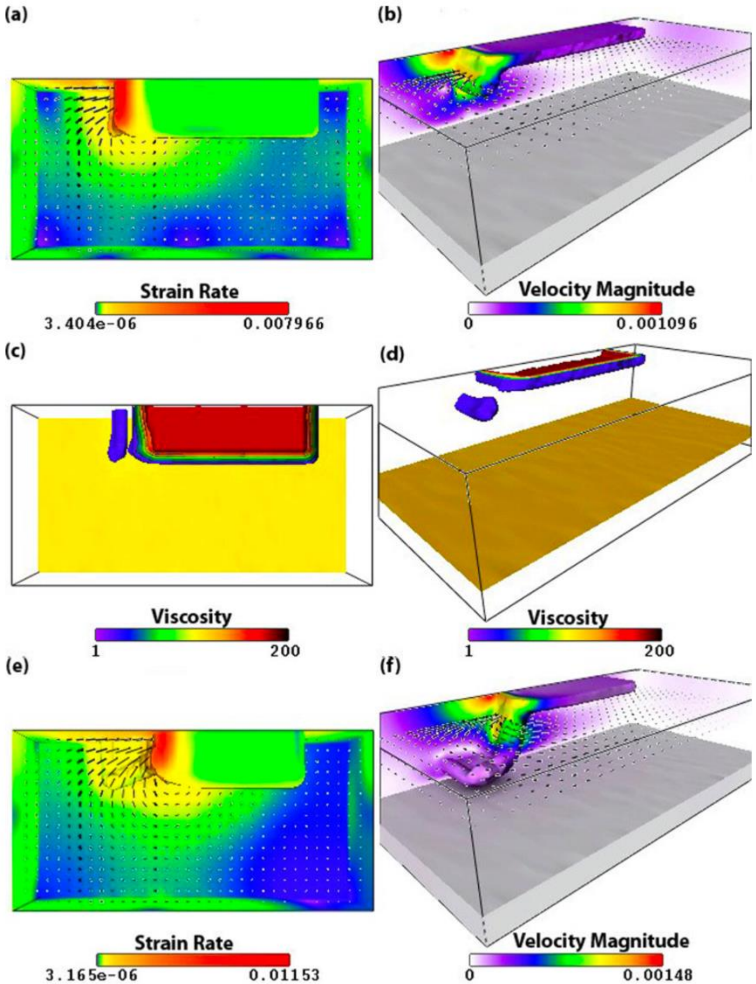


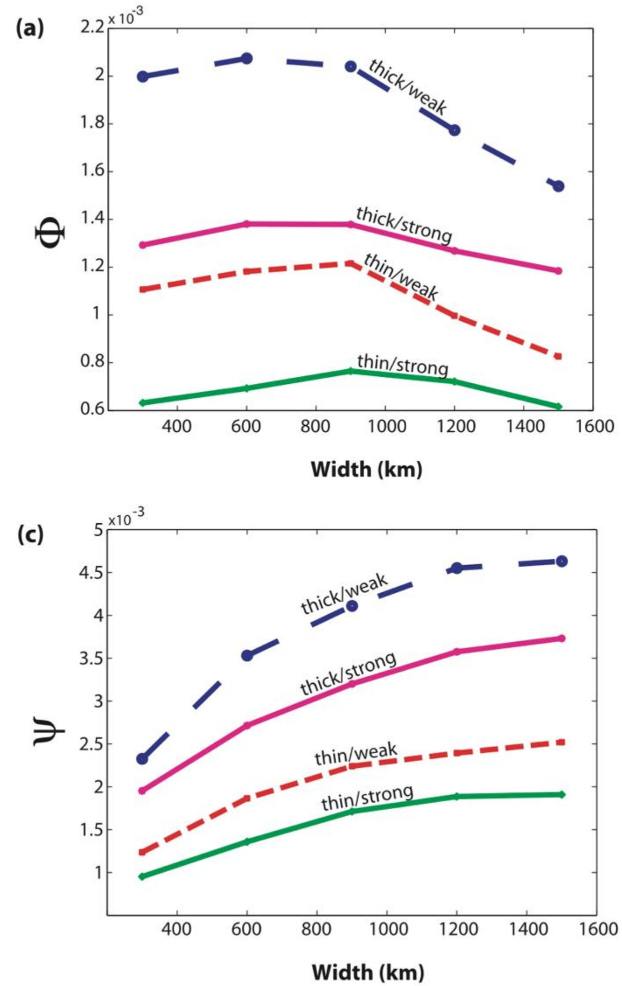

- Poloidal flow, as well as absolute max. velocities, decrease for increasing slab strength: stiffer slabs suffer from more viscous dissipation.
- Toroidal flow increases up to ~100 and decreases for larger contrasts. Peak in toroidal flow is due to interplay between induced toroidal motion (significant once viscosity contrasts are > 10) and increased slab bending resistance (which tends to inhibit motions, in general).
- Produces a TPR that increases with slab strength up to ~1000, then plateaus.

