The link between mantle flow and magmatism in subduction zones

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Monks judging our slides
• Composition of the subducting plate
• Slab dehydration pattern
• Thermal structure of the subduction zone
• Mantle wedge dynamics
• Mantle source
• Melt migration
• Thickness and composition of the overriding plate
• Overriding plate stress regime
• Fractional crystallization processes
• ...
Back-arc basins

Stern and Dickinson, 2010
Back-arc magmatism

Arai and Dunn, EPSL, 2014
Back-arc magmatism

Arai and Dunn, EPSL, 2014
Back-arc magmatism

Dunn and Martinez, Nature, 2011
Back-arc magmatism

Dunn and Martinez, Nature, 2011

Dunn and Martinez, Nature, 2011

Harmon and Blackman, EPSL, 2010
Temperature increase in the mantle wedge due to onset of back-arc spreading

Sub-arc mantle becomes increasingly more depleted with time following the onset of spreading, as mantle that has experienced decompression melting and melt extraction beneath the BA flows into the mantle wedge above the slab
Subduction zones geometry
Subduction zones mantle flow

Faccenna et al., 2014
The Central Mediterranean

Wortel and Spakman, Science, 2000

Magni et al., Geology, 2014
(tomographic data from: Piromallo and Morelli, JGR, 2003)
The Central Mediterranean

Newly formed oceanic crust

Miocene mountain chain

Thrust front

Guillaume et al., 2010

The Central Mediterranean

30 Ma

21 Ma

16 Ma

5 Ma

present-day

Rifting

Spreading

Rifting

Spreading

Guillaume et al., 2010
Subduction-related volcanism

- Arc: slab dehydration and mantle wedge melting
- Back-arc spreading: adiabatic decompression melting due to extension at the back-arc
- STEP faults volcanoes: mantle upwelling through transform faults focusing volcanism
How do these different types of volcanism interact with each other? How do they evolve through time?

What is the source of melting?
Where does the mantle that melts at the arc and back-arc come from?
How does mantle flow affect the source of magmatism in the different regions of a subduction zone?
Mantle flow from geochemistry

Nb/Yb: proxy for mantle fertility

Pearce and Stern, 2006
3D model setup

- Finite element code CITCOM (Moresi and Gurnis, 1996)

- Temperature and stress dependent rheology

\[ \eta = A \dot{\varepsilon}_I \frac{1-n}{n} \exp \left( \frac{E^*}{nRT_{abs}} \right) \]

\[ \eta_{by} = \frac{\tau_y}{\dot{\varepsilon}} \quad \eta_{eff} = \min (\eta, \eta_{by}) \]

- Melting computed with the parameterization of Katz et al. (2003)
Back-arc basin formation

**Only oceanic subduction**

- No backarc basin formation
- No episodes of fast retreat

**Along trench variations**

- Backarc basin formation
- Slab windows formation
- Two episodes of fast retreat

Magni et al., 2014
The occurrence of continental collision nearby oceanic subduction is important to trigger the formation of a back-arc basin.
Melt production

Link to video:
https://www.sciencedirect.com/science/article/pii/S0012821X19302766#ec0020
Source of mantle melting

Magni, EPSL, 2019
Source of mantle melting

**Magni, EPSL, 2019**
Source of mantle melting

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Source of mantle melting

Magni, EPSL, 2019
3D mantle flow

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https://www.sciencedirect.com/science/article/pii/S0012821X19302766#ec0020
3D mantle flow

**Slab window**
Sub-horizontal mantle flow through slab window
3D mantle flow

Link to video:
https://www.sciencedirect.com/science/article/pii/S0012821X19302766#ec0040
3D mantle flow

**Slab window**
Sub-horizontal mantle flow through slab window

**Slab edge**
Toroidal flow + strong upwelling component around slab edge

Magni, EPSL, 2019
• Toroidal mantle flow is suggested to occur around the Calabrian slab, on both sides.

• The upwelling component of the flow can be different at the African margin and the Apennines.

• Toroidal flow does not necessarily bring fertile mantle to the arc and back-arc melting regions.

Baccheschi et al., 2011
Depleted mantle from back-arc to arc

10-15 Myr

Magni, EPSL, 2019
Large amount of highly depleted mantle flows in the mantle wedge

↓

Much harder to produce melt beneath the arc

↓

Decrease/stop or compositional change of magmatic activity at the arc
Large amount of highly depleted mantle flows in the mantle wedge

Much harder to produce melt beneath the arc

Decrease/stop or compositional change of magmatic activity at the arc

Do we see this in volcanic arcs today?
Tyrrhenian basin

Rosenbaum et al., 2008
Timing of arc and back-arc magmatic activity
High-Ca boninites presence in Tonga arc explained with residual peridotite brought by mantle flow to the mantle wedge from the back-arc (Cooper et al., 2010)

Mantle wedge was depleted in incompatible elements during multi-stage back-arc basalt extraction (Turner and Hawkesworth, 1997)
Izu-Bonin-Marianas

Brandl et al., EPSL, 2017
Mantle flow can influence the amount and composition of arc magmatism.

During back-arc spreading, for about 10 Myr, highly depleted mantle flows into the mantle wedge, beneath the arc.

During trench retreat, back-arc spreading can correspond to minimum or no activity of the volcanic arc. Alternatively, it can temporarily change the composition of arc lavas.

Toroidal mantle flow pattern is associated with a much stronger upwelling component at slab edges than at slab windows.
1. Guillaume et al., 2010
2. Faccenna et al., 2005
3. Malusa' et al., 2016
4. Jolivet et al., 2012 (Fig. 11) (also Jolivet and Brun, 2010)
5. Jolivet and Faccenna, 2000
6. Chakraborty and Khan, 2009
7. Lallemand 2016
8. Letouzey and Kimura, 1986
9. Beier et al., 2010
10. Woodhead et al., 1998
11. Greene et al., 1994
12. Lagabrielle et al., 1997
15. Ewart and Hawkesworth, 1986
16. Leat et al., 2003, 2004
17. Larter at a., 2003