

# Melting of a deep subcontinental lithospheric mantle during the early stages of rifting

**Sara Mana**

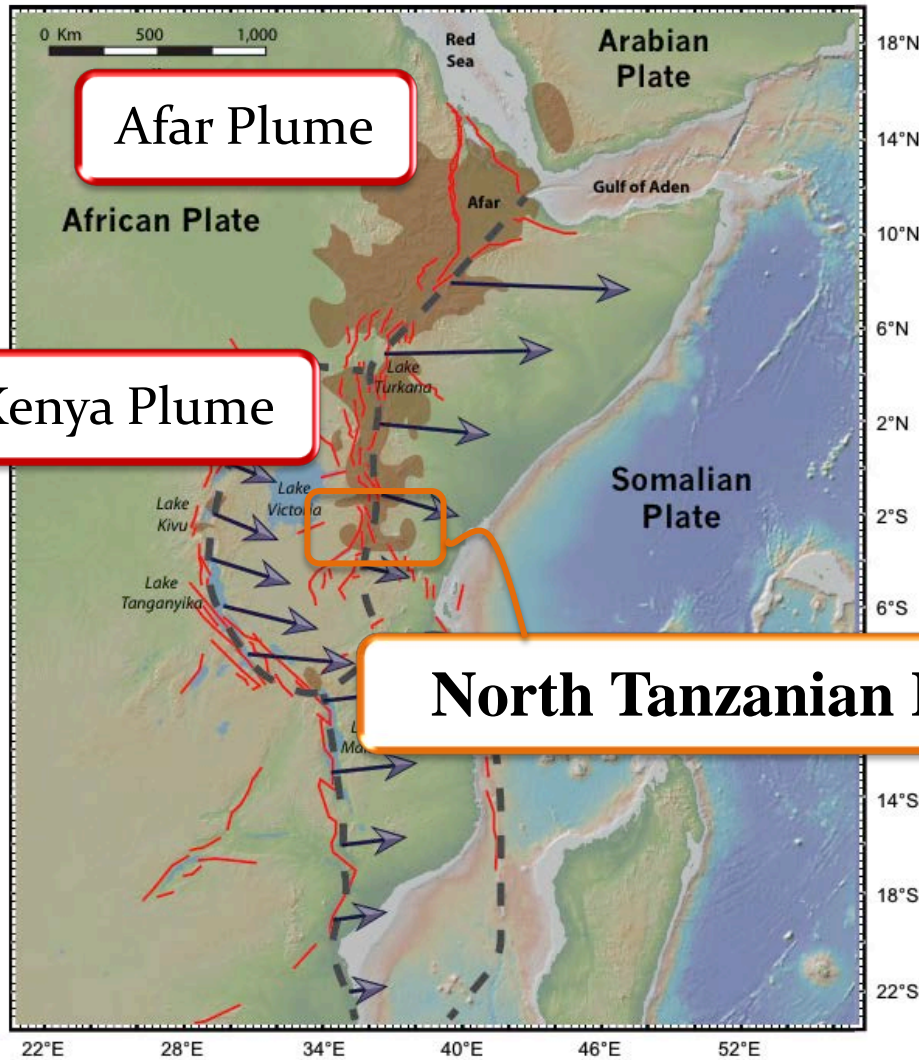
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Mana *et al.* JGS 2015



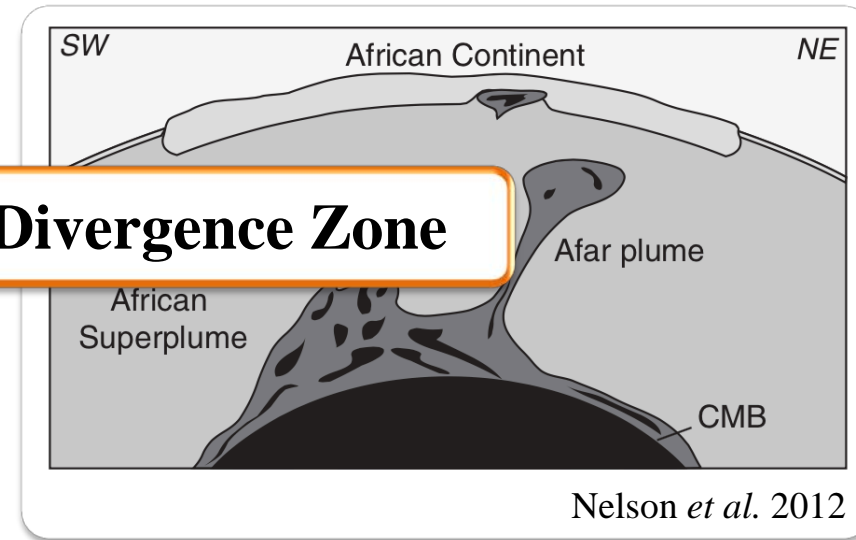
# East African Rift System (EAR)



Continental Rifting

Extensional Setting

Mantle Plume(s) ?