Piromallo et al., 2006

# Flow decomposition

Plate width seems to have a stronger effect in time-dependent models:

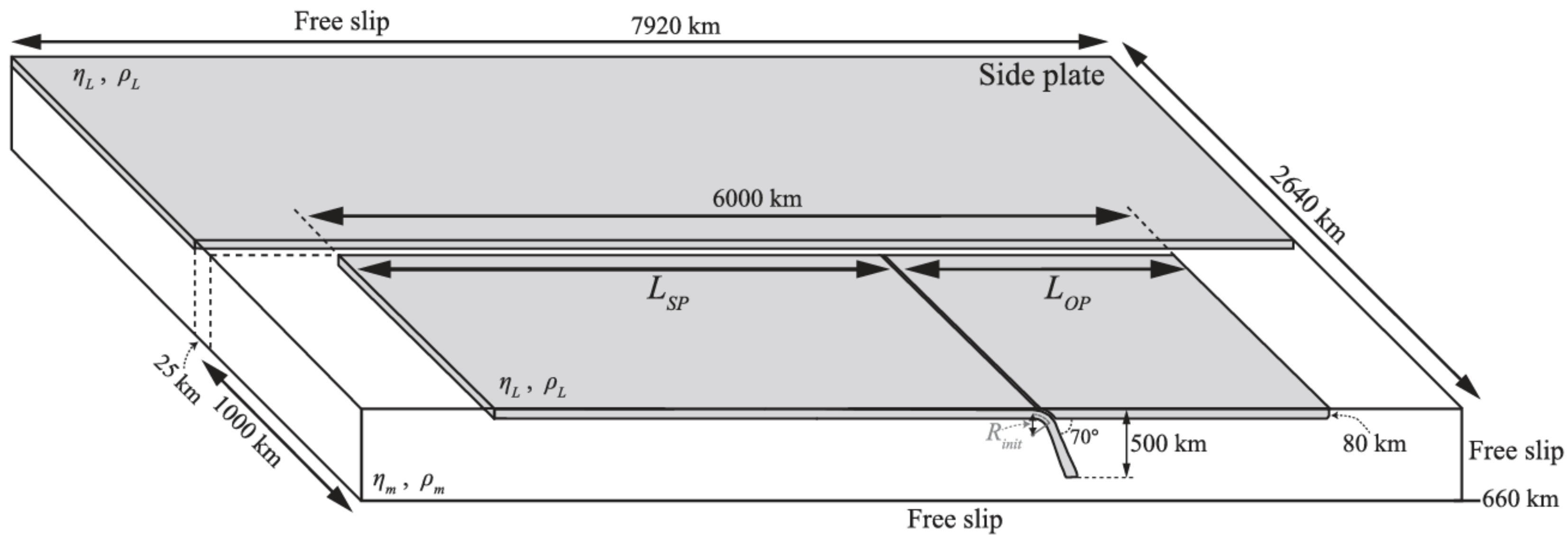



Stegman et al., 2006

