Linked plate motion and mantle convection models of the India–Eurasia collision

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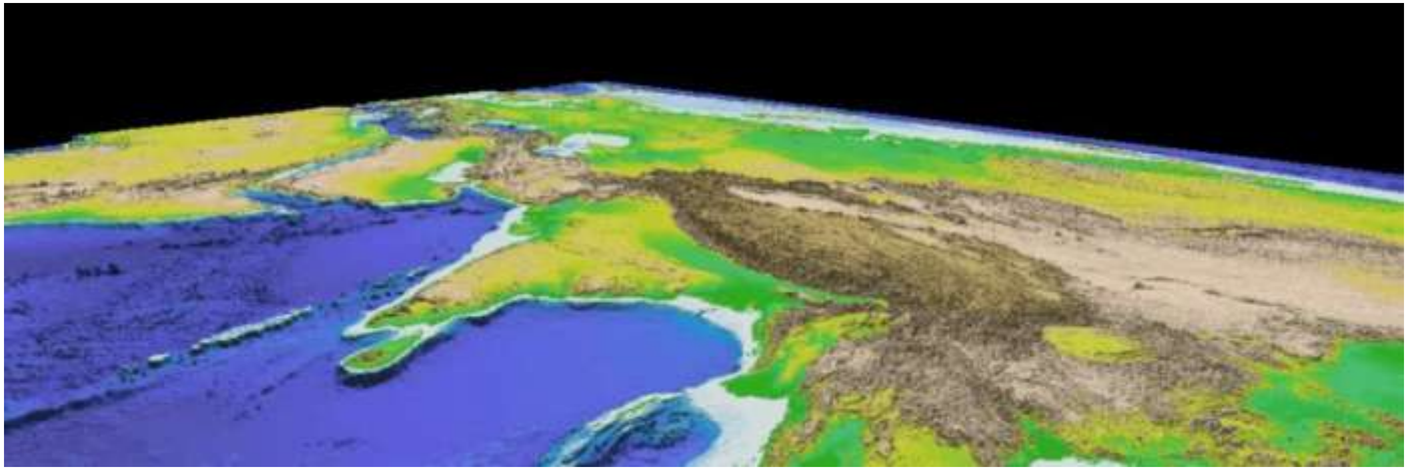
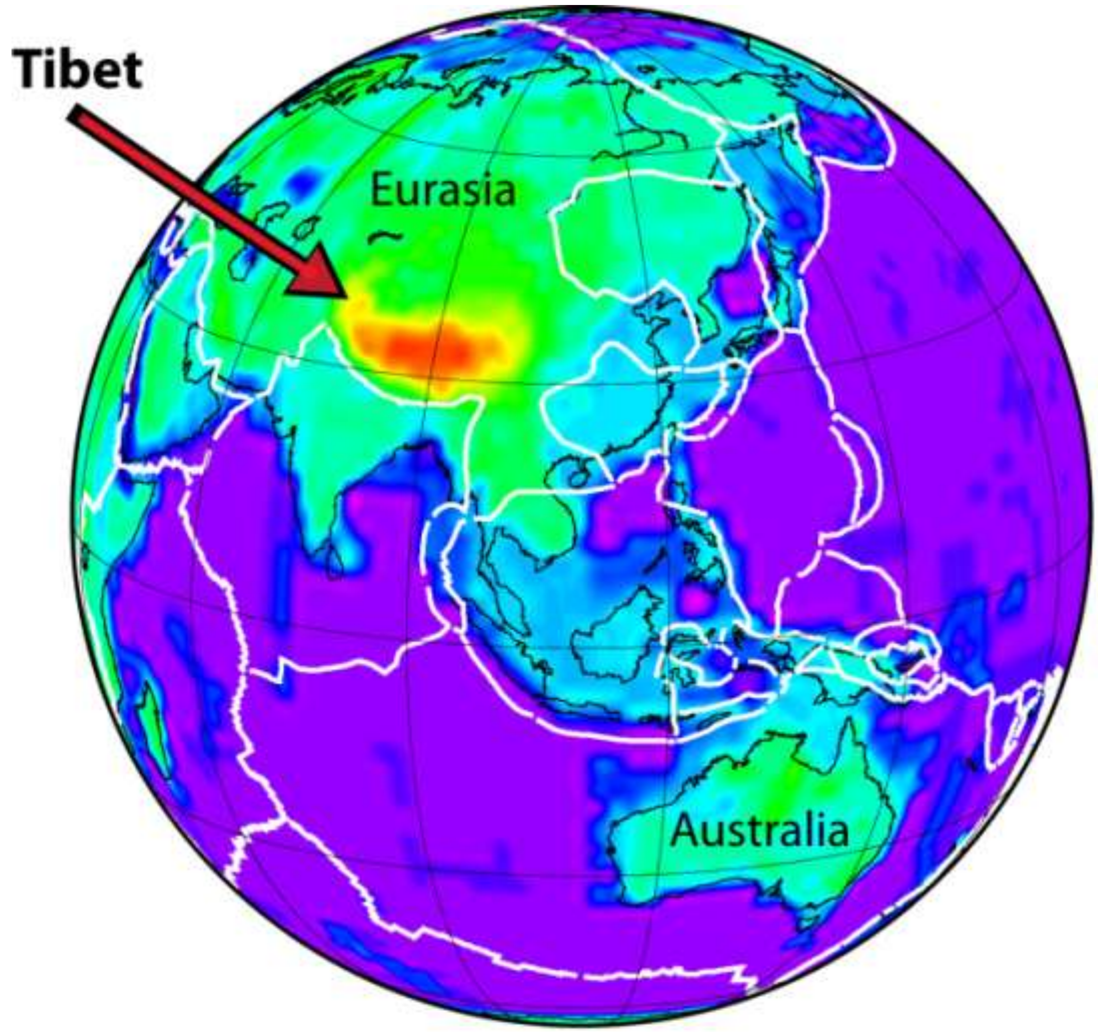
Earth BYTE
Linking observations to kinematic and dynamic models

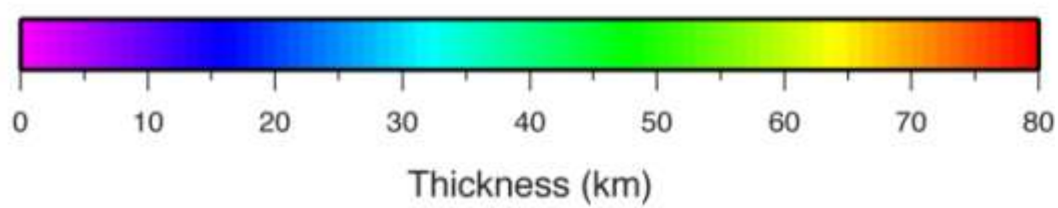
Context: India-Eurasia collision

- Breakup of Gondwana
- India-Eurasia collision ~70 and 35 Ma
- Why study the area?
  - Significant impacts on NW Australian margin evolution
  - Ocean circulation – Tethyan ocean basins
  - Uplift of Himalayas and Tibet affecting climate
  - Regional tectonics, deformation, volcanism, etc.



