Recipe for Rifting

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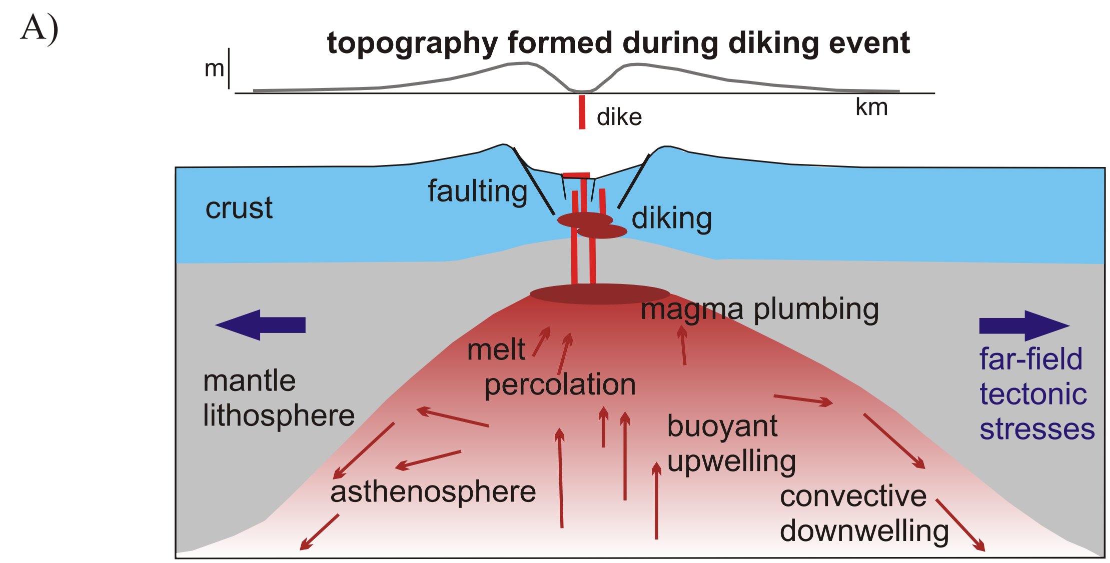
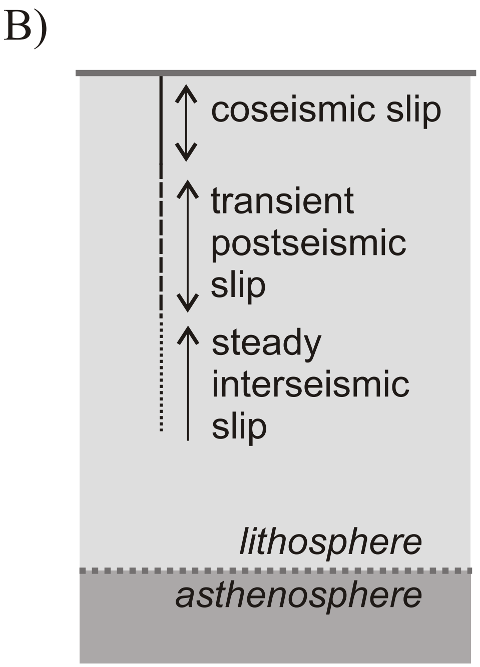
King Cake

AGU 2017 in New Orleans

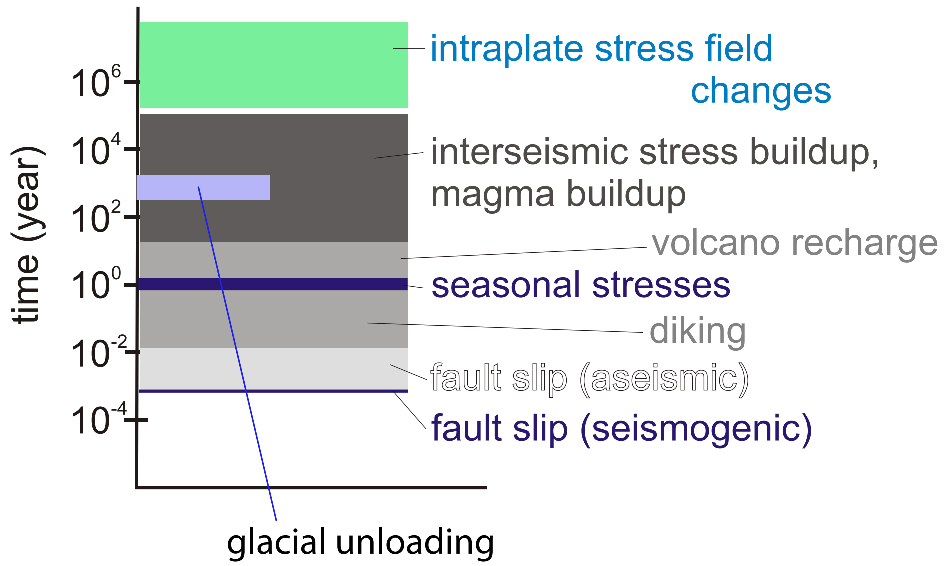


Volcanic systems respond to tectonic forces; density contrasts, fluid pressures modify ambient stress field



rheology-dependent behavior

C)