# Flow decomposition

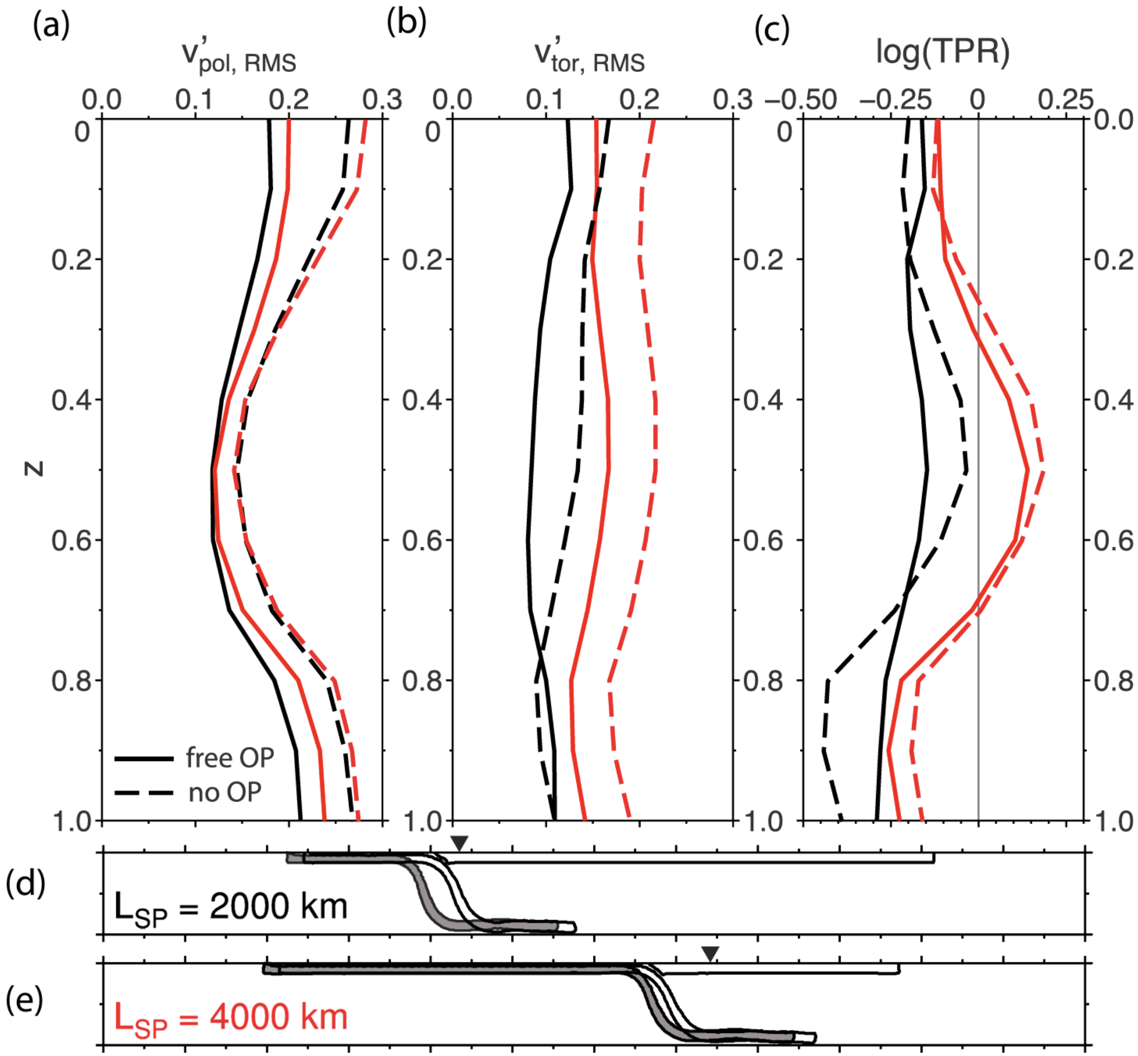
Models with an overriding plate:




- Effect of plate length?
- Effect of overriding plate?
- Effect of power law flow?

