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EARLY EARTH: Solid Earth Processes

Subaqueous Archean continental flood basalts were emplaced on hot continental crust

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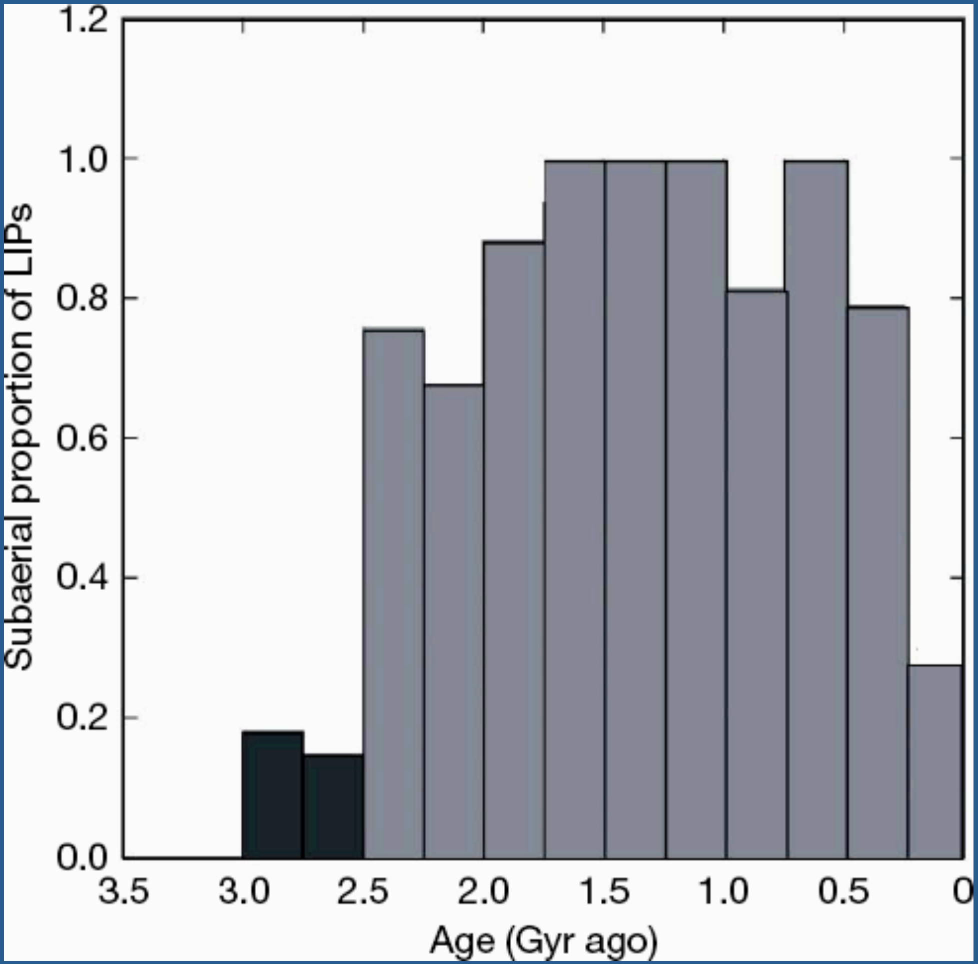
Archaean pillow basalts in
flood basalts up to 10 km thick
Photo P. Rey

Predominance of subaqueous flood basalts in the Archean



Kump & Barley (2007)

Subaqueous flood volcanism on continental platforms is:

- common in the Precambrian
- rare to absent in the Phanerozoic

Arndt (1999)

Examples of subaqueous Archean CFBs

Name	Craton	Events*	Thickness (km)	Age (Ma)	Duration (Myr)	References
Lower Maddina Fm., Fortescue Gp.	**Pilbara**	1	**~ 0.6**	2718 ± 3 to 2713 ± 3	**≤ 11**	Blake et al. (2004)
Kylena Fm., Fortescue Gp.	**Pilbara**	1	**≤ 1.4**	2749-2735	**14**	Thorne and Trendall (2001)
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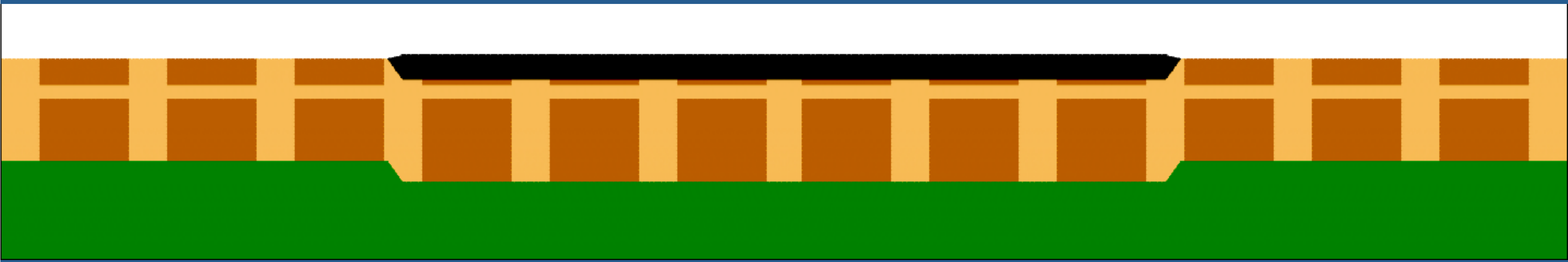
Balmer assemblage	**Superior**	sequence	**< 10**	2992-2964	**> 28**	Tomlinson and Condie (2001)
Lumby Lake gr. B.	**Superior**	sequence	**≤ 7**	< 2963-2898	**< 70**	Tomlinson and Condie (2001)
Kolar schist belt	**Dharwar**	sequence	**~ 4**	~ 2700	**?**	Krogstad et al. (1989)