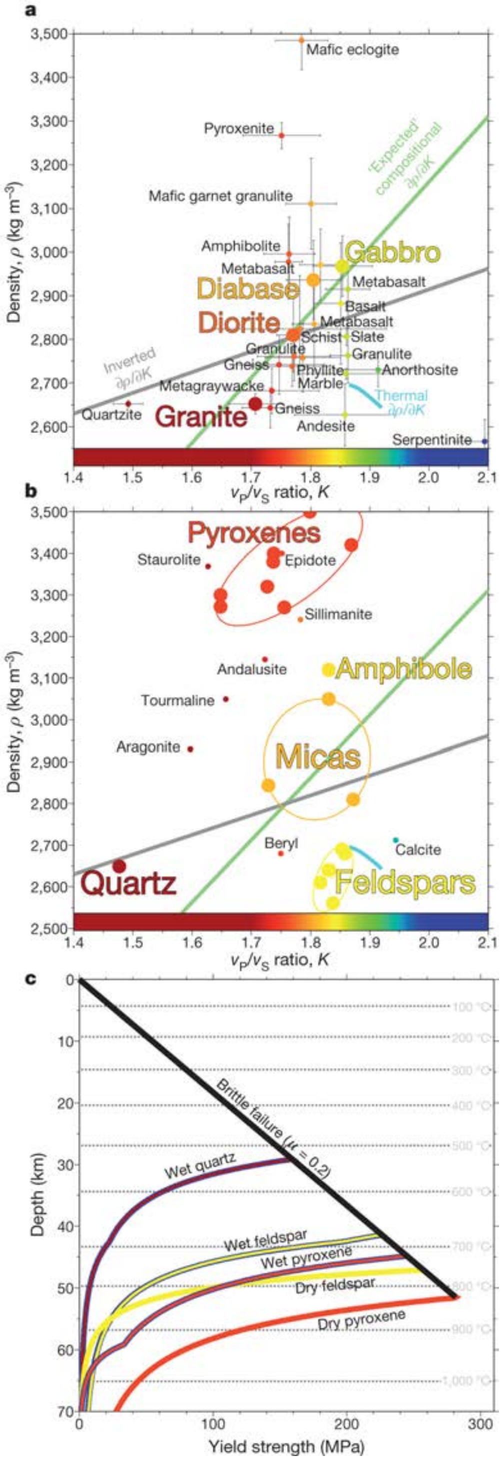


Foundations I

Scales and architecture of extensional systems spatially variable. Endmembers, plus all between

1) ‘cratonic’ rifts – develop in cold lithosphere
2) ‘orogenic’ rifts – develop in collapsing orogens where crust is hot, mantle may be hydrated

Differences confirm critical importance of crust and mantle rheology



Rheology - We know we need to know hydration state and composition of lower crust, but we have few tools to measure in situ:

Density

Vp, Vs, Vp/Vs

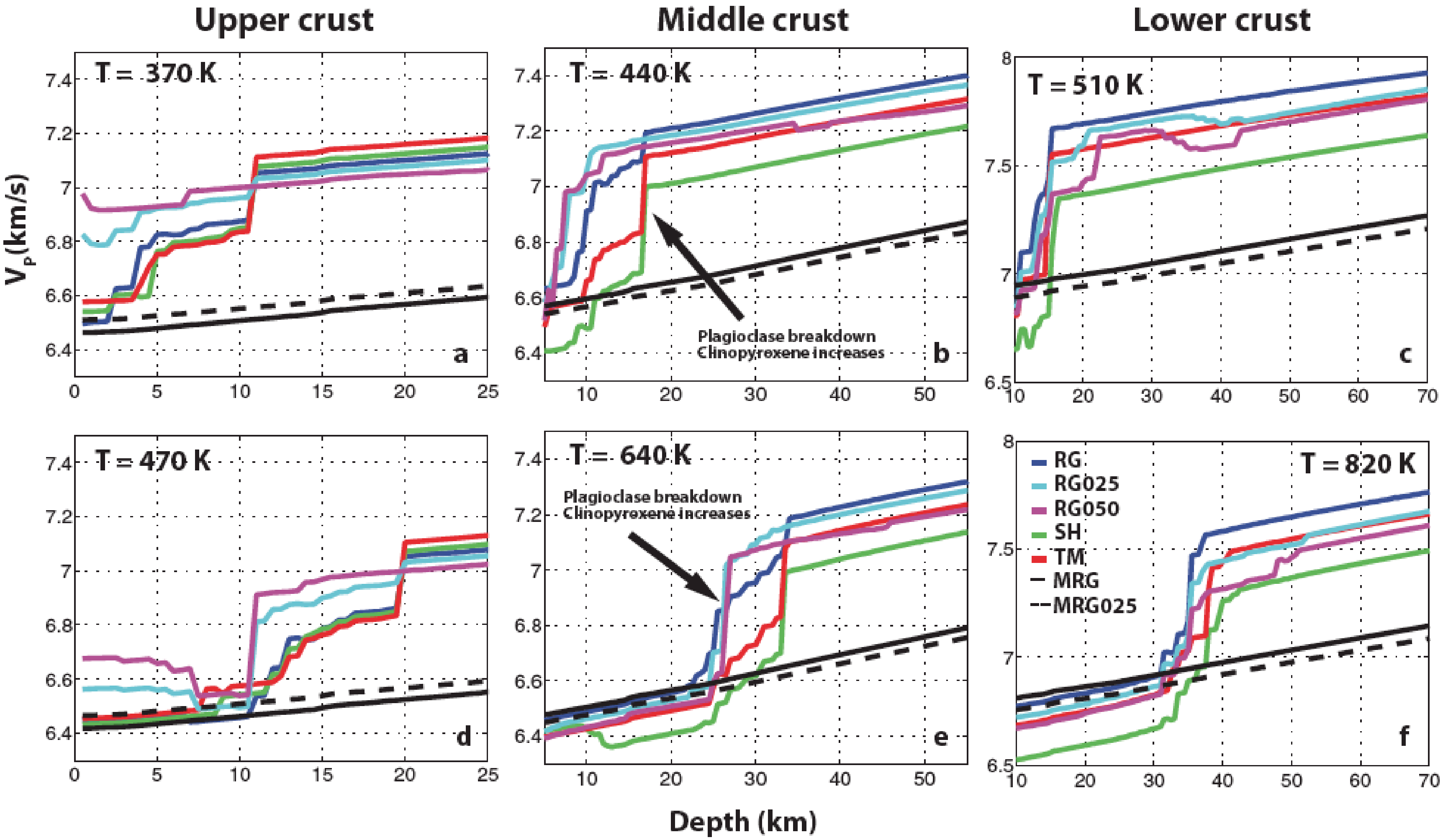
Xenoliths

Magma petrology

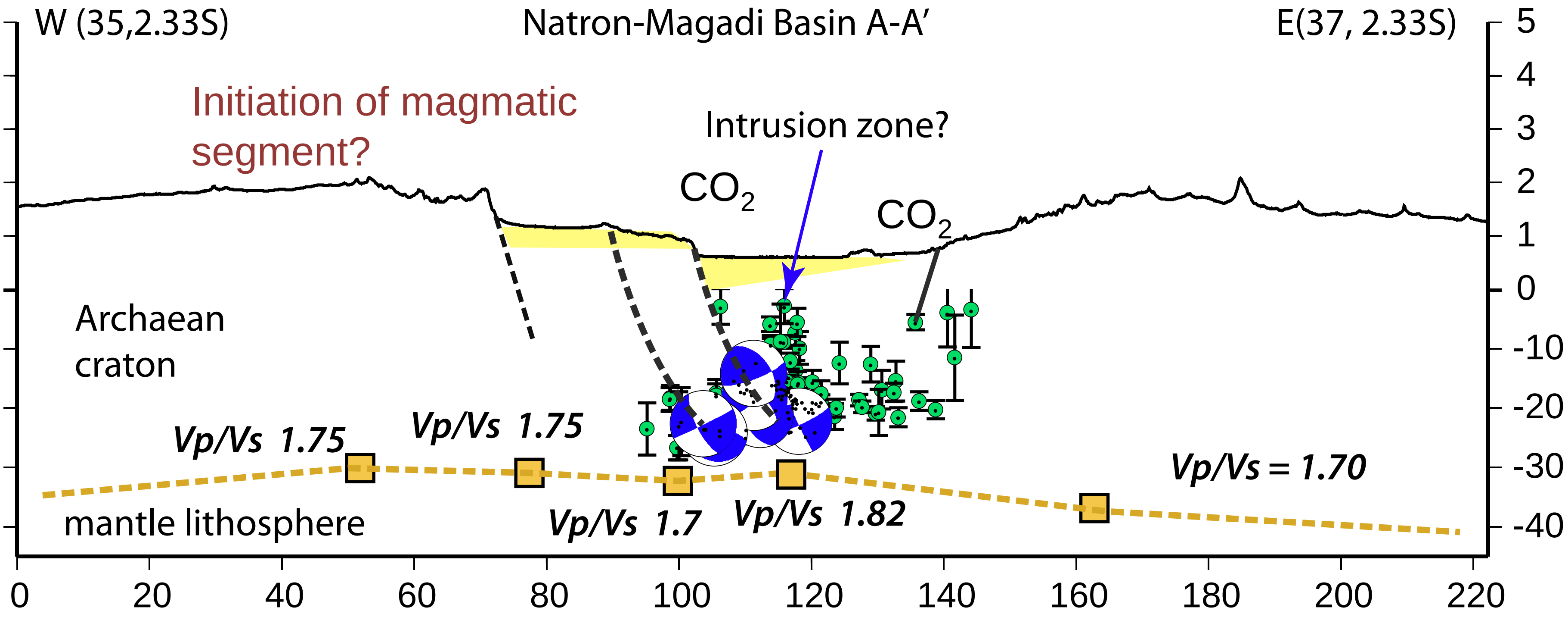
Volatiles as inclusions, soil and water measurements

AR Lowry & M Pérez-Gussinye *Nature* **471**, 353-357 (2011) doi:10.1038/nature09912

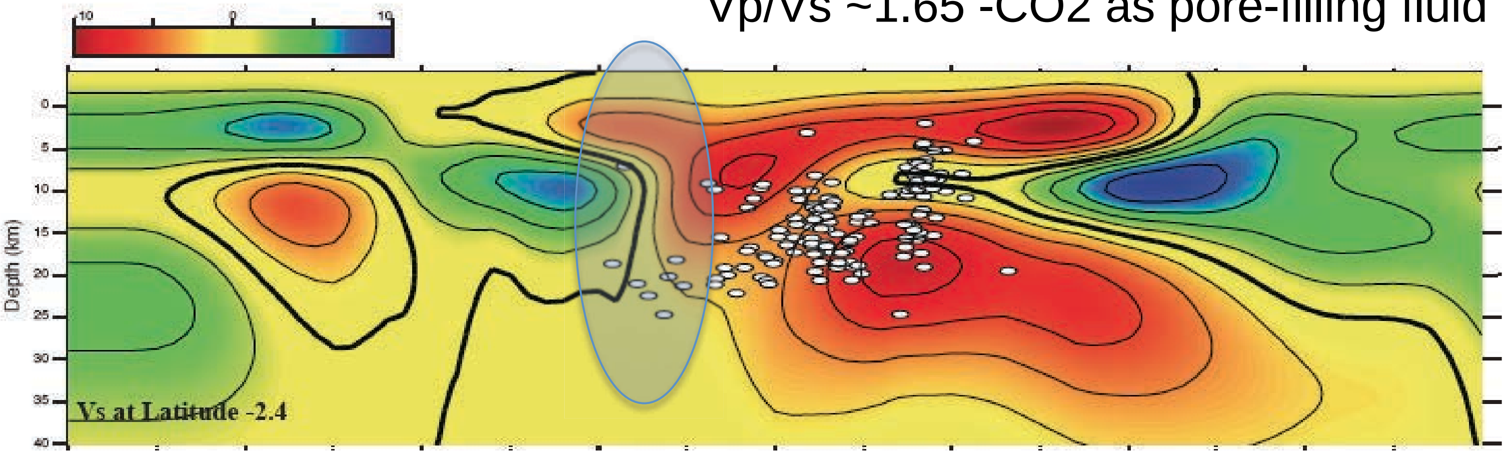
nature



Mineralogical reactions and enhanced geothermall gradients = considerable complexity in Vp and Vs; Compressible (volatiles) vs incompressible fluids (magma) changes Vp/Vs



