Institute of High Energy Physics
Chinese Academy of Sciences

The post-Jurassic tectonic and geodynamic evolution of Southeast Asia

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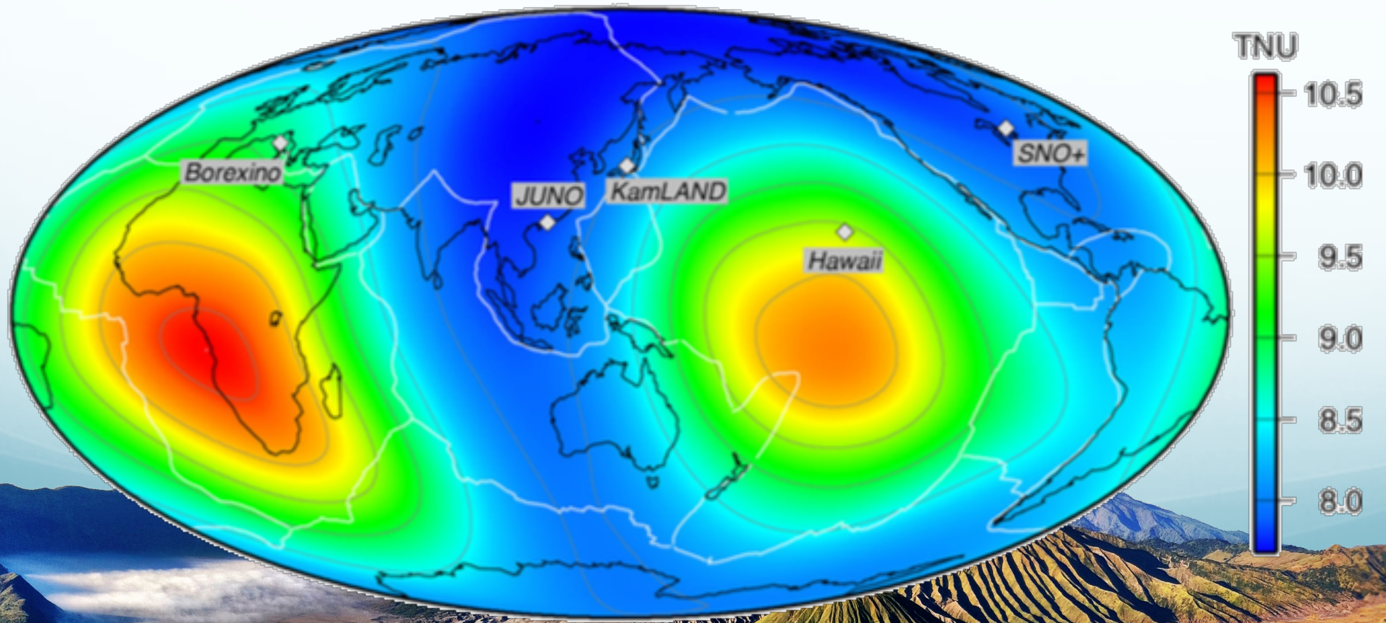
THE UNIVERSITY OF SYDNEY

EarthBYTE
Building a Virtual Earth

BGH

Overview

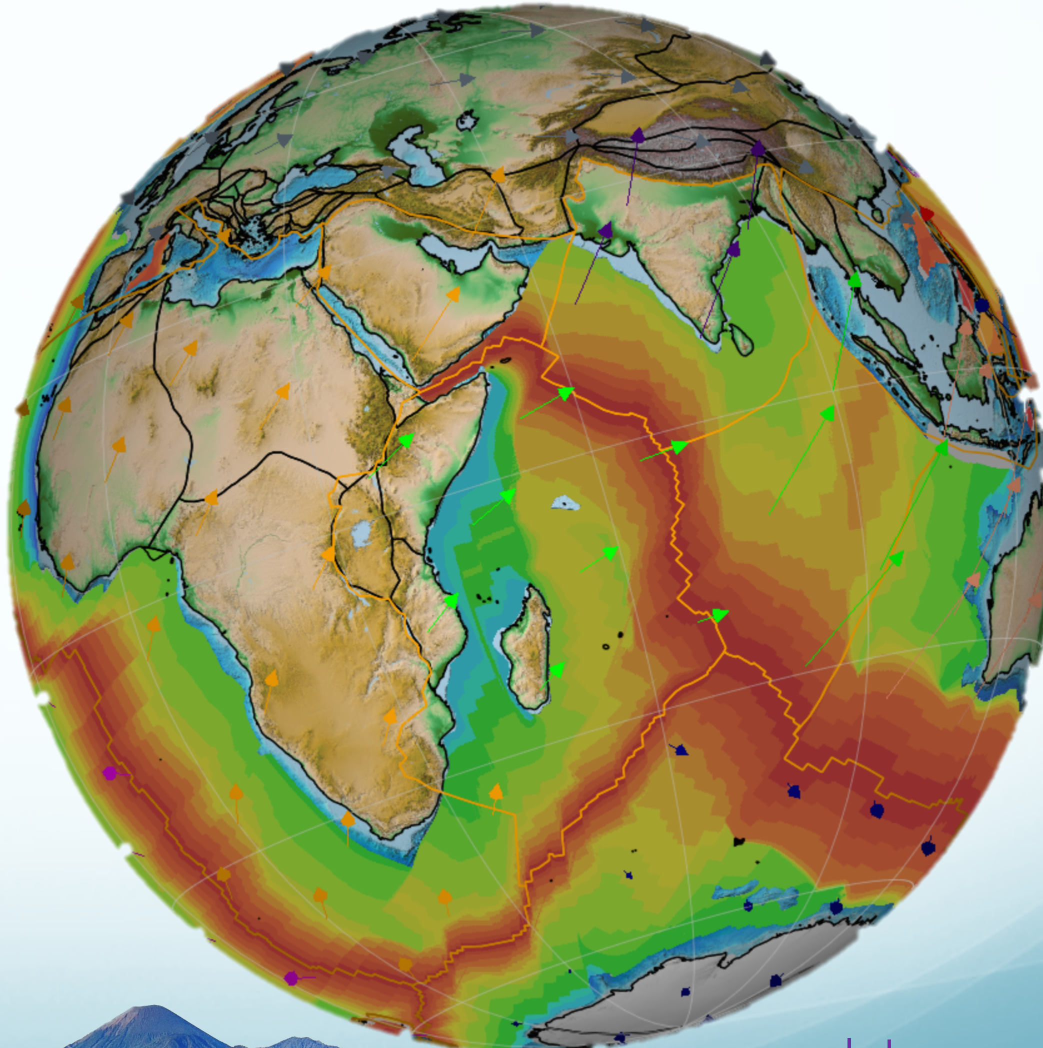
- Global and regional plate tectonic reconstructions
- Link to mantle convection
  - Lowermost mantle structure, Primordial mantle reservoirs?
- Evolution of the South China Sea margins in the regional context
  - Crustal extension, driving forces, etc.



Sramek et al. (2013)

Plate reconstructions in GPlates

- Digital, community models such as Seton et al. (2012), and Muller et al. (2016), etc. in GPlates
  - Magnetic picks, fracture zones and hotspot chains from oceans
  - Geological and geophysical constraints on the continents



www.gplates.org

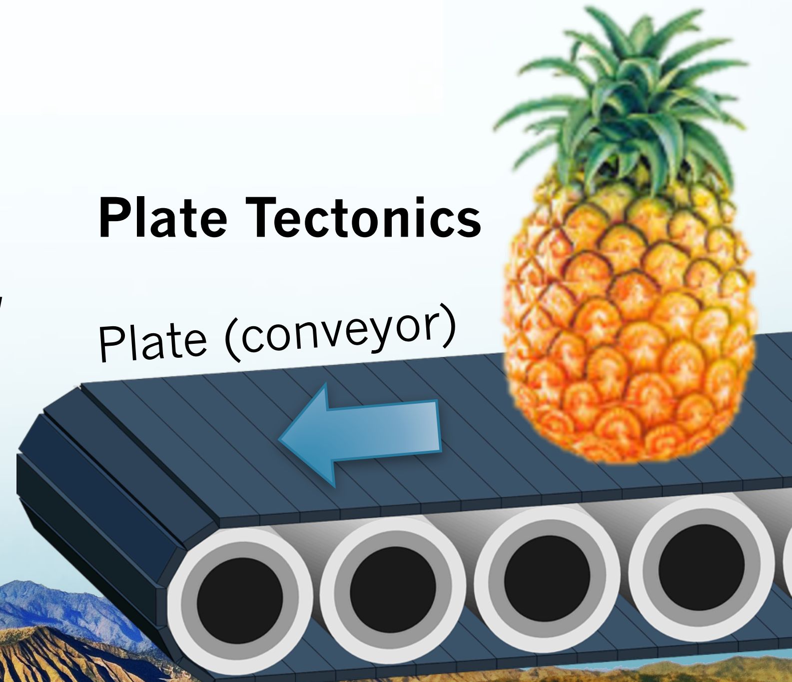
- **"Classical" plate reconstructions** are typically snapshots, with no plate boundaries, and invoke **"continental drift"**
- **Modern plate reconstructions** use seafloor spreading histories and **plate tectonic principles**, with evolving plate boundaries

Continental Drift

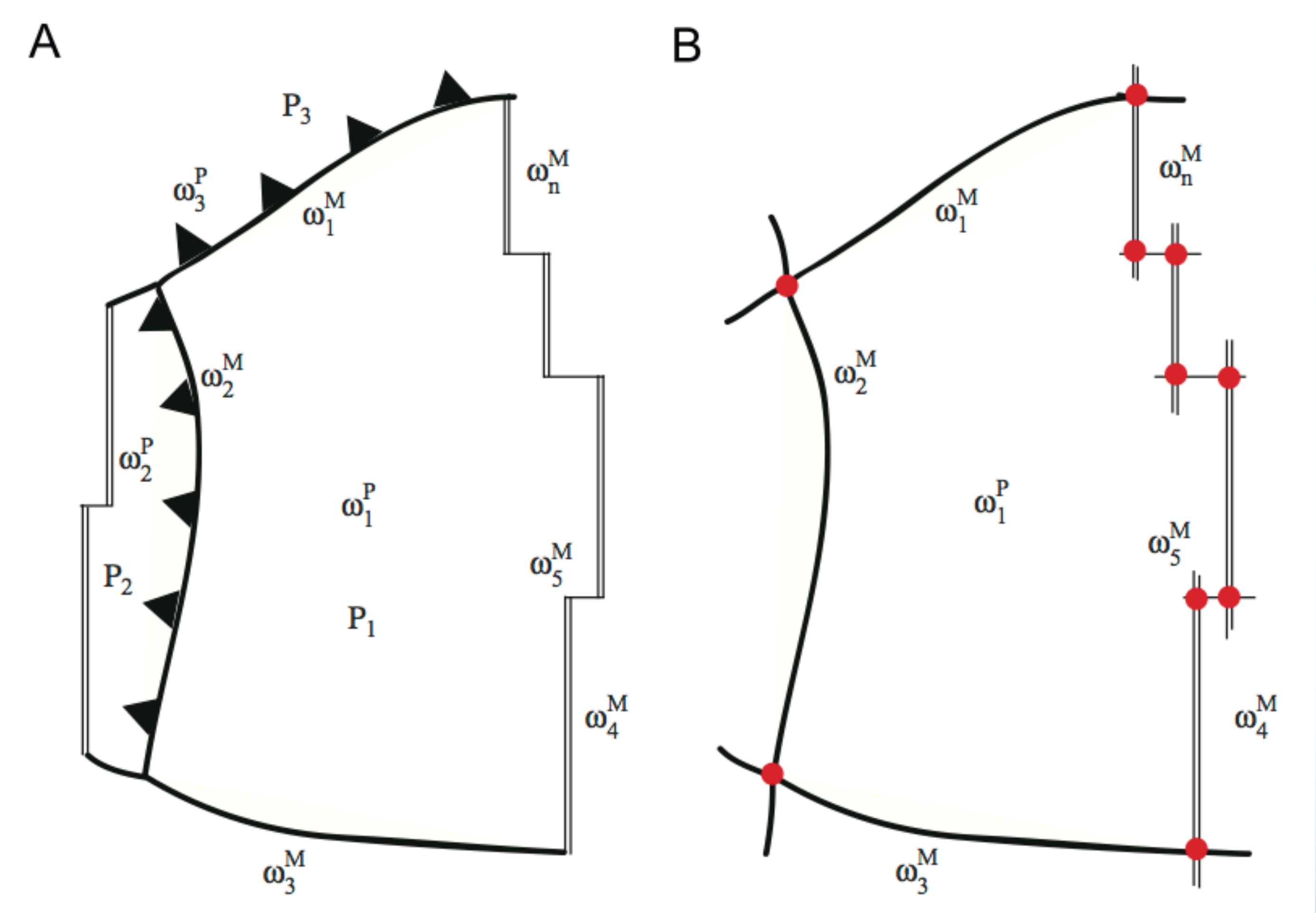
"Ice Age" (Fox)

VS.

Plate Tectonics



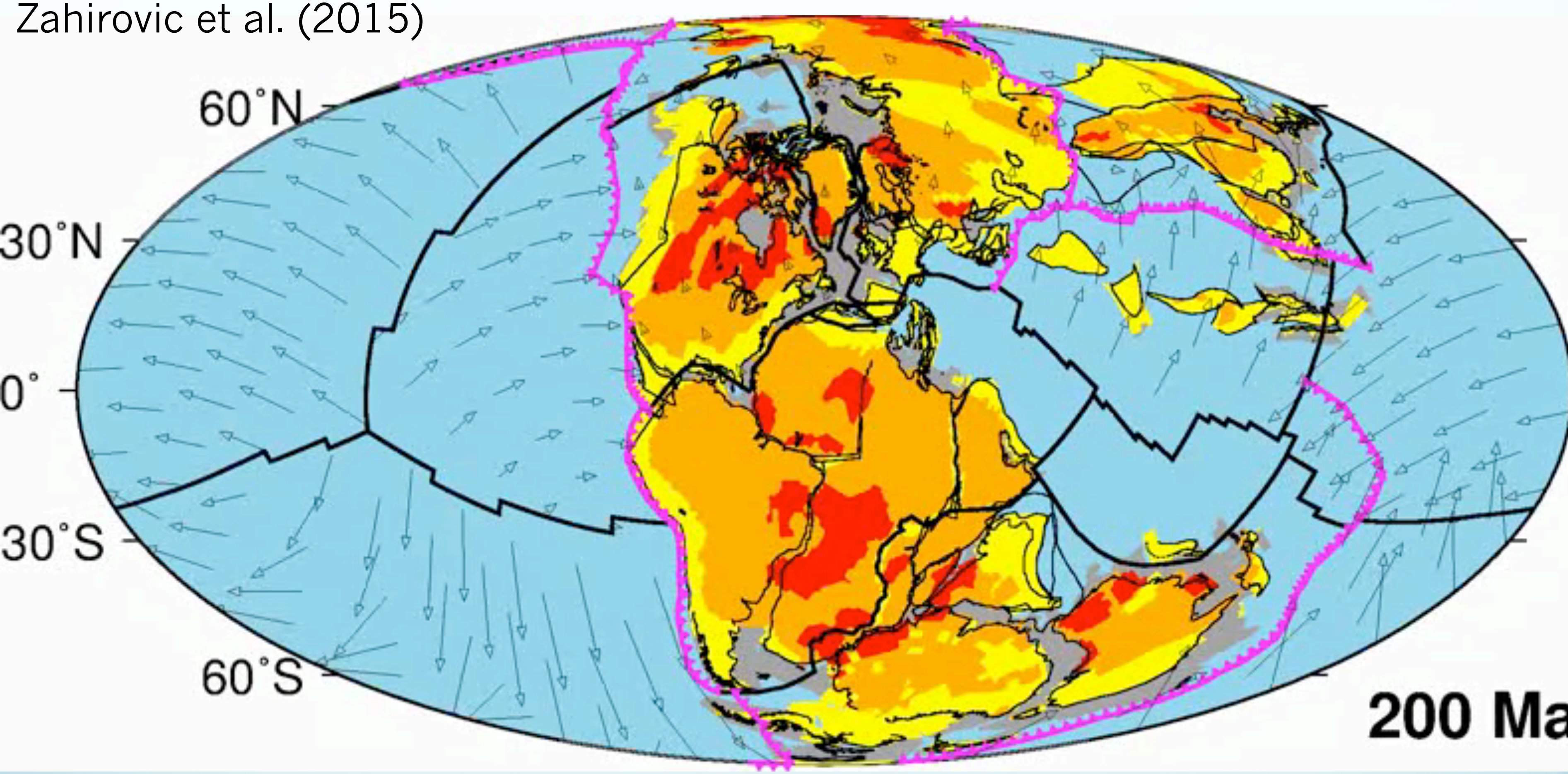
Evolving plate topologies in GPlates



Gurnis et al. (2012)

Plate Reconstructions

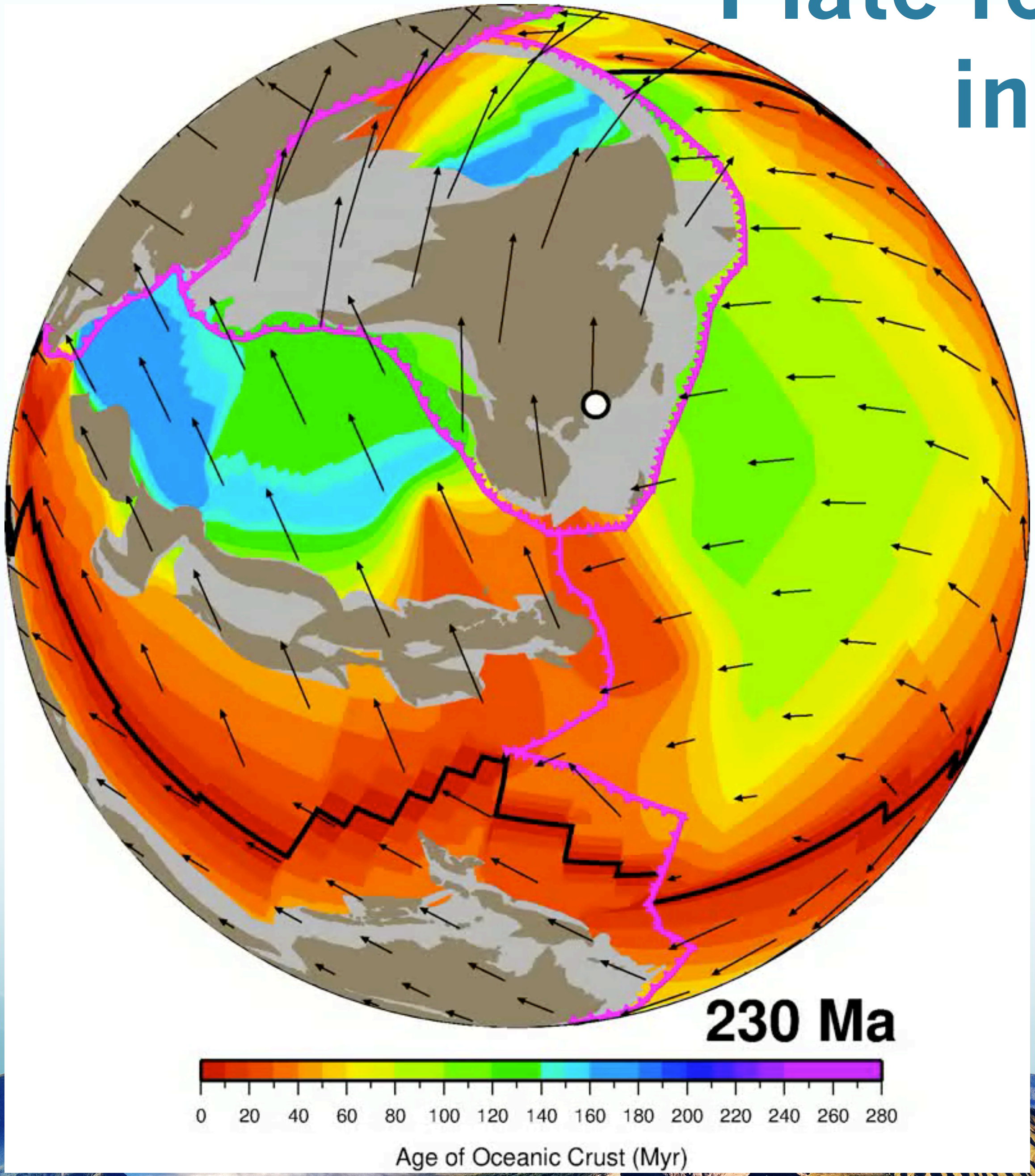
Zahirovic et al. (2015)