Holt and Becker, 2017

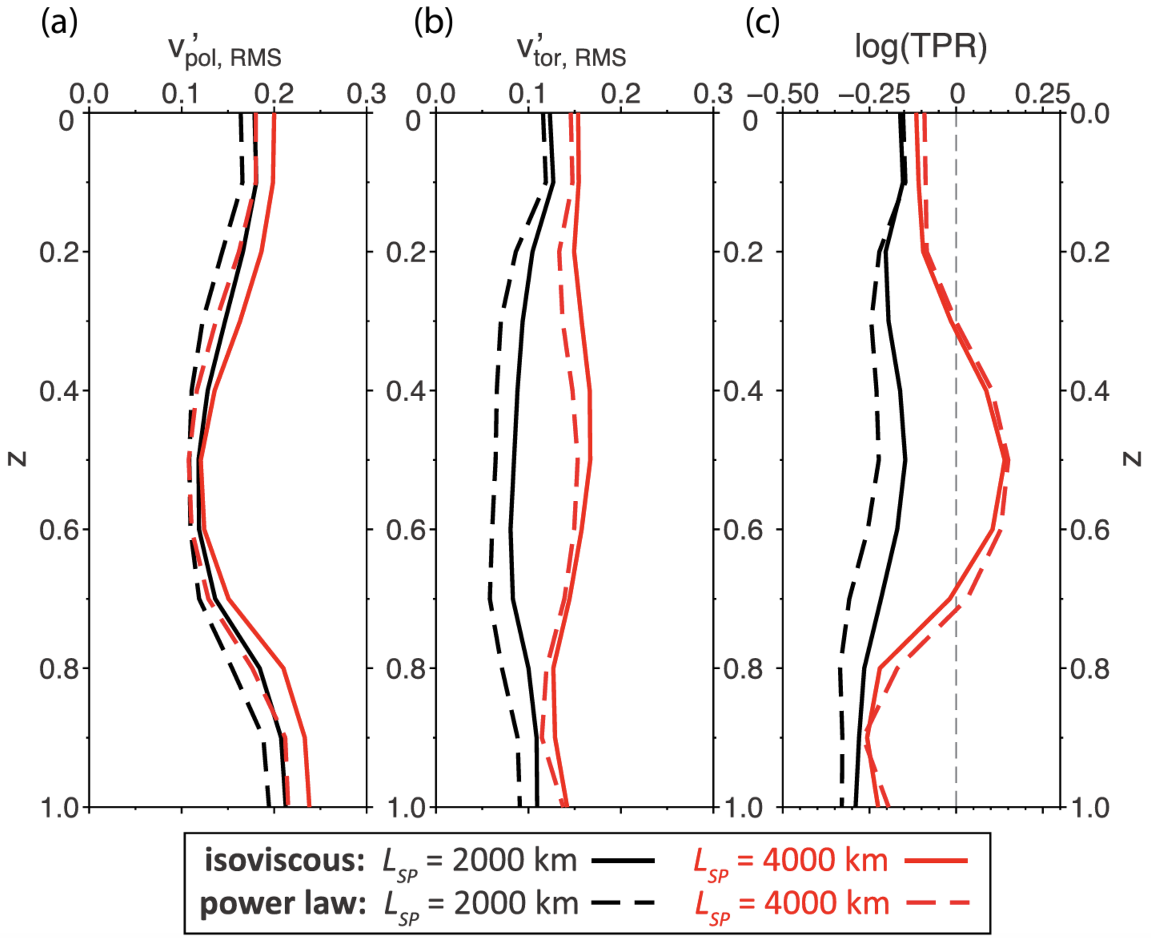
# Flow decomposition




- Toroidal flow more dominant at mid-upper mantle depths.
- Toroidal flow more dominant for long subducting plates (more rollback).
- TPR reduced by inclusion of upper plate (less rollback).

Holt and Becker, 2017

# Flow decomposition



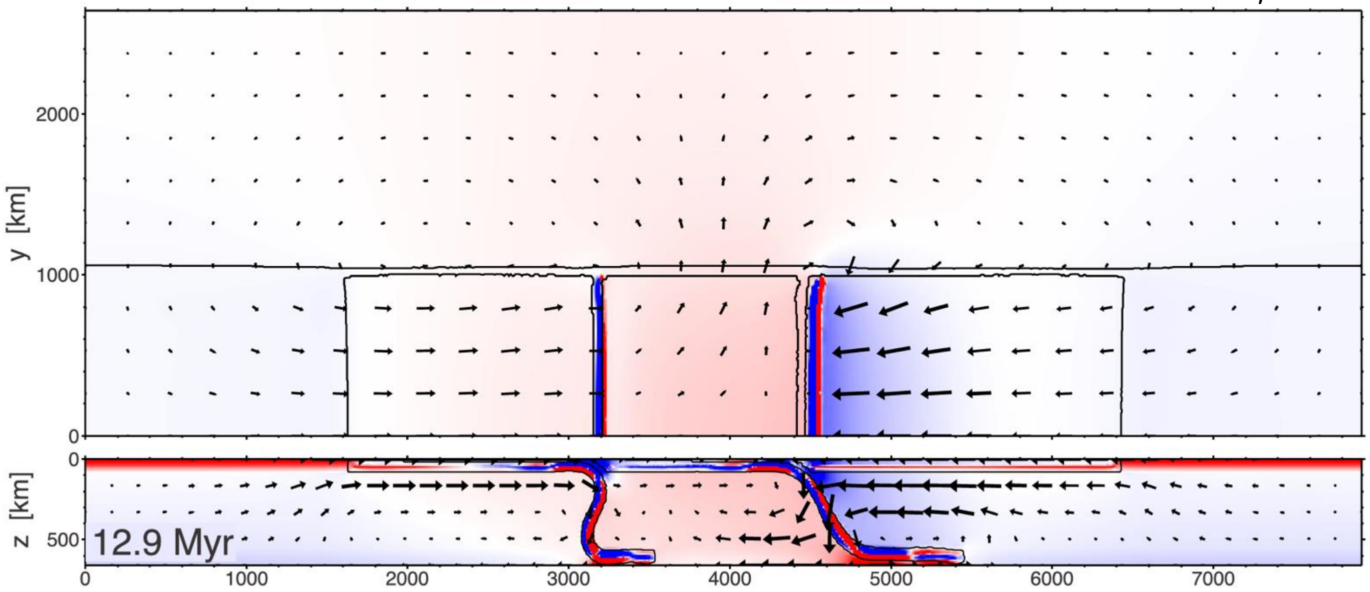

Inclusion of power law mantle rheology does not have a significant impact on the TPR (slight reduction).