Vp/Vs ~1.65 -CO2 as pore-filling fluid



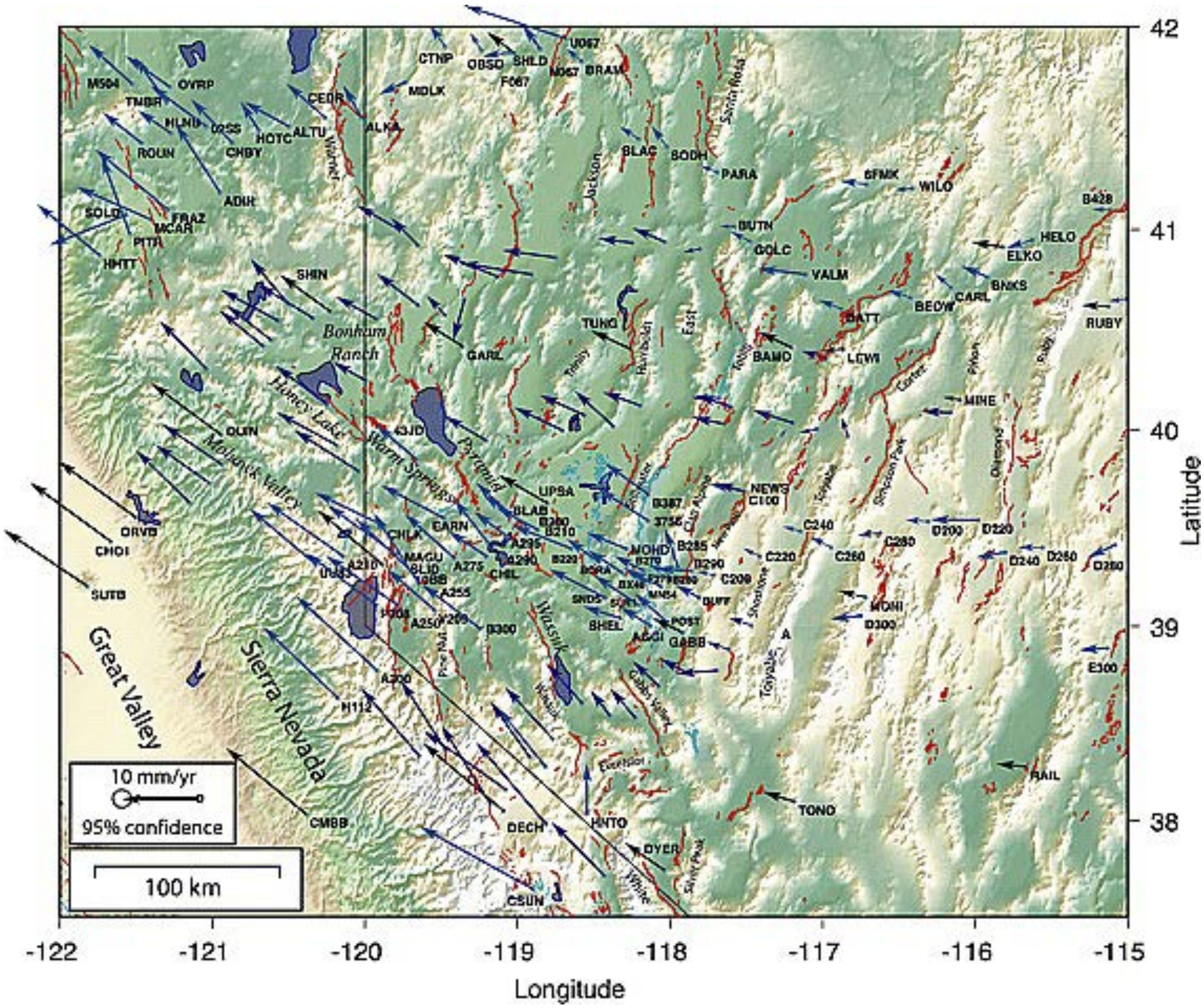
S-wave velocities; ANT, body wave, gravity joint inversion –Roecker et al., GJI, 2017; RF – Plasman et al. GJI, 2017; Weinstein et al., in review

Foundations II

Rocks are weak in extension

Extensional strains widely distributed in continental regions

- Scale with mantle upwelling
- Orogen



Hammond and Thatcher, JGR, 2007

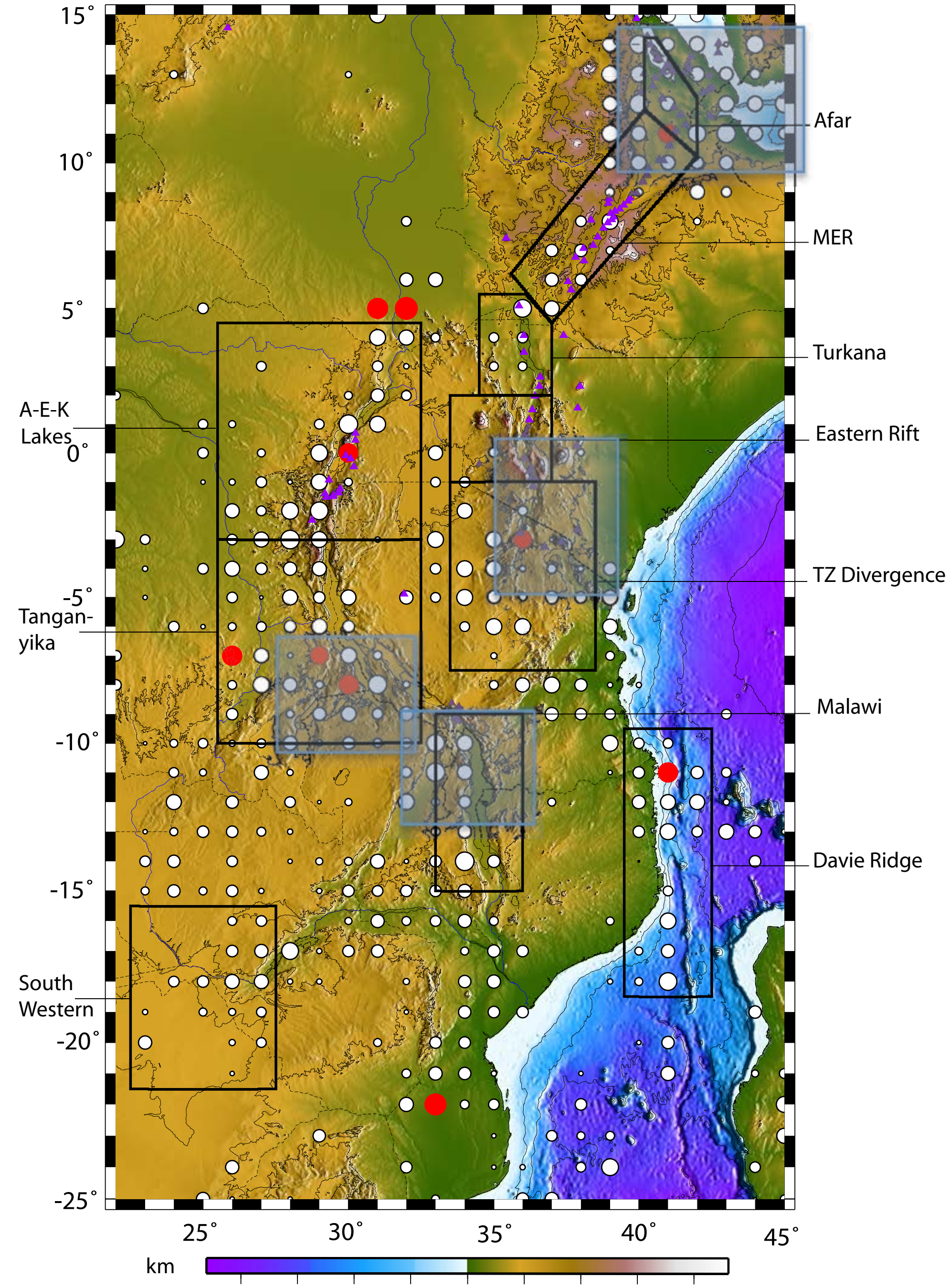


Fig. 3

Extensional strain and magmatism beneath > 100 km-thick lithosphere widely distributed – what is stable?

