William Smith Meeting
Plate Tectonics at 50
GSL - October 2017

Intra-ocean Ridge Jumps, Oceanic Plateaux & Upper Mantle Inheritance

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[5] *Rio de Janeiro State University, Brazil;*
[6] *CPRM, Brazil*

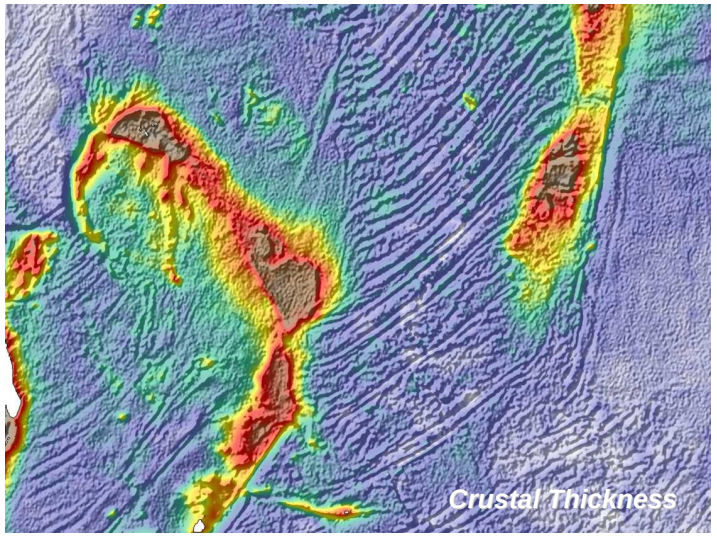

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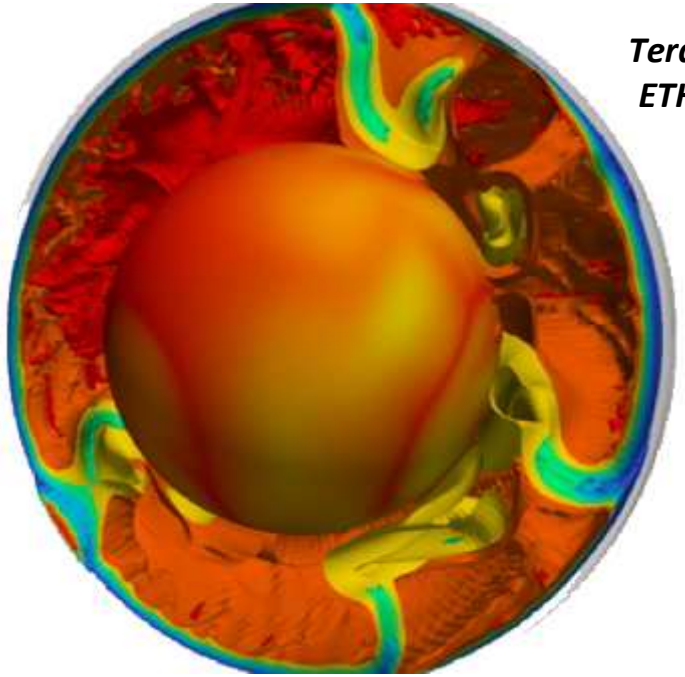
Plate tectonics at 50 years!

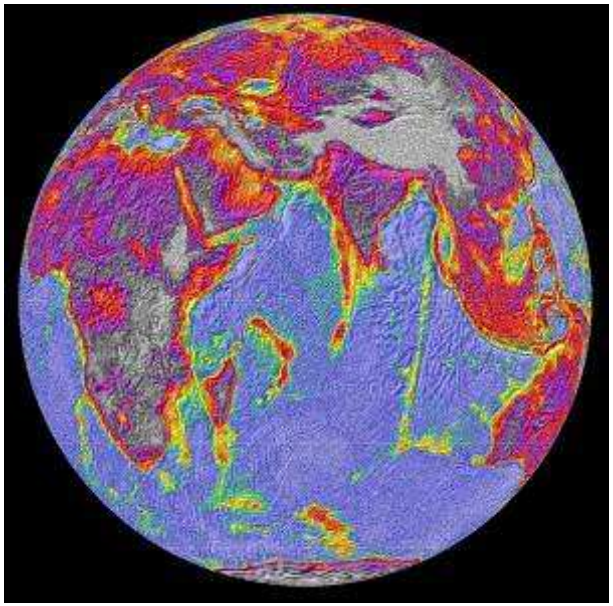
- Extremely successful unifying theory
- Fundamental implications for
    - Surface processes
    - Deep mantle processes
- Thermal-boundary layer convection
- Implications for mantle chemical heterogeneity (*Barry et al 2017*)



Teras Gerya
ETH Zurich

Aims

- To use oceanic crustal thickness mapping to investigate intra-ocean ridge jumps and oceanic plateaux
- To explore complexity of sea-floor spreading and implications for mantle heterogeneity



Crustal Thickness from Gravity Inversion

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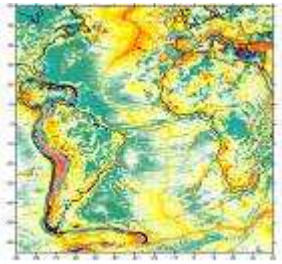
Mapping Oceanic Crustal Thickness Using Gravity Inversion

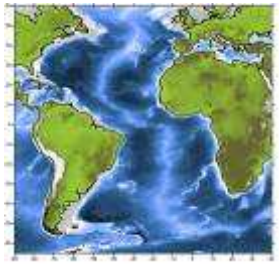
Input Data

- Free air gravity
- Bathymetry
- Ocean isochrons
- Sediment thickness

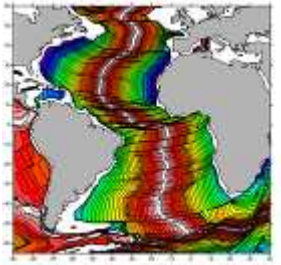
Free Air Gravity (mgal)



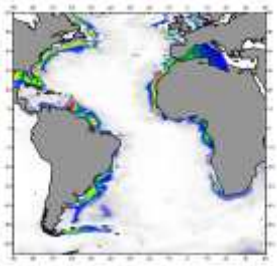
Bathymetry (m)



Ocean Isochrons (Ma)

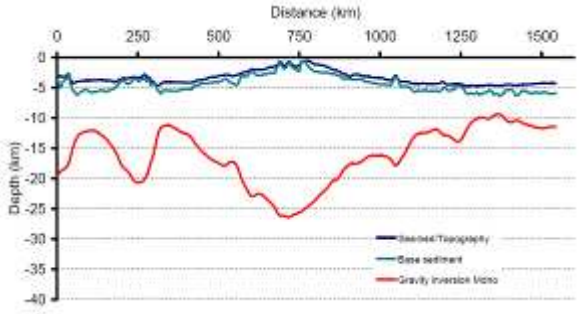


Sediment Thickness (m)

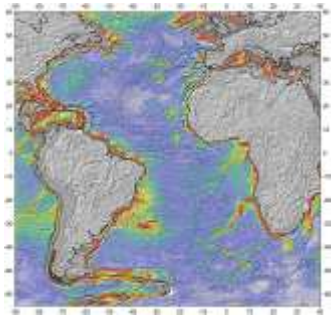


Outputs

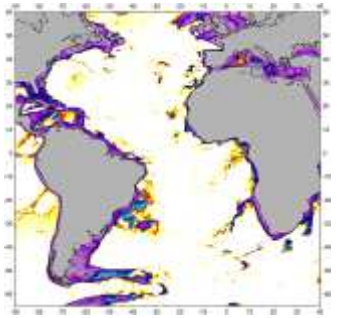
- Moho depth
- Crustal thickness
- Lithosphere thinning factor
- Crustal cross-sections



Crustal Thickness (km)



Lithosphere Thinning (1-1/β)



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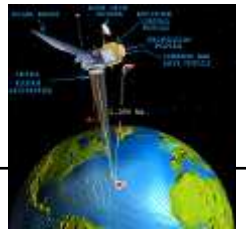
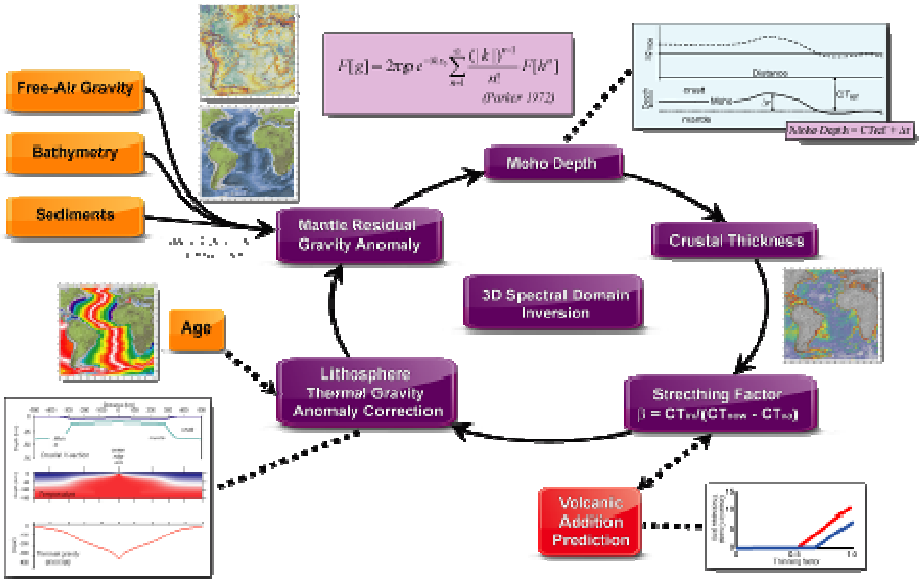
Mapping Oceanic Crustal Thickness Using Gravity Inversion



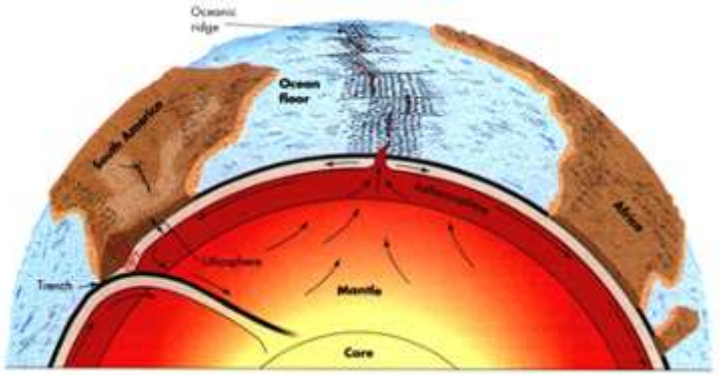


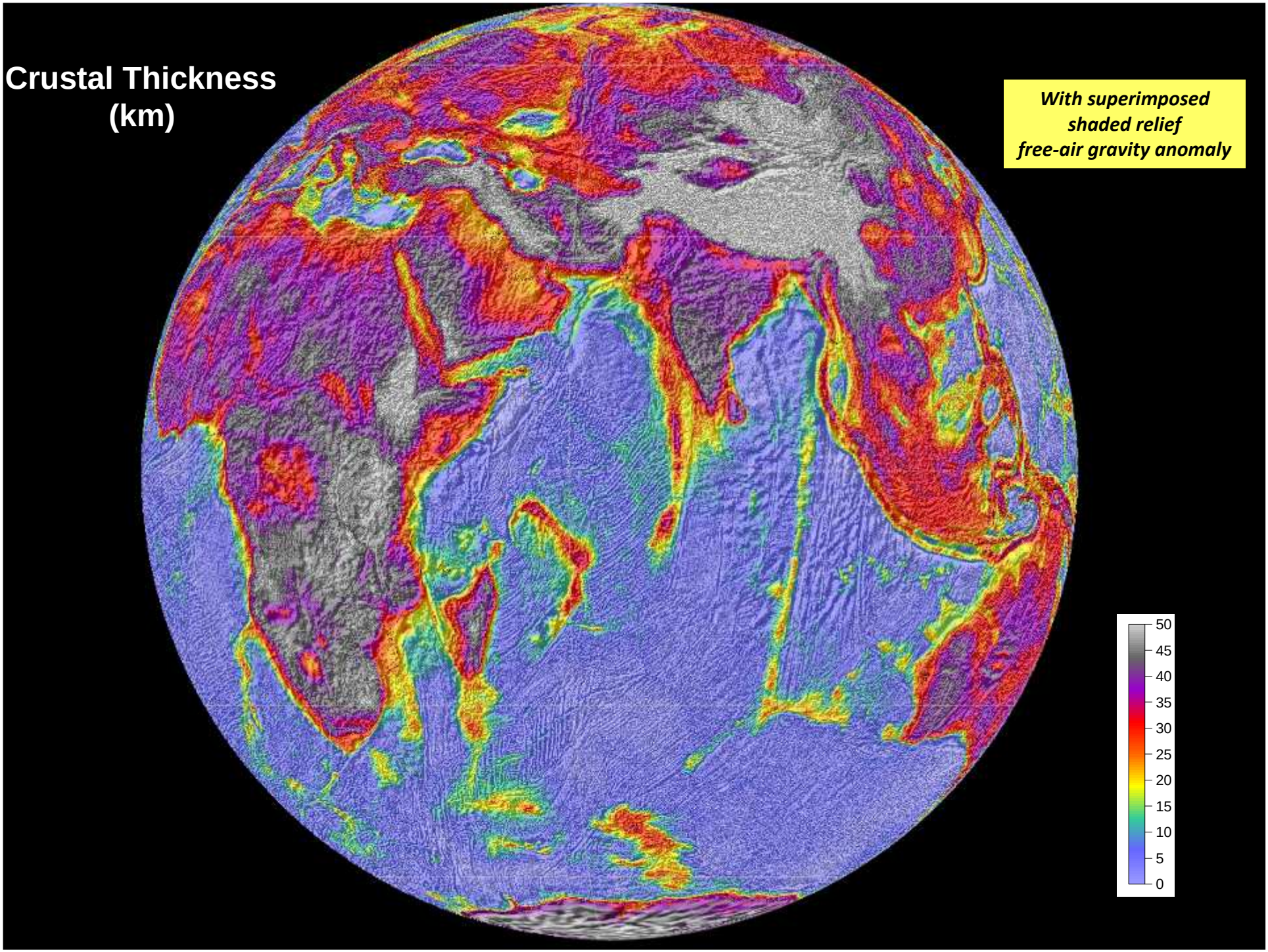
- Satellite gravity anomaly data
- Lithosphere thermal gravity anomaly correction
- 3D spectral inversion for Moho depth
- Low pass Butterworth filter (λ = 100 km)
- Smith's theorem – unique solution for assumptions made
- Magmatic addition prediction uses decompression melting model of White & McKenzie (1989)
- Sediment density model assumes normal compaction

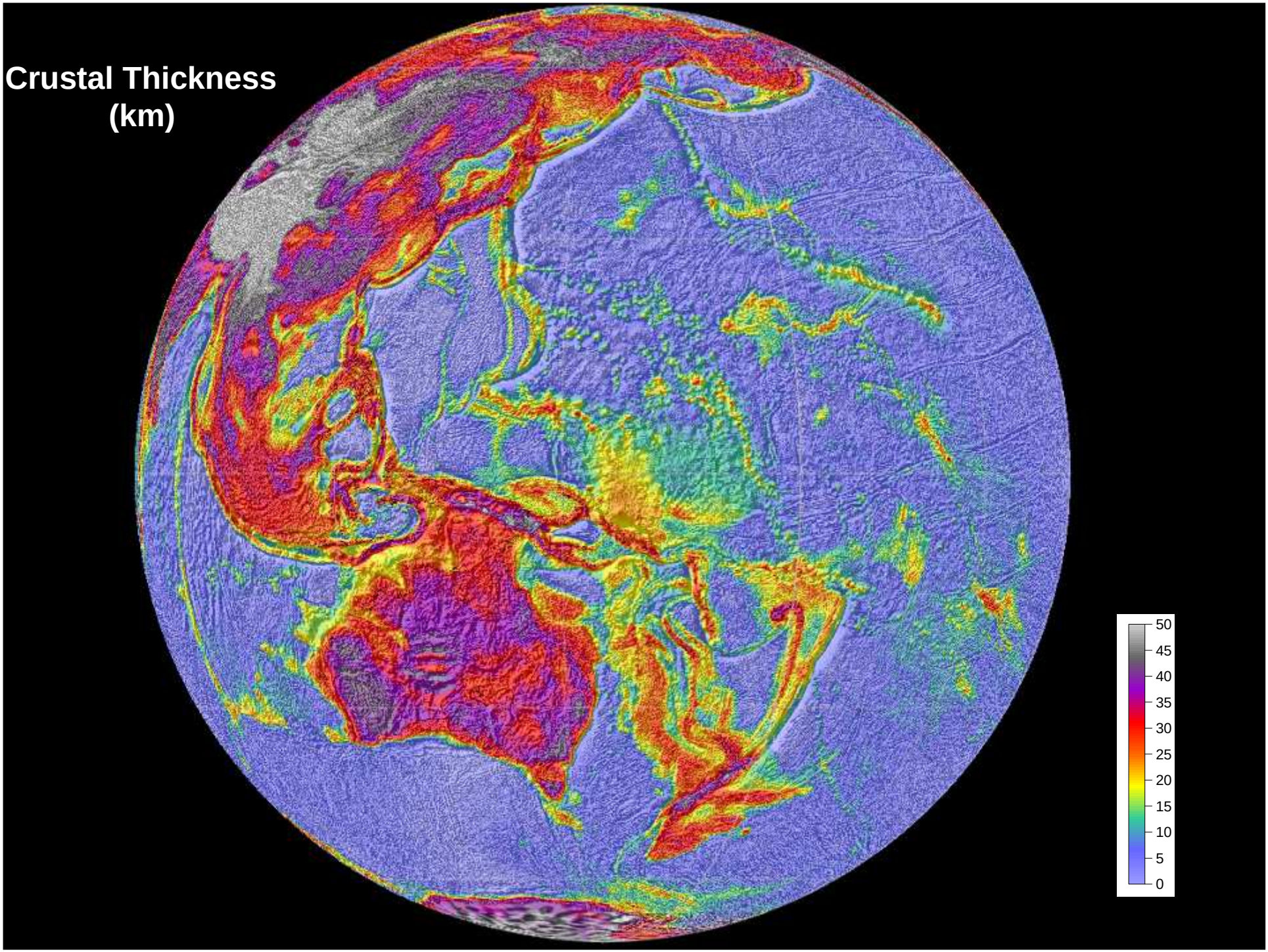
Greenhalgh & Kusznir, Geophys. Res. Lettr., 2007
Chappell & Kusznir, Geophys. J. Int., 2008
Alvey, Gaina, Kusznir & Torsvik, EPSL, 2008
Cowie & Kusznir, J. Petrol Geol., 2012