Subaqueous flood basalts erupted through continental crust

(Arndt, 1999; Tomlinson and Condie, 2001)

Topography associated with CFBs



- Elevation

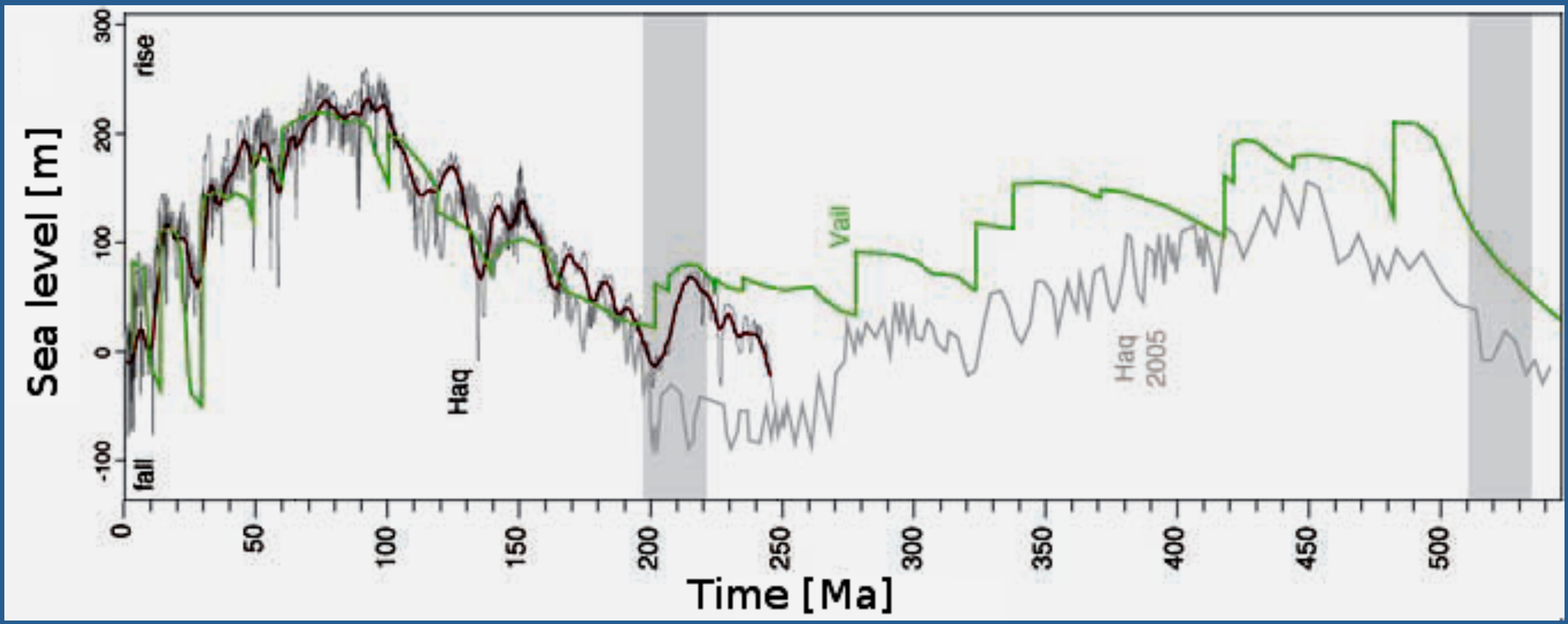
$$e = t_{CFB} \times \left(1 - \frac{\rho_{CFB}}{\rho_M}\right)$$