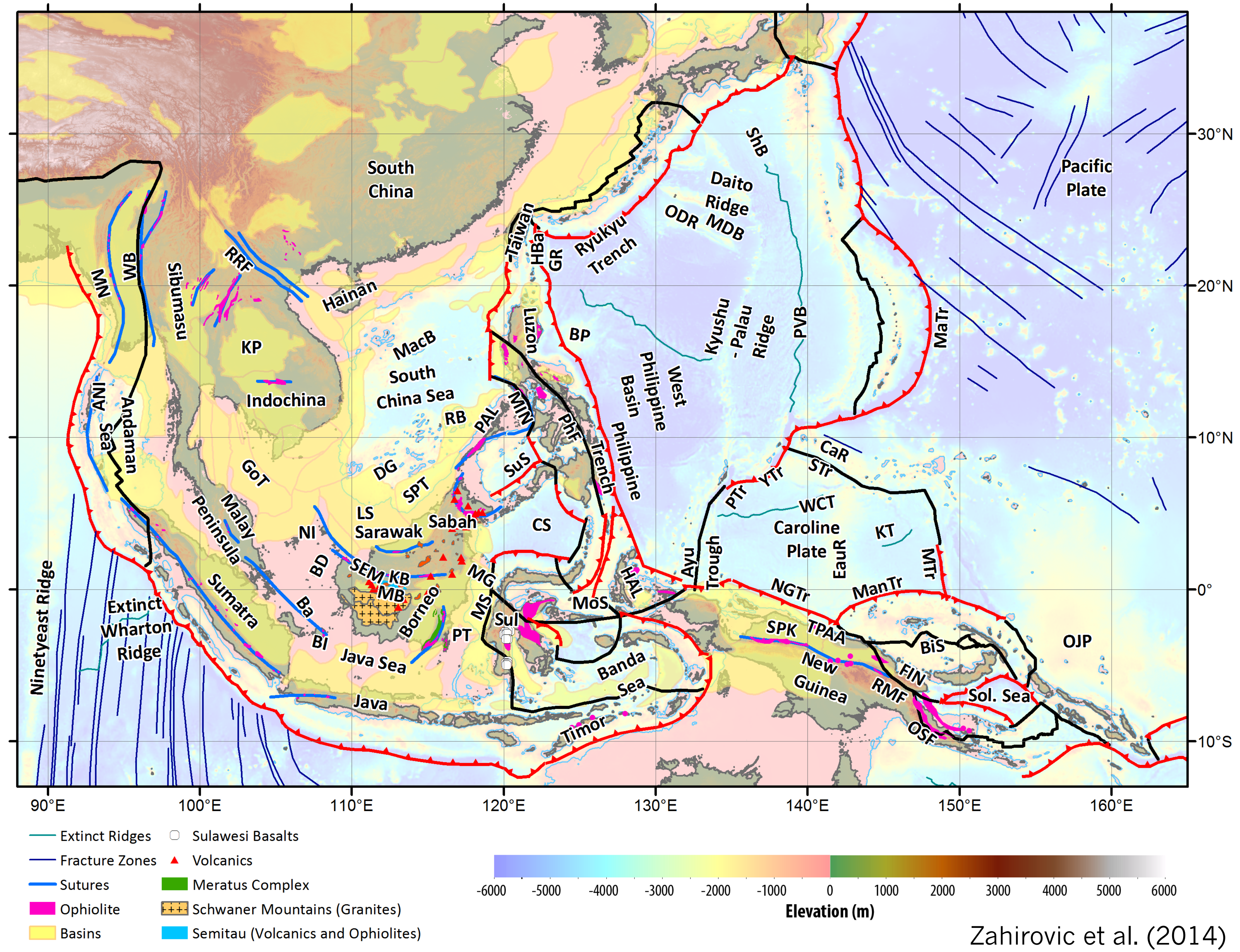
Continental Lithosphere
Artemieva (2006)

Zahirovic et al. (2016)

Plate reconstructions in GPlates

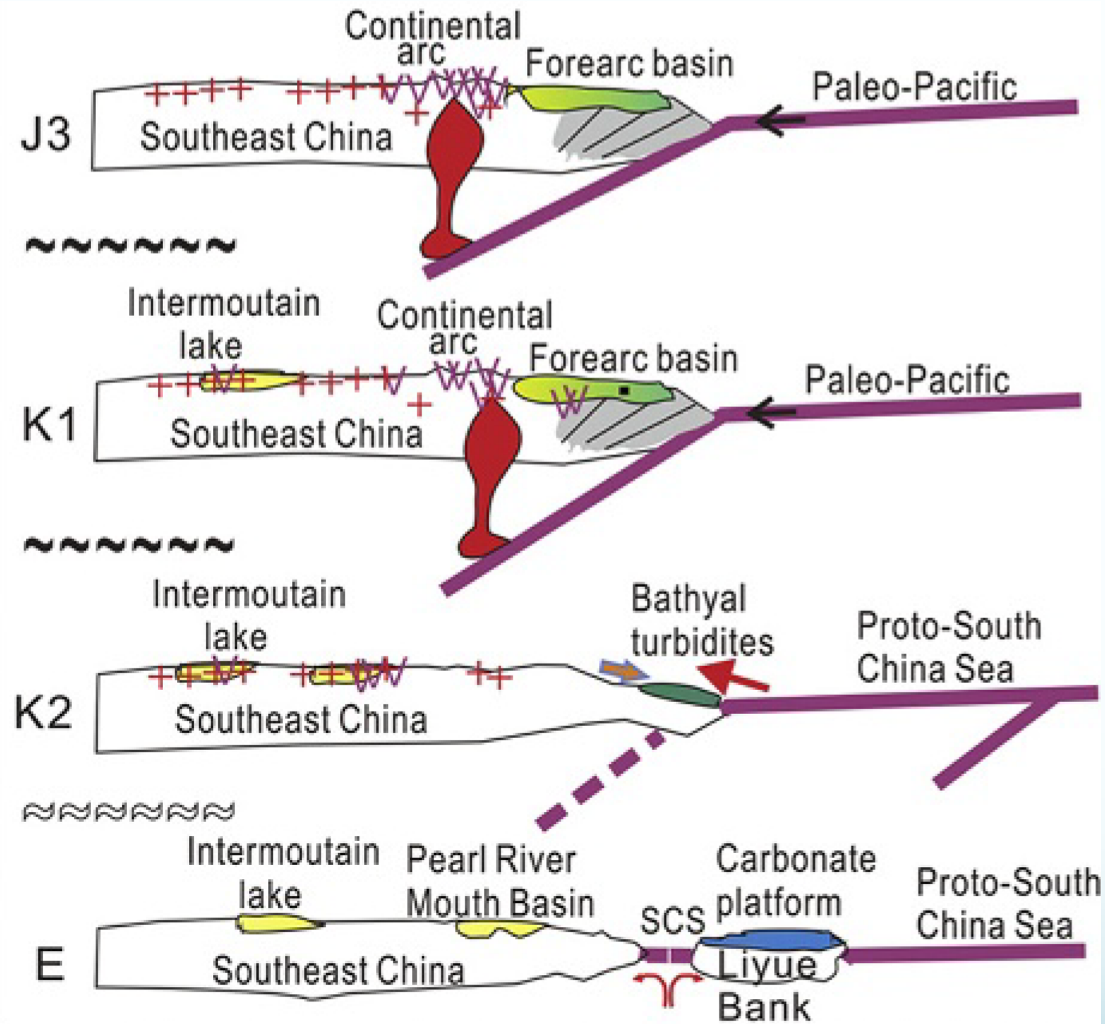


- Evolving plate boundaries
- Plate velocity field
- Oceanic age-grids
- Models released in digital format enabling modification and improvement in GPlates
- Plate motions as recorders of past mantle convection



Zahirovic et al. (2014)

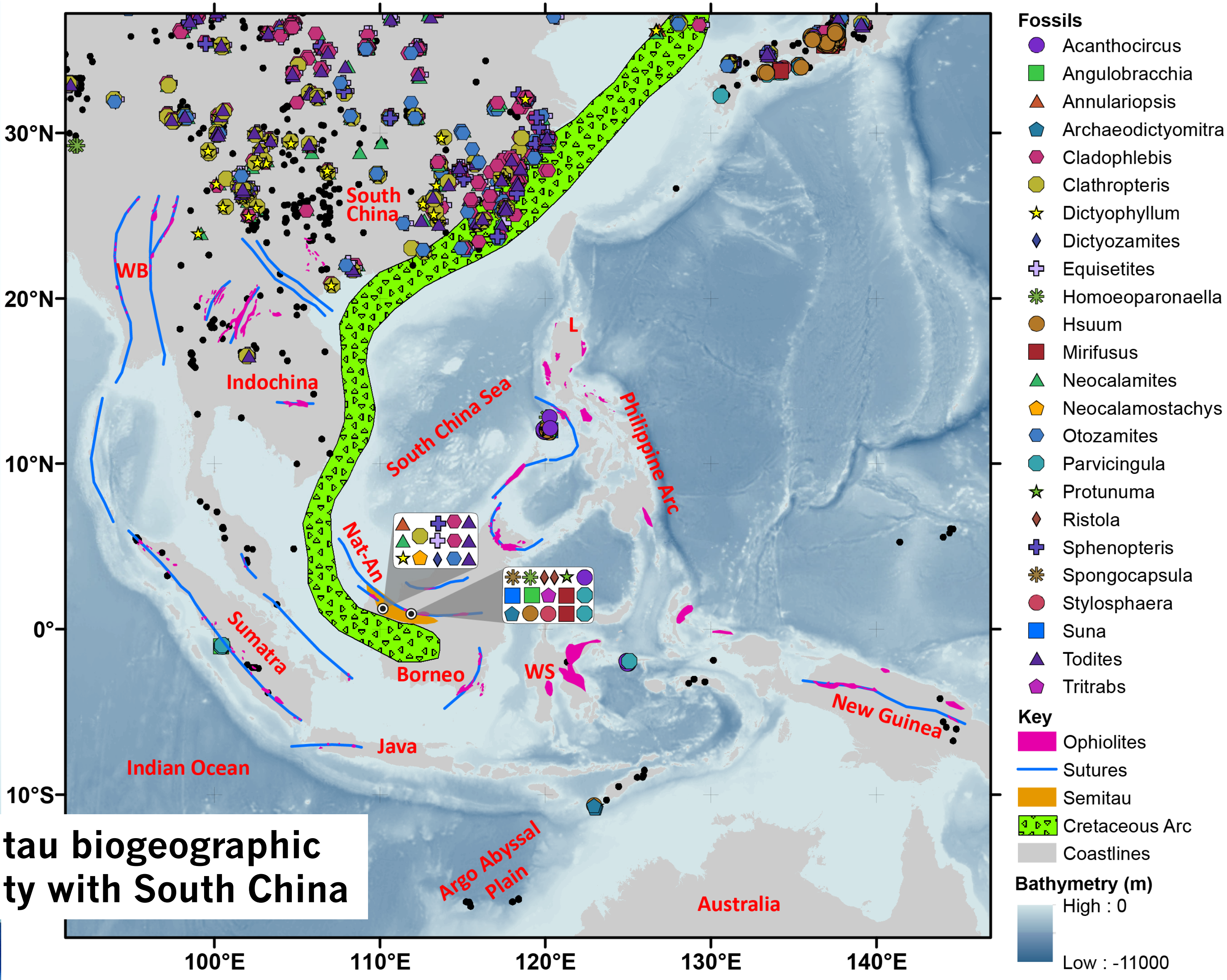
Asian active margin



Shi and Li (2012)

- A number of models propose Andean (flat slab?) subduction along East Asia in the Jurassic and Cretaceous (~200 to 65 Myr ago)
  - Foundering slab in the transition zone?
- Switch to back-arc and intra-oceanic subduction style from Late Cretaceous (~100-65 Myr ago)
  - Initial extension and lithospheric stretching

Triassic-Jurassic (~250-145 Myr ago) fossil occurrences: Paleobiology Database



Semitau biogeographic affinity with South China

Zahirovic et al. (2014), Honza and Fujioka (2004)

Proto South China Sea

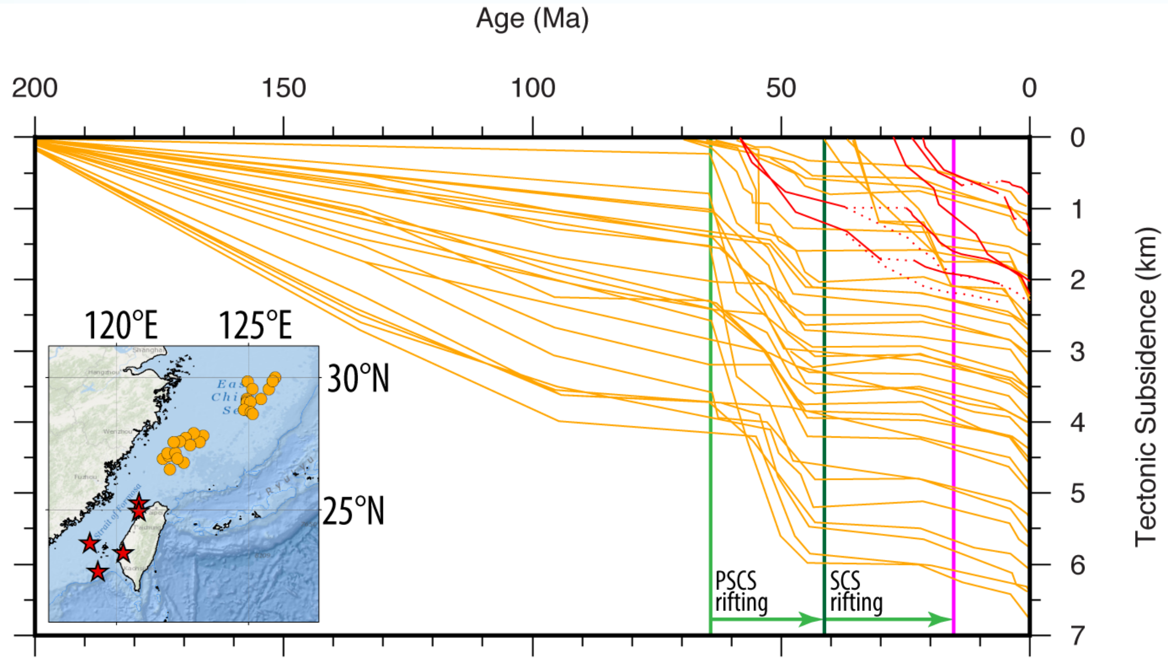
- South Palawan and Mindoro basement have China margin affinities

- Mindoro/Amnay Ophiolite (I): ~59 Ma, K-Ar (Faure et al., 1989)
- Supra-subduction zone affinity suggest **BACK-ARC** (Izanagi rollback)
- Obducted onto Luzon at ~15 Ma

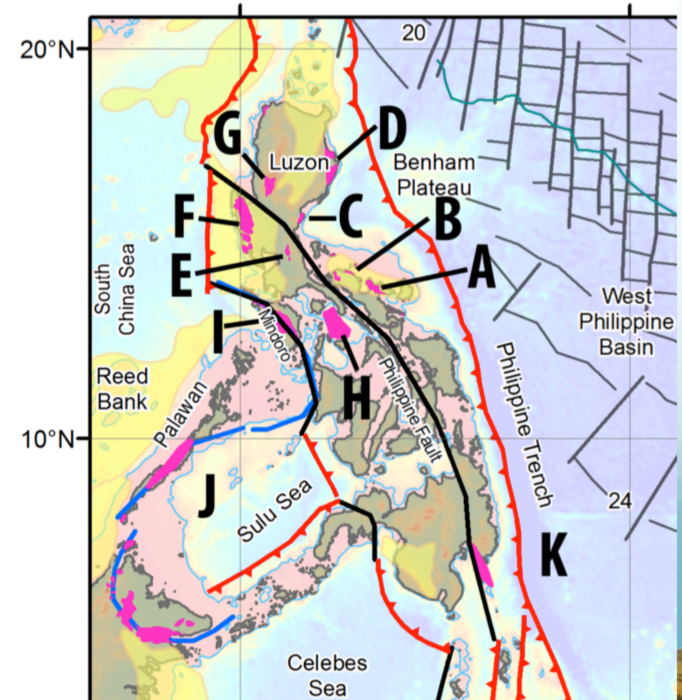
- Onset of rapid tectonic subsidence from ~65 Ma

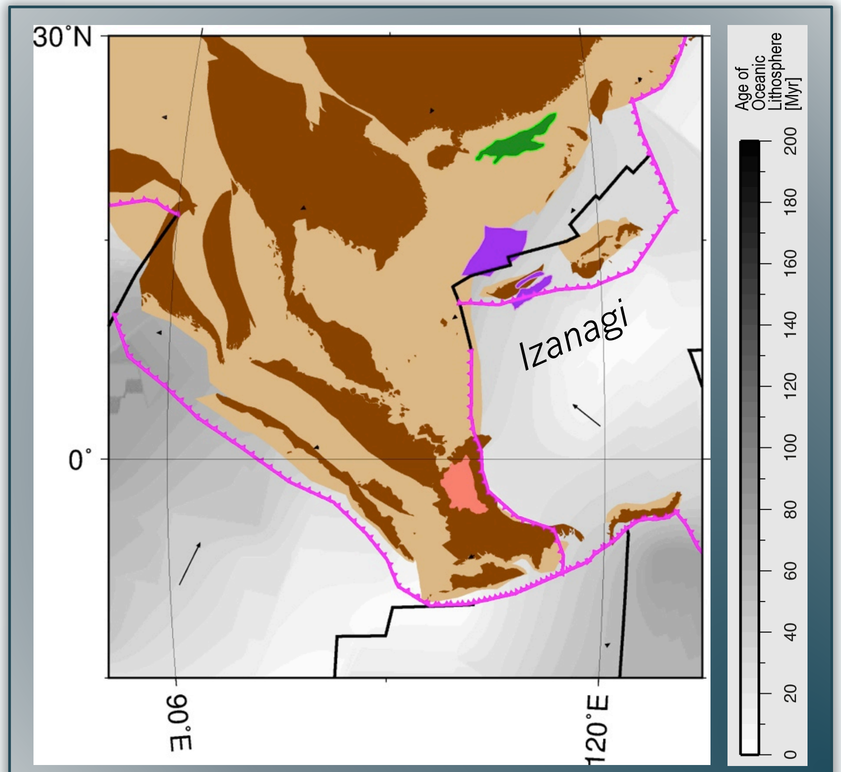
- Collision of Semitau/Luconia with Borneo: early-mid Eocene Sarawak Orogeny (Hutchison 1996, Fyhn et al. 2010)