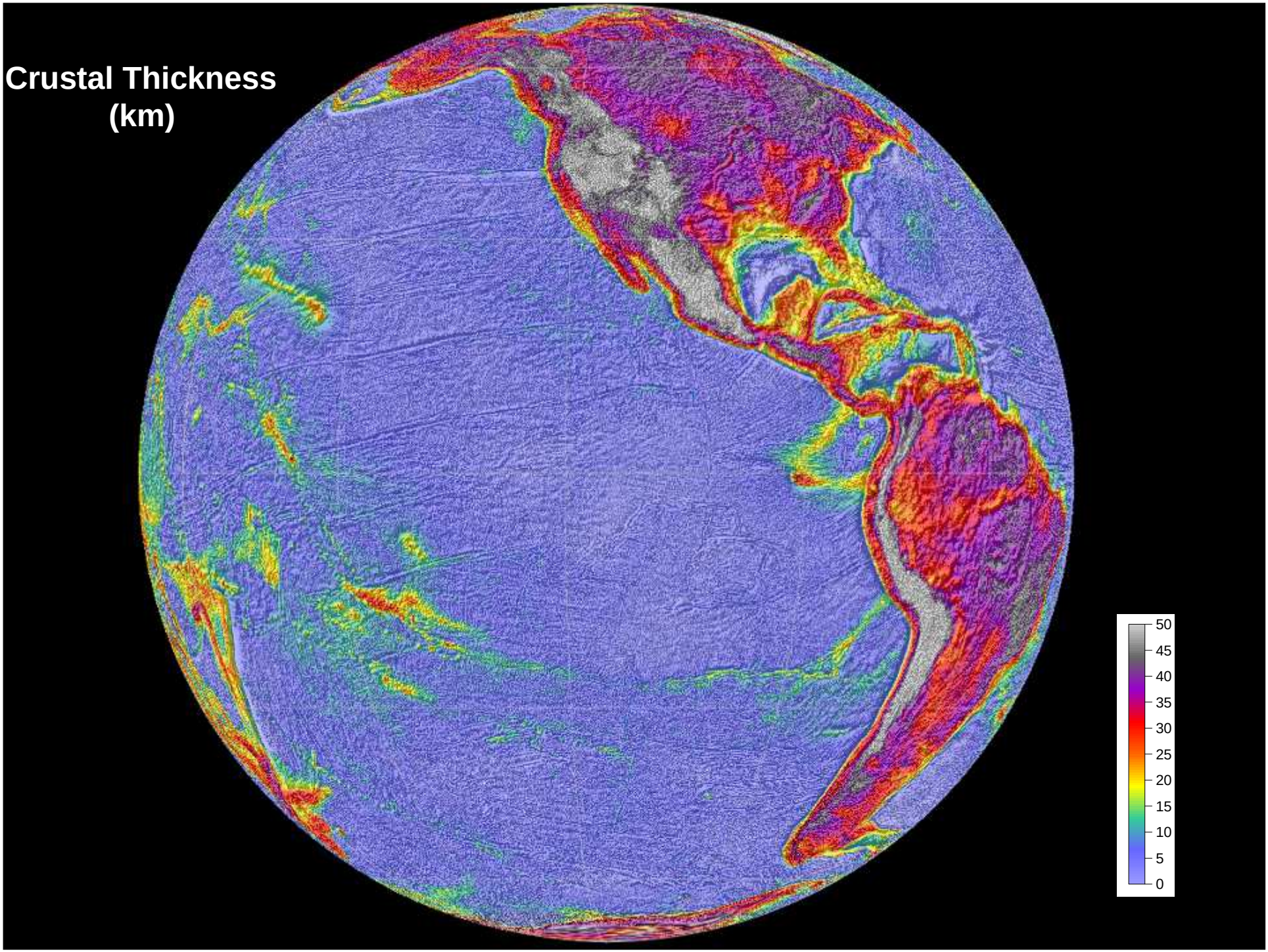
Lithosphere Thermal Gravity Anomaly Correction

- Oceanic and rifted continental margin lithosphere have elevated geothermal gradients => large negative thermal gravity anomaly (< -350 mgal)
- Lithosphere thermal gravity anomaly correction needed to determine Moho depth from gravity inversion




Crustal Thickness
(km)
With superimposed
shaded relief
free-air gravity anomaly
50
45
40
35
30
25
20
15
10
5
0


Crustal Thickness
(km)
50
45
40
35
30
25
20
15
10
5
0


Crustal Thickness
(km)
50
45
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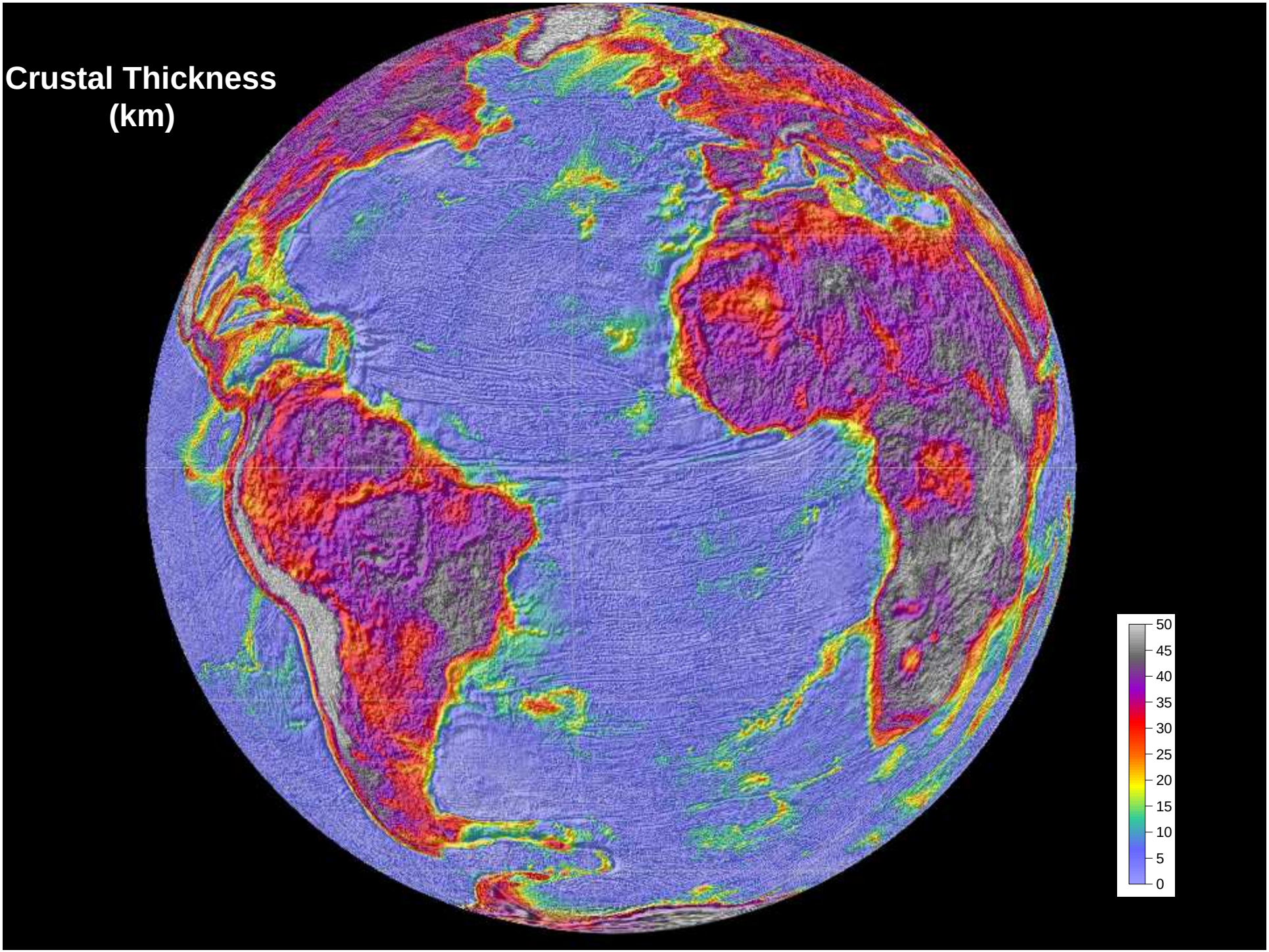
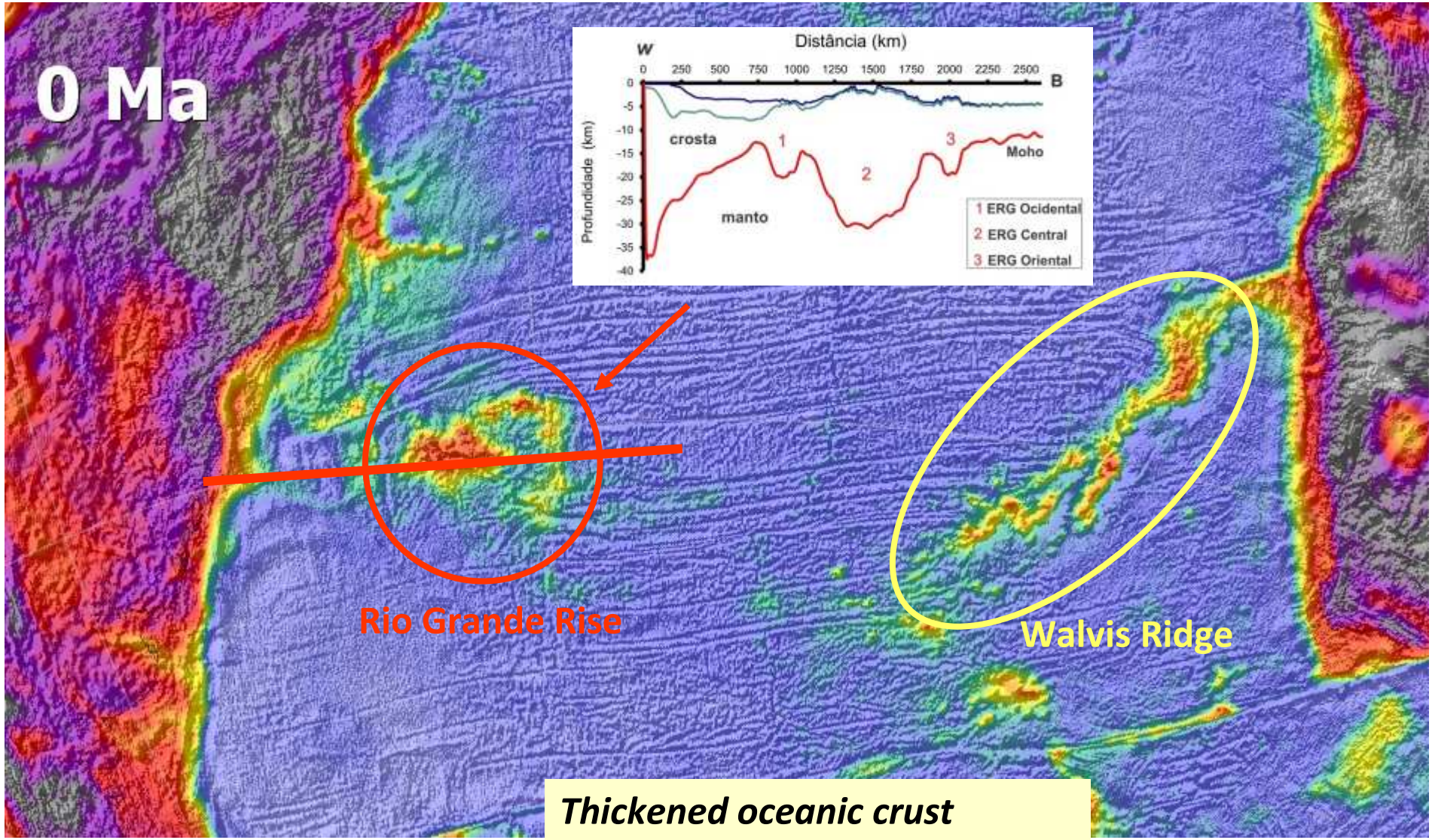
5
0


Crustal Thickness
(km)
50
45
40
35
30
25
20
15
10
5
0

Rio Grande Rise (& Walvis Ridge)



Thickened oceanic crust

- RGR & WR ~ 25 km (max)

Crustal Thickness (km)

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Rio Grande Rise

Ocean Drilling (DSDP-516F, RC11-2RDP5)
- Basalts
- Ages 80 – 87 Ma, 46 Ma

Submersible Sampling by CPRM
- Also some continental lithologies
- Granites, Granulites, Gneisses, Pegmatites
- Ages 500 Ma – 2200 Ma *(Fioravanti 2014)*

Crustal Thickness (km)

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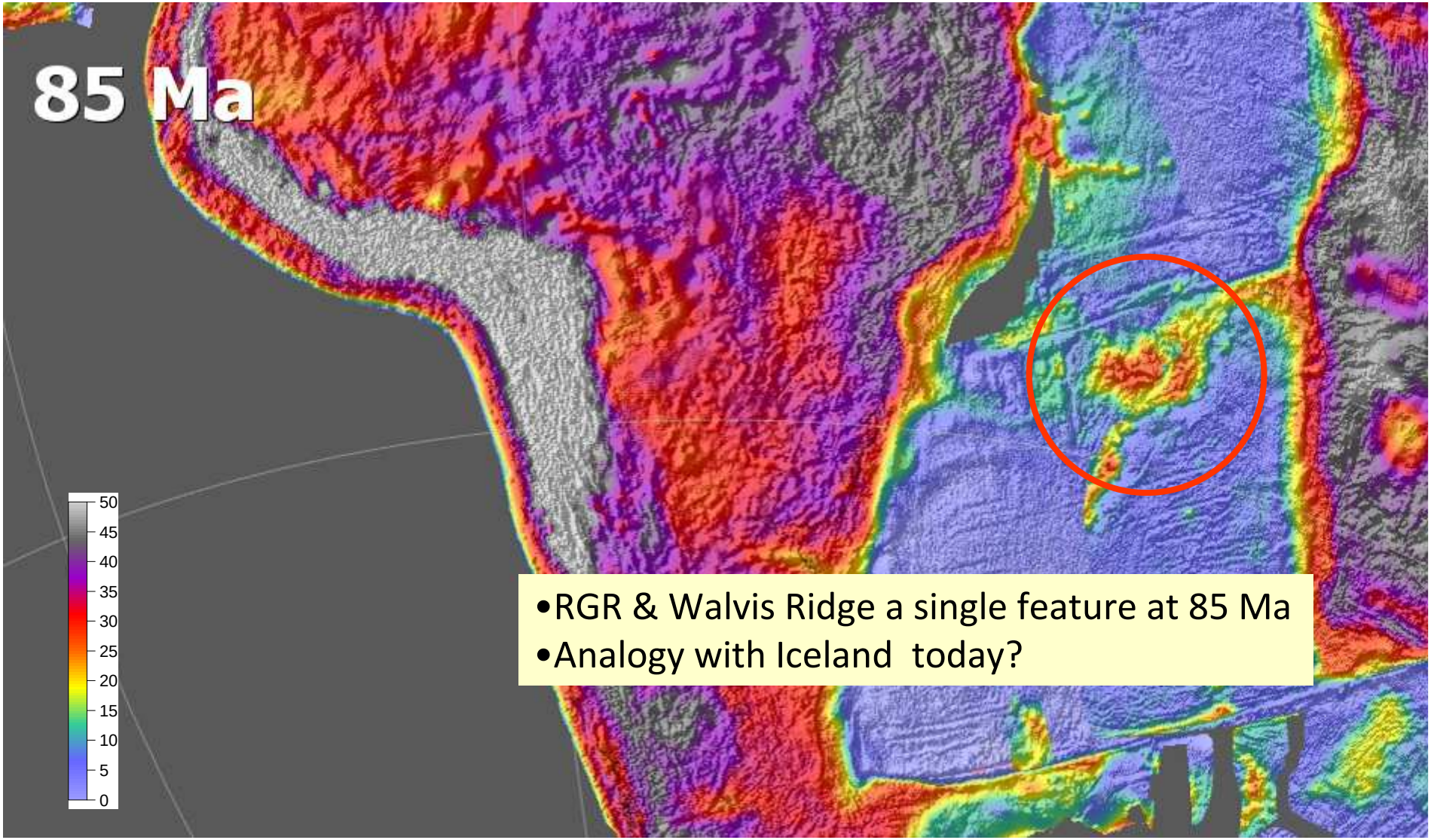
Rio Grande Rise & Walvis Ridge



Crustal Thickness (km)

Restoration using GPlates v1.5

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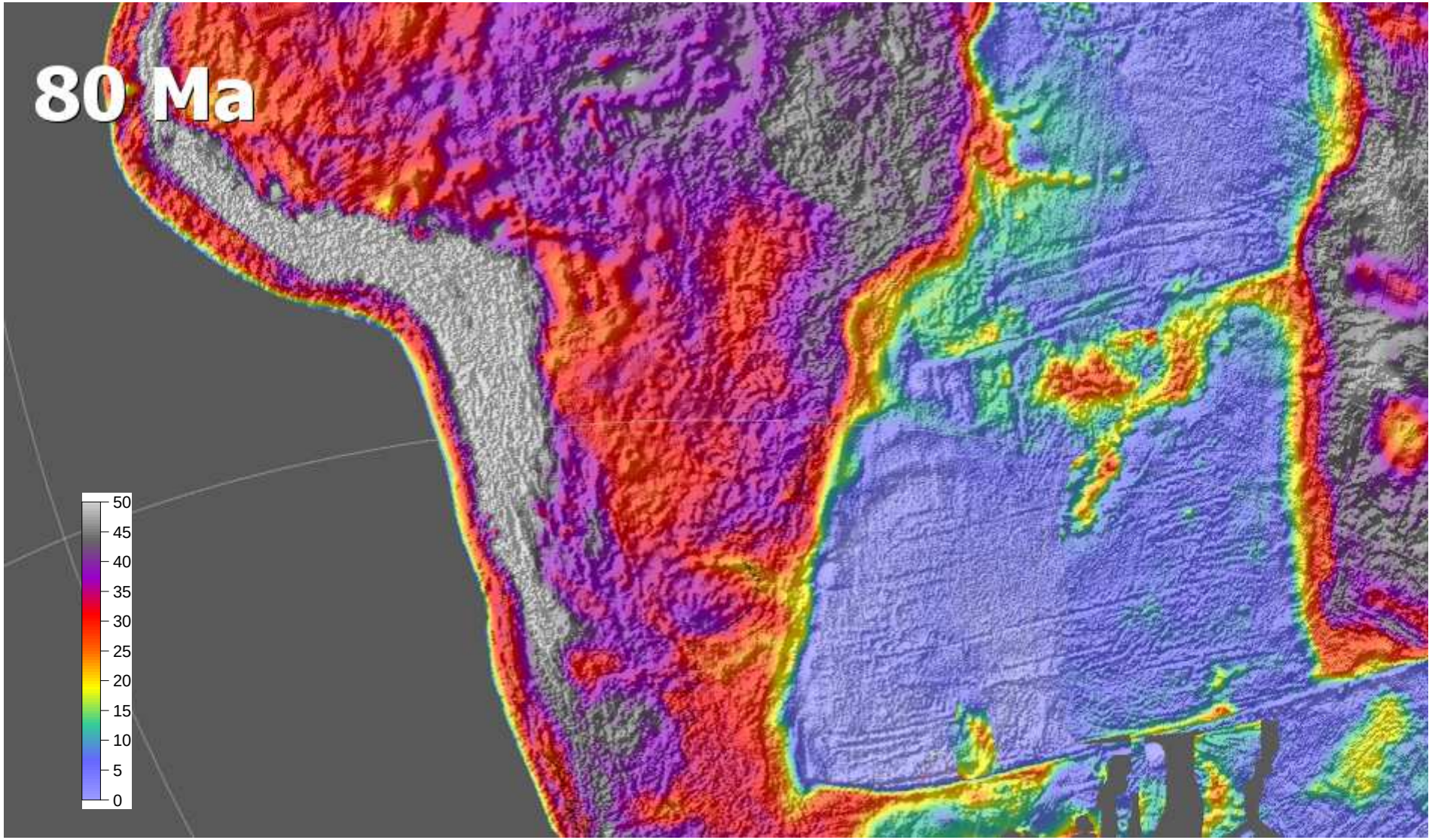
Rio Grande Rise & Walvis Ridge



