Tectonics and Petroleum Systems of East African Rifts

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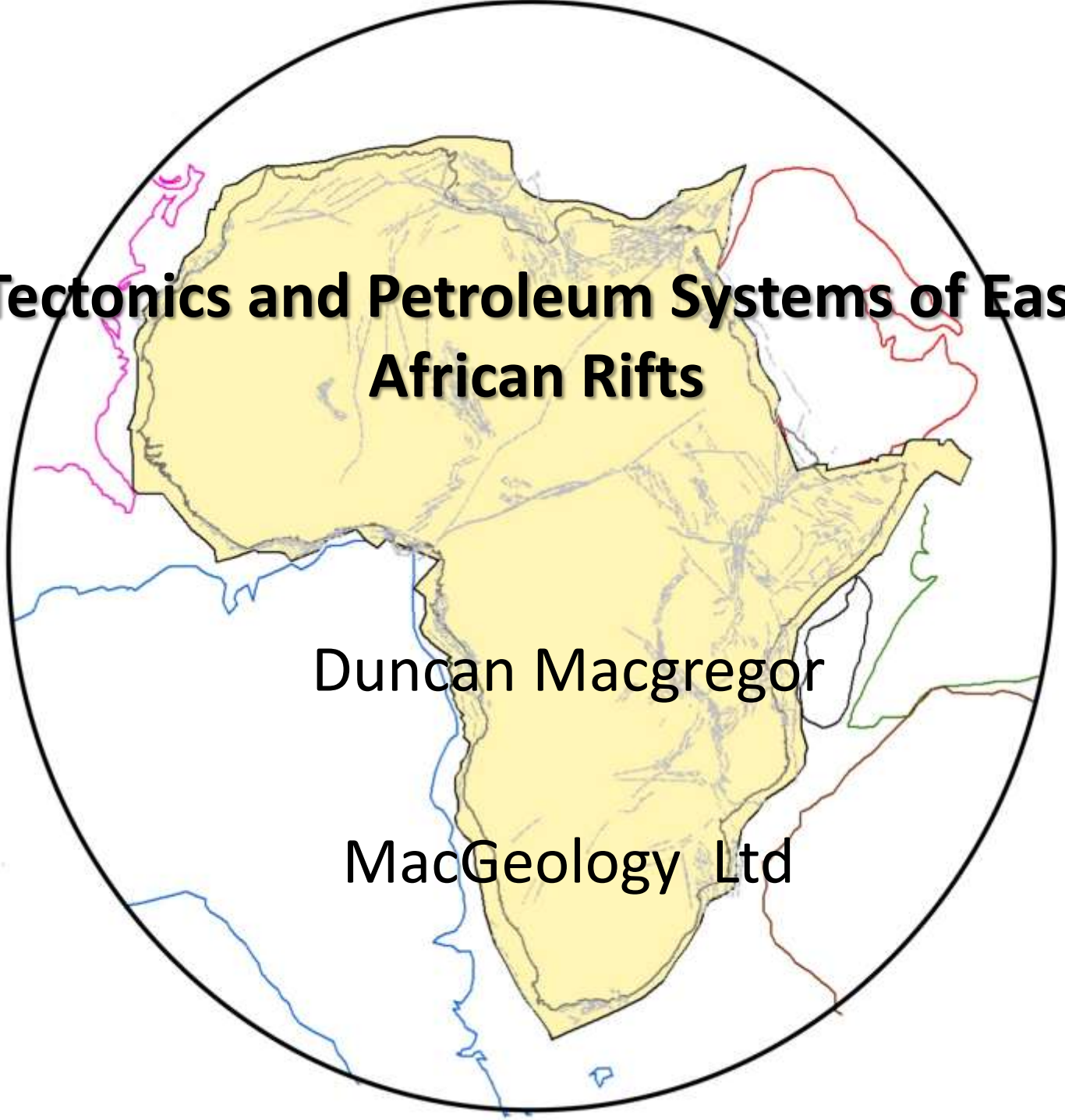
Tectonics and Petroleum Systems of East African Rifts



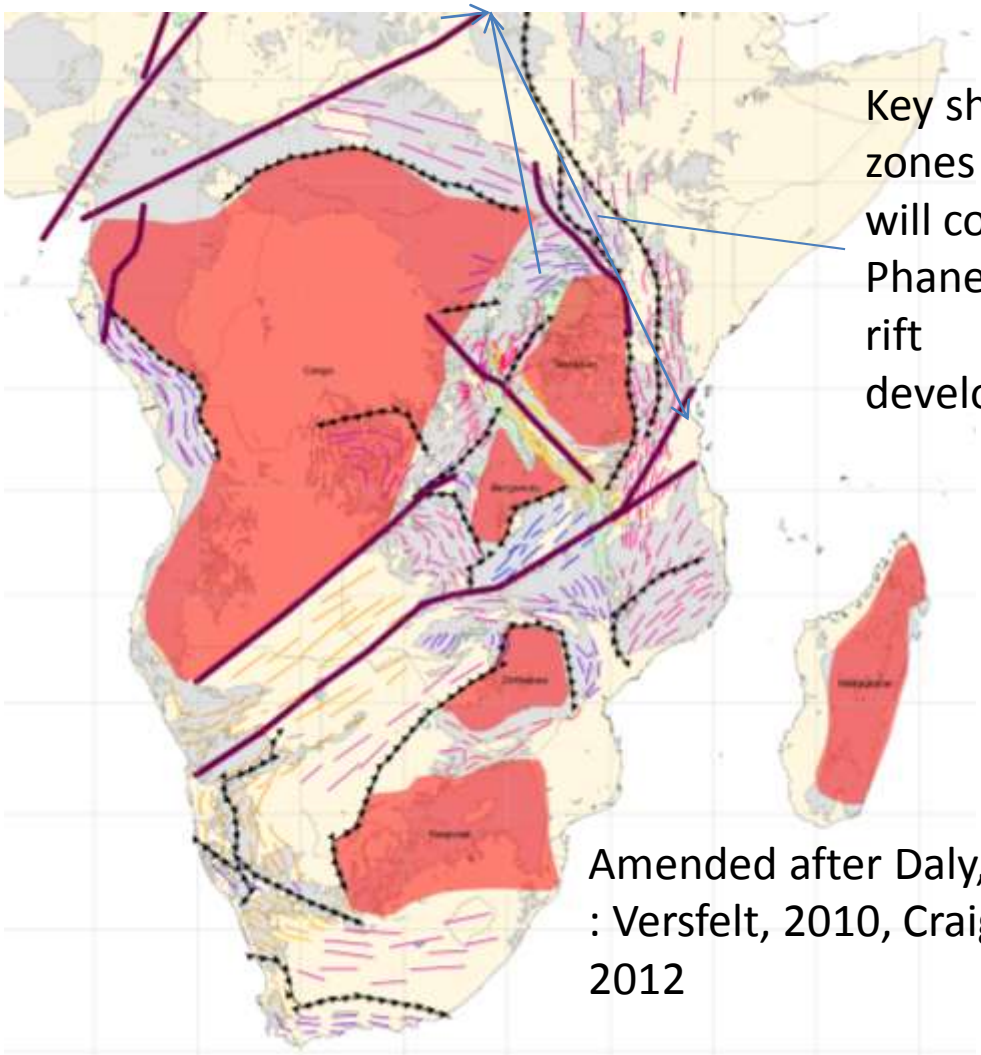
Duncan Macgregor

MacGeology Ltd

Agenda

- 1. Overview
- 2. Permo-Triassic Rifts
- 3. Jurassic Rifts
- 4. Cretaceous Rifts
- 5. Tertiary Rifts (EARS)
- 6. Conclusions

Basement Cratons and Lineaments, Southern Africa



Key shear zones that will control Phanerozoic rift development

Amended after Daly, 1992 : Versfelt, 2010, Craig, 2012

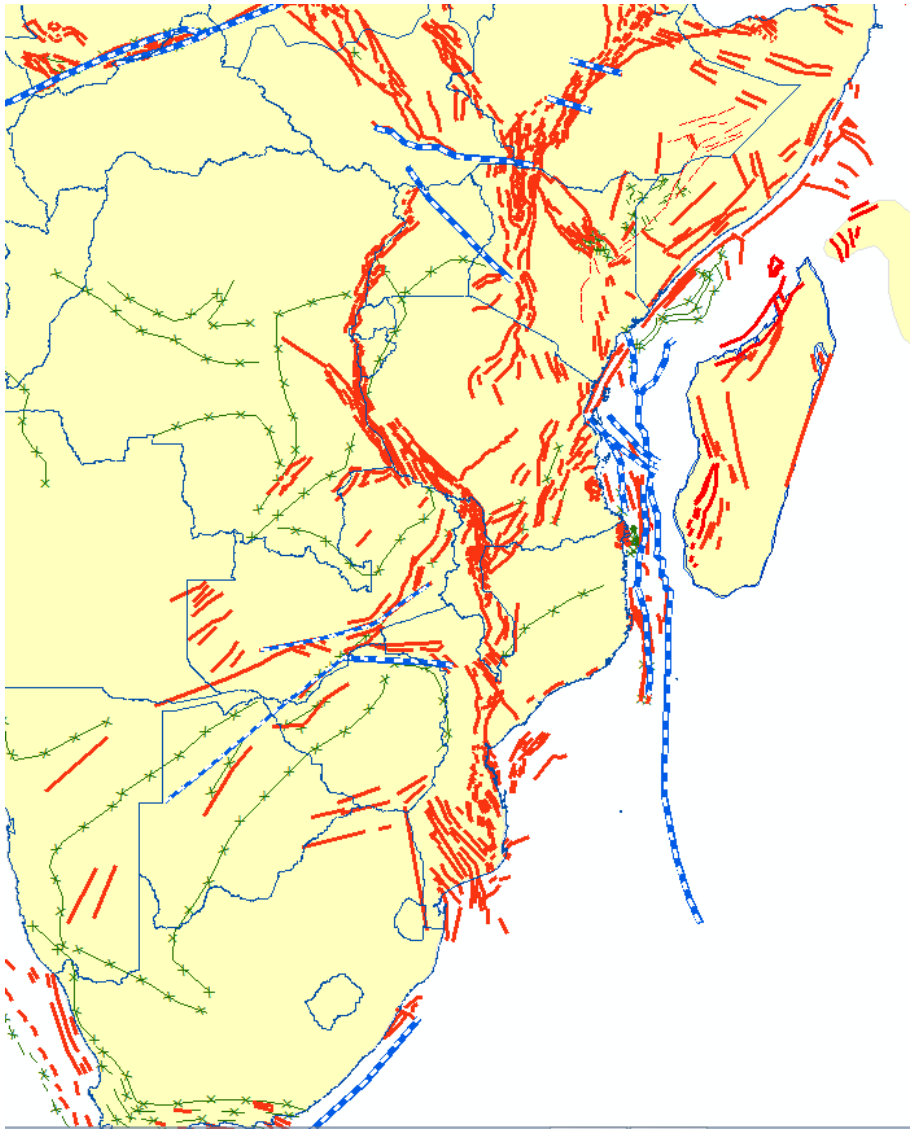
Legend

- shear zones
- reverse faults and thrusts

basement lineaments

- <all other values>
- <Null>
- Anti-Atlas
- Central African
- Damaride
- Irumide
- Kibaran
- Limpopo
- Lufilian
- Mauritanide
- Mozambique
- Namaqua-Natal
- Ubendian
- Usagaran
- cratons
- basement

East African Tectonic Elements



- Most rifted portion of the world
- At least 9 discrete phases of rifting
- Aim to time lineaments and define development through time
- Aim to constrain models for rift development in poorly controlled offshore areas
- Implications for petroleum systems

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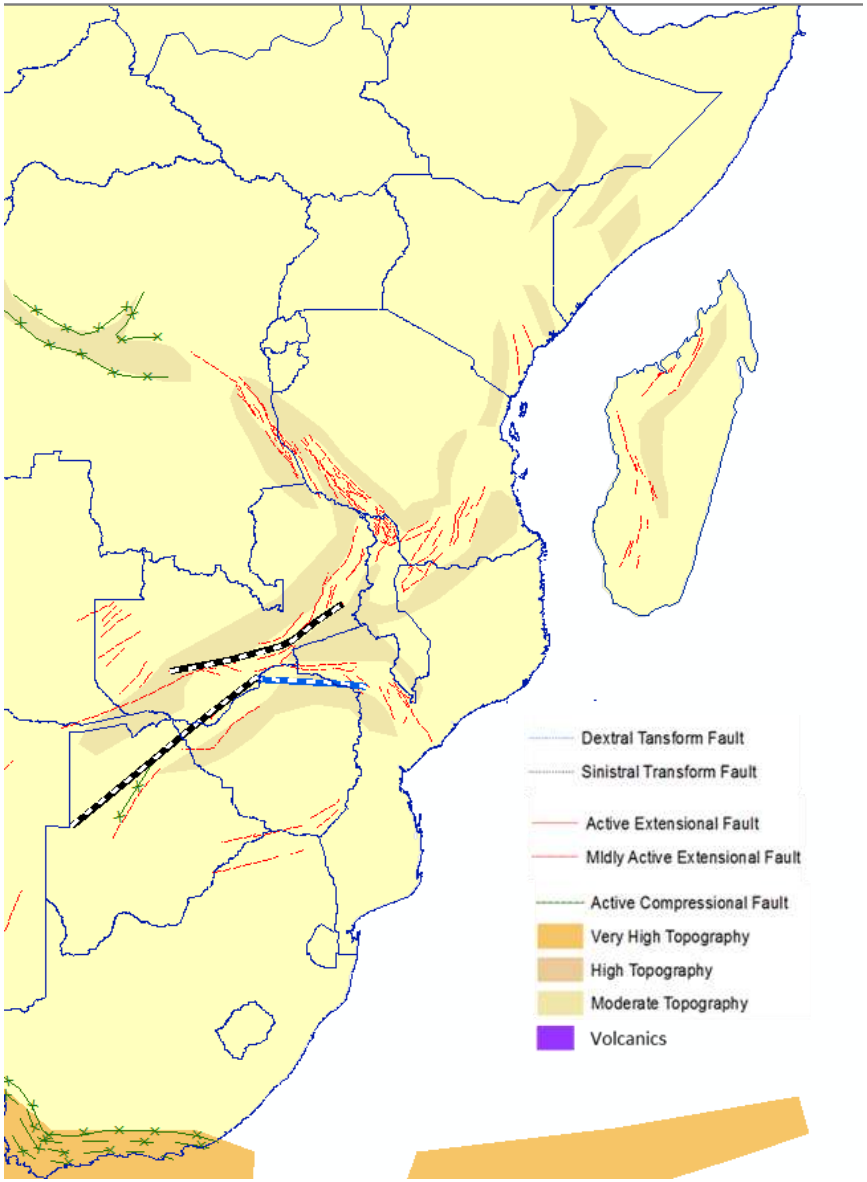
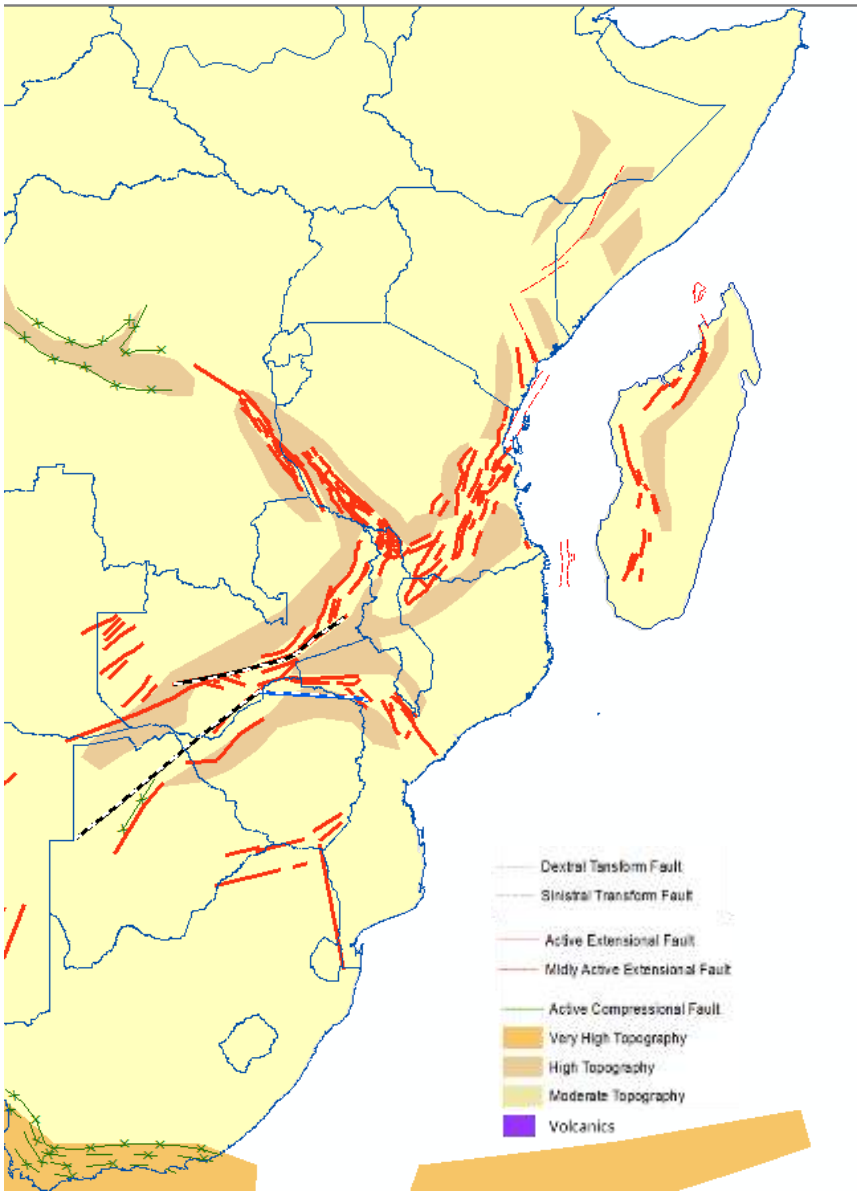
Stephanian-Earliest Permian Sags (Sakmarian 290Ma)