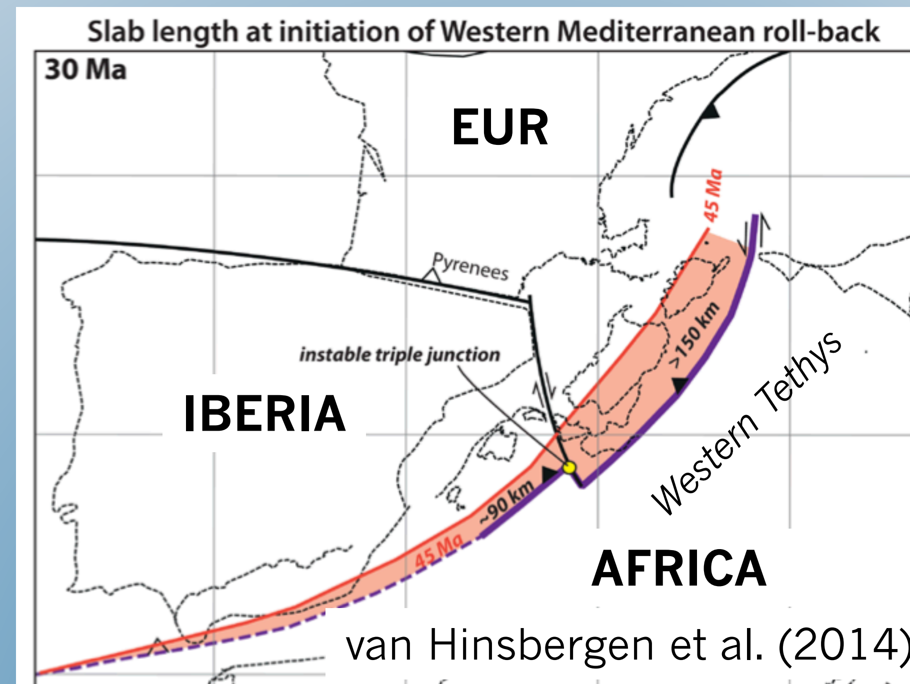
(Modified from Lin et al., 2003 and Yang et al., 2004)



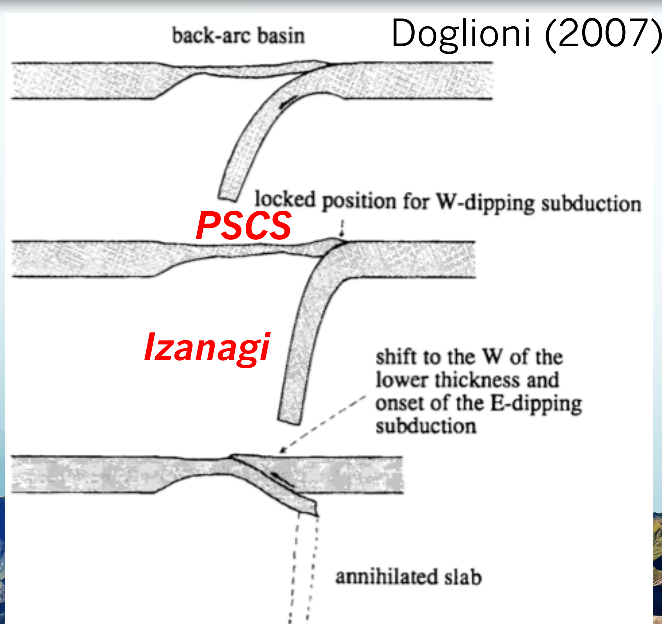
Zahirovic et al. (2014)

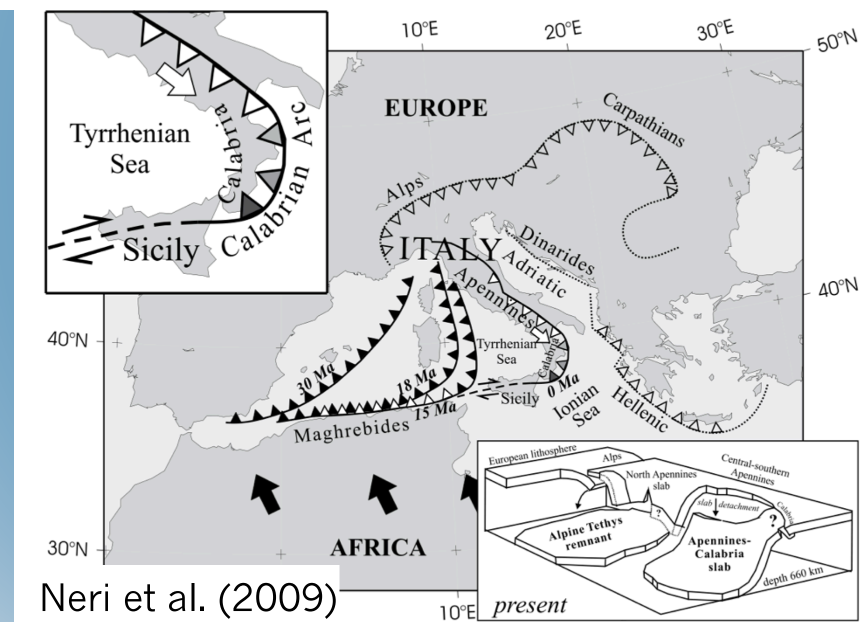




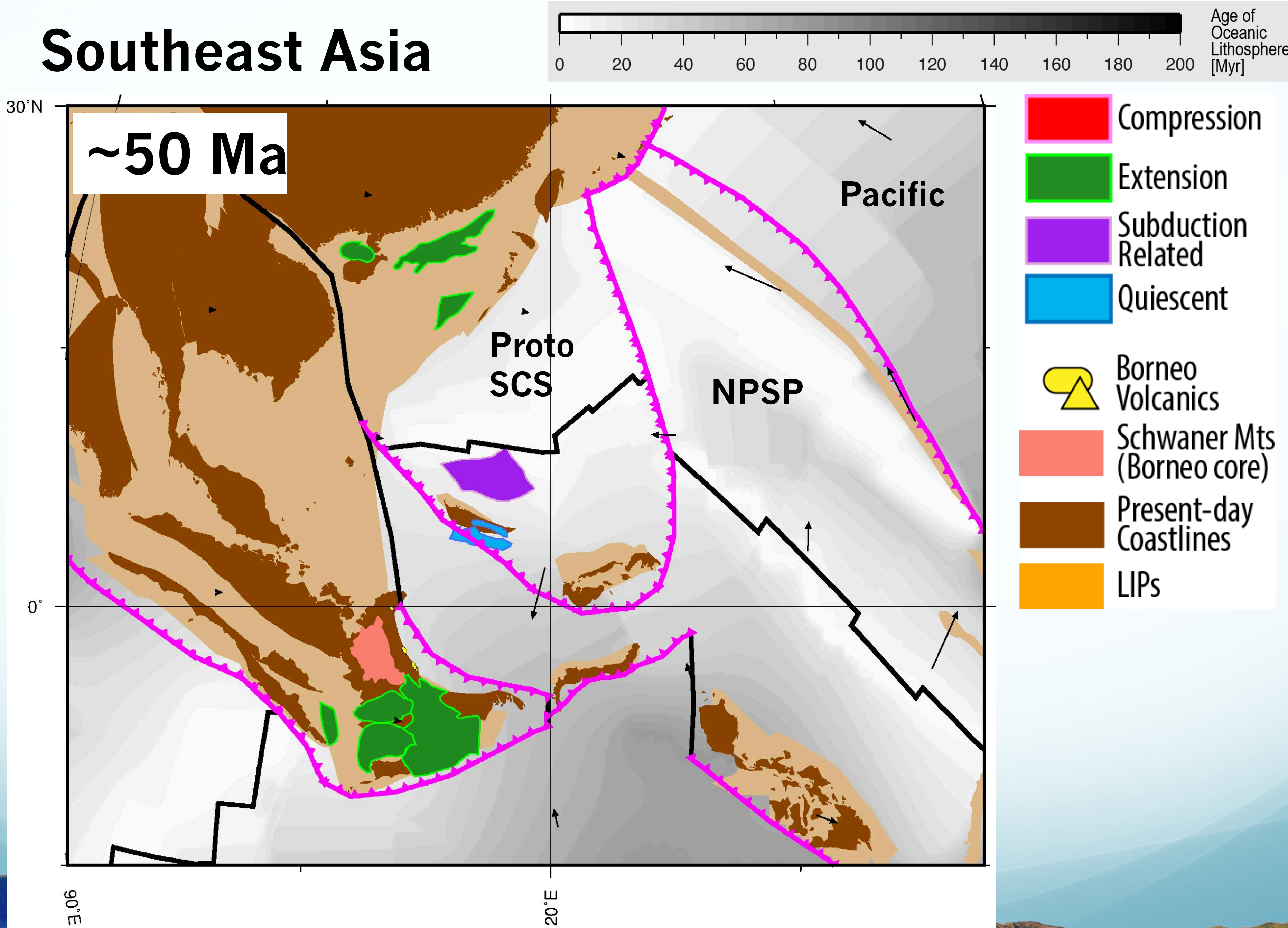


Tyrrhenian Sea ≈ Proto South China Sea



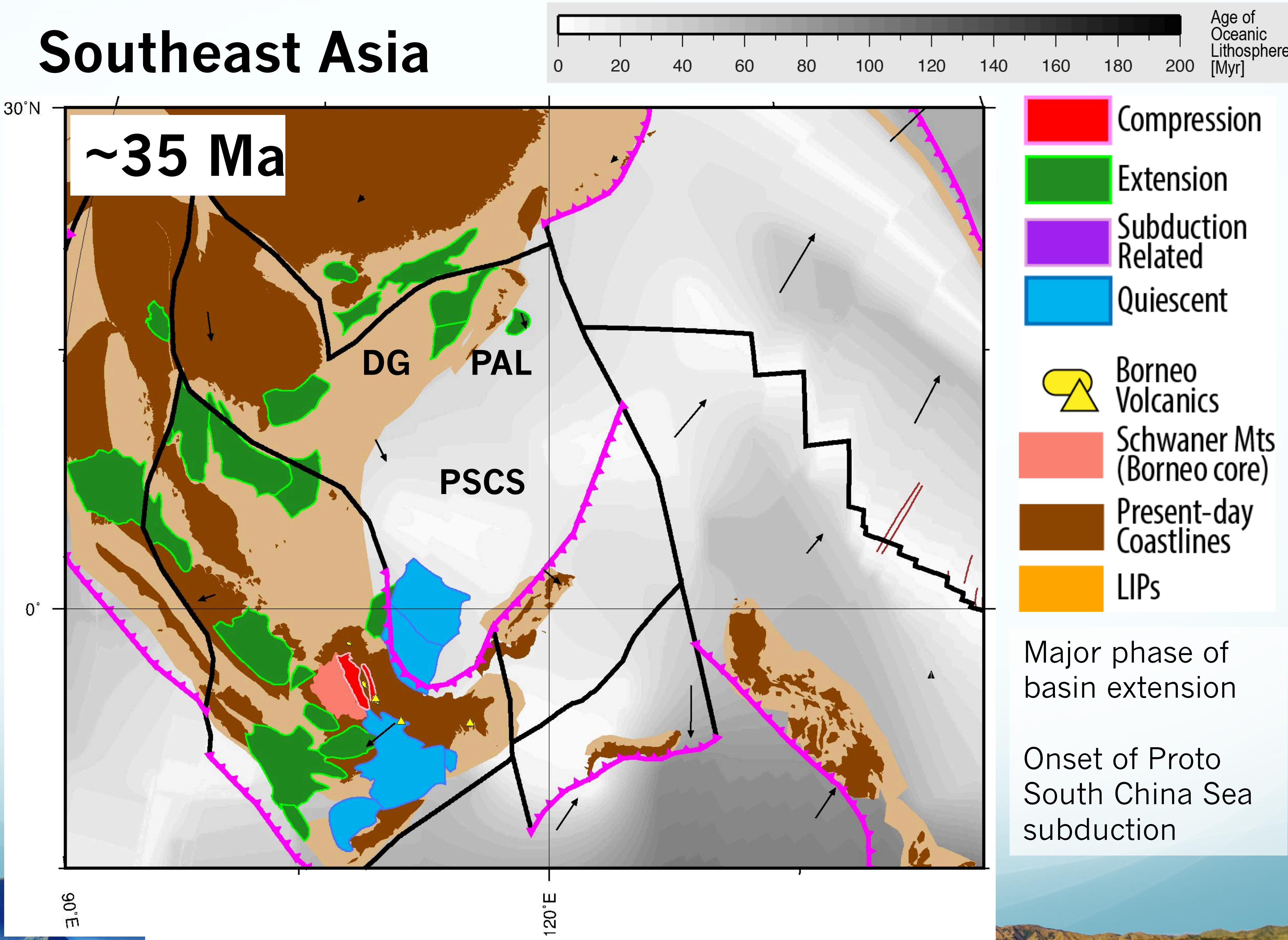


Southeast Asia



Basin tectonic regimes = Doust and Sumner (2007)

Southeast Asia

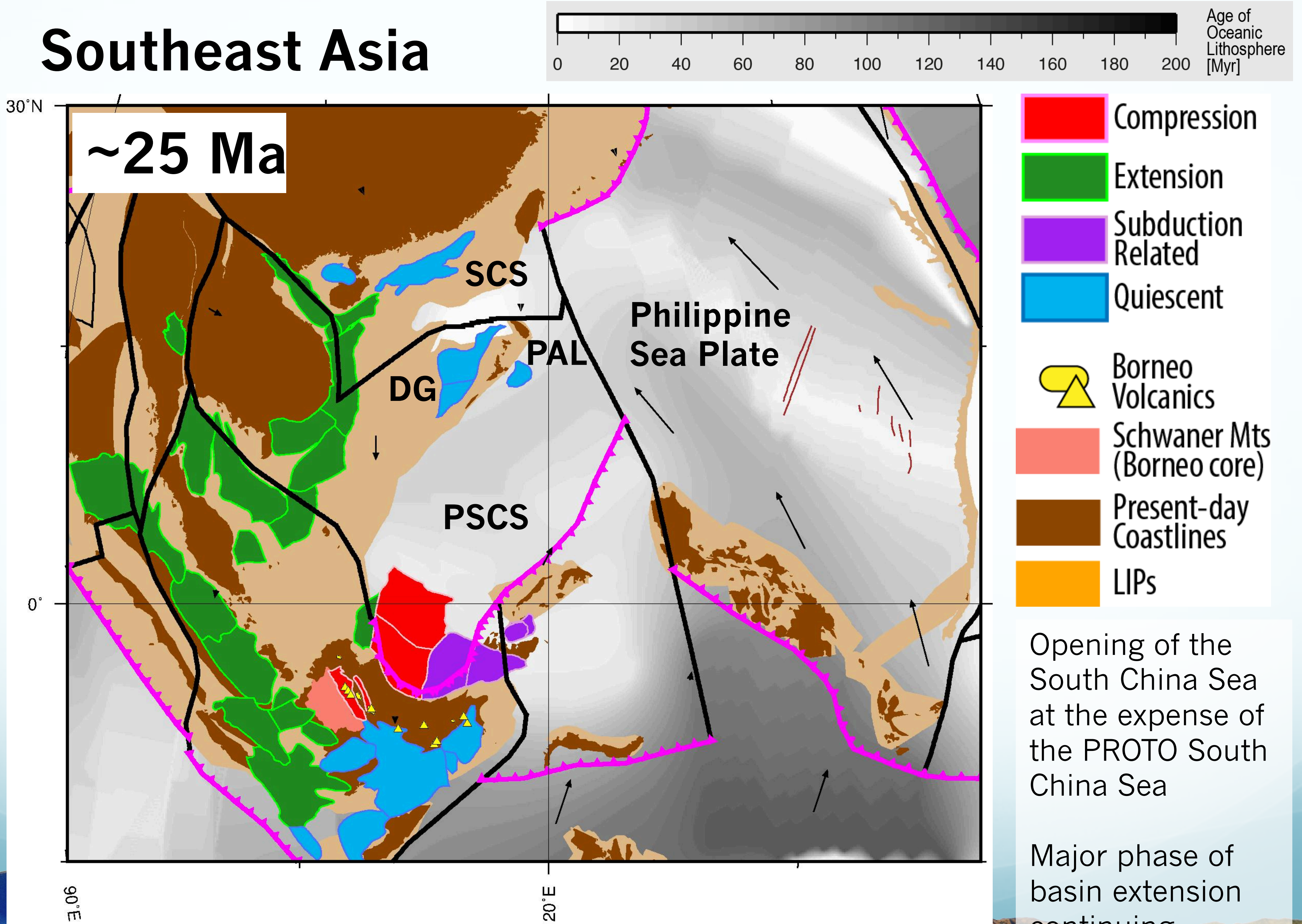


Major phase of basin extension

Onset of Proto South China Sea subduction

Basin tectonic regimes = Doust and Sumner (2007)

Southeast Asia

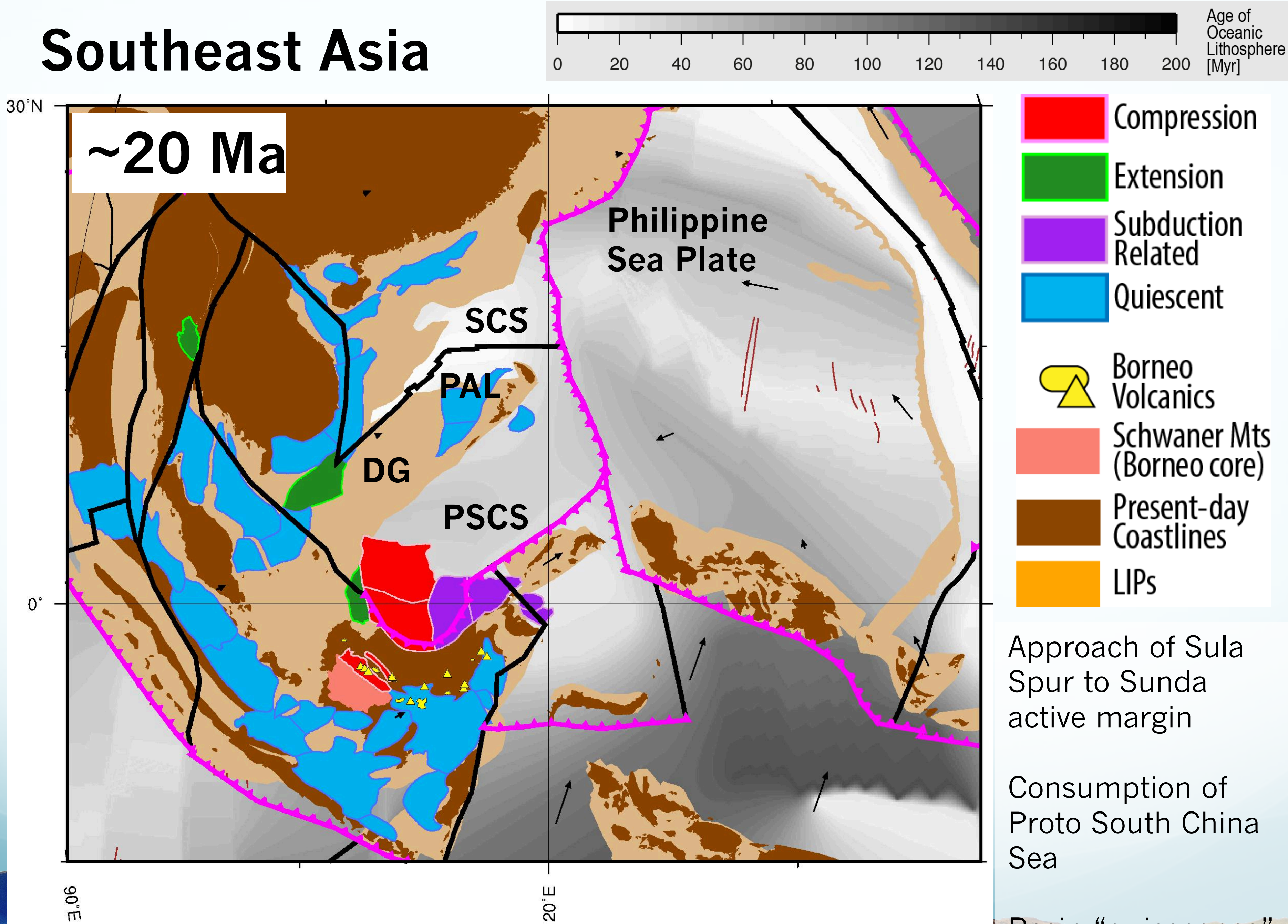


Opening of the South China Sea at the expense of the PROTO South China Sea

Major phase of basin extension continuing

Basin tectonic regimes = Doust and Sumner (2007)