- t_{CFB}: thickness
- ρ_{CFB} = 2840 kg m $^{-3}$
- ρ_M = 3370 kg m $^{-3}$

- $e \approx$ 950 m for t_{CFB} = 6 km
- $e \approx$ 1500 m for t_{CFB} = 10 km

➔ Need to explain a change in sea level of up to 1.5 km in < 70 Myr

Not explained by change in eustatic sea level



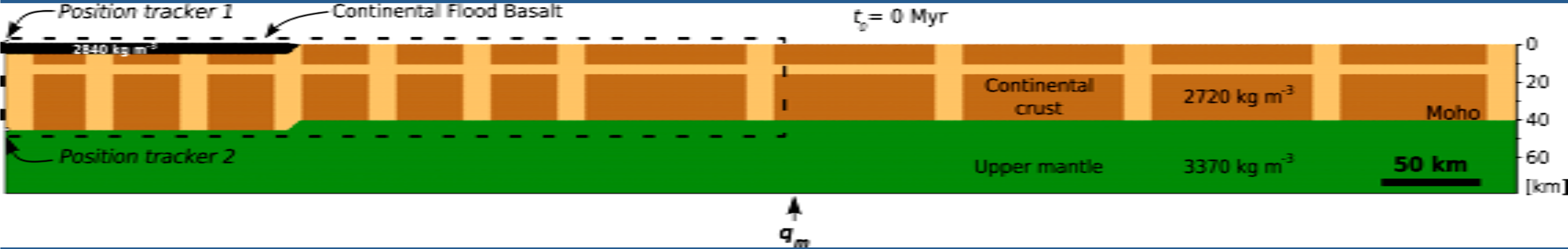
- Phanerozoic rate ~ < 2 m Myr $^{-1}$

Miller et al. (2005)

- Secular rate ~ 0.5 m Myr $^{-1}$ *(Flament et al., 2008)*
- Subaqueous Archean CFBs 15 m Myr $^{-1}$

Hypothesis and model

<u>Hypothesis:</u> flow of continental crust can remove thickness anomalies associated with a CFB in a few tens of million years



- Ellipsis, particle-in-cell, finite element code

(Moresi et al., 2003)

Model setup – geotherm & rheology

- 1D, steady-state

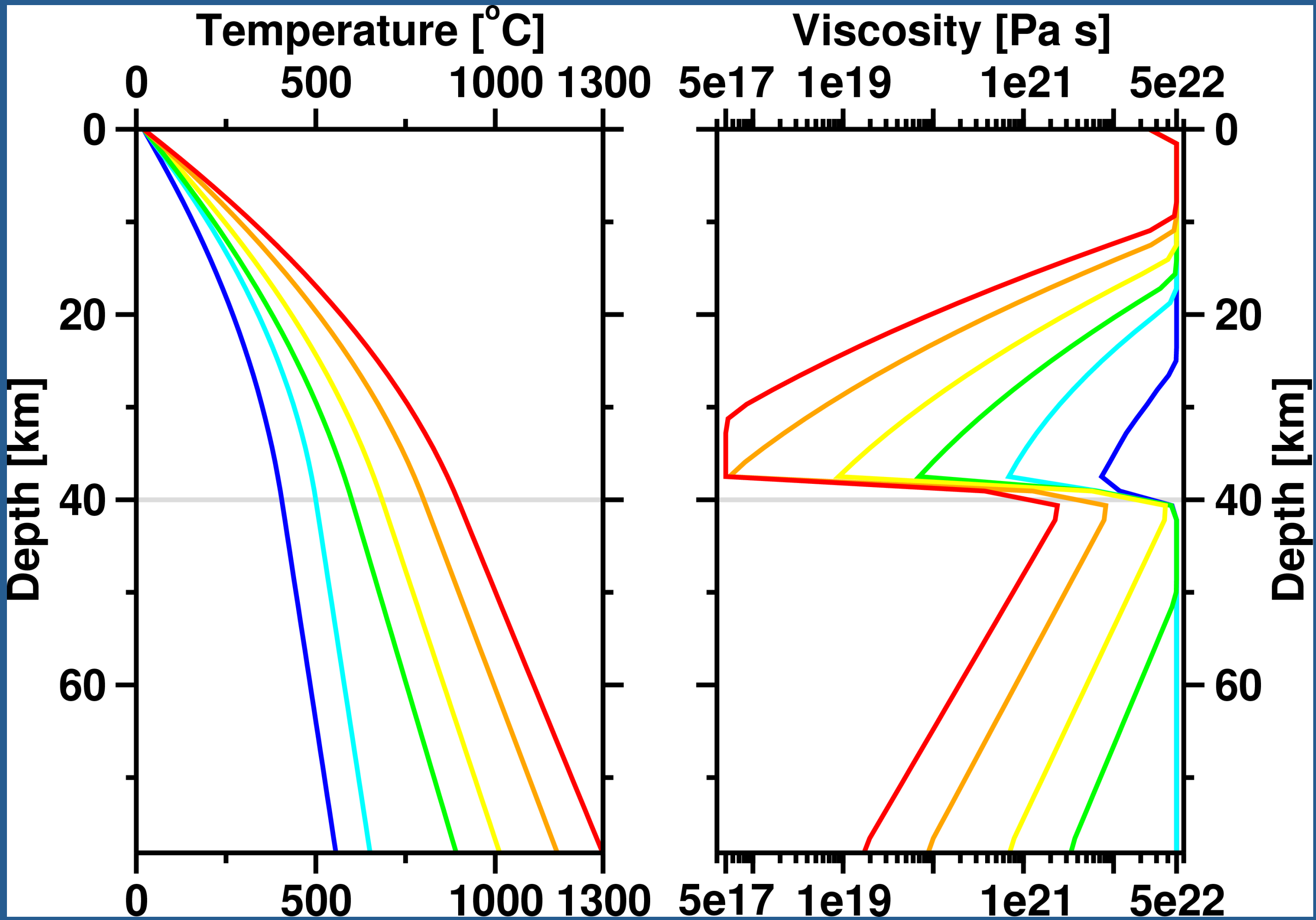
$$k\frac{d^2T}{dz^2} + \rho_{cc}H(t) = 0$$