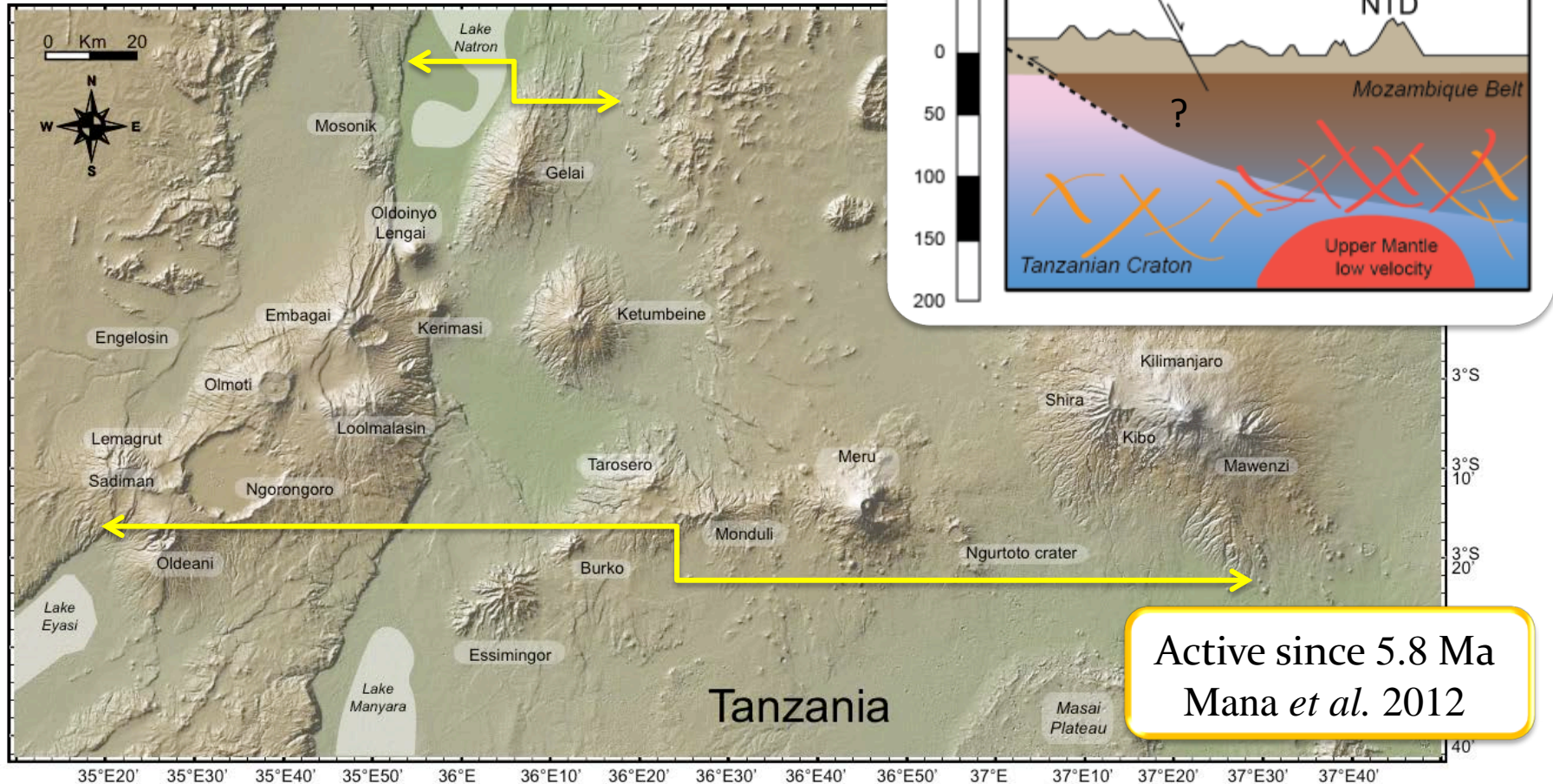


Nelson *et al.* 2012

Modified from *GeoMapApp* after Chorowicz 2005  
Plate borders and velocity vectors as in Stamps *et al.* 2008

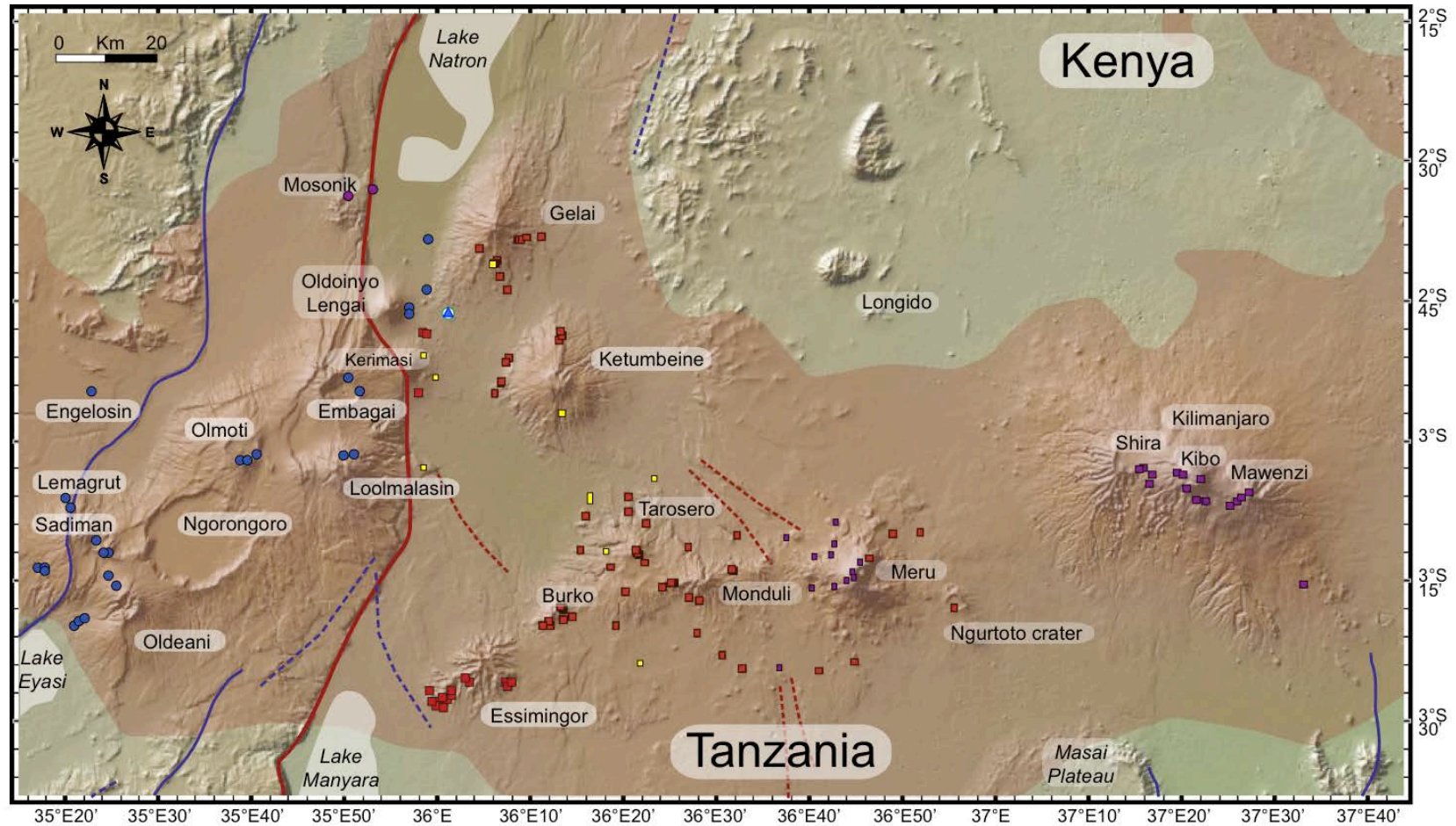
e.g. Ebinger & Sleep 1998; George *et al.* 1998; Nyblade *et al.* 2000; Lin *et al.* 2005; Furman *et al.* 2006; Pik *et al.* 2006, Rogers *et al.* 2006; Chang & Van der Lee 2011