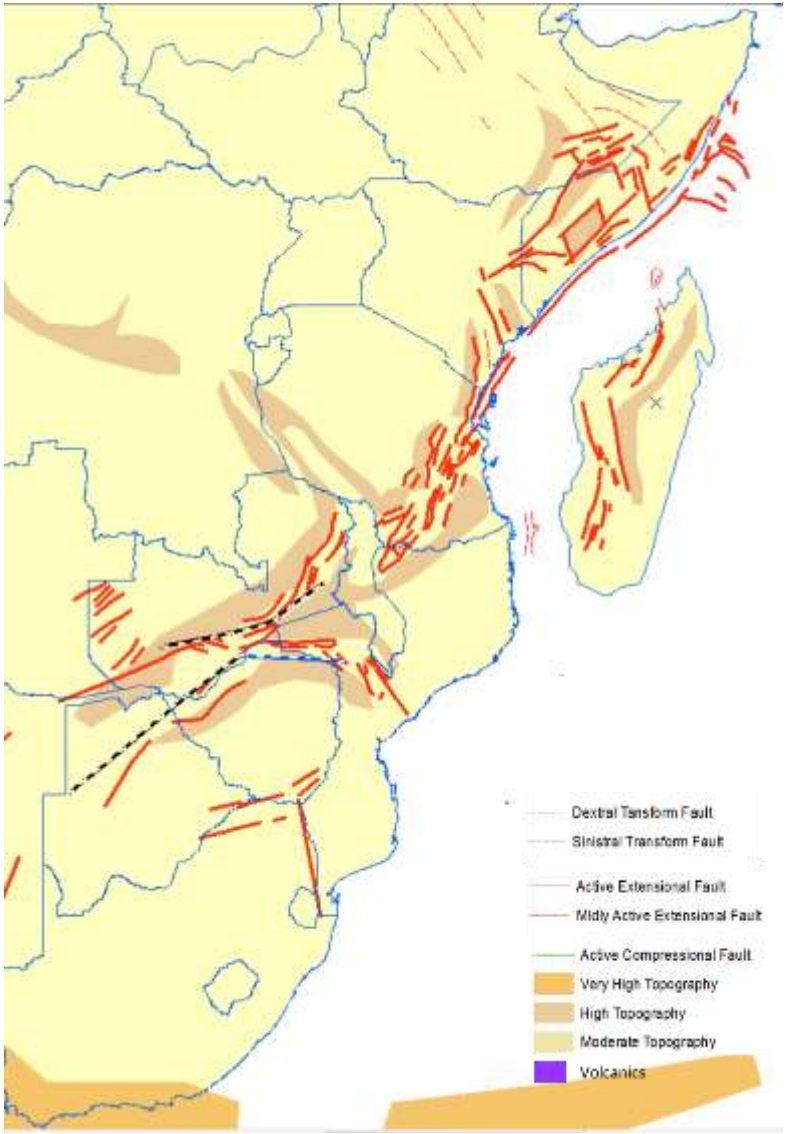
- Start of current Wilson Cycle of rifting (no significant rifts from Cambrian to Carboniferous)
- Initial ‘sag’ like subsidence filled at base with tillites (‘Dwyka’ of Stephanian age)
- Initial collision of Africa with Patagonia initiates Southern Trans Africa Shear System (STASS) aka. Falklands-Tethys transform (similar to younger CAL)
- Identified either by dating or through presence of basal tillites, extends as far north as Mombasa Basin of Kenya

Mid Permian Rifts (Roadian 270Ma)



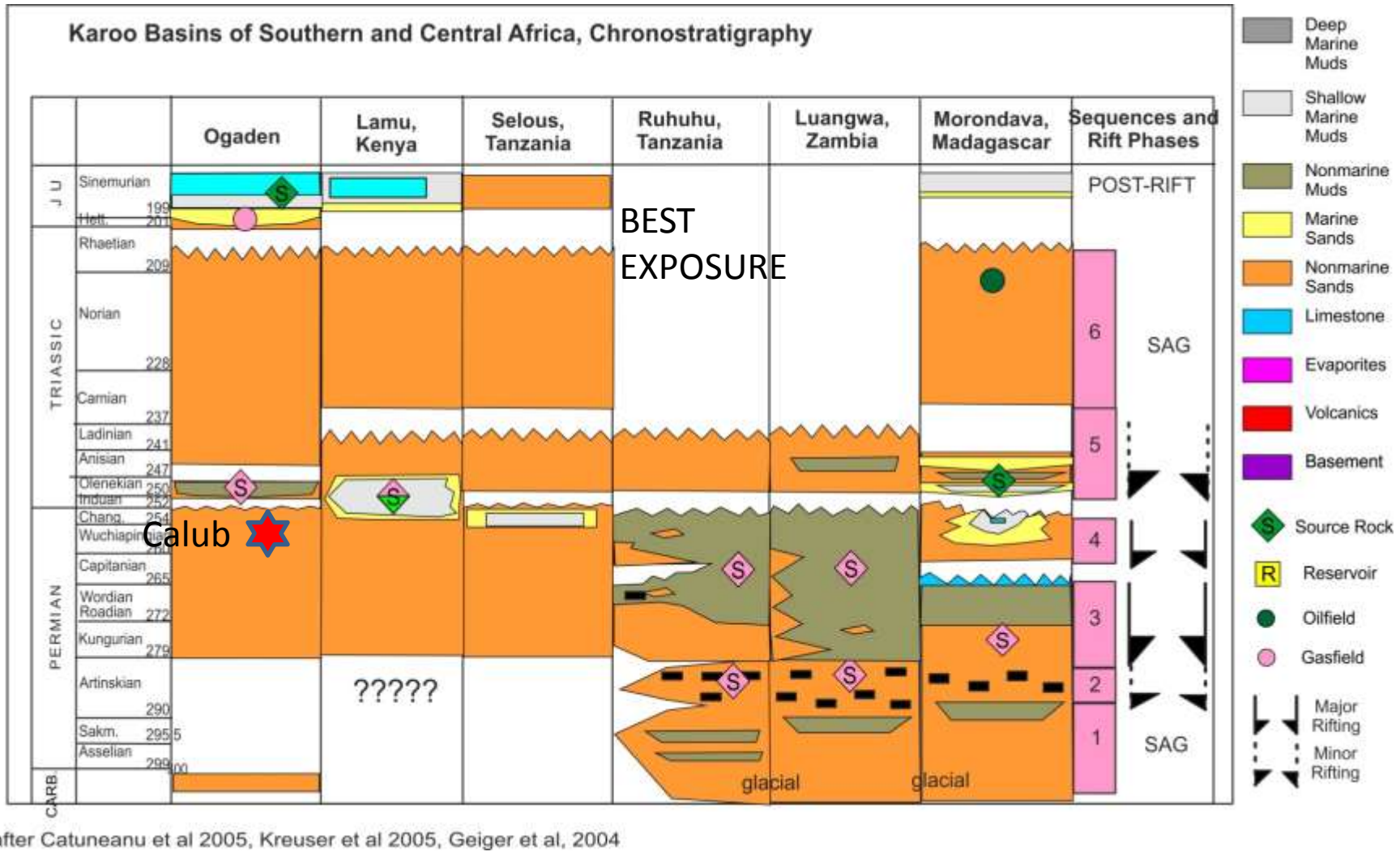
- Main stage of rifting from Tanzania southwards
- Several 'Karoo' rifting cycles , peak in Roadian, circa 270Ma
- Collision with Patagonia on S margin – Cape Fold Belt
- Deep Pull-Apart Basins in N Zambia and Tanzania
- Extensional rifts oblique to STASS – Madagascar, Rukwa, extinct by Triassic
- Extend across whole 'STASS' trend from Botswana to Kenya

Earliest Triassic Rifts (Induan 250Ma)



- Rifting spreads to NE, main rift phase in Ogaden, Mandera Lugh and Mombasa Basins
- Expansion and deepening of rifts in Madagascar (Sakamena Fm.)
- Level of significant mainly lacustrine source rock, event marking basin deepening
- Weaker rift reactivation in Zambia etc, filled with sands

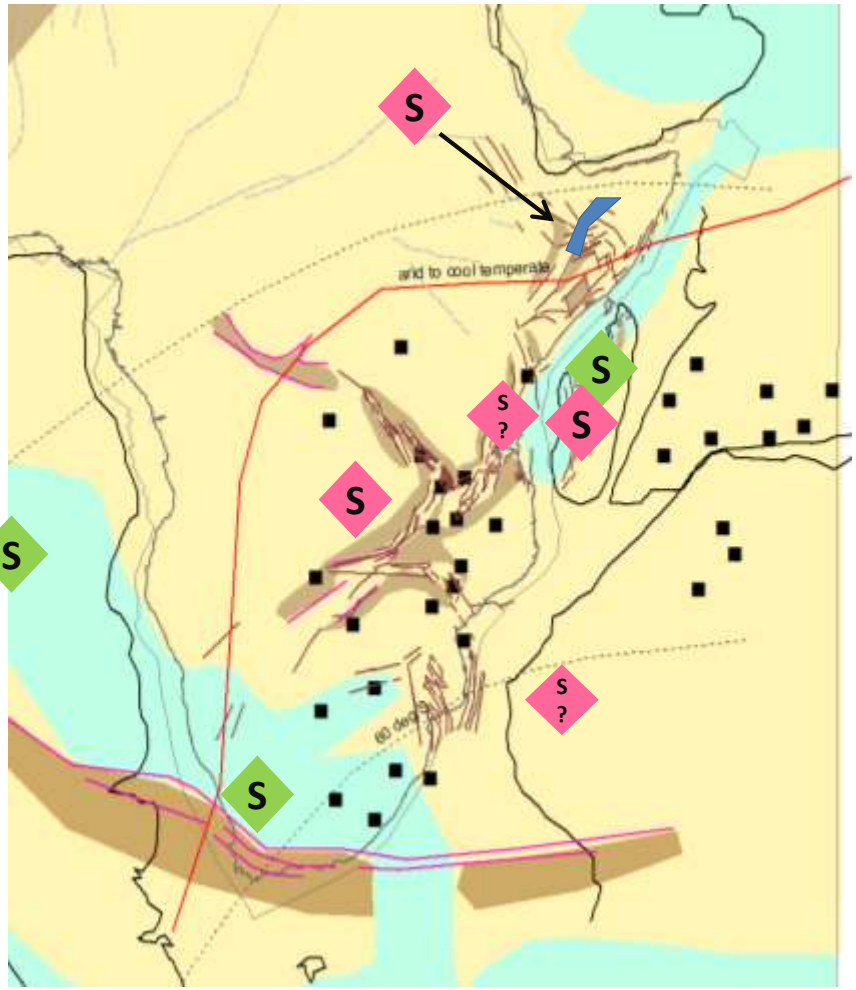
East Africa Karoo (Permo-Trias) Stratigraphy



after Catuneanu et al 2005, Kreuser et al 2005, Geiger et al, 2004

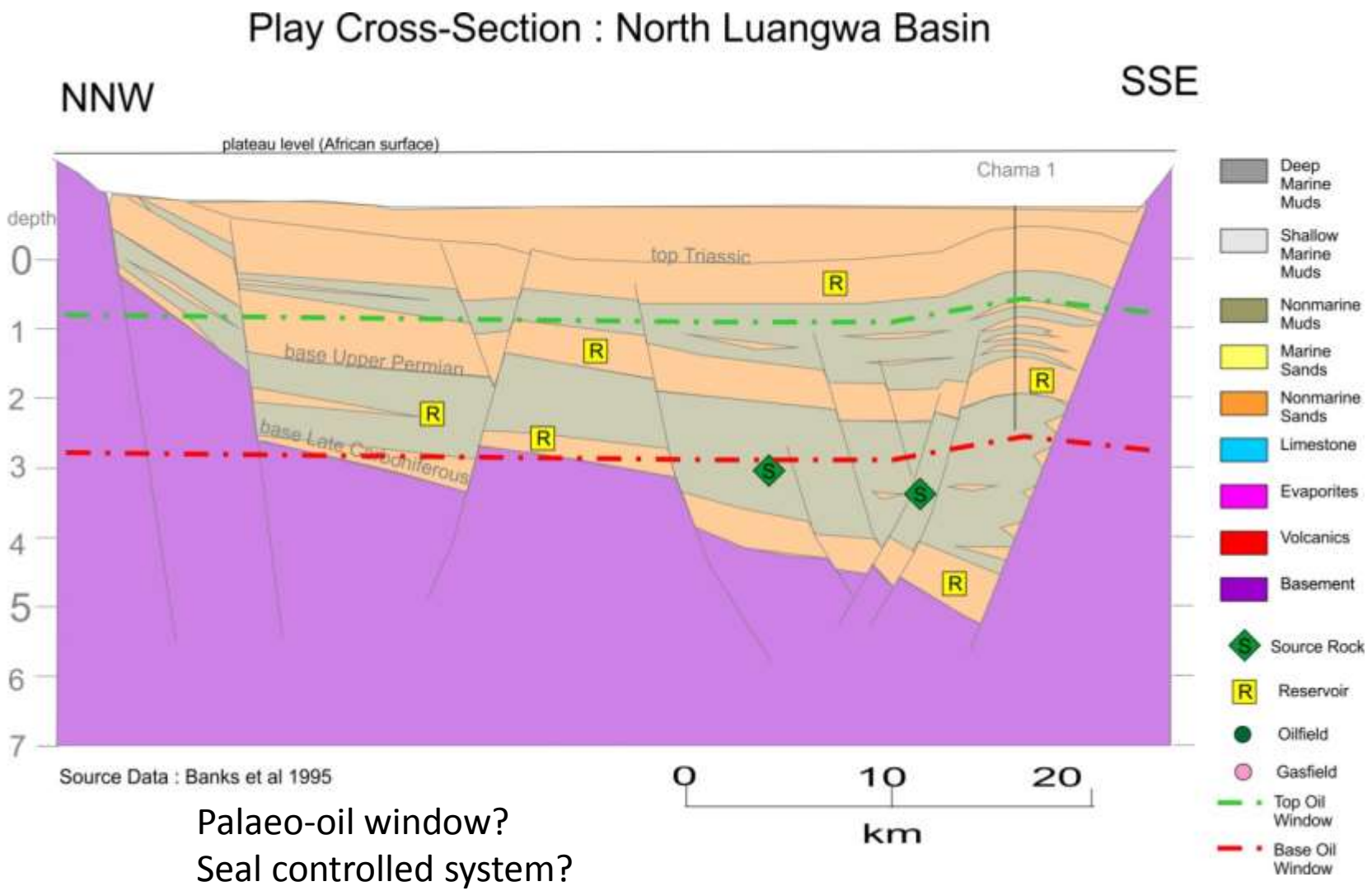
Multiple generation rifts, peak in Mid Permian (south) and Early Triassic (north

Regional Source Rocks : Late Permian to Earliest Triassic (marine and lacustrine)



- Middle Sakamena Fm (basal Trias) (Madagascar) –saline lacustrine and restricted marine?, <300m, original TOC original 4%, HI < 750 (Clark 2003)
- Bokh Fm (Ethiopia) – basal Trias, lacustrine , TOC 1.6%, Type III (Hunegwa, 1998)
- Lukuledi well, Tanzania, TOC 78%, HI 253, S2 200 kg/t
- Coals usually gas prone, lacustrine shales in mid Permian elsewhere often Type III (e.g. Selous Basin) – (Dypvik, 1990)
- Presumed contribution to Rovuma-Tanz. gas on basis of gas maturity (Rego et al 2012) and possibly also to high maturity Pande/Temane fields
- Cooper Basin oil analogue in Australia
- Are there more oil prone marine inlets and where are they?
- Shale gas – Great Karroo Basin
- High overburdens – usually in gas window

