Magma-Lithosphere Interaction

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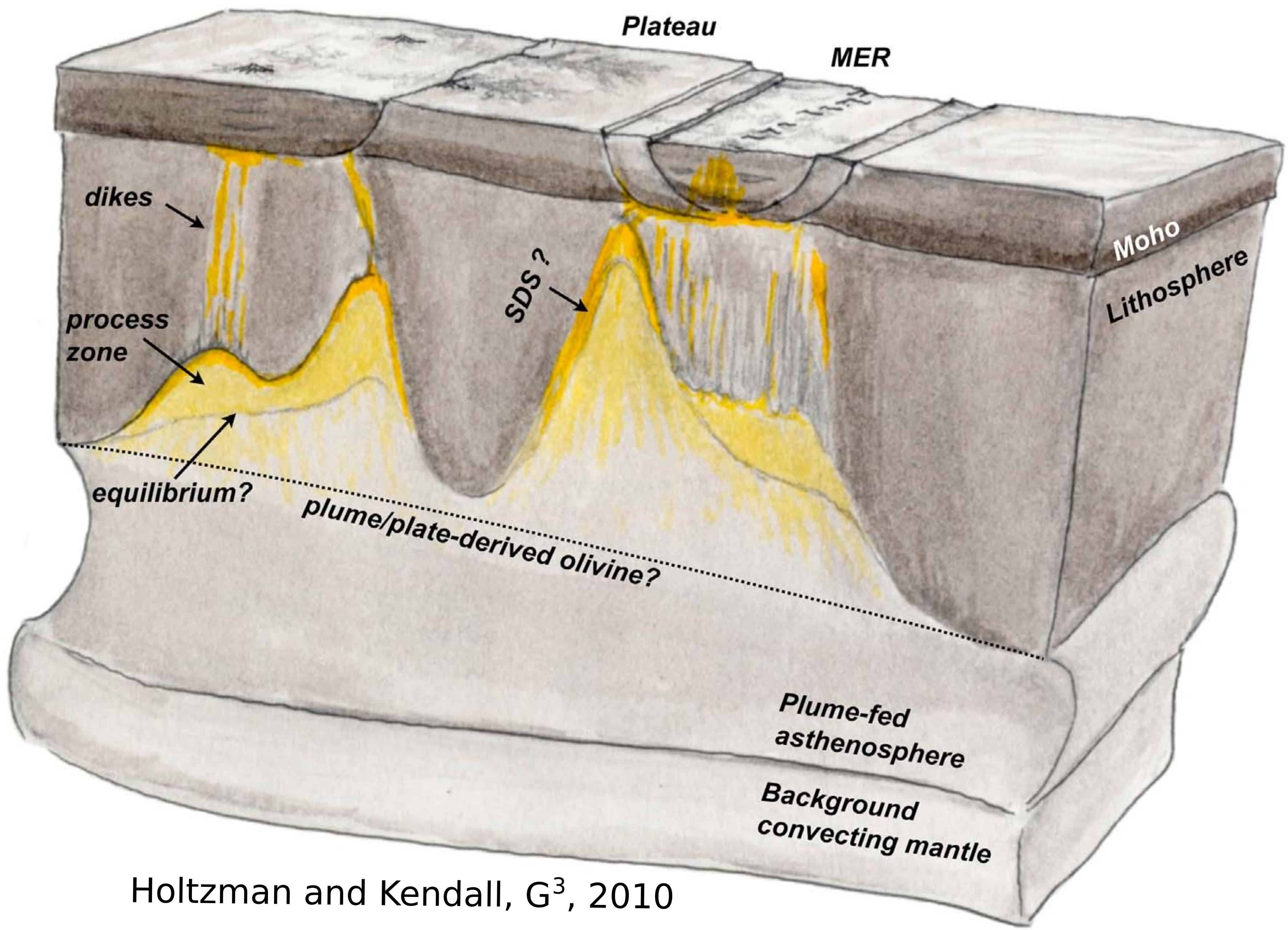
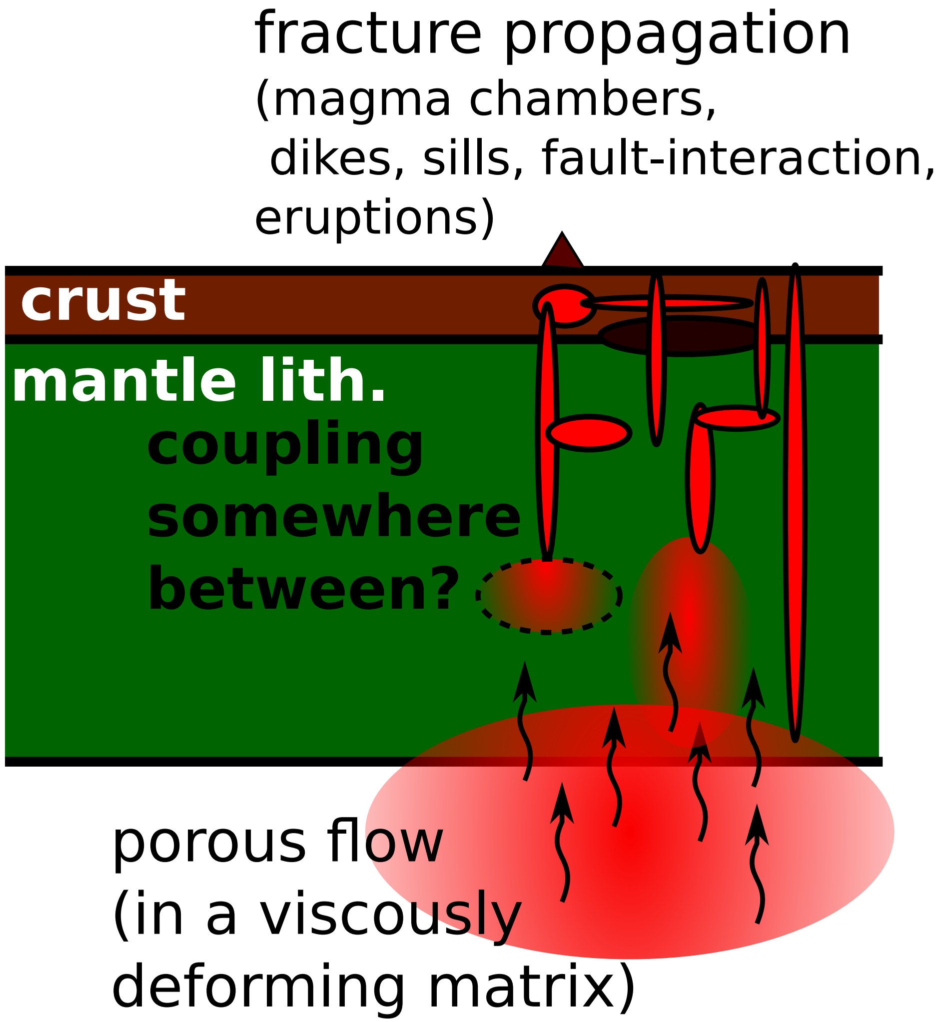
Mousumi Roy[2], Marc Parmentier[3], Greg Hirth[3], Karen Fischer[3],
1. Lamont-Doherty Earth Observatory; 2. University of New Mexico; 3. Brown University



Holtzman and Kendall, G^3, 2010

Magma-Lithosphere Interaction

Melt Transport



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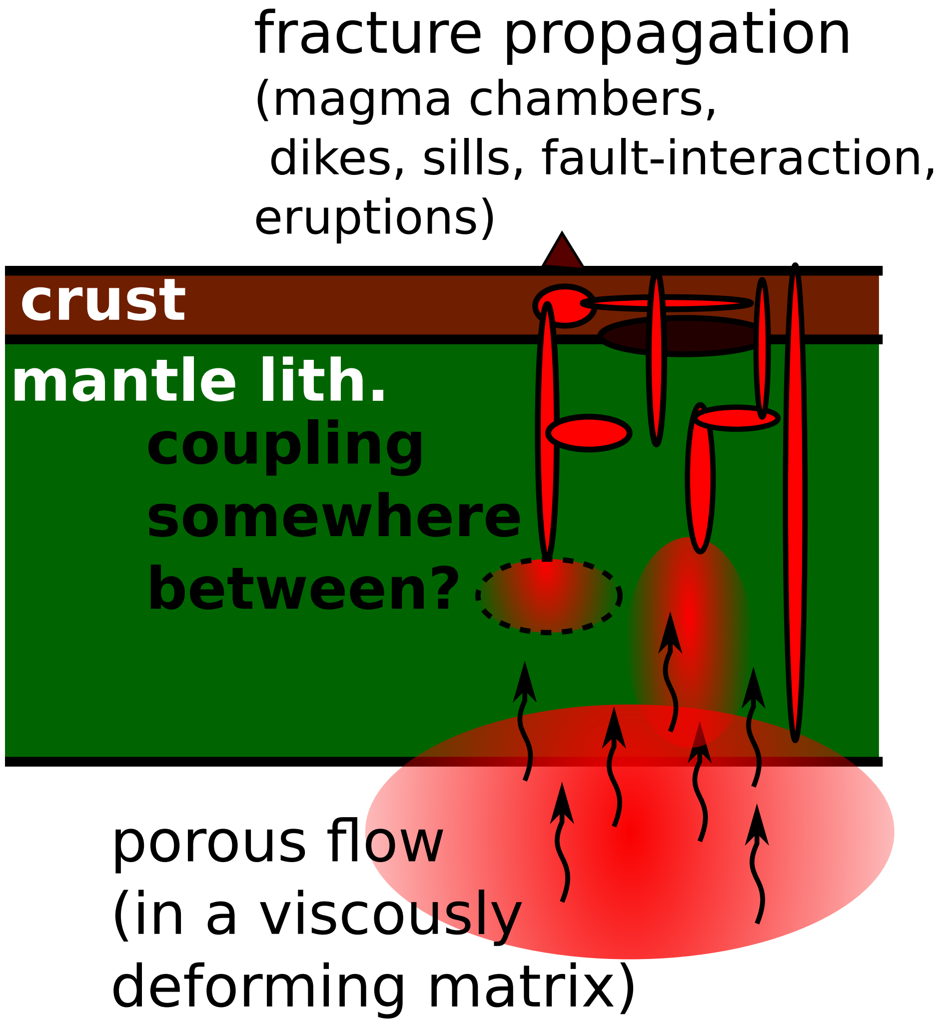
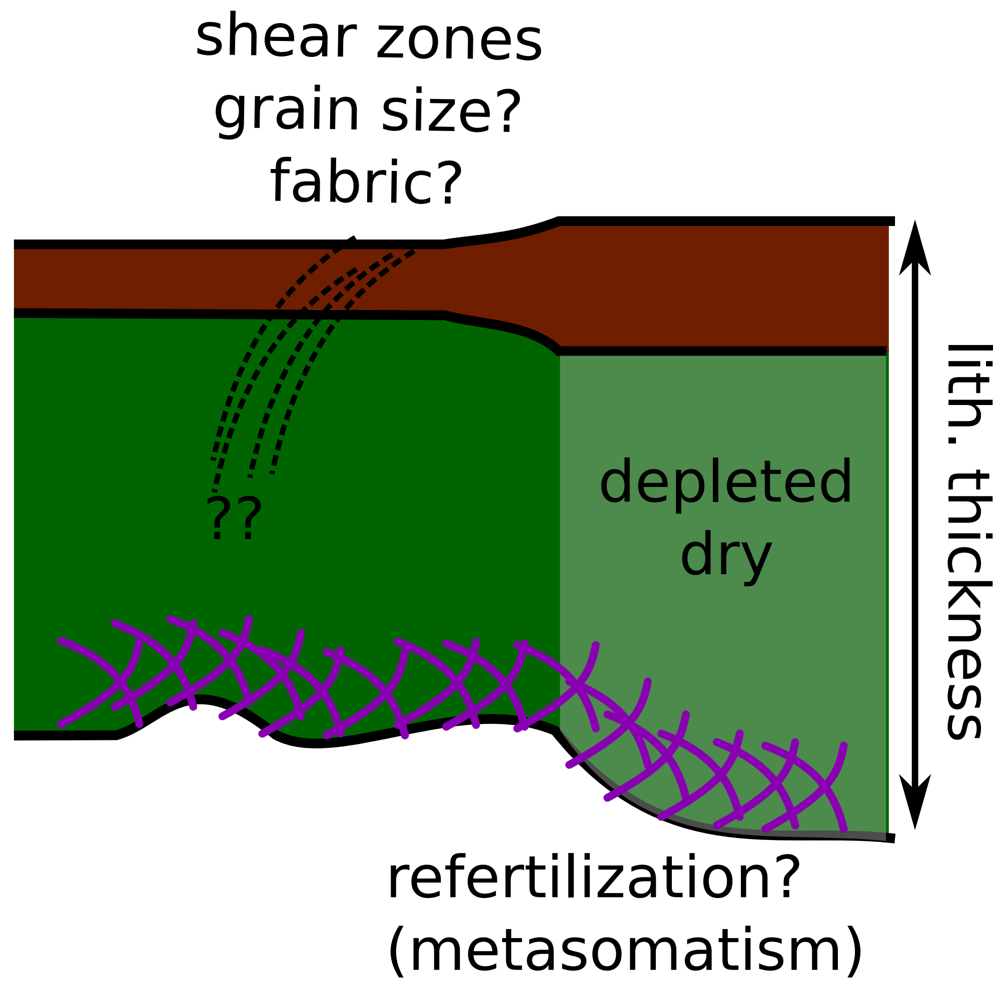
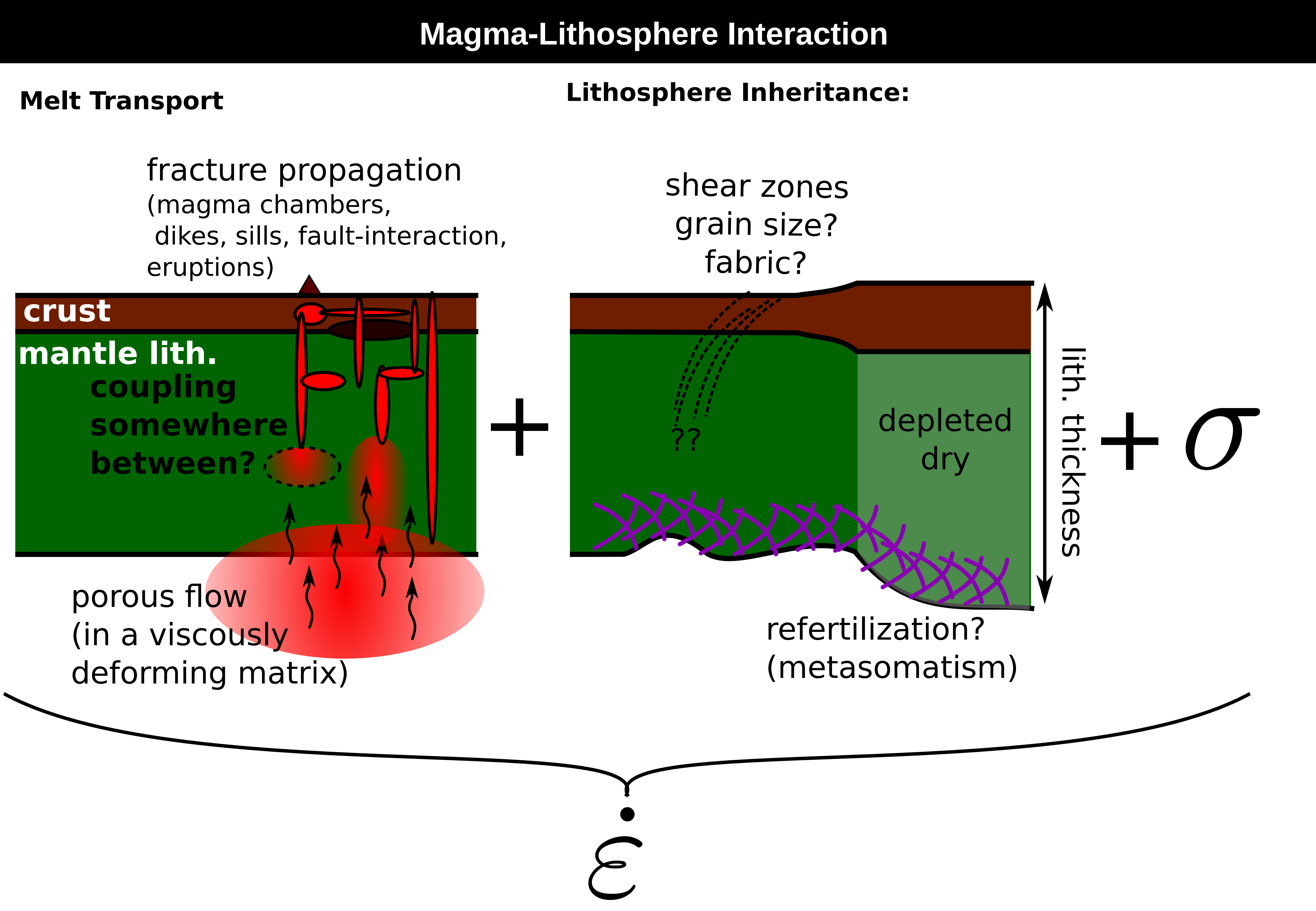
Lithosphere Inheritance:






Magma-Lithosphere Interaction
Melt Transport
Lithosphere Inheritance:
fracture propagation
(magma chambers,
dikes, sills, fault-interaction,
eruptions)
crust
mantle lith.
coupling
somewhere
between?
porous flow
(in a viscously
deforming matrix)
+
shear zones
grain size?
fabric?
??
depleted
dry
lith. thickness
+ σ
refertilization?
(metasomatism)
ε̇