# North Tanzanian Divergence zone (NTD)



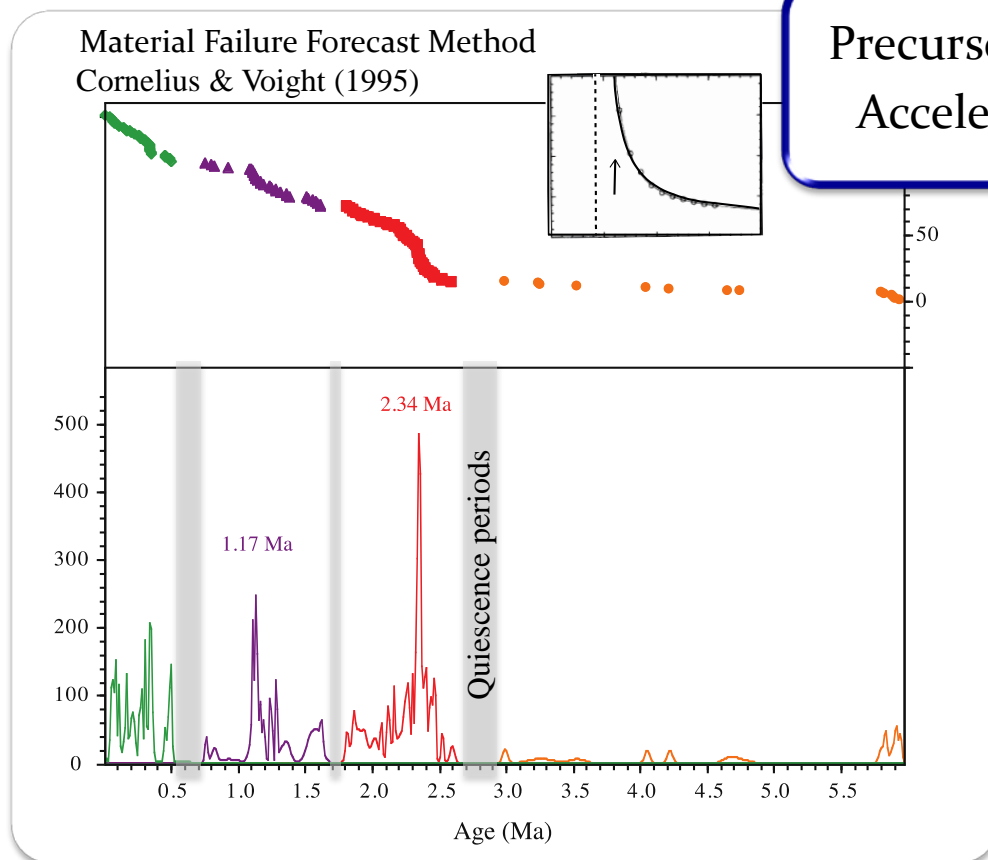


# NTD Samples Distribution



Ages from: Evans *et al.* 1971; Fairhead *et al.* 1972; Isaac *et al.* 1974; MacIntyre *et al.* 1974; Hay *et al.* 1976; Wilkinson *et al.* 1986; Mollé *et al.* 2008-2011; Nonnotte *et al.* 2008; Mana *et al.* 2012; Sherrod *et al.* 2013; Mana *et al.* 2015

# Stages of Magmatic Activity



Precursory phenomena = volcanic eruption  
Accelerating volcanism = onset of rifting

Rifting 1.2-2 Ma

MacIntyre *et al.* 1974

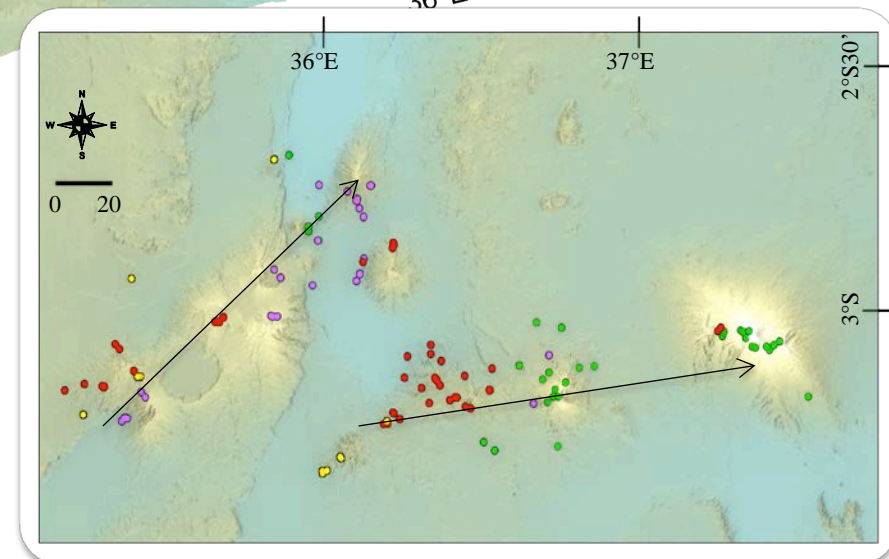
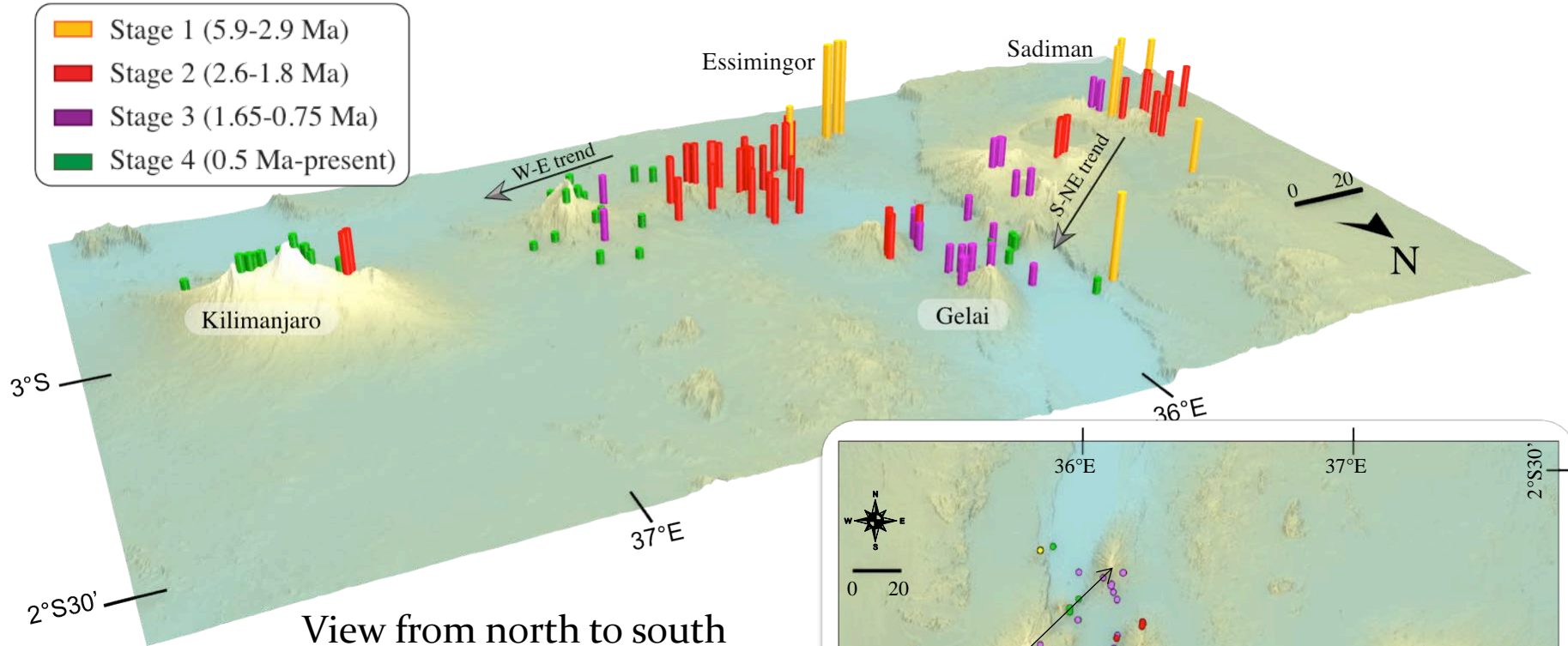
Activity was episodic

- Stage 1 (5.9-2.9 Ma)
- Stage 2 (2.6-1.8 Ma)
- Stage 3 (1.65-0.75 Ma)
- Stage 4 (0.5 Ma-present)