- *H(0)* for present-day cratons

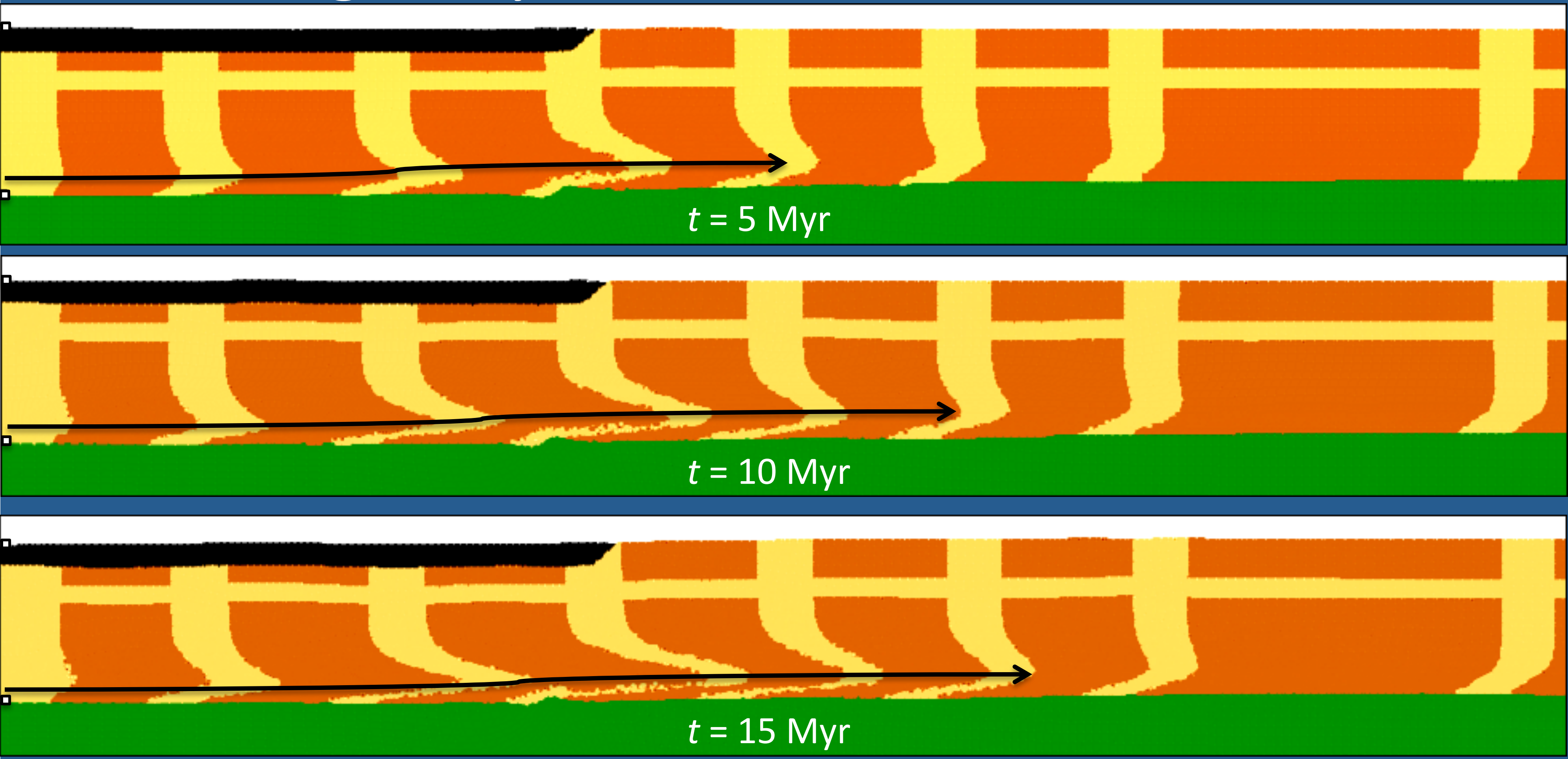
  Taylor & Mclennan (1995)