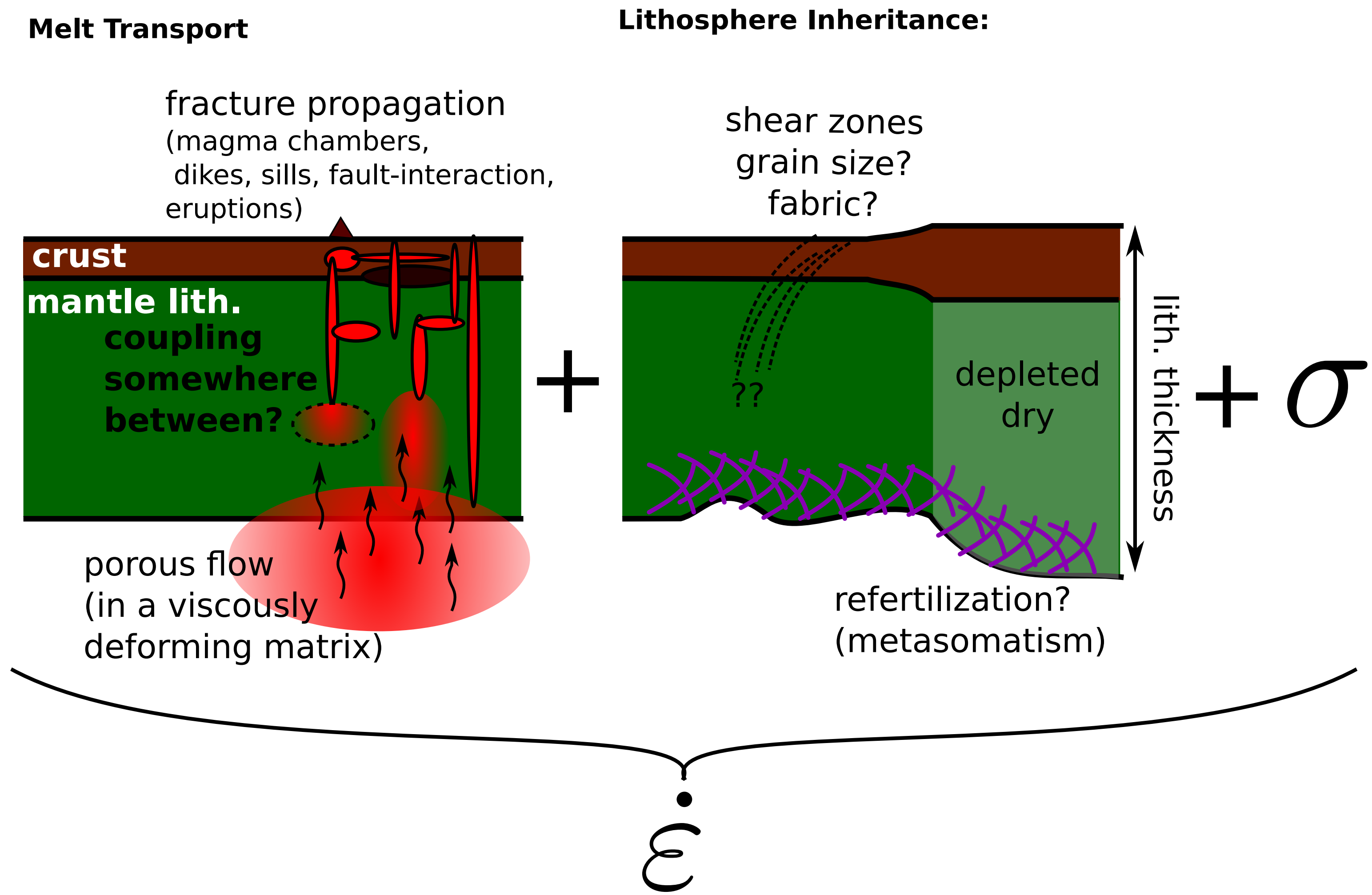
Magma-Lithosphere Interaction

I. lithosphere inheritance and melt migration, accumulation, infiltration

II. Intrusional heating

III. Thermal-chemical-mechanical feedbacks (in the mantle lith.)

IV. Geophysics and the quest for melt



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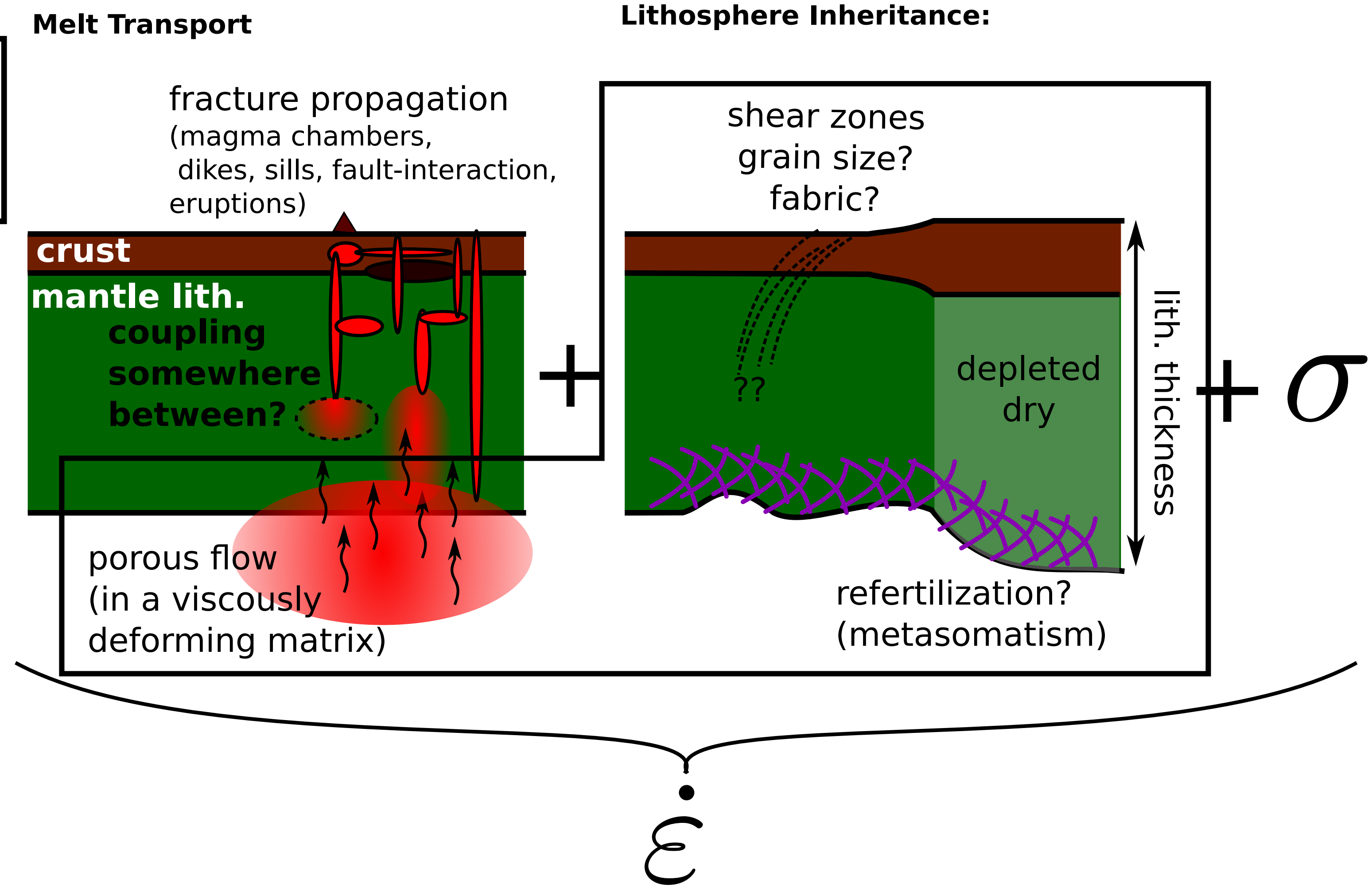

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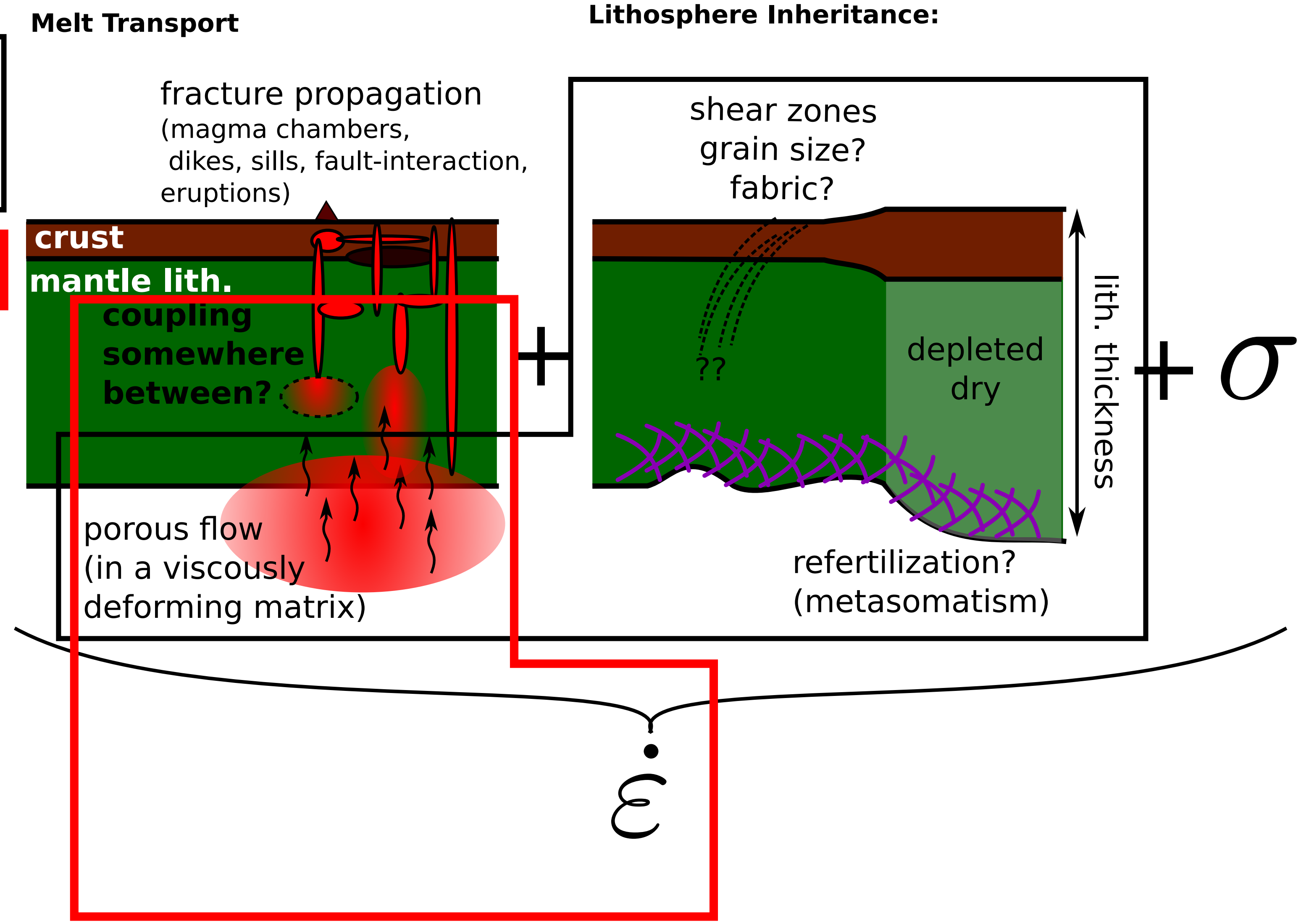

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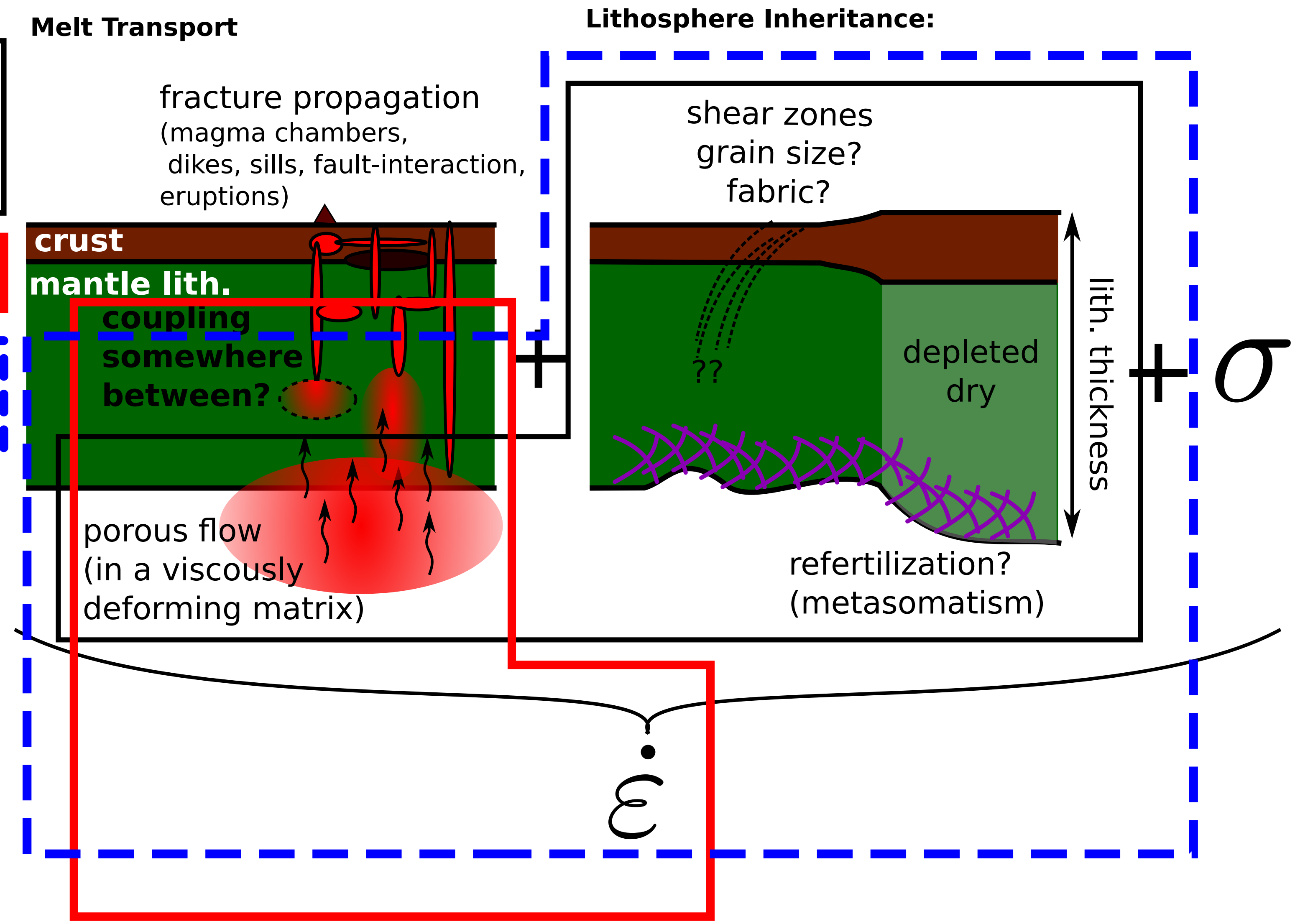

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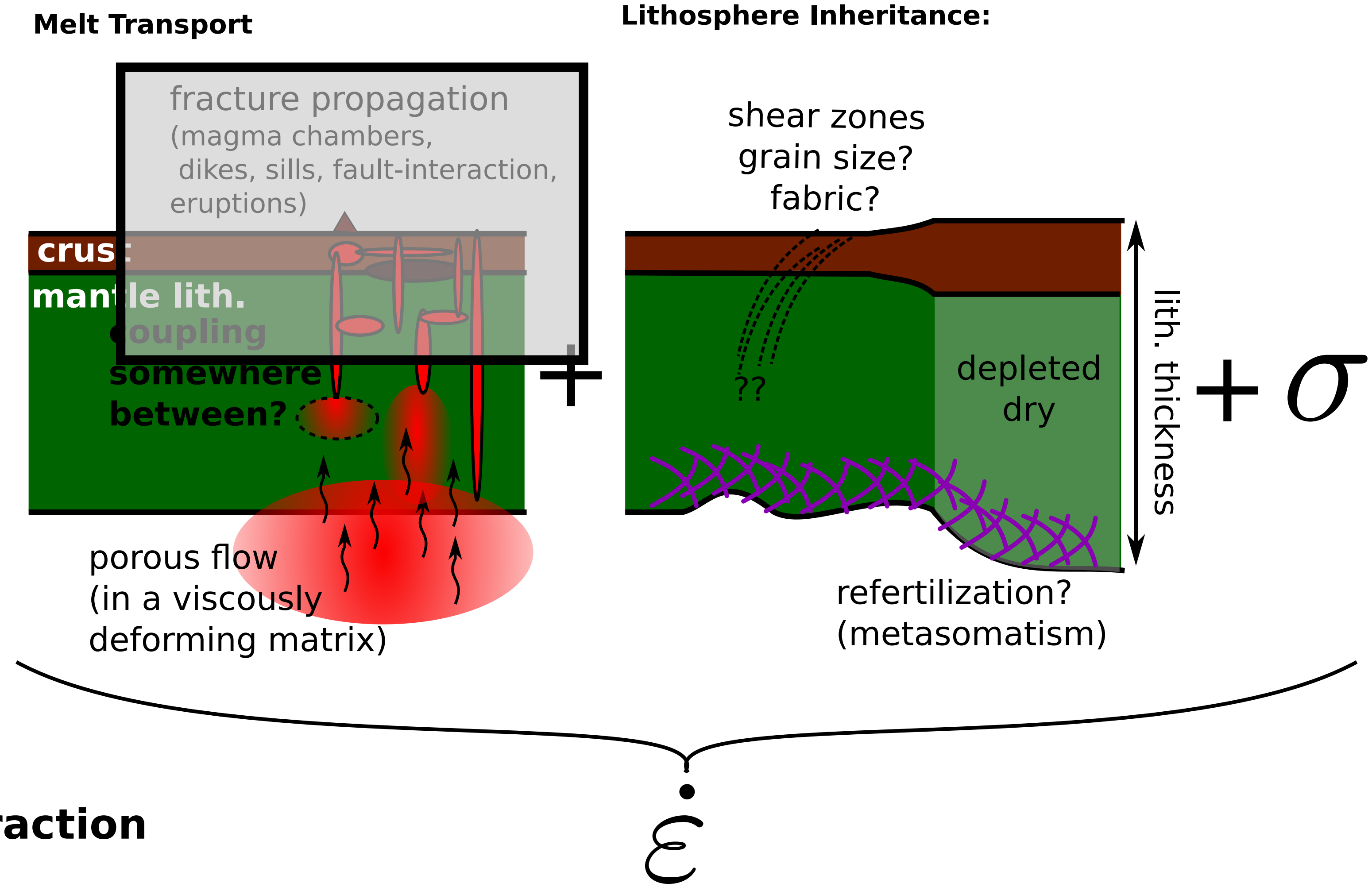

Shallow magma-lithosphere interaction

Strain accomodation/localization, rift segmentation
(e.g., Muirhead et al., G^3,2015; Corti et al., Tectonophysics 2002; Ebinger and Casey, Geology 2001;)

Dikes, faults and stress
(e.g, Hamling et al., Nature Geo., 2010; Nobile et al., GRL 2012; Bedard, GSA Bulletin, 2012)

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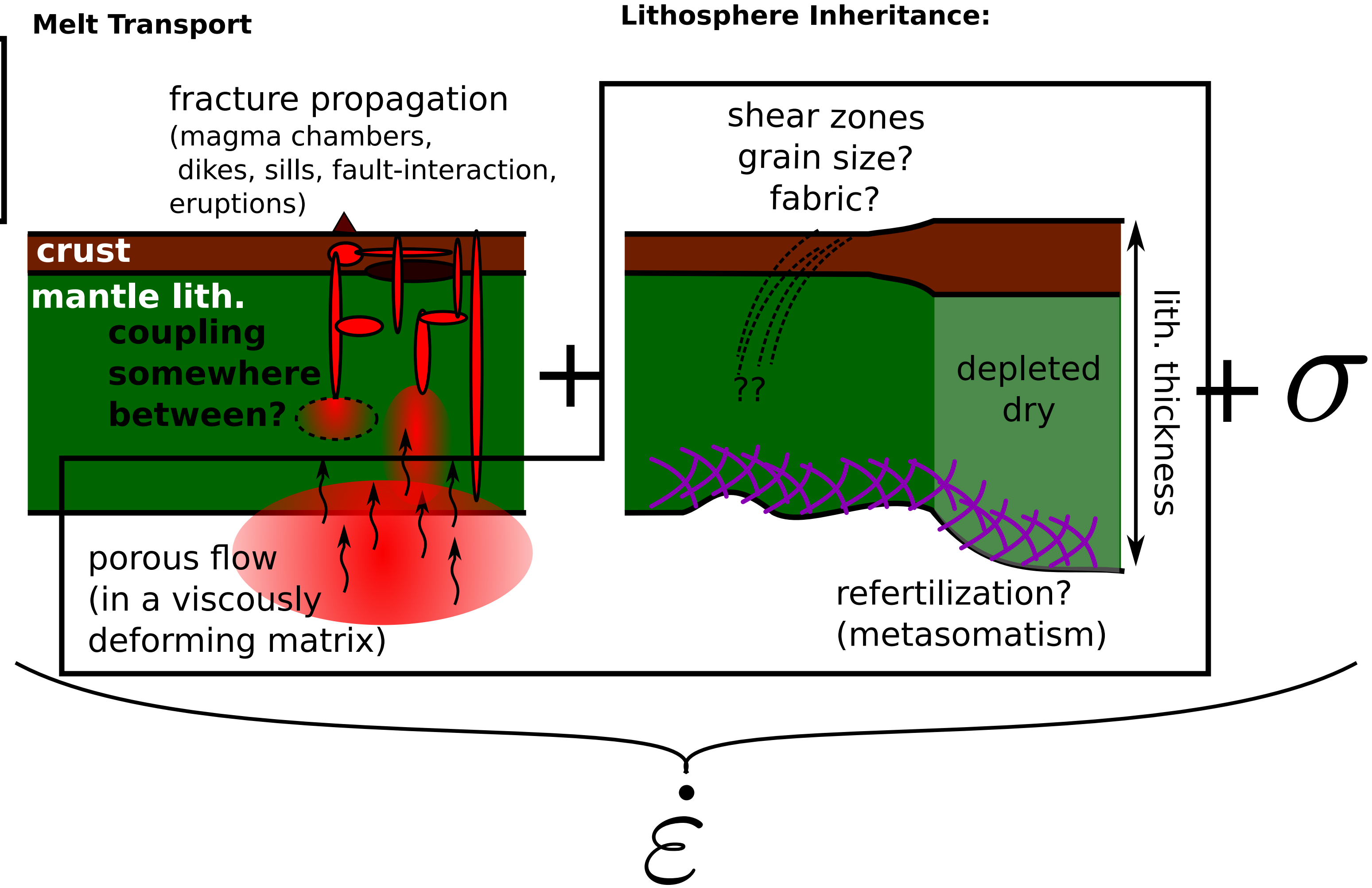


Melt: where does it go?