# New Chronological Framework

Two pulses of enhanced magmatism

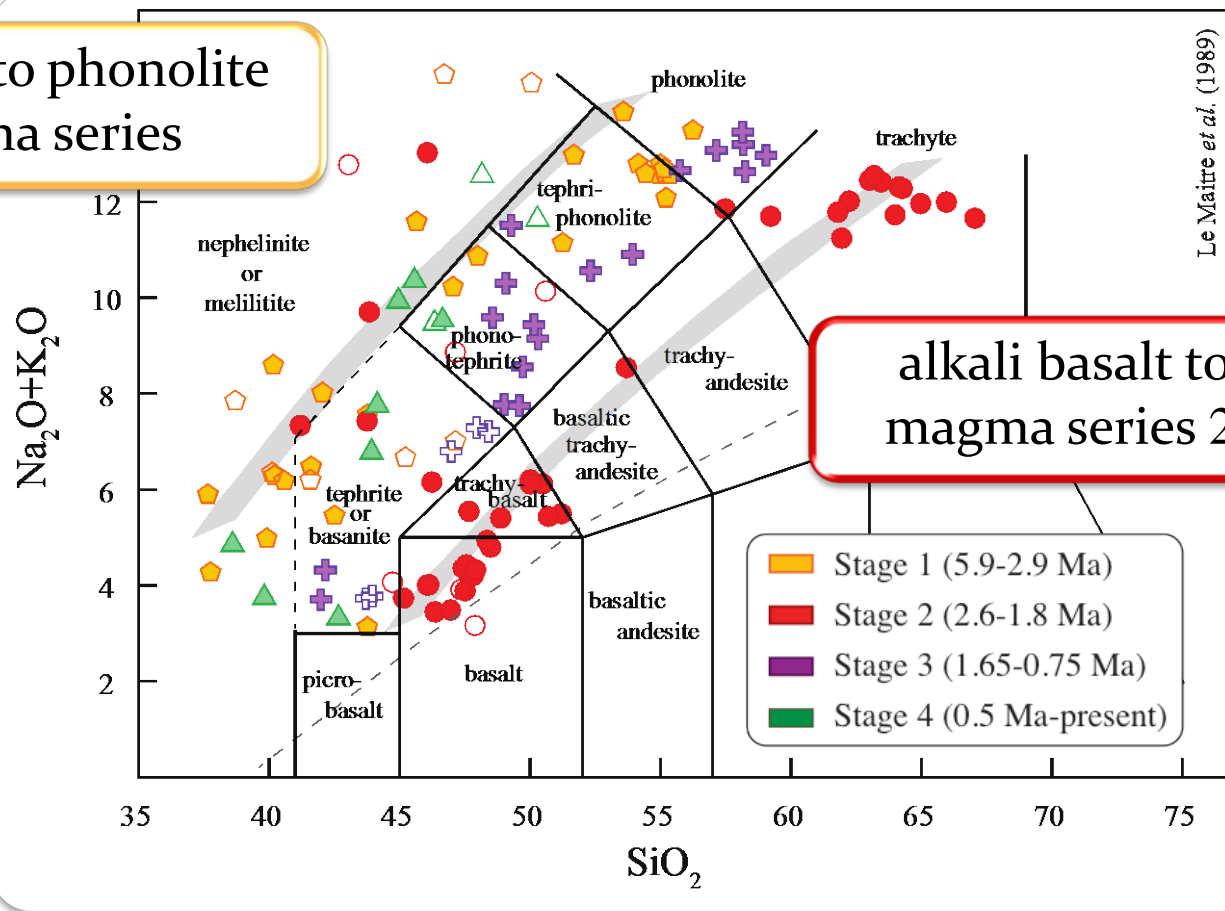
Two main volcanic lineages



Ages from: Isaac *et al.* 1974; Wilkinson *et al.* 1986; Mollé *et al.* 2008-2011; Nonnotte *et al.* 2008; Mana *et al.* 2012; Sherrod *et al.* 2013; Mana *et al.* 2015