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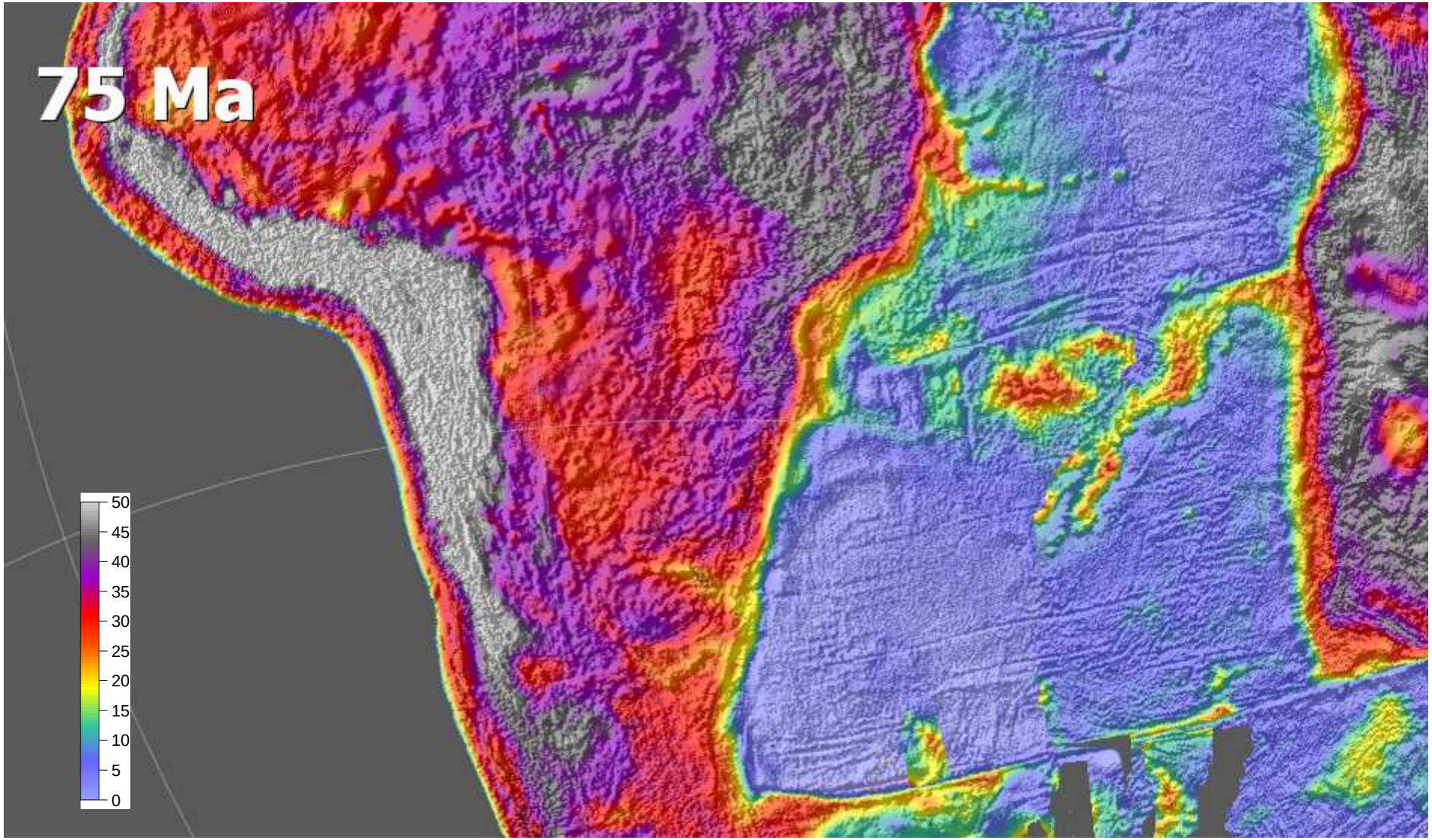

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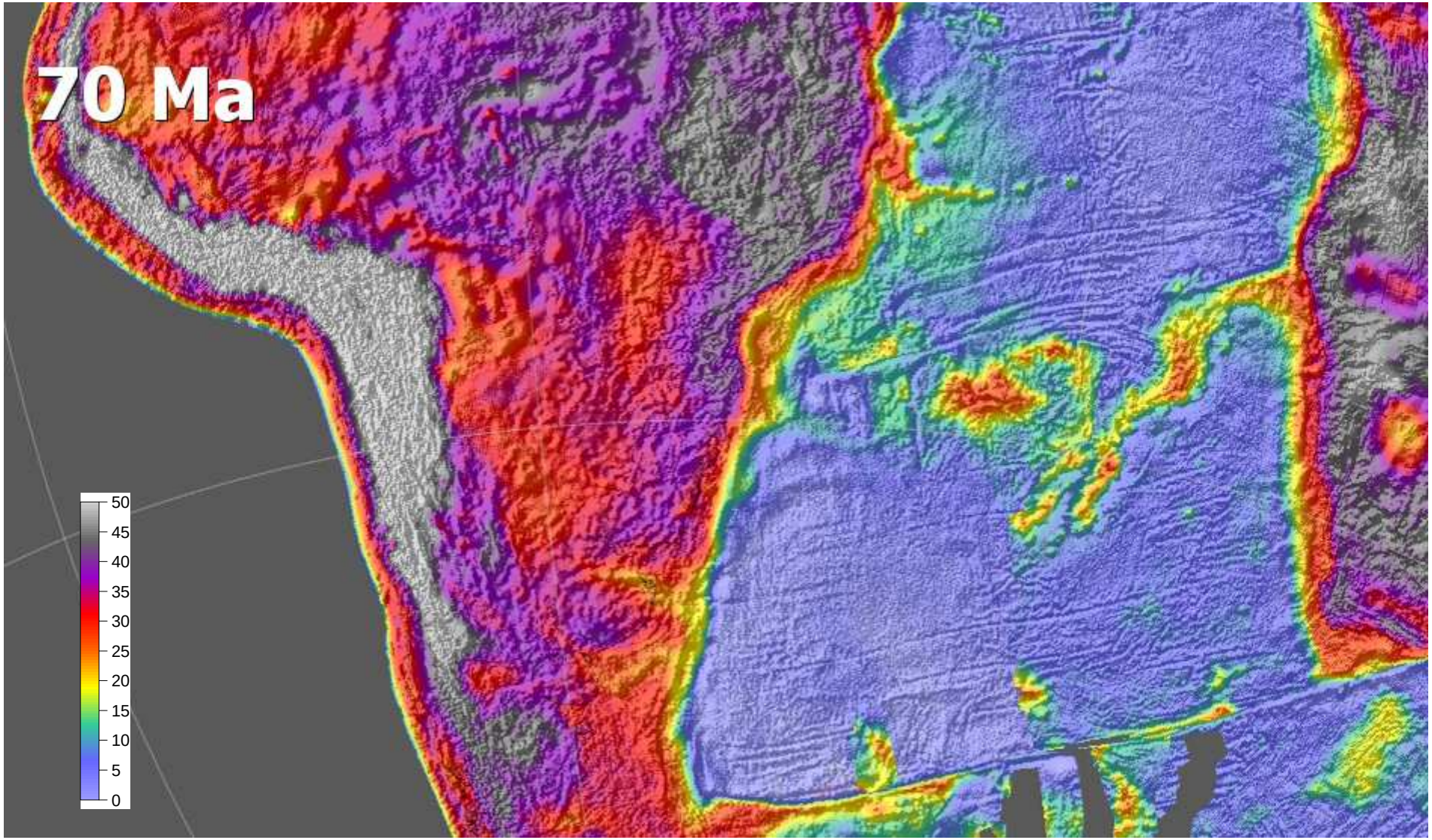

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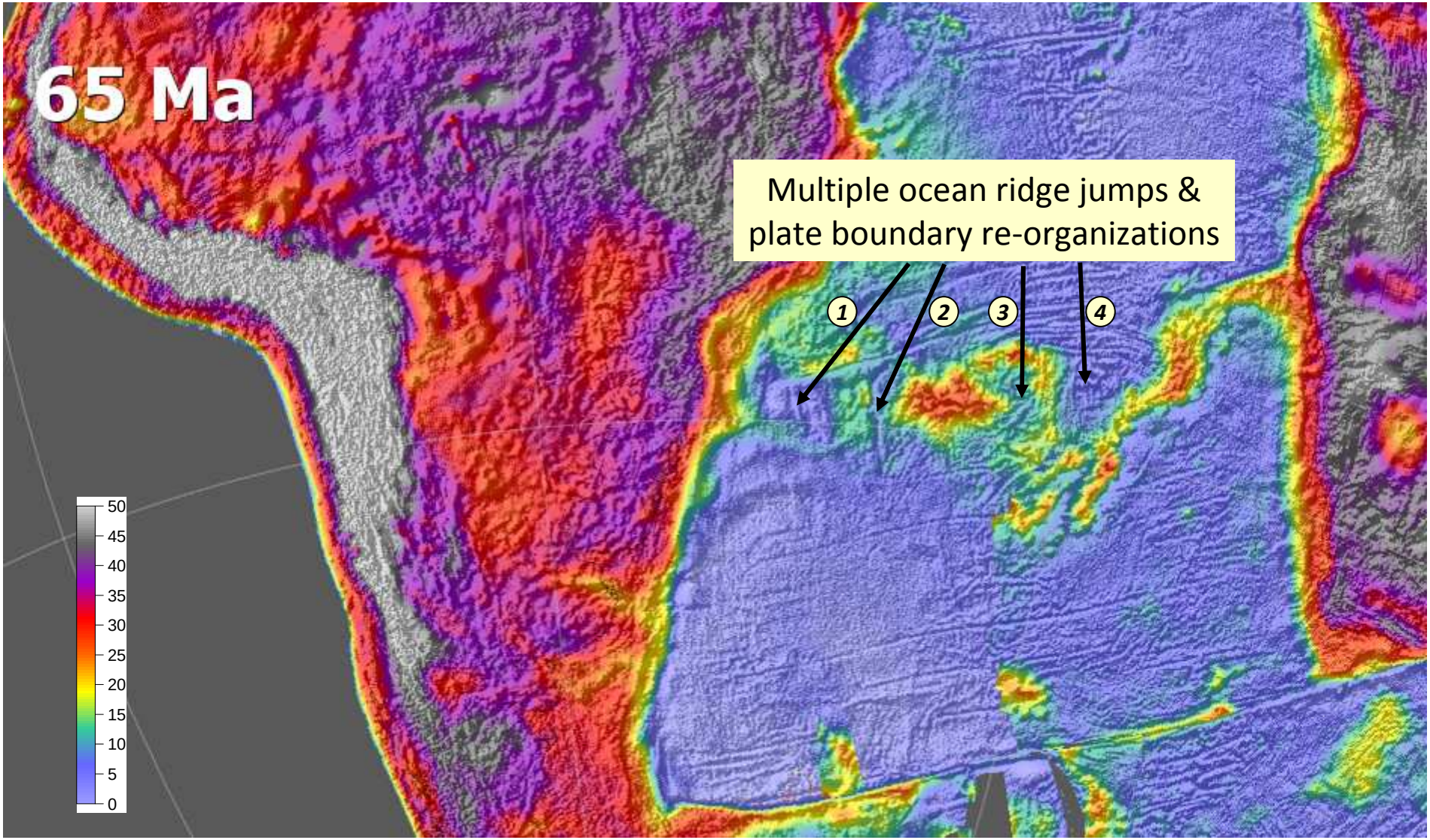

Crustal Thickness (km)

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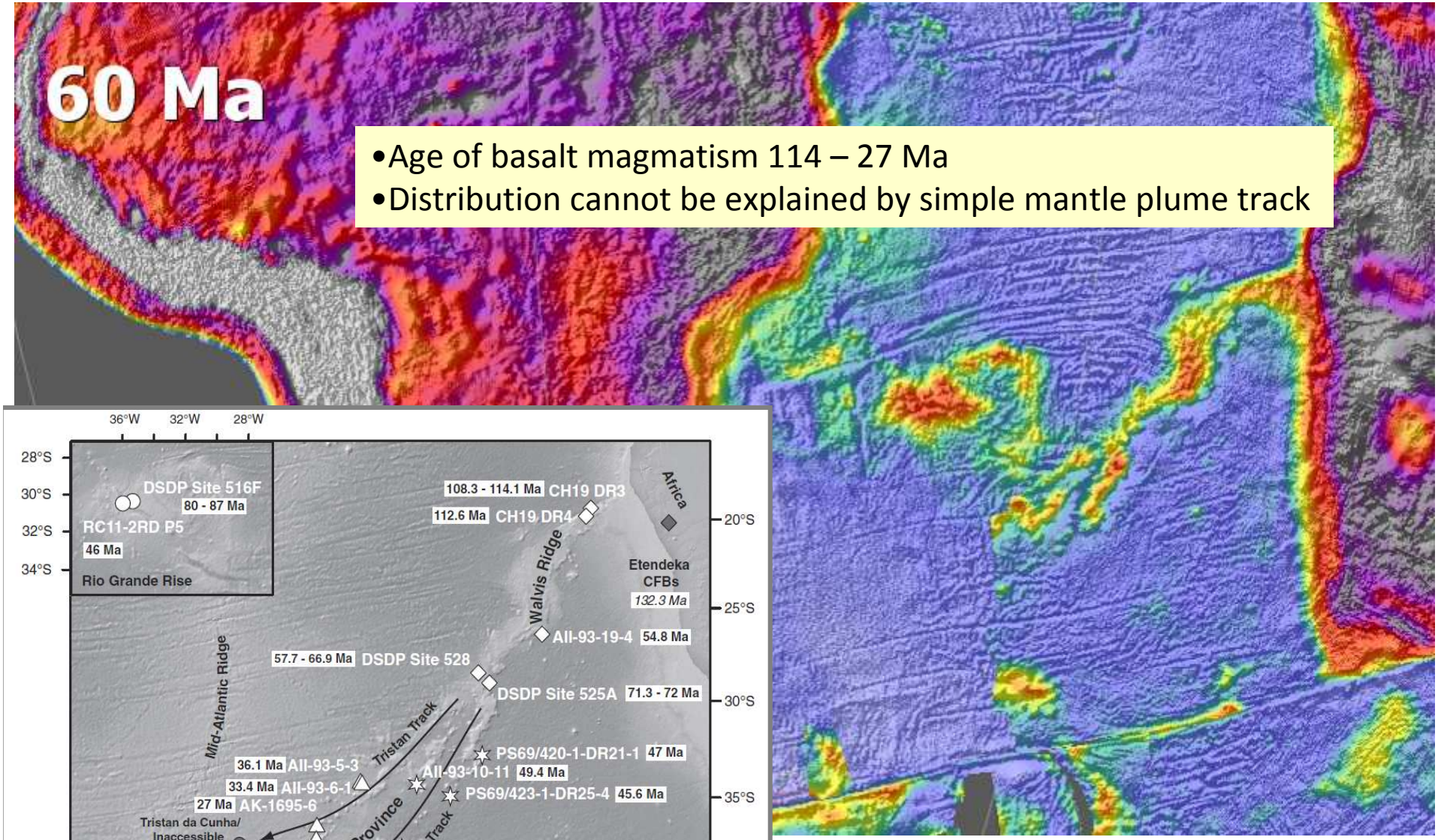

Restoration using GPlates v1.5

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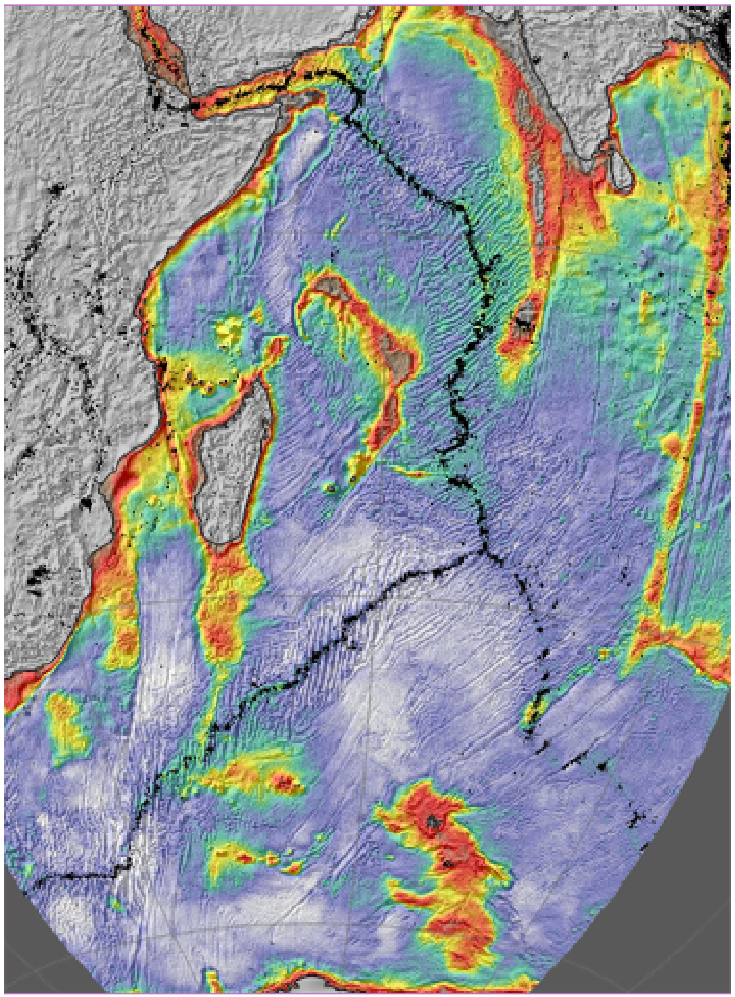
Conrad Rise, Crozet Plateau, Madagascar Plateau & SWIR - Indian Ocean