Fluid velocity:

$$\boldsymbol{v}^f = \boldsymbol{V}^s + \frac{k}{\phi\eta_f}\underbrace{\left(\Delta\rho\boldsymbol{g} + \nabla P_{\mathrm{c}} + \nabla P_{\mathrm{d}} + \nabla P_{\mathrm{st}} + \ldots\right)}_{\text{pressure gradients driving segregation}}$$

P_{c} compaction pressure

P_{d} dynamic pressure (matrix shear, stokes)

P_{st} surface tension

ϕ porosity

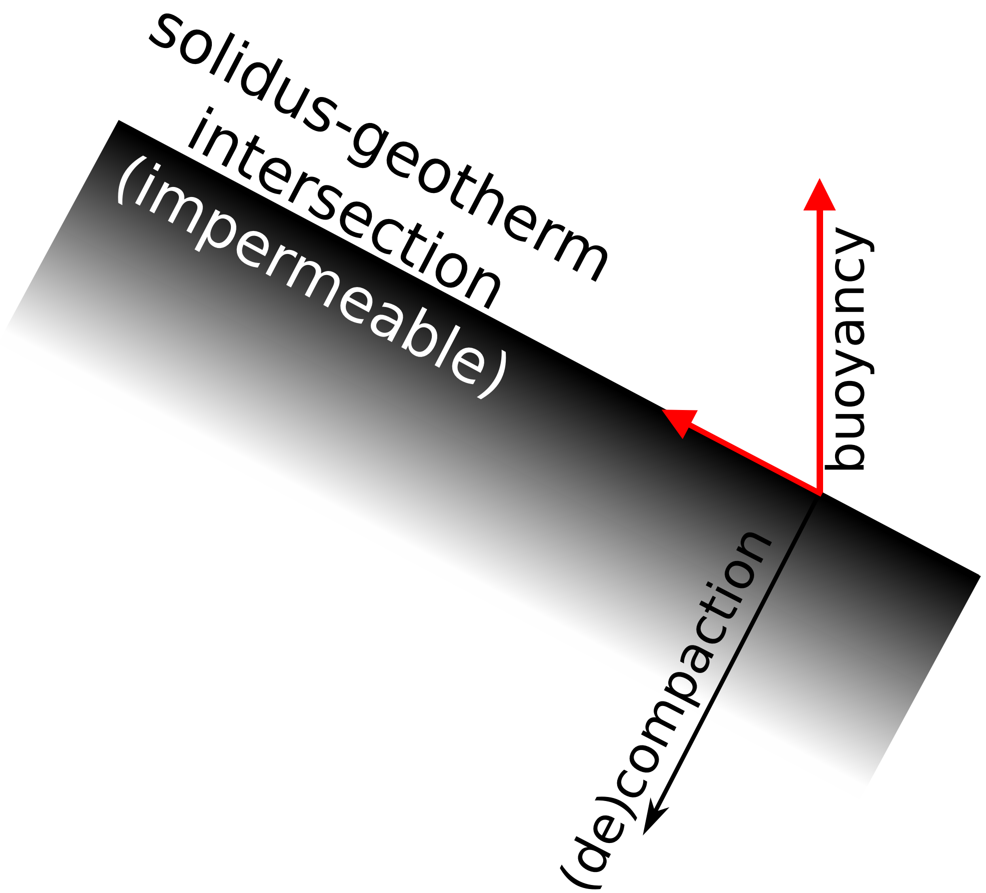
k permeability $\frac{a^2\phi^n}{C}$ (n between 2,3... 2.6 Miller et al., EPSL 2014)

$\Delta\rho g$ melt-buoyancy

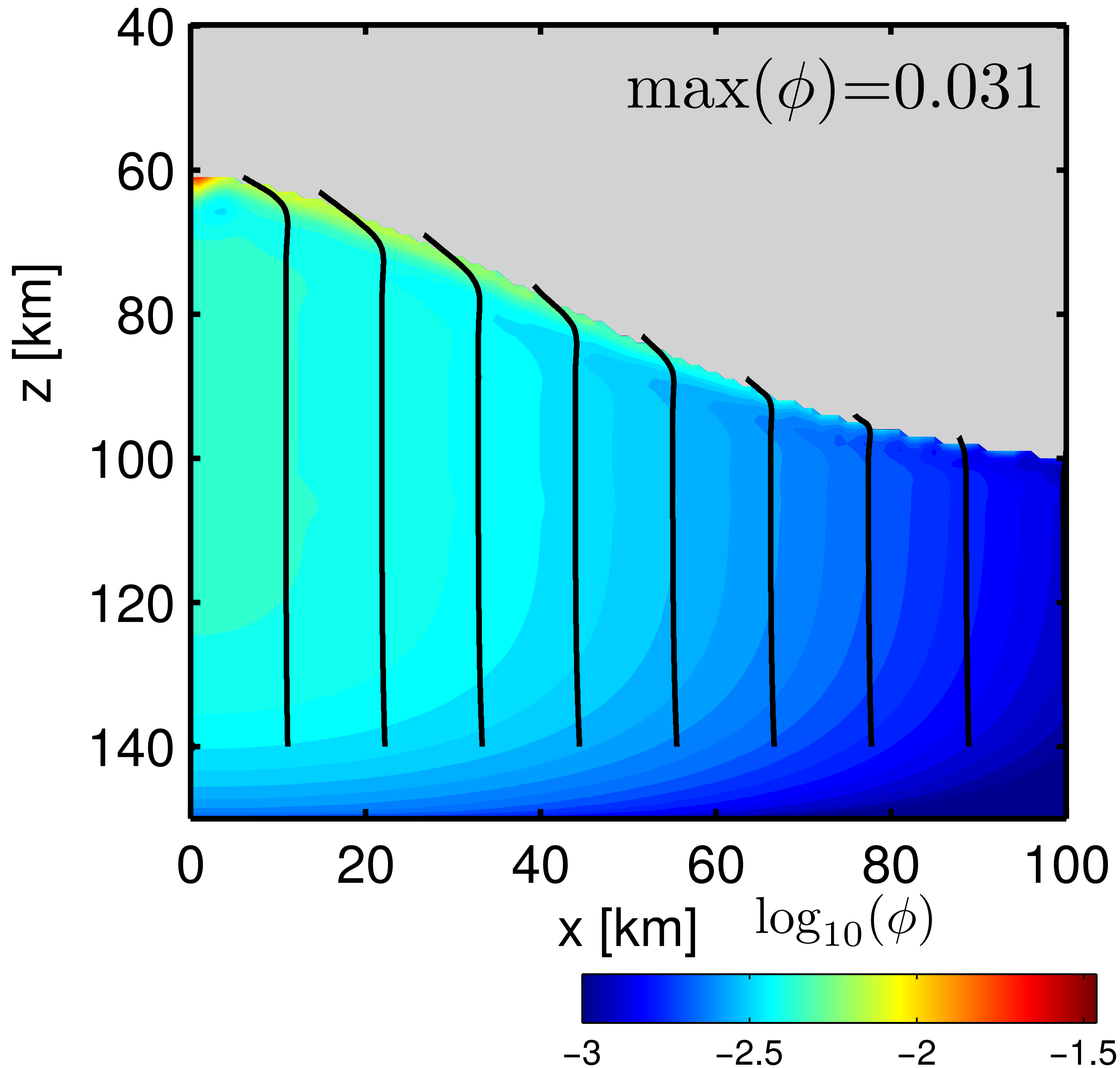
η_f fluid shear viscosity

Lithosphere Thickness: Melt Focusing & Decompaction Channels

$$\boldsymbol{v}^f = \boldsymbol{V}^s + \frac{k}{\phi\eta_f}(\Delta\rho\boldsymbol{g} + \nabla P_\mathrm{c} + \nabla P_\mathrm{d} + \nabla P_\mathrm{st} + \ldots)$$



Sparks and Parmentier, EPSL 1991
Spiegelman, Phil. Trans. 1993
Katz, G^3 2010



Amount of focusing depends on how "leaky" the boundary is

Havlin et al., in prep.

Lithosphere pressure gradients and melt transport

$$\boldsymbol{v}^f = \boldsymbol{V}^s + \frac{k}{\phi \eta_f}(\Delta\rho \boldsymbol{g} + \nabla P_{\mathrm{c}} + \nabla P_{\mathrm{d}} + \nabla P_{\mathrm{st}} + \ldots)$$

Dynamic pressure gradients (matrix shear, stokes flow)

Spiegelman and McKenzie, EPSL 1987

Phipps Morgan, GRL 1987

Strong lithospheric keel moving relative to asthenosphere:

Roy et al., in review

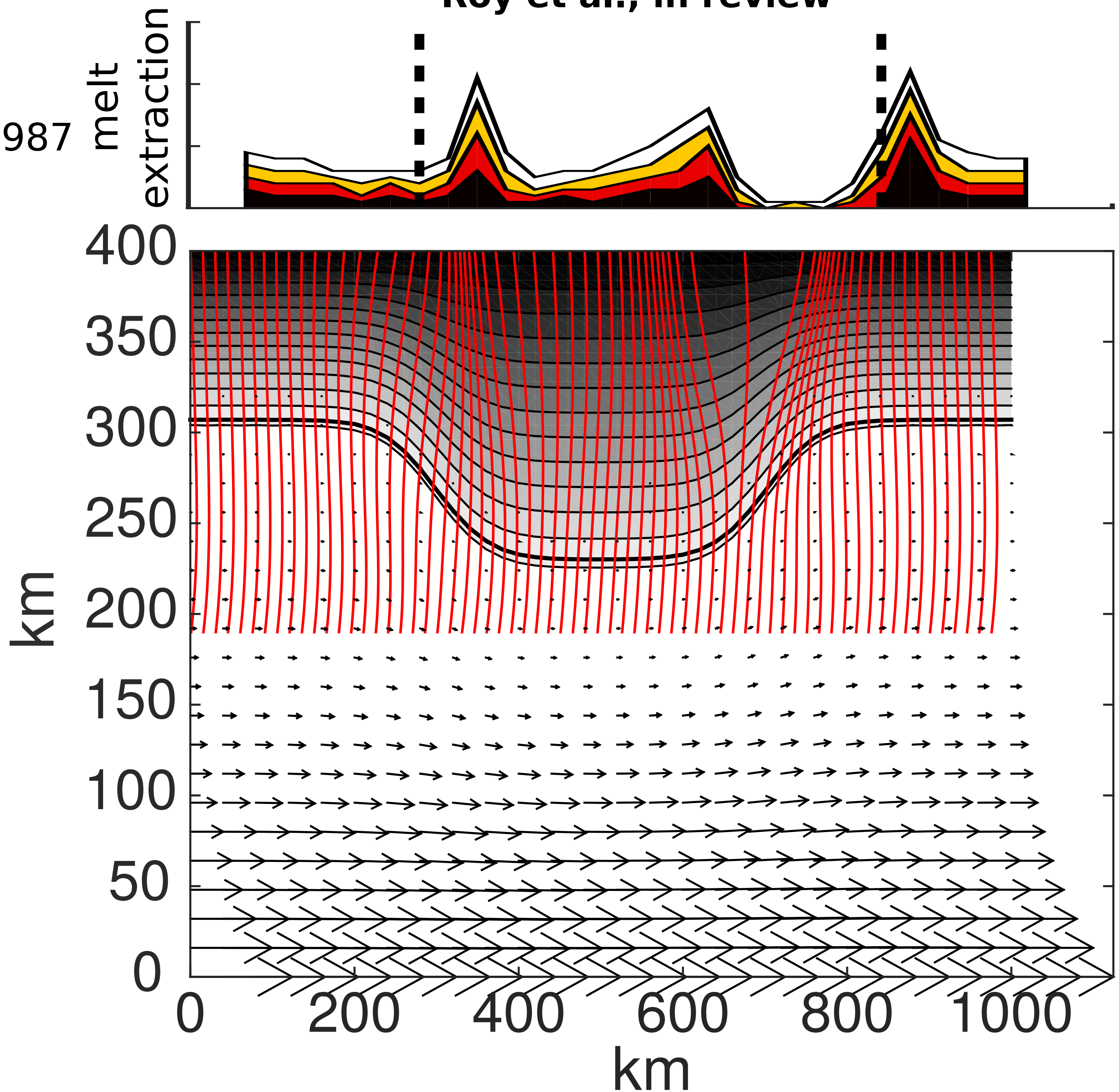
red curves - melt streamlines

arrows - solid flow field

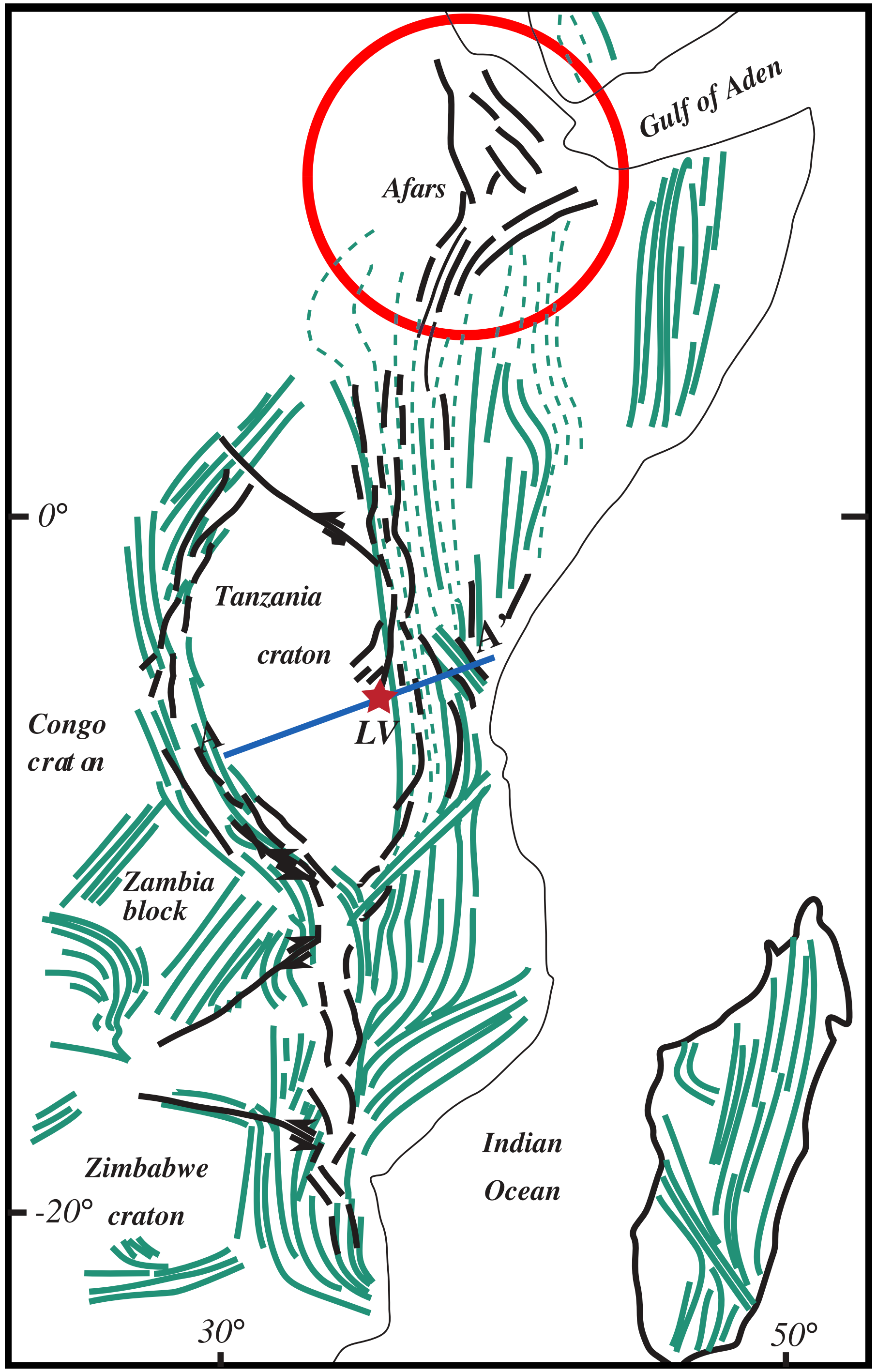
contour - temperature

melt deflected towards margins

Roy et al., in review



Inherited heterogeneity and shear zones: pathways for melt?