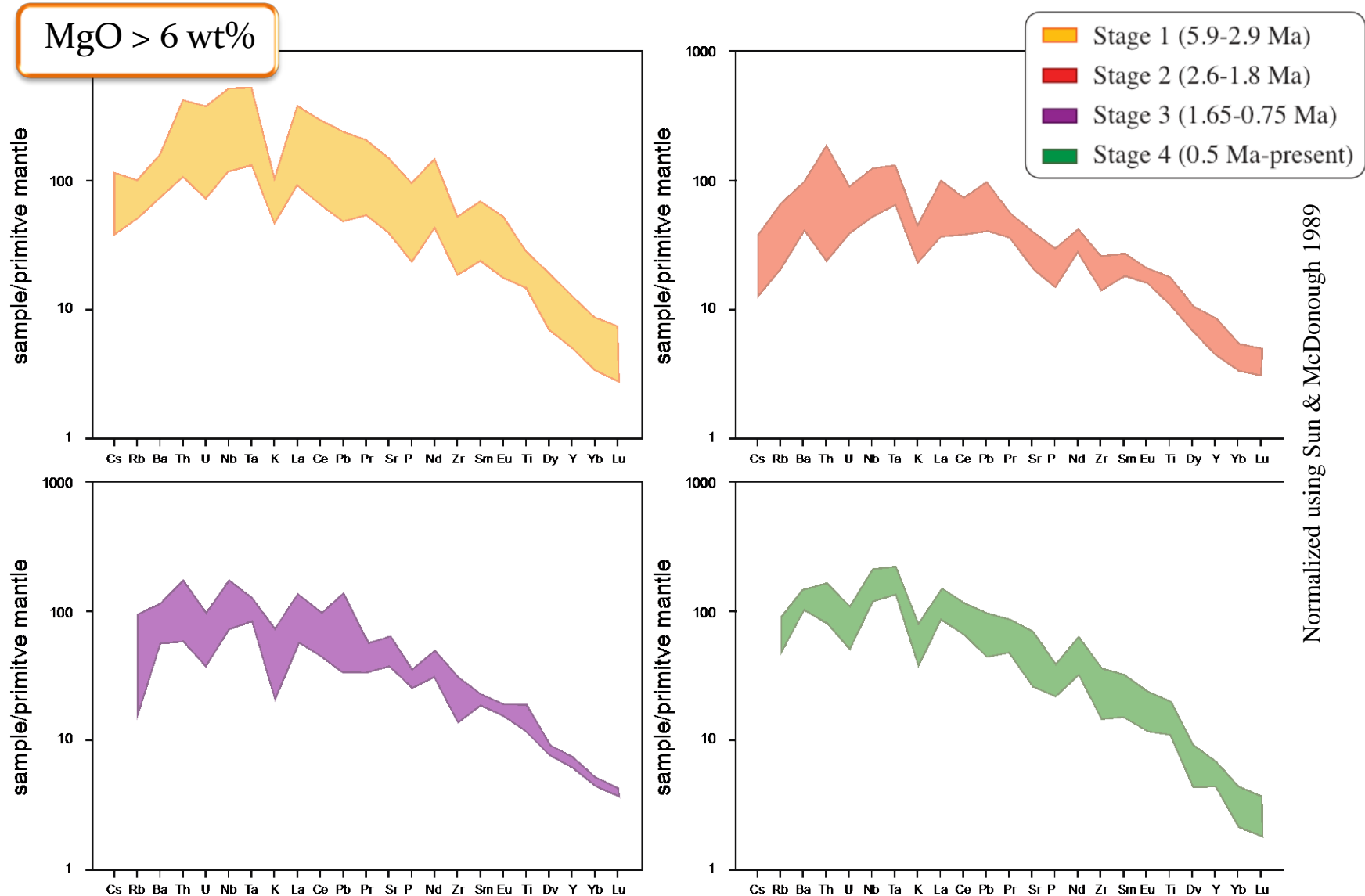
# Synrift Major Elements Variation

basanite to phonolite  
magma series



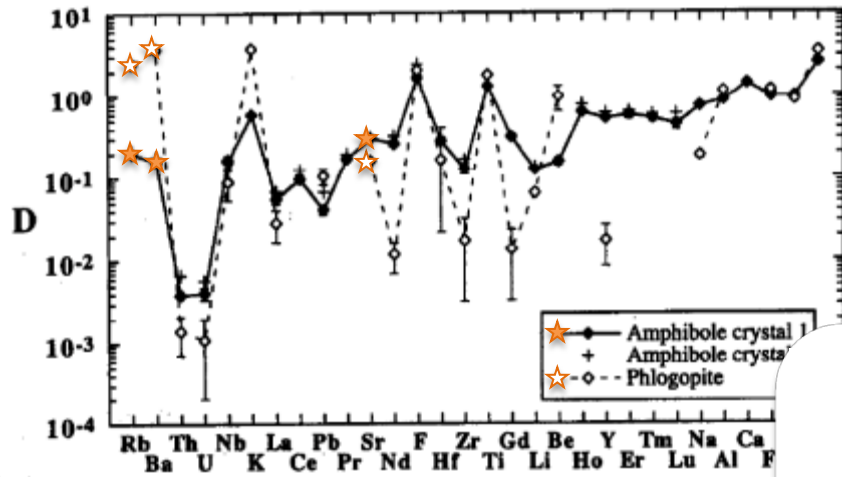
alkali basalt to trachyte  
magma series 2.6-1.8 Ma

# Trace Elements Variations



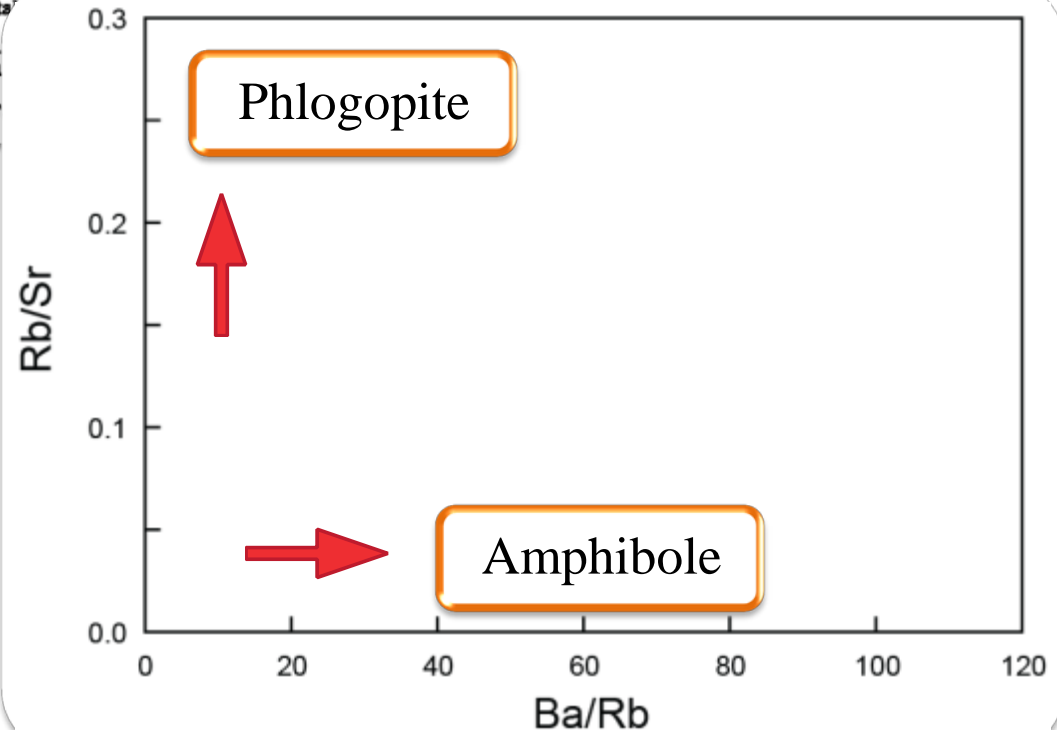


# Hydrous Phases: Phlogopite vs Amphibole

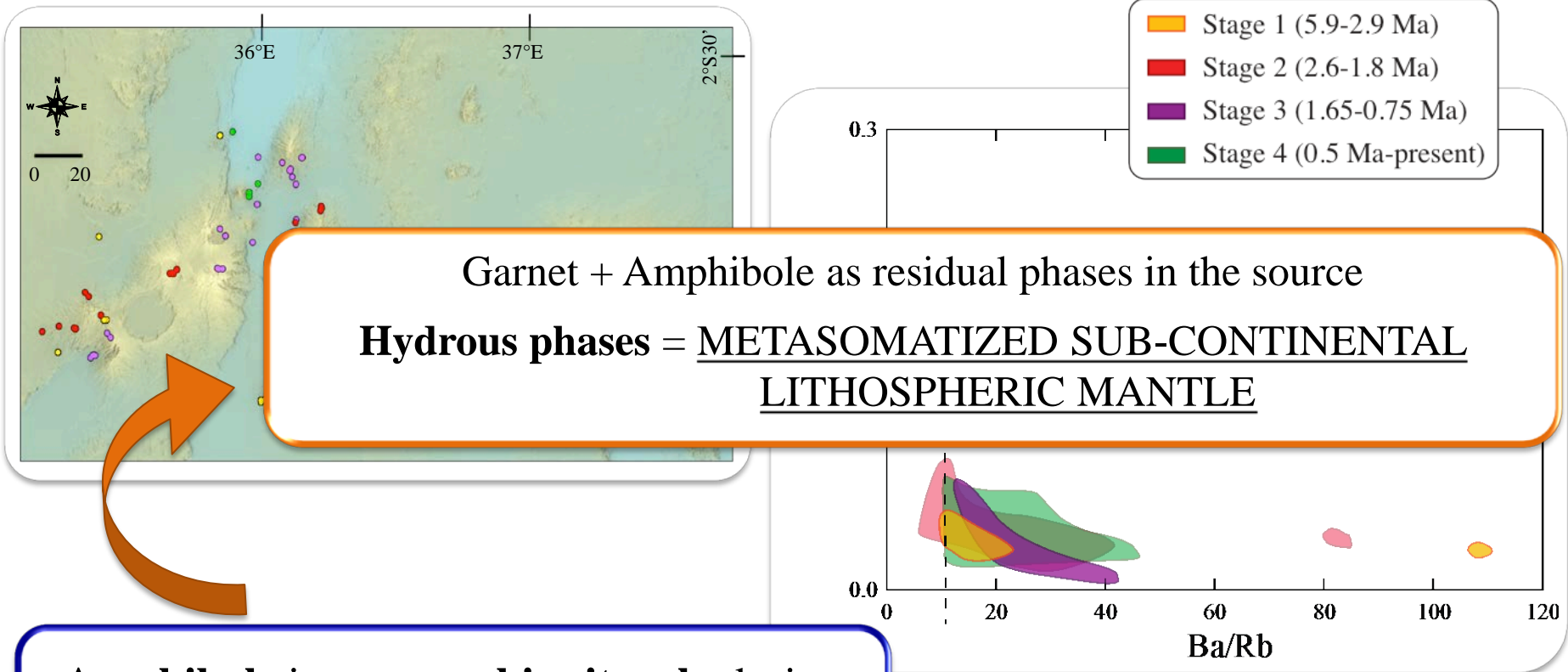


LaTourette *et al.* 1995

Partitioning of large-ion lithophile elements (LILE)