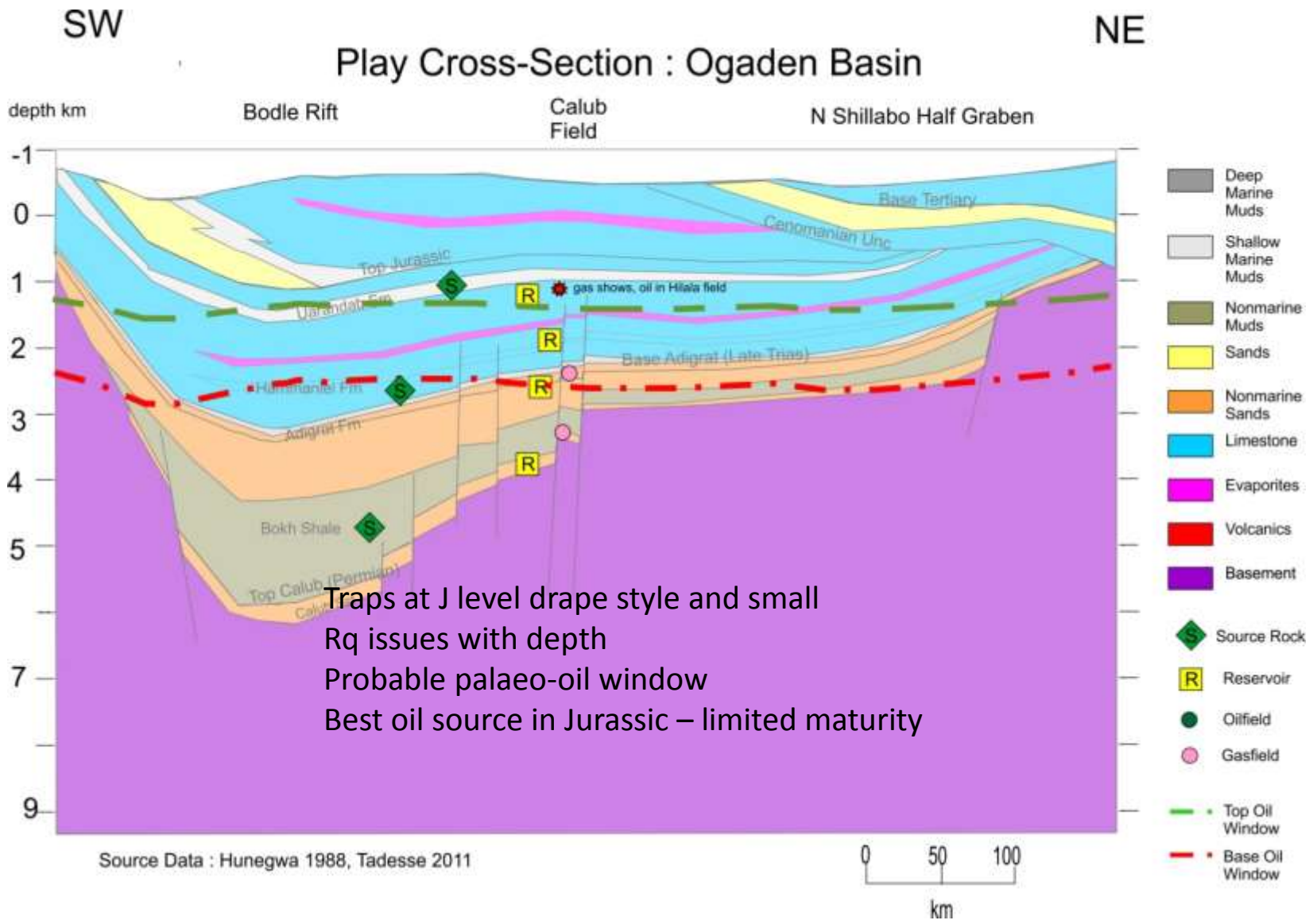
North Luangwa Basin : Petroleum Systems



Palaeo-oil window?

Seal controlled system?

Ogaden Basin : Petroleum Systems



Permo-Trias Rifts: Key Regional Technical Issues

- Res pr : Plenty Clastic Reservoir (non-marine)
- Res q : Potentially deeply buried with loss of poroperm with depth due to immature mineralogy
- So pr : Mid Permian lacustrine shales appear gas prone (climate?), oil prone in earliest Triassic associated with marine influxes?
- So eff : Significant timing issues, generation may be in Trias, petroleum system successes are in areas of later burial (and are gas)
- C (seal) : Poor seals apart from marine levels
- Traps: Fault blocks and inversion structures
- Preservation : Long term preservation difficult with thin seals and later movements except in areas of continued burial (e.g. E Africa margin)

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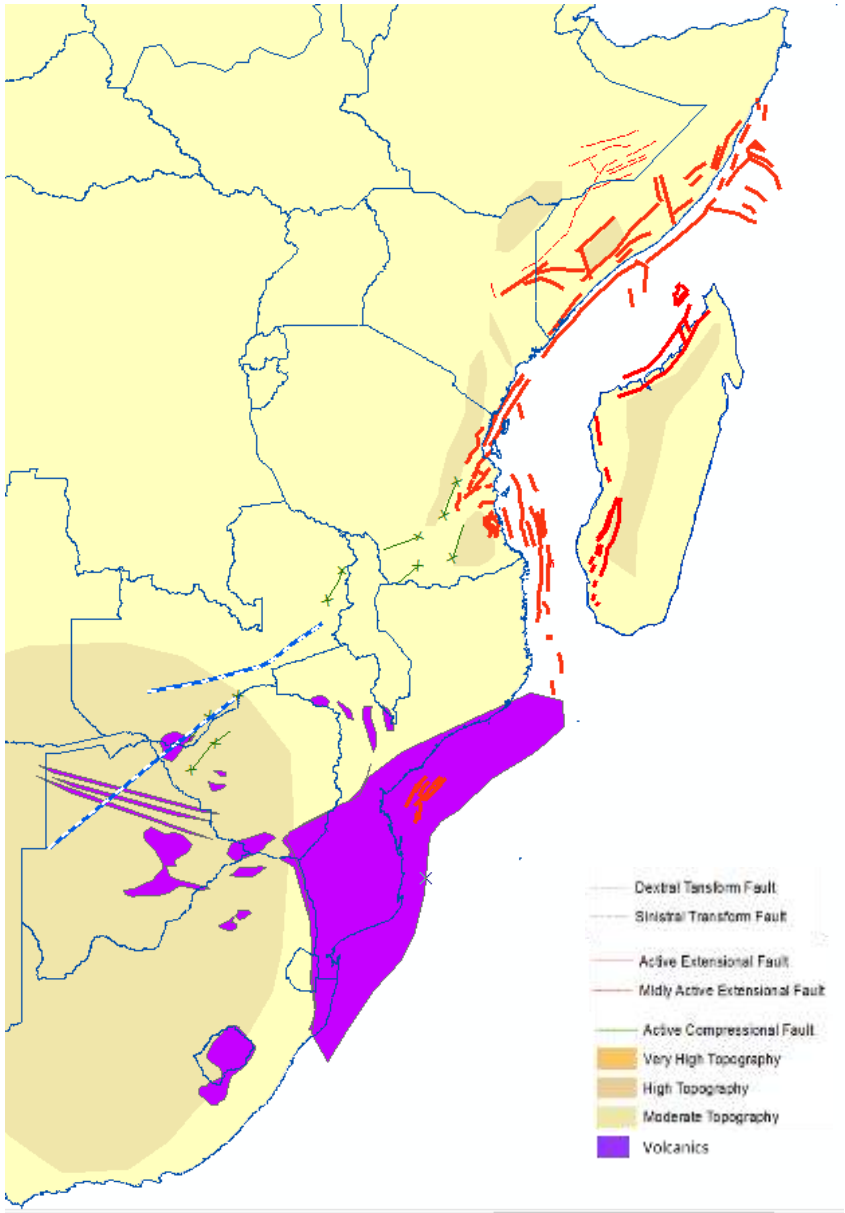
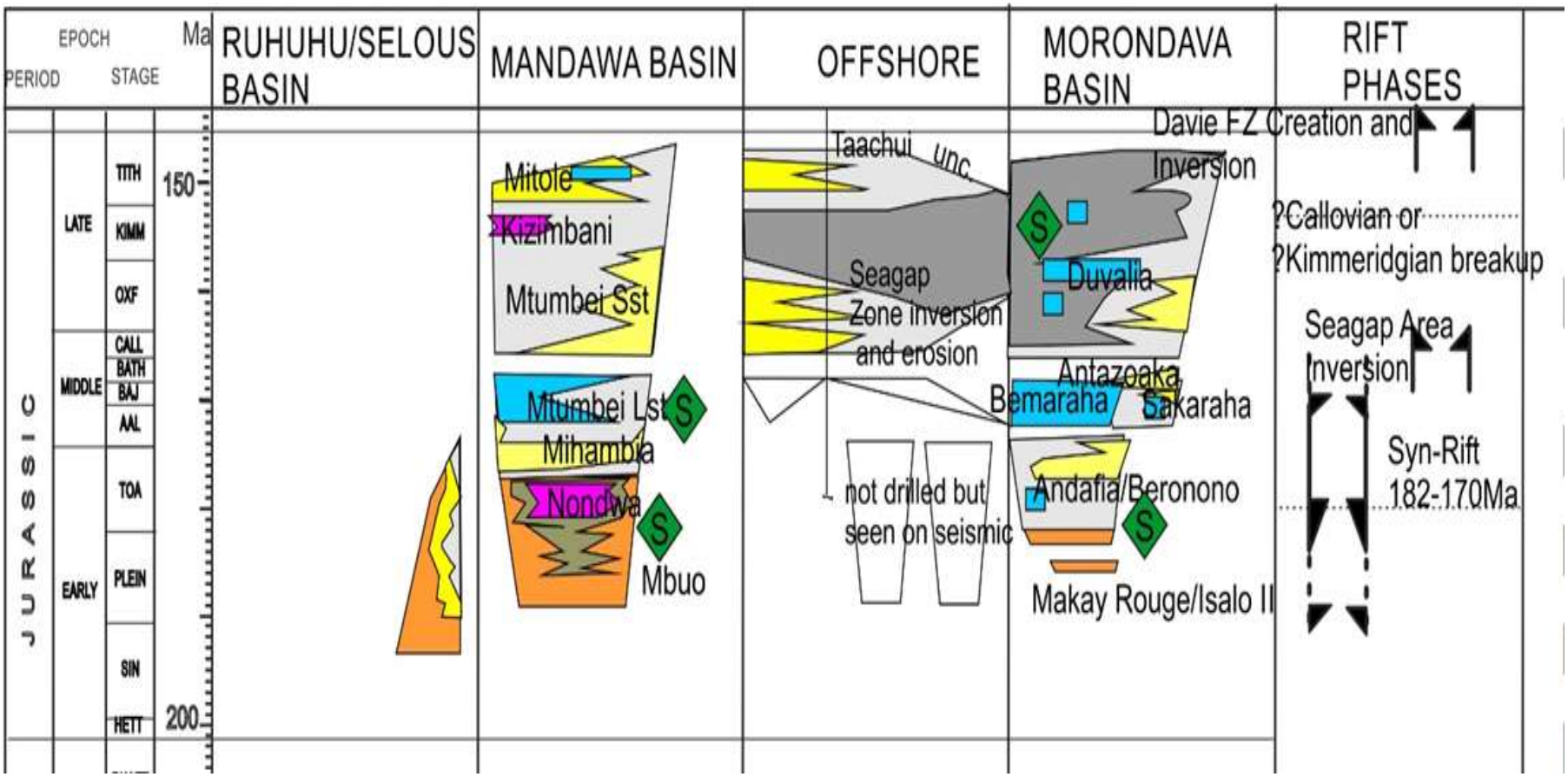
Early Jurassic ~ 180Ma Tectonics

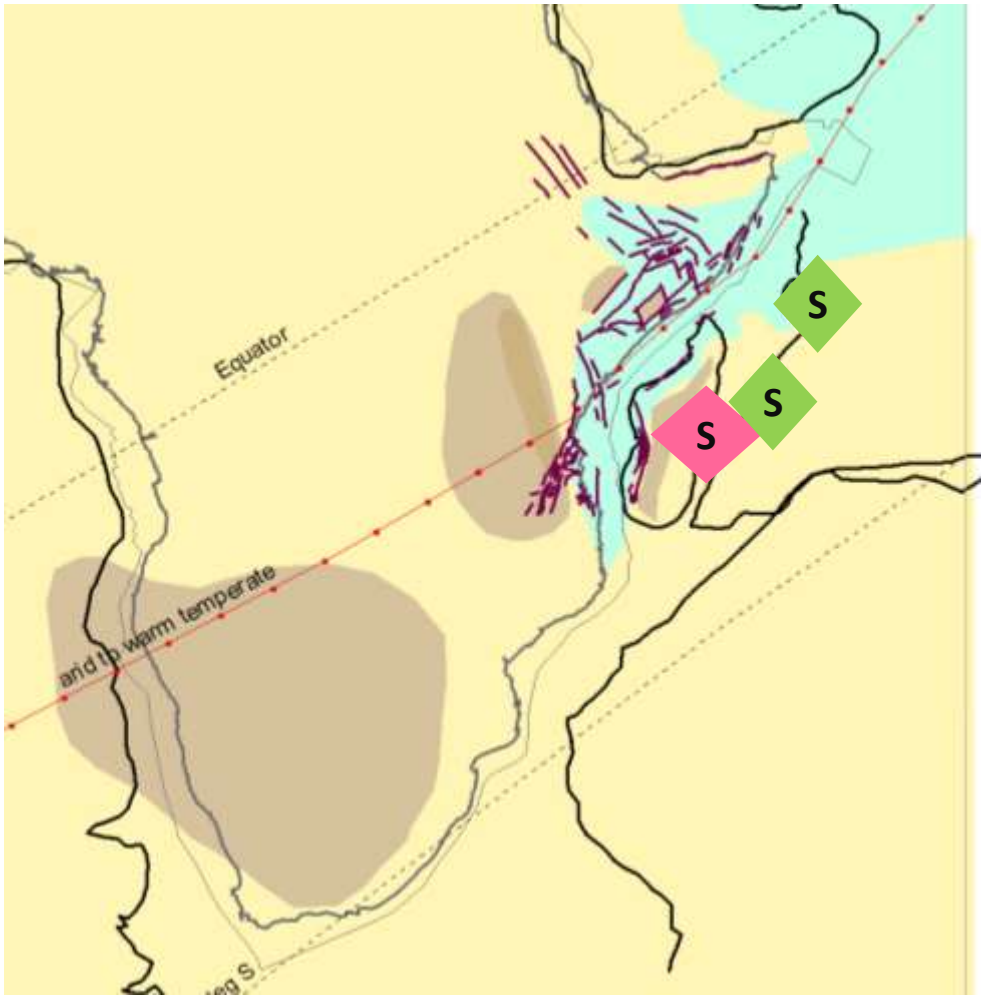


- Syn-rift Toarcian to Aalenian
- Peak of rifting in E Africa, preceding breakup
- Typical feature developed is half graben wedges
- Often in more basinward (now oceanward) positions to earlier rifts
- Often reactivated recently so seabed features
- Tethyan marine inlet extending south as far as volcanics in Mozambique
- Main East African source rocks in Toarcian-Aalenian syn-rift, Bajocian and Oxfordian post-rift