- Visco-plastic
- T-dependent viscosity:

$$\eta = \eta_0 \exp(-\gamma\, T)$$

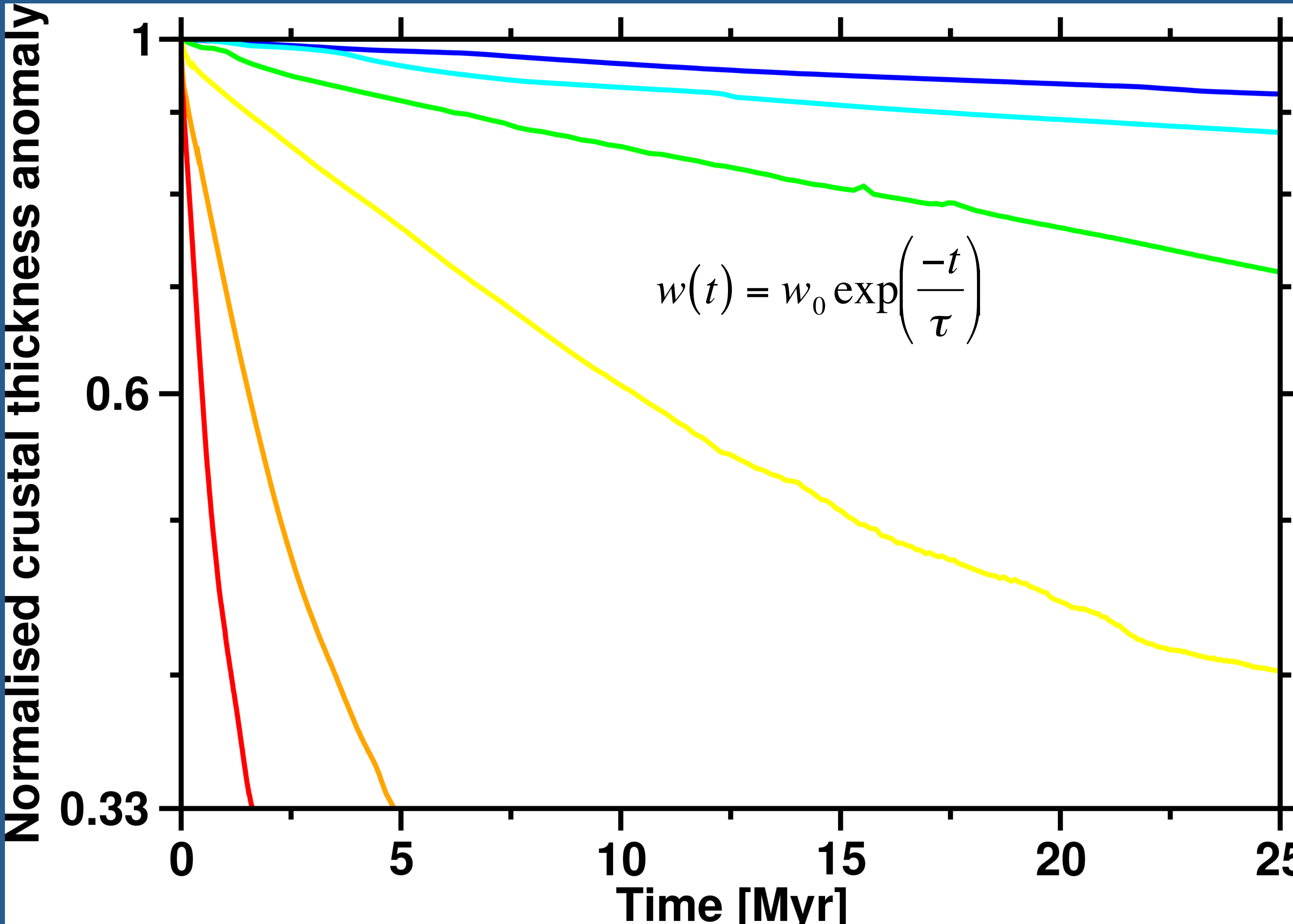


Relaxation of the thickness anomaly via gravity-driven lower crustal flow