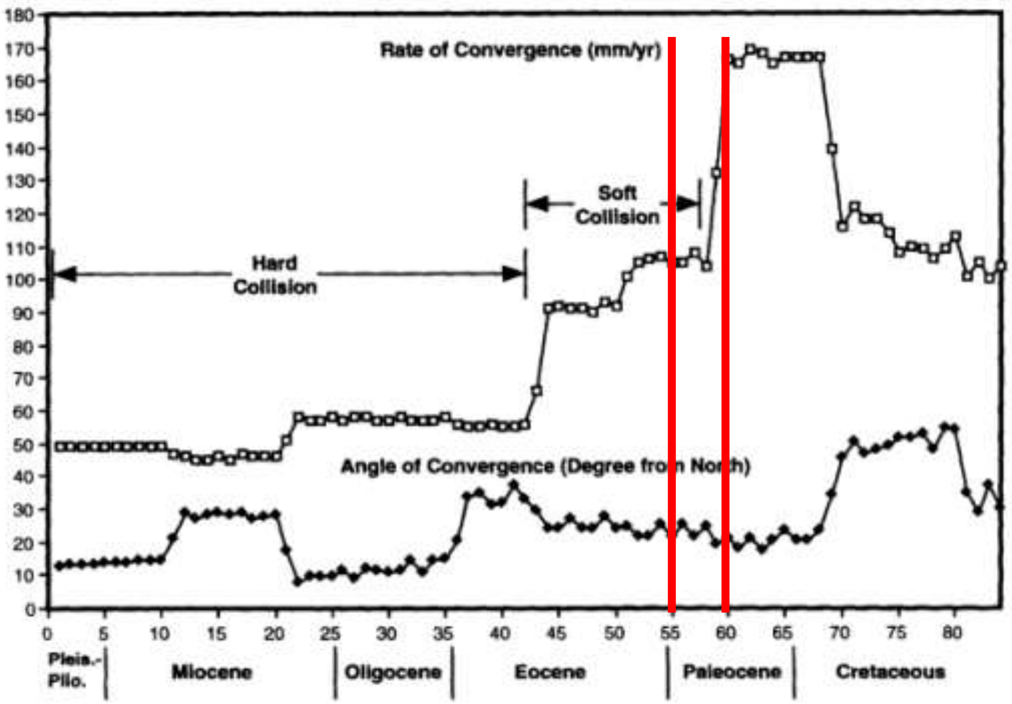


Crustal thickness (Lakse et al. 2000)

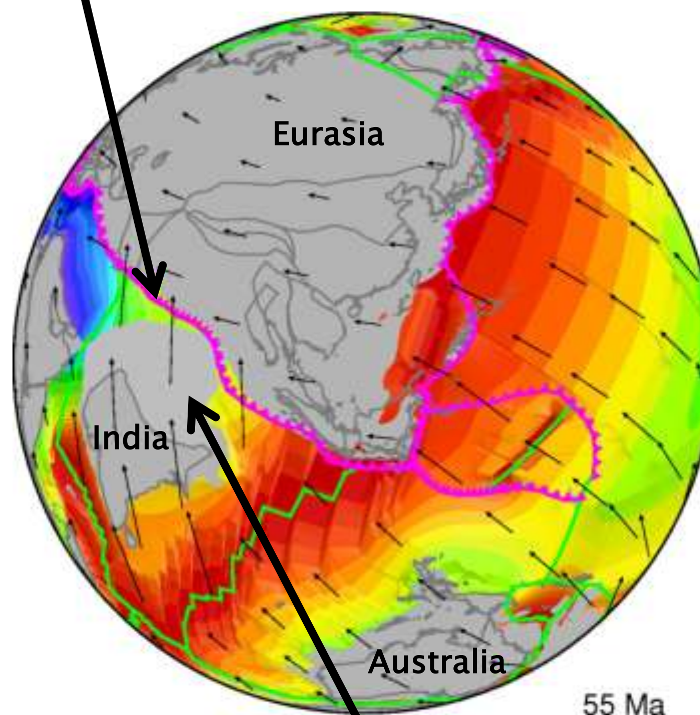


Conventional model of collision

Lee & Lawver (1995)