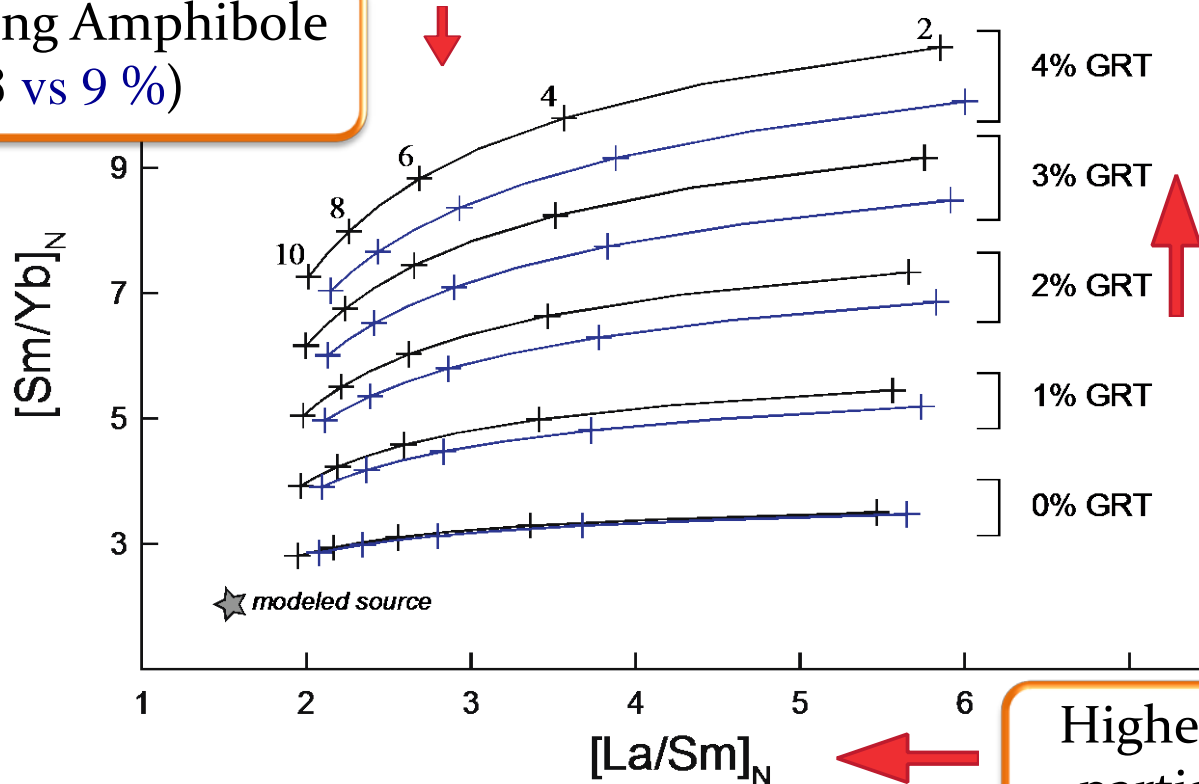


# Evidence for a Metasomatized Source



# Partial Melting Model

Increasing Amphibole  
(3 vs 9 %)



Increasing  
Garnet %

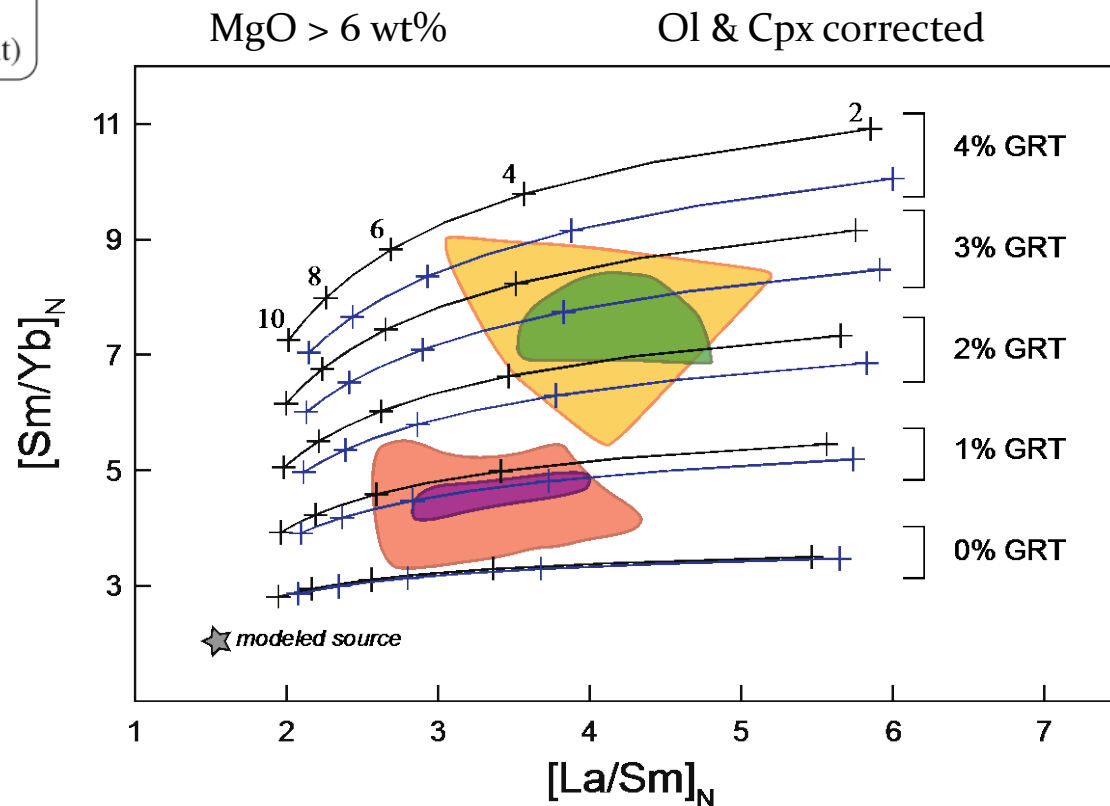
Higher degree of  
partial melting



# Partial Melting Model

- Stage 1 (5.9-2.9 Ma)
- Stage 2 (2.6-1.8 Ma)
- Stage 3 (1.65-0.75 Ma)
- Stage 4 (0.5 Ma-present)