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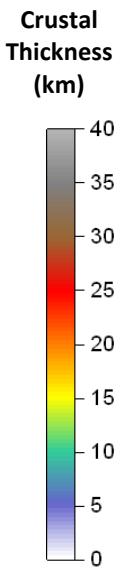

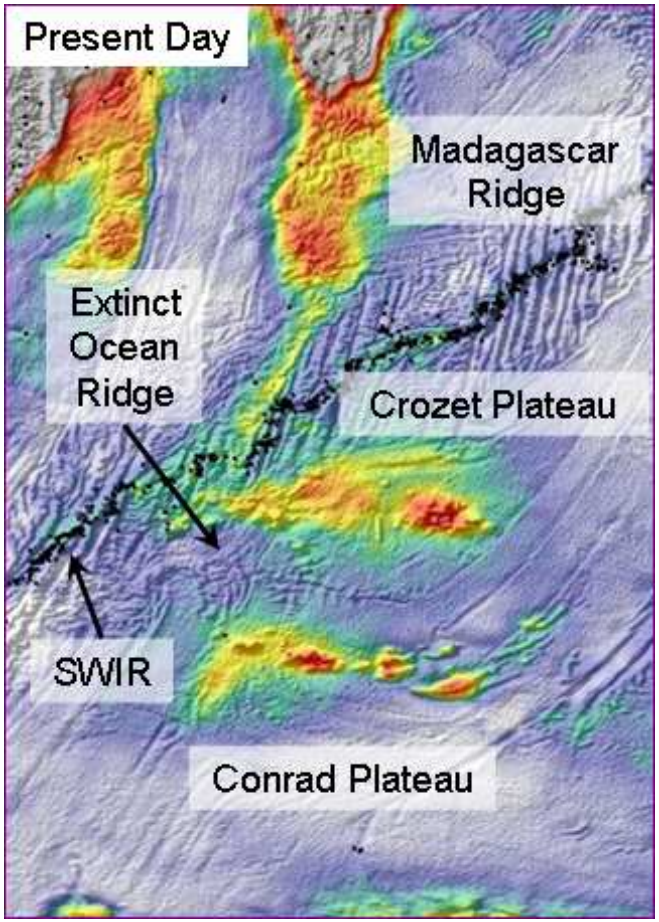

Intra-oceanic ridge jumps & plate boundary re-organizations

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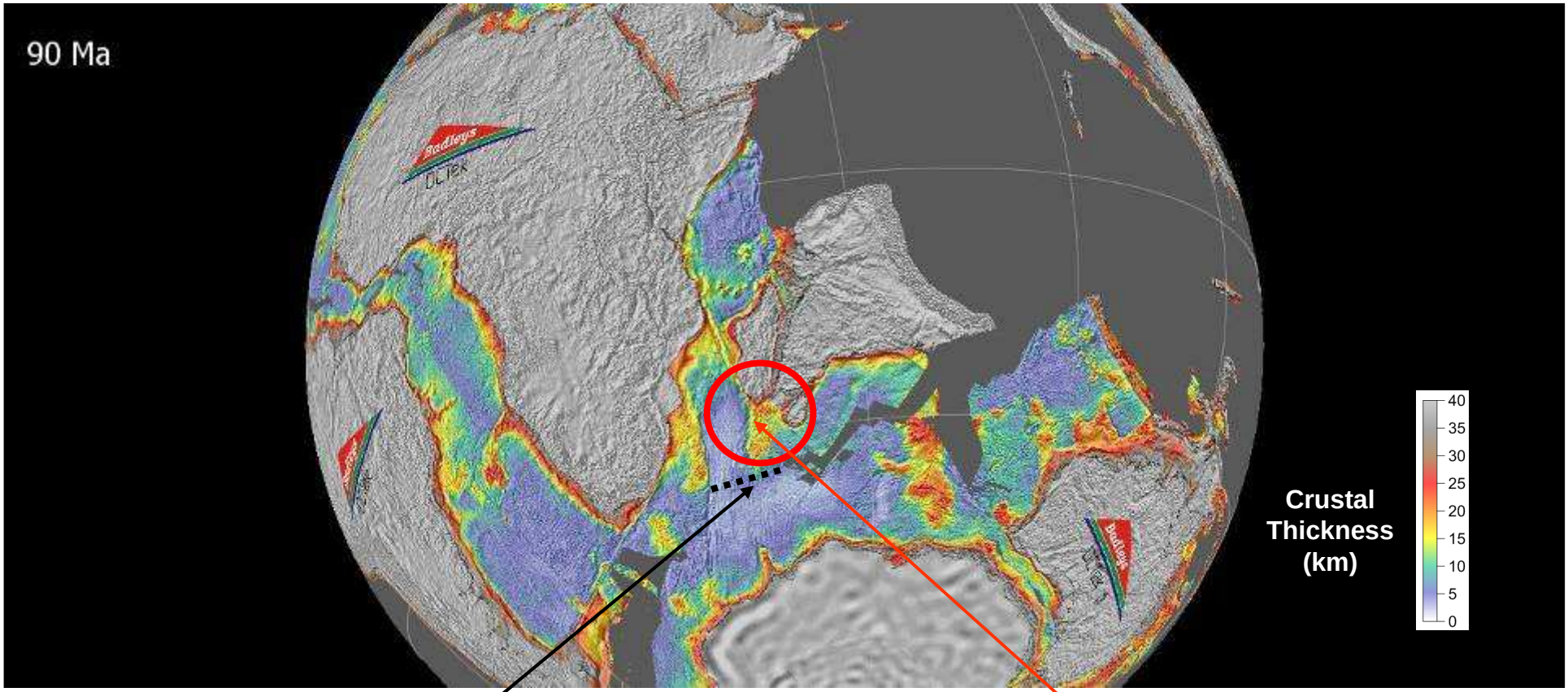
Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

Restoration of Crustal Thickness using GPlates v1.5



Approximate position of ocean ridge at 90 Ma

Anomalous (fertile) mantle?

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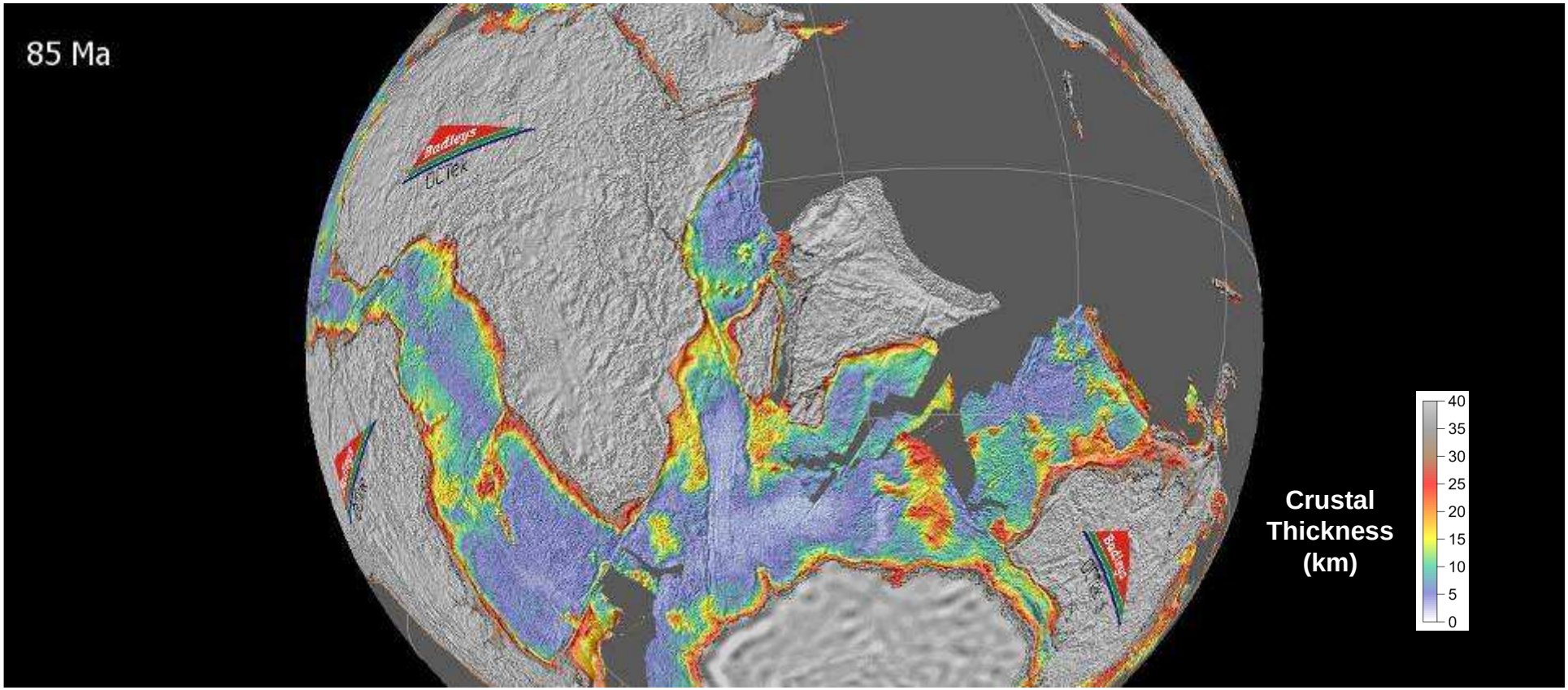
Restoration of Crustal Thickness using GPlates v1.5



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Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

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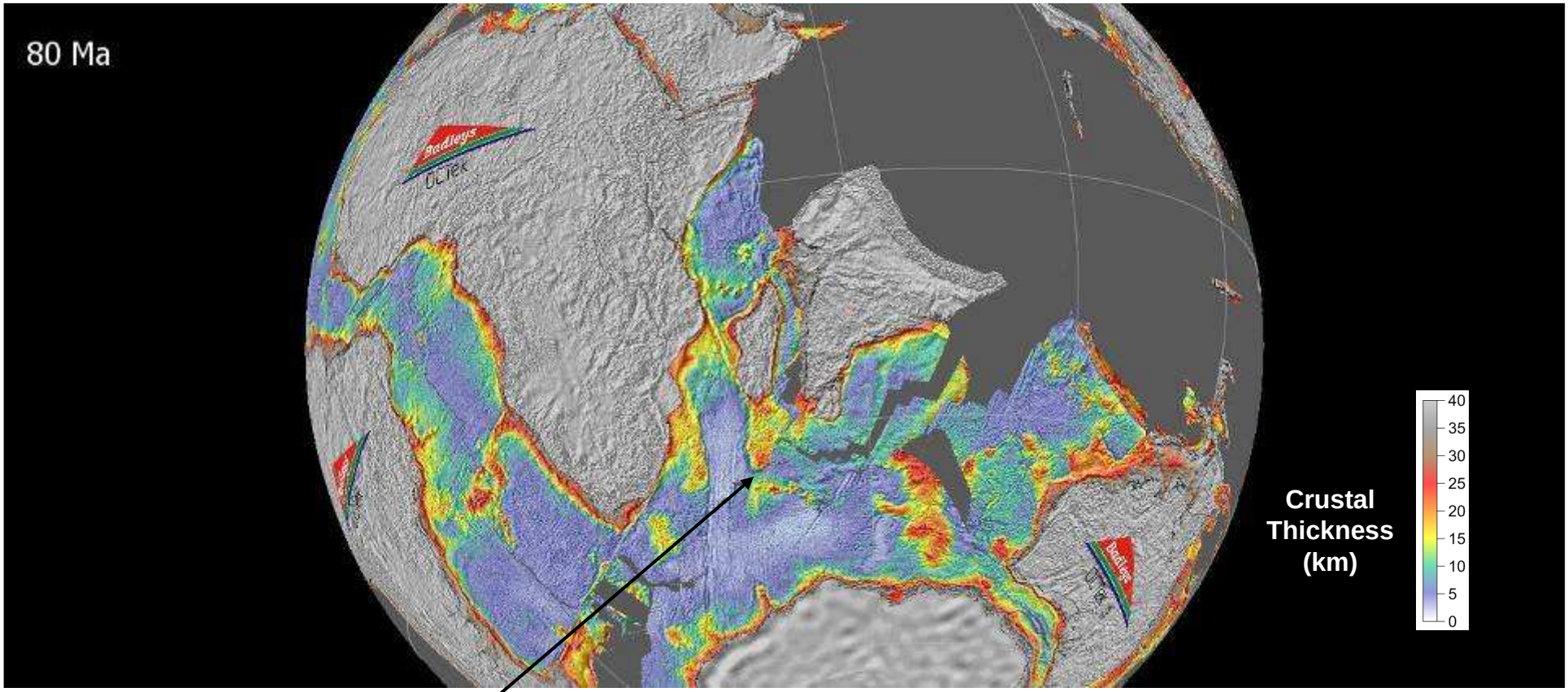

- Ridge jump & plate boundary re-organization
- To between Conrad Rise and Crozet Plateau

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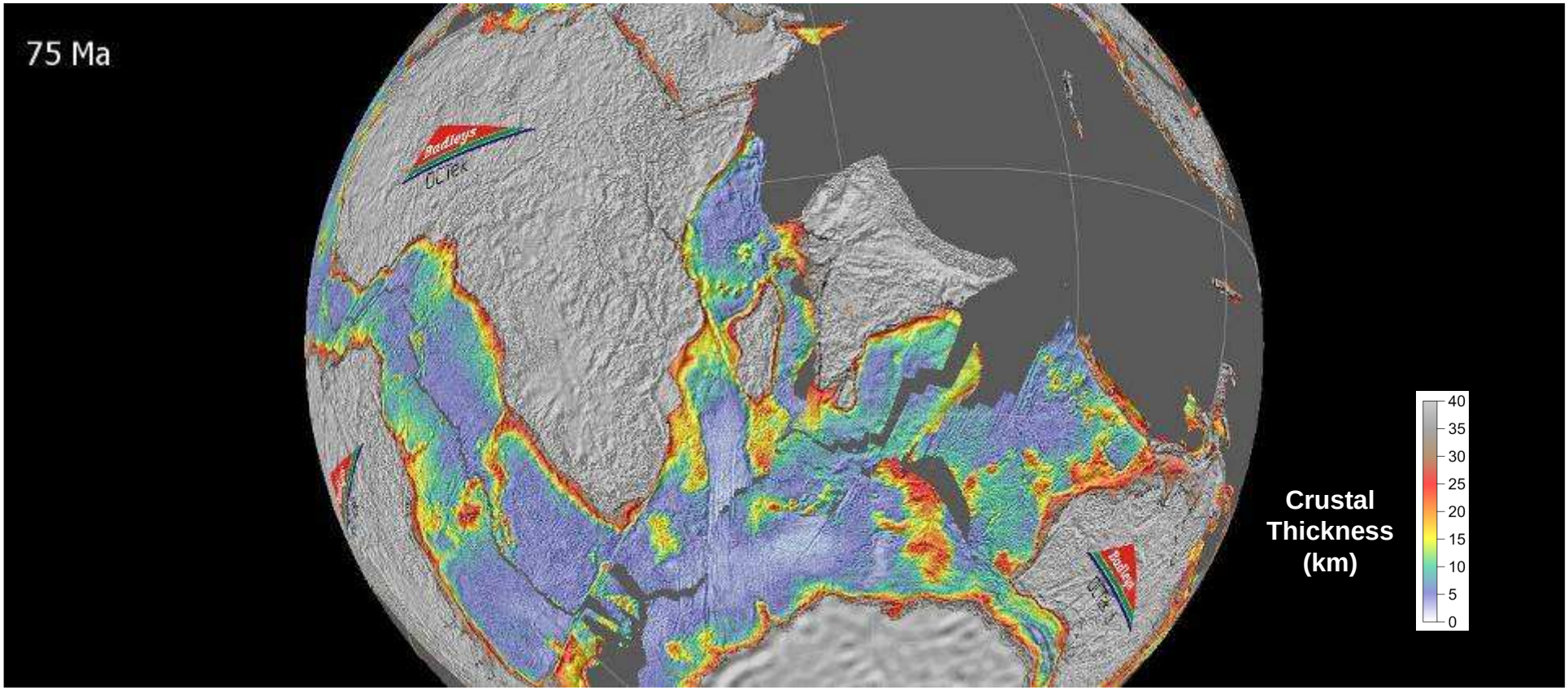
Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

Restoration of Crustal Thickness using GPlates v1.5



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Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

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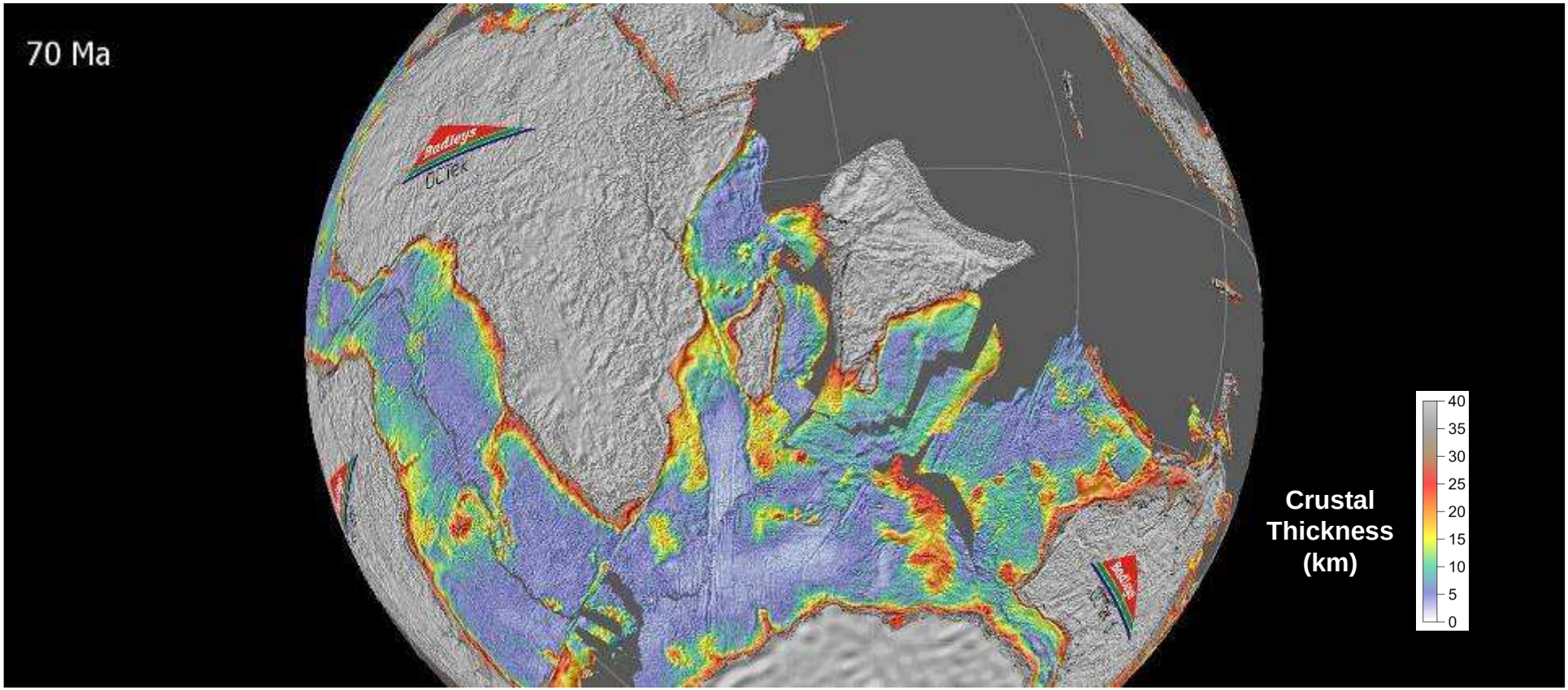