Compatible with that seen in global flow models (Cadek et al., 1993; Becker, 2006)

Holt and Becker, 2017

# More complex slab shapes -> More complex flow

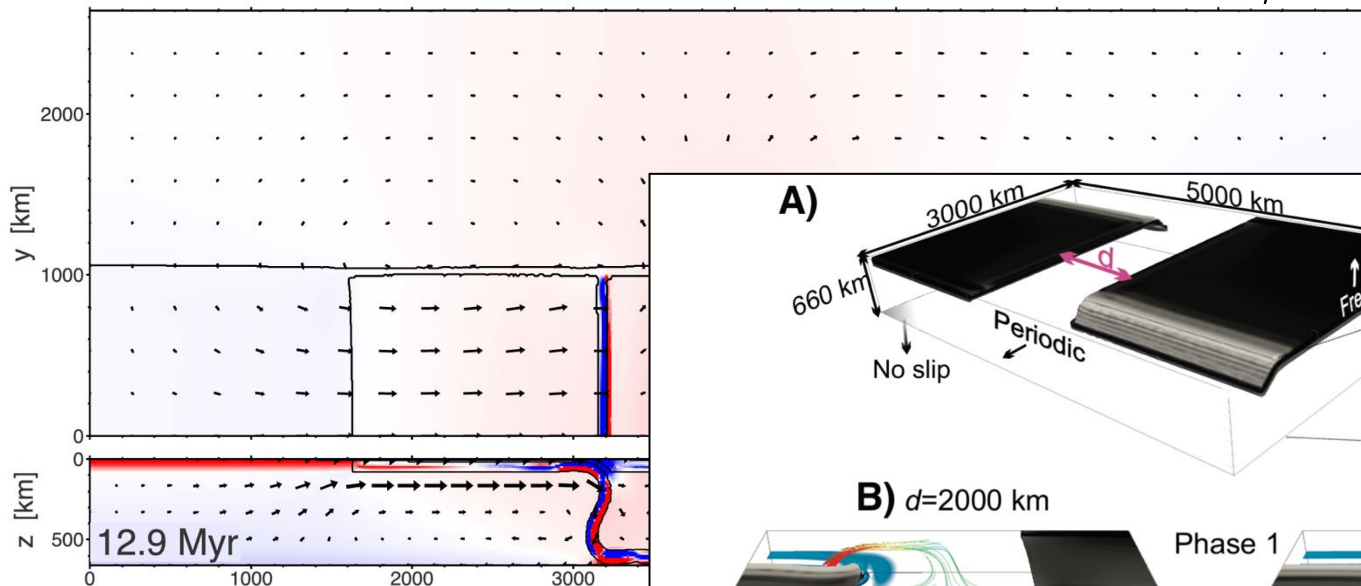
Holt et al., 2017




e.g., double subduction systems

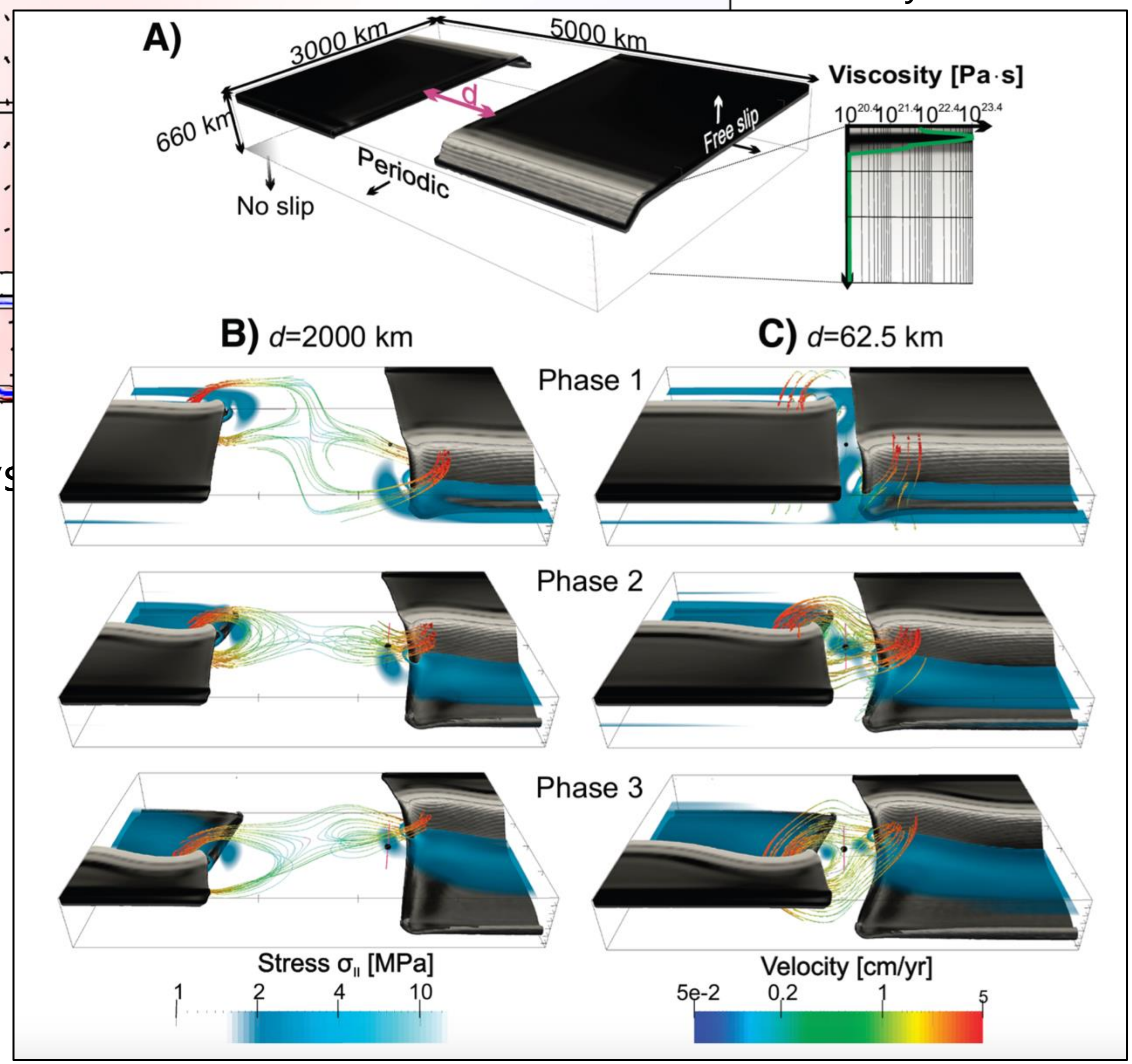
# More complex slab shapes -> More complex flow