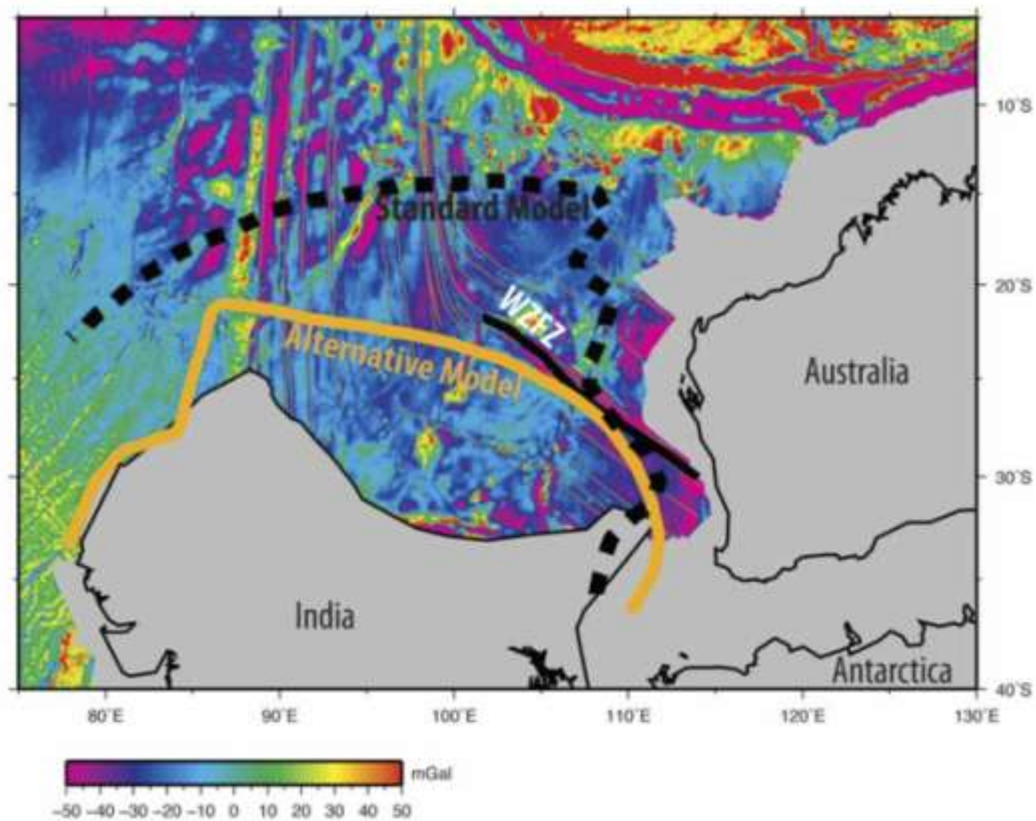


Andean-style subduction

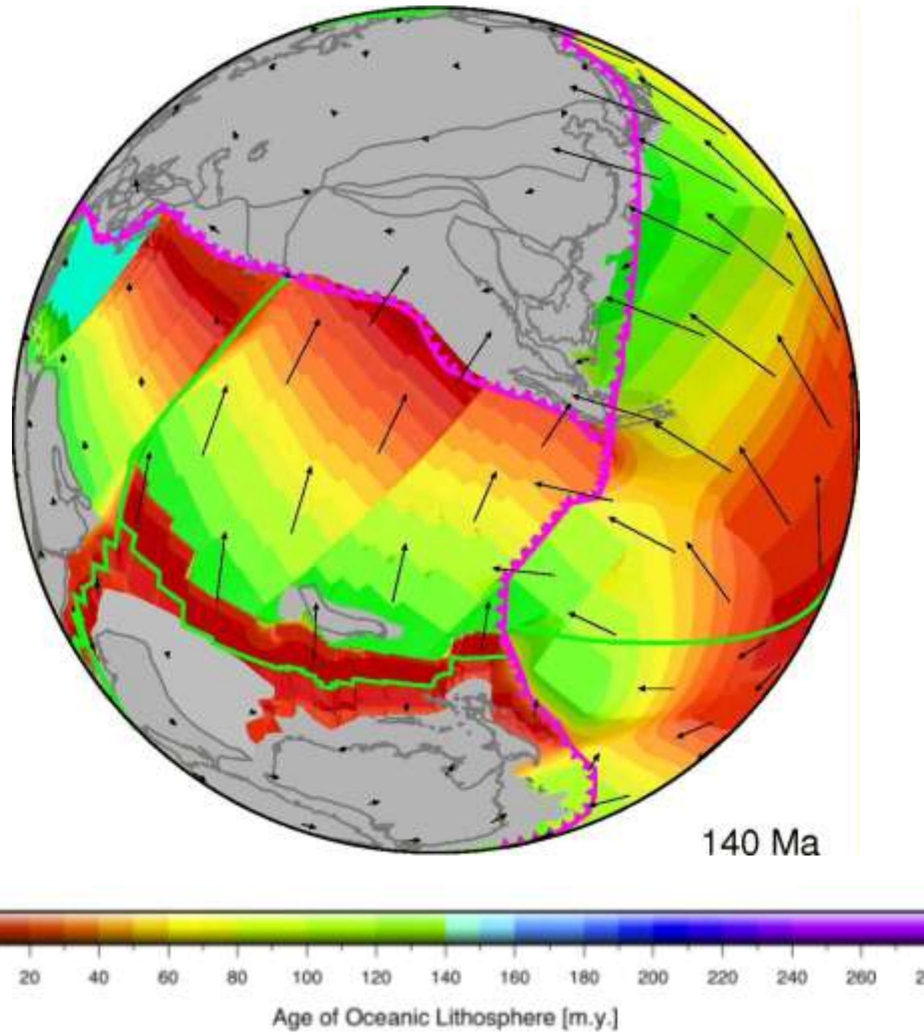


Greater India extent made to fit collision

Greater India



Conventional model of collision



Geological responses to continental colision

~60 Ma: Transhimalayan granitoid emplacement

~40 Ma: High P/T metamorphism near Mt Everest

~34 Ma: Red River Fault activation

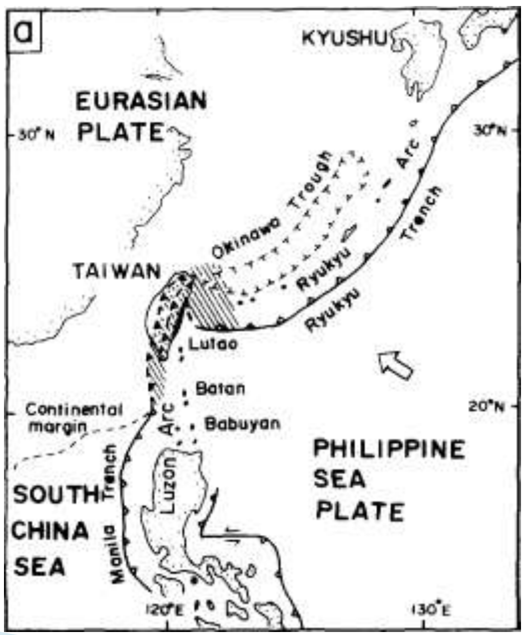