Seismic moment release using NEIC (complete to ca M 4.5).

$M_0 = \mu A s$ where is shear modulus of rock at EQ source, and A is area of fault plane, and s is slip

~10^2 y of 10^3-10^5 y interseismic cycle

Lindsey et al., submitted

Foundations III

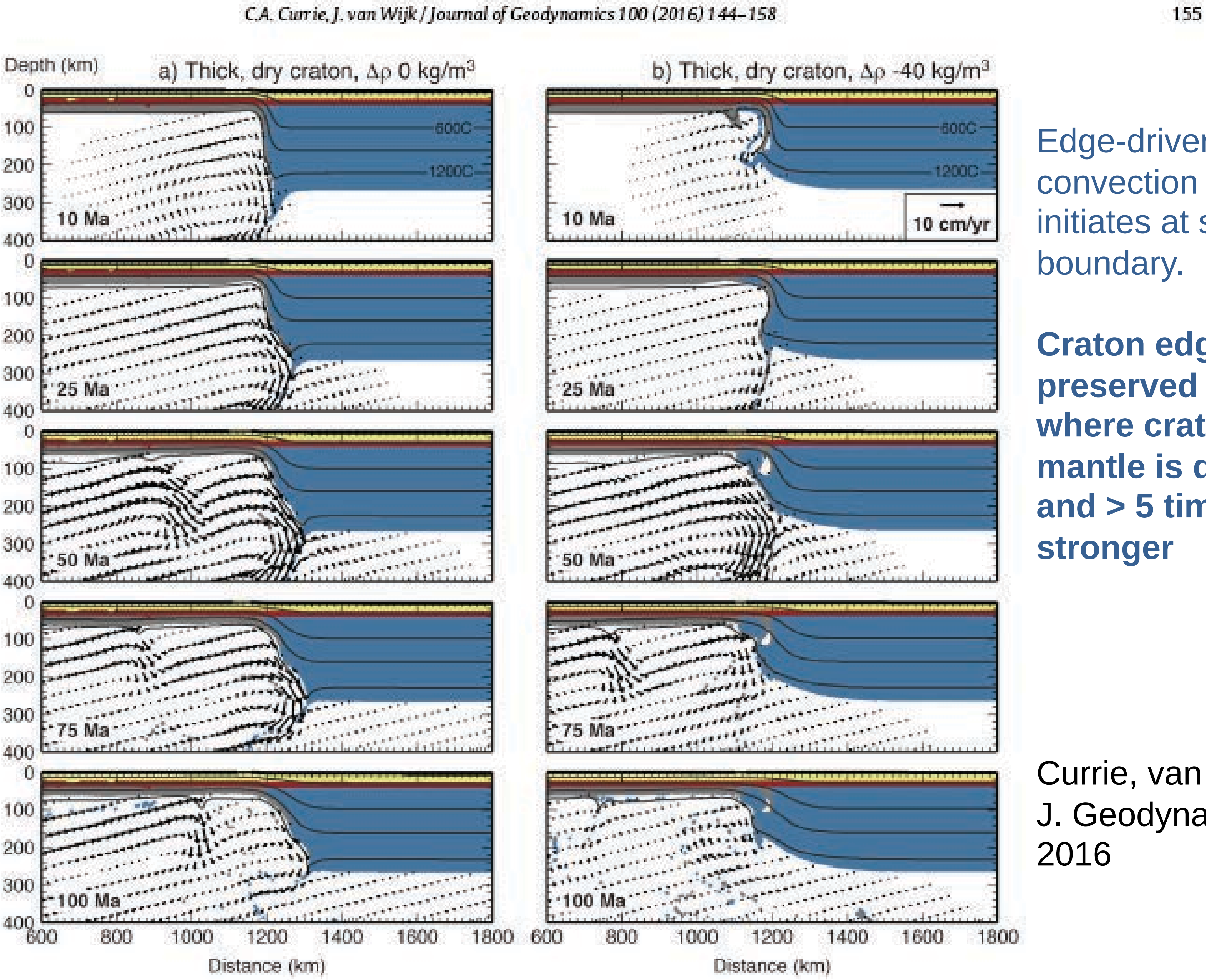
Cratons are too strong to rift, yet they do. Magma-assisted rifting is important, but can’t generate magma under thick lithosphere.

Additional forces + strength reducers:

A) Cratonic roots and slabs divert mantle flow, enabling enhanced melt production and tractions + volatile release.

B) Metasomatism – volatile-enriched mantle from prior subduction; mantle upwelling

Jolante, Tyrone talks



Edge-driven convection initiates at sharp boundary.