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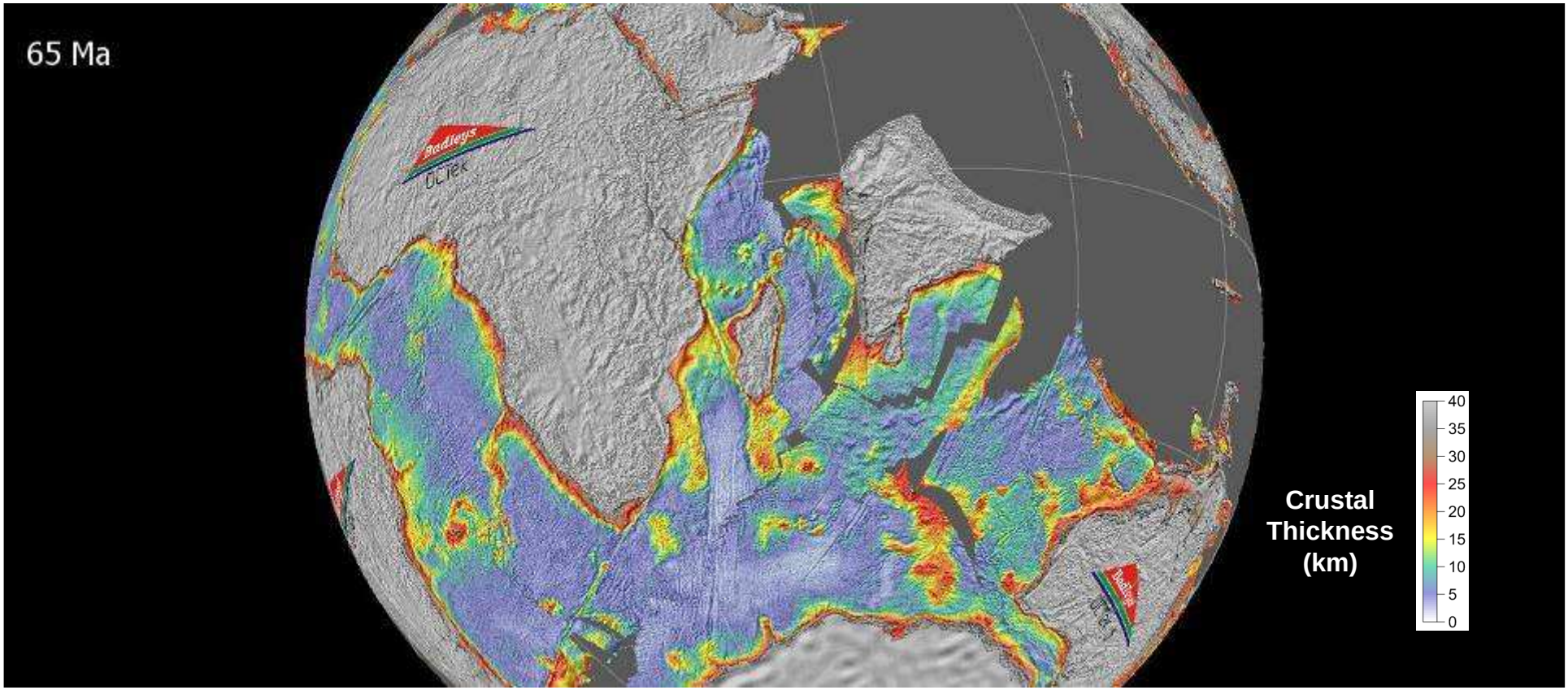
Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

Restoration of Crustal Thickness using GPlates v1.5



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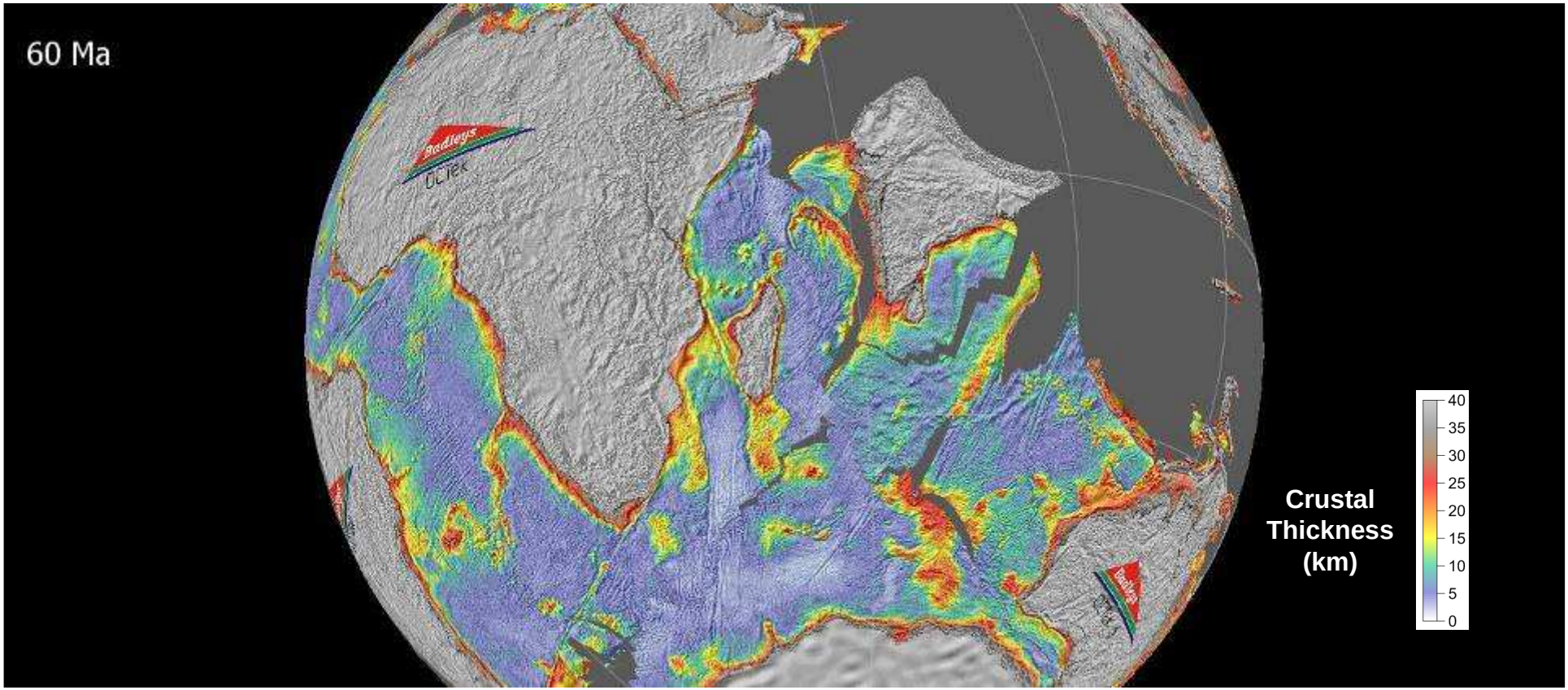
Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

Restoration of Crustal Thickness using GPlates v1.5



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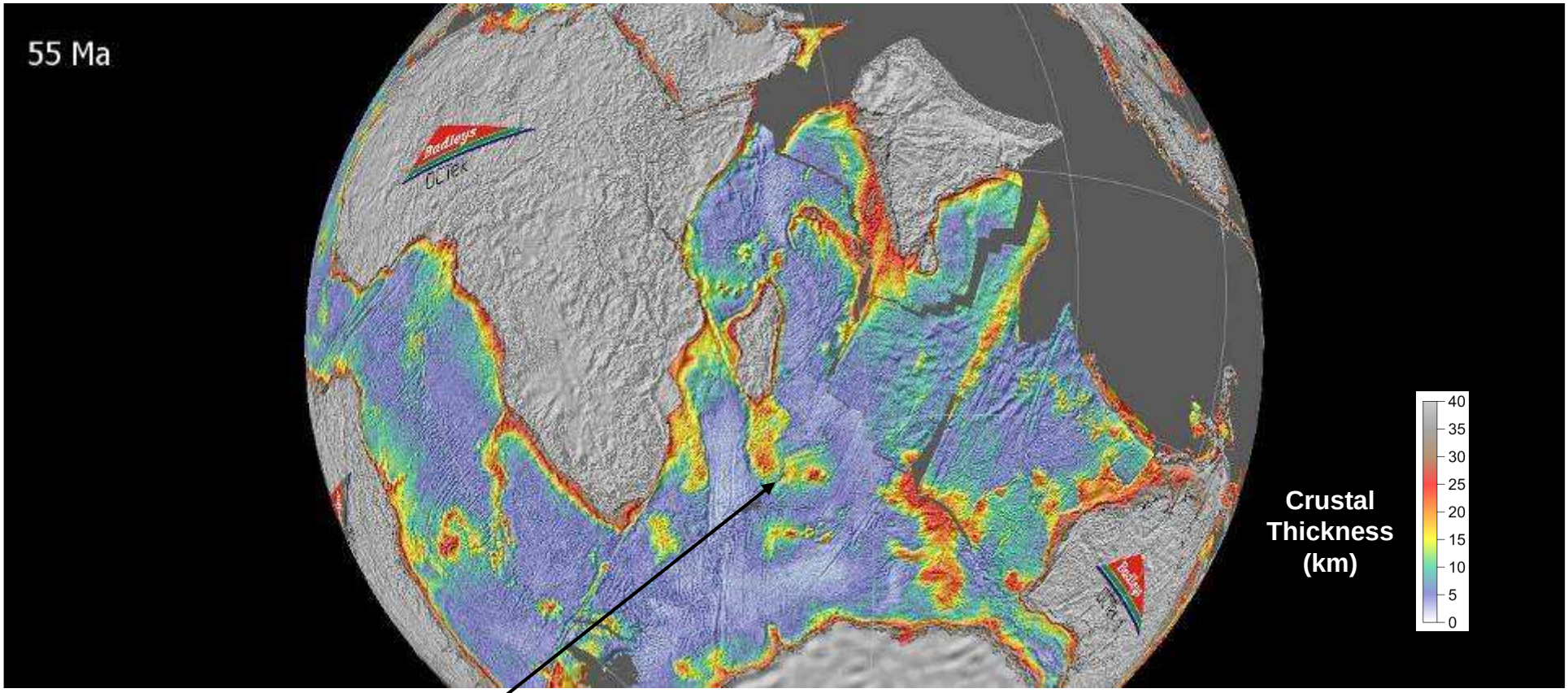

- Ridge jump & plate boundary re-organization
- To South West Indian Ridge (SWIR)

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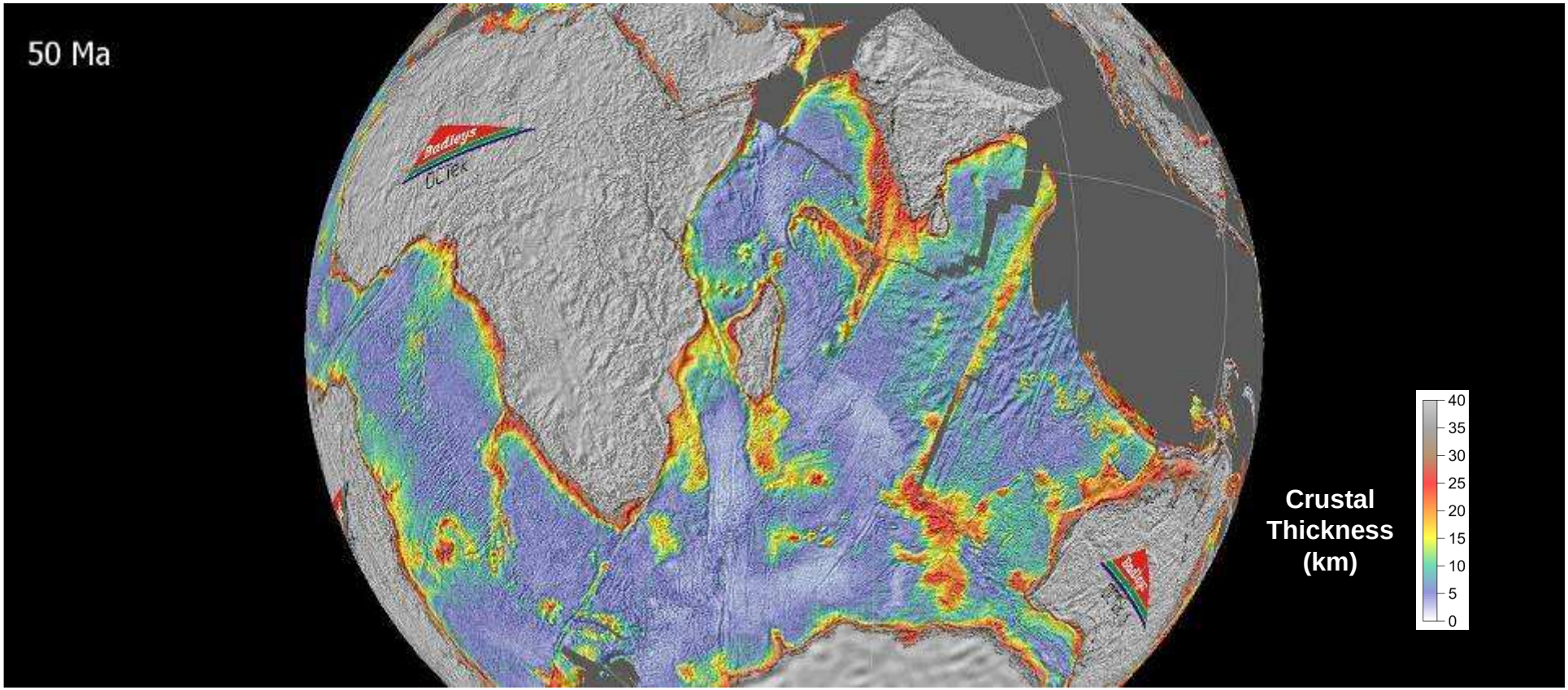
Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

Restoration of Crustal Thickness using GPlates v1.5



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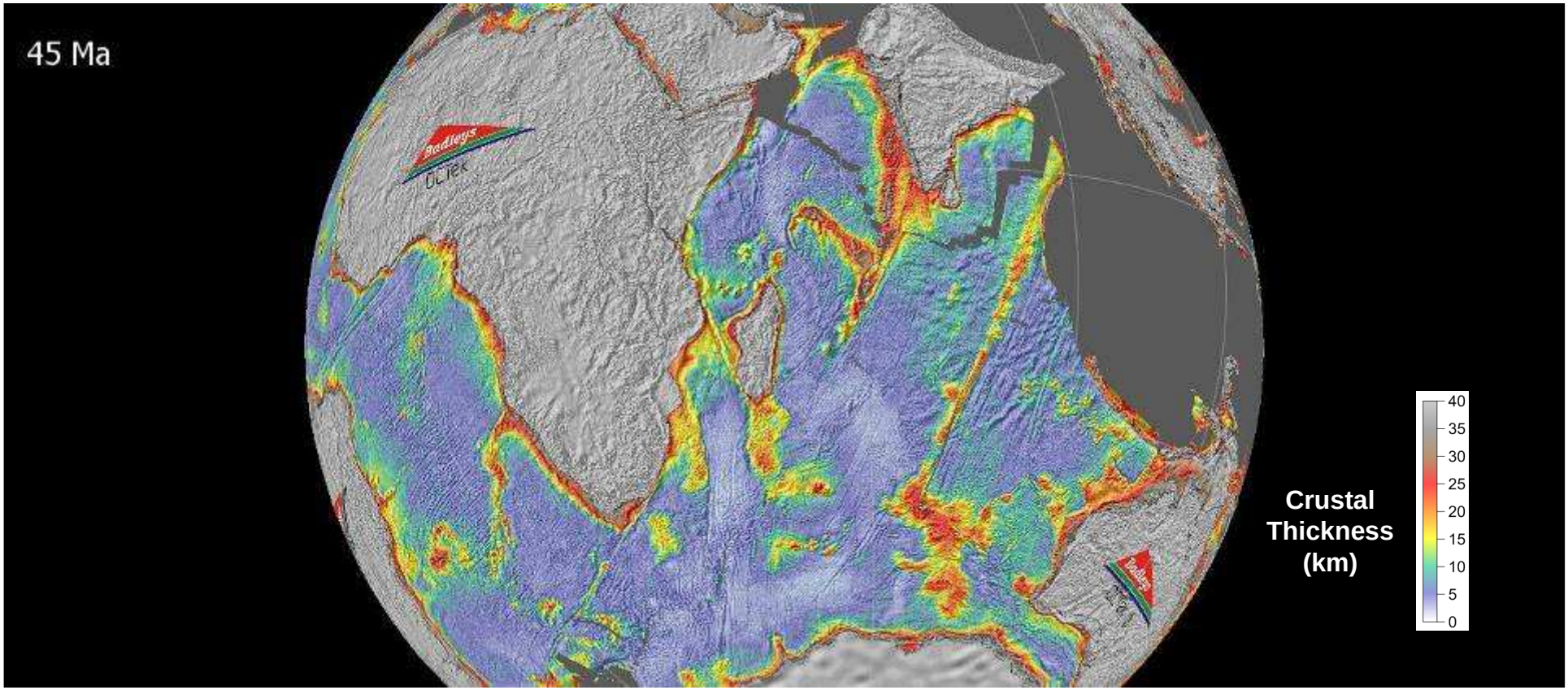