~32 Ma: South China Sea spreading

~20 Ma: Accelerated uplift of Tibet

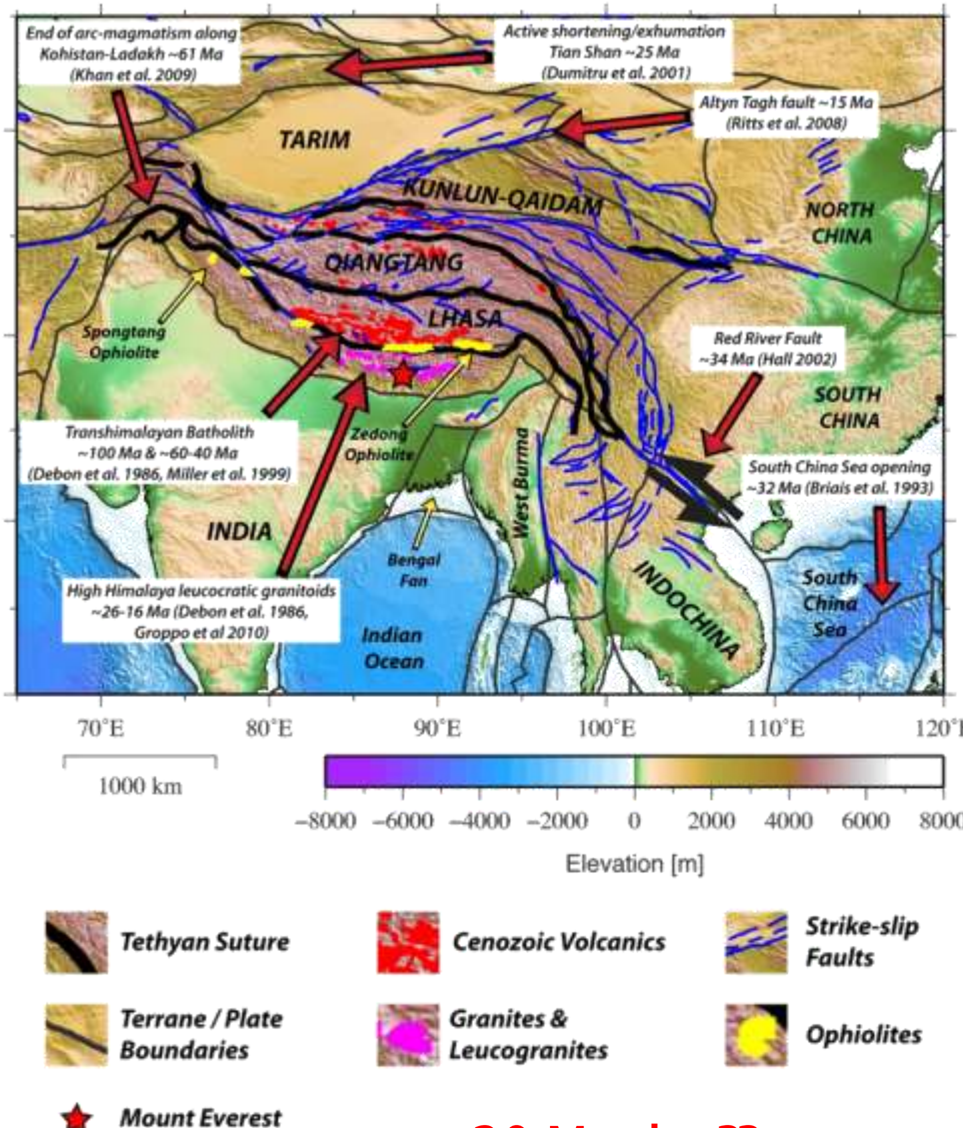
Taiwan–Luzon collision

5 Ma onset

3 Ma orogeny

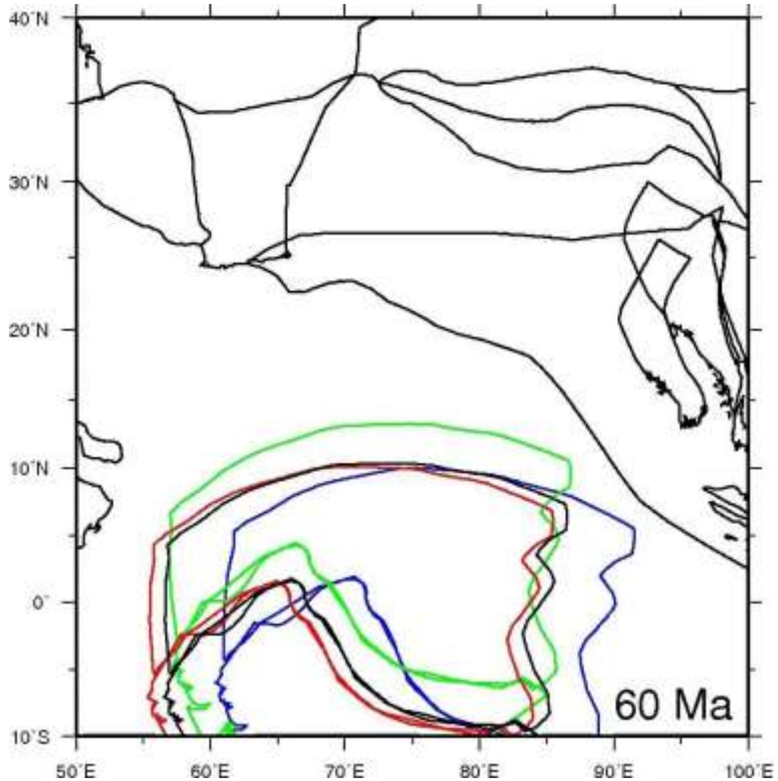


Teng (1990)



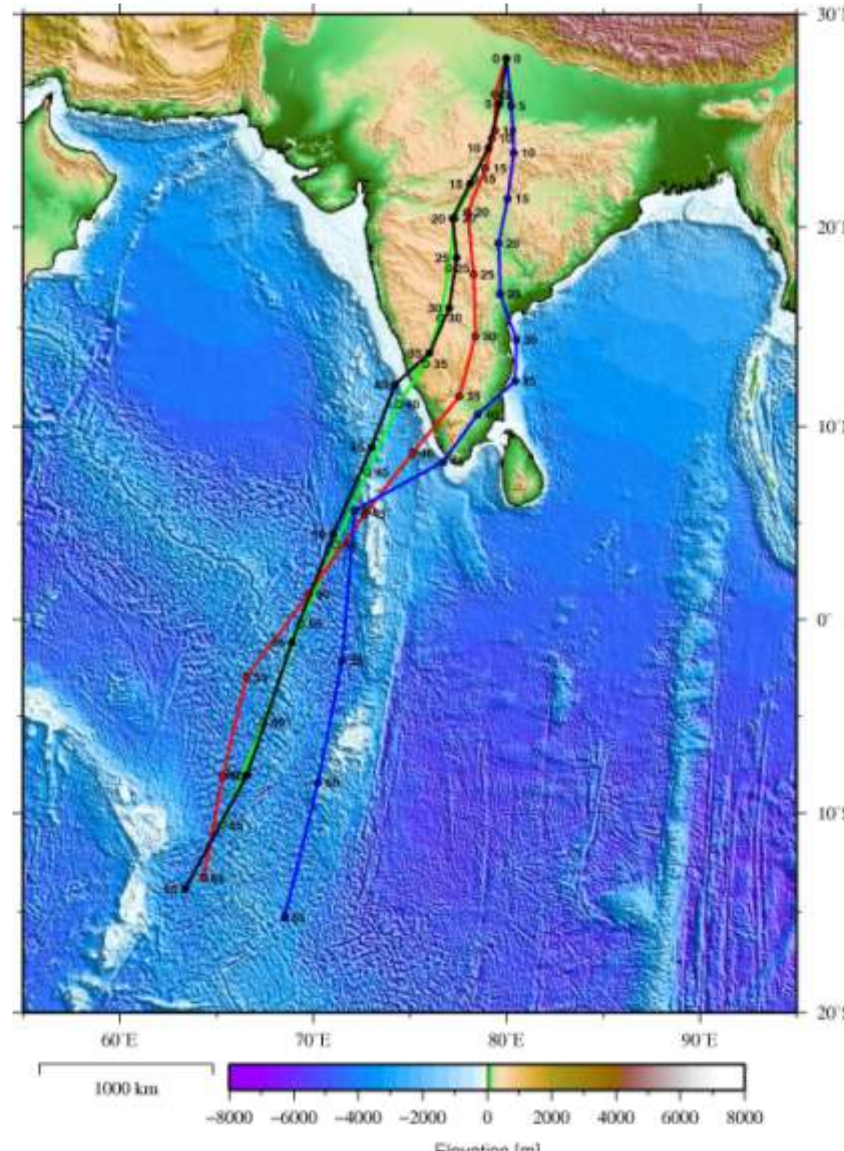
20 Myr lag??

Rotation models of India



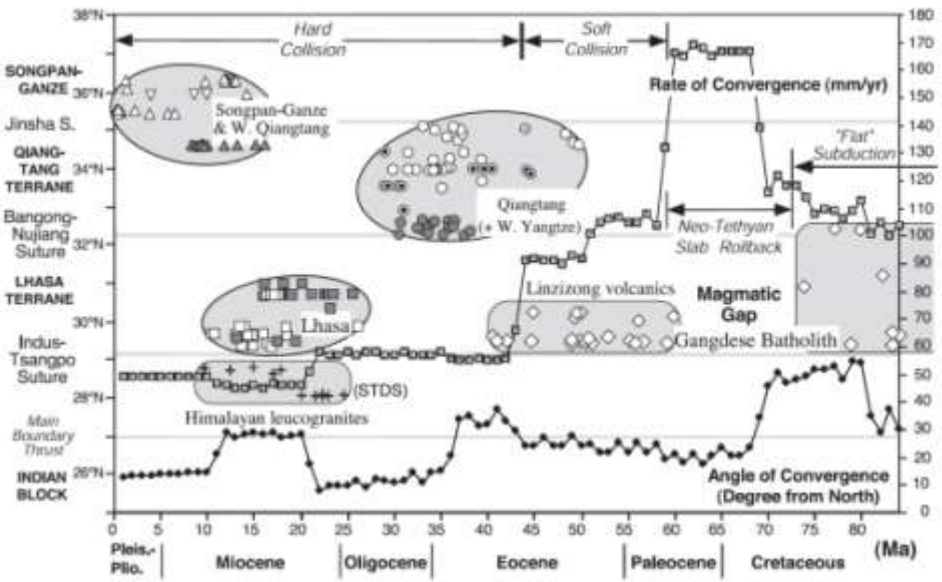
Muller et al. (2008a)
Lee & Lawver (1995)
Molnar & Stock (2009)
Patriat & Achache (1984)