Tanzanian to Madagascar Rift Chronostratigraphy

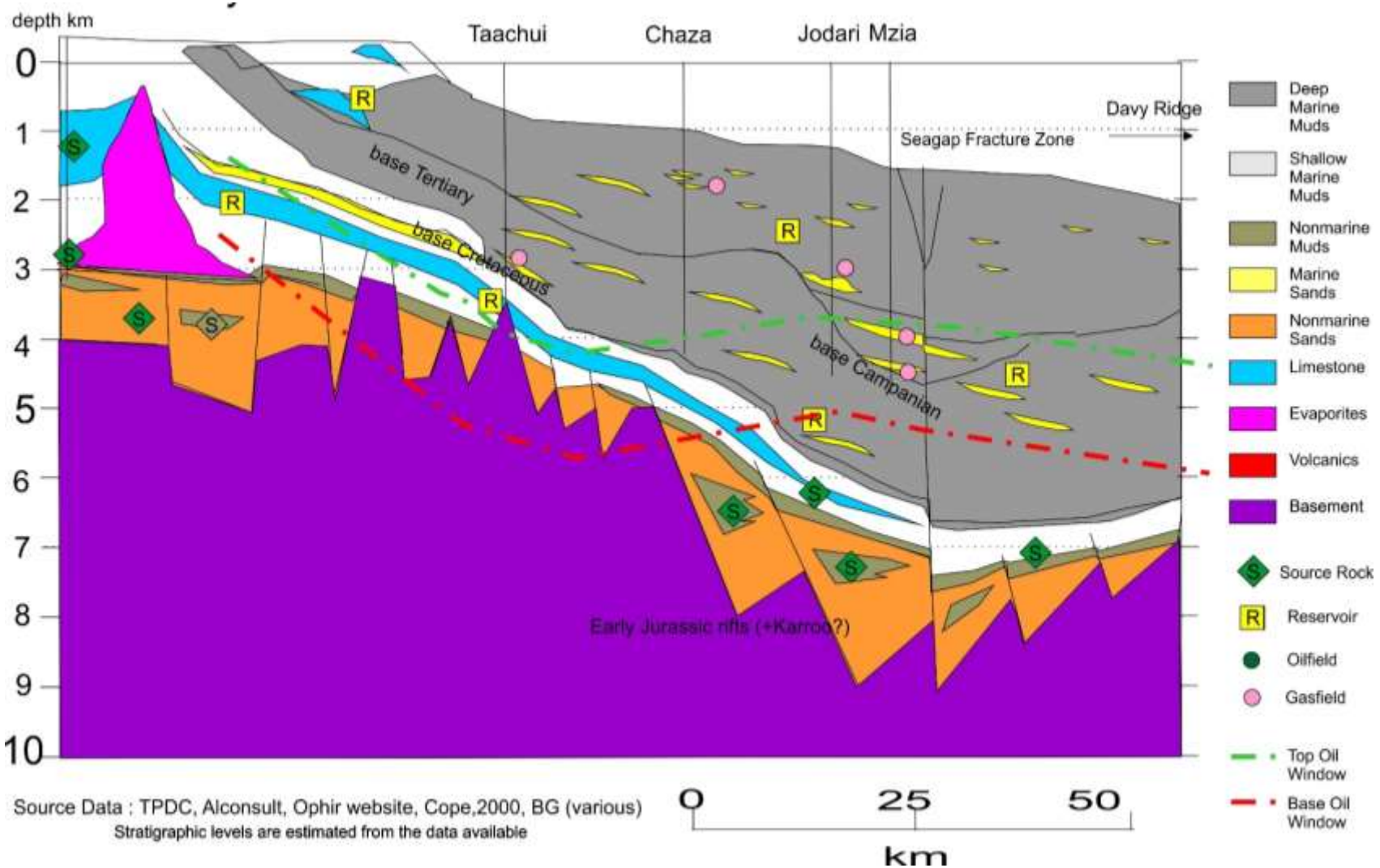


Regional Source Rocks : Early Jurassic (marine/?lacustrine)

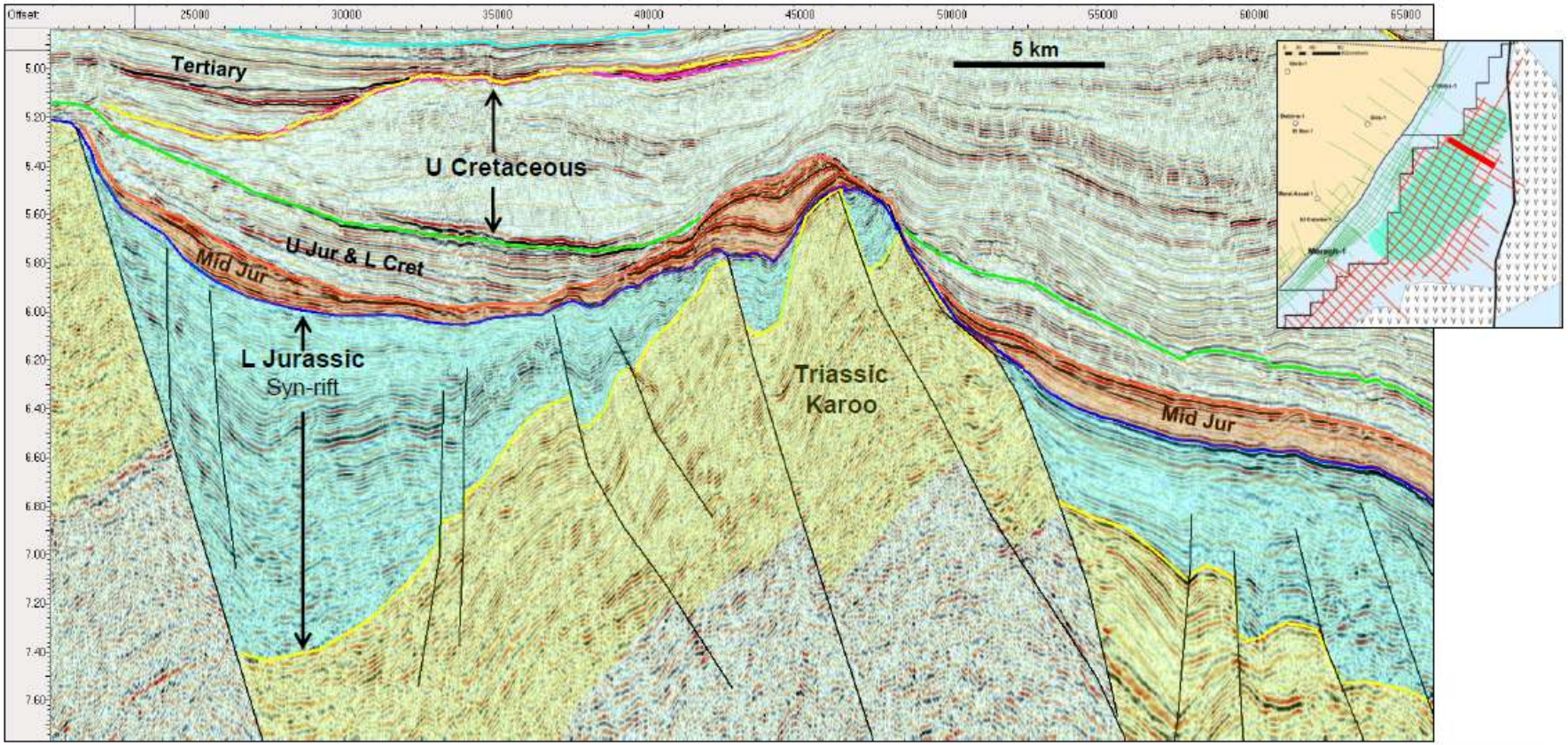


- Early Jurassic lacustrine and earliest Mid Jurassic marine carbonate source rocks best known from Tanzania and Madagascar
- Typed to condensate in Rovuma basin gases , presumed to be main source of East Africa gas
- Tanzania TOC 1.7-8.7%, Type I-II, HI 272-1000 (TPDC), Madagascar, TOC 1-7%, S2 4-268 kg/t (Clark 2003), extension offshore questionable

Example : Tanzanian Offshore Rifts

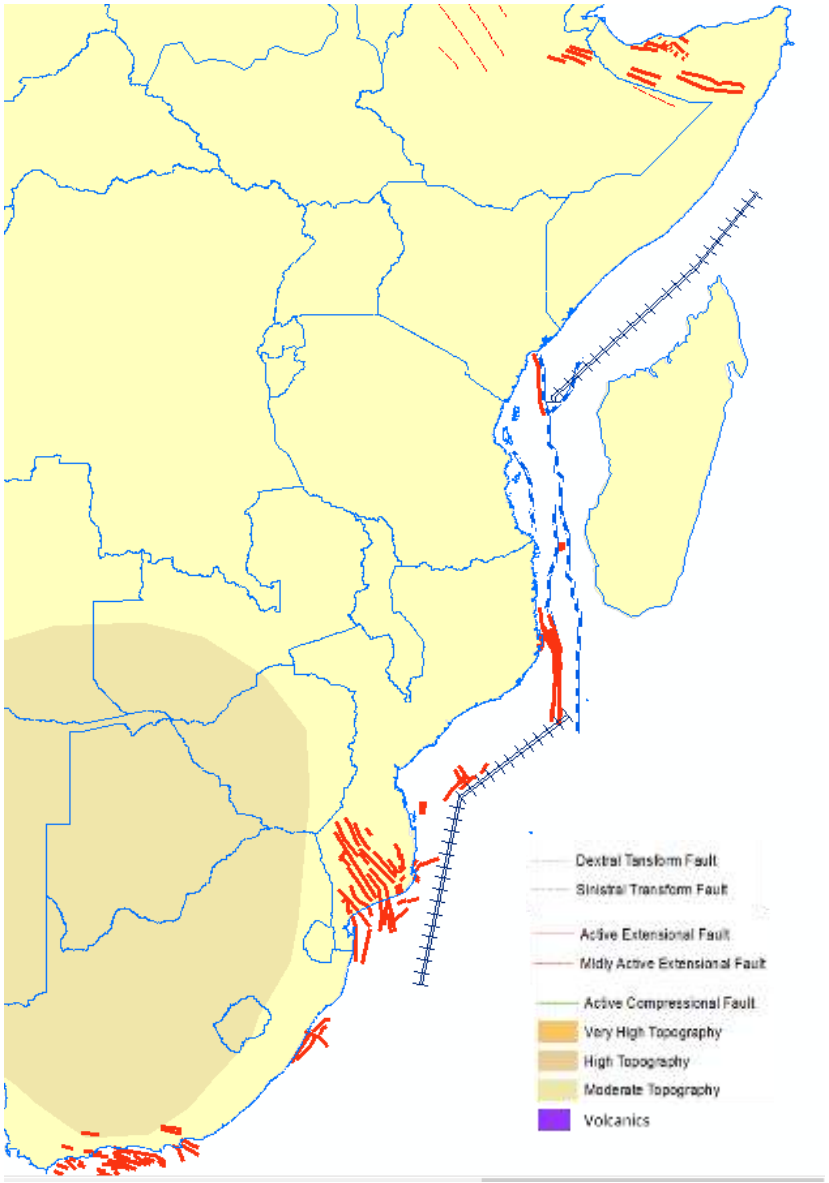


Somalia-Early Jurassic Half Graben



Soma 2014

Late Jurassic Tectonics



- Significance of Kimmeridgian rifting in NE Africa not as great as in Yemen – analogues difficult to apply
- Africa-Mozambique drifting from ?160-120Ma
- Pullapart basins created along Davie Fracture Zone at end Jurassic
- Rifts in south Mozambique and South Africa, possibly associated with drift of 'Limpopia'

Plate Tectonics : gplates
Shorelines : Smith et al, 1994, Guiraud et al 2005, Salman et al 1995
Tectonics : multiple papers, esp Reeves, various
Climate : Morley (2007), Scotese (2011),

Example : Late Jurassic Pull-Apart, Lacerda Basin, Mozambique

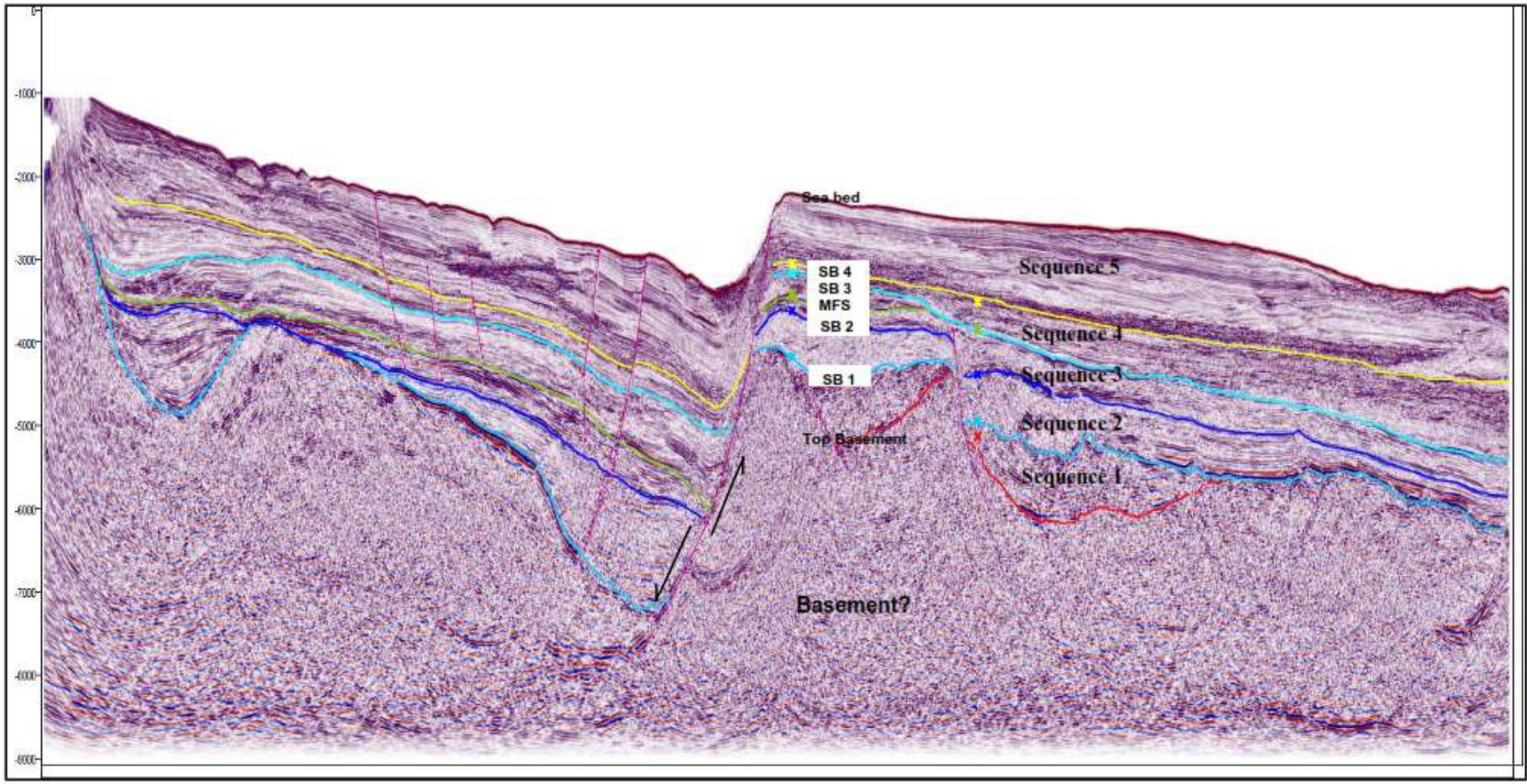


Figure 2 The identified sequences and sequence boundaries in Areas 3 & 6, Rovuma Basin, Mozambique.