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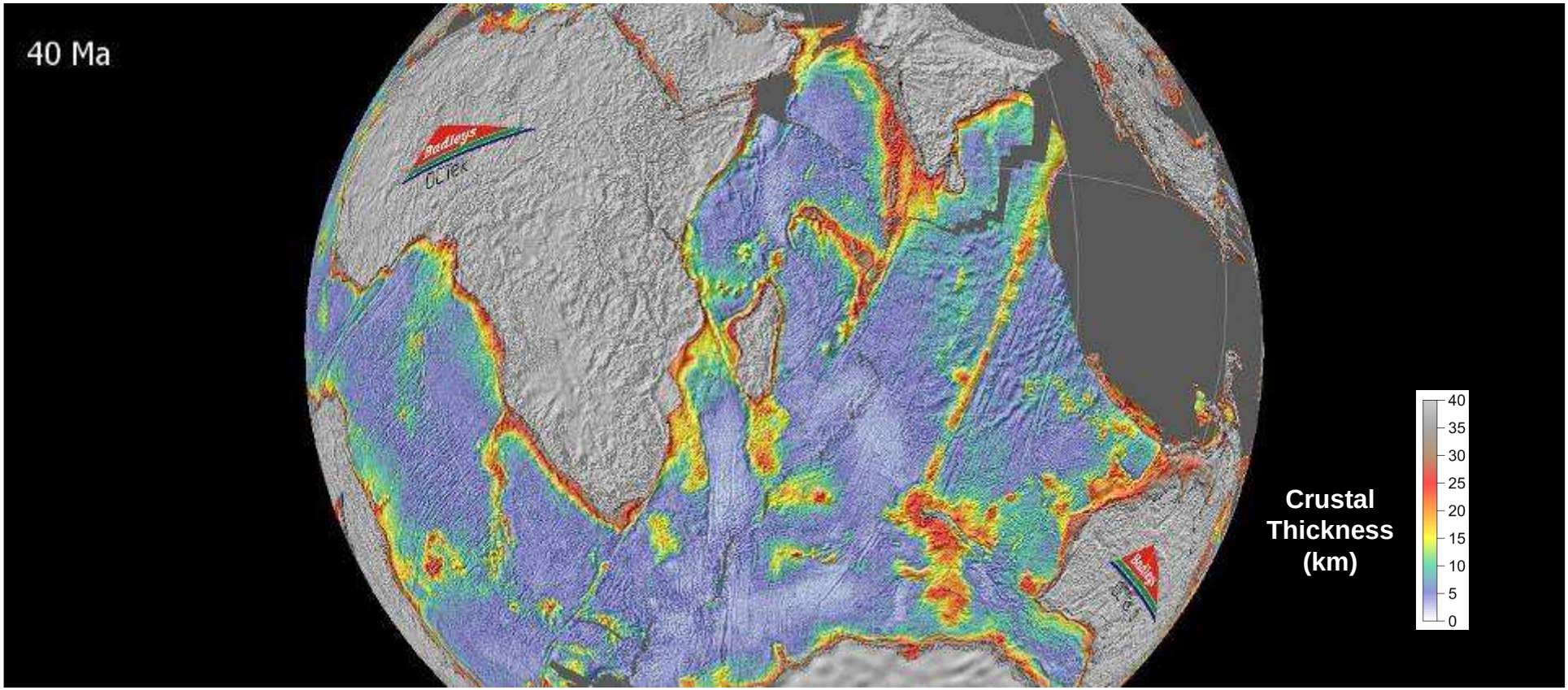
Restoration of Crustal Thickness using GPlates v1.5



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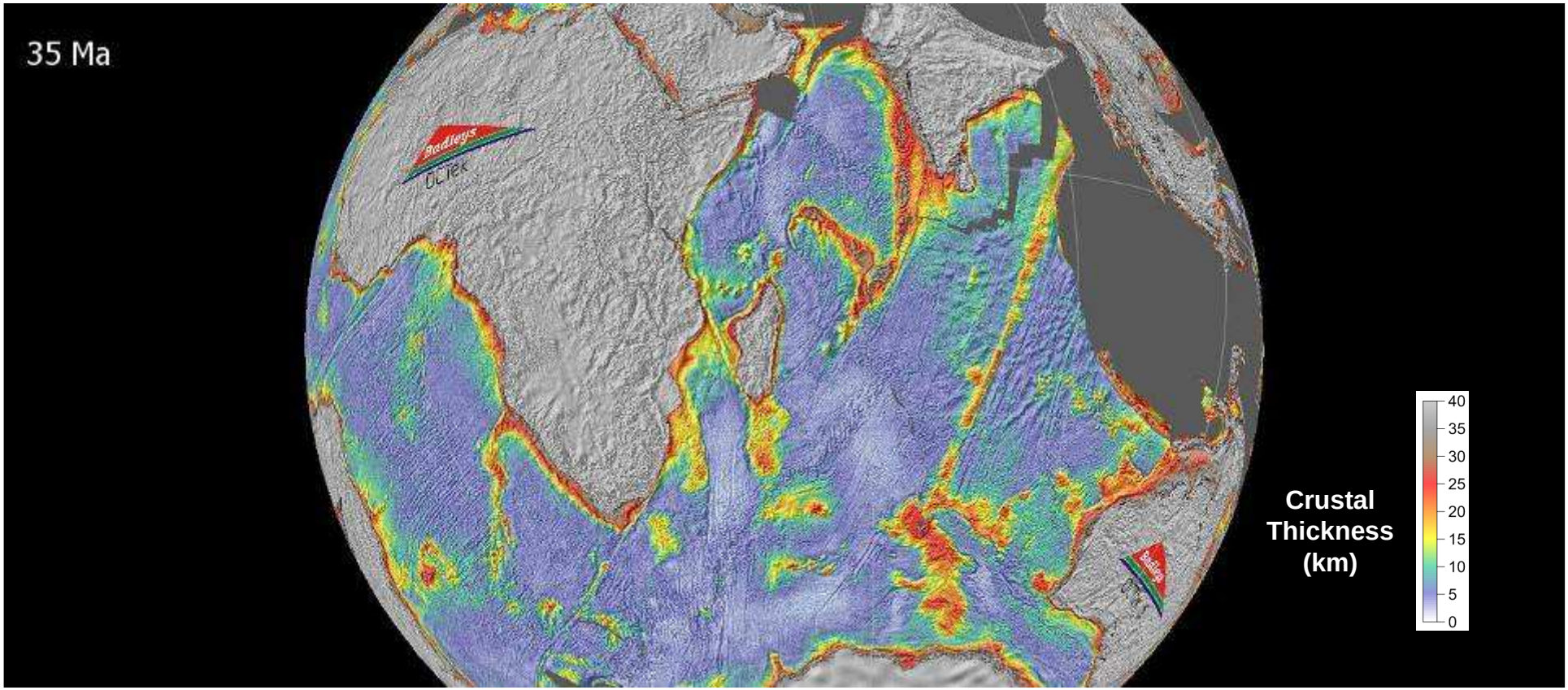
Restoration of Crustal Thickness using GPlates v1.5



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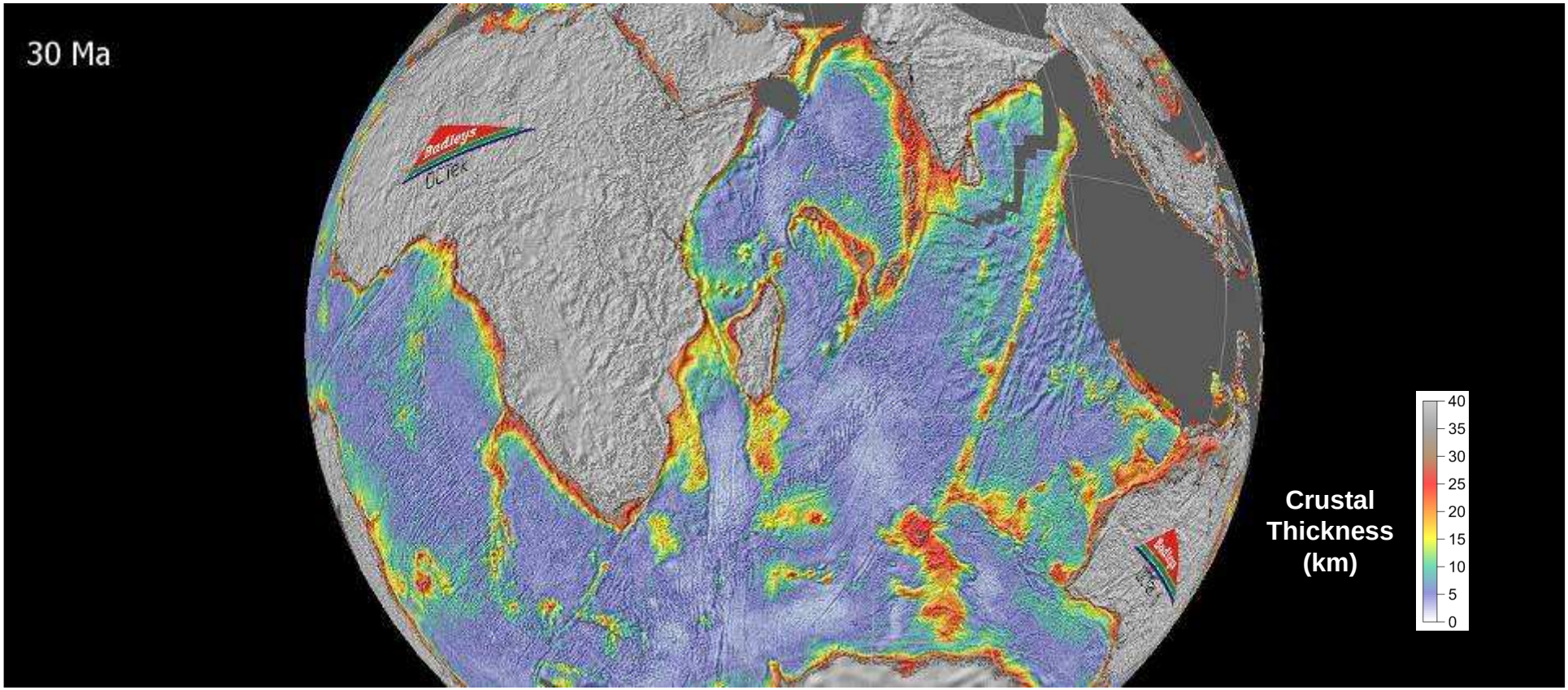
Indian Ocean - Conrad Rise, Crozet & Madagascar Plateaux & SWIR

Restoration of Crustal Thickness using GPlates v1.5



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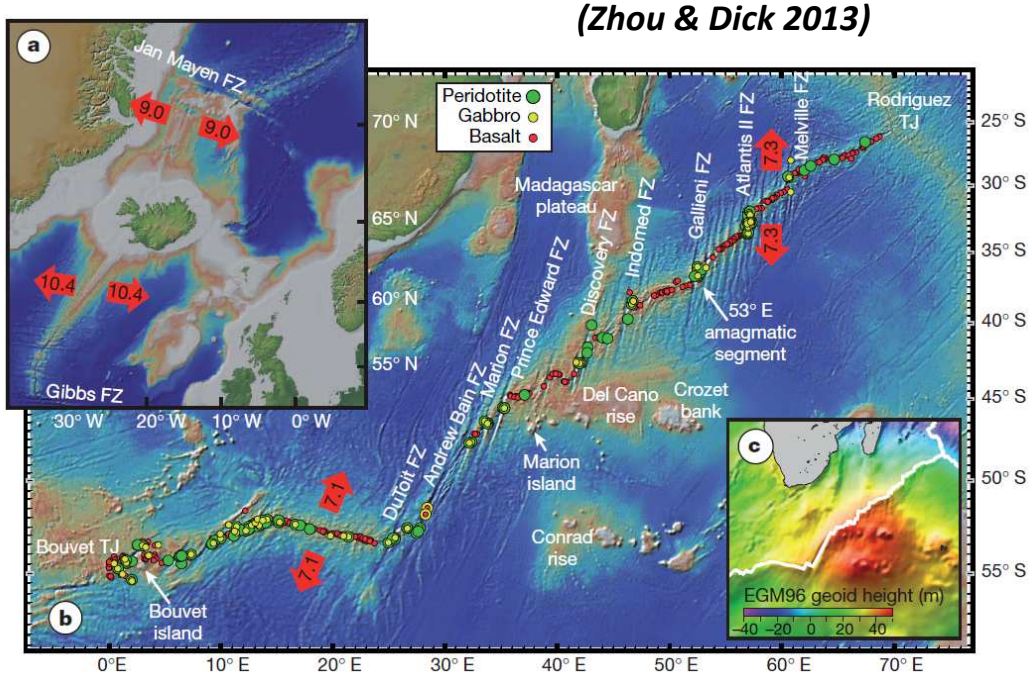
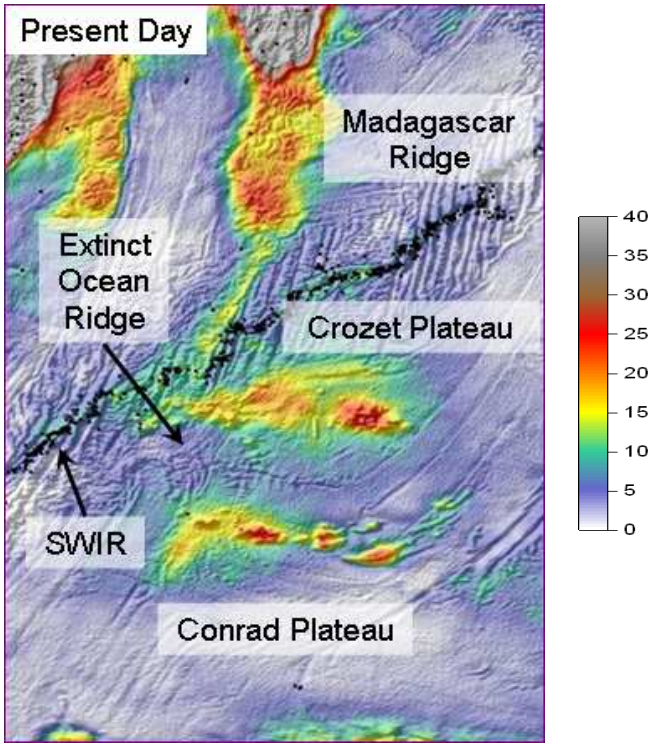
Conrad Rise, Crozet & Madagascar Plateaux & SWIR

•Oceanic plateaux (Conrad, Crozet, Madagascar Ridge) formed during ridge jumps – fertile mantle?

•Variable lithologies along SWIR ridge axis implies lateral variation in mantle chemistry

(Zhou & Dick 2013)



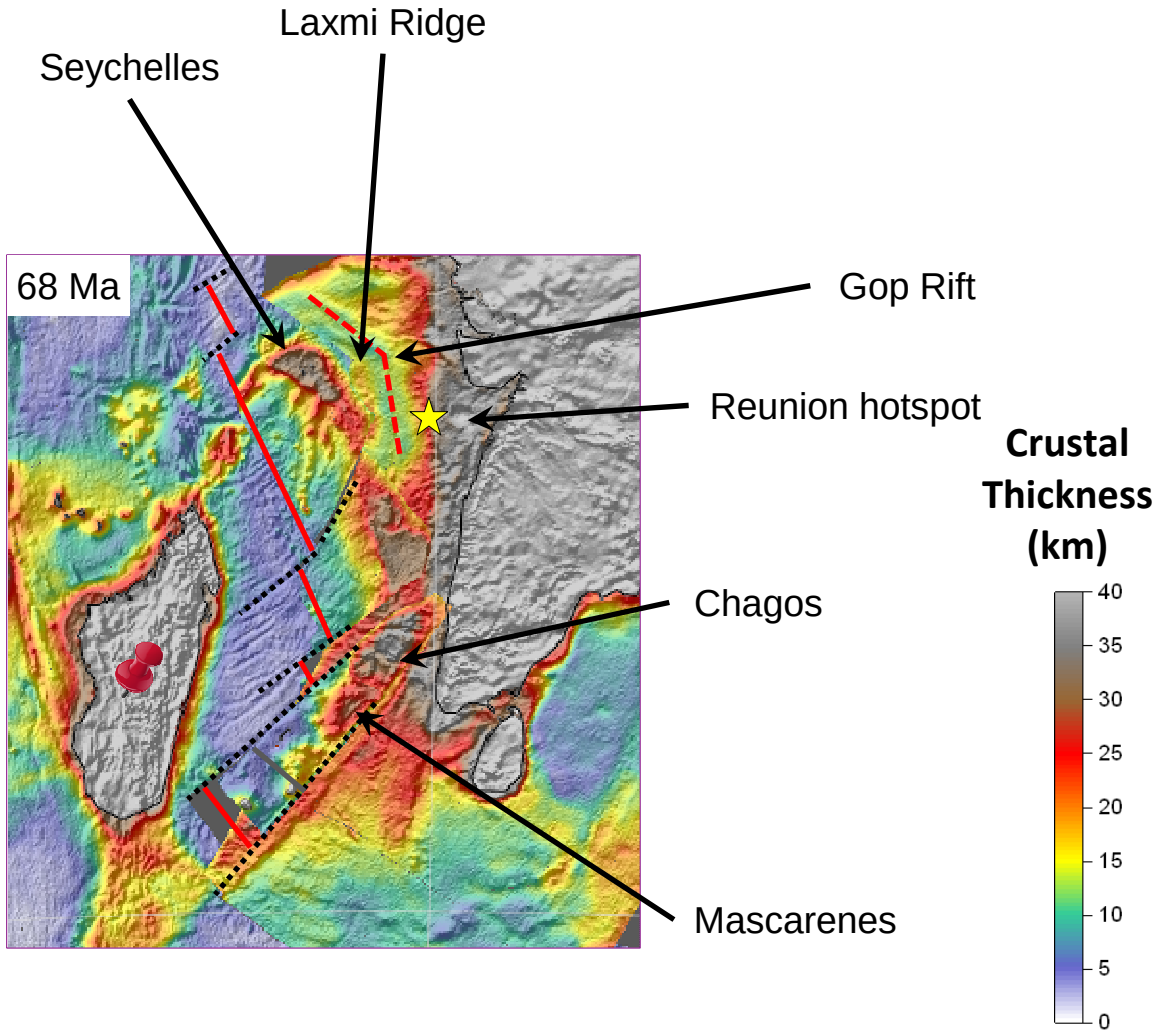


•Mantle is heterogeneous?

Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

68 Ma

- ***Restoration of crustal thickness from gravity inversion***
- ***New poles & polygons***



(Alvey & Kusznir)

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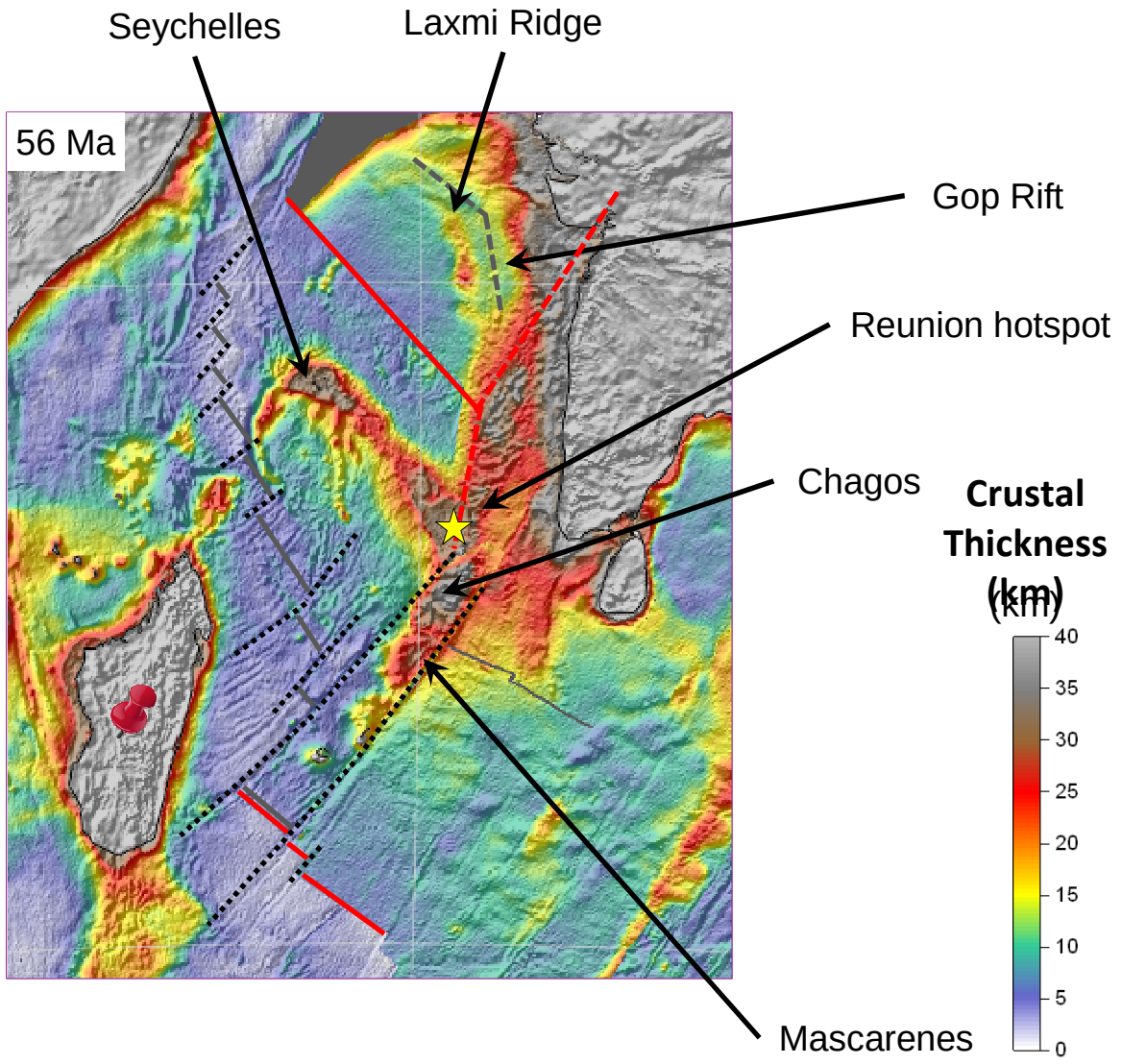
Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

56 Ma

- ***Restoration of crustal thickness from gravity inversion***
- ***New poles & polygons***



(Alvey & Kusznir)

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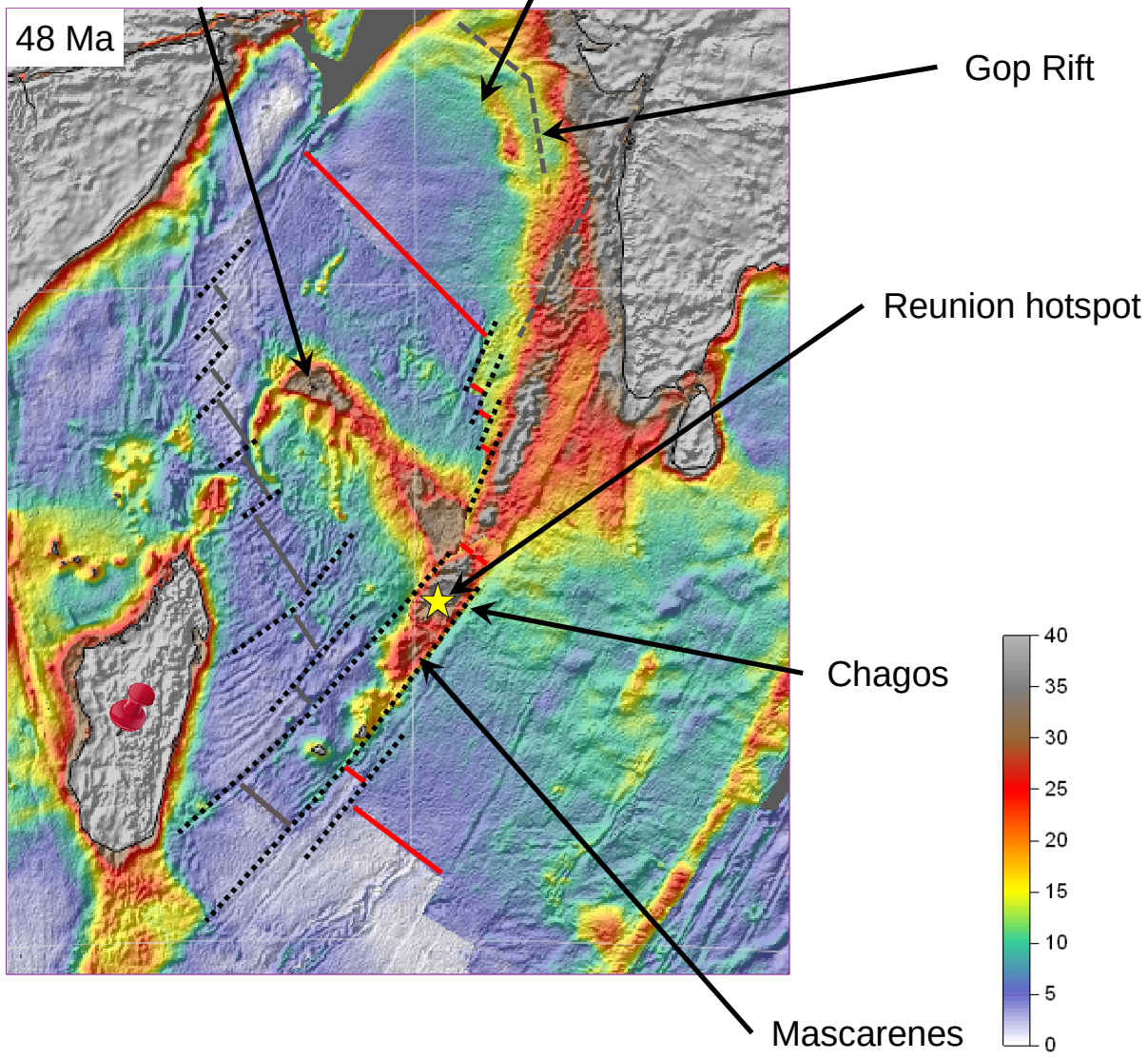
Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

48 Ma

- ***Restoration of crustal thickness from gravity inversion***
- ***New poles & polygons***

55 – 35 Ma
No discrete plate boundary

(Alvey & Kusznir)



Reconstructed using GPlates

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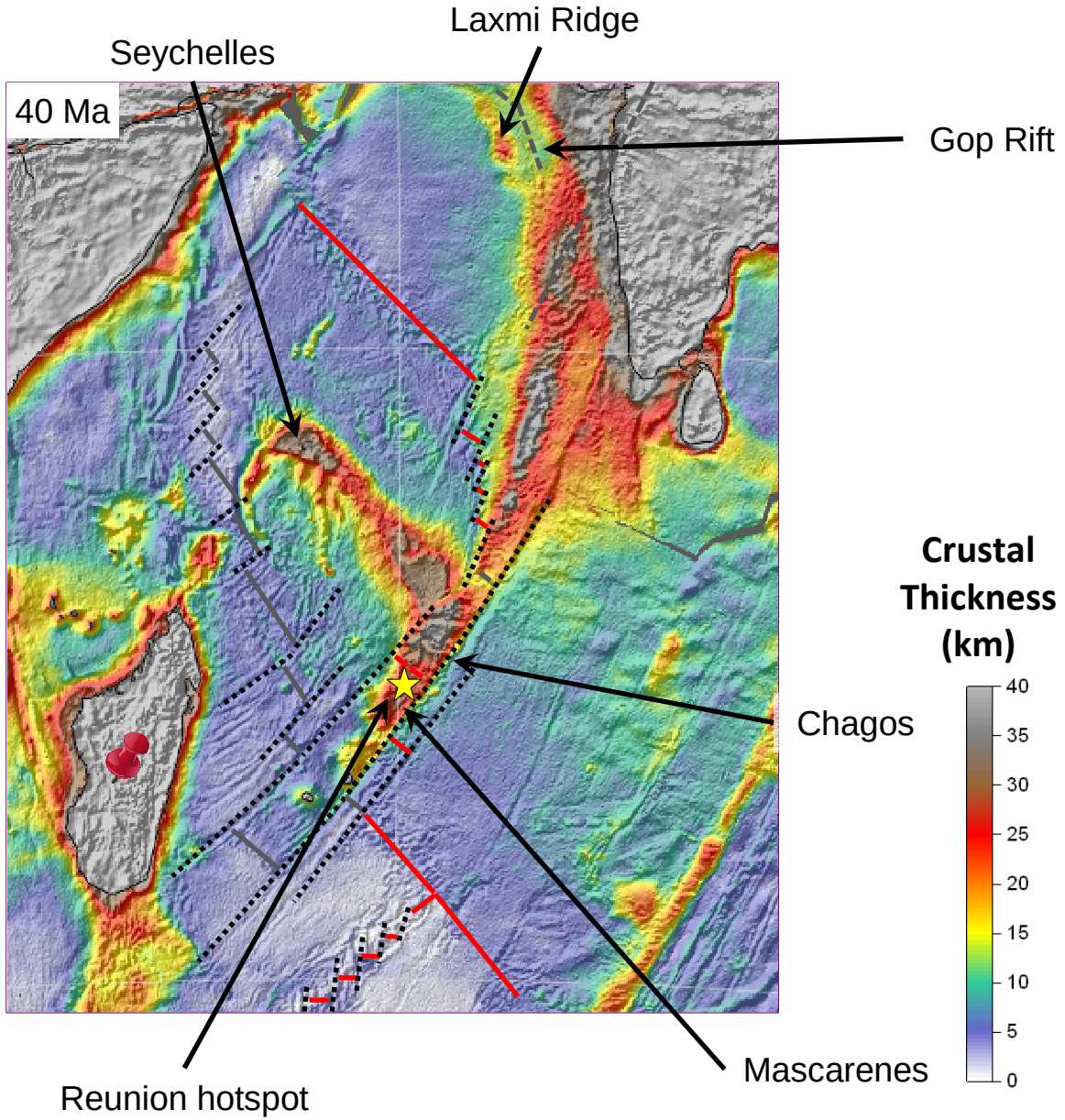
Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

40 Ma

- ***Restoration of crustal thickness from gravity inversion***
- ***New poles & polygons***

55 – 35 Ma
No discrete plate boundary

(Alvey & Kusznir)



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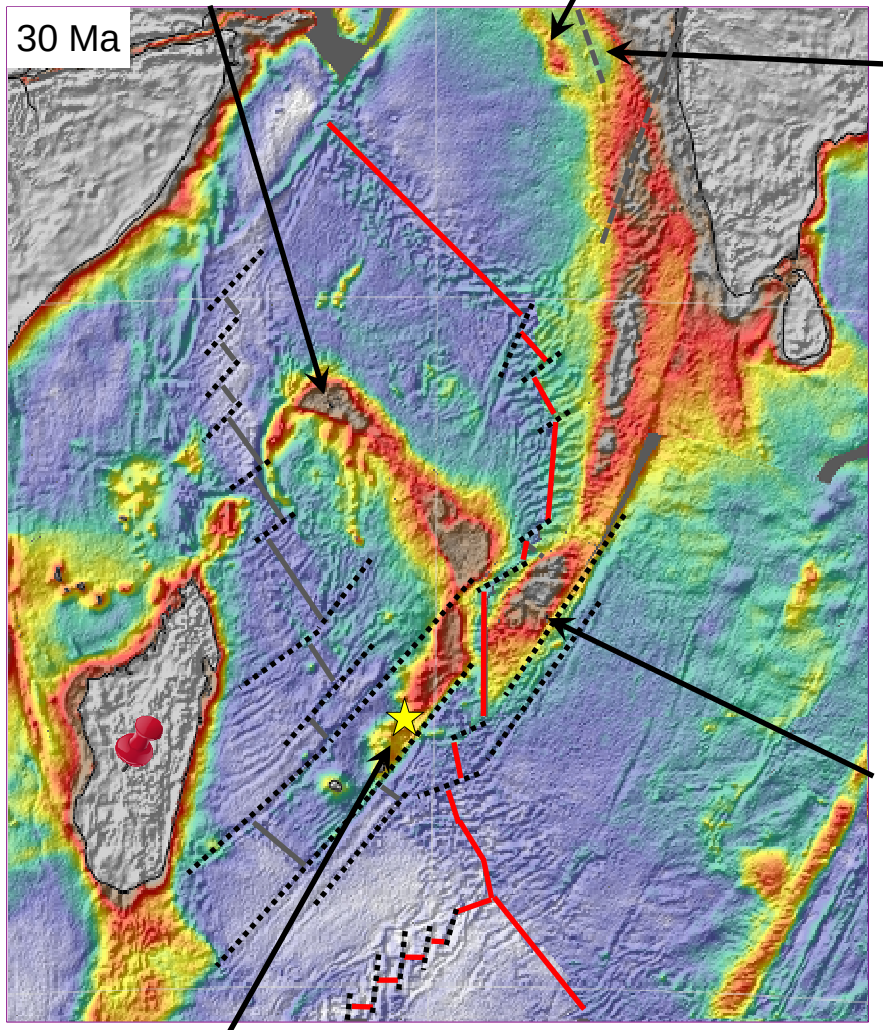
Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

30 Ma

- ***Restoration of crustal thickness from gravity inversion***
- ***New poles & polygons***

Discrete plate boundary

(Alvey & Kusznir)



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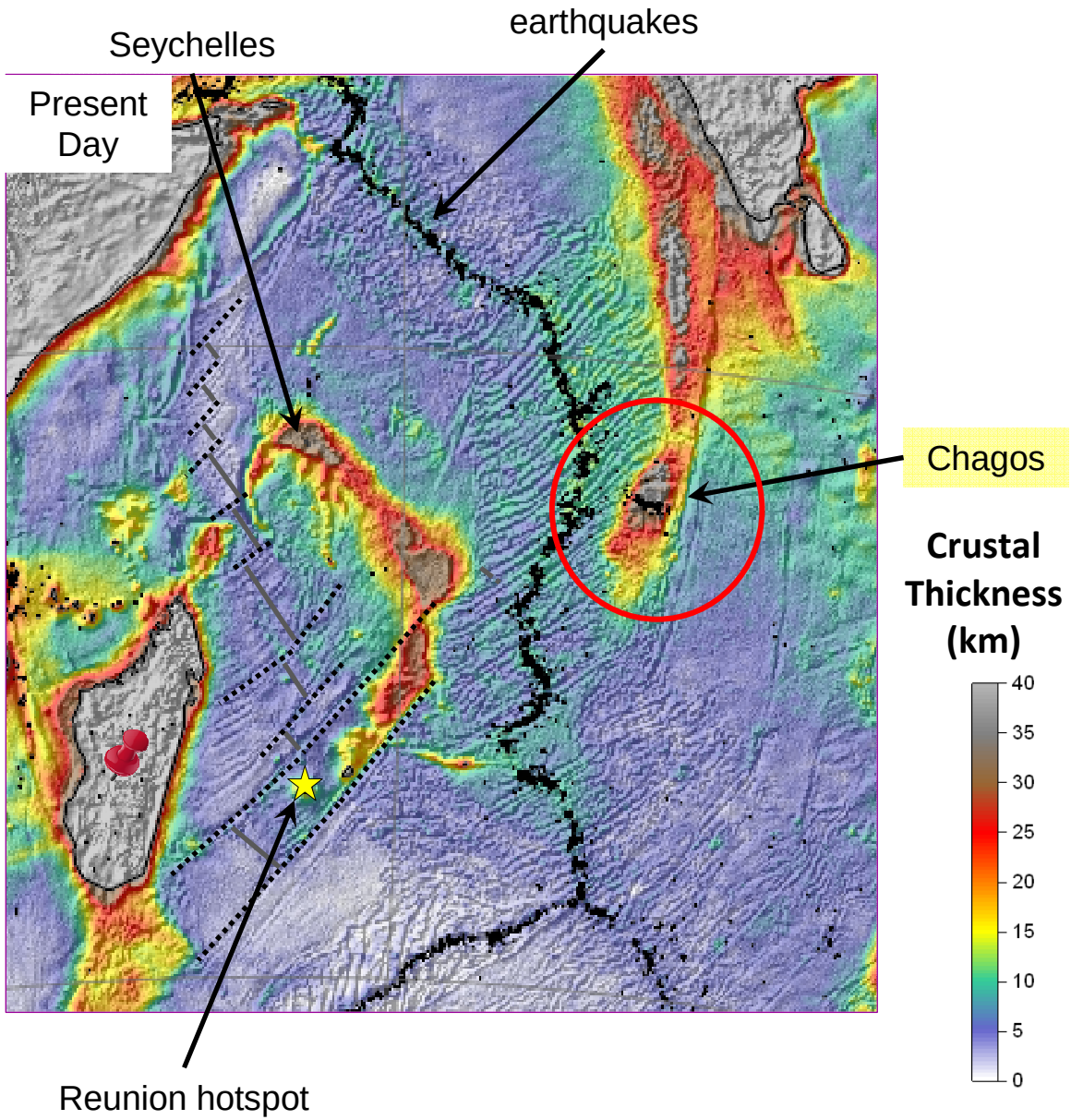
Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

Present day

Start of ridge jump into Chagos Banks?