Holt et al., 2017




e.g., double subduction sys

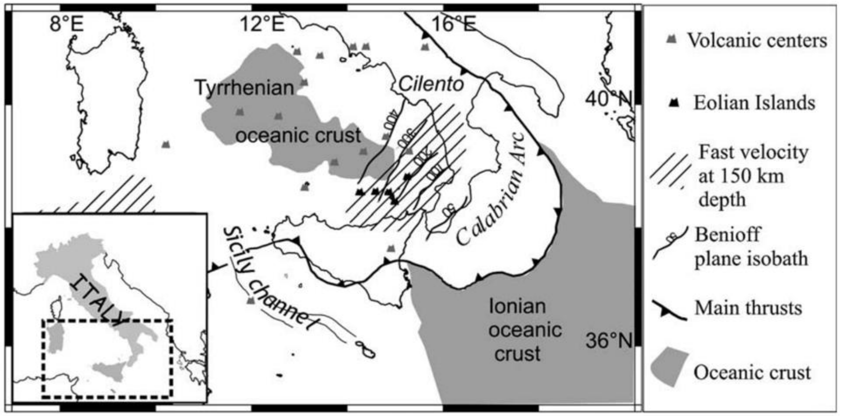
Kiraly et al., 2016

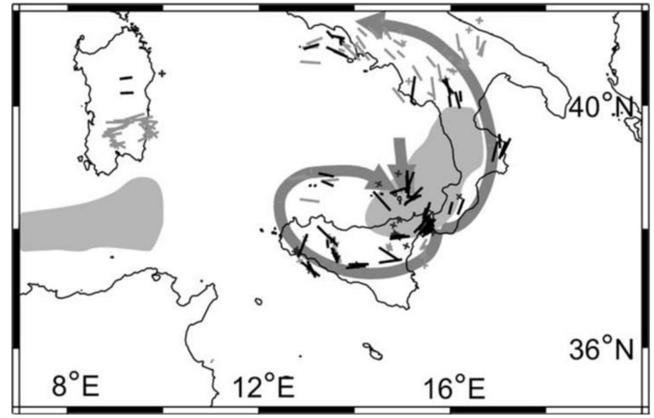



e.g., nearby slabs

# Toroidal flow in the wild…

Civello & Margheriti (2004)