Vauchez et al., EPSL, 2005

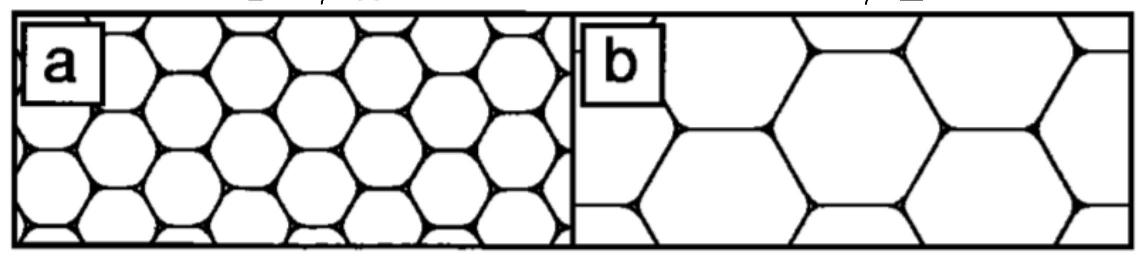
$$\boldsymbol{v}^f = \boldsymbol{V}^s + \frac{k}{\phi \eta_f}(\Delta\rho \boldsymbol{g} + \nabla P_c + \nabla P_d + \nabla P_{st} + \ldots)$$

Grain size and surface tension:

smaller grains = more grains in a given volume

1. higher porosity
2. higher surface area for reactions

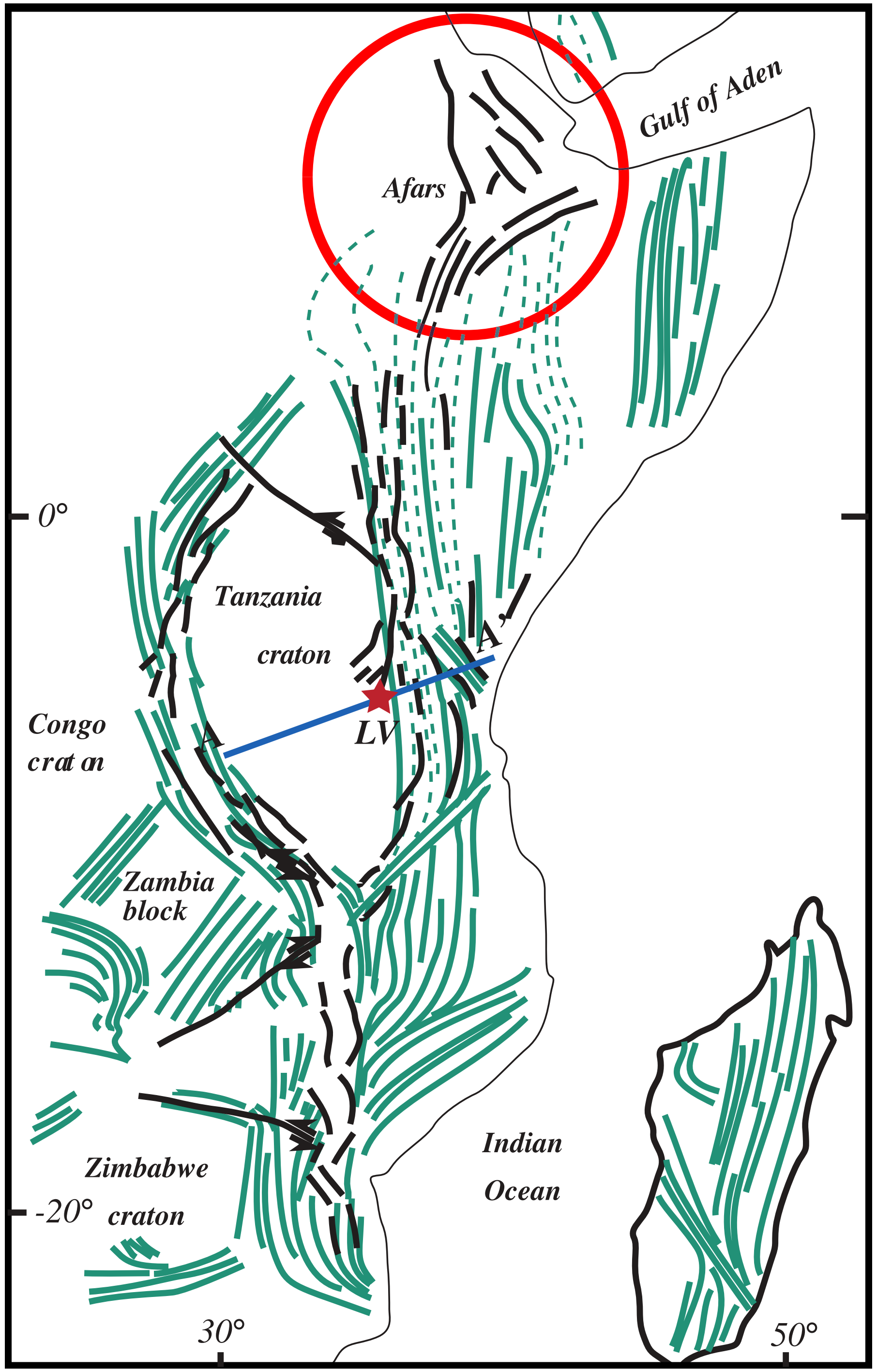
D_1 ϕ_1 D_2 ϕ_2

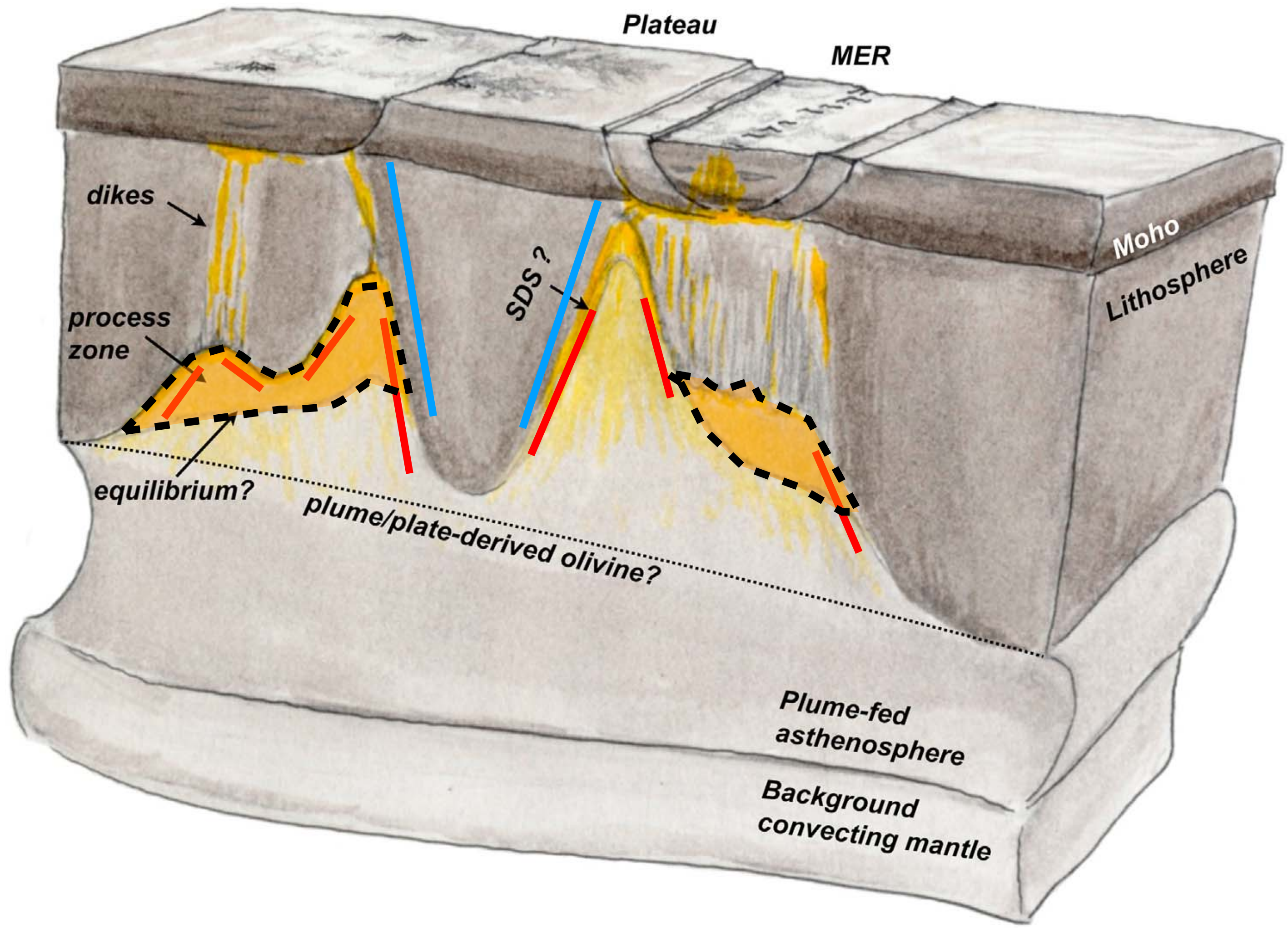


Wark and Watson, GRL, 2000

Lithology? More fusible?

$$\boldsymbol{v}^f = \boldsymbol{V}^s + \frac{k}{\phi \eta_f}\left(\Delta\rho \boldsymbol{g} + \nabla P_{\mathrm{c}} + \nabla P_{\mathrm{d}} + \nabla P_{\mathrm{st}} + \ldots\right)$$





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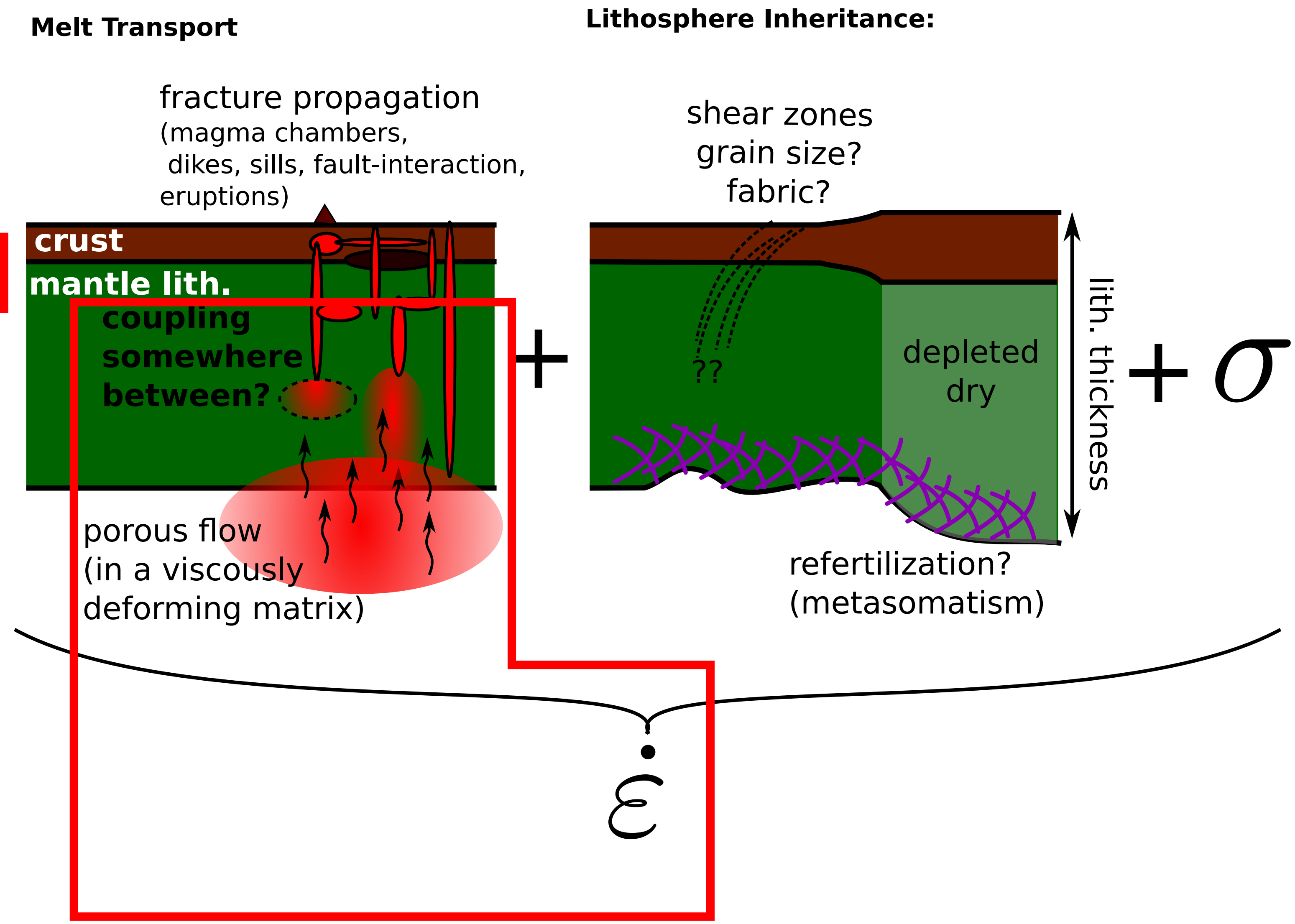


Dike transport: intrusional heating

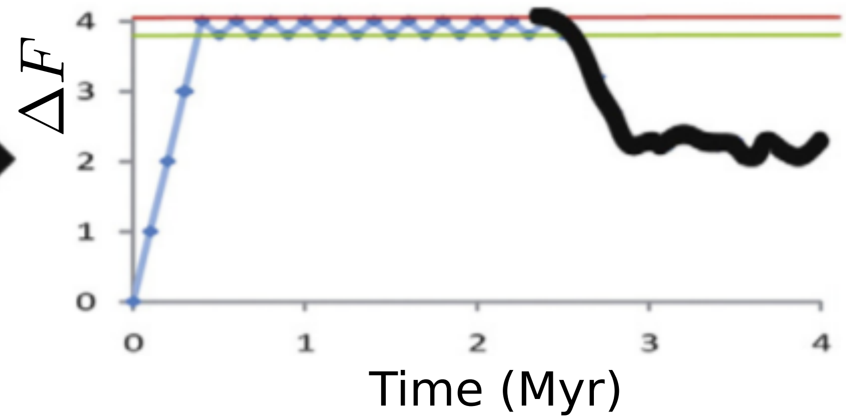
"Whole-lithosphere" heating
(dike height: 10s of km)

"Basal" heating (dike height << 10 km)

Dike transport: intrusional heating

"Whole-lithosphere" heating (dike height: 10s of km)

Bialis, Buck and Qin, EPSL, 2010



Also:
Schmeling, Tectonophysics, 2010
Schmeling and Wallner, G^3, 2012

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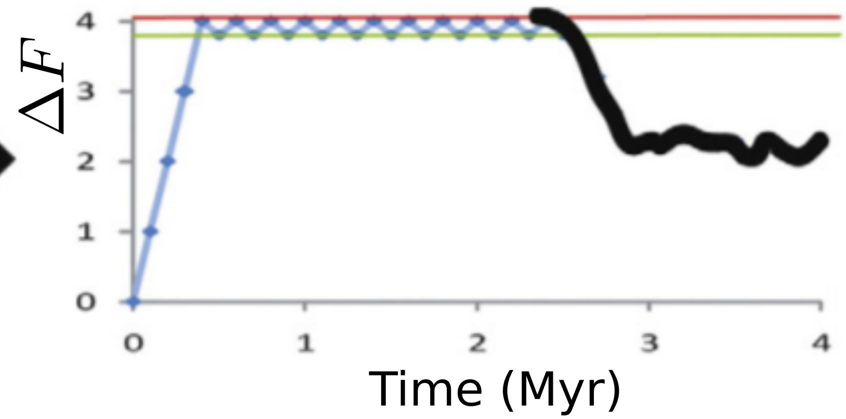

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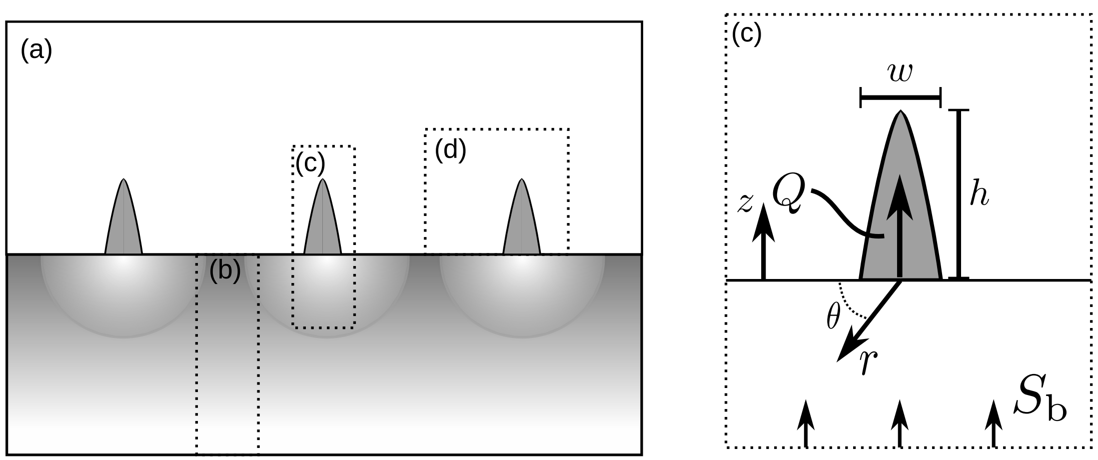
"Basal" heating (dike height << 10 km)

Dike propagation from melt accumulation zone at low (<0.25) melt fraction



$$S_{\mathrm{dike}} \approx A\phi^3$$

Havlin, Parmentier and Hirth, EPSL, 2013

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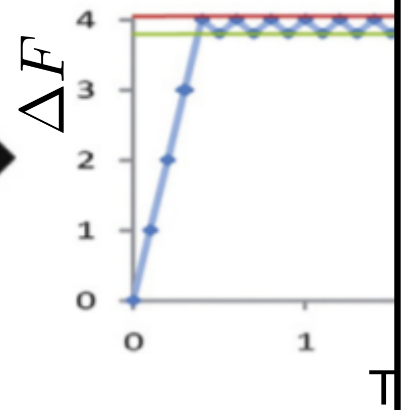