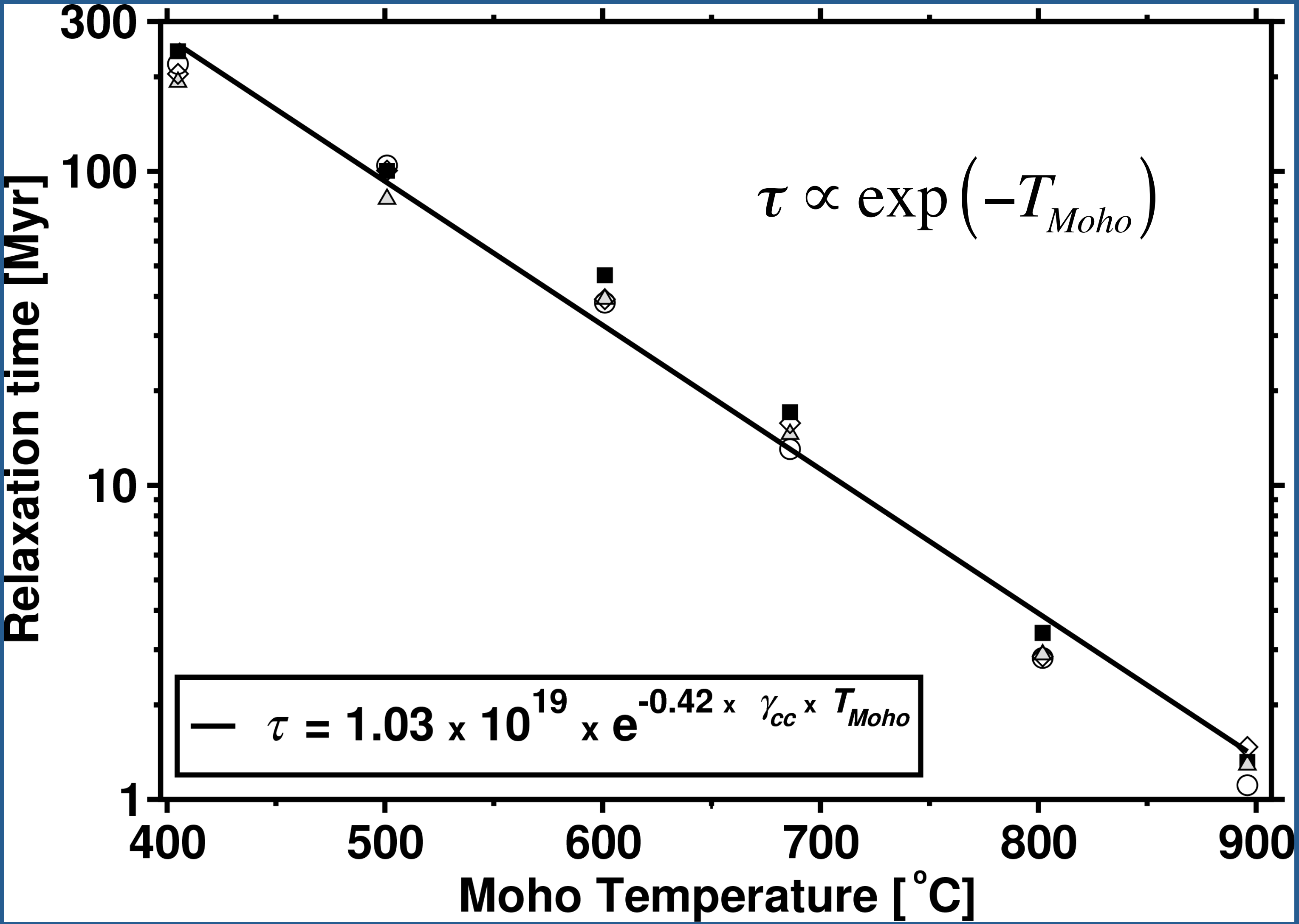


- CFB 6 km thick
- $T_{Moho} \approx 700ºC$

Characteristic relaxation time τ

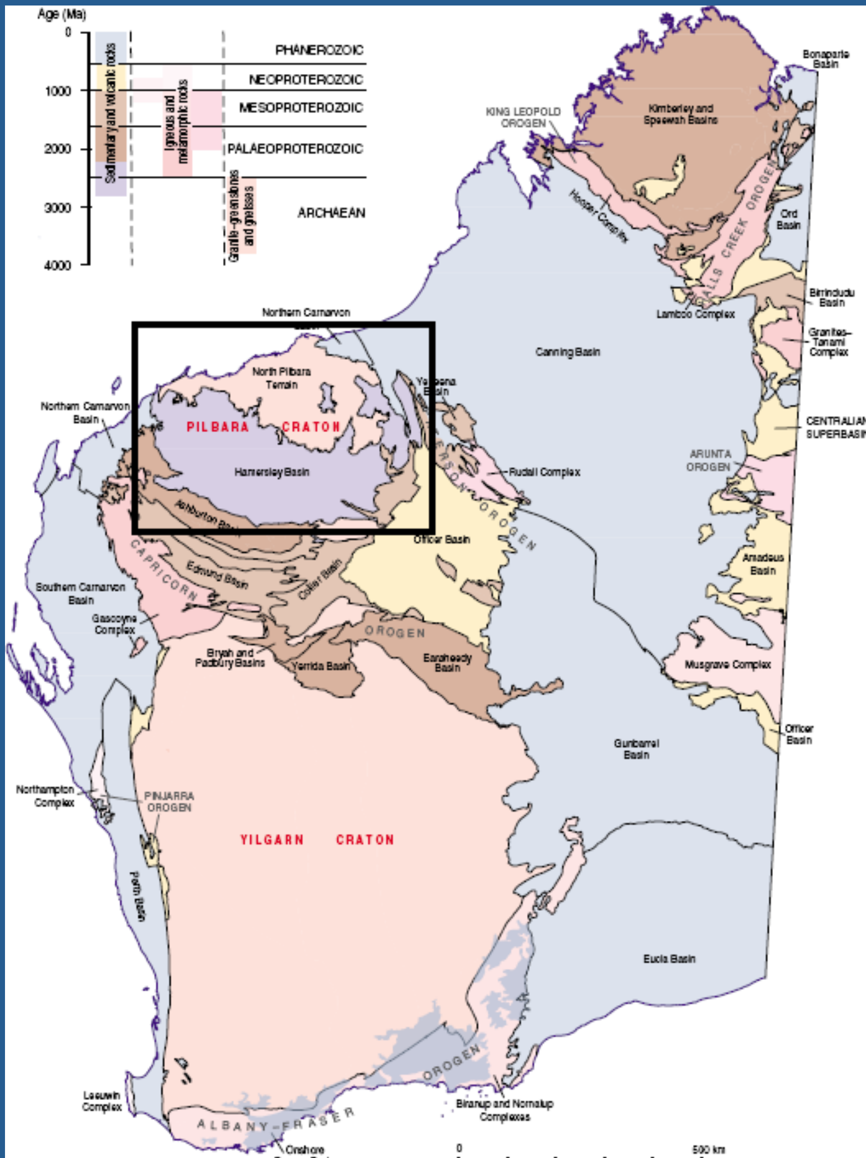