Shear wave splitting directions

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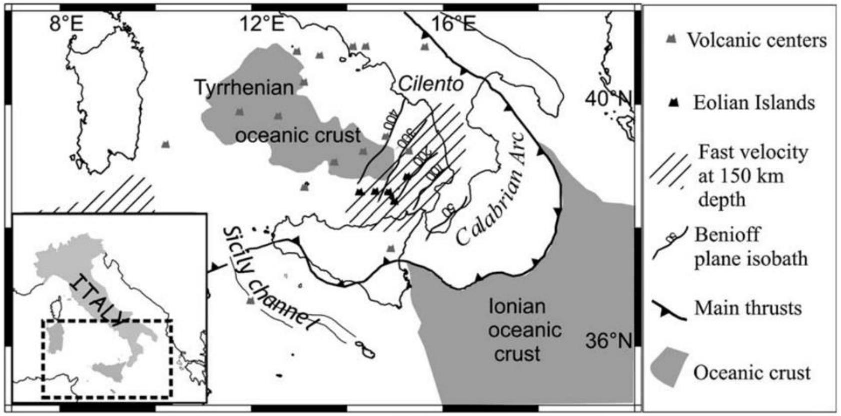
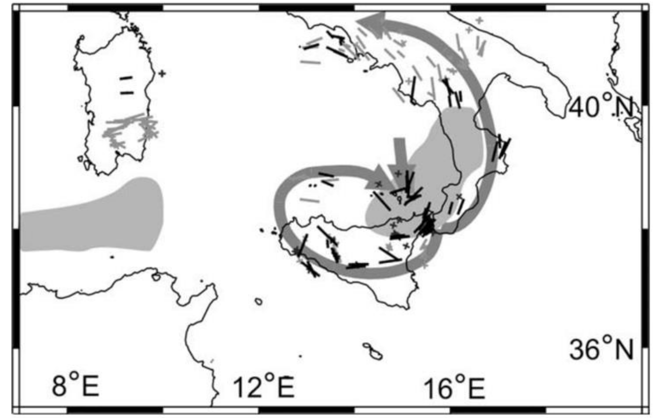
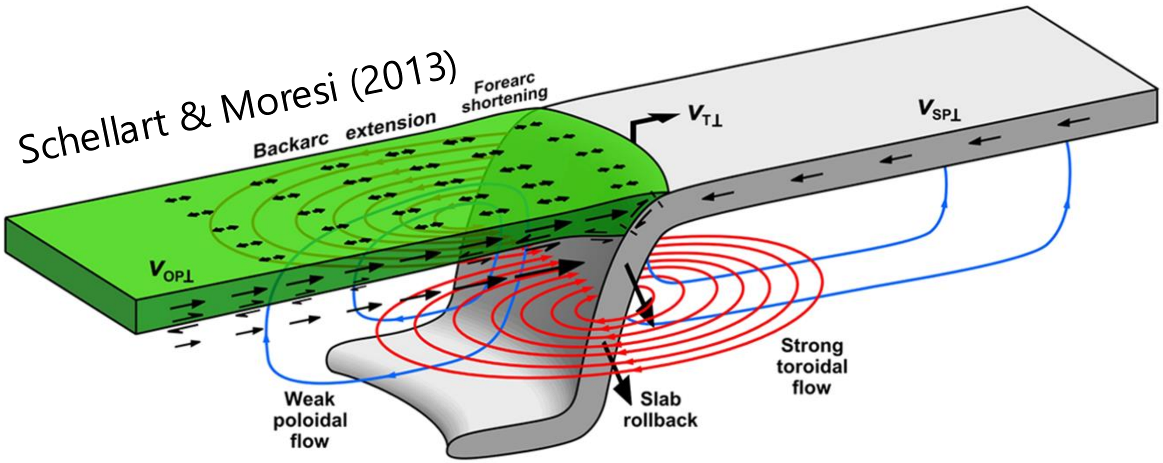



Shear wave splitting directions

Schellart & Moresi (2013)




Contributes to back-arc extension in narrow subduction zones (e.g., Scotia, Calabria)?

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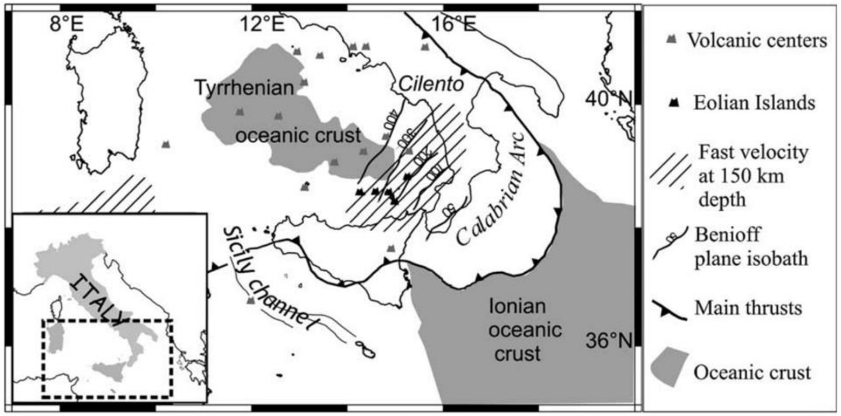