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Schmeling, Te
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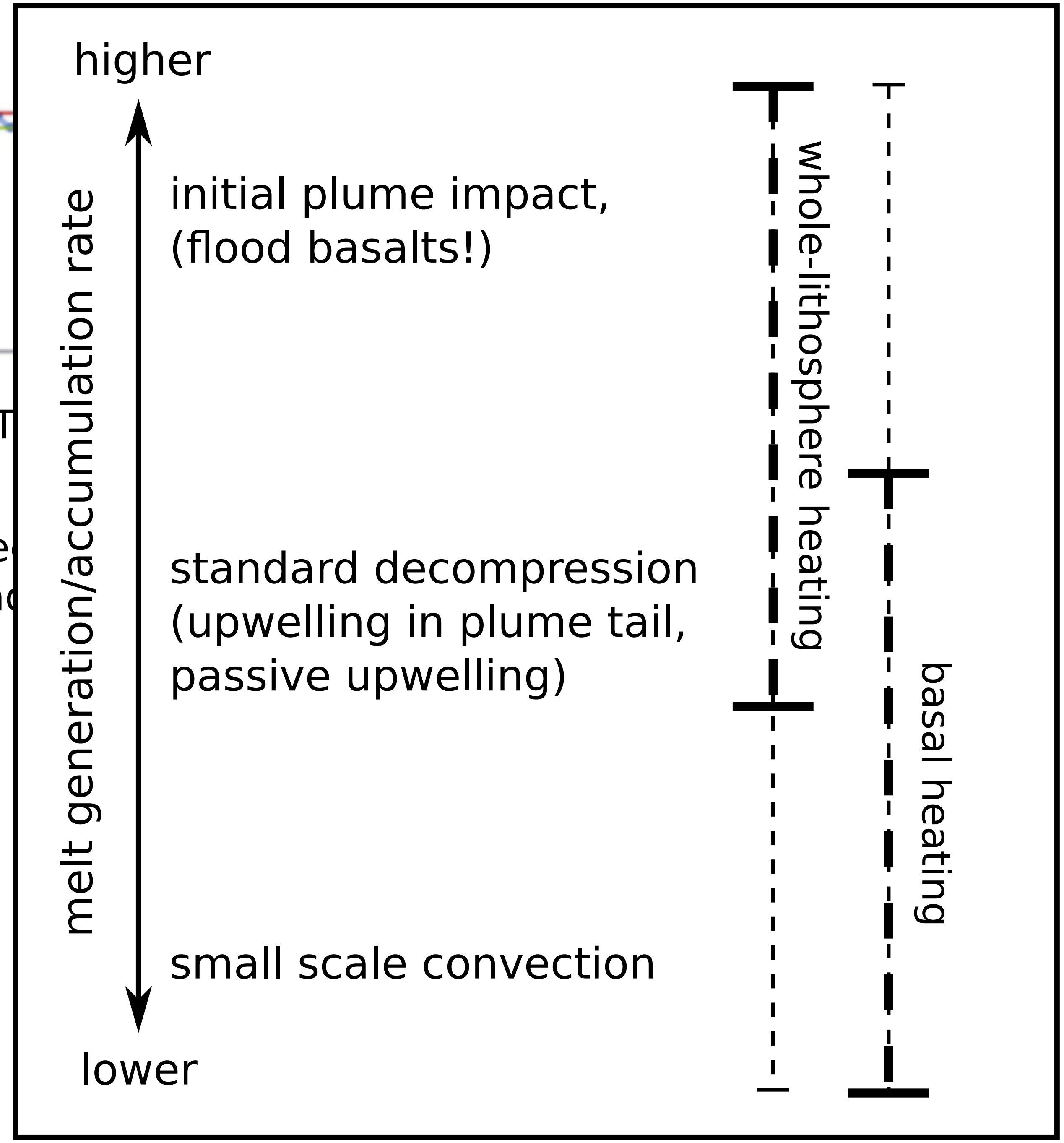

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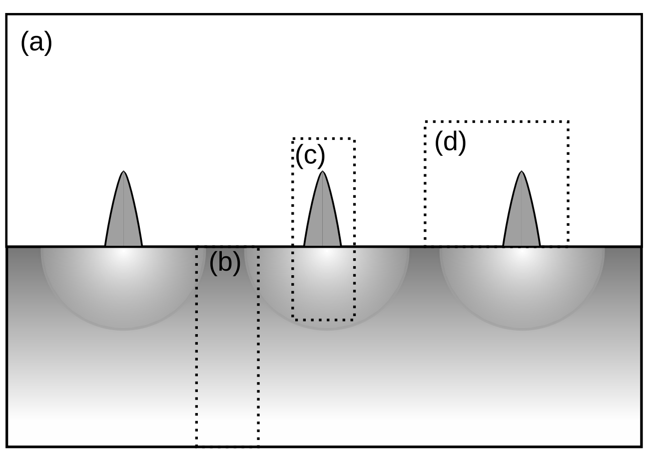

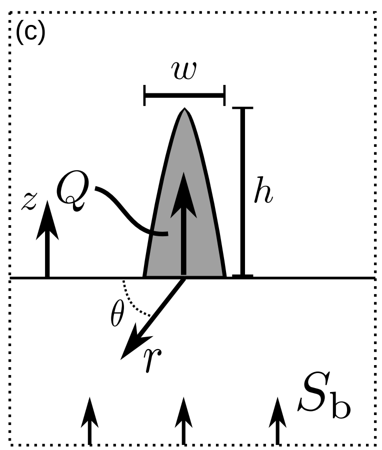

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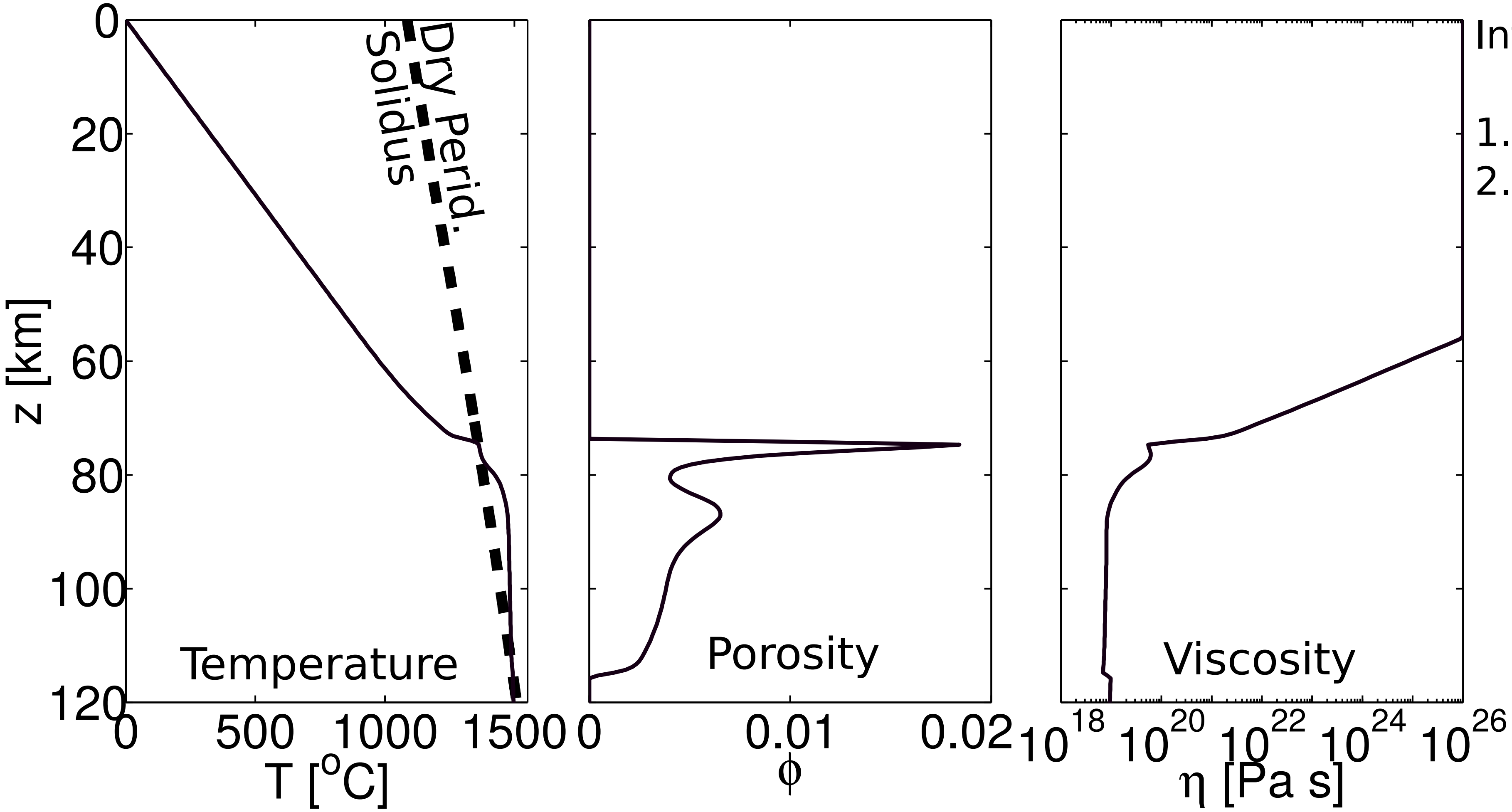
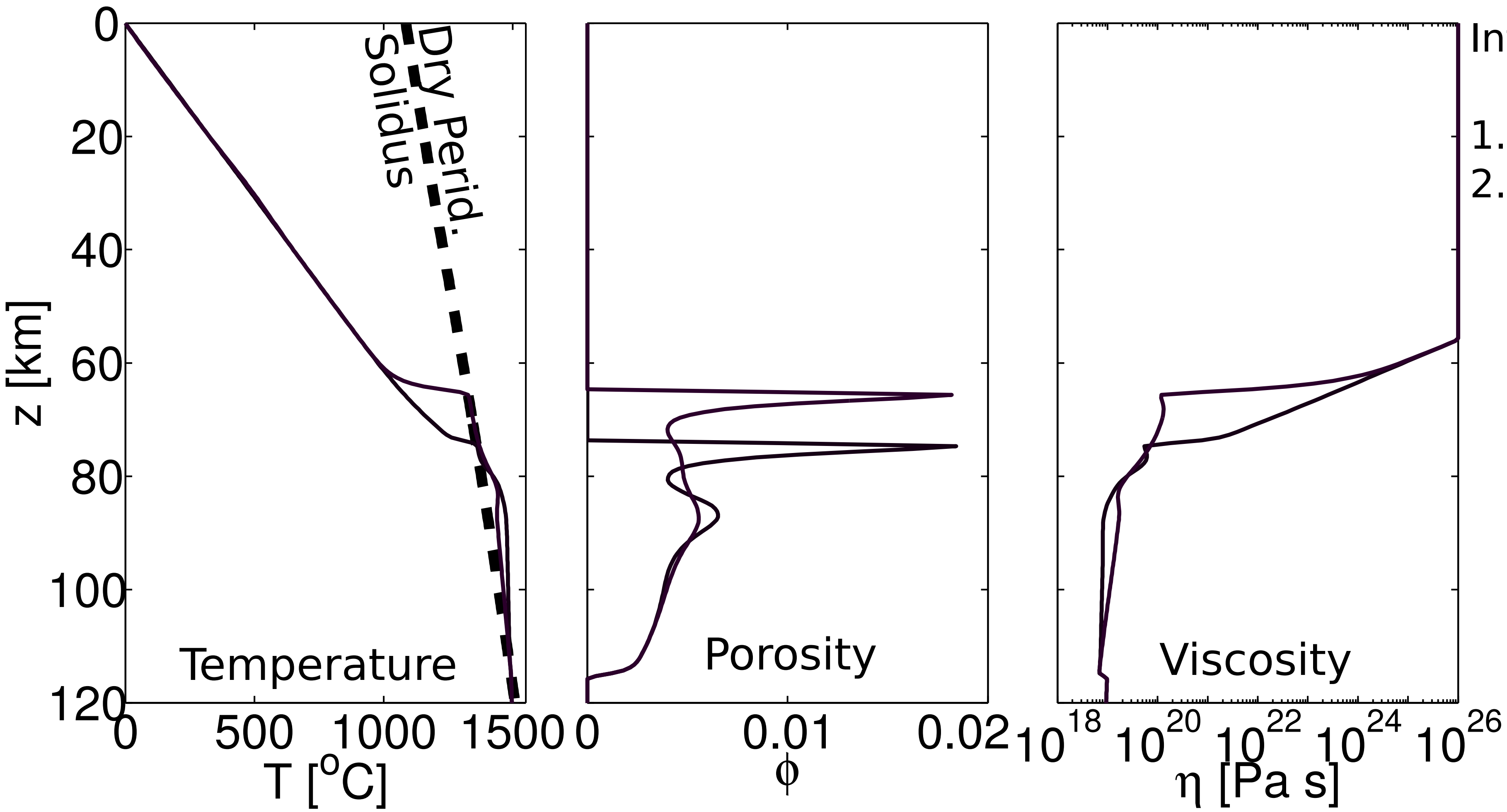


Intrusional heating at the LAB:

1. Geotherm heated to solidus
2. Porosity front advances

Basal heating (Havlin et al., in prep.)



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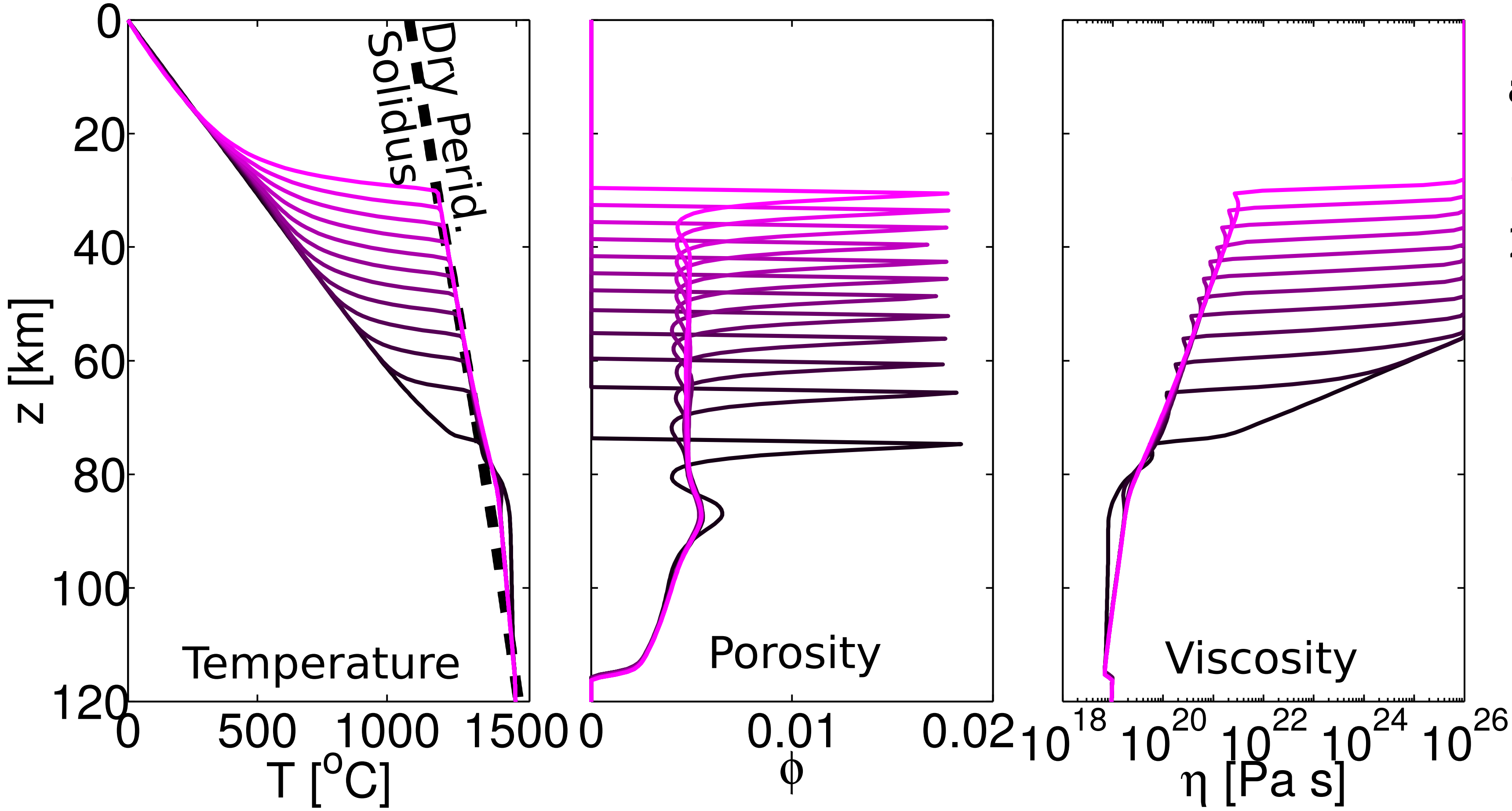

1D Intrusional heating at the LAB

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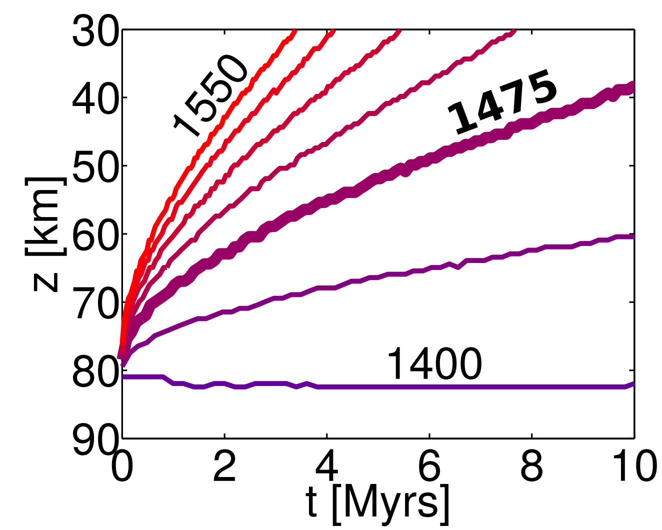
2. Porosity front advances



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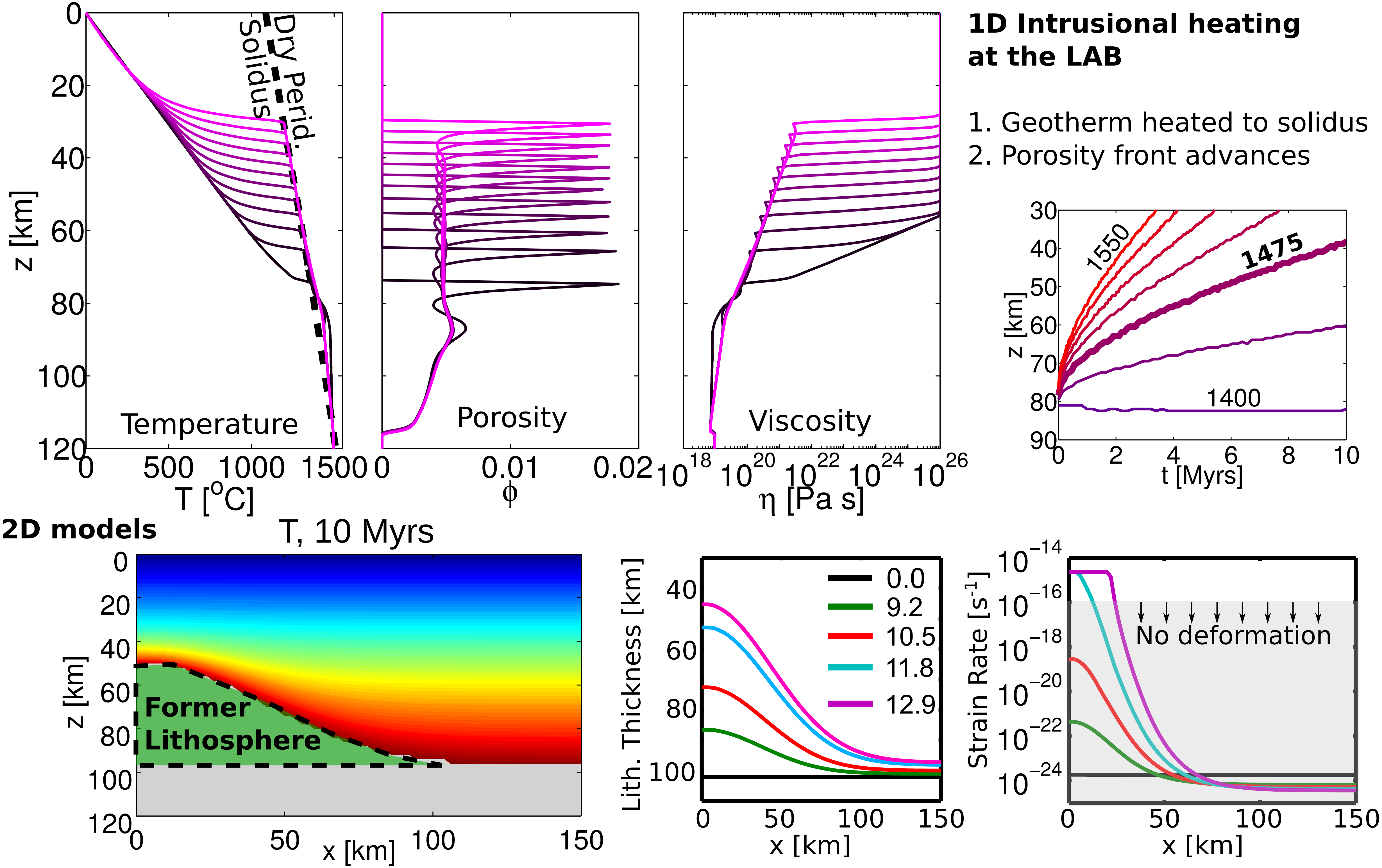