Scaling laws for τ as a function of T_{Moho}

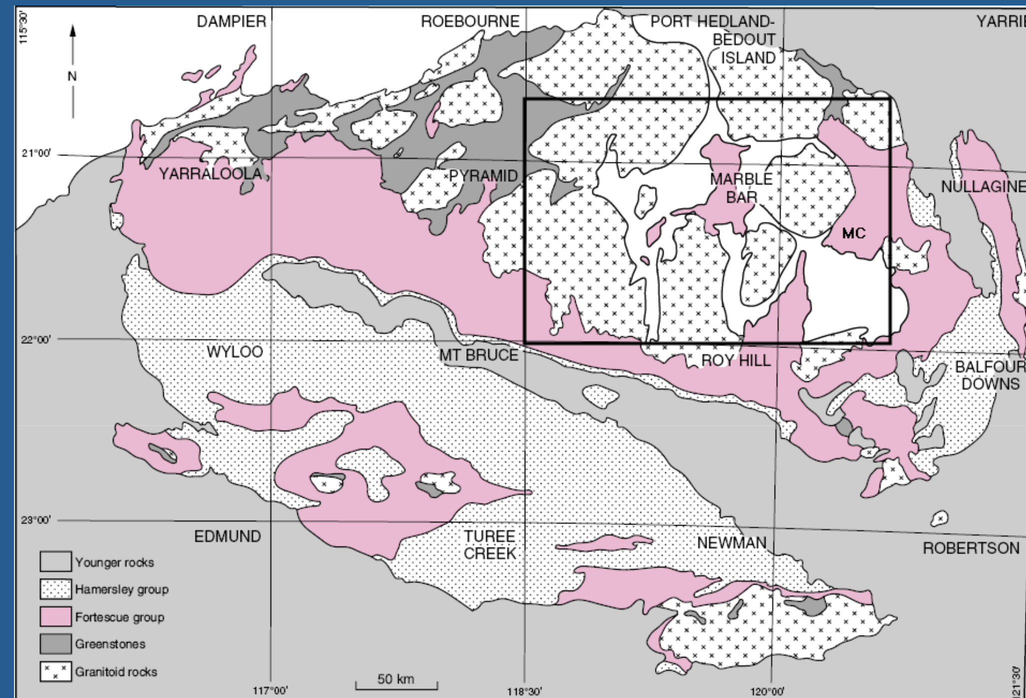


- Efficiency of lower crustal flow increases with T_{Moho}
- Estimate T_{Moho} from the subsidence history of a CFB