Southeast Asia



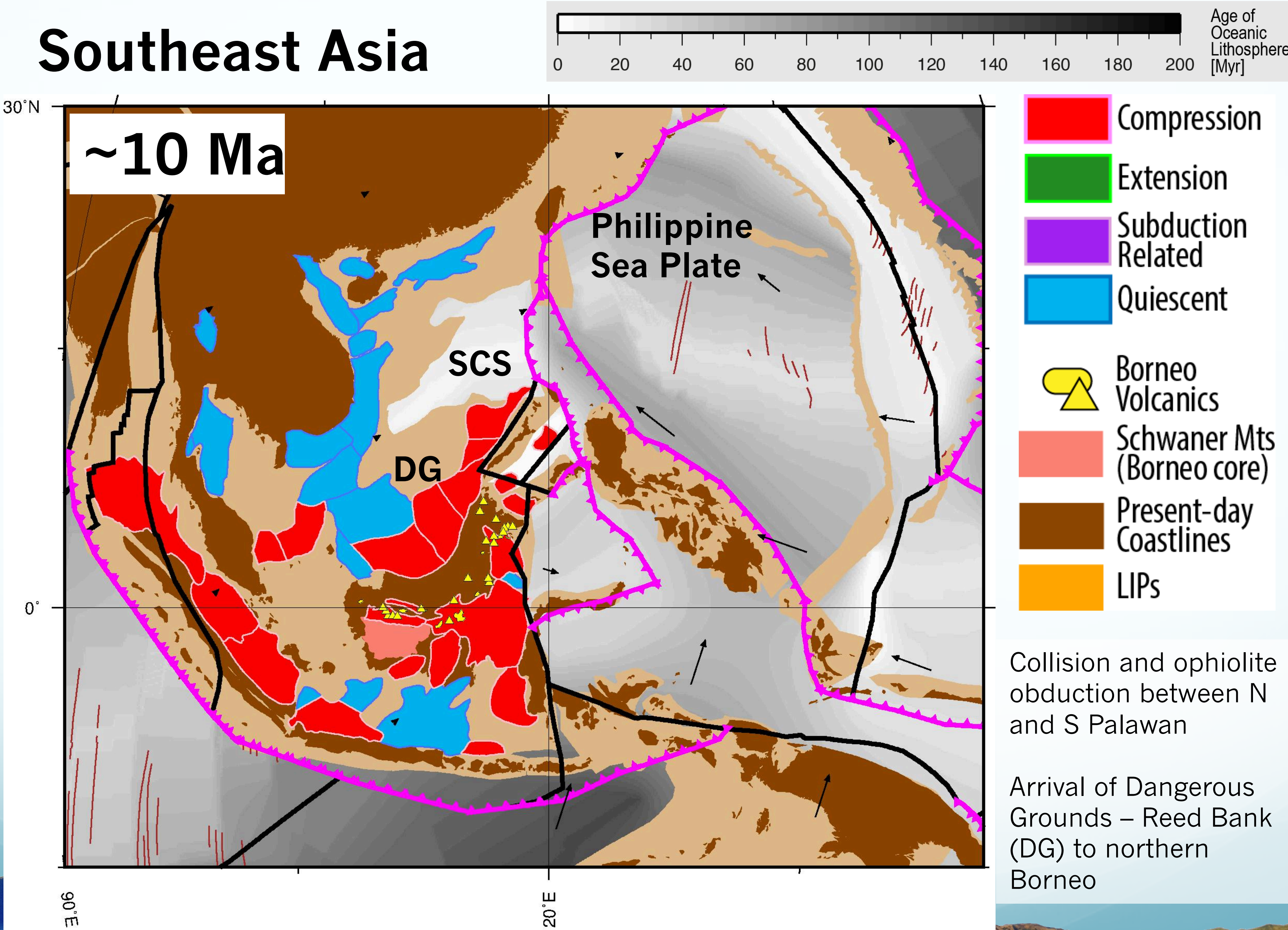
Approach of Sula Spur to Sunda active margin

Consumption of Proto South China Sea

Basin "quiescence"

Basin tectonic regimes = Doust and Sumner (2007)

Southeast Asia

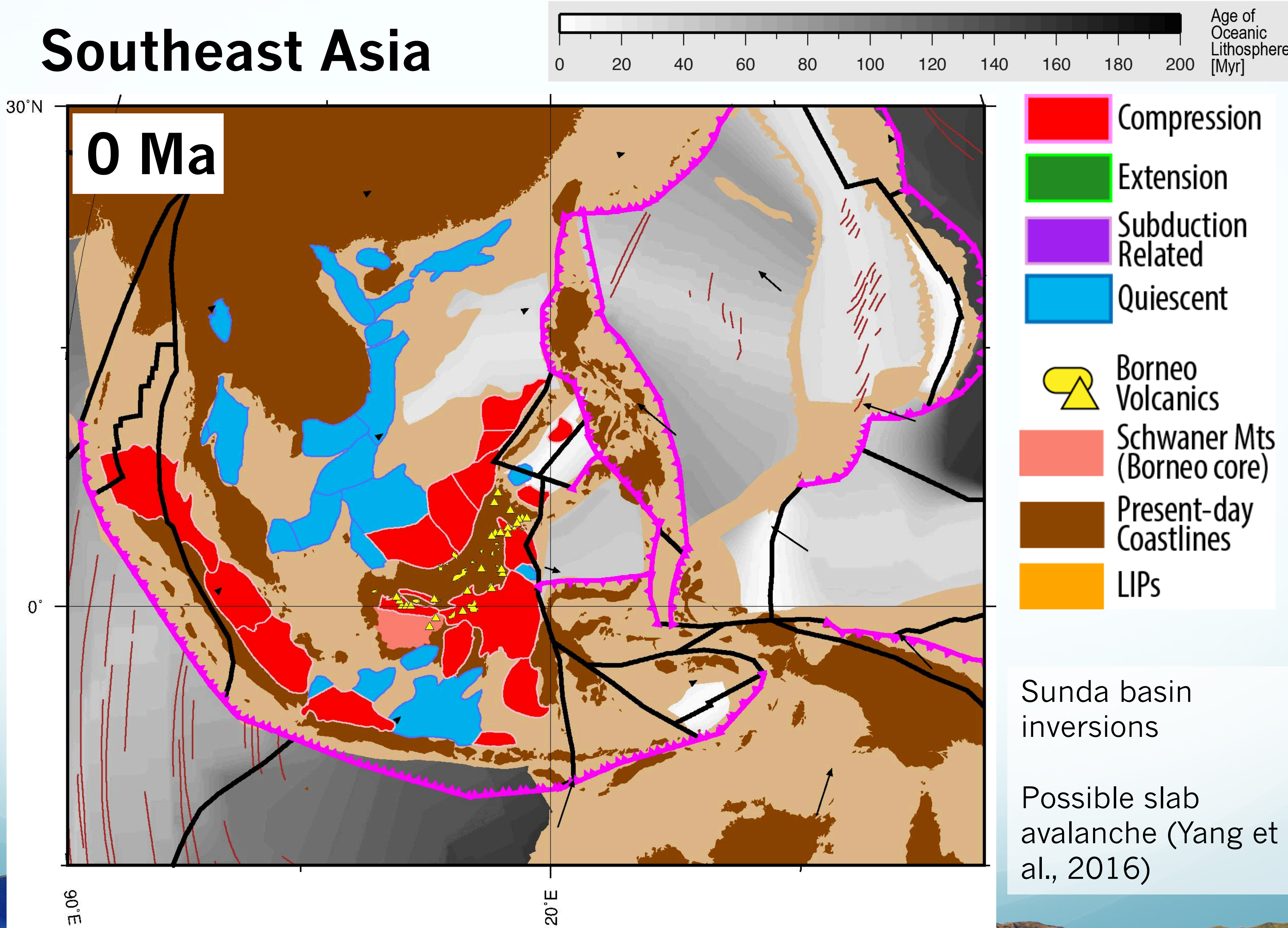


Collision and ophiolite obduction between N and S Palawan

Arrival of Dangerous Grounds – Reed Bank (DG) to northern Borneo

Basin tectonic regimes = Doust and Sumner (2007)

Southeast Asia



Sunda basin inversions

Possible slab avalanche (Yang et al., 2016)

Basin tectonic regimes = Doust and Sumner (2007)

Plate reconstructions and mantle convection

Hotspot trails +
Seafloor spreading +
Paleomagnetism +

Constraints (Input)

Volcanism

Sedimentation (Basins)

Geology

Metamorphism

Ophiolites

Applied Rules

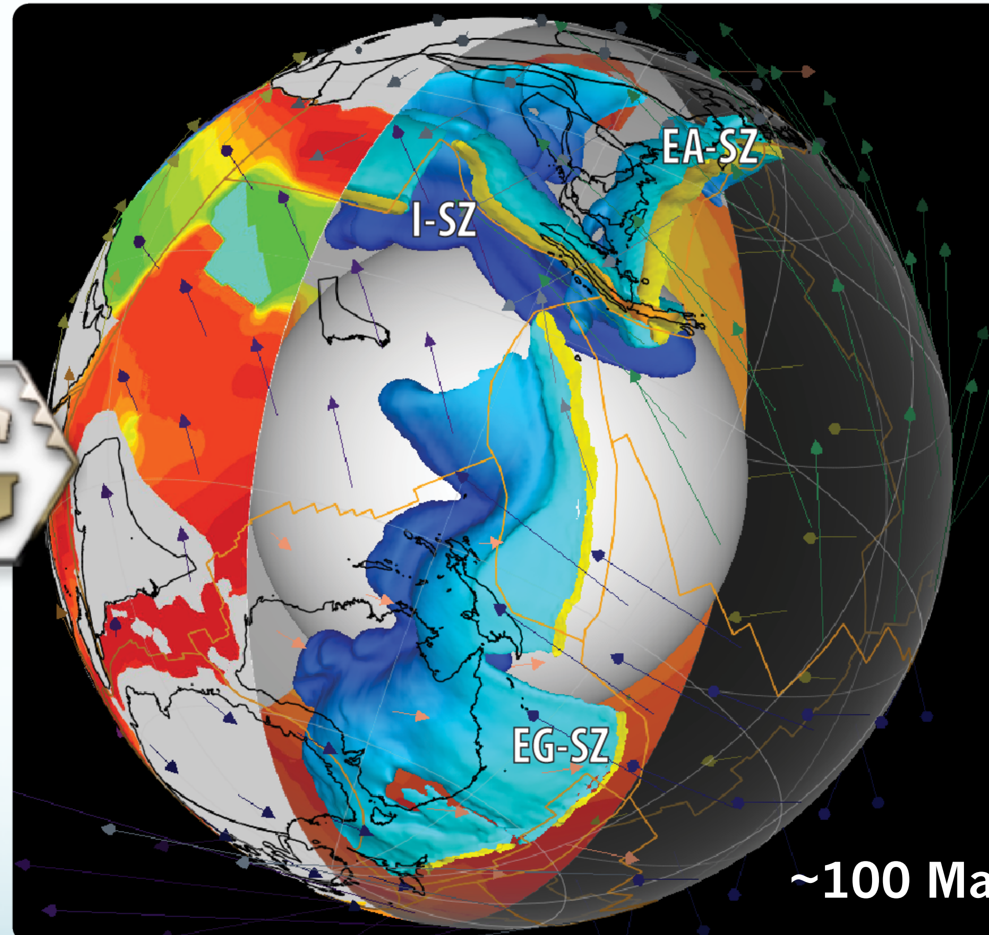
Geometrical rules (e.g. triple junctions)

Plate boundaries (relative plate motions)

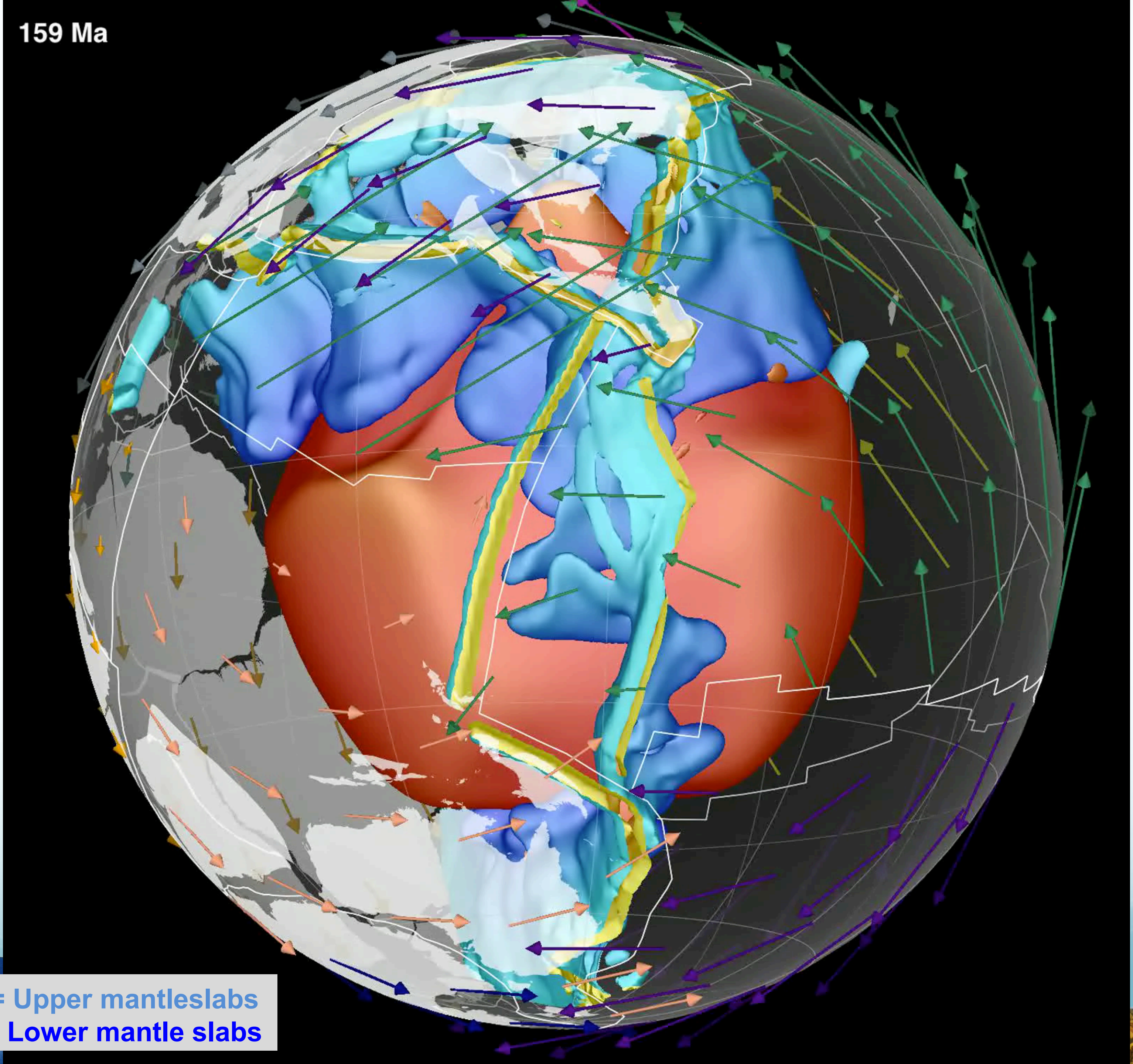
Plate tectonics

Plate driving mechanisms

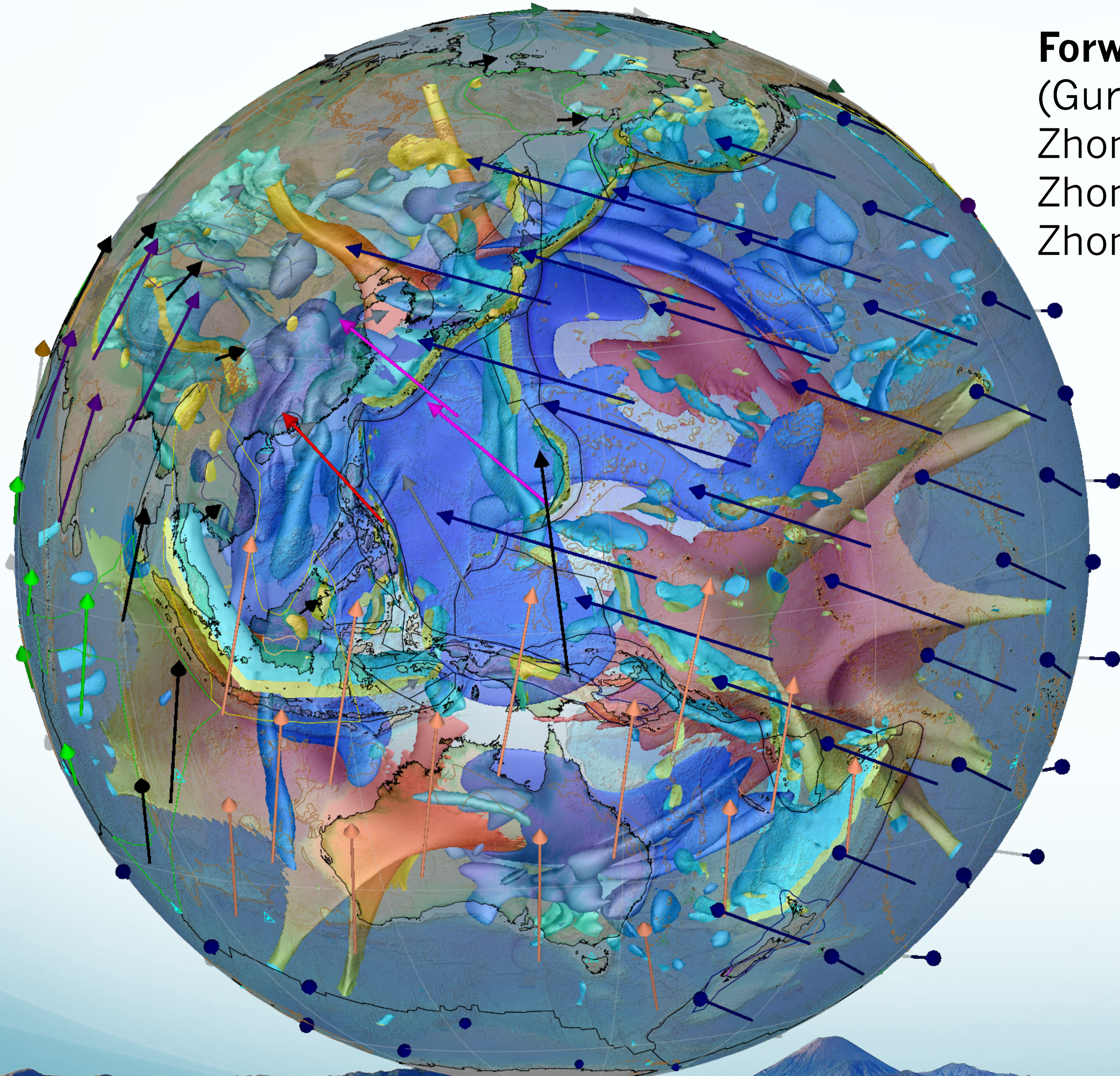
Plate velocities



www.gplates.org



Light blue = Upper mantleslabs
Dark blue = Lower mantle slabs



Forward models in CitcomS
(Gurnis and Zhong, 1991
Zhong and Gurnis, 1993
Zhong and Gurnis, 1994
Zhong et al., 1999)