Craton edge preserved only where cratonic mantle is dry and > 5 times stronger

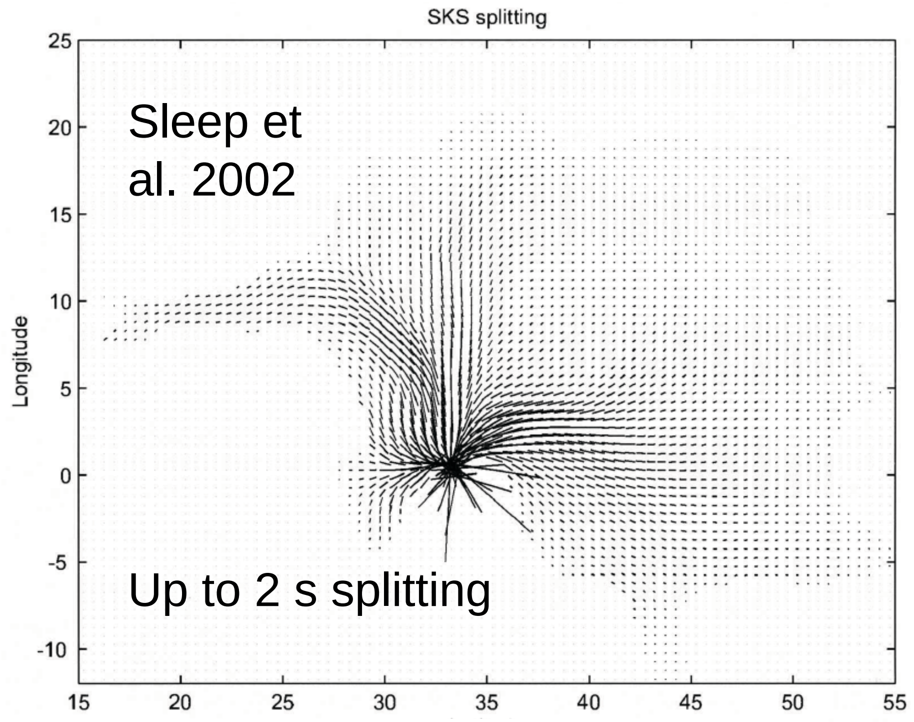
Currie, van Wijk, J. Geodynamics, 2016

Aims: Use shear wave splitting patterns (SKS, SKKS) to evaluate craton edge flow diversion; fluids

Sensitive to LAB dip

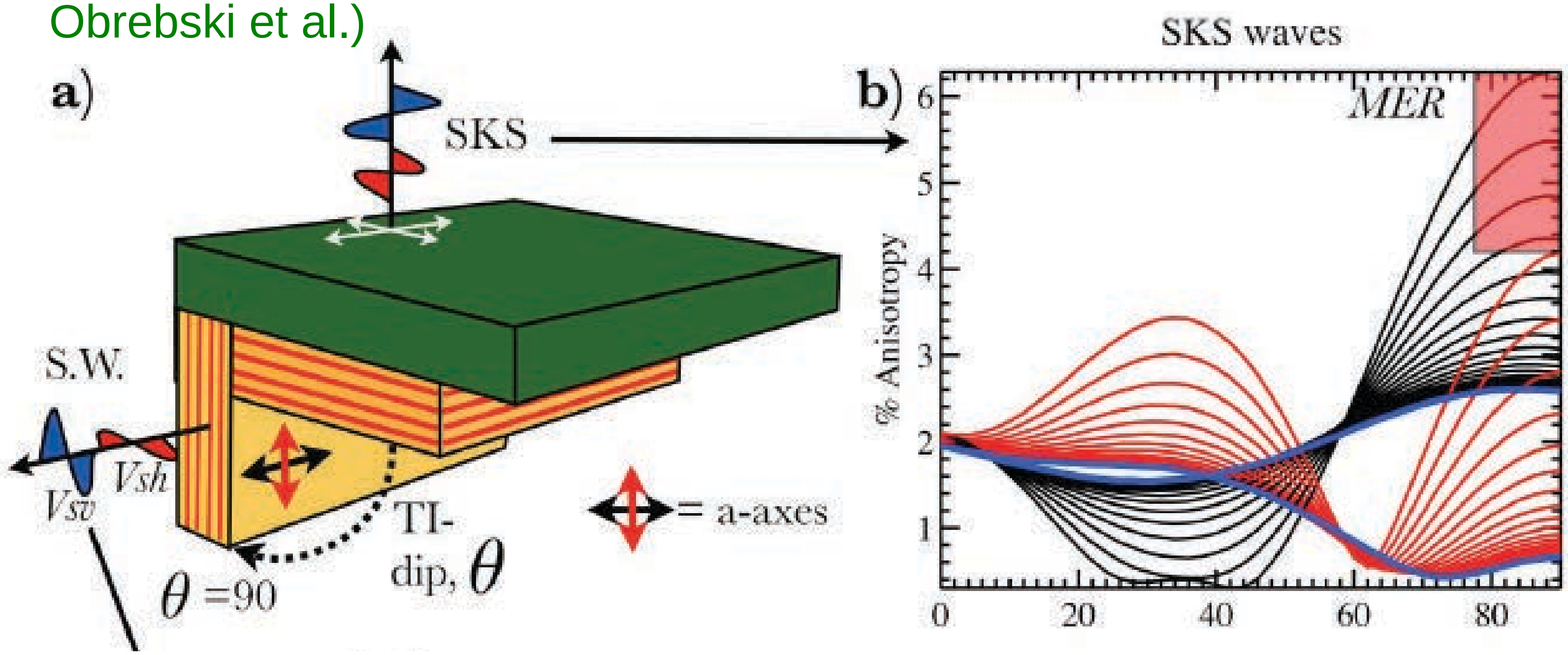
Contributions from LPO; oriented melt pockets (OMP); layered melt

Data: New results from E, SW, NW margins of Tanzania craton (Tepp, Obrebski et al.)