Cande & Kent (1995) timescale

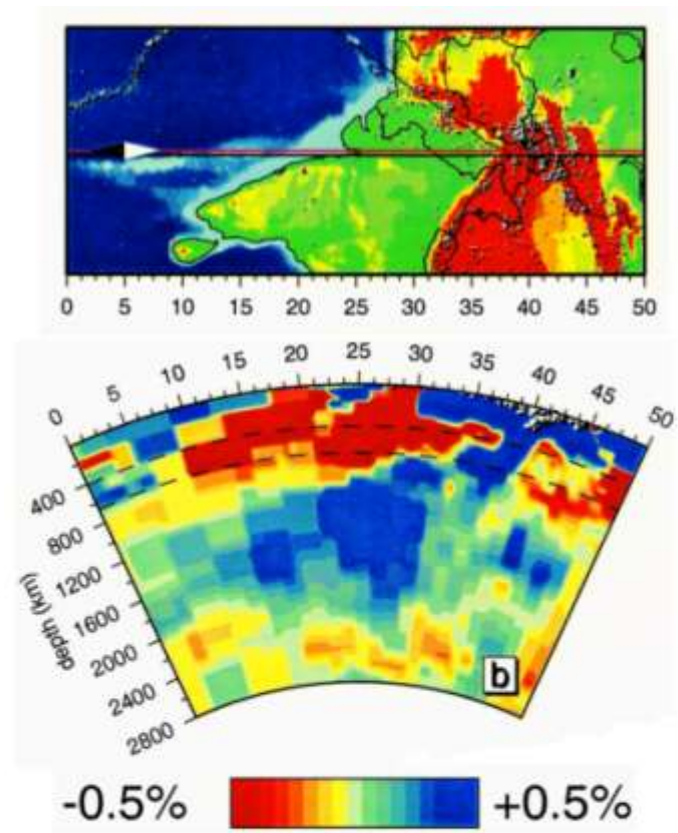


Evidence for a back-arc

- Ophiolites within suture zone
- Seismic tomography
- Magmatic “gap”

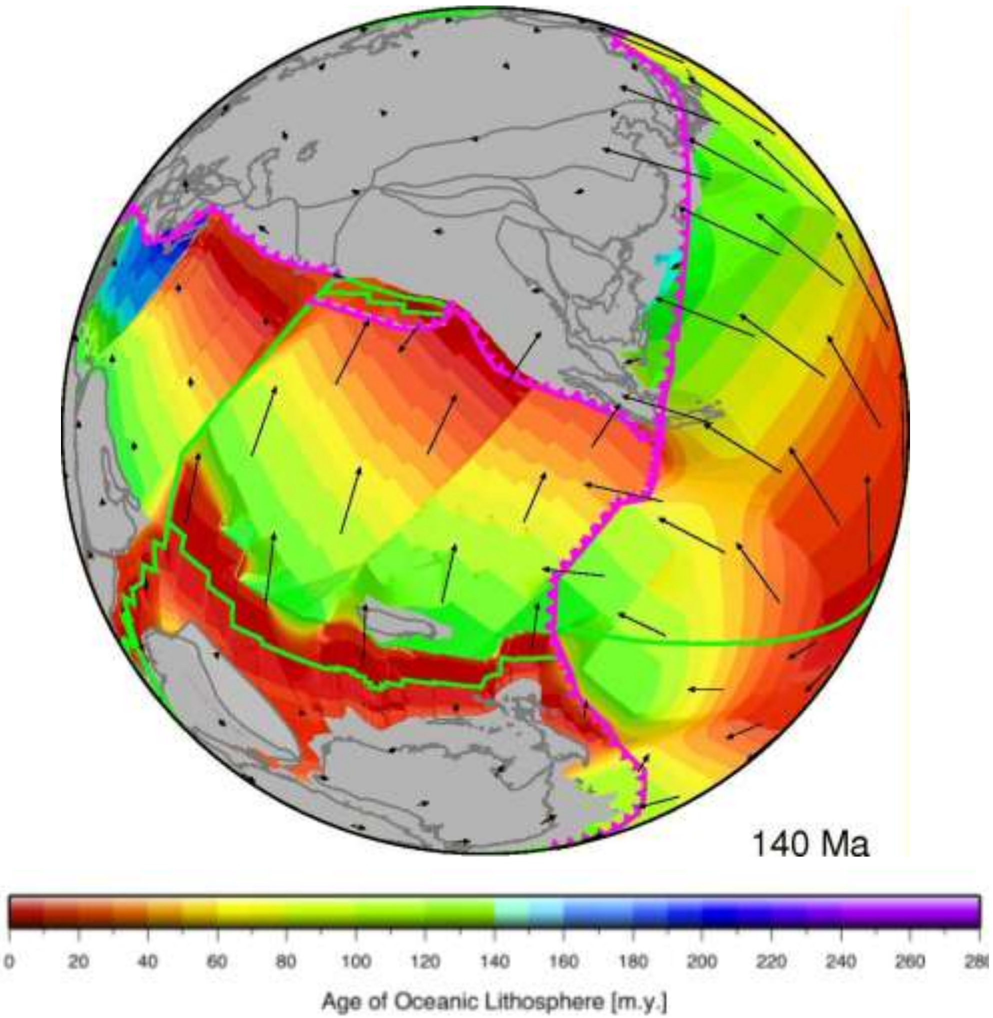


Chung et al. (2005)



Van der Voo et al. (1999)

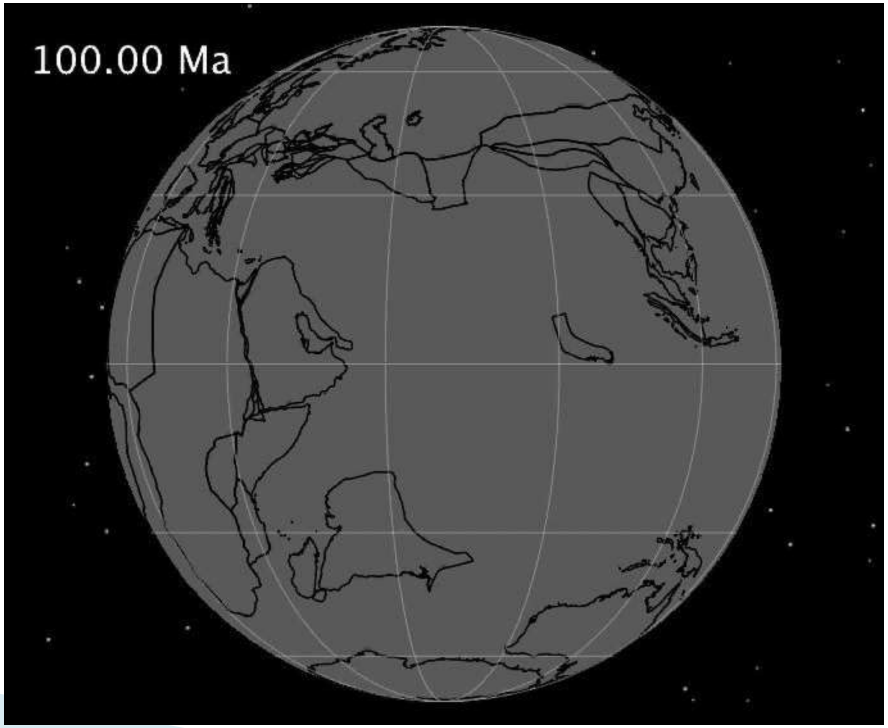
Alternative Scenario



Methodology – Kinematics

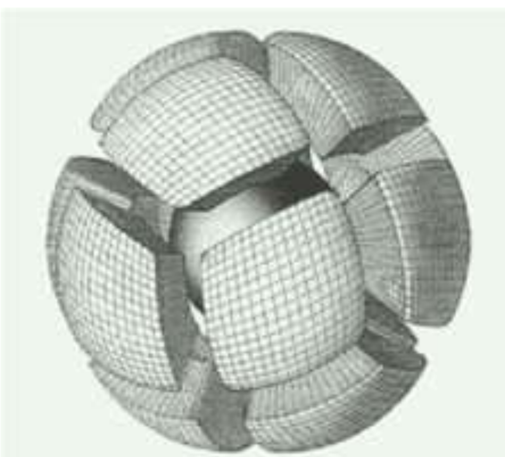
1. Implement plate motion models in GPlates, **only change pre-collision margins**
2. Generate seafloor age-grids
3. Export plate velocities