Sapri et al 2013

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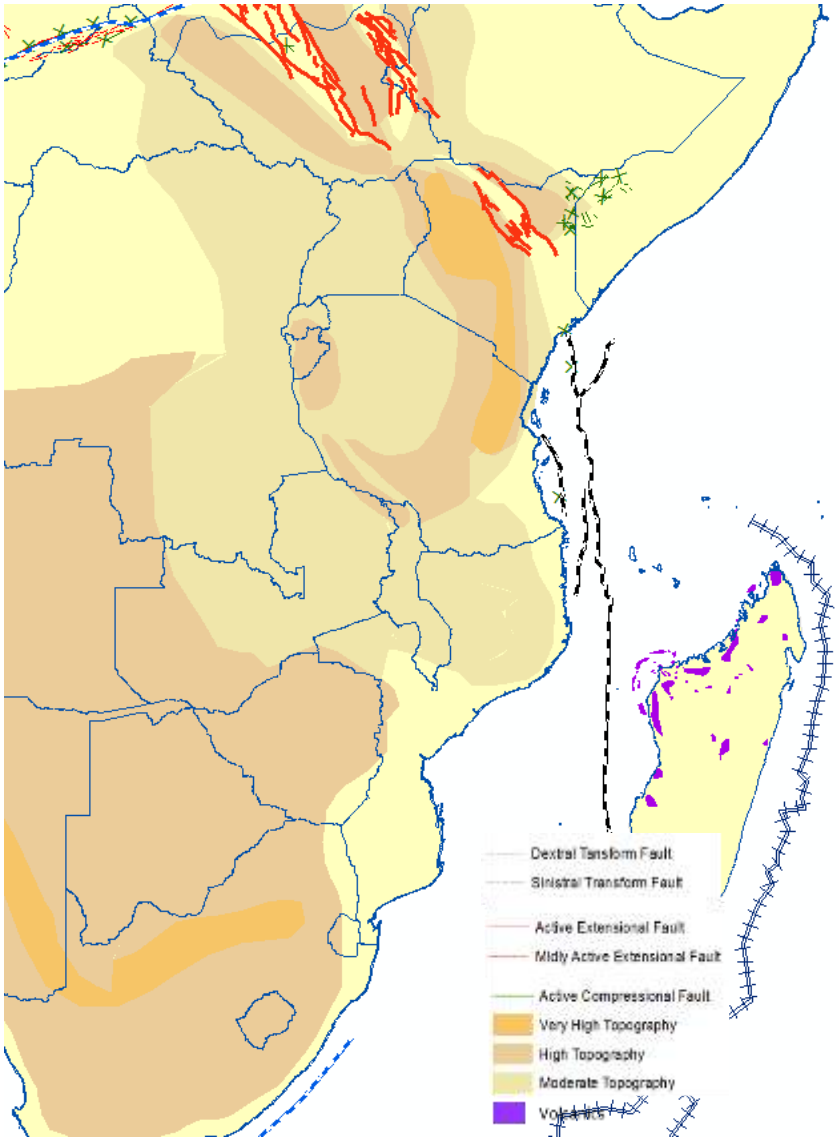
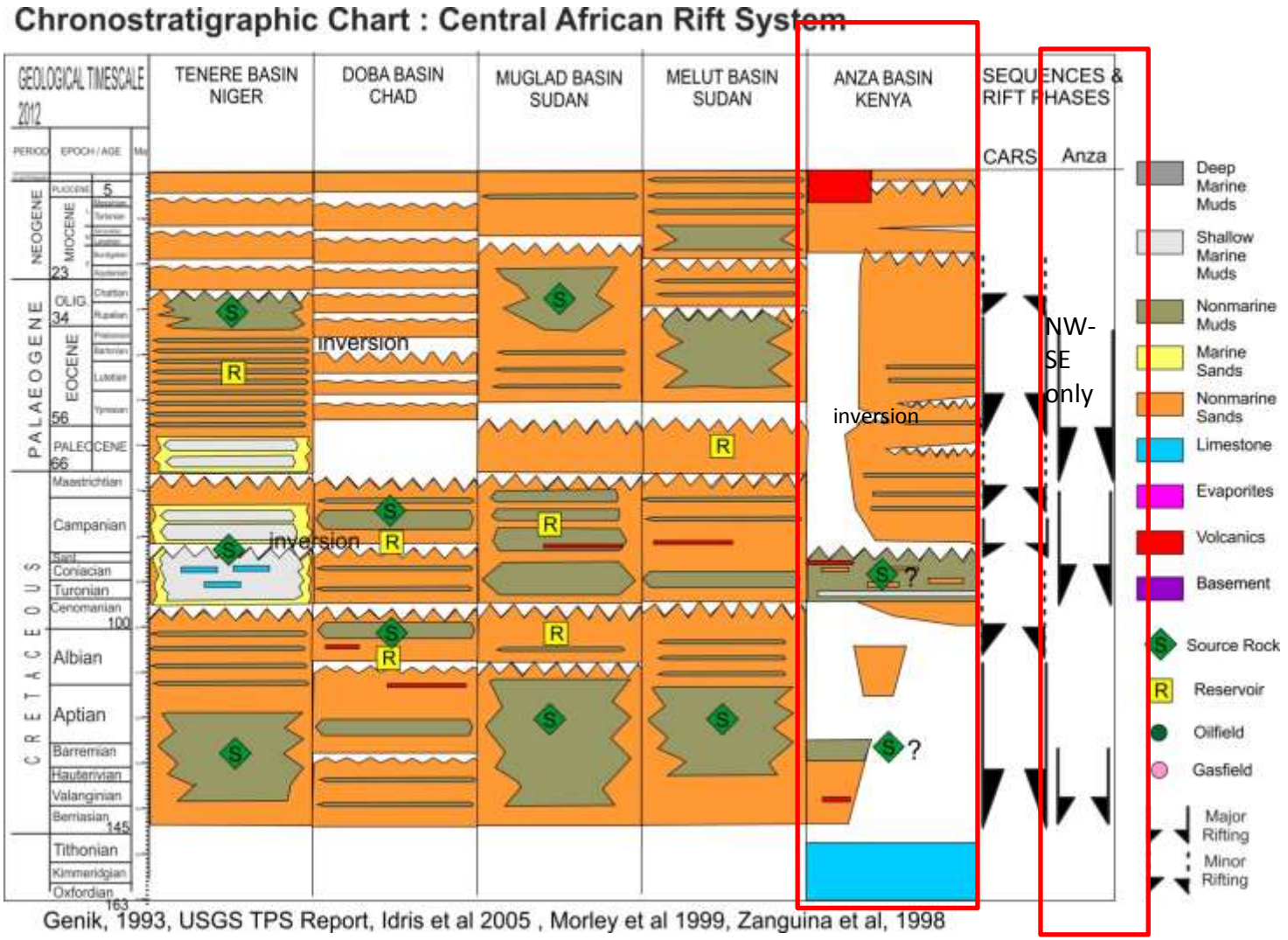
Late Cretaceous Campanian 80Ma Rifting



- Extensive Cretaceous rifting across Africa, mainly NW-SE. commences Barremian
- Central African and Benue lineaments activated
- Main phase of rifting in Anza Basin is Late Cretaceous-Paleocene, associated with building of high rift shoulders

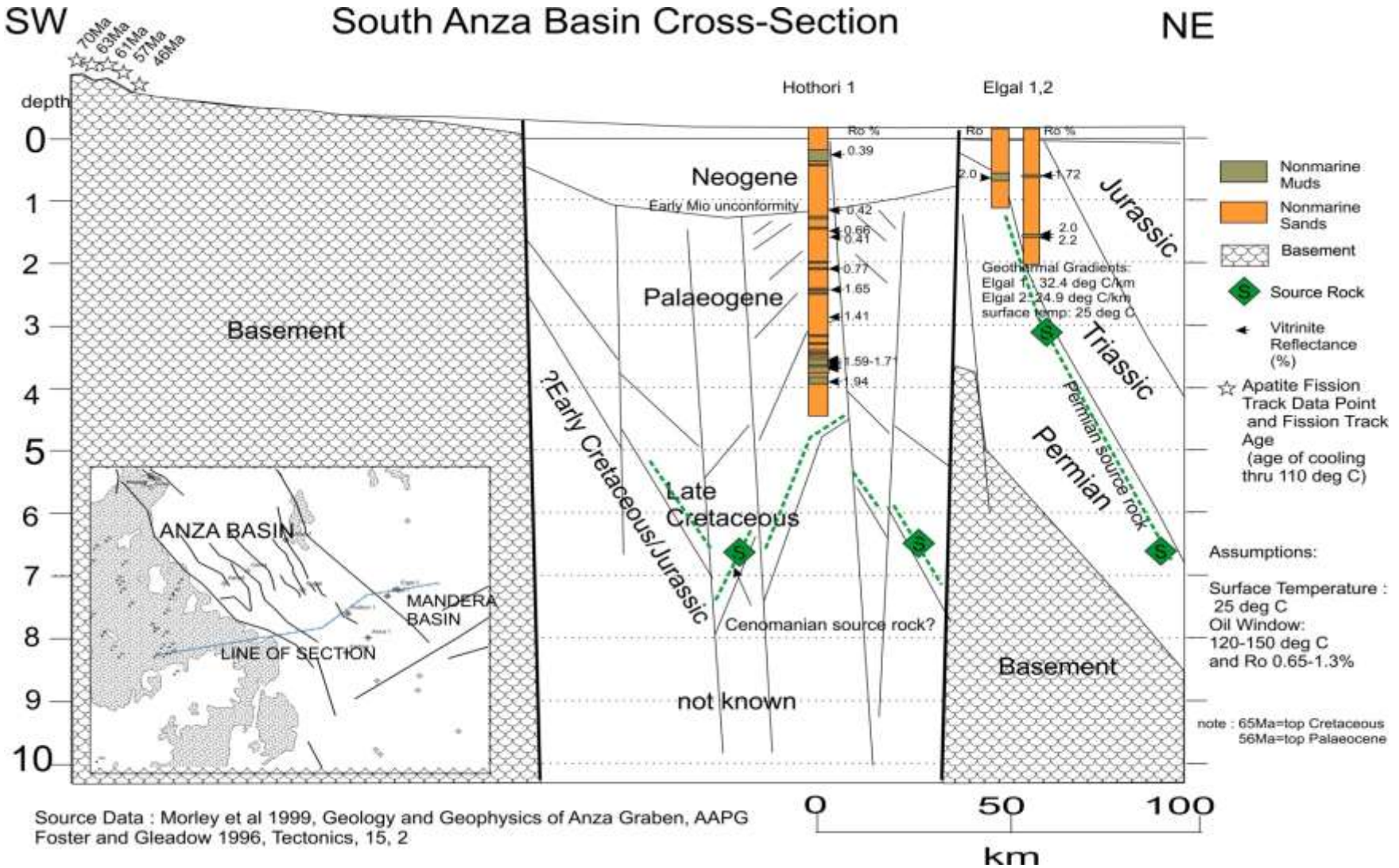
Central African Rift System Chronostratigraphy



Genik, 1993, USGS TPS Report, Idris et al 2005 , Morley et al 1999, Zanguina et al, 1998

Anza Rift is not in phase with rest of CARS and a different model must be sought

South Anza Basin, Kenya



Source Data : Morley et al 1999, Geology and Geophysics of Anza Graben, AAPG
Foster and Gleadow 1996, Tectonics, 15, 2

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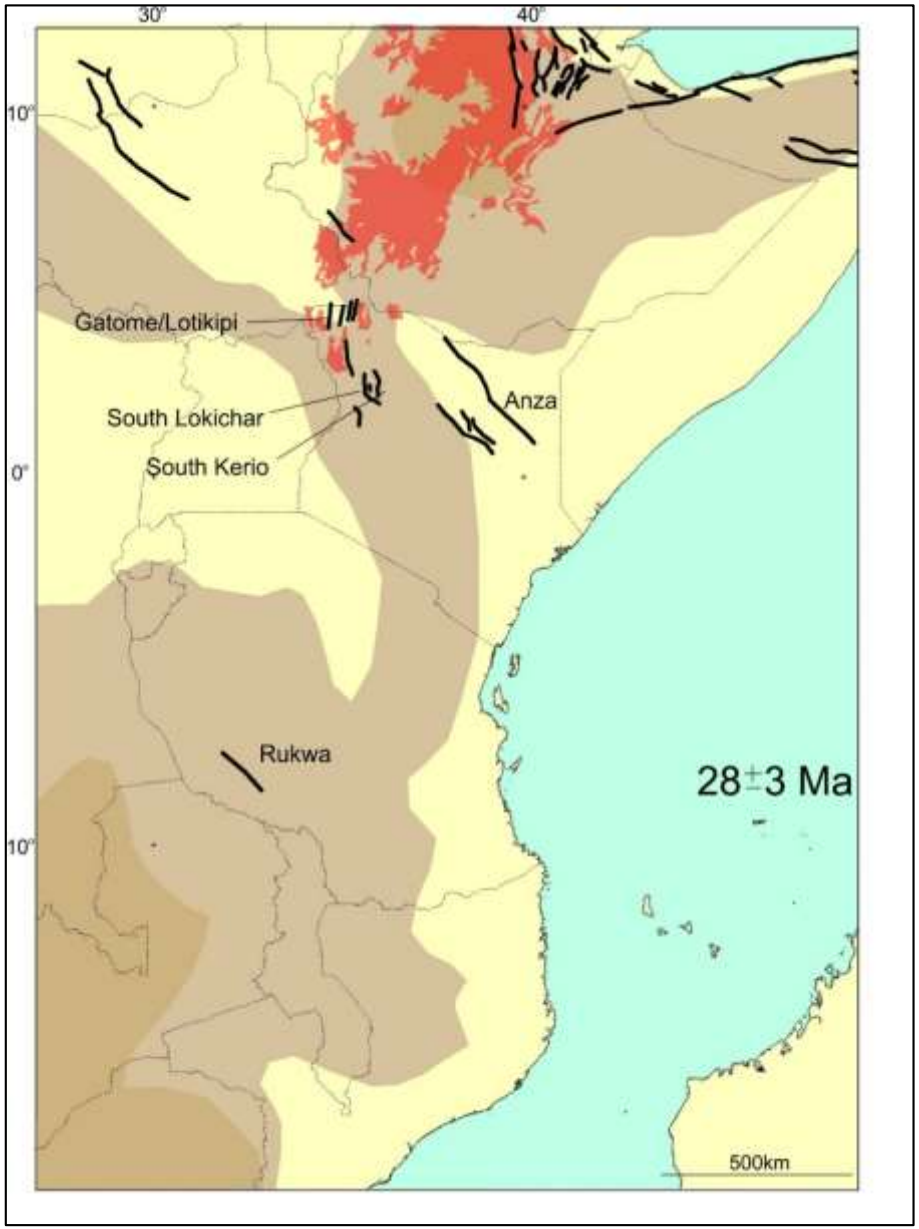
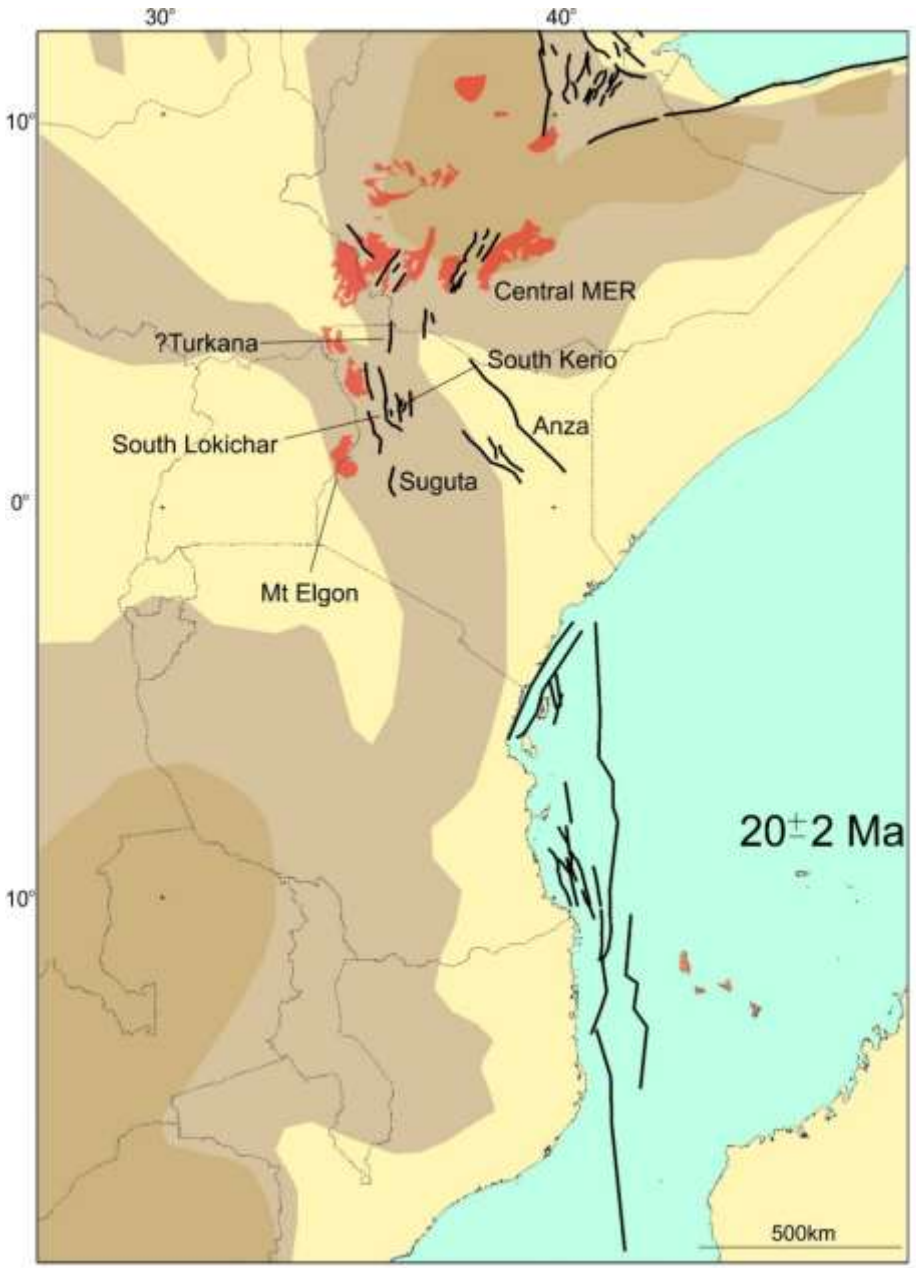
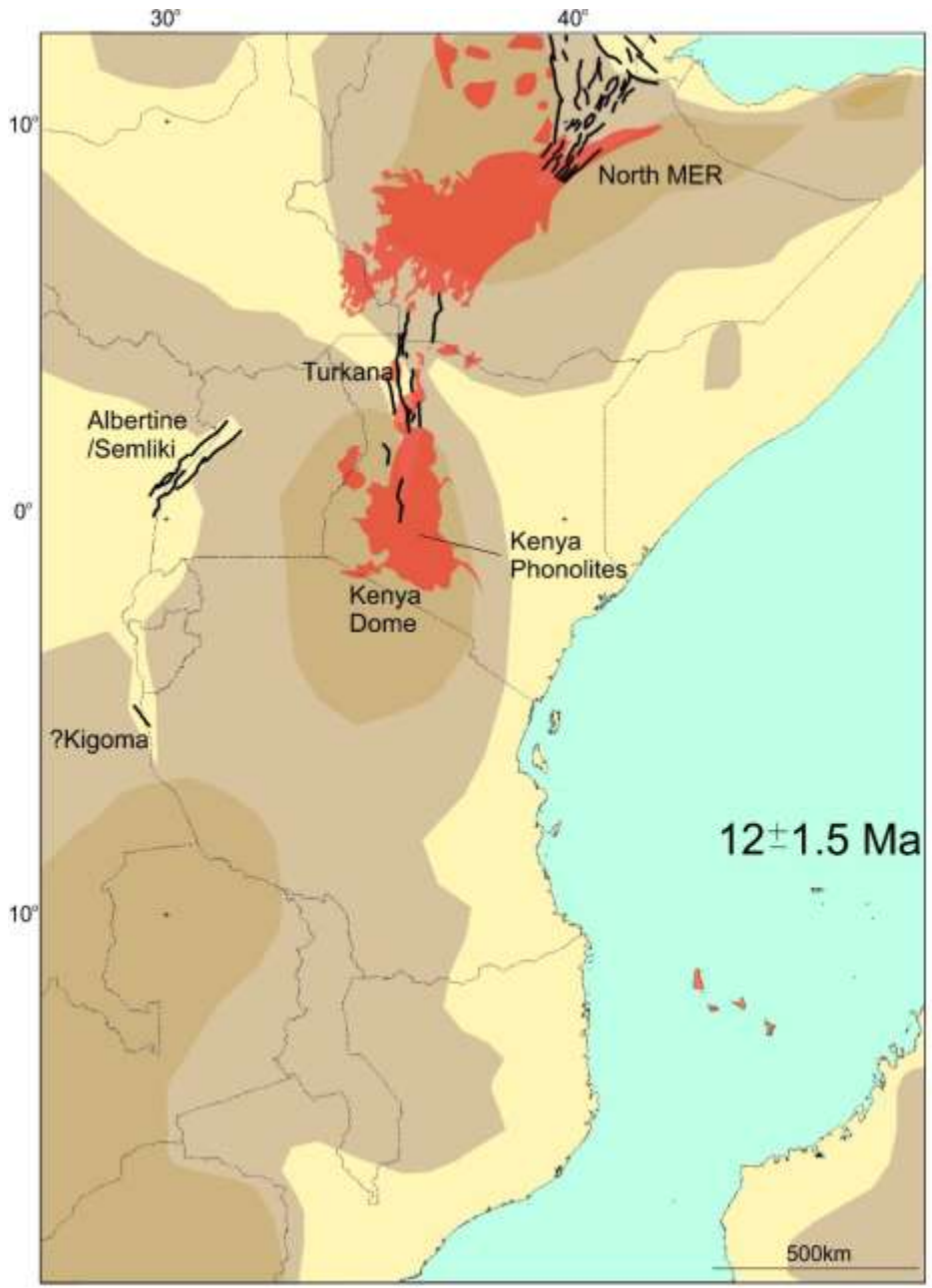
Development of EARS Rifts : Oligocene