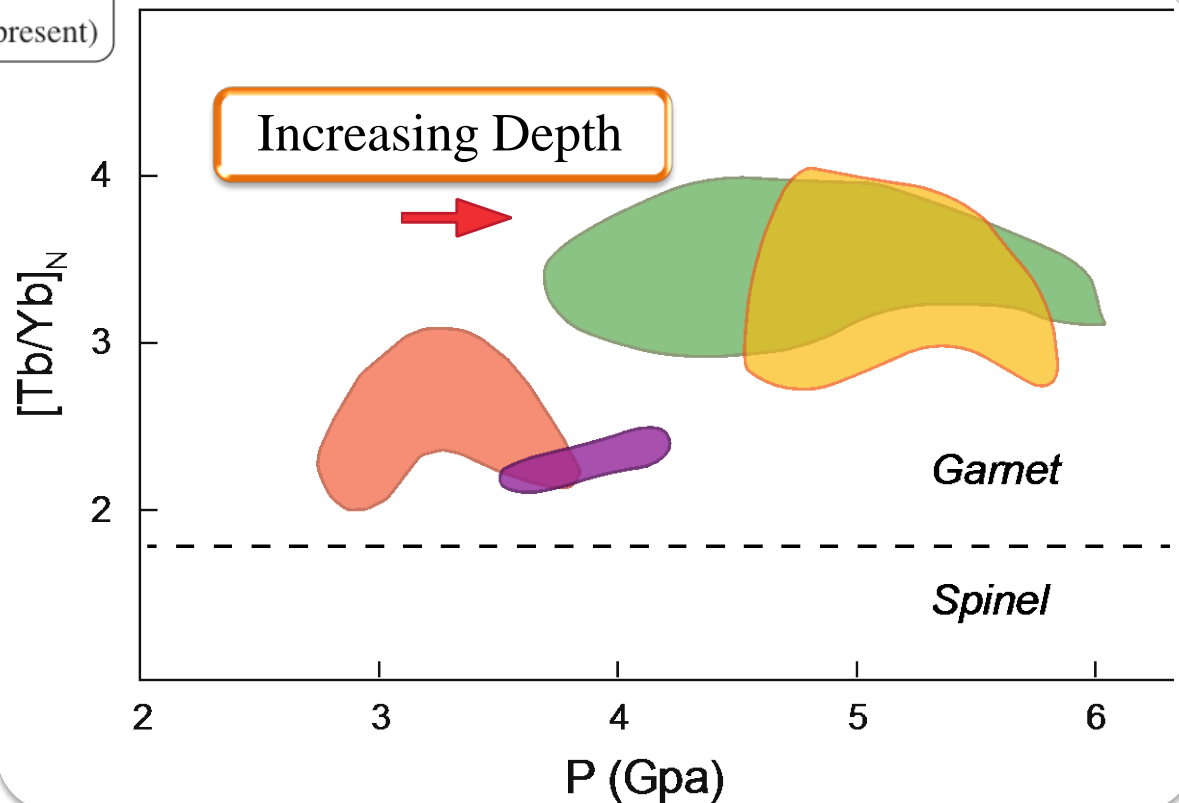
Melting in the Garnet stability zone



Variation in GARNET content through time = DEPTH ???

# Depth of Melting

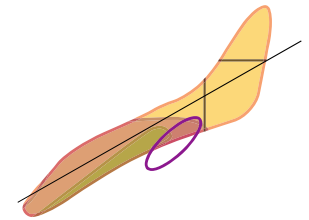
- Stage 1 (5.9-2.9 Ma)
- Stage 2 (2.6-1.8 Ma)
- Stage 3 (1.65-0.75 Ma)
- Stage 4 (0.5 Ma-present)



P (Gpa) from algorithm developed by Haase 1996 after correcting SiO<sub>2</sub> for fractional crystallization

# Sr-Nd and Pb Isotopic Signature

- Stage 1 (5.9-2.9 Ma)
- Stage 2 (2.6-1.8 Ma)
- Stage 3 (1.65-0.75 Ma)
- Stage 4 (0.5 Ma-present)



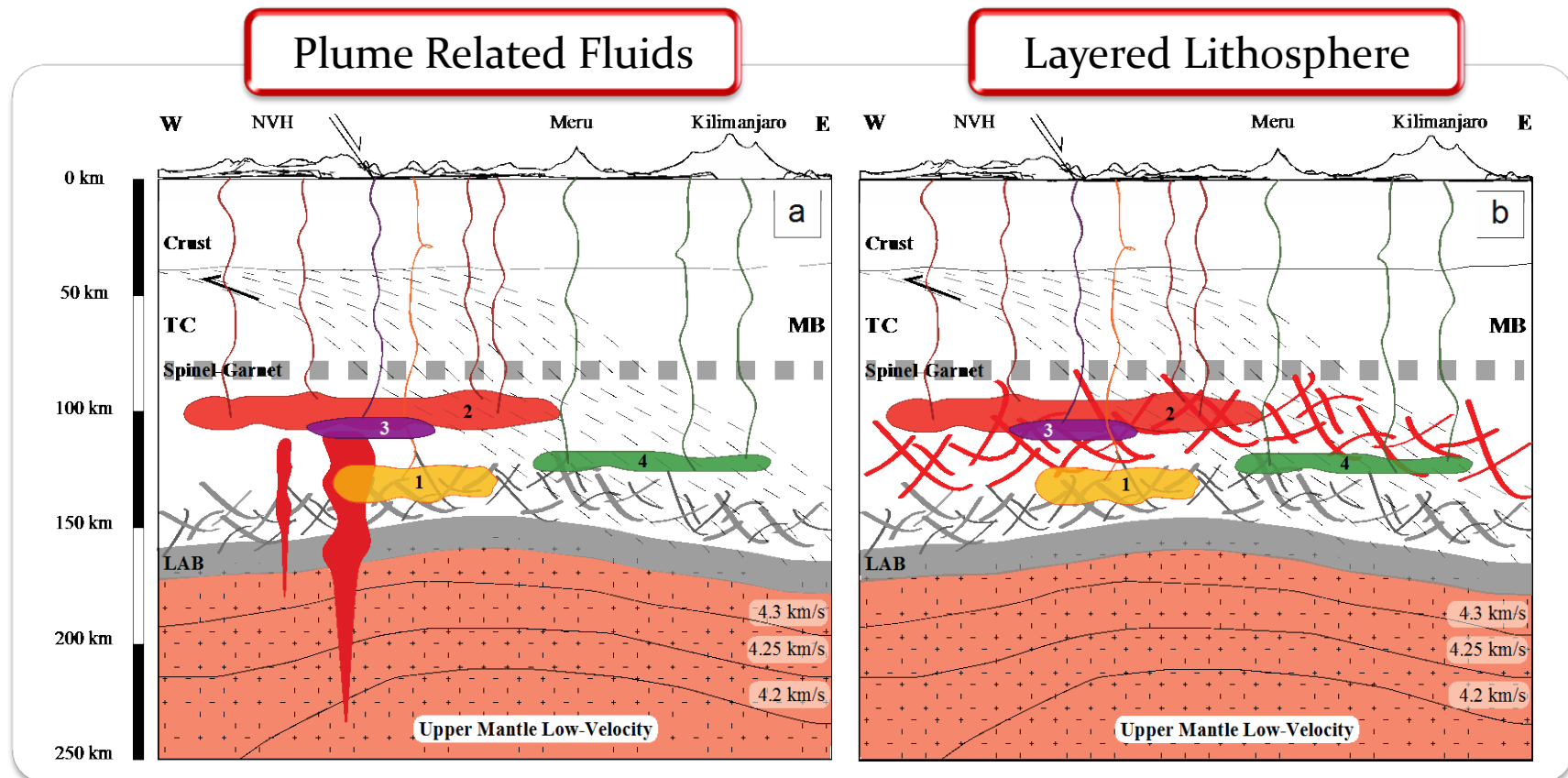
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# Two Proposed Tectonic Models