GPlates
www.gplates.org



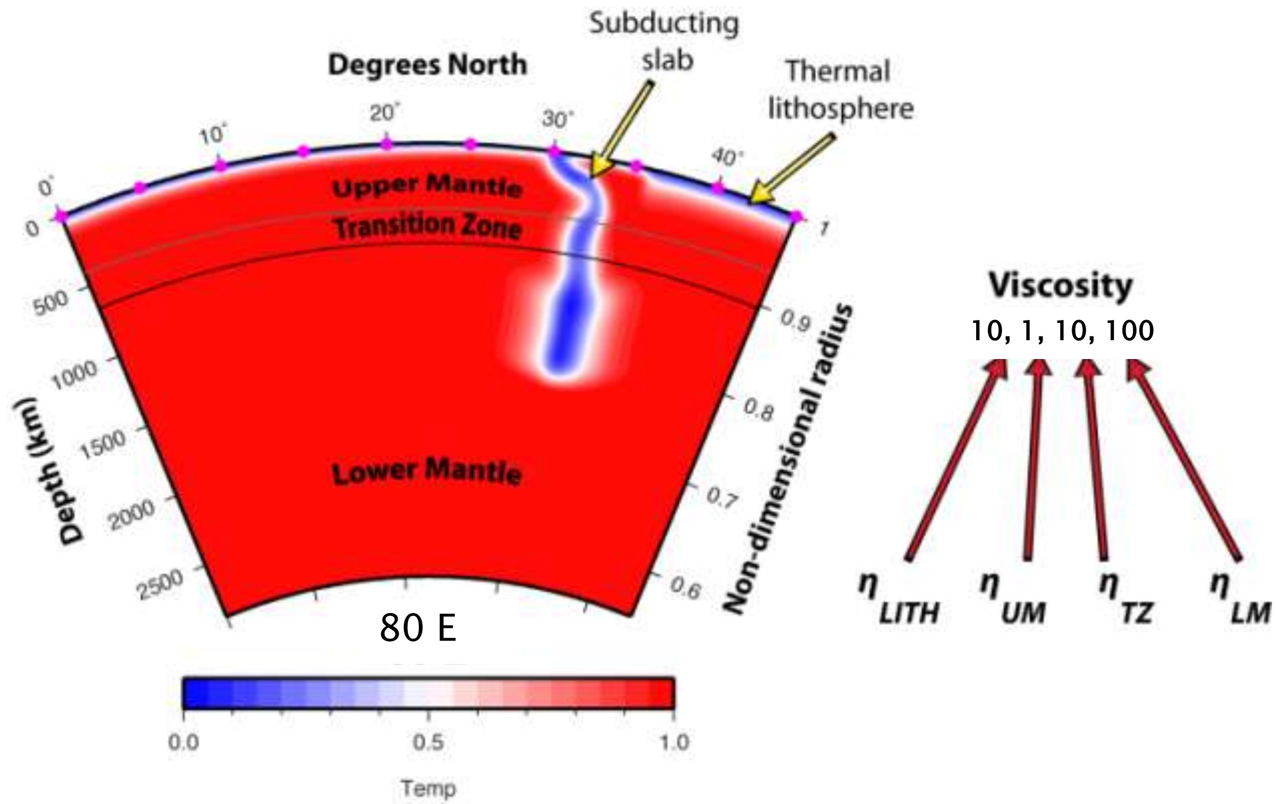
Methodology – Geodynamics

4. Specify parameters – viscosity, etc.
5. Generate initial conditions
6. Run global 4D CitcomS thermo–chemical models



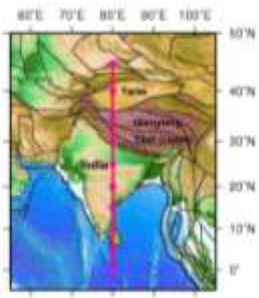
http://epsc.wustl.edu/geodynamics/figures/CitcomS.jps

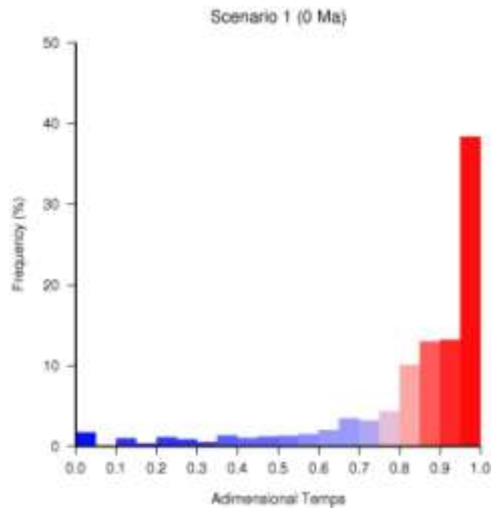
Model parameters

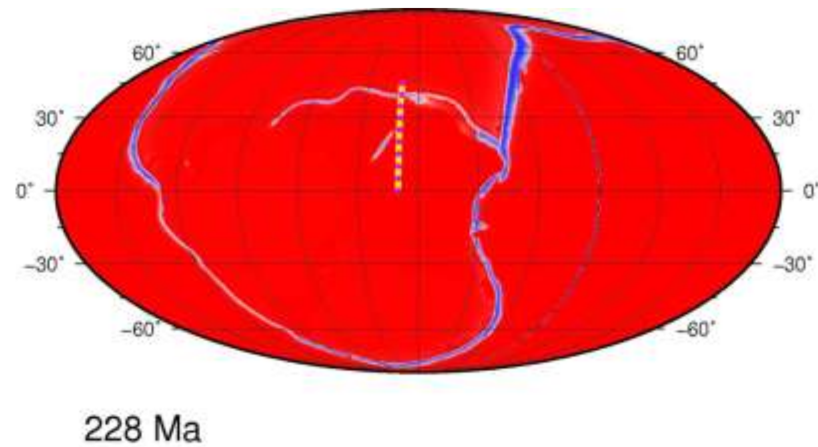


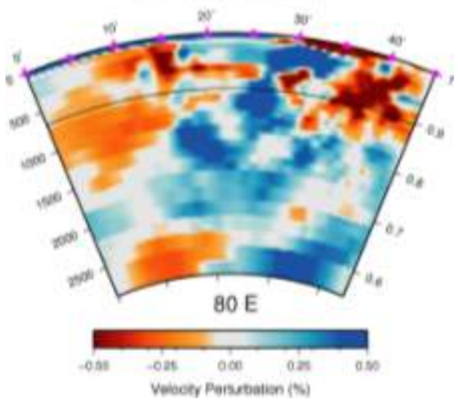
- 30-60X viscosity contrast between upper and lower mantle insufficient to maintain slabs at mid-mantle depths as observed in seismic tomography
- 240 – 140 Ma: Initialisation, introduce mantle heterogeneities
- 140 – 0 Ma: Model run
- CPU hours: ~20,000 per model run (~14 days on 96 processors)

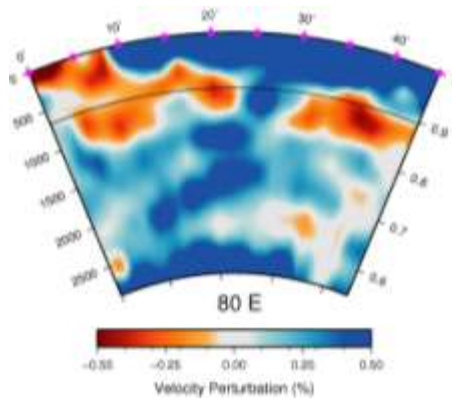
Results: Conventional model of the collision