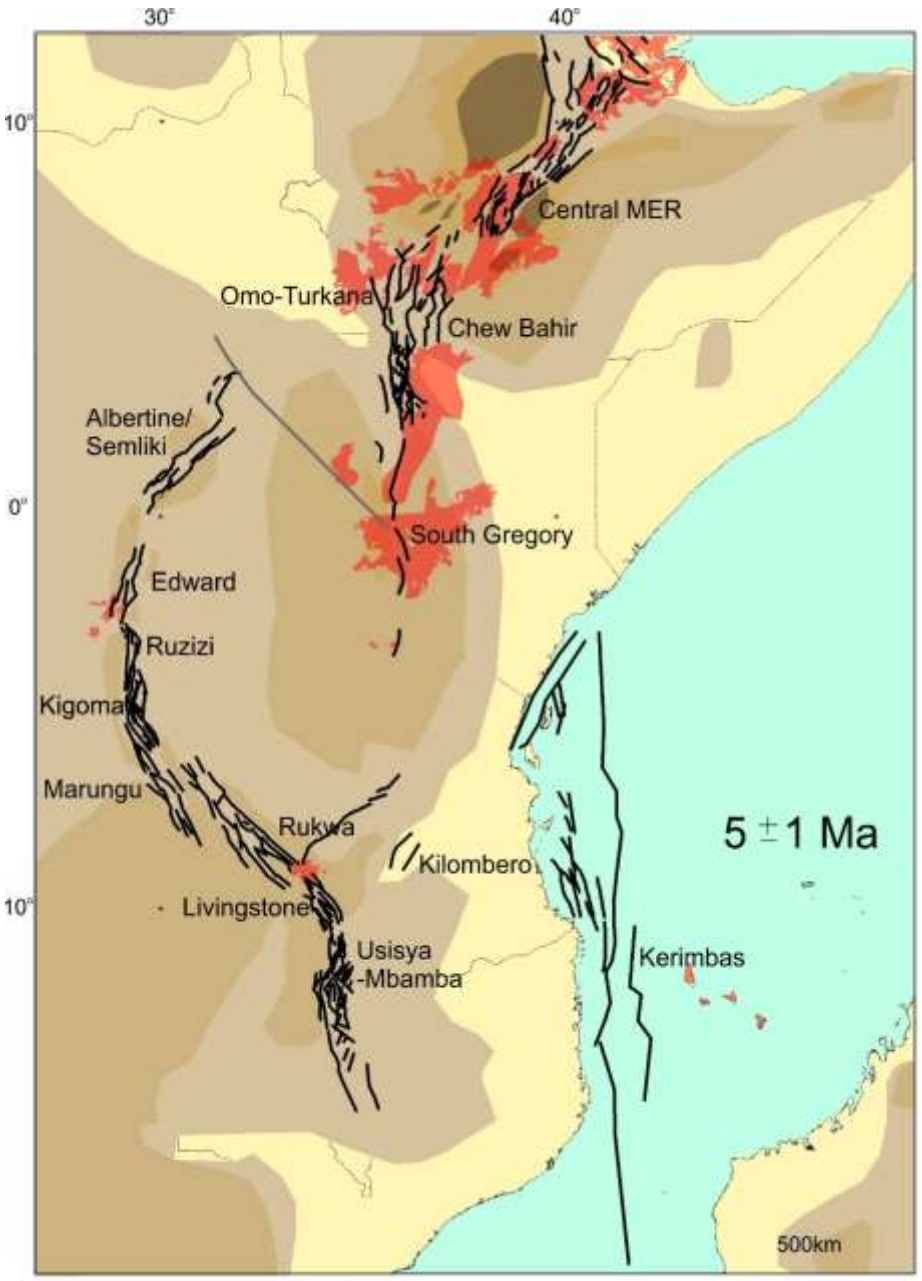
Development of EARS Rifts : Early Miocene



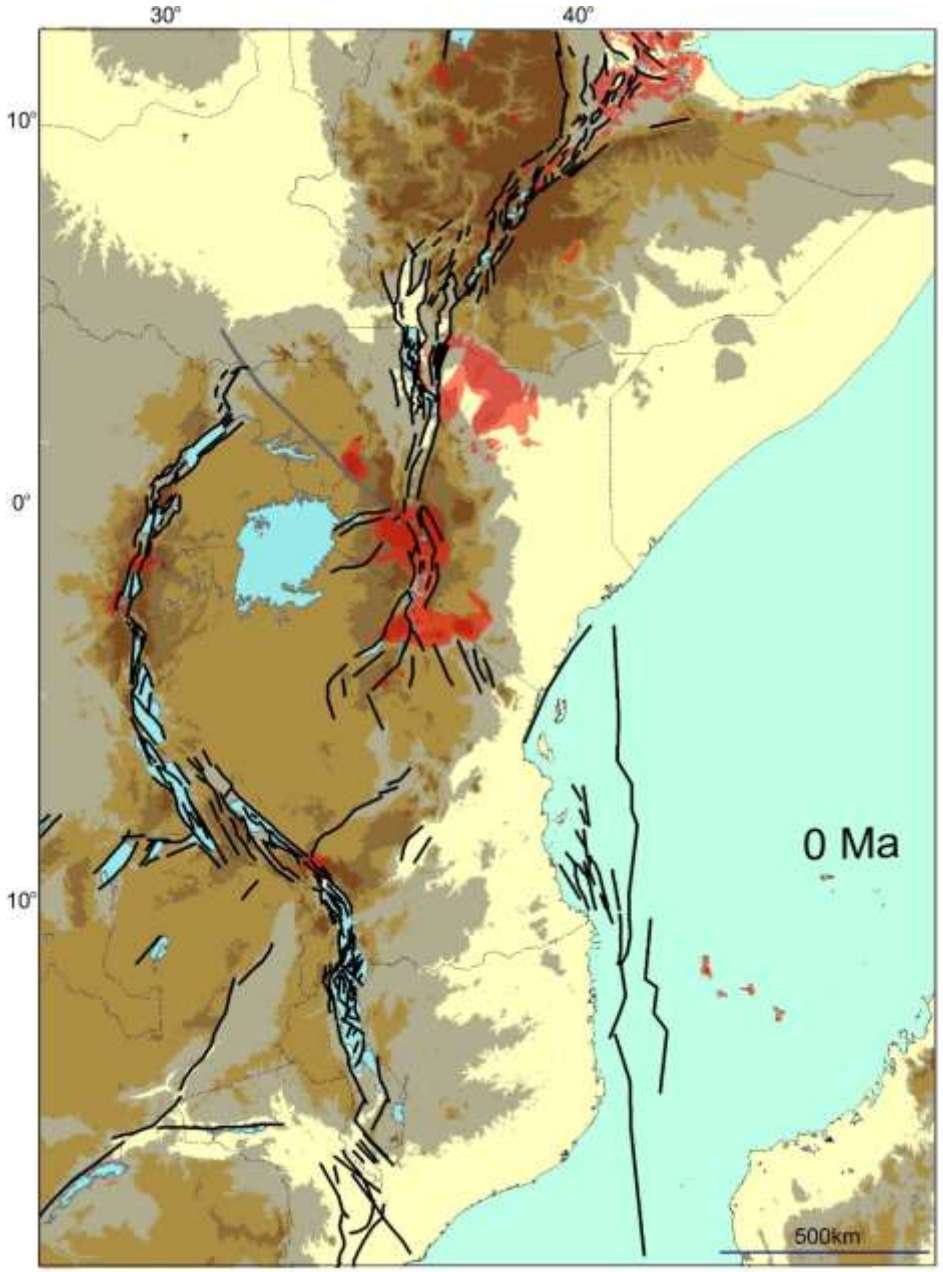
Development of EARS Rifts : End Mid Miocene



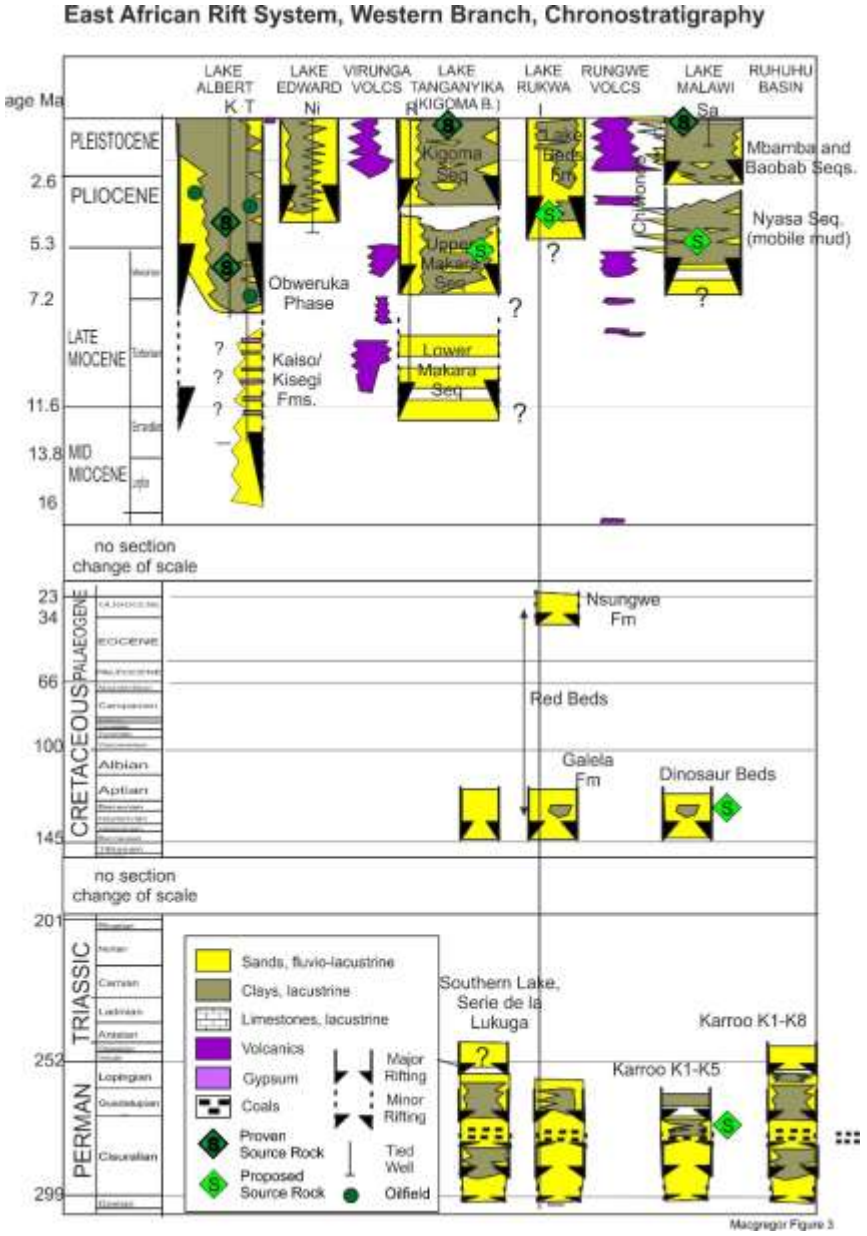
Development of EARS Rifts, Base Pliocene