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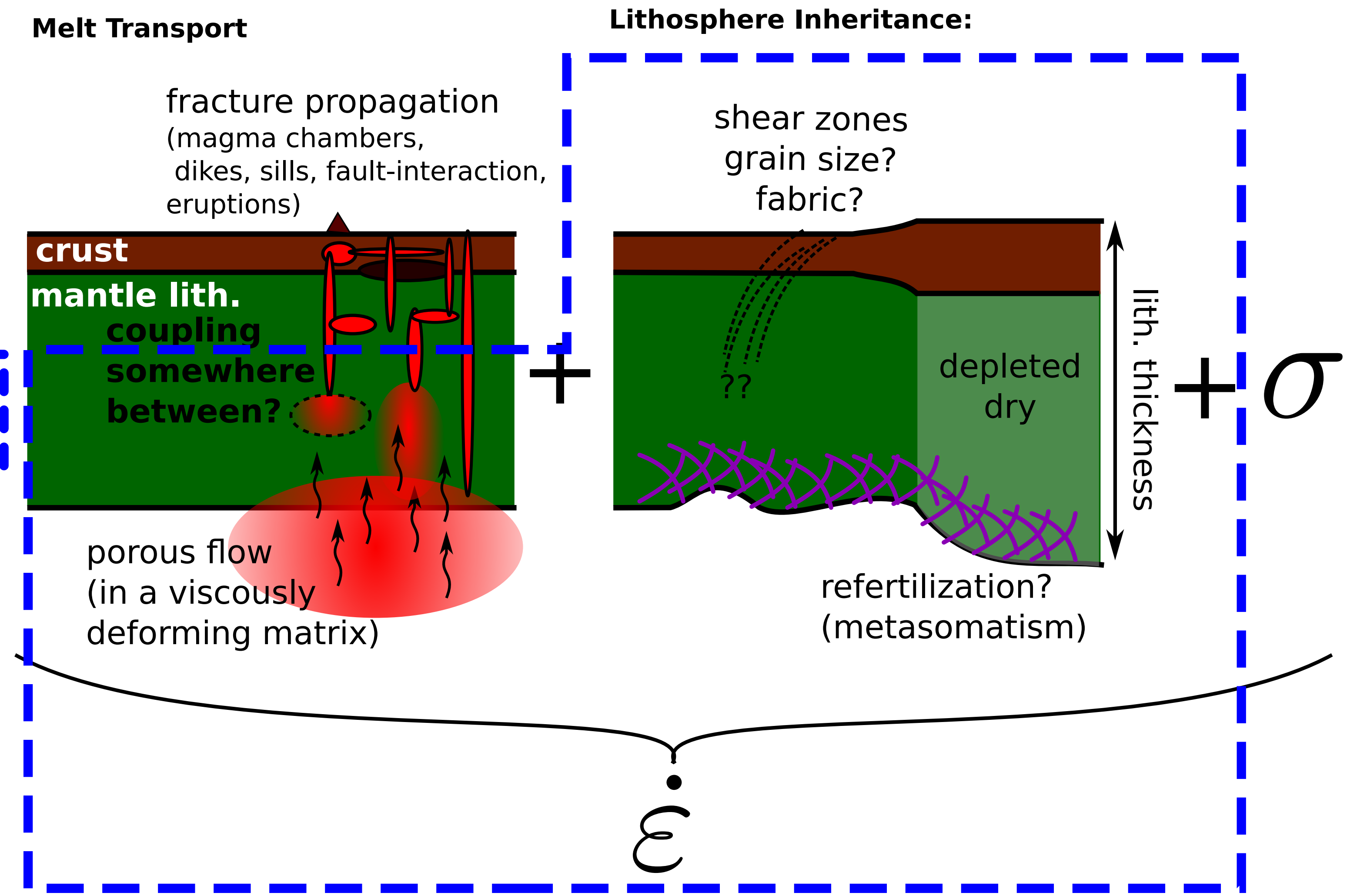
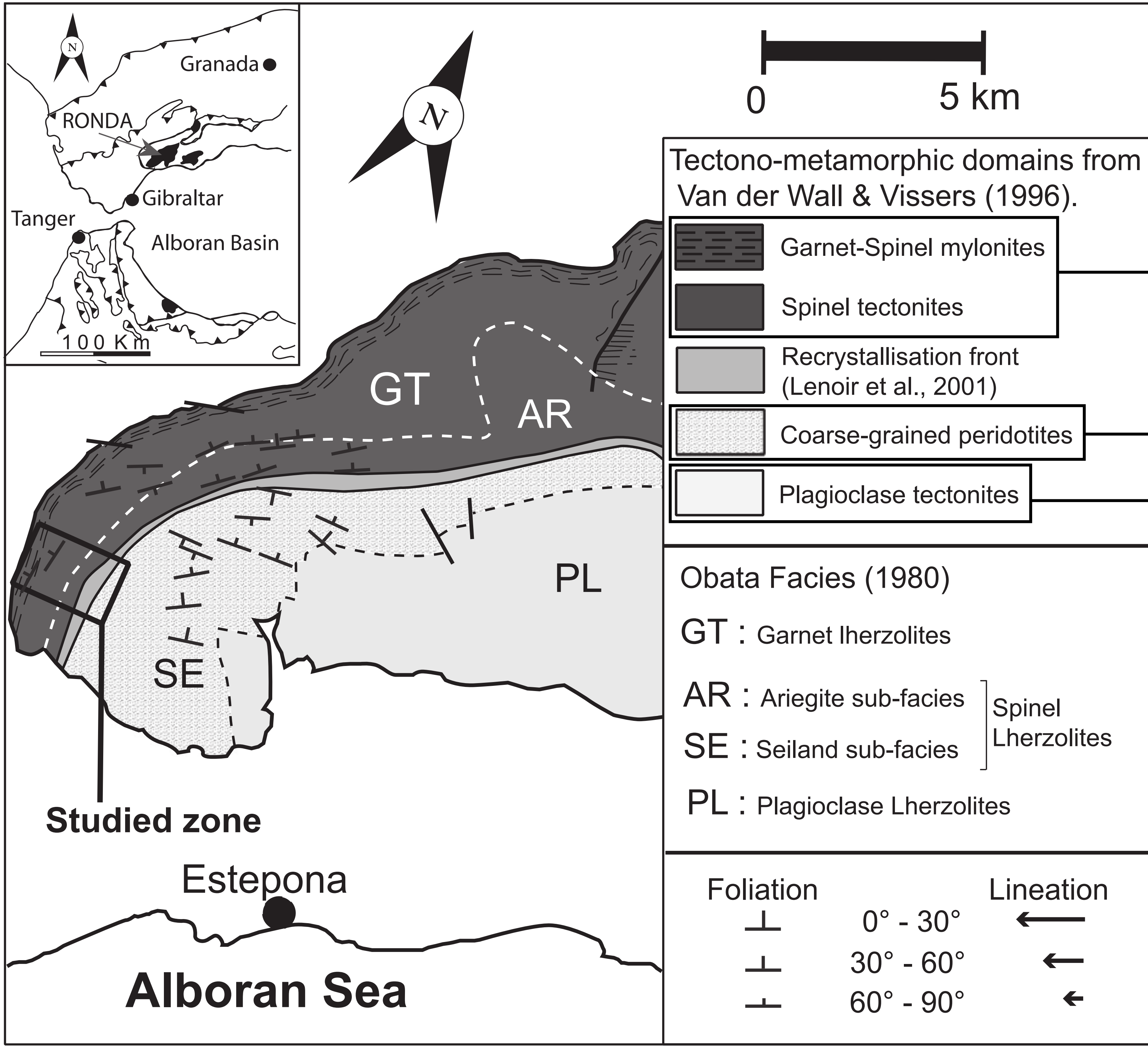


Deformation and melt transport in the lithosphere



A preserved LAB in the Ronda Massif

Preserved lithosphere

Partially molten

formed during emplacement

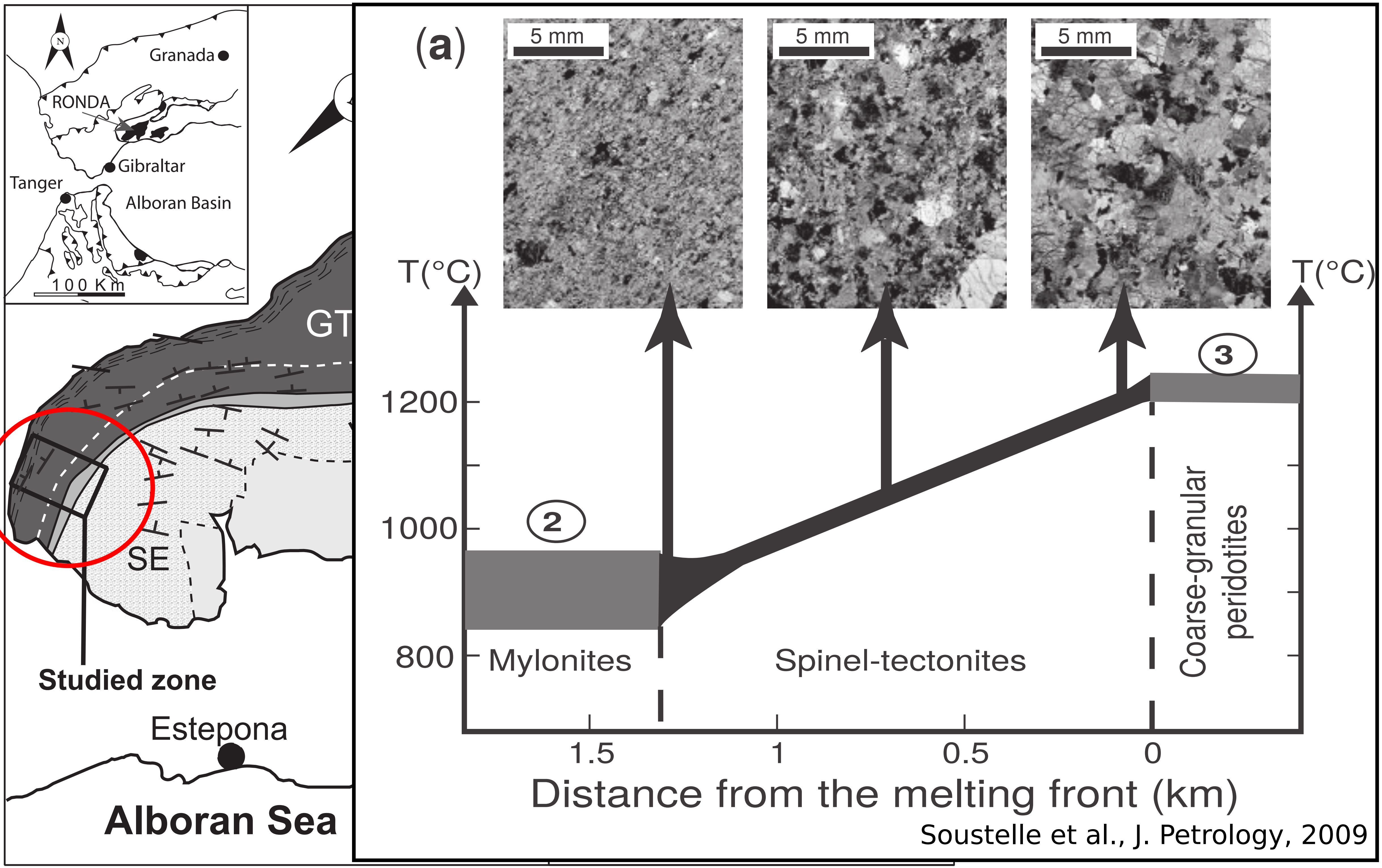
reactive melt percolation
(refertillization rxn's)

large thermal gradient

melt infiltration and deformation coupled

Soustelle et al., J. Petrology, 2009

Deformation and melt transport in the lithosphere



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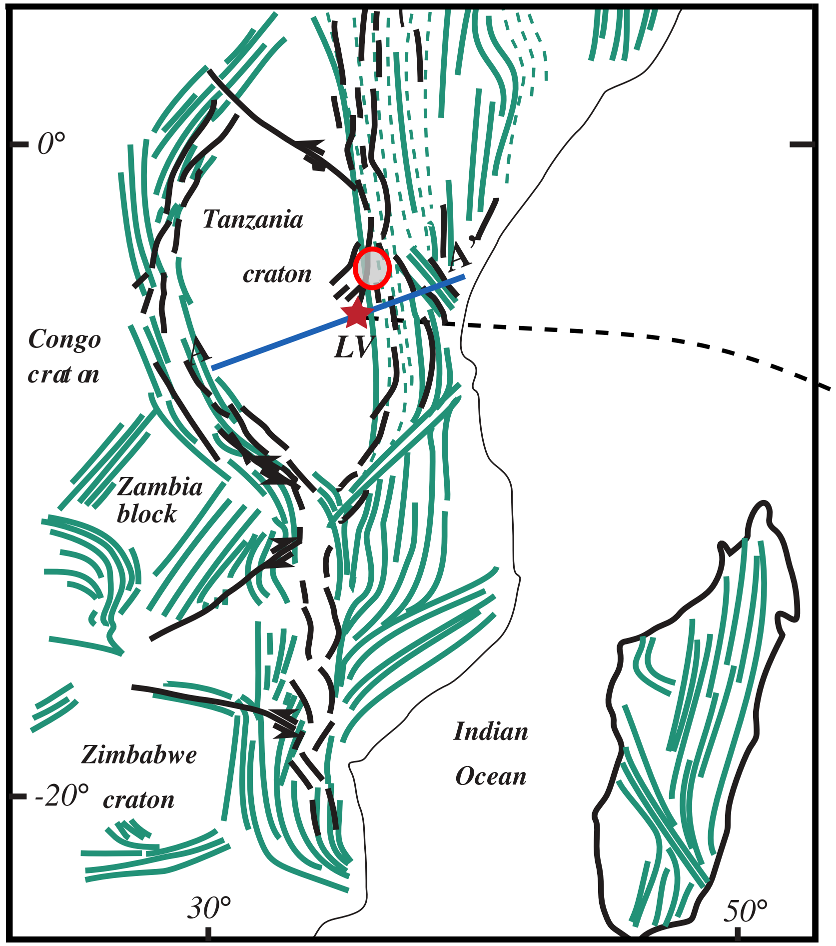
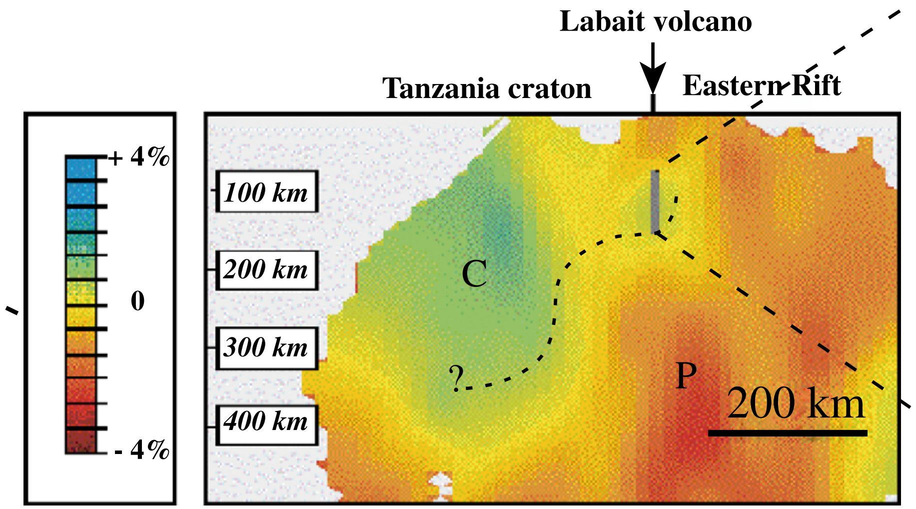
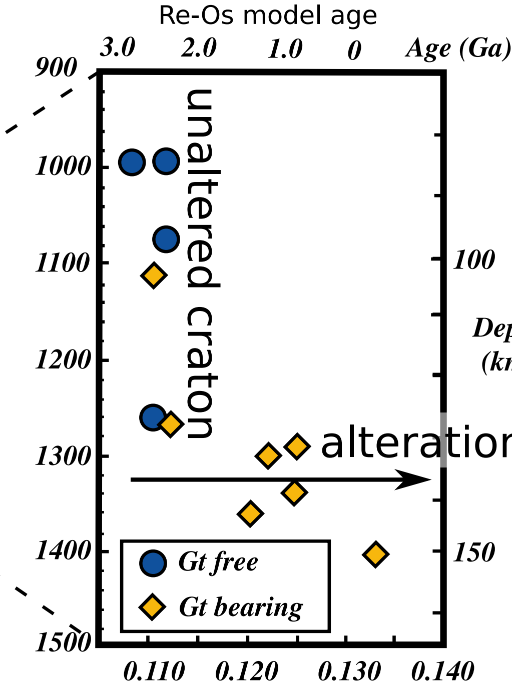
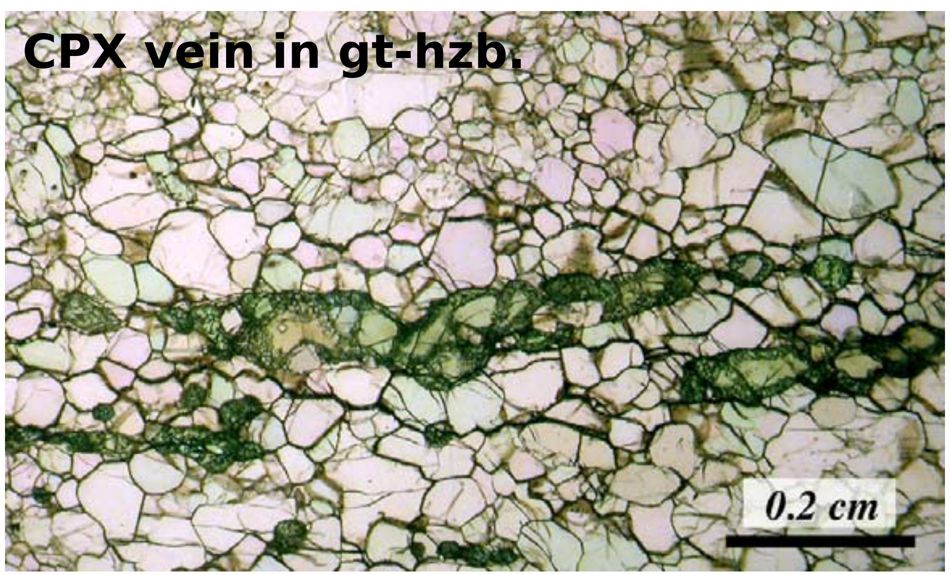