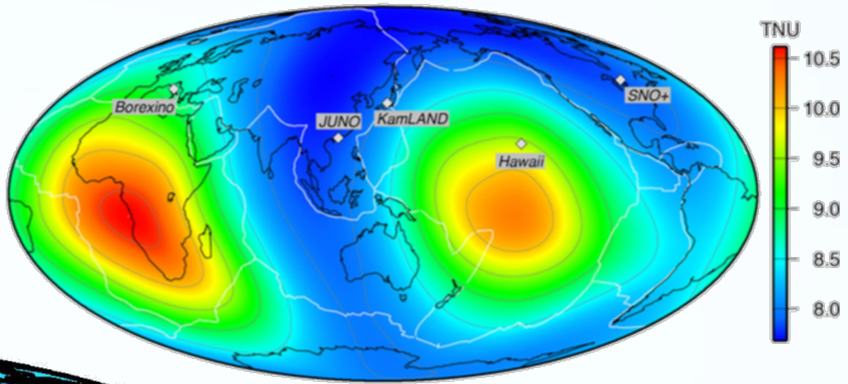
Extended Boussinesq Approximation (pseudo-compressible)
Hassan et al. (2015)

Visualised in **GPlates** (open-source and cross-platform)
www.gplates.org

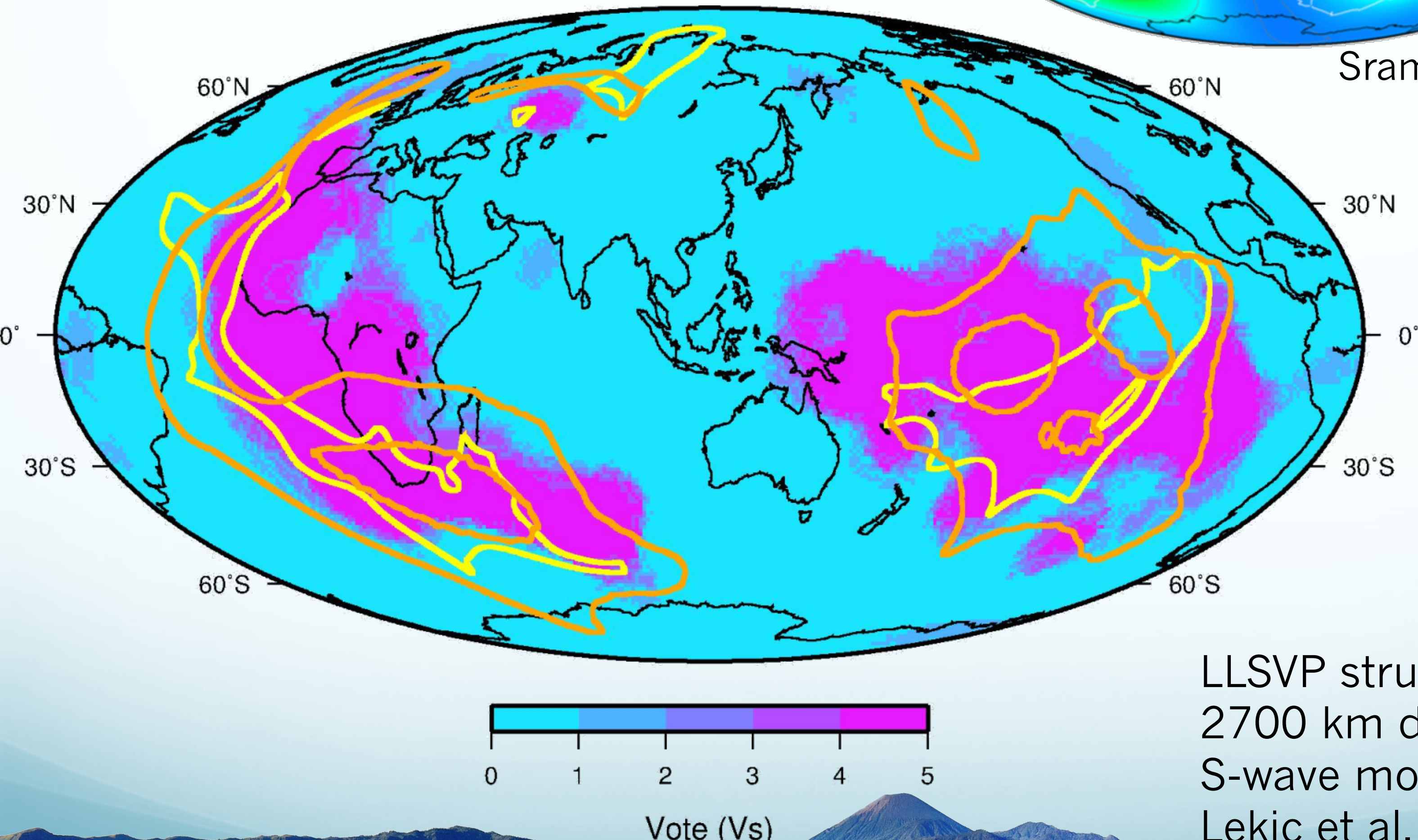
GPlates

Lower Mantle

Yellow = Boussinesq Approx.
Orange = Extended Boussinesq Approx.



Sramek et al. (2013)

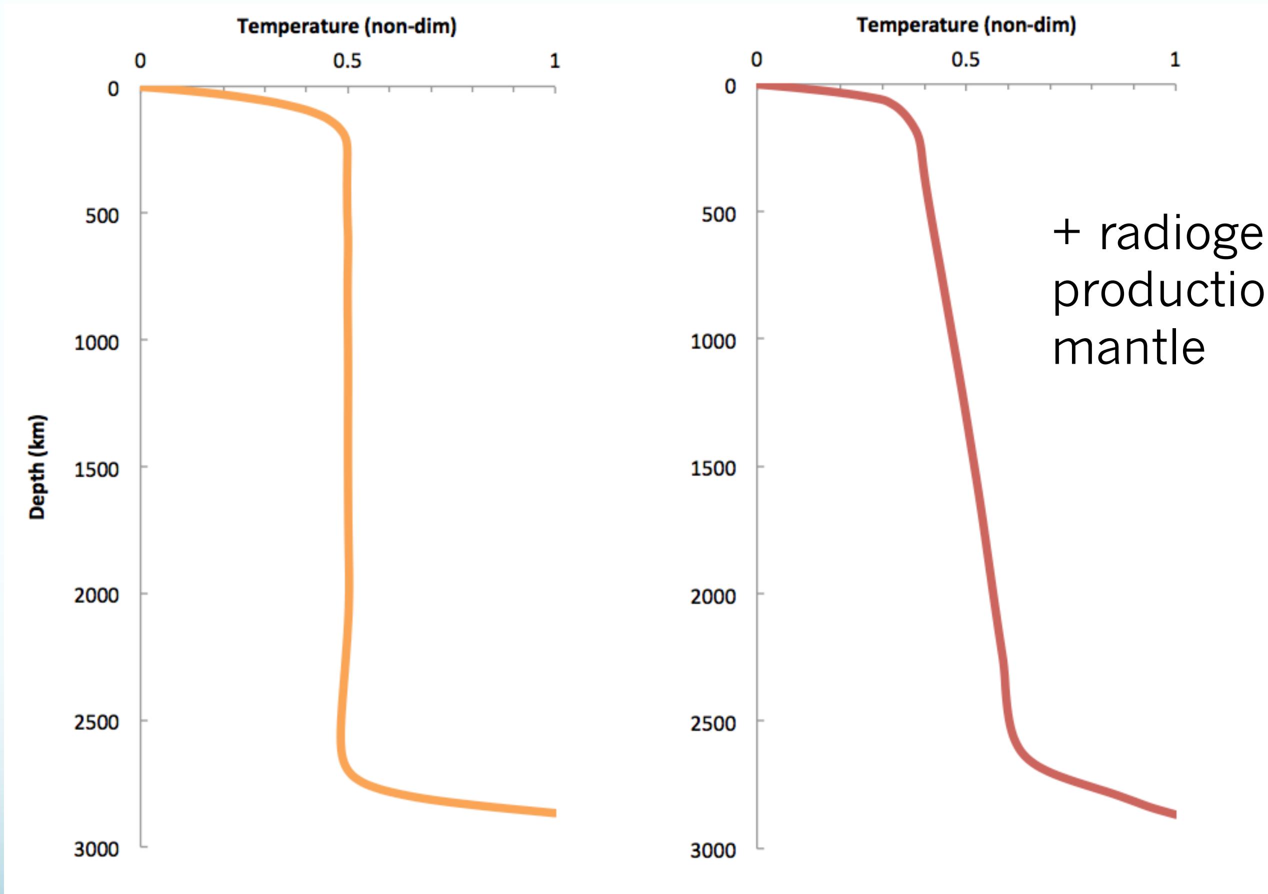


LLSVP structure
2700 km depth
S-wave models
Lekic et al. (2012)

Radial Temperature

Incompressible
Boussinesq Approx.

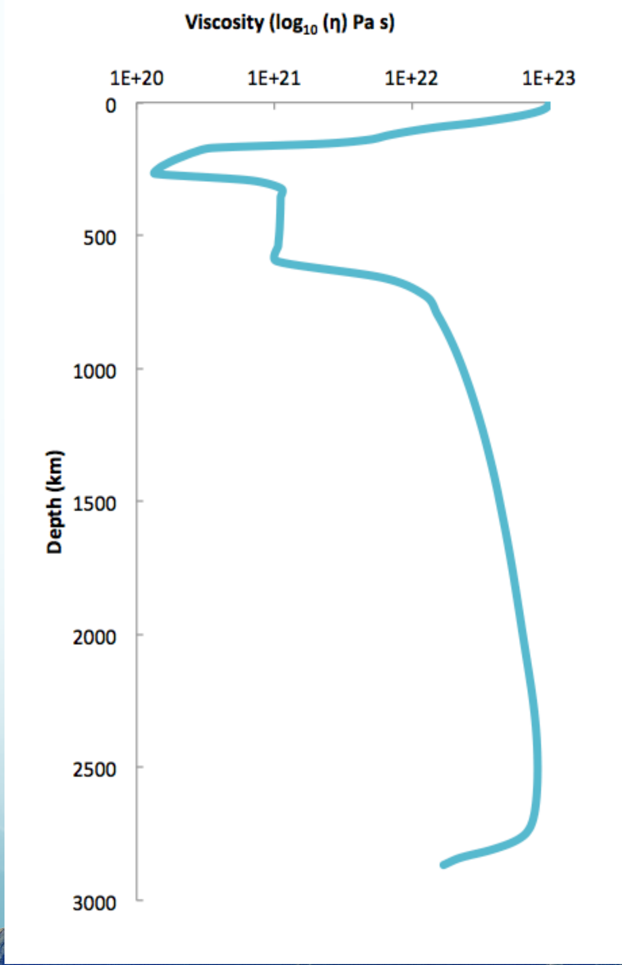
Pseudo-compressible
Extended Boussinesq Approx.



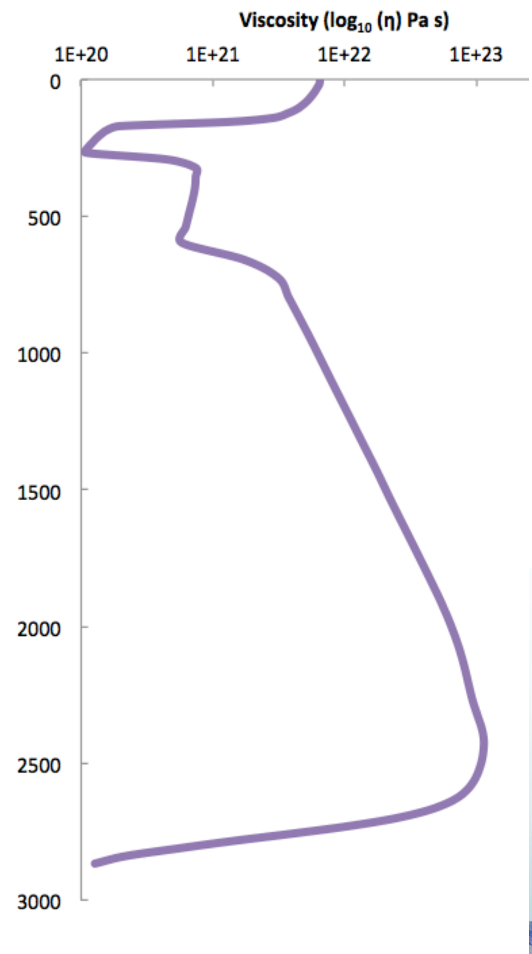
+ radiogenic heat production in the mantle

Radial Viscosity

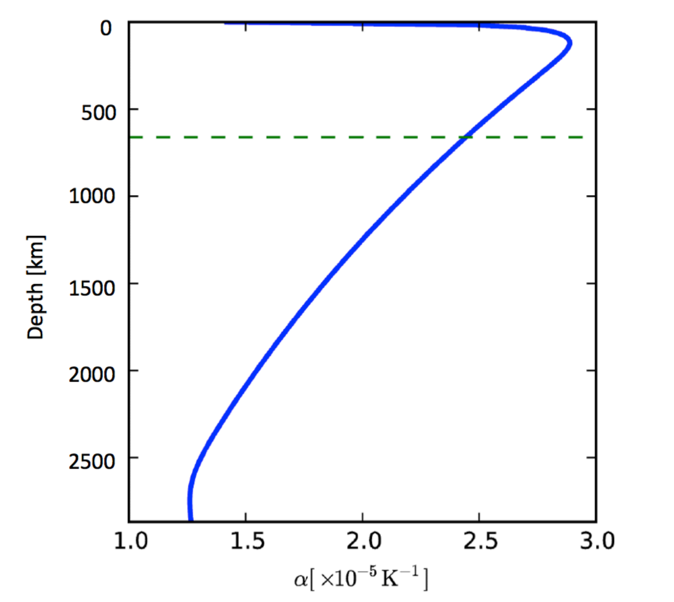
Incompressible
Boussinesq Approx.



Pseudo-compressible
Extended Boussinesq Approx.

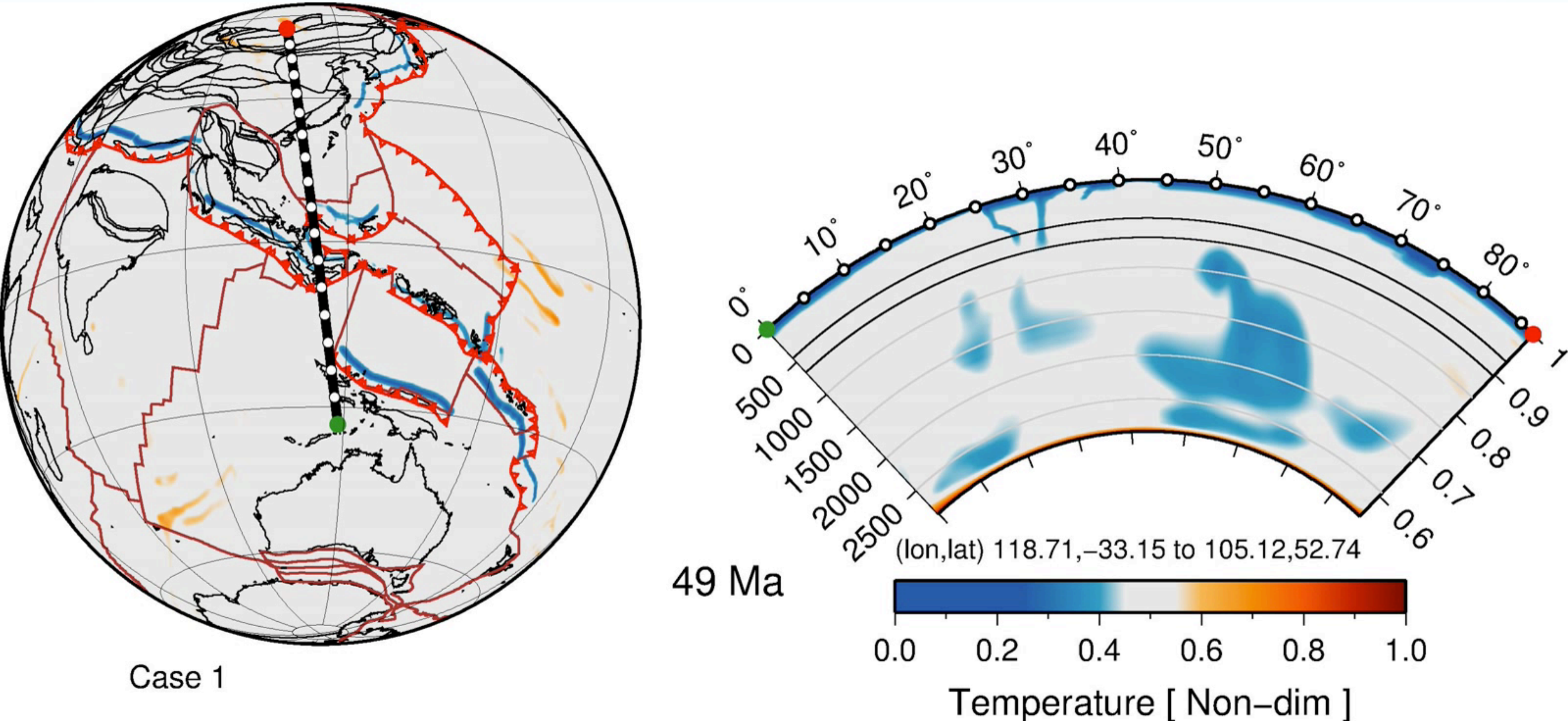


Thermal expansivity

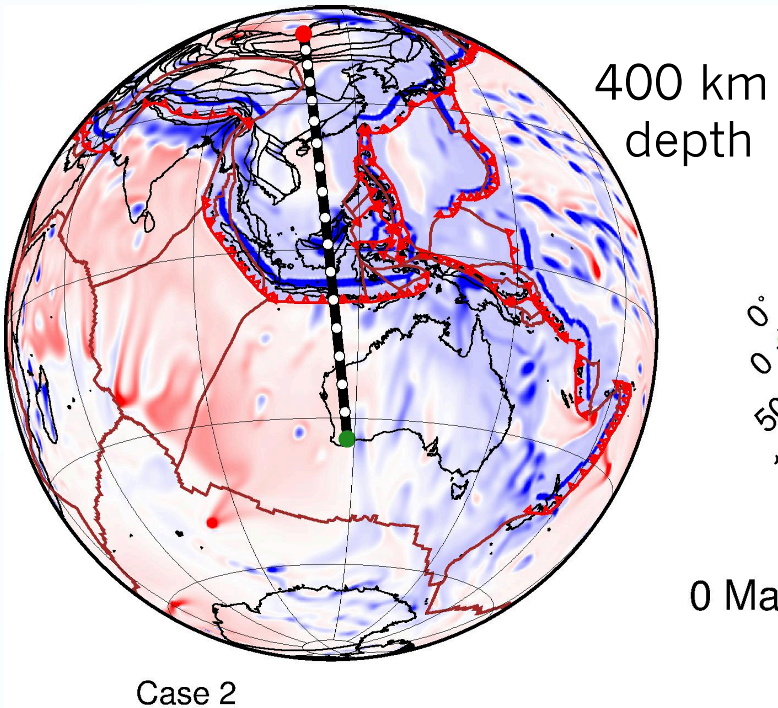


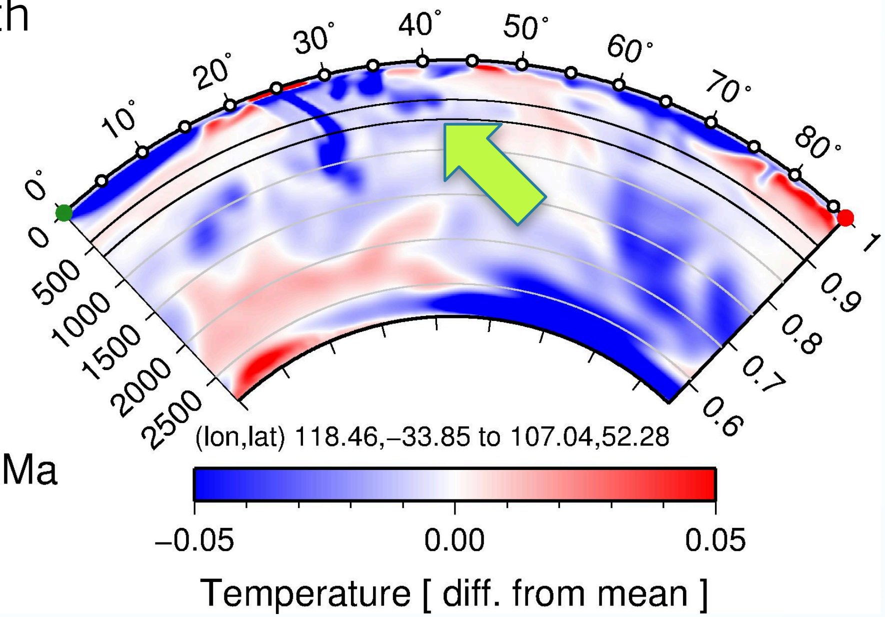
Derived from
Tosi et al. (2003)