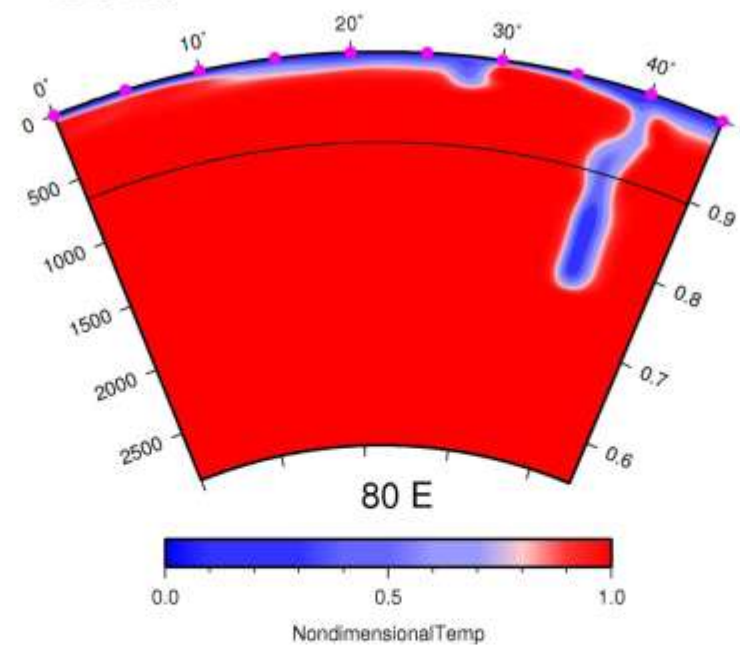




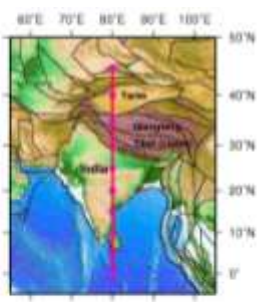


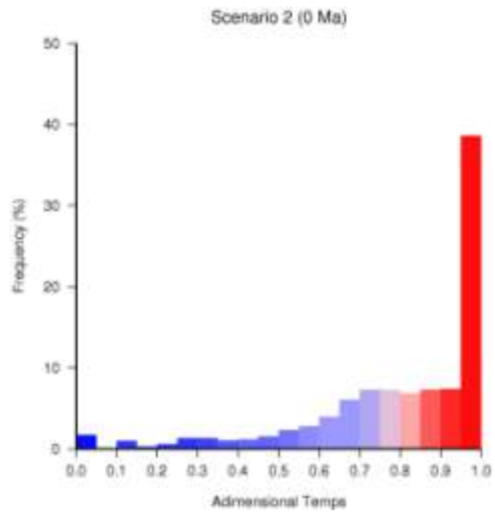


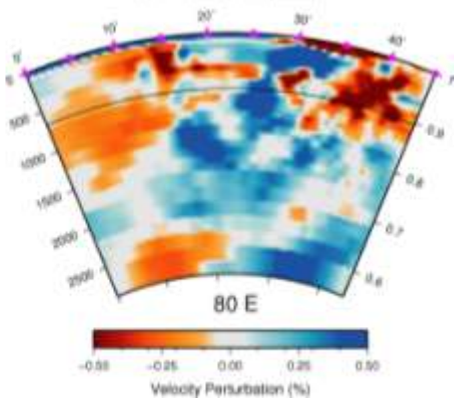


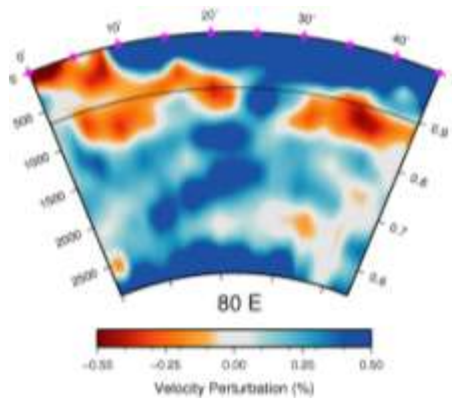


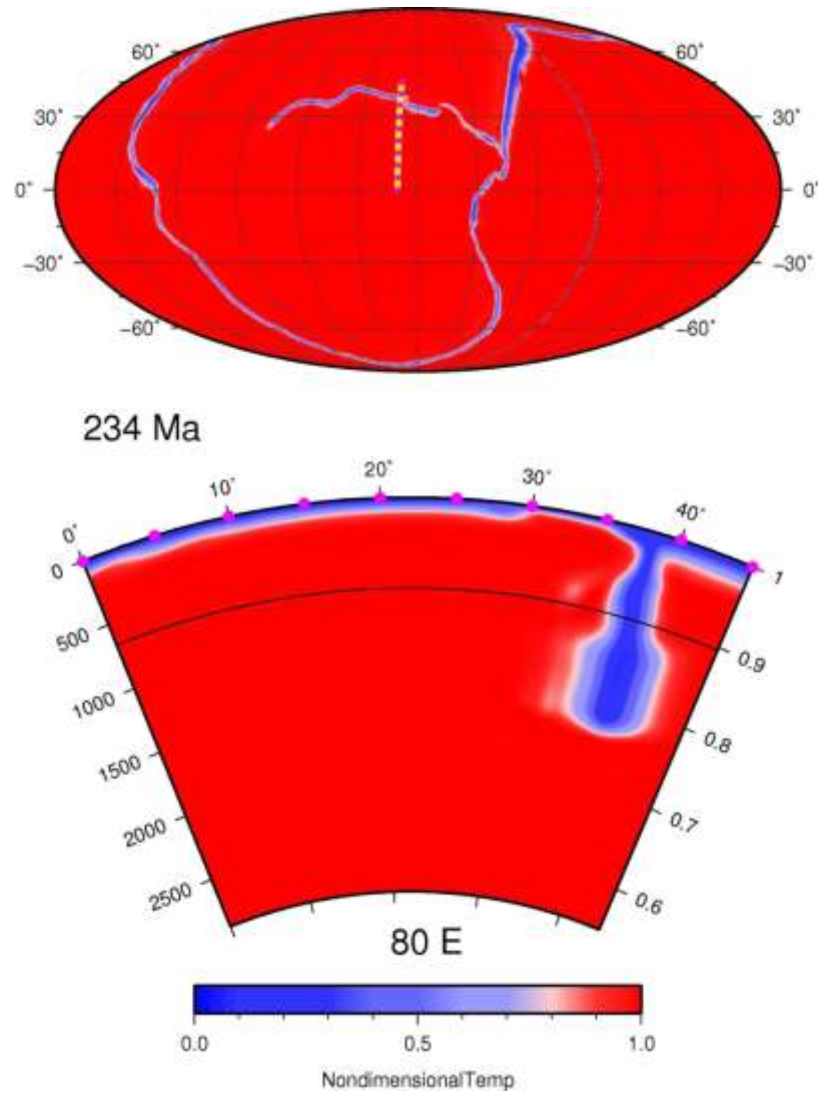
Results: Alternative model of the collision