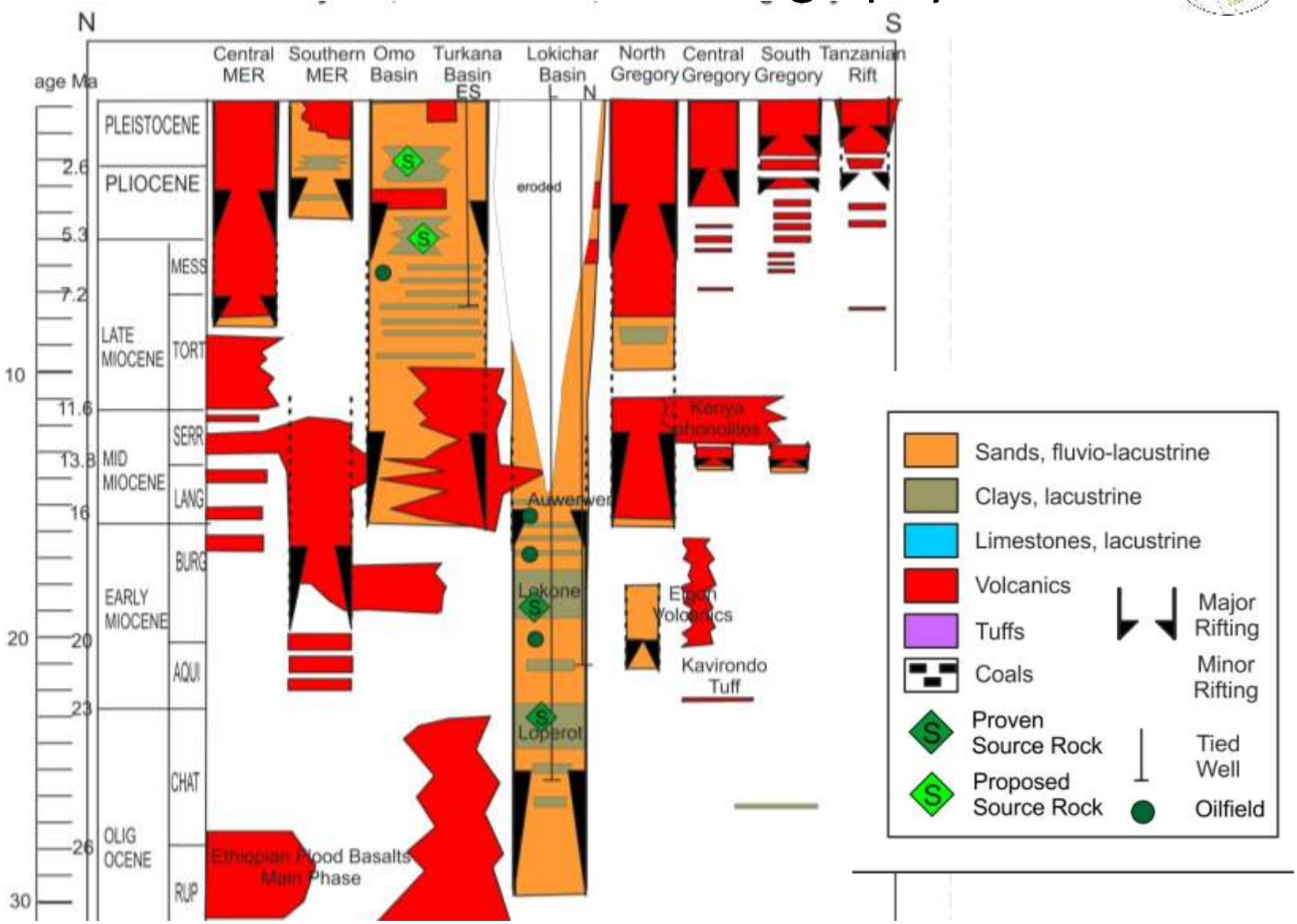
Current Development of EARS Rifts



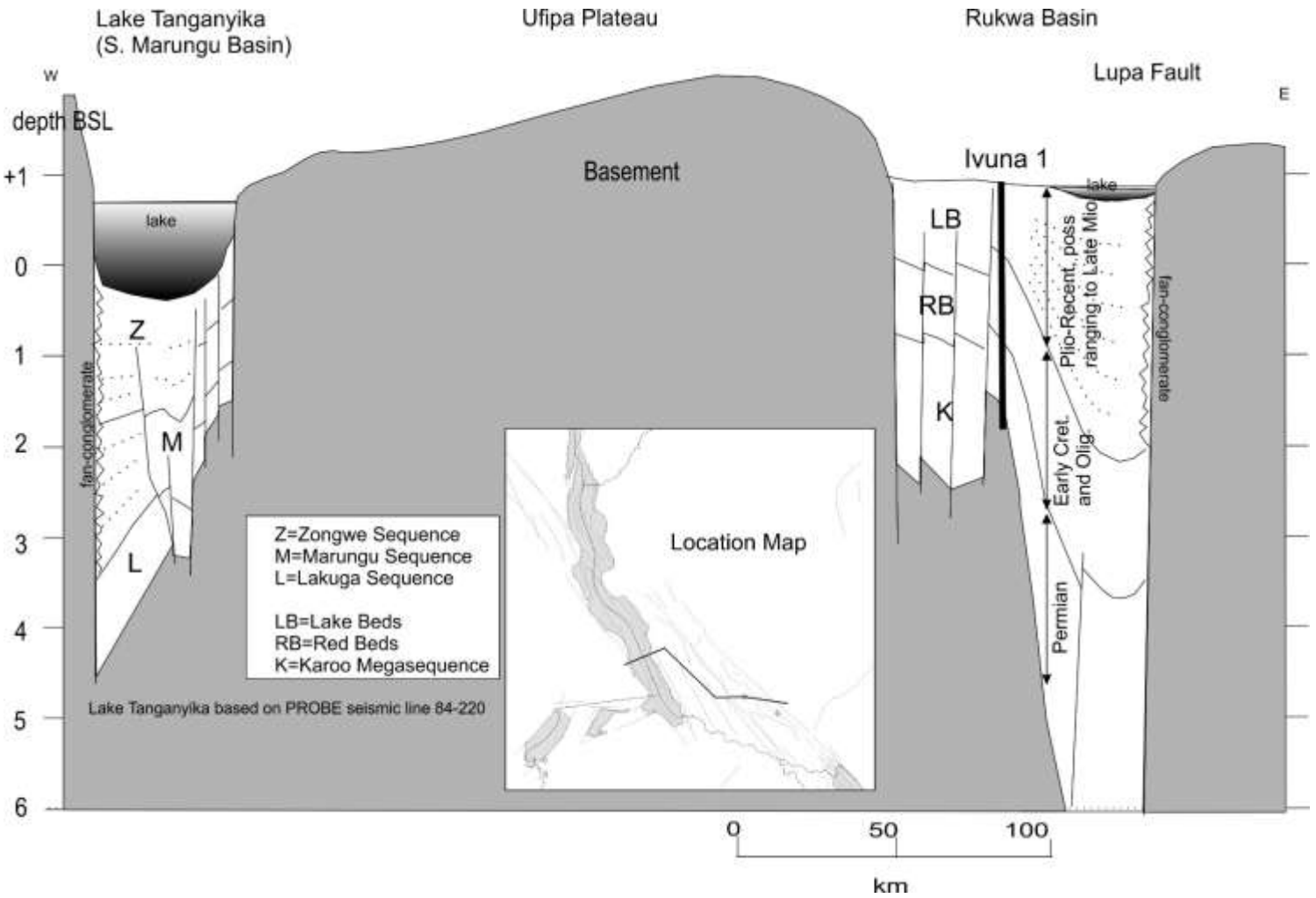
Albertine Basin and Western EARS Stratigraphy



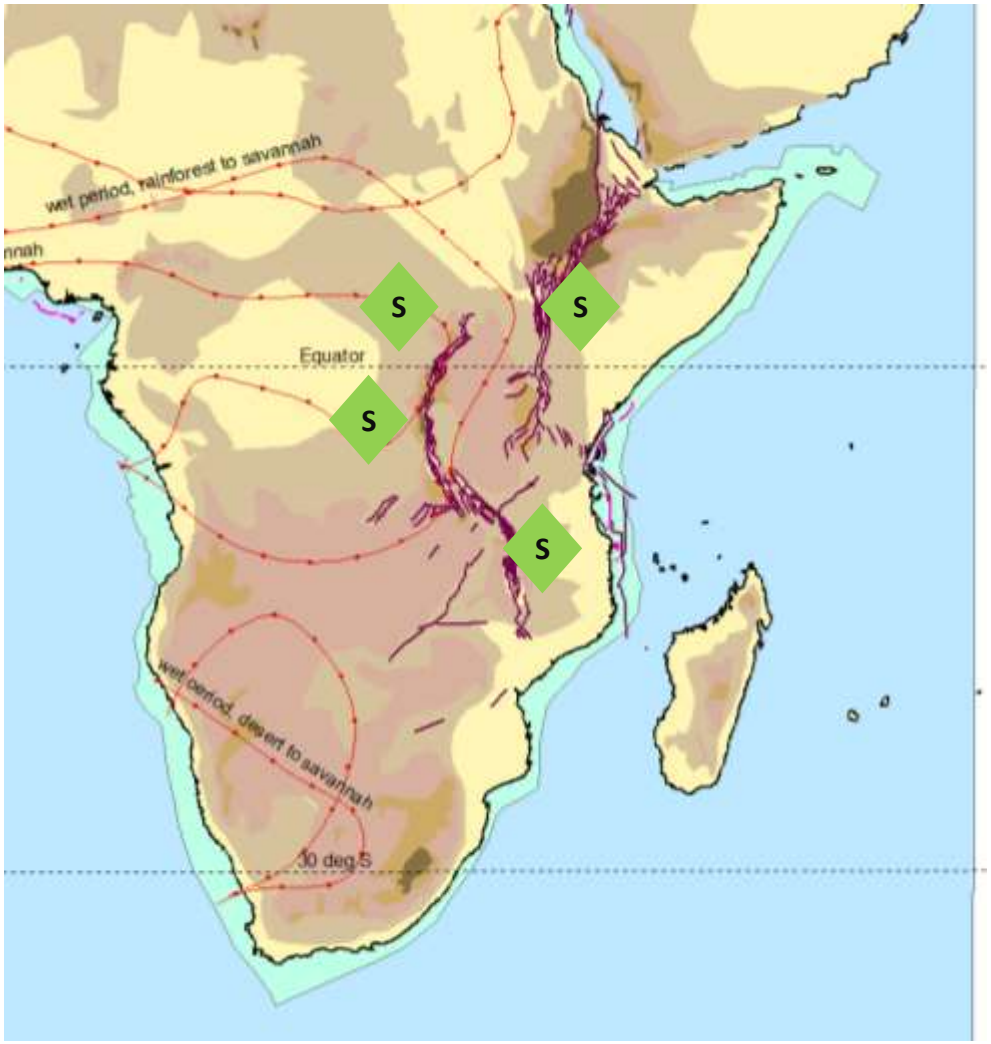
Eastern Branch EARS Stratigraphy



Southern Lake Tanganyika and Rukwa Basin

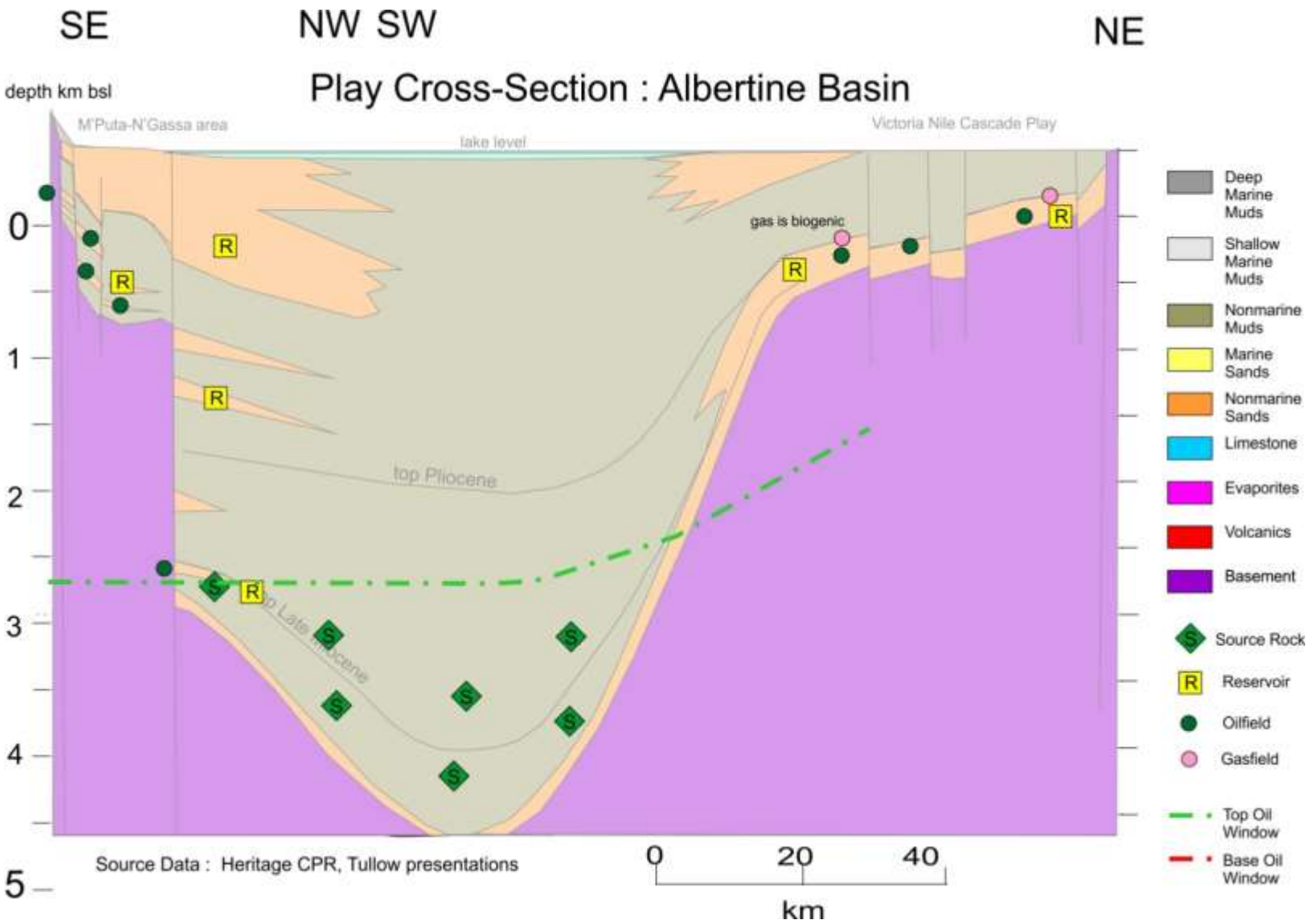


Regional Source Rocks : Neogene Lacustrine

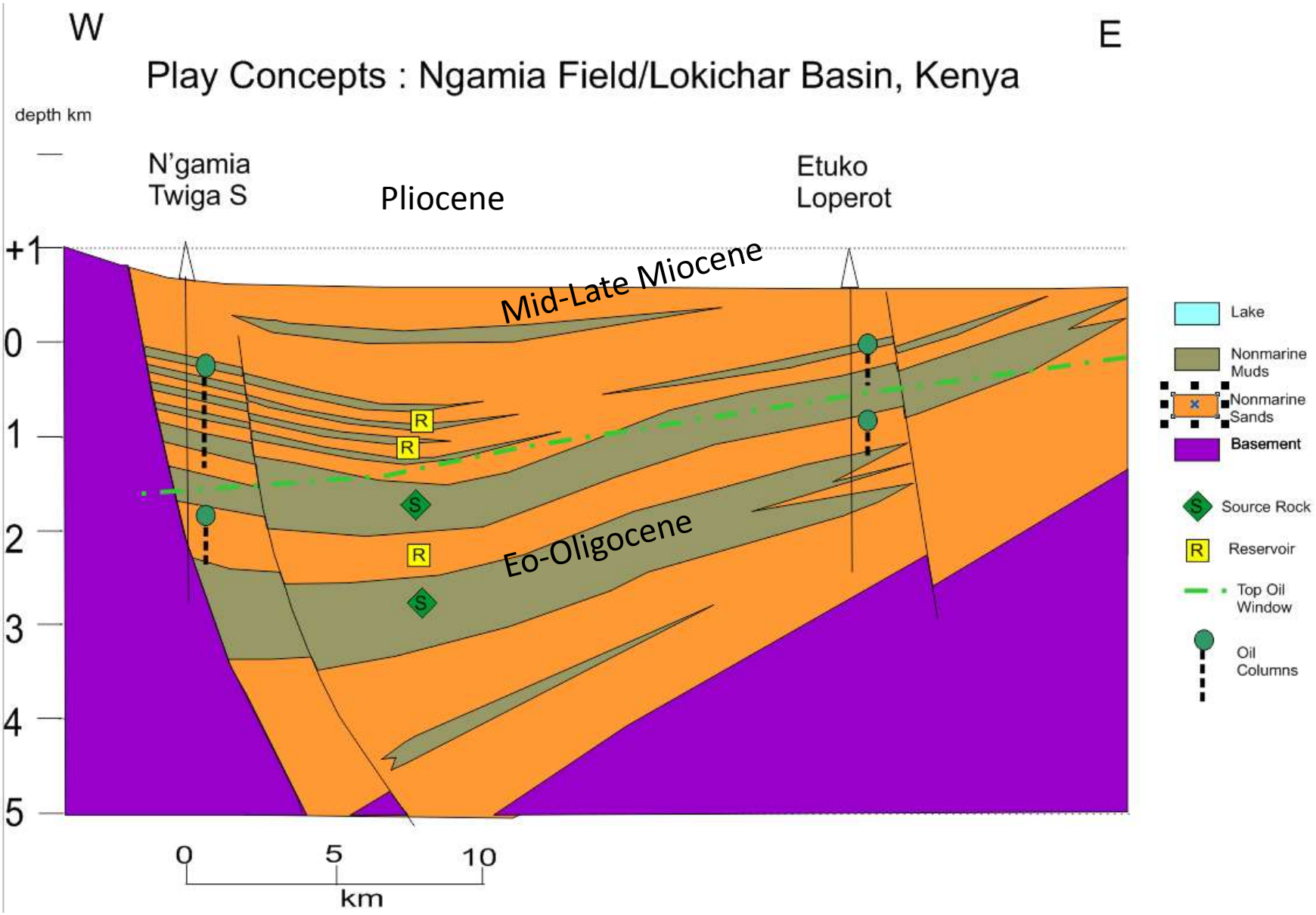


- Source rocks at Present Day in rift lakes deeper than 100m, becoming oil prone at circa 150-200m (Lake Tanganyika, Huc)
- Form in peak subsidence phases of EARS – Late Olig-Ey Mio and Messinian- Recent
- Some shallower examples, e.g. Lake Bogoria, Kenya: Lake Victoria
- Buried examples include Lake Albert and Lokichar Basin
- Typical Values : 150m, TOC 2-10%, HI 200-600, Type I-II (Talbot, 2003, Kenya)