Sleep et al. 2002

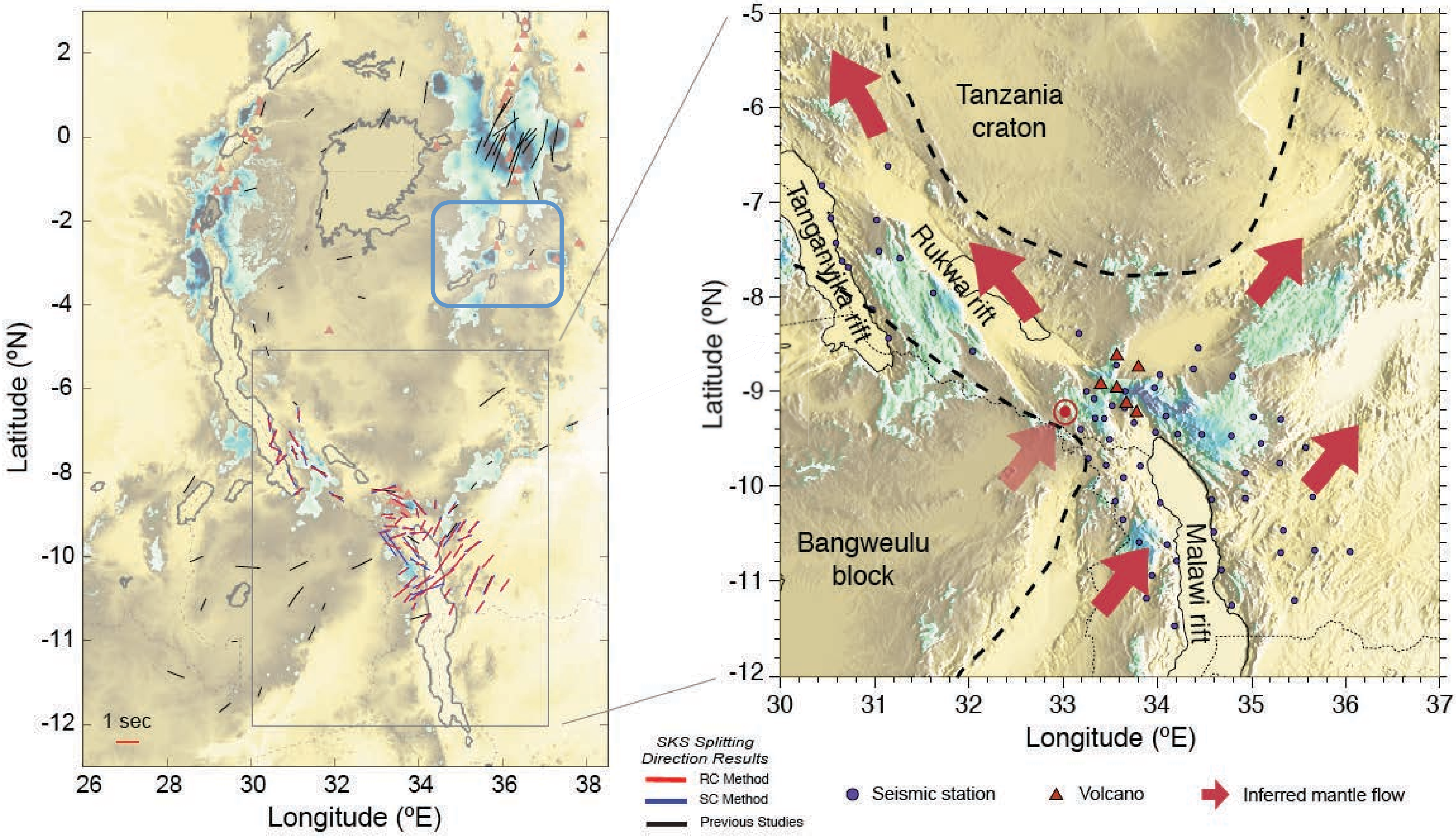
Up to 2 s splitting



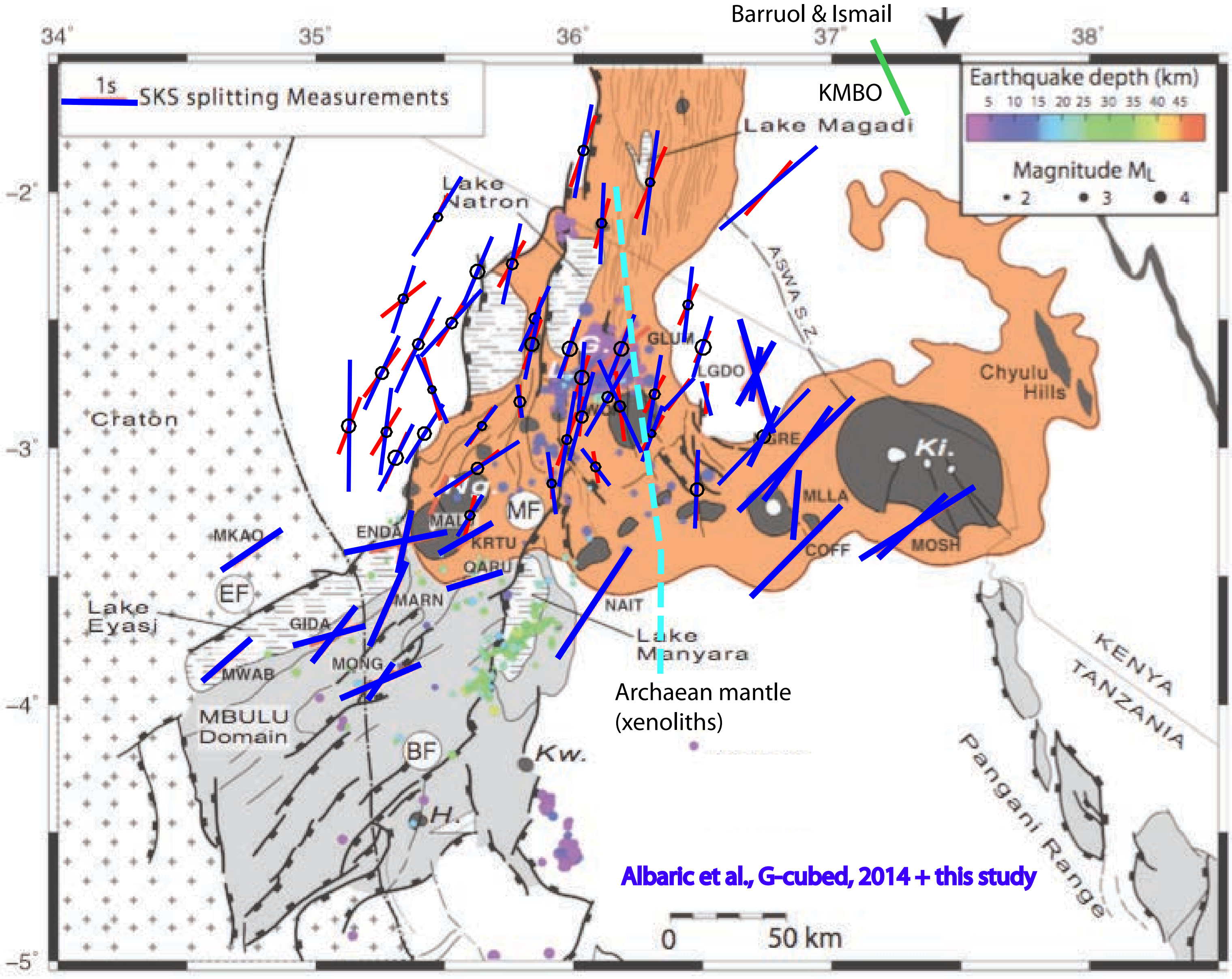
Holtzman and Kendall, 2010

Gabrielle Tepp

a-axis aligned with flow diverted between cratonic keels along rift thin zones?



Craton-edge signal?