Incompressible mantle flow

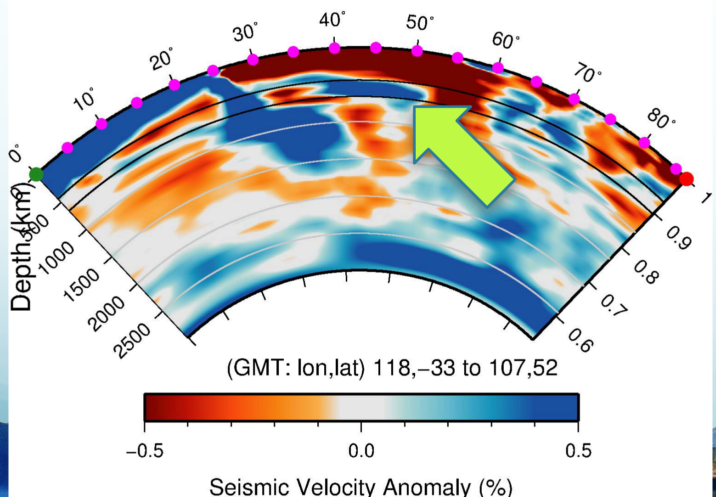


Mantle flow vs. Seismic tomography

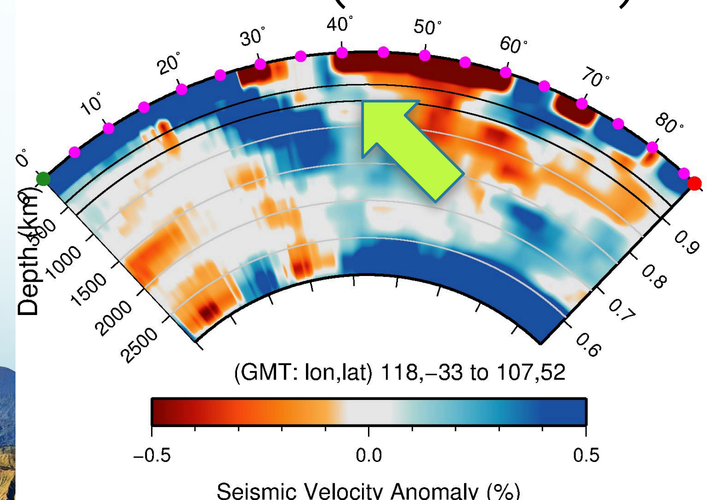


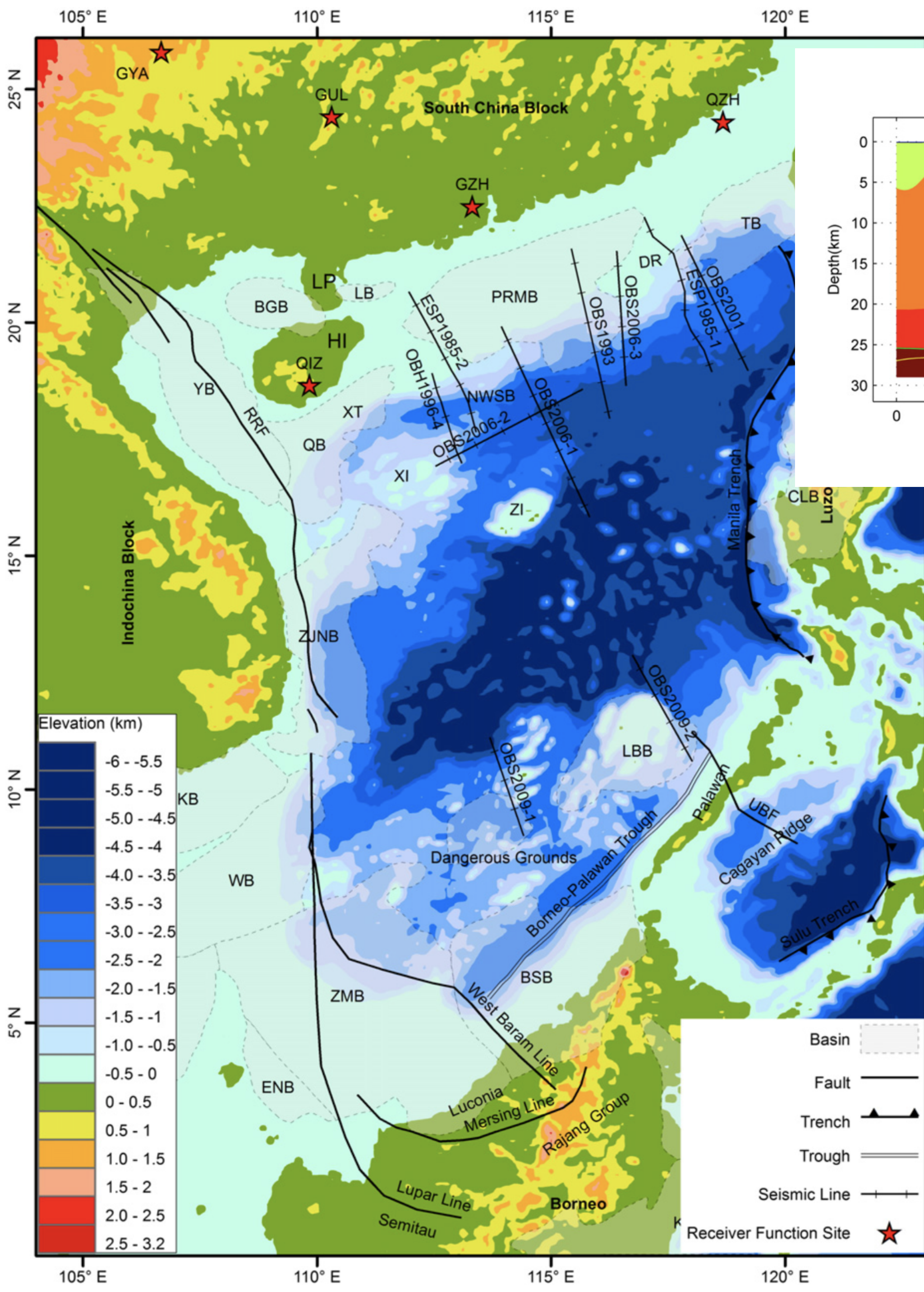


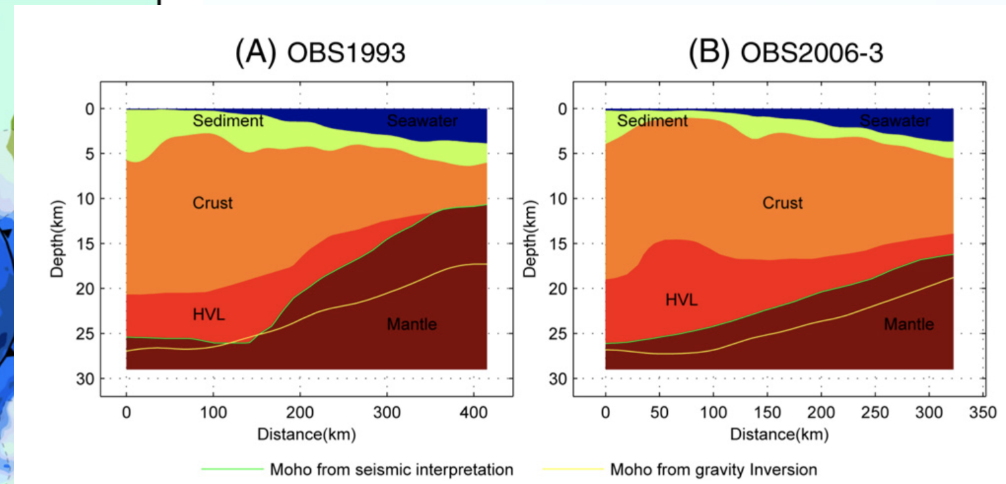
GAP_P4 (Obayashi 2013)

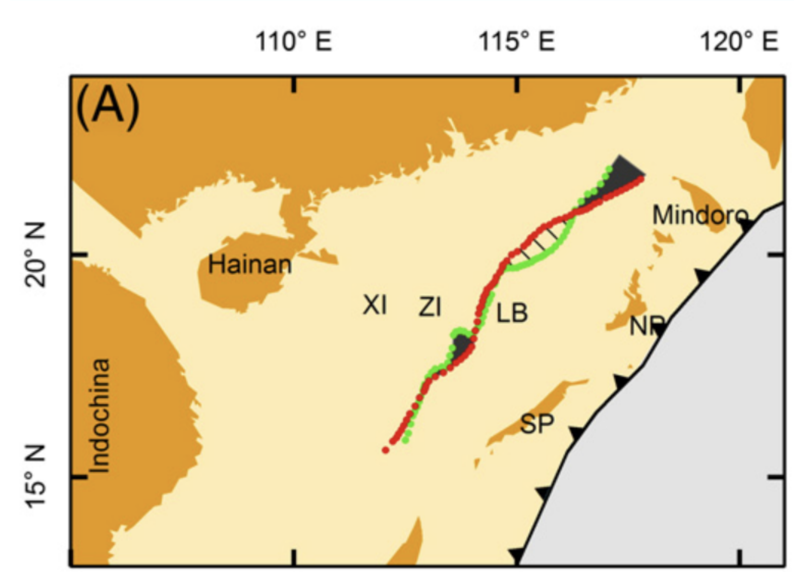


Grand-S (Grand 2002)





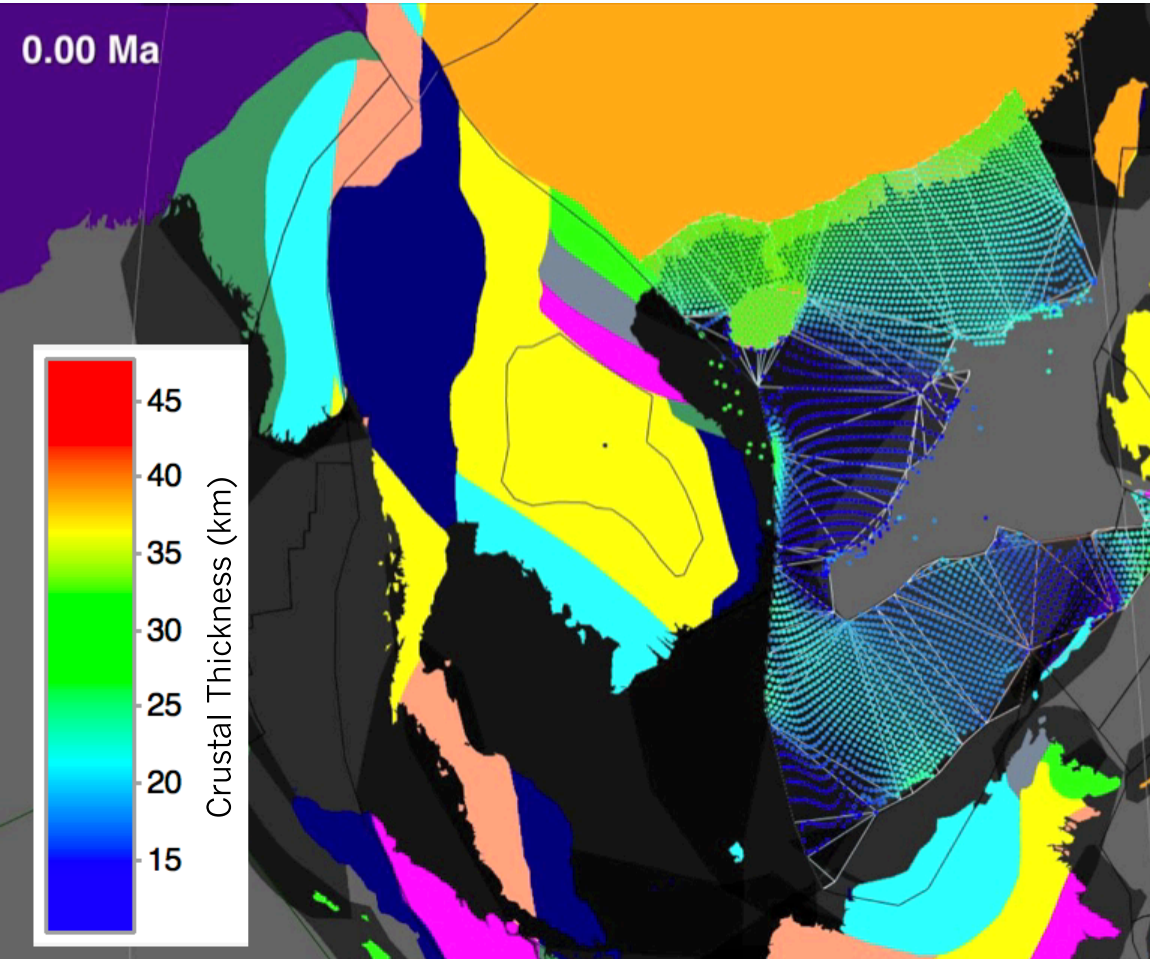


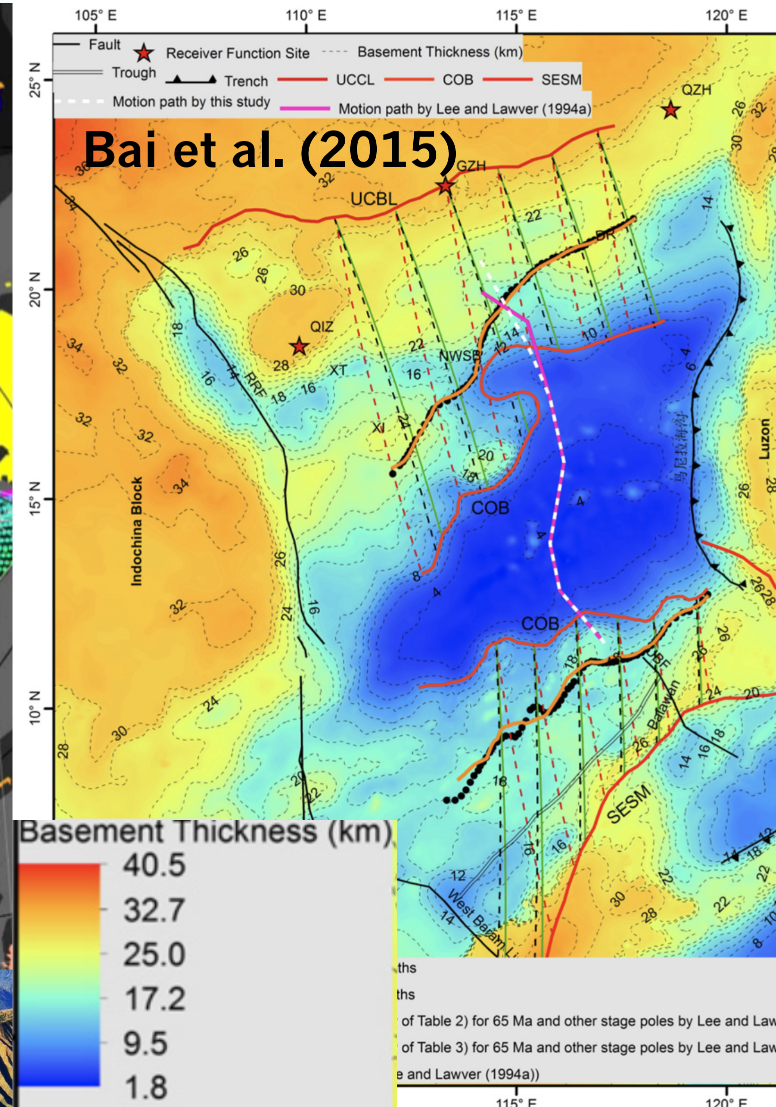


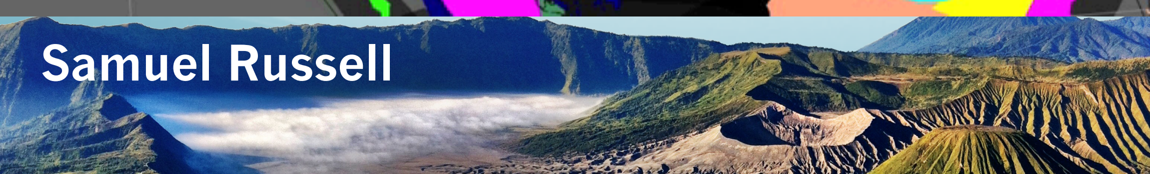
Bai et al. (2015), Full-fit reconstruction of the South China Sea conjugate margins