Stage 1 and 4 - Melting of Amphibole Rich Veins

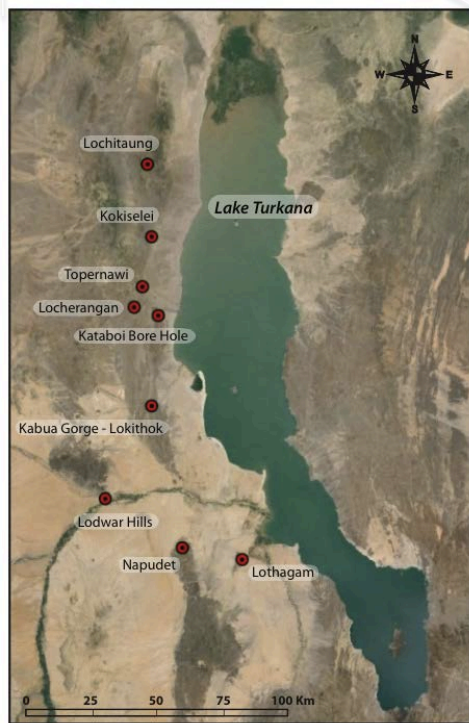
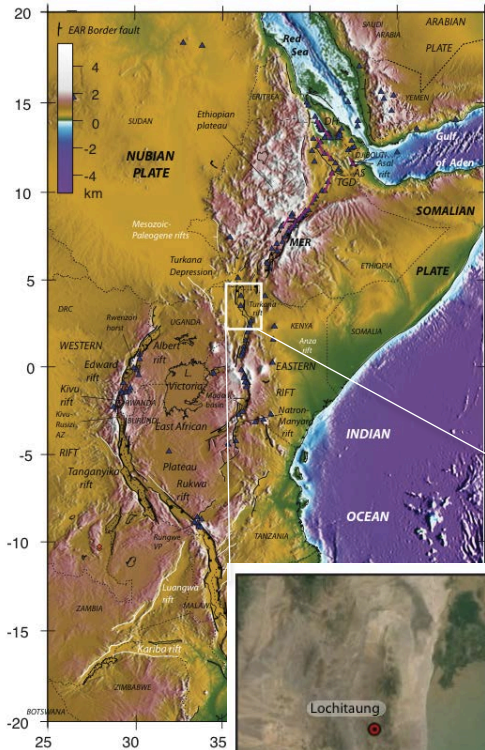
Stage 2 and 3 - Contributions from hydrous veins was drowned out by melting of a different source component



Upper mantle low-velocity from 3-D shear wave velocity model presented by Adams *et al.* (2012)

# West Turkana Basin

- unique intra-domal region
- evidence for the **earliest** phases of both magmatism and extension co-occur
- opportunity to track magma evolution throughout the history of the basin and constrain **plume-lithosphere interactions**



# Preliminary data...



## Tectonomagmatic evolution of the East African Rift System as documented in West Turkana, Kenya


Lamont-Doherty Earth Observatory  
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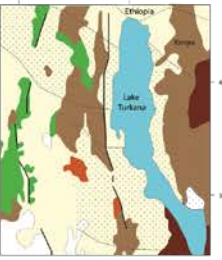
### BACKGROUND INFORMATION



A set of igneous samples were collected with the aim to better constrain and explore the tectonomagmatic development of the Turkana Basin within the East African Rift System (EARS). This study seeks to combine new high-precision <sup>40</sup>Ar/<sup>39</sup>Ar dating analyses with whole rock geochemistry and radiogenic isotope data.




The Turkana Basin is a unique intra-domal region, where we see evidence that both magmatism and extension occurred during the earliest phases of rifting (Morley et al., 1992; George et al., 1998). The onset of magmatism during the Late Eocene in the Turkana Basin shares the distinction of being the earliest magmatism in the EARS, together with the Amaro and Gamo tholeiitic basalts in southern Ethiopia. Magmatism continued in the Turkana Basin until modern times providing the opportunity to track the evolution of the mantle throughout the history of the basin. Previous geochemical studies in the Turkana Basin revealed a sub-lithospheric mantle sources as well as a plume component with melting depths shallower than those recorded elsewhere along the rift. However, no data exist from West Turkana.



Map modified from Baker et al., 1971

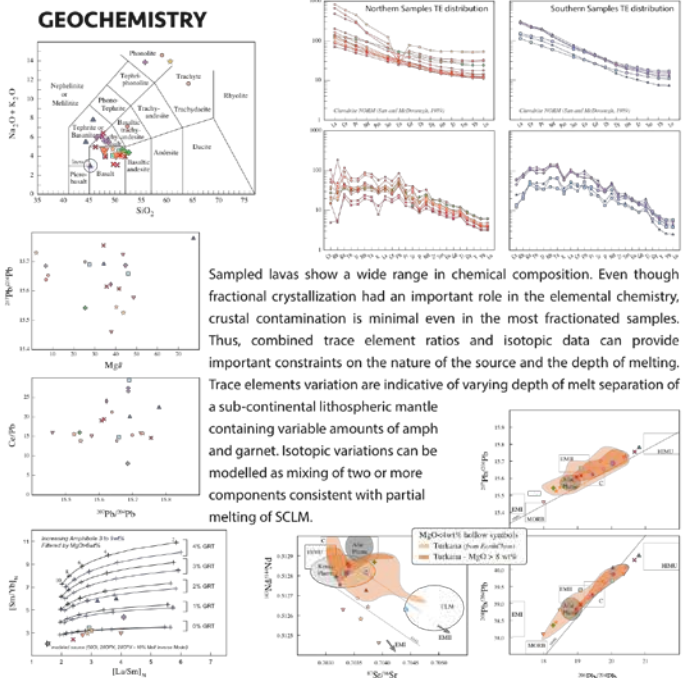
- Great ANZA rift (BEICP, 1984)
- Late Cenozoic sediments
- Pliocene and Quaternary basalts
- Pliocene rhyolites and mugearites
- Miocene basalts
- Miocene alkaline complexes (Nephelinites, Phonolites)
- Main Faults

### SAMPLES DISTRIBUTION



- Lokitaung 20-36 Ma [K/Ar] Basalts
- Kokiselei Basaltic trachy-andesite to trachyte, phonolite
- Topernawi 16 Ma [K/Ar] Basalts
- Locherangan 17.5 ± 0.3 Ma [K/Ar] Basalts
- Lodwar Hills 12-16 Ma [K/Ar] Picrite to basanites
- Lothagam 4; 8; 16.8 Ma [K/Ar] Trachybasalts
- Napudet 13.31 ± 0.04 Ma [Ar/Ar]; Trachybasalts
- Katabei Bore Hole Basalt to basaltic andesite
- Kabua Gorge - Lothidok 13-18 Ma [K/Ar] Basalts

### GEOCHEMISTRY



Sampled lavas show a wide range in chemical composition. Even though fractional crystallization had an important role in the elemental chemistry, crustal contamination is minimal even in the most fractionated samples. Thus, combined trace element ratios and isotopic data can provide important constraints on the nature of the source and the depth of melting. Trace elements variation are indicative of varying depth of melt separation of a sub-continental lithospheric mantle containing variable amounts of amphibole and garnet. Isotopic variations can be modelled as mixing of two or more components consistent with partial melting of SCLM.

### RELEVANCE - FUTURE WORK

- Evaluate the role of magmatism on rift inception and the breakage of the continent
- Link magmatic ages with basin development through time
- Constrain plume dynamics and plume lithosphere interaction in west Turkana region
- Refined geochronology of the West Turkana basin will allow better understanding of the response of environmental variables to climate change in the East Africa region
- Implications on human evolution studies during Miocene and Pliocene

# ...Come to see my poster



# Thank you!

## Collaborators:

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