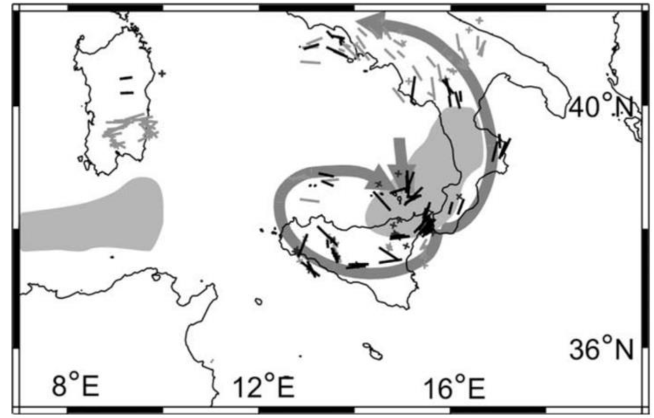


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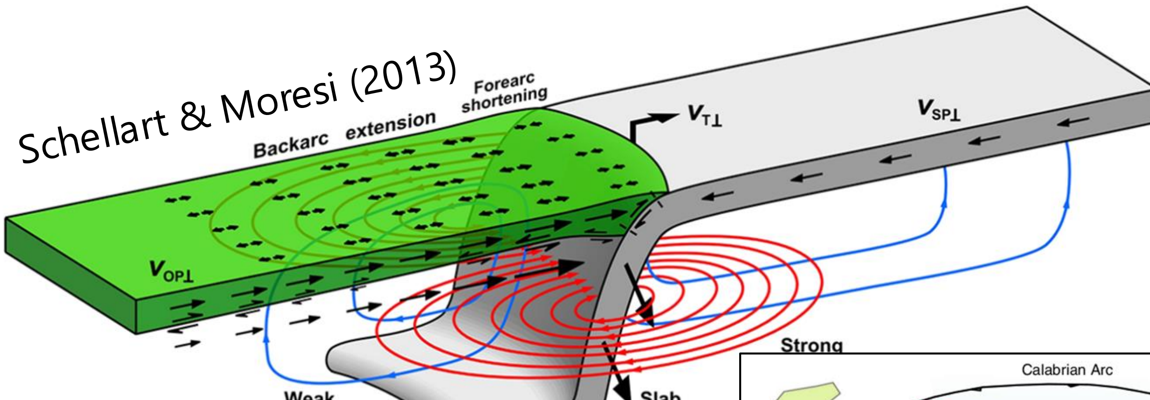


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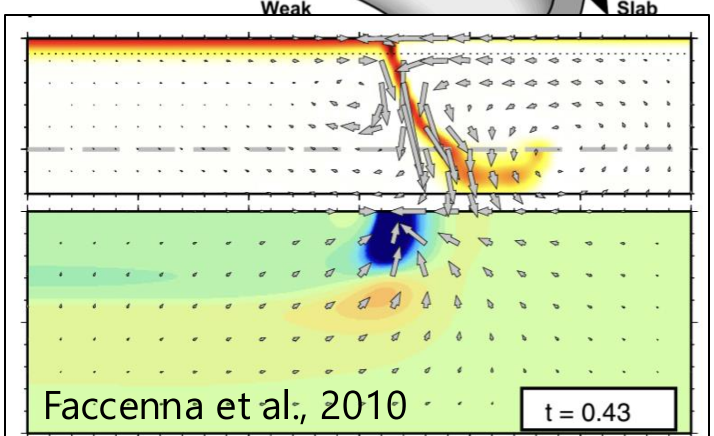
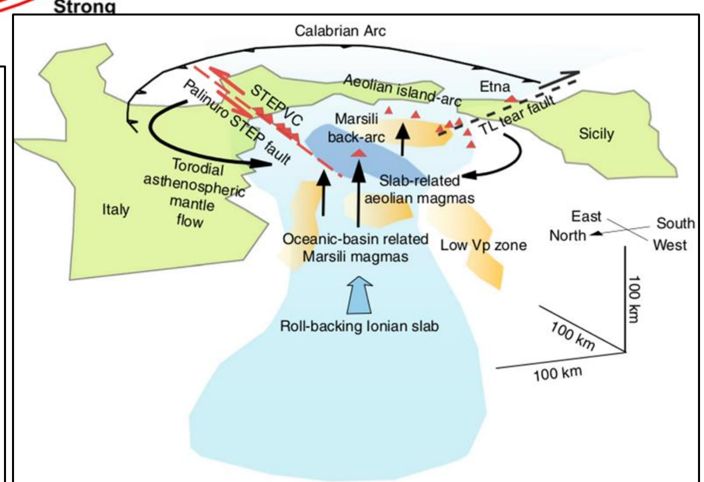



Faccenna et al., 2010




Contributes to off-arc volcanism?