Deforming plate reconstruction

Rifting from ~40 Myr ago, initial crustal thickness of ~29 km

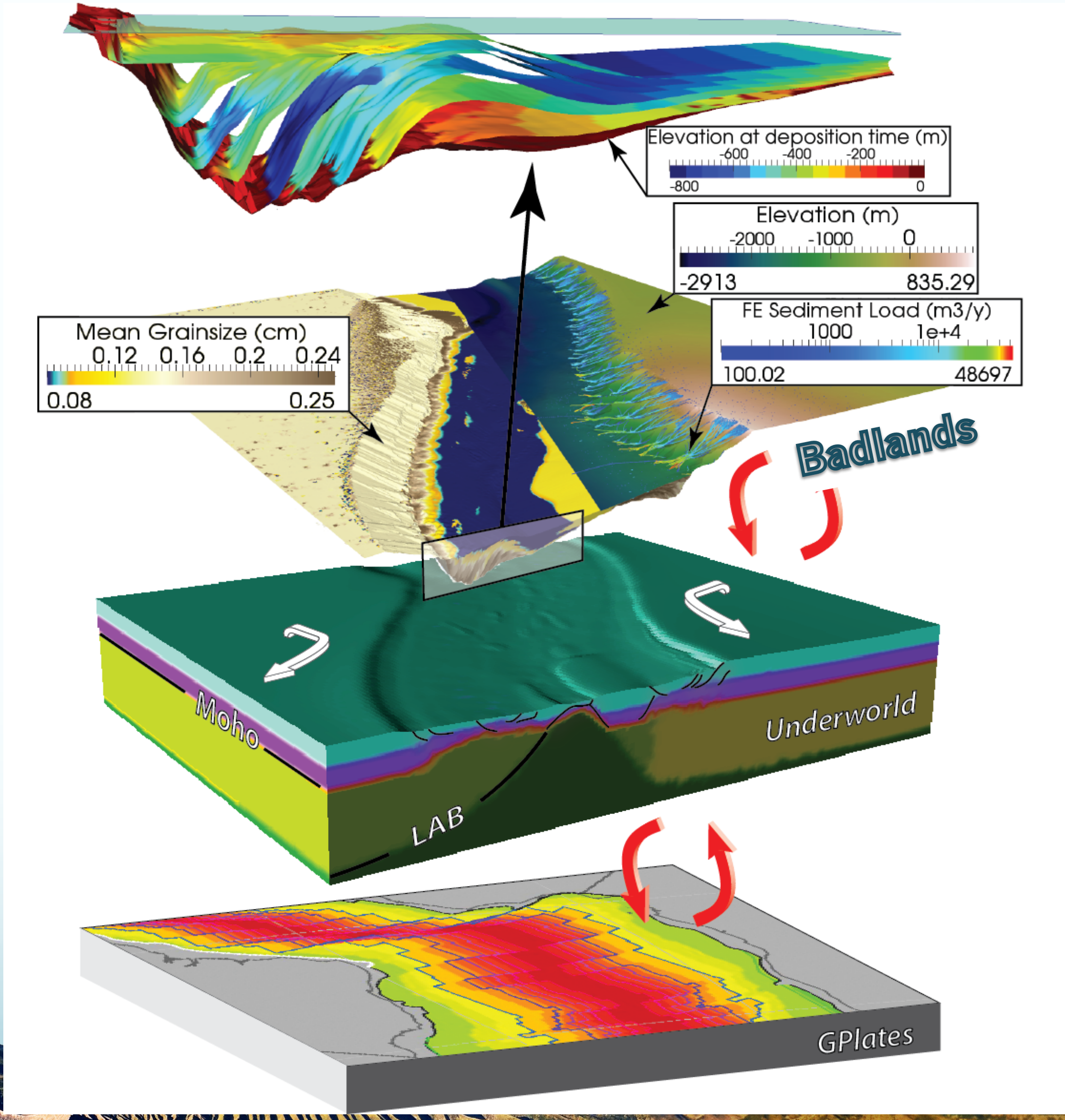






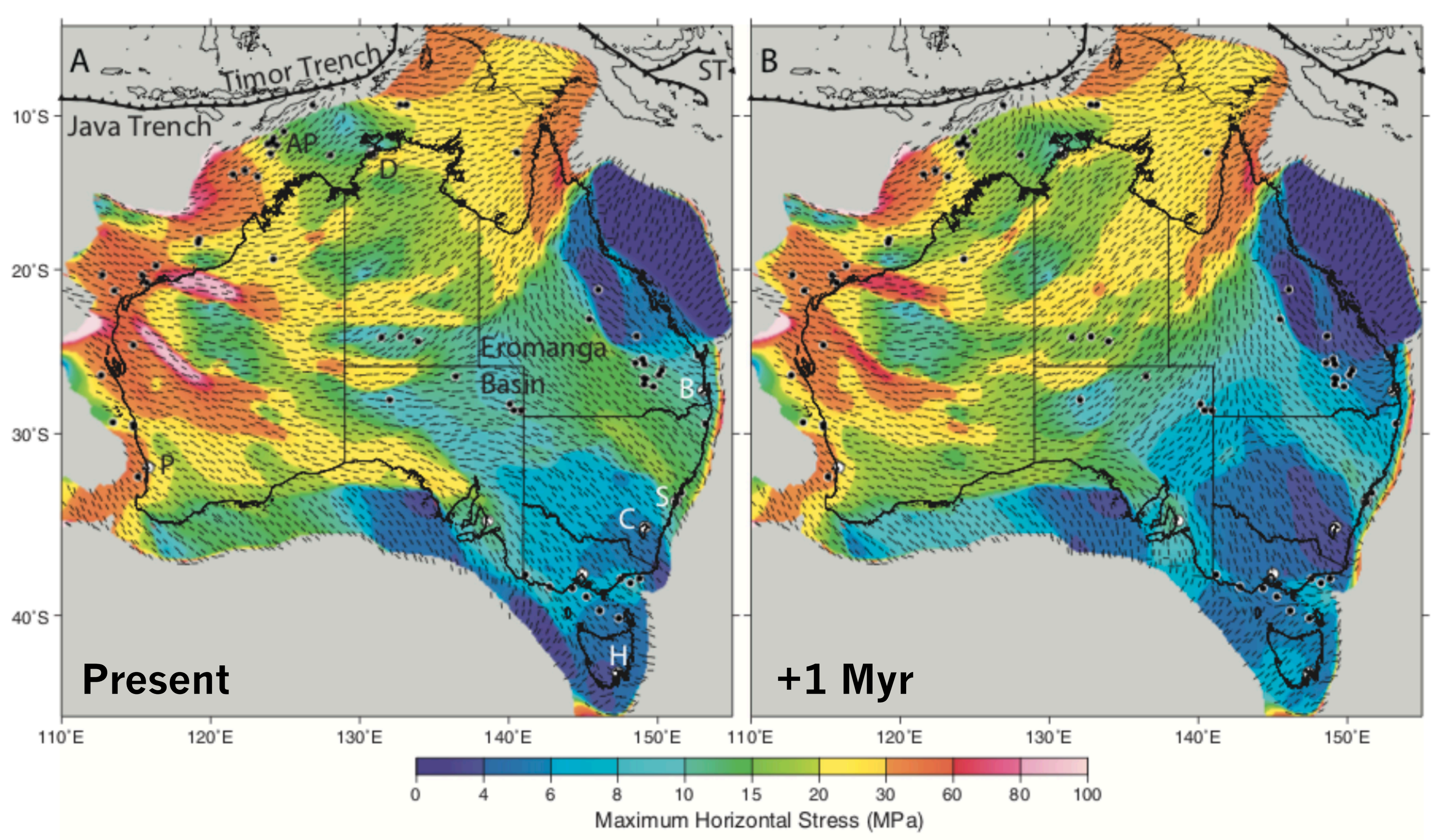
Future Work

- Deforming plate reconstruction can be linked to mantle flow and surface process modelling
  - Role of mantle dynamic topography
  - Lithospheric and crustal processes
  - Sea level
  - Estimate carbonate platform development and sedimentary histories



Some other ideas…

- Current and future lithospheric stress field
  - Earthquakes, carbon capture and storage, etc.



Dyksterhuis and Muller (2017)

Conclusions

- Necessity of regional and global observations to constrain numerical models of crustal, lithosphere and mantle processes
- Potential origin of Proto South China Sea as a Late Cretaceous back-arc
- Subduction of Proto South China Sea, and rotation of Indochina, drive opening of South China Sea
- Forward models of mantle flow can help us track the trajectory of slabs, but also provide insights on LLSVP and mantle plume evolution

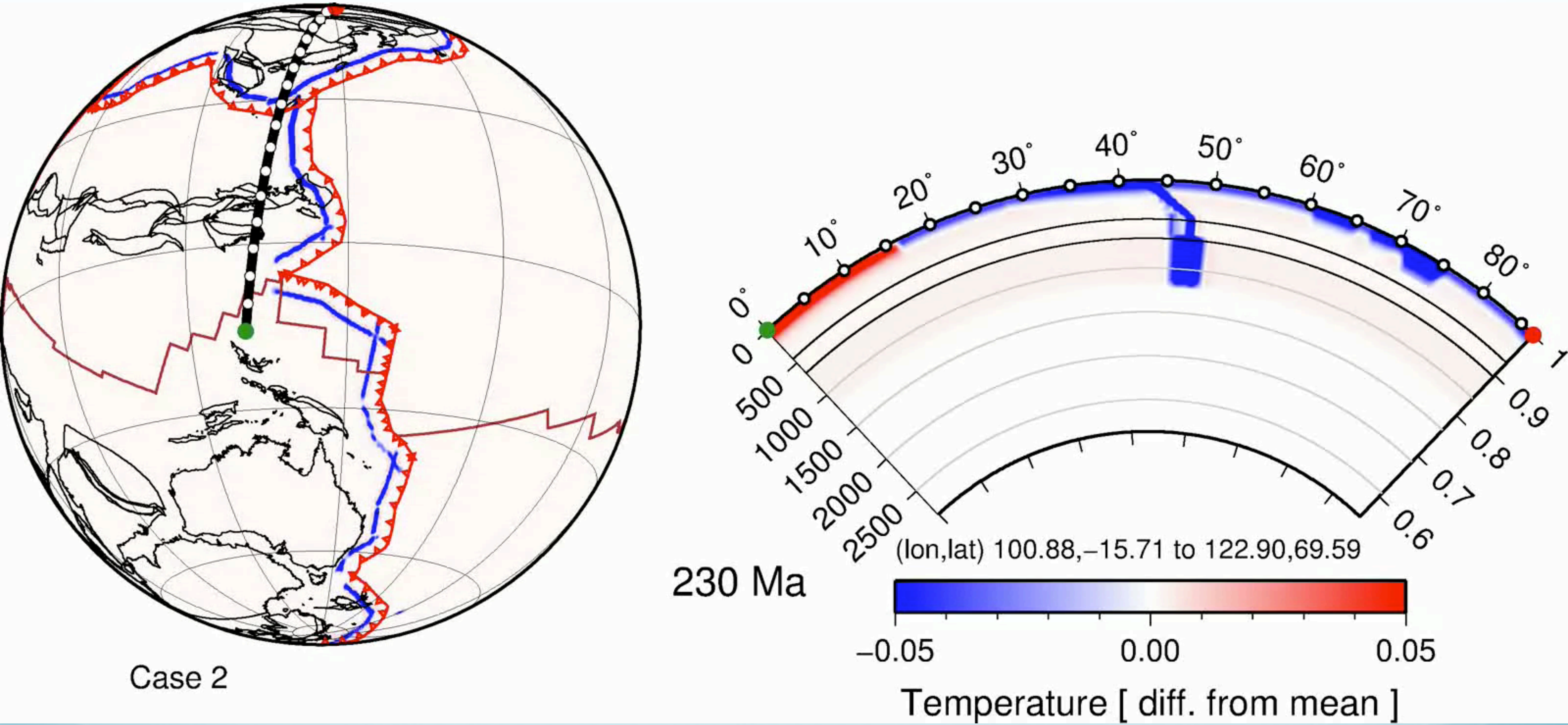
References

- GPlates plate reconstruction software
  www.gplates.org
- CitcomS mantle flow code
  https://geodynamics.org/cig/software/citcoms/
- Underworld geodynamic code
  https://github.com/underworldcode/underworld2
- Badlands surface processes code
  https://github.com/badlands-model/badlands
- EarthByte plate reconstructions and resources
  https://www.earthbyte.org/category/resources/

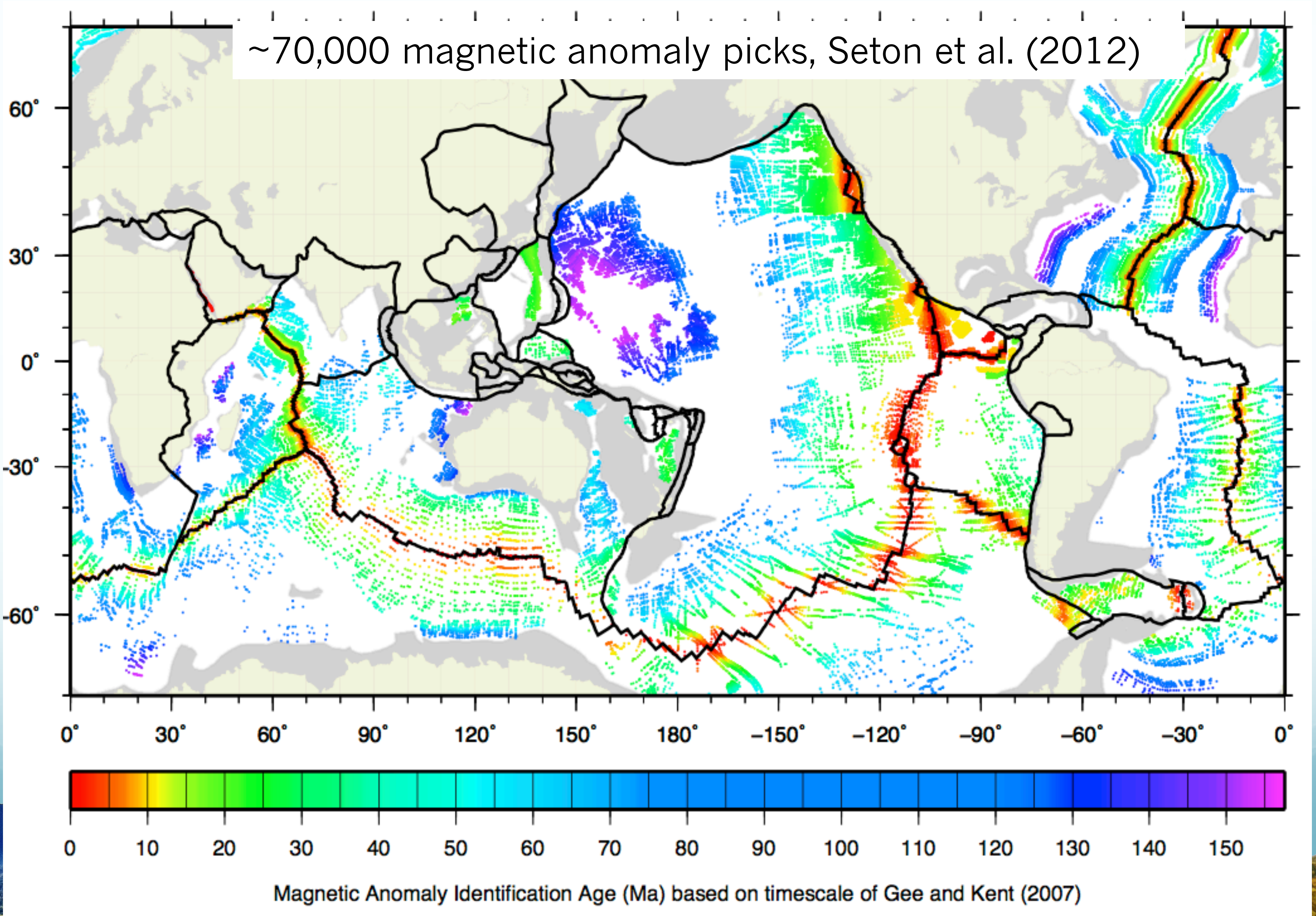
- Footer of Java volcano from
  Paul Williapanoramams
  https://www.flickr.com/photos/ironammonite/9335382518