Vauchez et al., EPSL, 2005







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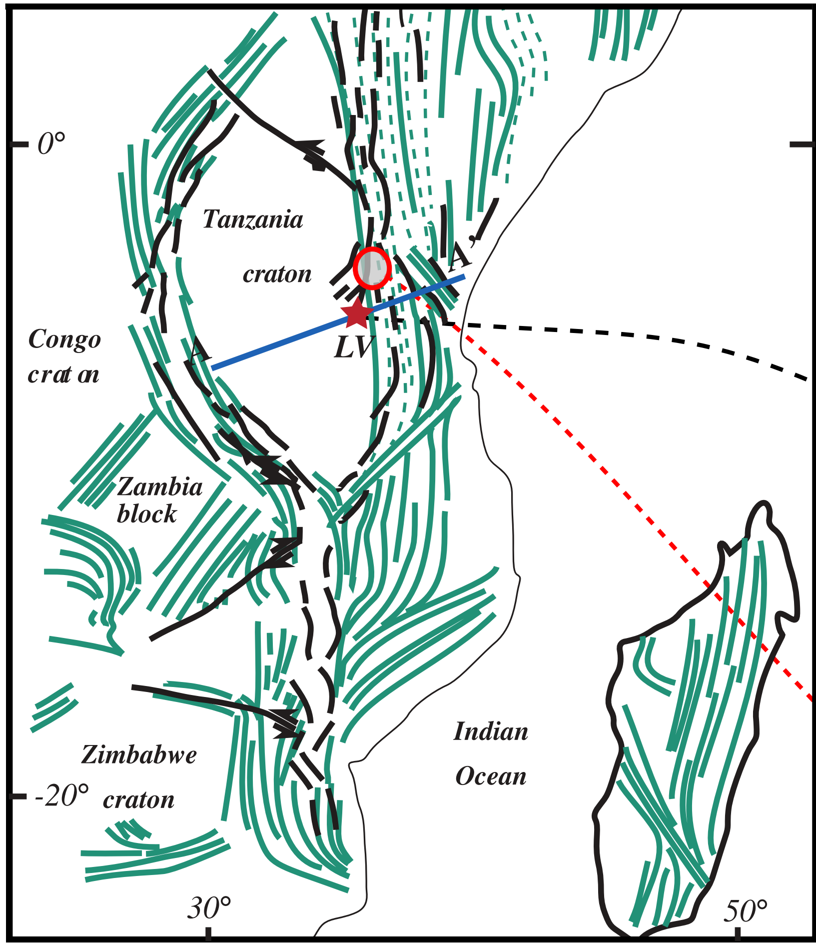

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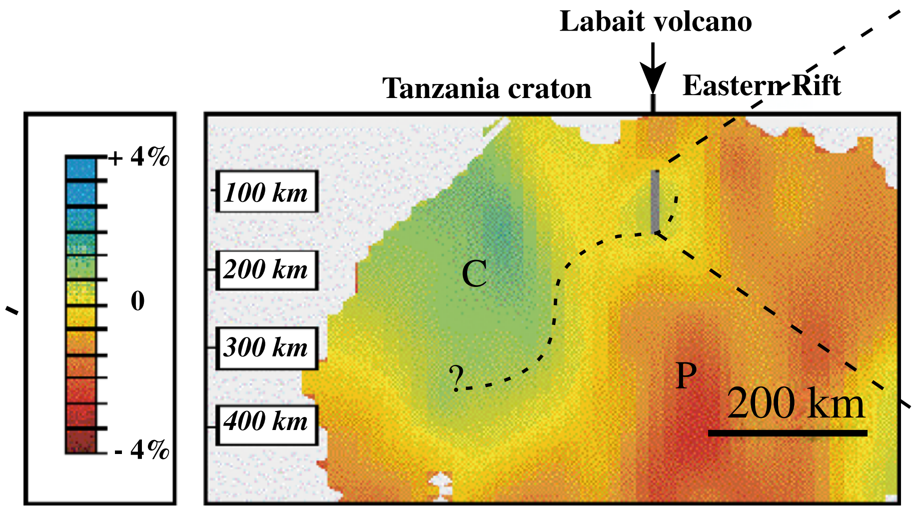

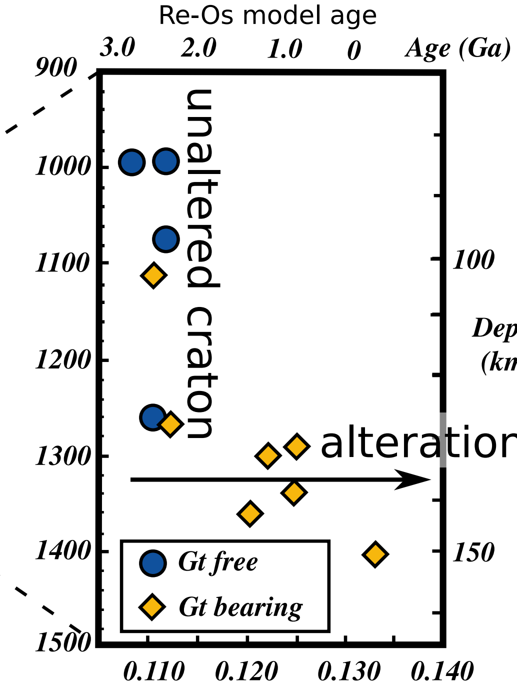

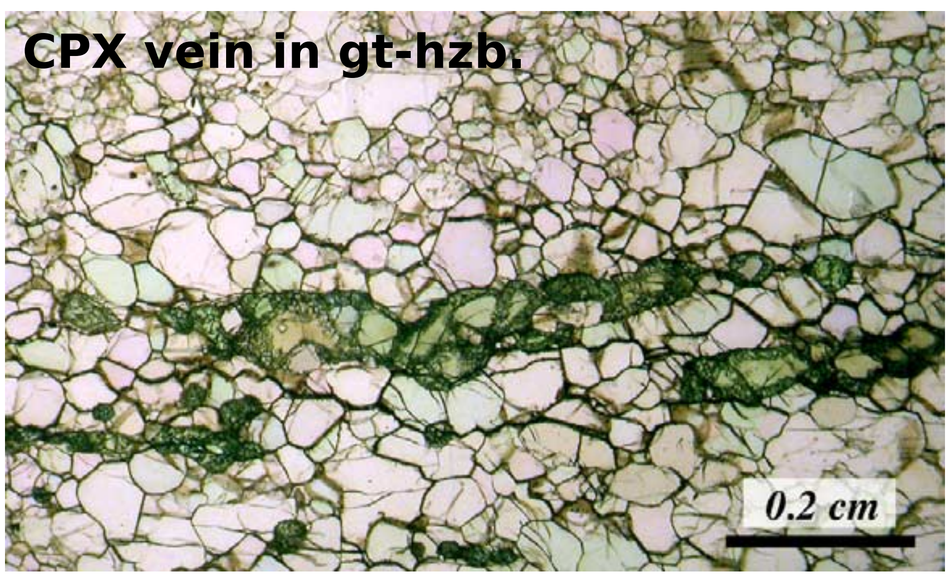

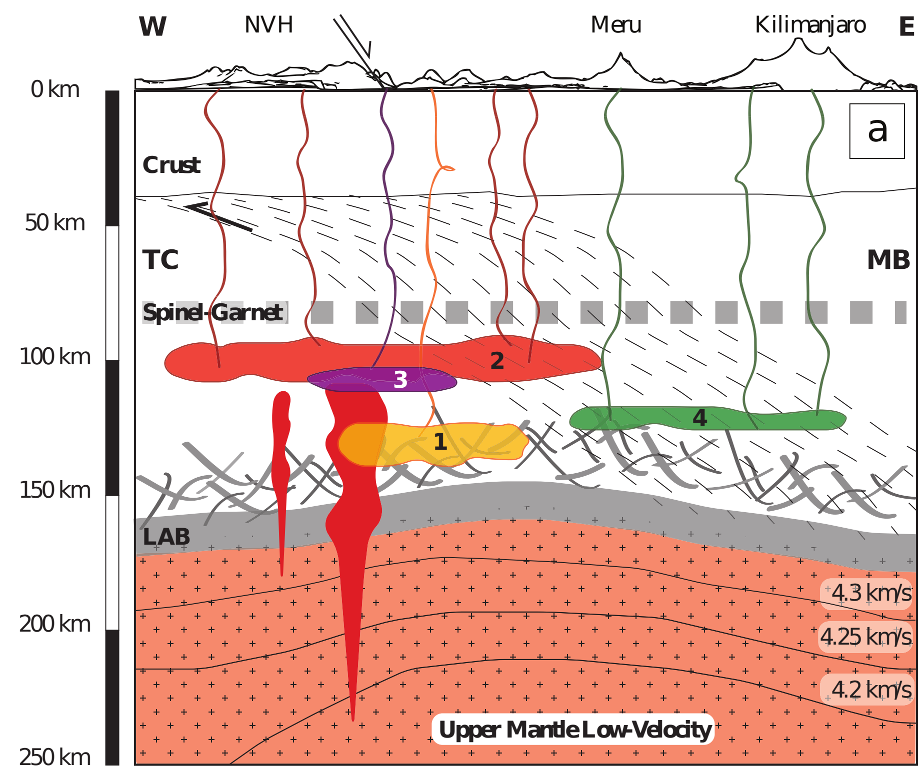

Mana et al., JGS 2015

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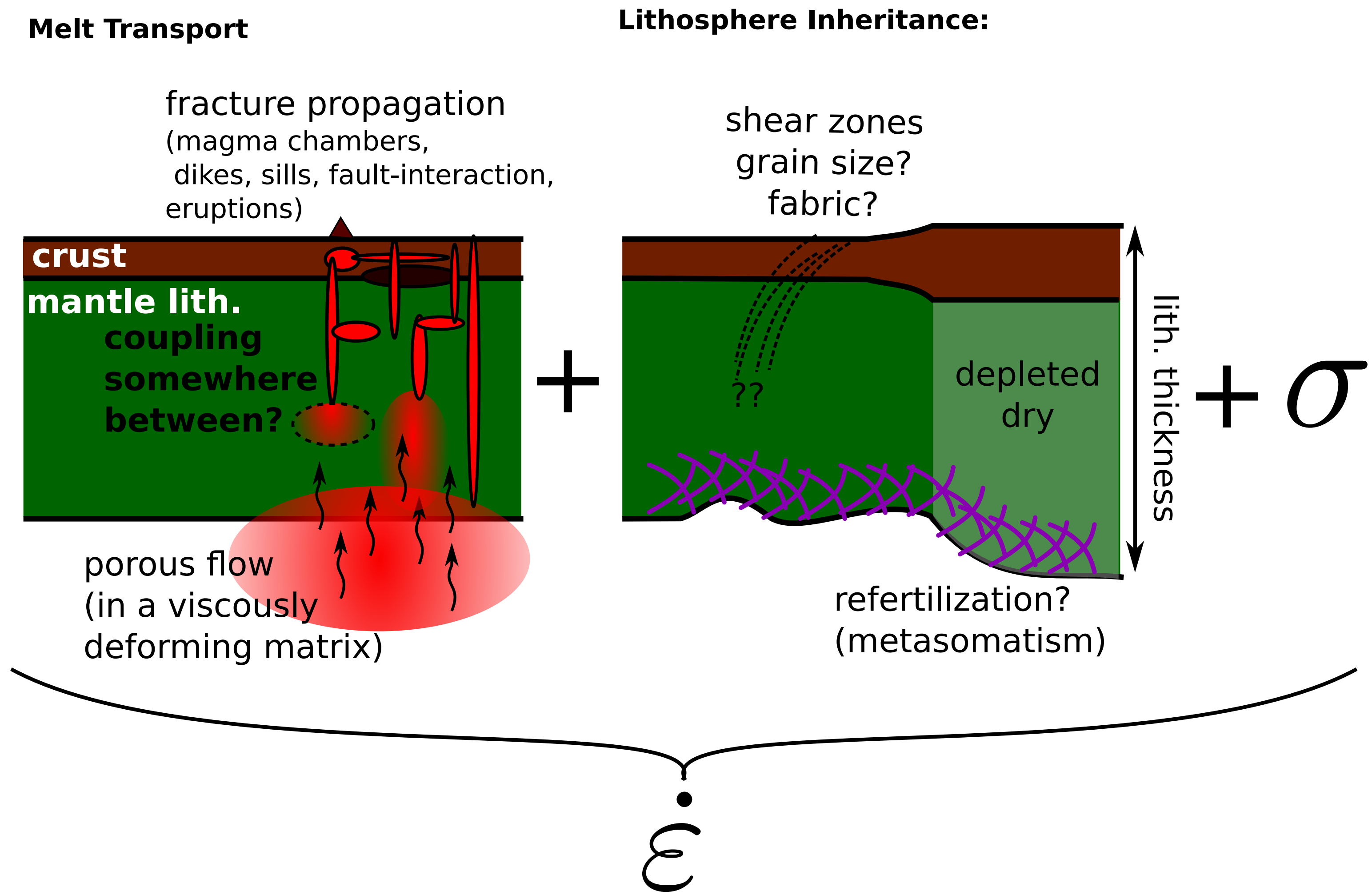
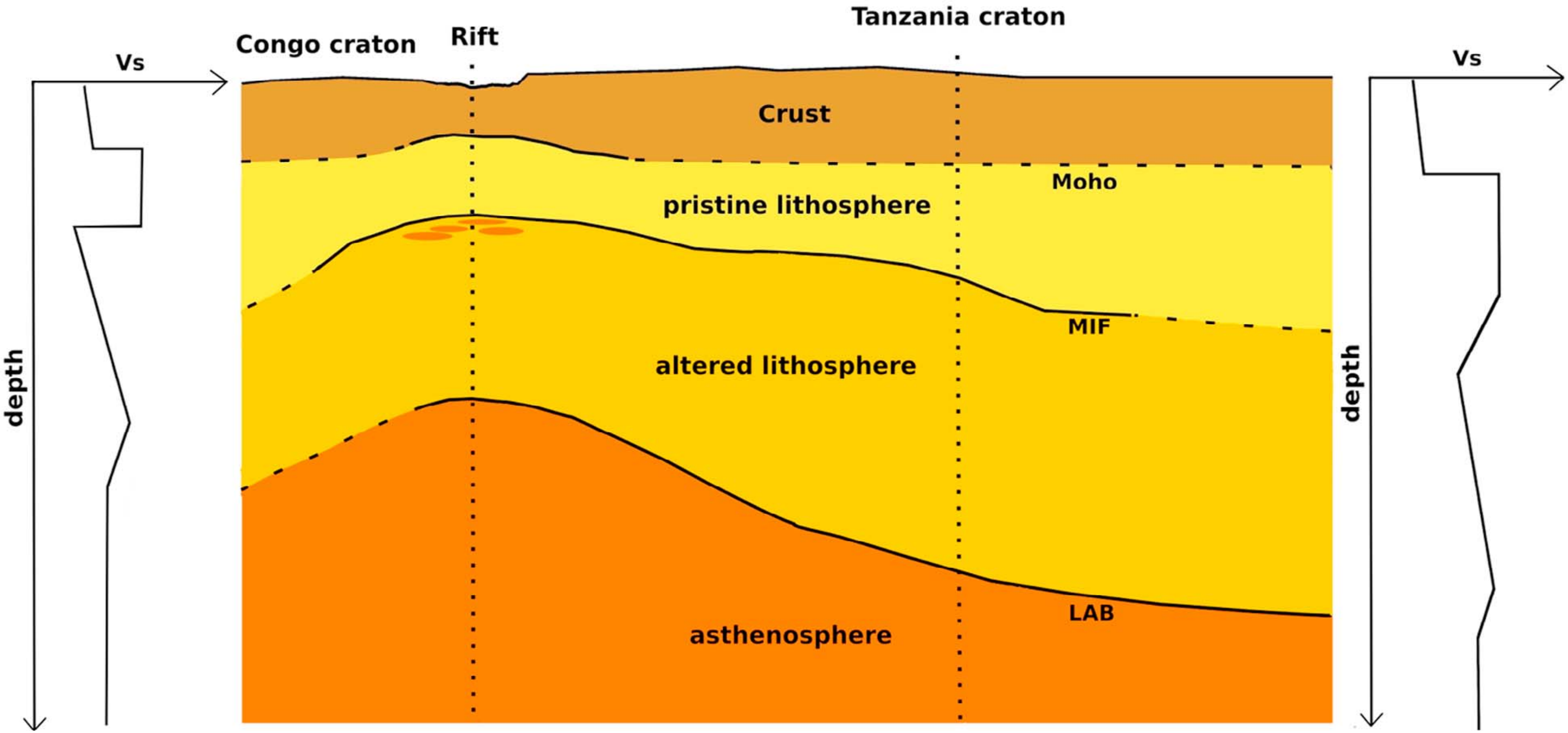


Geophysics and the search for melt...

Wölbern et al., G^3, 2012



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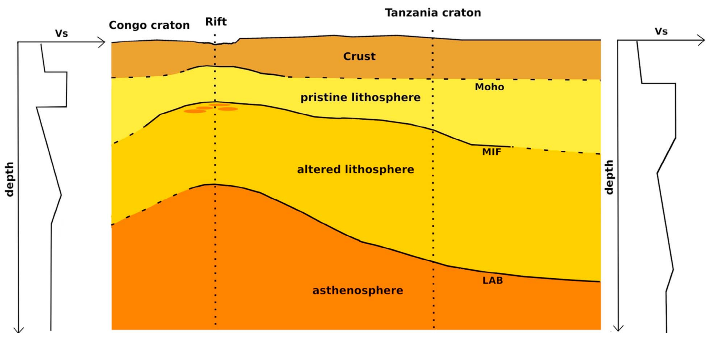
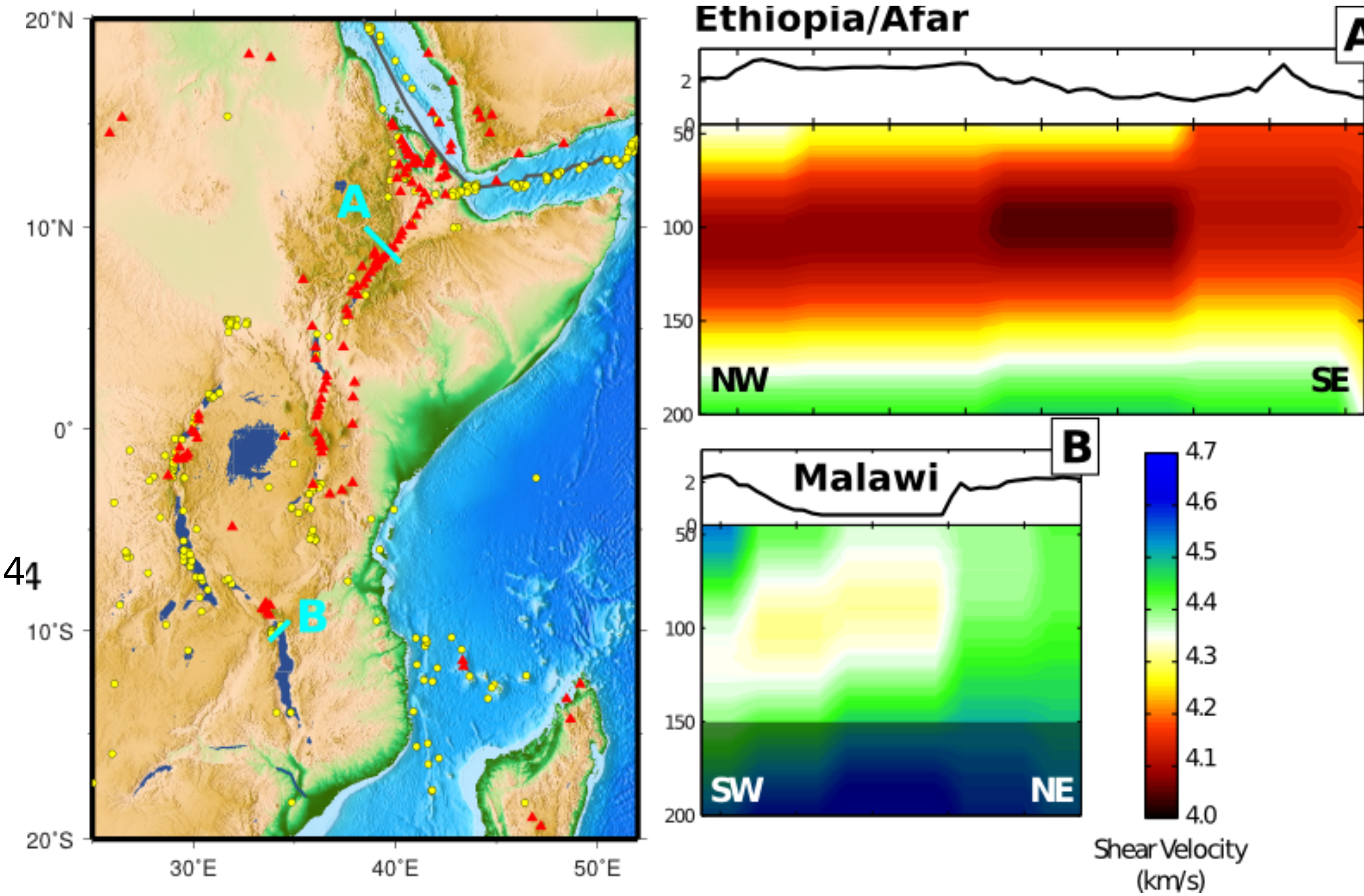
Accardo et al, in prep.