Barruol & Ismail

KMBO

Archaean mantle (xenoliths)

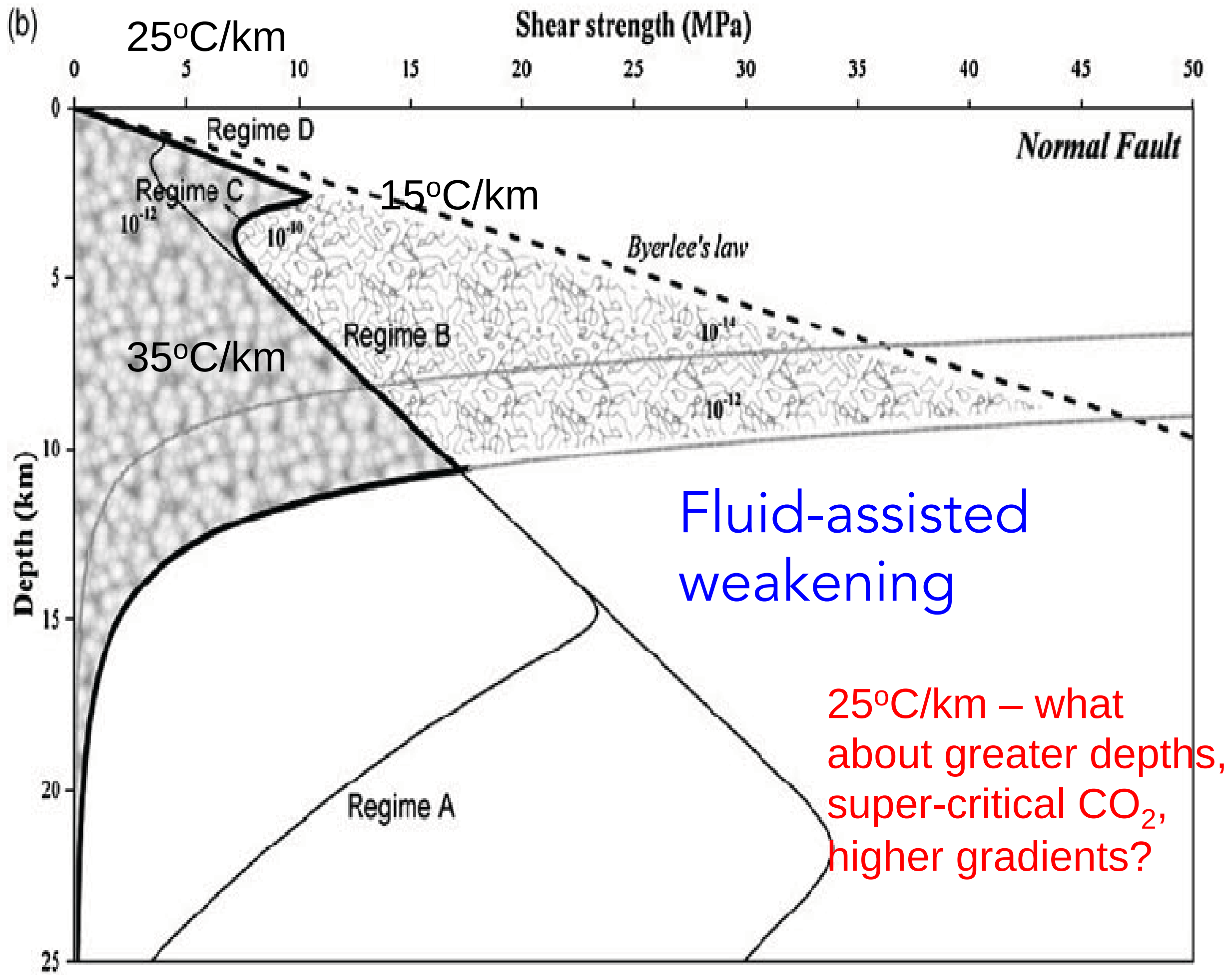
Albaric et al., G-cubed, 2014 + this study

Foundations IV

Strain localization within the crust strongly influenced by volatiles and magma

Rapid stressing by magma intrusion, high pore pressures, super-critical CO_2 may induce lower crustal fault zones that localize strain and promote creep/slow-slip processes. – Muirhead talk to follow

Large strain, steady-state rheological models for phyllosilicates allow for foliation development, cataclasis, pressure-solution - show velocity-dependent behavior



Fluid-assisted weakening

25ºC/km – what about greater depths, super-critical CO_2, higher gradients?

Fig. 15. Crustal strength profiles for four different tectonic regimes. Geothermal gradients used are 25, 35, 15 and 25 °C km^{-1} for cases A, B, C and D, respectively. The grain size used is 50 μm in all cases. Regime A, plastic flow in the phyllosilicate foliae. Regime B, frictional sliding in/over the phyllosilicate foliae. Regime C, pressure-solution-

A = plastic flow in phyllosilicates
B = frictional slip over foliae
C = pressure solution controlled strength
D = dilatational cataclasis – sliding by dilatation

Niemeijer & Spiers, Geol Soc London 2005;

Recipe for Strain Localization

- Start with LAB topography and enhanced mantle tractions/small-scale convection. Use this to produce:
- Small volume melting.
- Release some volatiles to explode some kimberlites, lamproites,and to
- Metasomatise mantle lithosphere and lower crust to reduce strength, increase melt production. *If 'rapid rise' results needed, start with previously metasomatised mantle.*
- ***Keep elevated to encourage high GPE***
- Allow volatile expansion to increase fluid pathways, and fill pores to further reduce strength
- Intrude magma to expedite heat transfer and enhance strain localization
- Volatile percolation along fault zones to reduce friction and enable slip at lower stressing rates
- Enhanced erosion and sediment loading = icing on 'cake' *

Note: If rupture required, maintain upwelling or far-field stresses

* Take with pinch of salt

What do we need to enjoy a better rift ‘cake’ ?

- Rock mechanics experiments at lower crustal conditions – super-critical CO_2 and fault friction
- Direct observation of lower crust and upper mantle hydration - xenolith, fluid inclusion, Vp/Vs, MT
- Continuous GPS and seismic monitoring along active fault zones – does aseismic creep occur in fluid-rich rift zones?
- Quantify magma intrusion rates across range of settings
- Compare and contrast crustal and mantle anisotropy patterns – role of fluid-filled fractures vs strain fabrics