Supplementary Slides

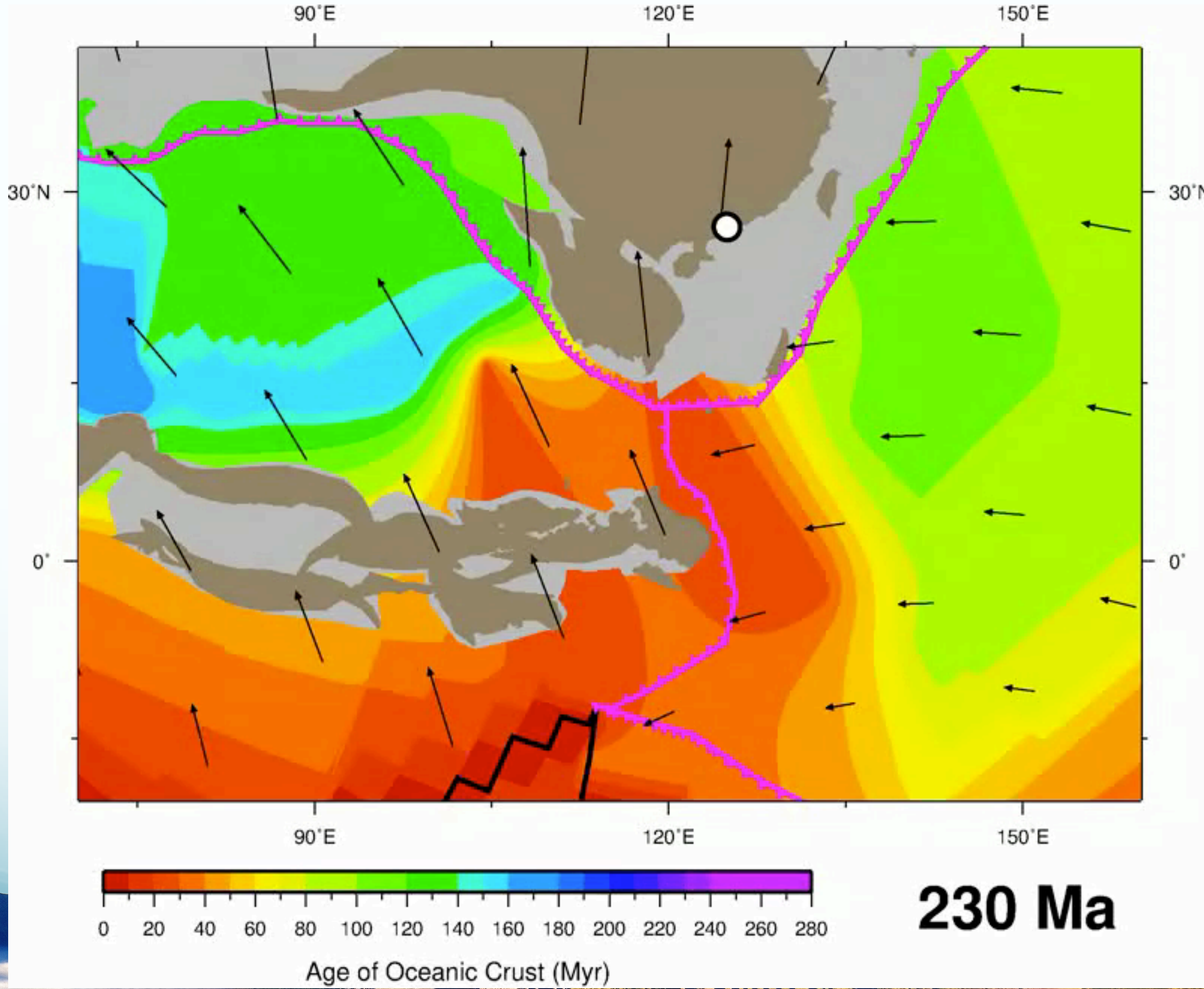
Pseudo-compressible mantle flow



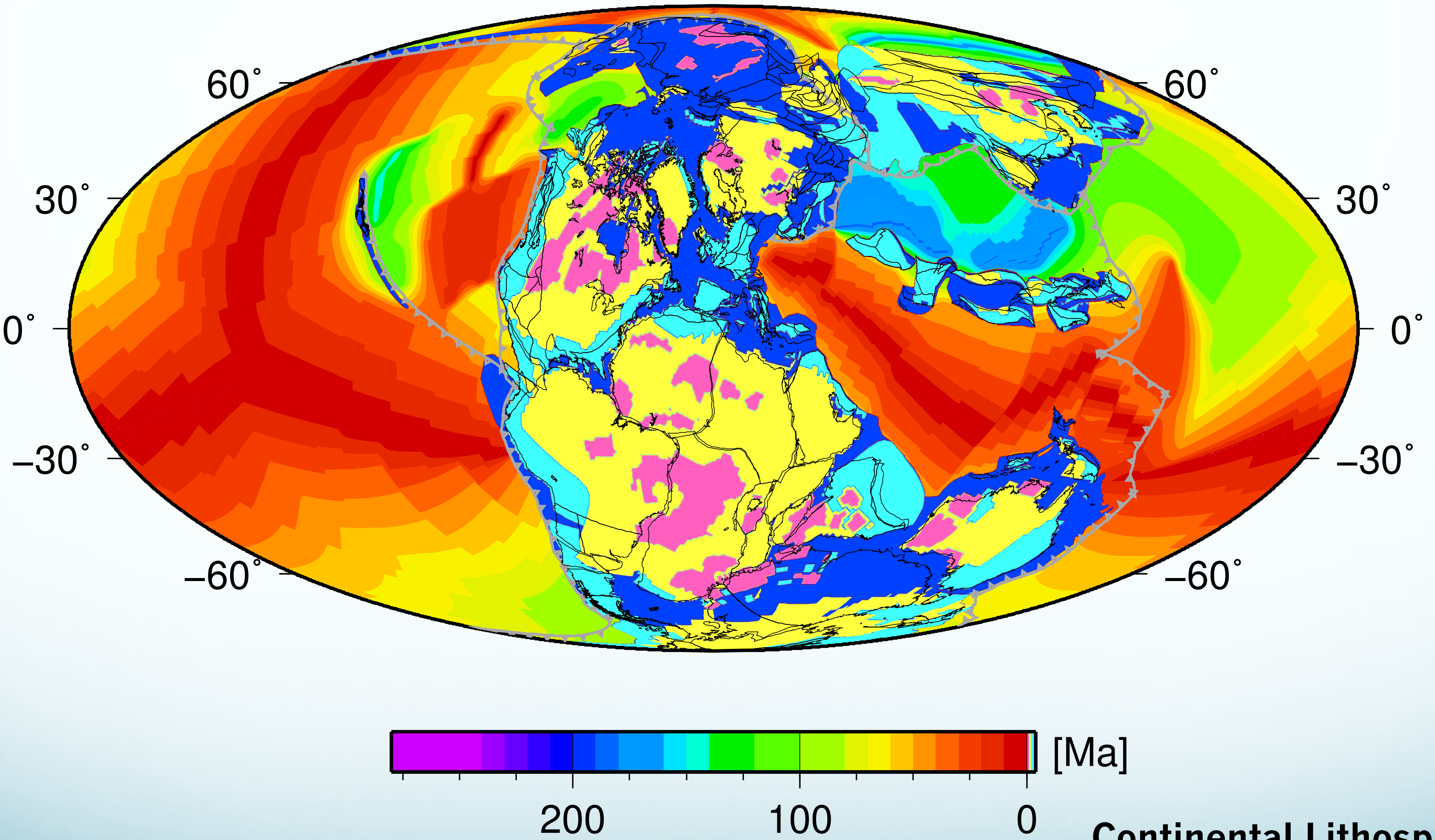
Global seafloor age



Regional view

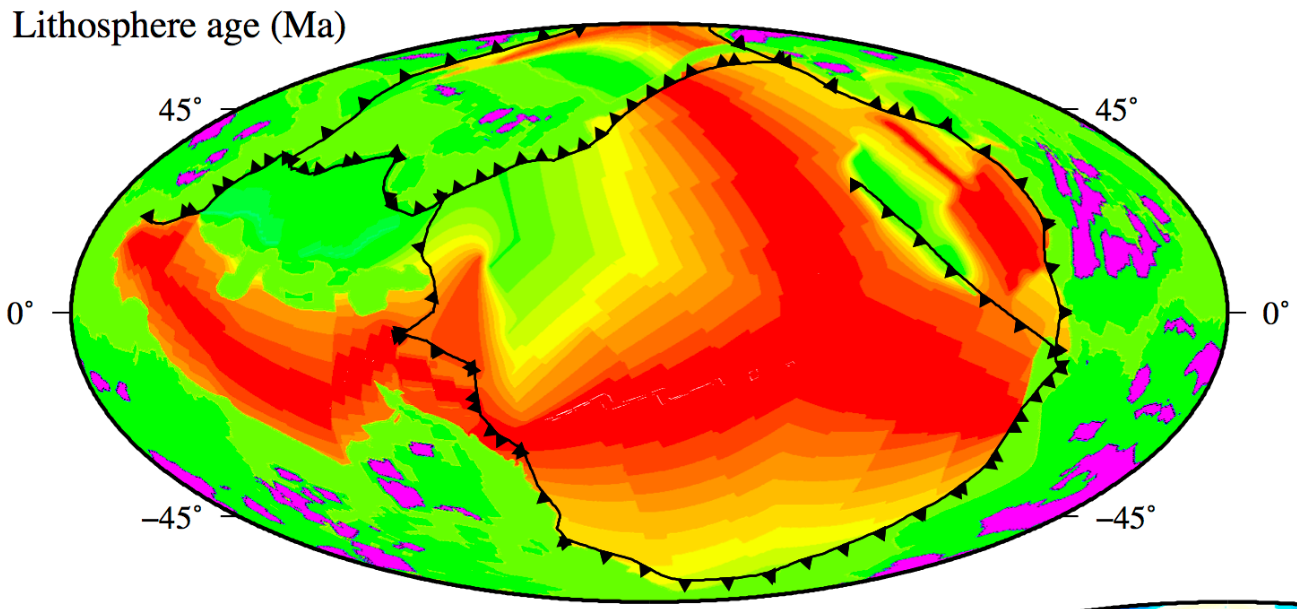


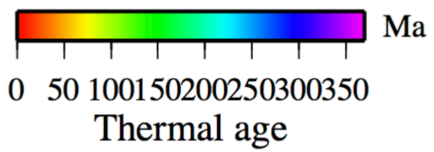
Lithosphere Structure

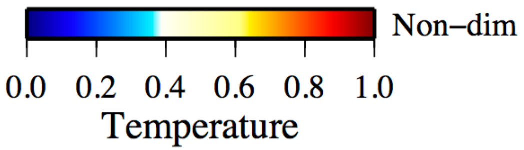


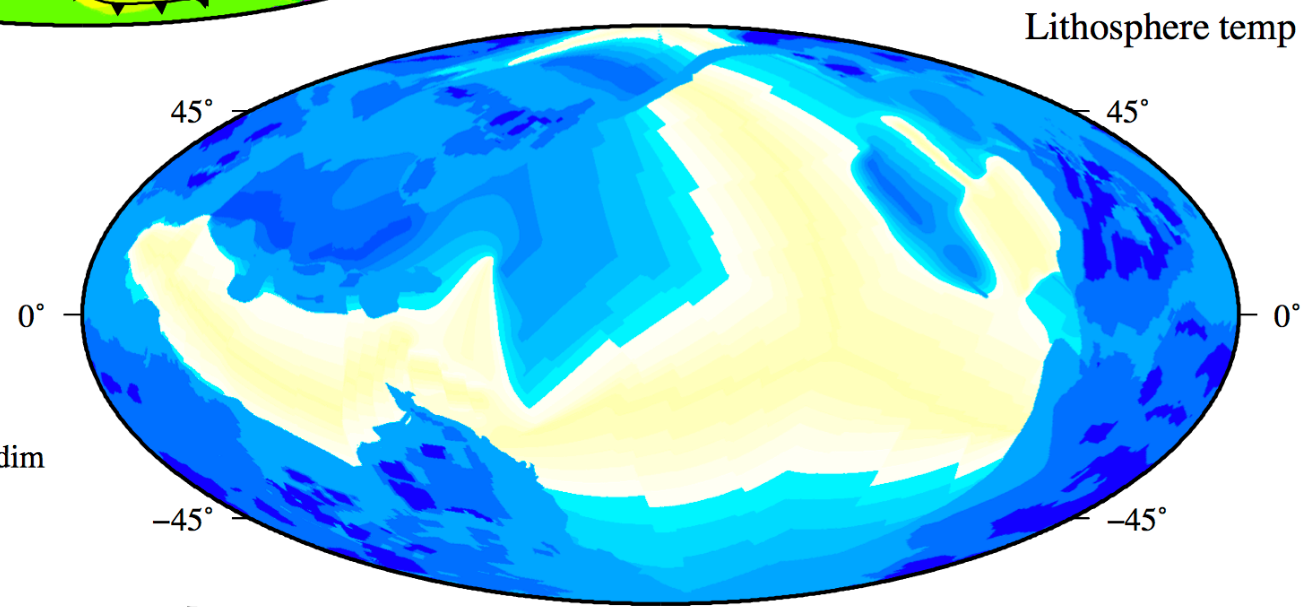
Continental Lithosphere
Artemieva (2006)

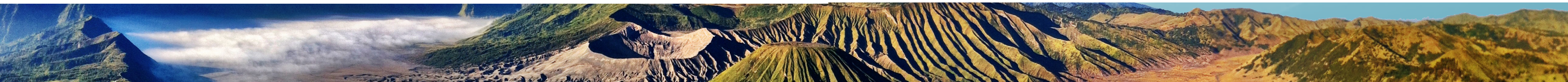
230 Ma
60 km depth







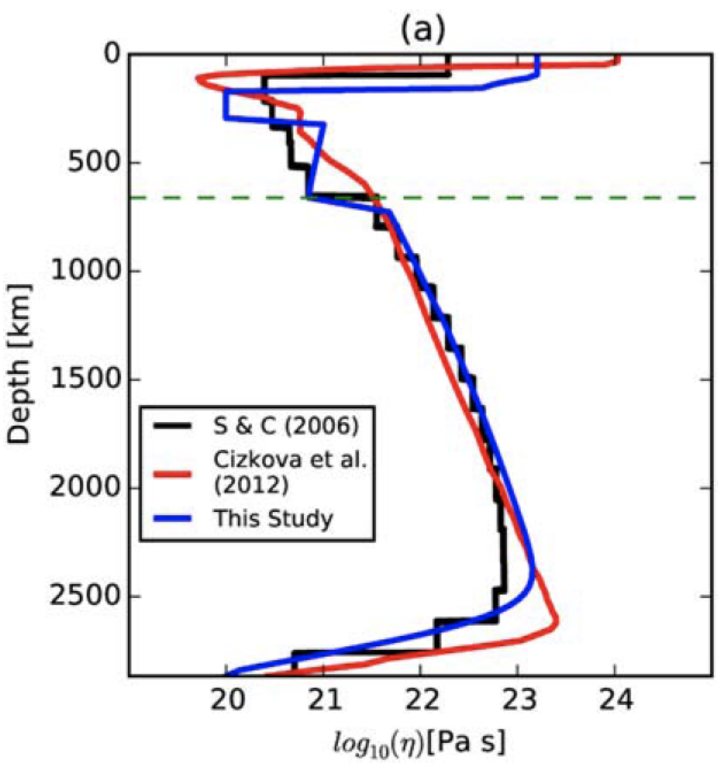




Hassan et al. (2015)

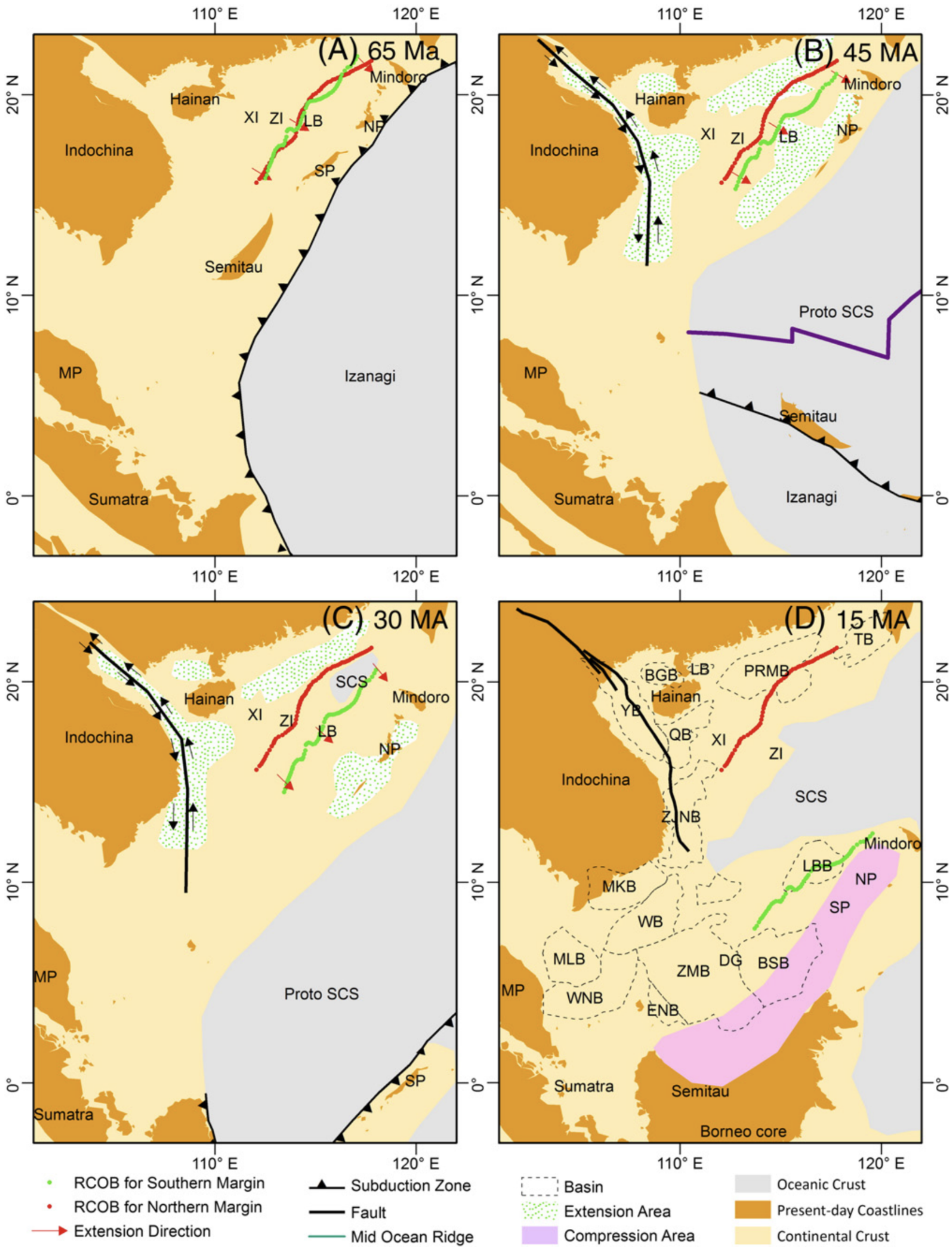
Table 1. Physical Parameters and Constants

Parameter	Symbol	Value	Units
Rayleigh number	Ra	5×10^{8}	
Earth radius	R_0	6371	km
Density	ρ_0	3930	kg m^{-3}
Thermal expansivity	α_0	1.42×10^{-5}	K^{-1}
Thermal diffusivity	κ_0	1×10^{-6}	$m^2 s^{-1}$
Specific heat capacity	C_p	1100	J $kg^{-1} K^{-1}$
Gravitational acceleration	g	10	m s^{-2}
Surface temperature	T_s	300	K
Dissipation number	Di	0.8	
Reference viscosity	η_0	1×10^{21}	Pa s
Internal heating	H	100	



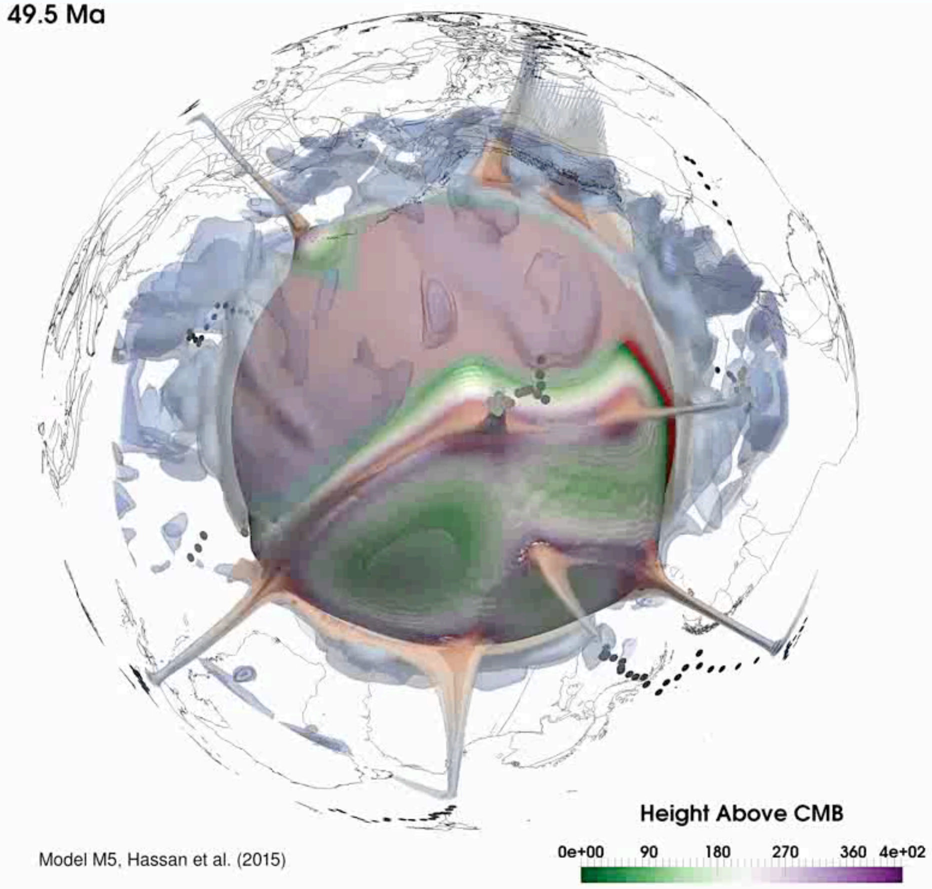
The top and the bottom TBLs each encompass a temperature drop of 1225 K and the initial adiabatic temperature profile has a potential temperature of 1525 K.

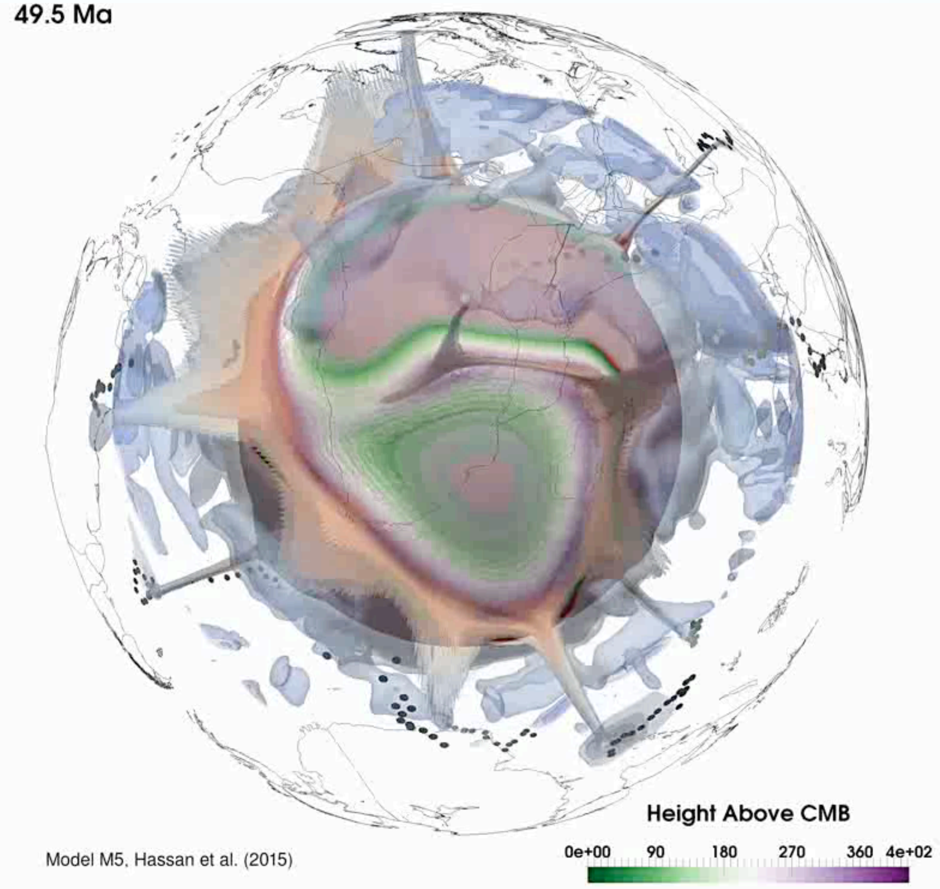
Nondimensional internal heat generation rate of 100 is applied in all test cases, which is similar to that used in earlier studies [e.g., Bunge, 2005; Zhong, 2006; Leng and Zhong, 2008; Zhang et al., 2010].



Bai et al. (2015)

Full-fit reconstruction of the South China Sea conjugate margins





Source: Hassan et al. (2015), EarthByte

A rapid burst in hotspot motion through the interaction of tectonics and deep mantle flow

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