(Alvey & Kusznir)



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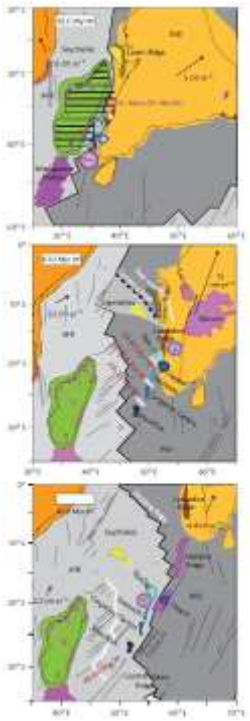
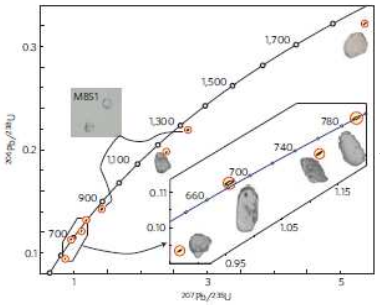
Indian Ocean - Mauritius, Nazareth, Mascarene & Chagos Banks

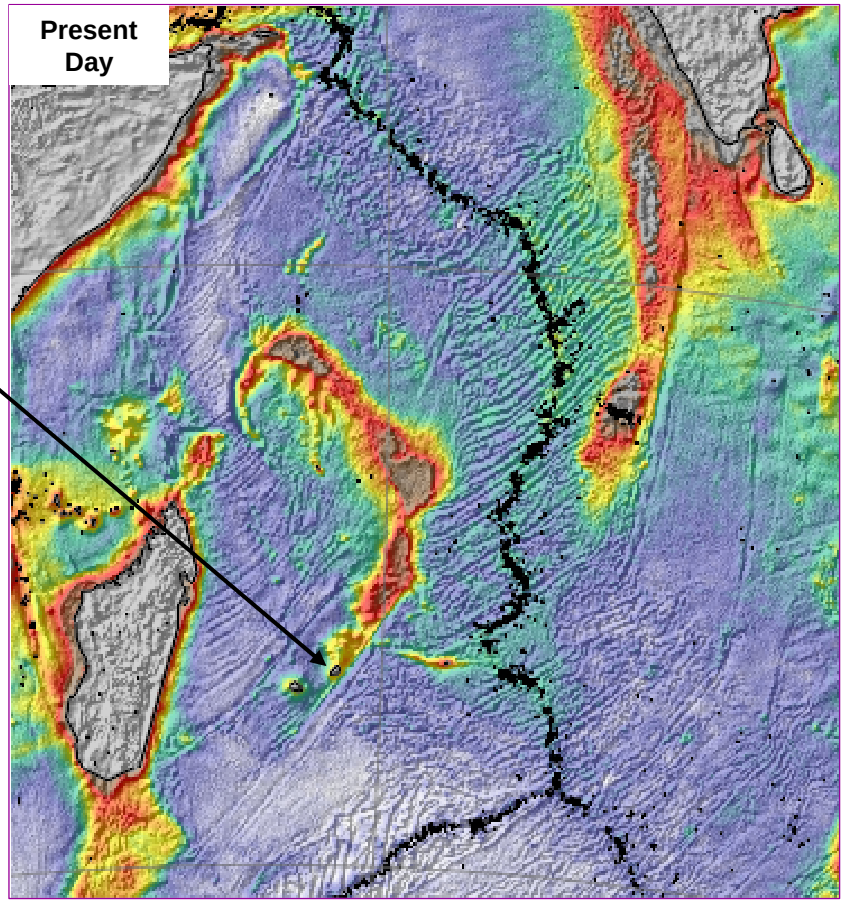
- Underlain by oceanic crust magmatically thickened and rifted ahead of propagating sea-floor spreading

- Some continental component - Precambrian age zircons found on Mauritius.





(Torsvik et al. Nature, 2013)



Mauritius Pre-Cambrian Zircons (Continental Lithosphere?)

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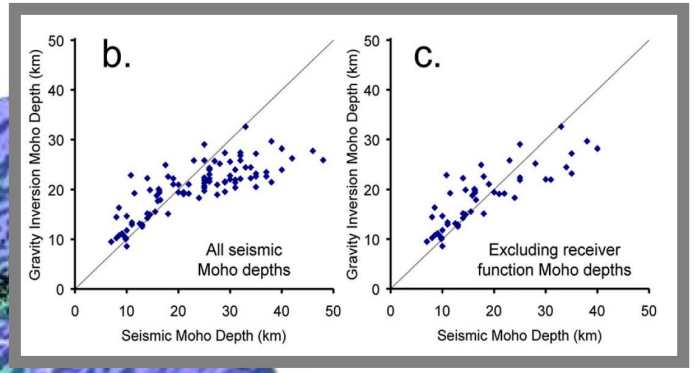
NE Atlantic & Iceland

Comparison of Gravity & Seismic Moho Depths



(Torsvik et al., PNAS, 2015)

Crustal Basement Thickness from Gravity Inversion

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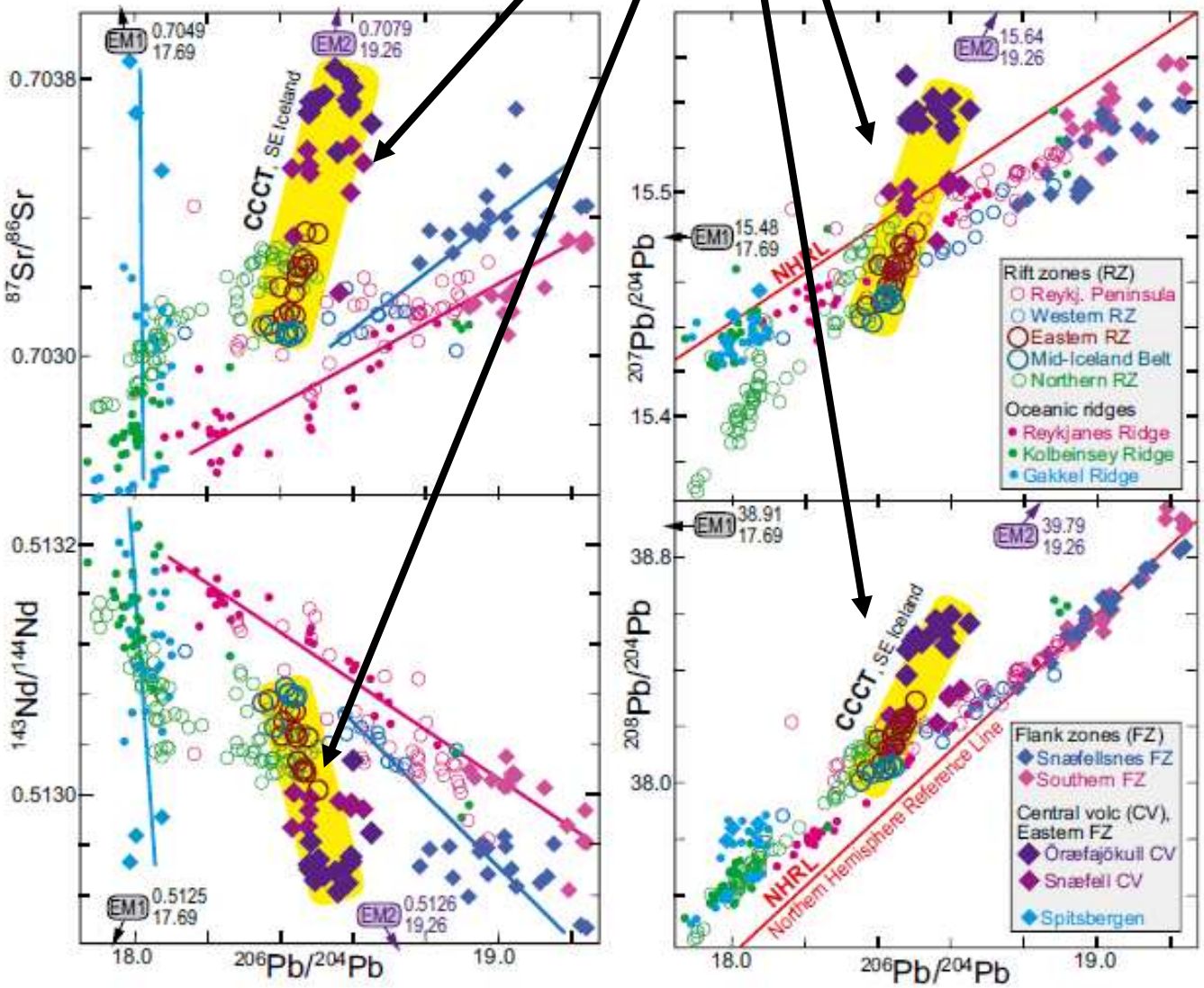
SE Iceland

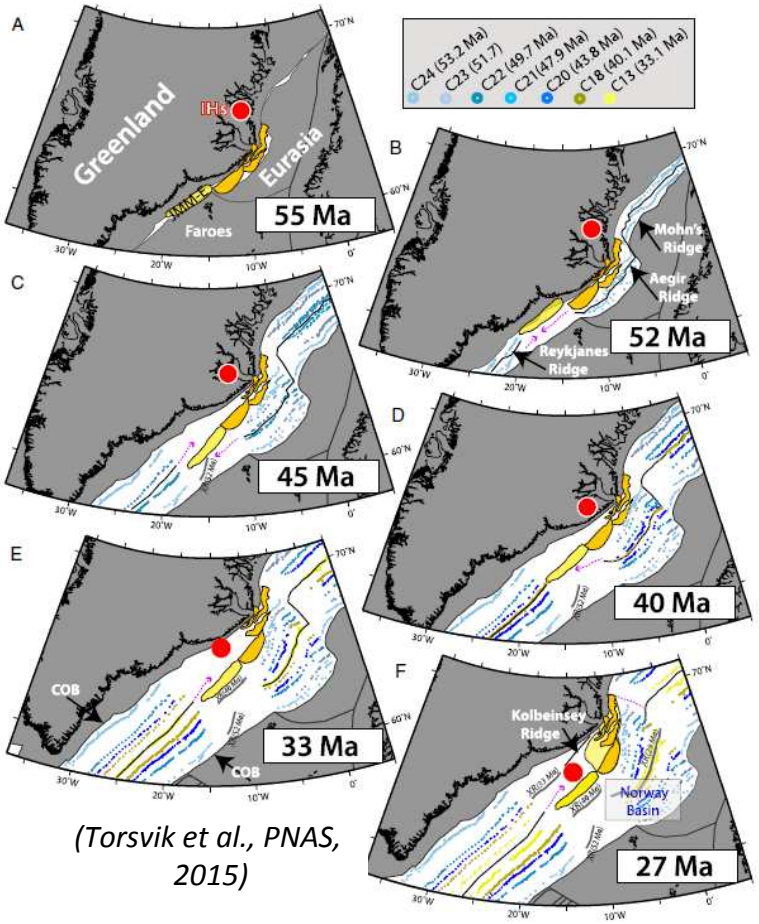
- SE Iceland
- EM2 - continental crust contamination trend



(Torsvik et al., PNAS, 2015)

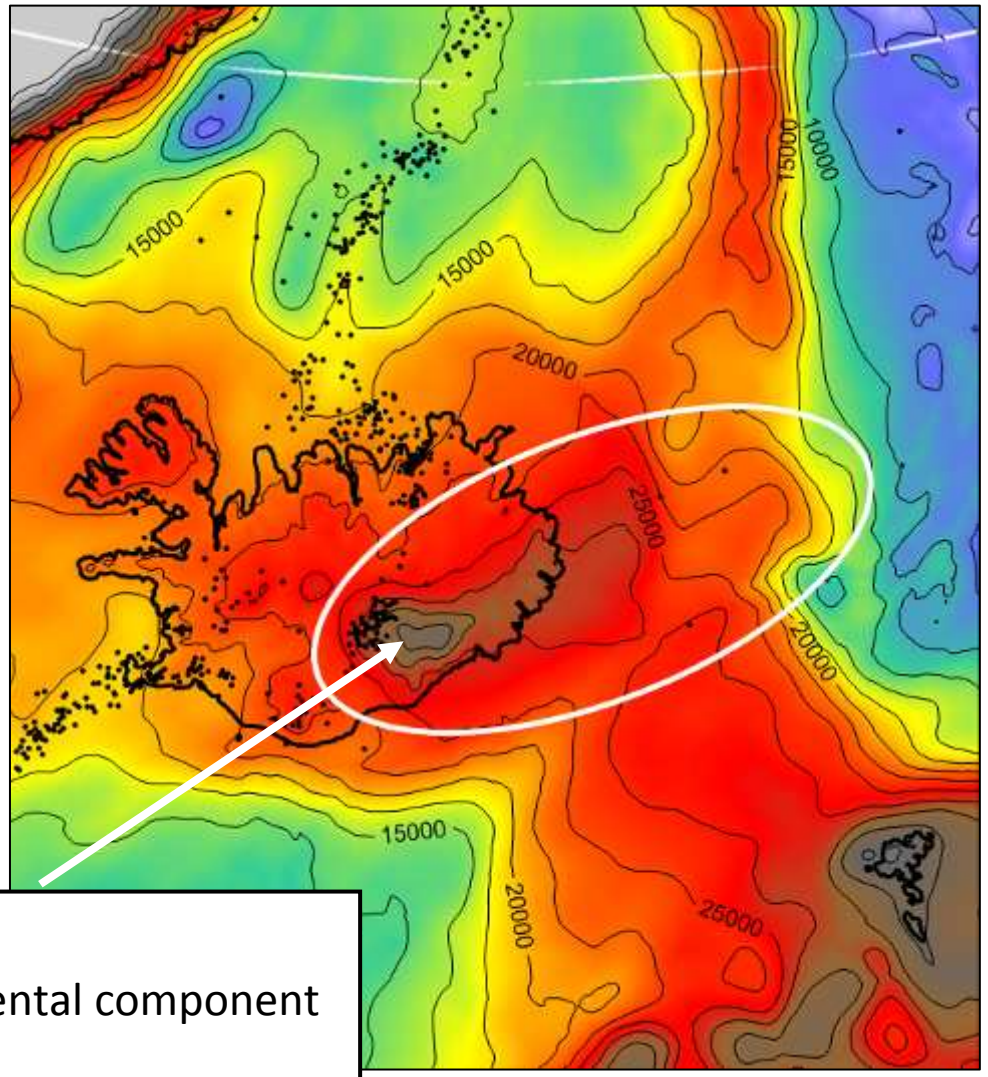
- Geochemical evidence consistent with some continental material under SE Iceland

SE Iceland



(Torsvik et al., PNAS, 2015)

Crustal Basement Thickness from Gravity Inversion (m)



- 30 km thick crust under SE Iceland
- Geochemical evidence for some continental component
- Extends to NE under Skjaldarsgrunn
- Distinct from Faeroes-Iceland Ridge
- Southward continuation of Jan Mayen micro-continent

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Summary

Sea-floor spreading is complex – we observe:

- Repeated intra-oceanic plate boundary re-organizations & ridge jumps
- Jumps are magmatic generating oceanic plateaux
- Evidence for intra-oceanic continental fragments

Questions

- Are these plate re-organisations locally or globally driven?
- Are these intra-oceanic regions underlain by mantle with some inherited continental component?
- Are these intra-ocean ridge jumps attracted by rheological weaknesses controlled by compositional or thermal anomalies?
- Can these ocean ridge re-organizations be explained by upper mantle chemical heterogeneity (water?) and mantle thermal fluctuations from plate tectonic thermal-boundary-layer convection?
- **Plate tectonics – the next 50 years – what have we still to learn?**

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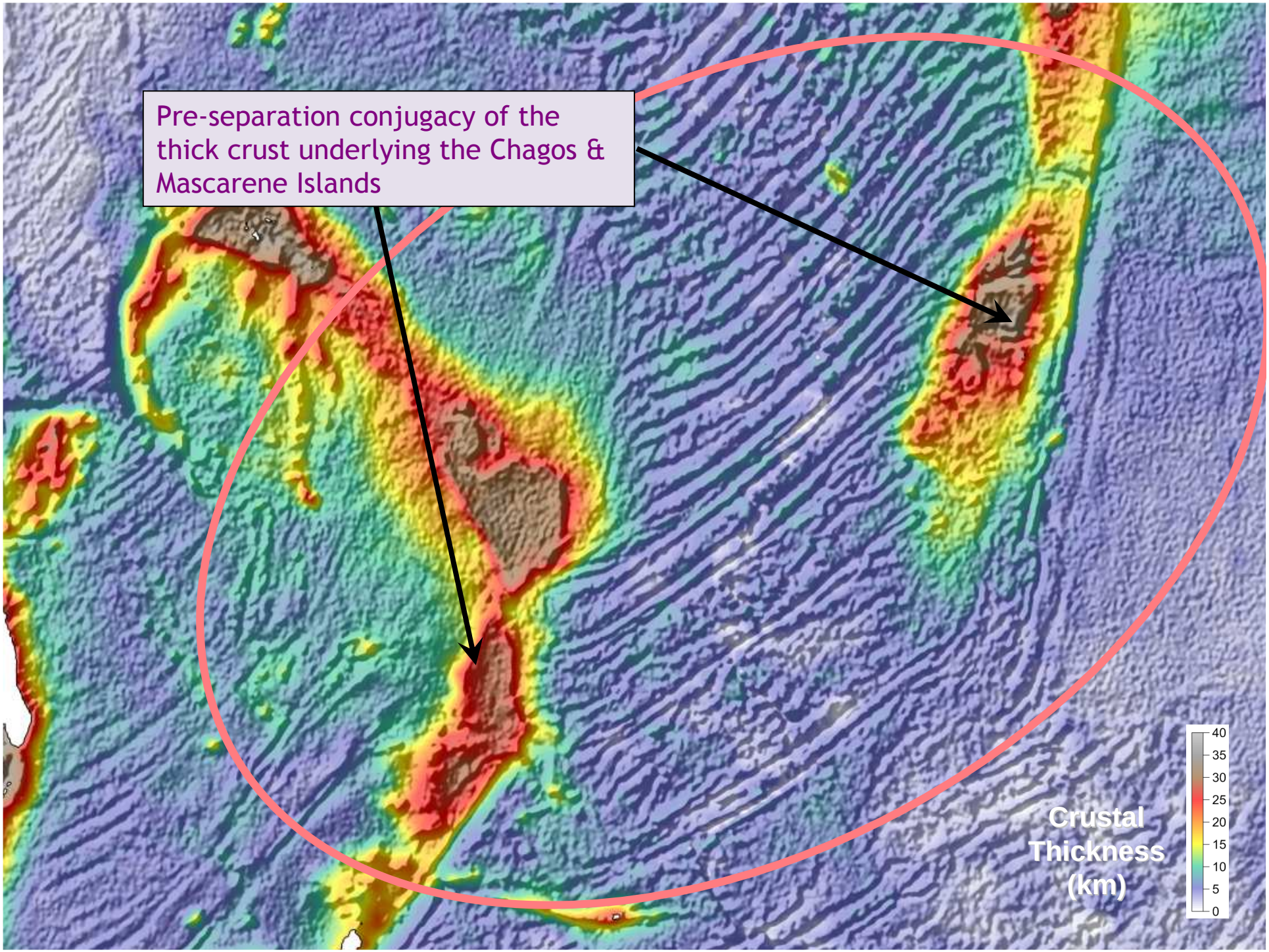
Pre-separation conjugacy of the thick crust underlying the Chagos & Mascarene Islands
Crustal Thickness (km)
40
35
30
25
20
15
10
5
0