Melt in Afar/MER:

Knox et al., GRL, 1998
Keranen et al., Geology, 2004
Bastow et al., G3, 2010
Hammond et al., G3, 2011, 2014
Rooney et al., Tectonics, 2014
Korostelev et al., GRL, 2015



Visit Natalie's poster T51G-3000, Friday 10am: *Rayleigh-wave imaging of upper-mantle shear velocities beneath the Malawi Rift; Preliminary results from the SEGMeNT experiment*

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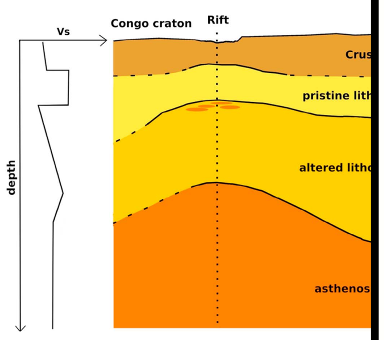

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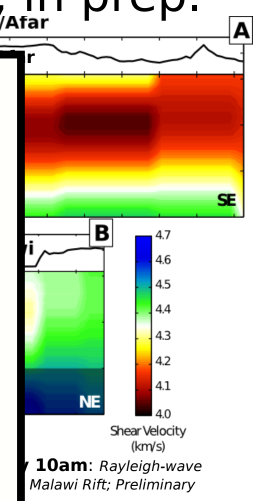

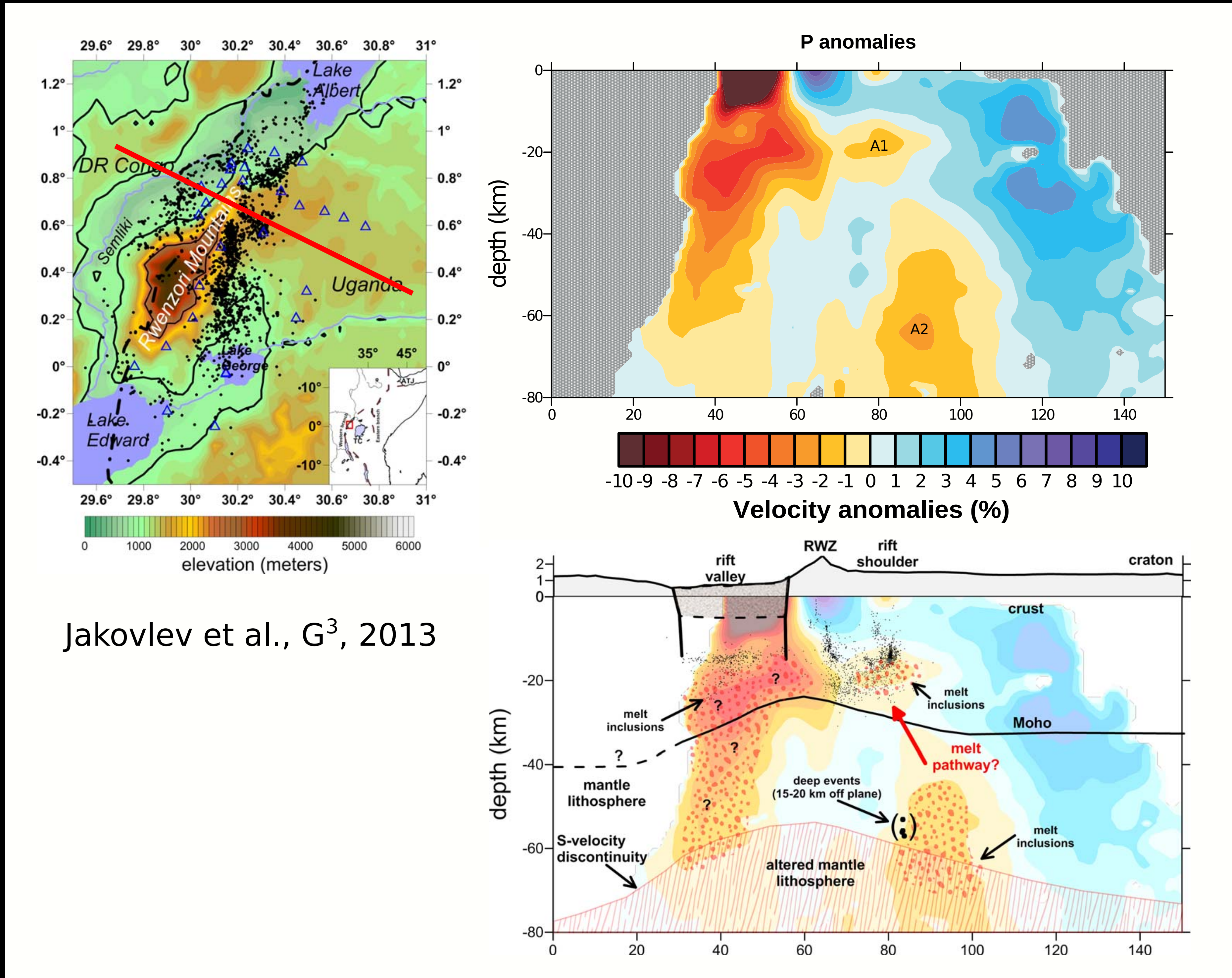

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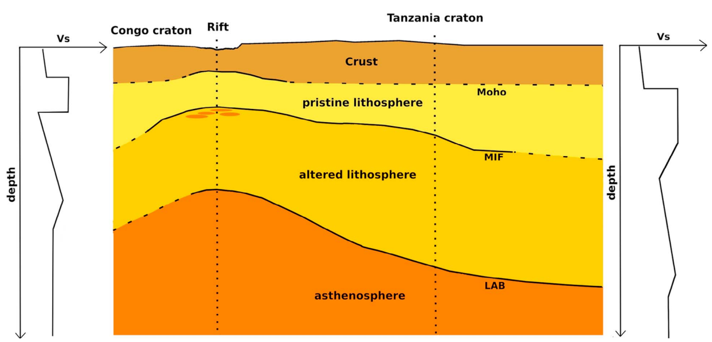

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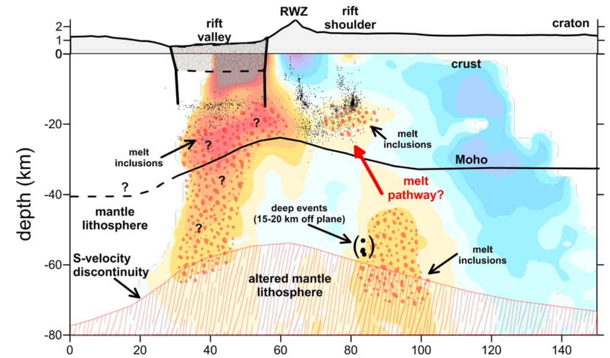
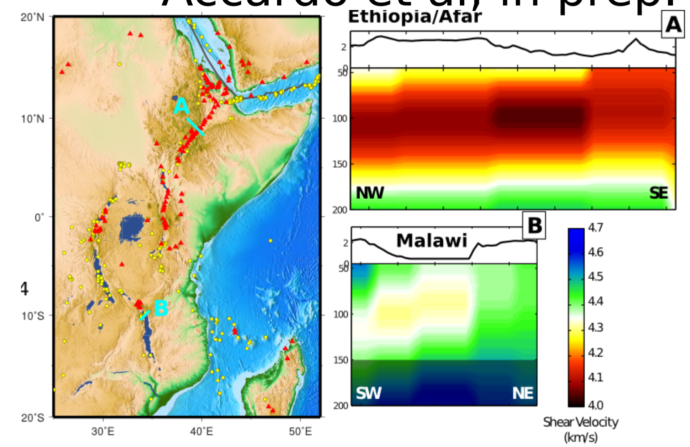


Accardo et al, in prep.

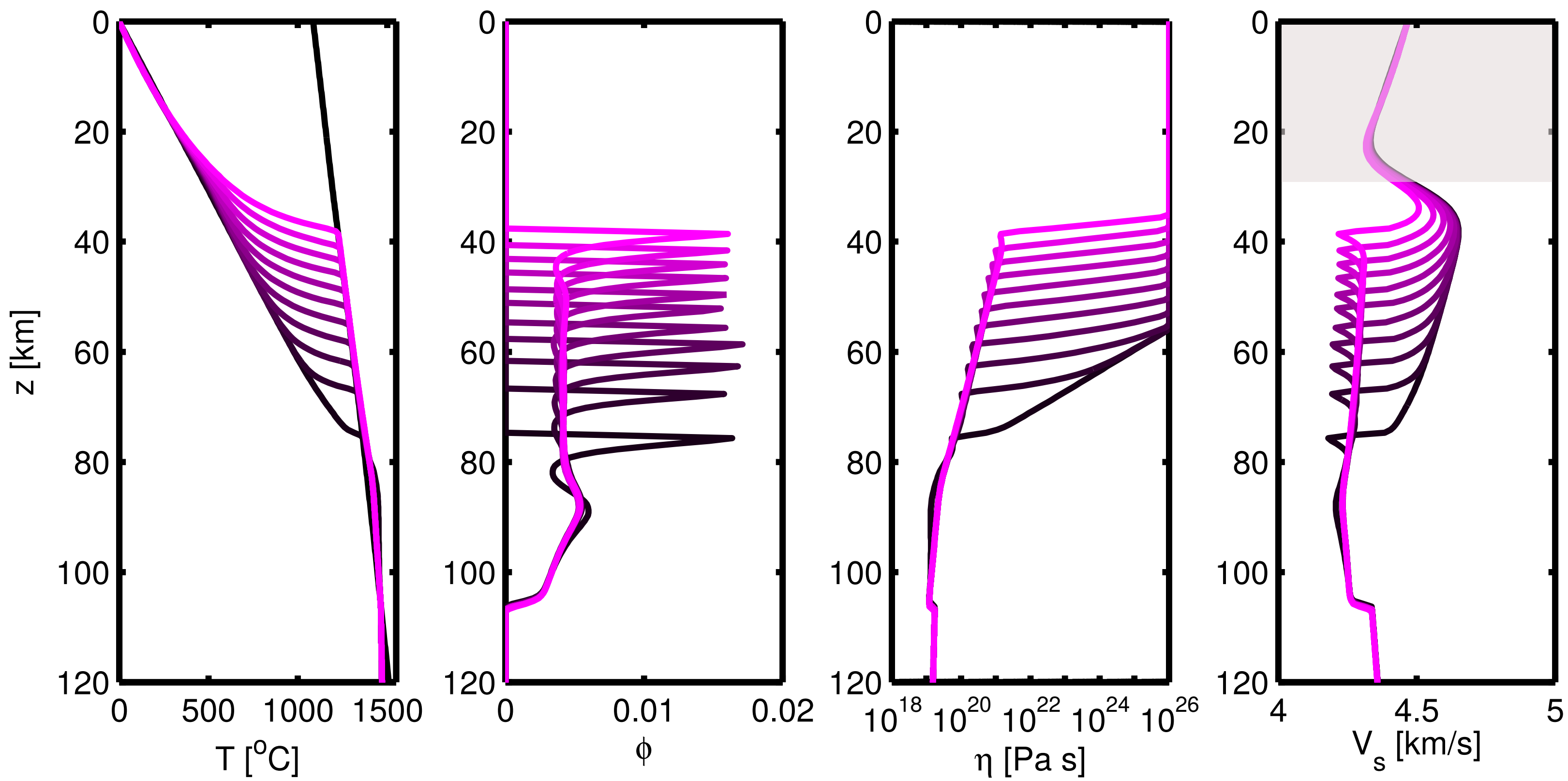


Visit Natalie's poster T51G-3000, Friday 10am: *Rayleigh-wave imaging of upper-mantle shear velocities beneath the Malawi Rift; Preliminary results from the SEGMeNT experiment*

Elastic + anelastic effects: $V_s(P, T, \chi, \phi, d, \mathrm{H_2O}, \sigma, f)$

Jackson and Faul, 2010; Jackson et al., 2006,2007
Karato, 2012; Aizawa et al., 2008
McCarthy and Takei, 2011; McCarthy aet al., 2011
Gribb and Cooper, JGR, 1998; Sundberg and Cooper, 2010
Holtzman, in review, 2015

.... also anisotropy(CPO, SPO)



Quantitative comparisons:
Absolute Vs
dVs, dVp
Synthetics receiver functions

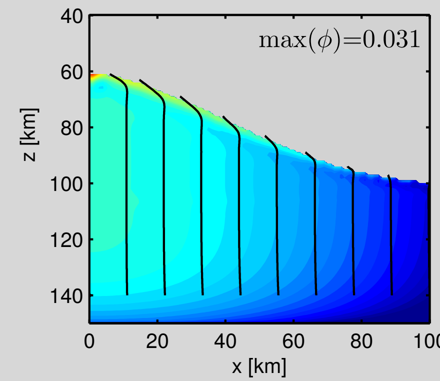
Havlin and Parmentier, GRL, 2014
Bellis and Holtzman, JGR, 2014
Olugboji et al., G^3, 2013
Goes et al., JGR, 2012
Hieronymus and Goes, GJI, 2010

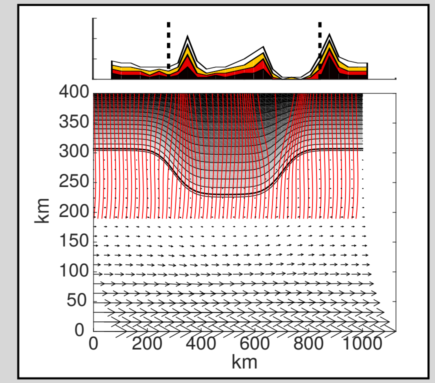
Summary

Melt transport and inherited lithosphere structure

initial lithosphere thickness: lateral melt transport
channelization along the LAB
focusing in thick lithosphere

shear zones:
preferential pathways for melt infiltration?

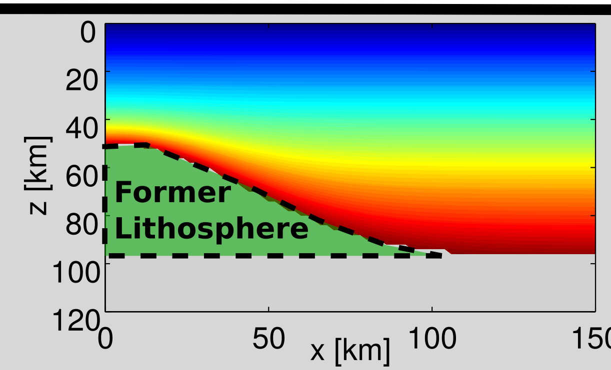


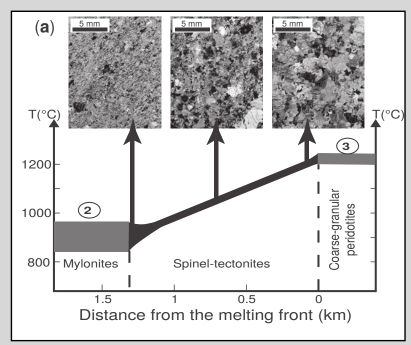


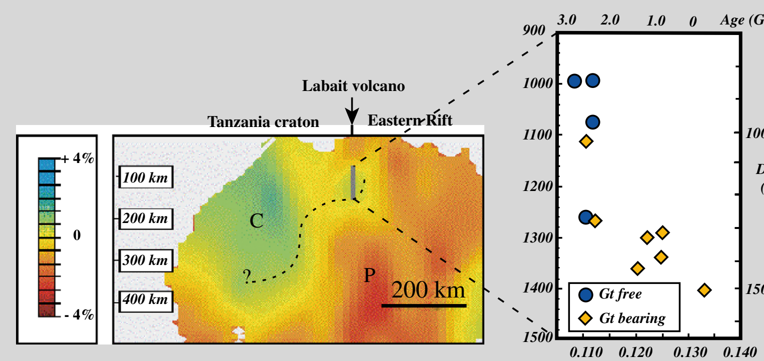
Interaction between melt transport & lithosphere

Intrusional heating: localizes deformation via thermal weakening
rates of basal erosion comparable to whole-lithosphere

thermal-chemical modification:
transport of volatiles, incompatible elements
reactive flow
melting of pre-existing fusible heterogeneity

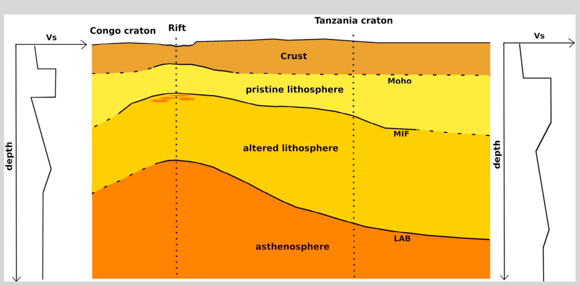


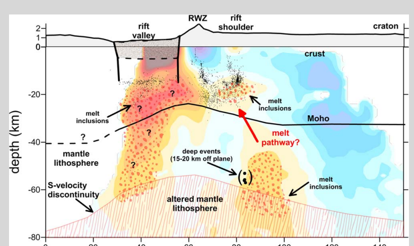




Geophysical Observations

increasingly compelling observations...





ambiguity remains (but there is progress!)

Thank you!

(missed some references? want to chat about
melt infiltration? chavlin@ldeo.columbia.edu)