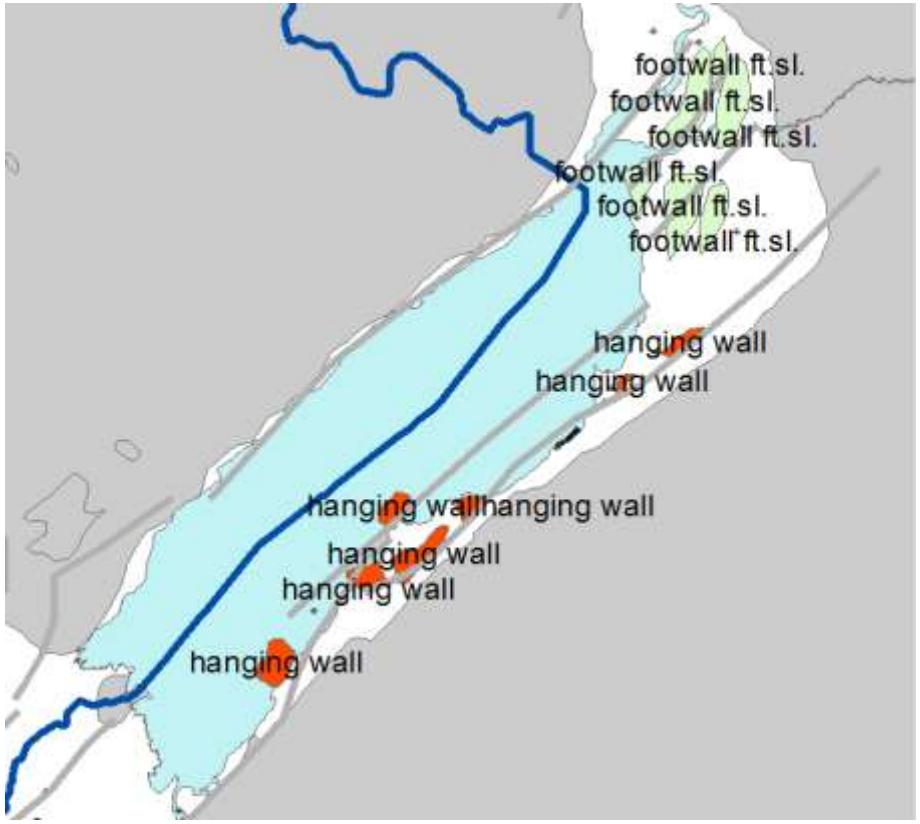
Albertine Basin : Petroleum Systems

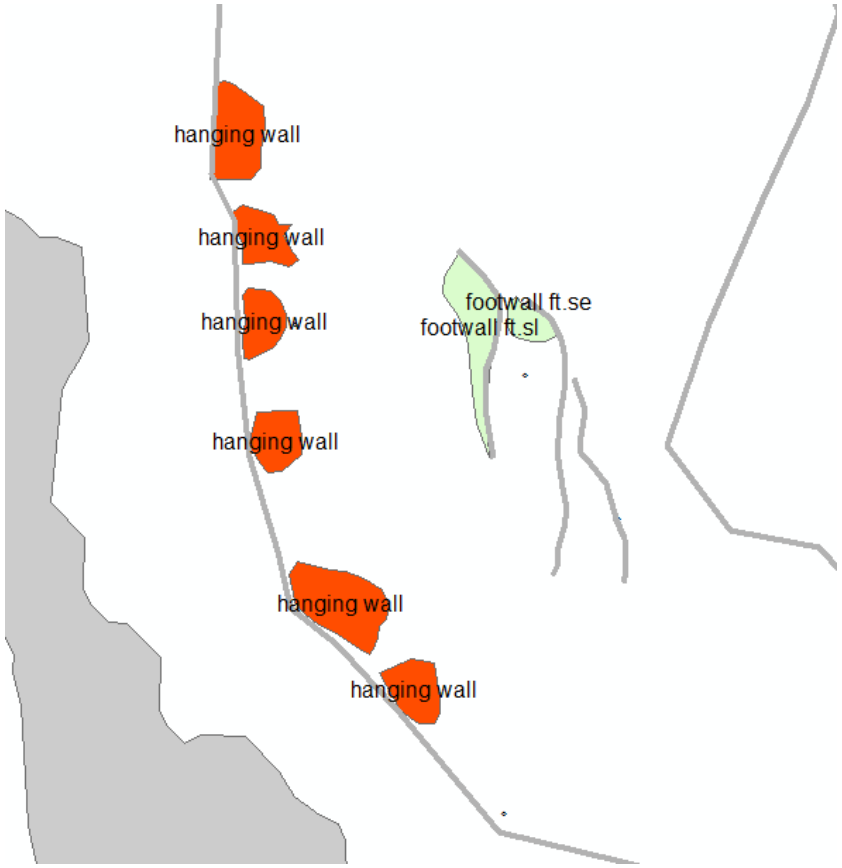


South Lokichar Basin Play Cross-Section

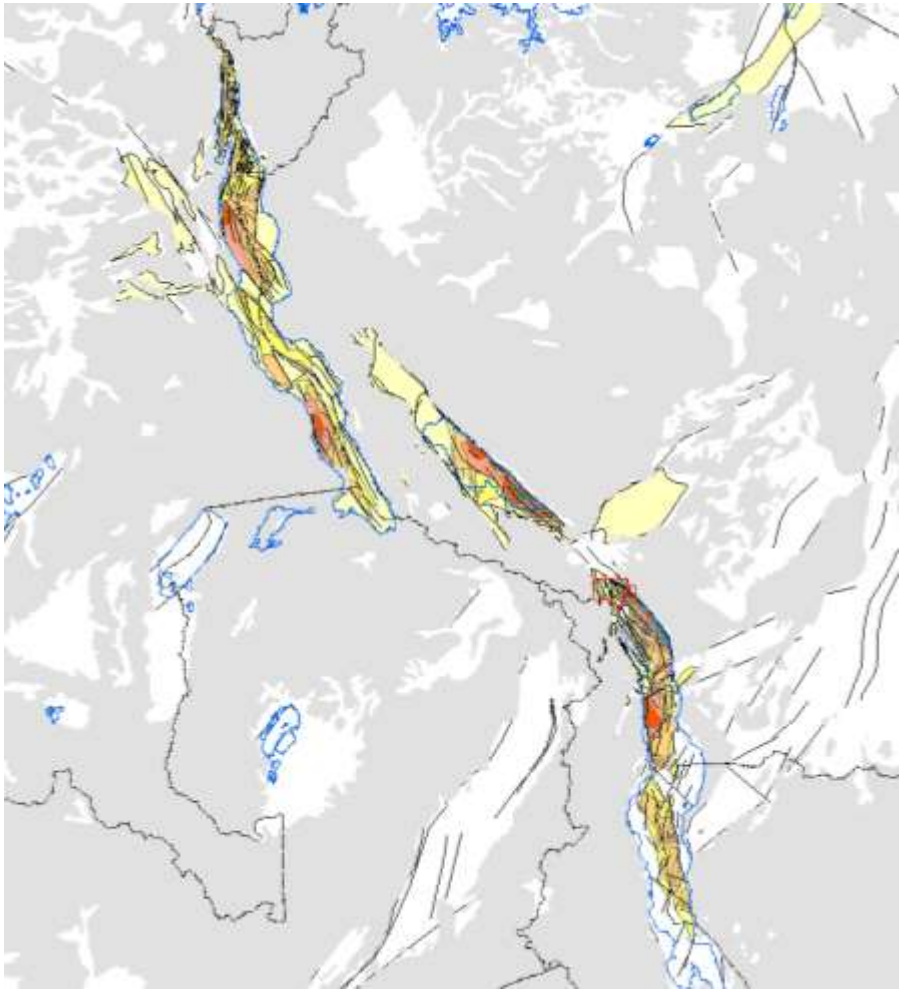


Lake Albert and Lokichar : Trap Types





EARS Frontier Basins : Western Branch



Tertiary (EARS) Rift Systems: Key Regional Technical Issues

- Res pr : Fluvial sands during filled phases and on faulted basin margin
- Res q : Provenance controlled – marginal where volcanic association and deeply buried (predom in Eastern Branch
- So pr : Deep lacustrine source rocks during underfilled phases (predom in Olig-E Mio and Late Mio-Recent)
- So eff : Maturity controlled by depth and heat anomalies. Migration up to 40km known
- C (seal) : Petroleum system seems to be so young and active that otherwise poorly rated top and side seals are effective – silts, fault planes etc
- Traps: Downthrown traps versus basement and intrabasinal fault blocks with fault plane seals
- Preservation : Seemingly not an issue, with active faults still sealing!

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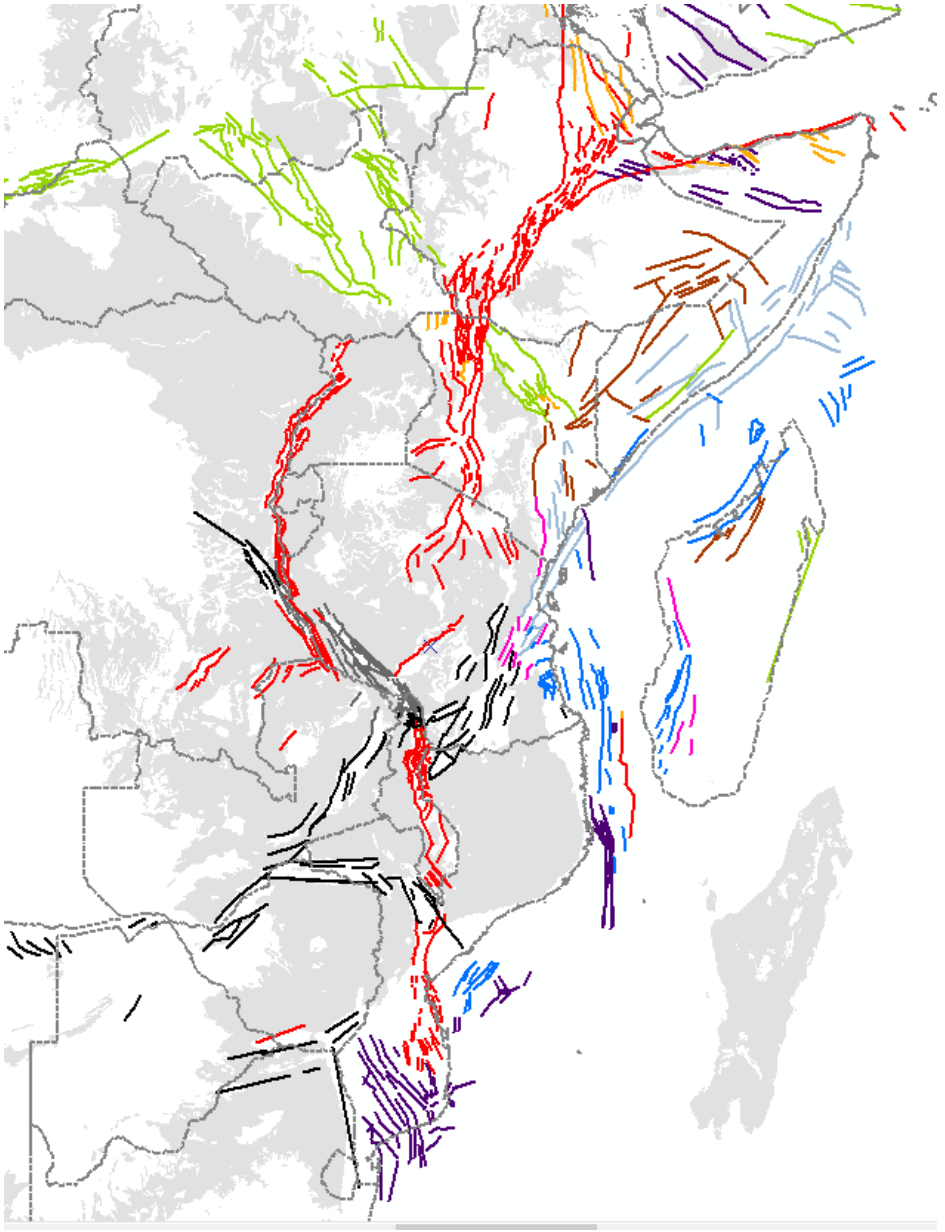
Main Ages of Mesozoic-Tertiary Rifting

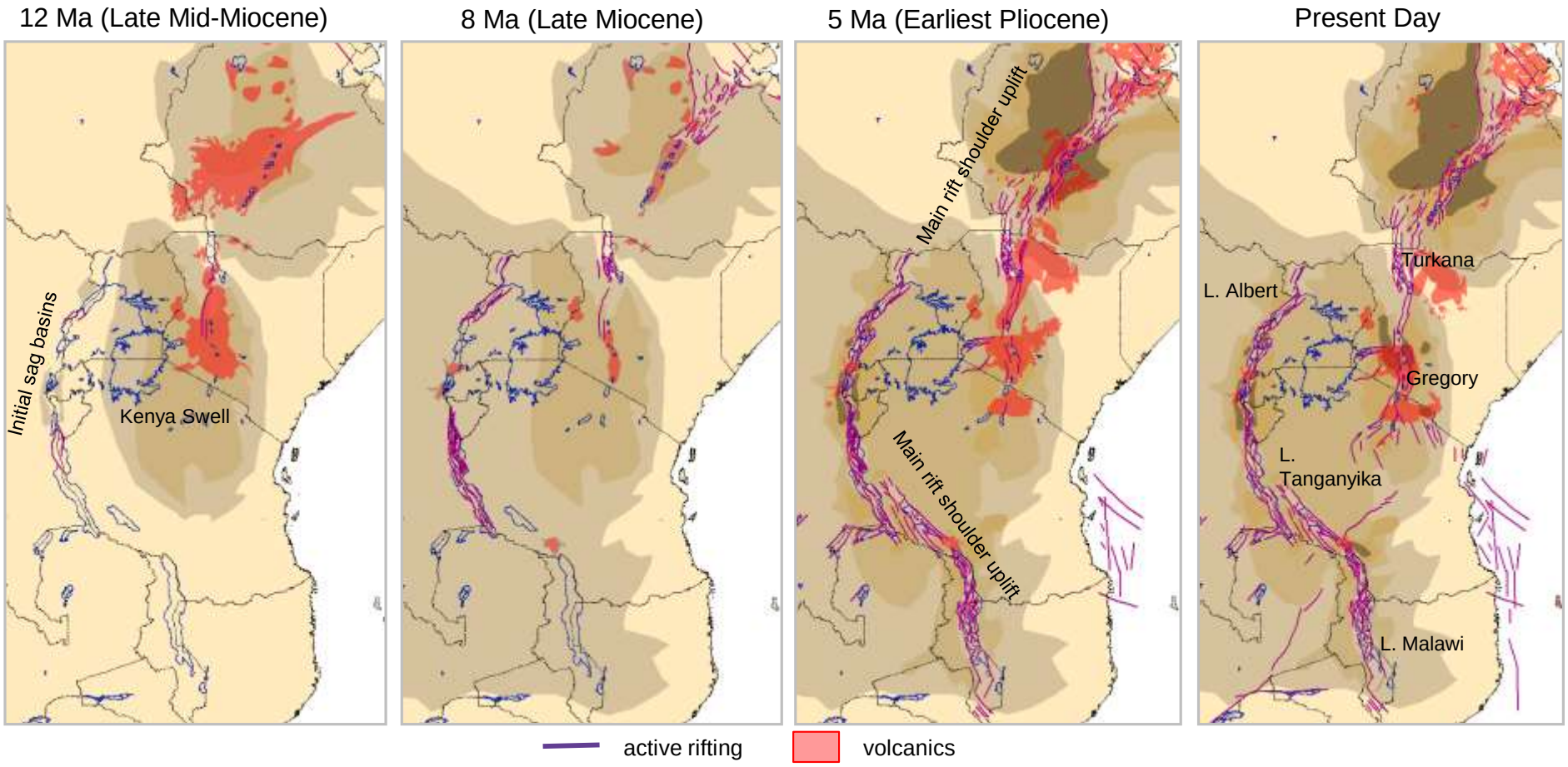


Summary (1) : Permian-Mesozoic

- Permian-Triassic (Karoo) Rifts
  - Along STASS shear system
  - Period of main rifting youngs northwards (from Mid Permian to Early Triassic)
  - Significant oil charge and seal issues
- Early Jurassic rifts along later coastal area
  - Often basinward of earlier rifts, main period of rifting in current offshore
  - Many reactivated and seen on Present Day bathymetry
  - Distribution of rifts and source rocks is key to charge model in offshore regions
- Late Jurassic Rifts
  - Nature of extension from Yemen into NE Africa much more complicated than expected
  - Pull-aparts along Davie Ridge, often inverted – source potential?
  - Well defined offshore South Mozambique but not onshore – frontier play
- Cretaceous
  - Multiphase
  - Anza is out of phase within CARS rifts and petroleum geology not related
  - Seems to be developing as minor gas province

Progressive Development of EARS: Mid Miocene to Recent Phase

Most prospective rifts, Rift has entered deep lacustrine phase
with overburden and heat sufficient to mature



Summary (2) : Cenozoic

- EARS is complex, very difficult to apply analogues
  - e.g. propagation can processed S to N as well as N to S

- East African Rift Phase 1 (EARS 1)
  - Commences Oligocene, peak in Early Miocene
  - Concentrated in Eastern Branch (minor in Rukwa), northern Kenya and southern Ethiopia
  - Type example = South Lokichar Basin
  - Early Miocene deep lacustrine conditions critical to prospectivity

- East African Rift Phase 2 (EARS 2))
  - Mid Miocene to Recent, peak in Plio-Holocene
  - Widespread, most EARS rifts – generally youngs to south
  - Most vertical movements Plio-Holocene
  - Highly active charge systems allow siltstone and fault plane seals to be effective, creating less conventional traps