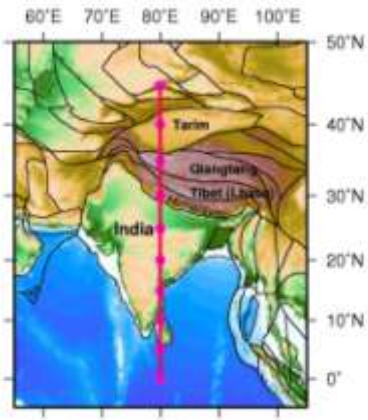


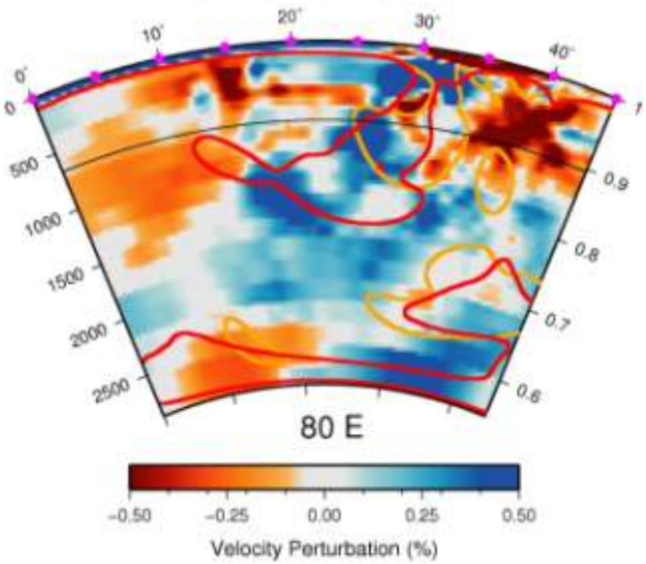


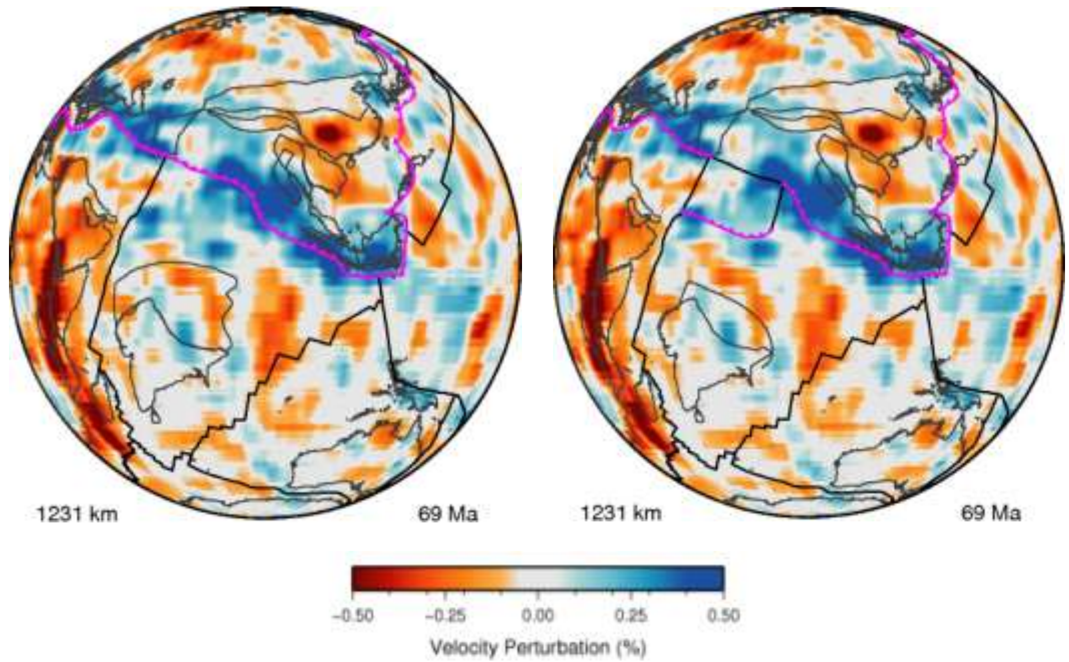




Results – Comparison







Upper mantle: 3 cm/yr
Lower mantle: 1.2 cm/yr

$$A = \frac{z}{m_{UM}} \quad \text{where } z \le 660$$
$$A = \frac{660}{m_{UM}} + \frac{z-660}{m_{LM}} \quad \text{where } 660 < z \le 2900$$

Equation 4.4.

where A is the age of the subducted material in Myr, z is the depth of the horizontal tomography slice in km, and m_{UM} and m_{LM} are the sinking rates applied to the upper and lower mantle respectively in mm/yr.

Advantages and disadvantages of method

- Advantages
  - Can implement and test multiple scenarios easily and interactively in GPlates
  - Global 4D spherical shell mantle convection
  - Control over all thermo-chemical parameters
  - Output timesteps – study evolution of subduction
  - Output dynamic topography

- Disadvantages
  - Difficulty in maintaining continuous slabs when subduction zone migrates QUICKLY (being addressed in new CitcomS workflow)

Main findings

- Chronology – TWO events
  - 60 Ma collision between Greater India and island arc to emplace ophiolites, initial drop in convergence rate
  - 60–40 Ma subduction of back-arc to emplace Transhimalayan Granitoids
  - 40 Ma continent–continent collision triggering major responses in geology, including sudden drop in convergence
- Alternative scenario (with back-arc) better accounts for slab material in tomography
  - Volumetrically
  - Laterally
  - Vertically

CitcomS Resolution

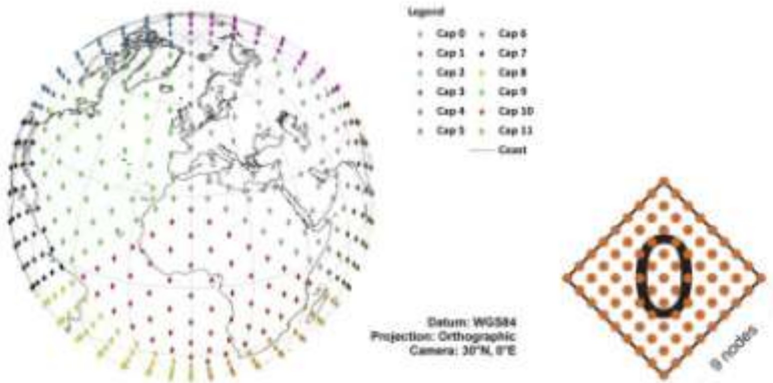


Figure 4.9. Equidistant distribution of mesh nodes in *CitcomS* distributed in 12 diamond-shaped caps [left], with a specific example of one cap with low-resolution 9×9 surface mesh

Table 4.2. Vertical and lateral mesh resolution in *CitcomS* models

Resolution		Surface: 33 mesh Vertical: 33 levels	Surface: 129 mesh Vertical: 65 levels
Vertical	Upper mantle	44 km	26.4 km
	Lower mantle	124 km	56 km
Lateral	Surface	225 km	58 km
	Core-mantle boundary	123 km	31 km
	Total mesh nodes	431,244	12,979,980

CitcomS Parameters

Table 4.3. *CitcomS* model parameters

Constant variables	
Reference density, ρ_0	3340 kg/m^3
Reference viscosity, η_0	1×10^{21} Pa s
Thermal diffusivity, κ	1×10^{-6} m^2/s
Coefficient of thermal expansion, α	3×10^{-5} K^{-1}
Earth radius, R	6371 km
Rayleigh number, Ra	2.4×10^8
Gravitational acceleration, g	9.81 m/s^2
Thermal gradient, ΔT	944 K