Case study: Fortescue Group, Pilbara Craton



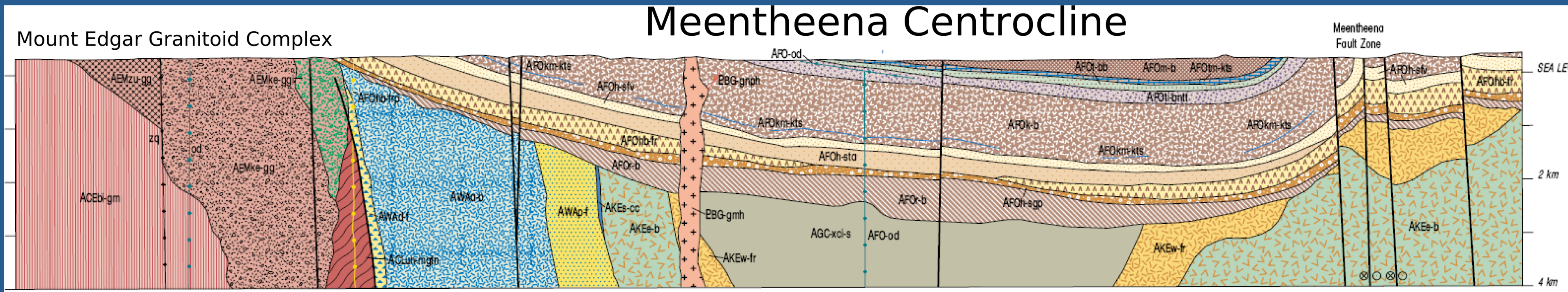
GSWA



Thorne & Trendall (2001)

- 6.5 km thick CFB
- 2775-2630 Ma

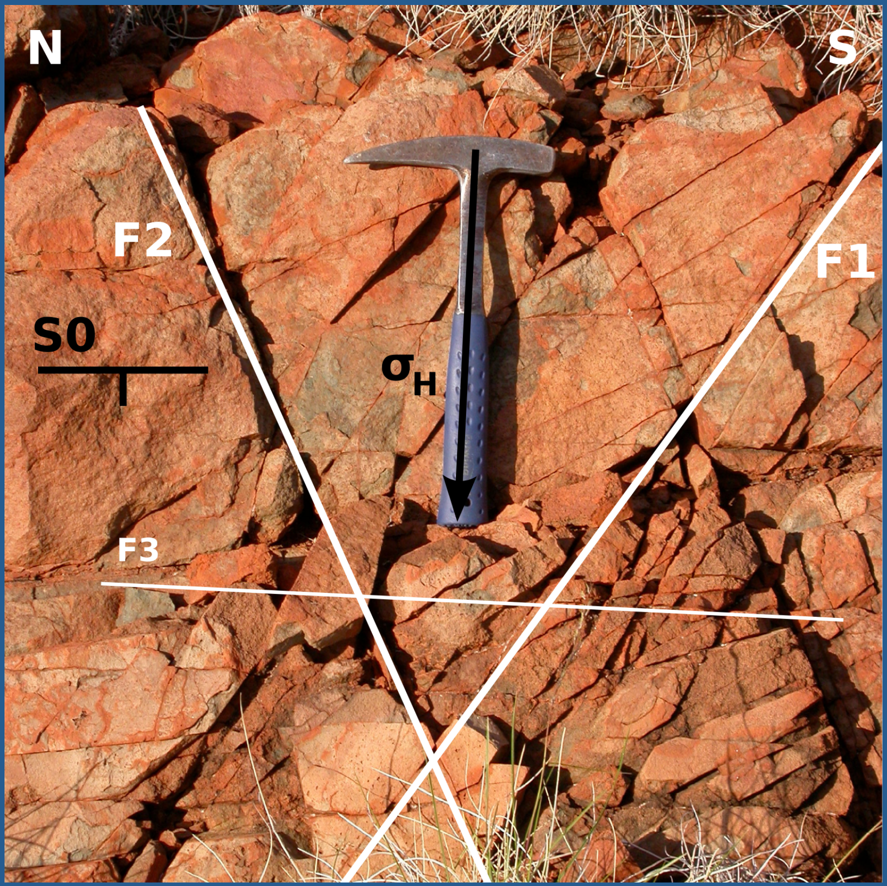
Structure of the Meentheena Centrocline

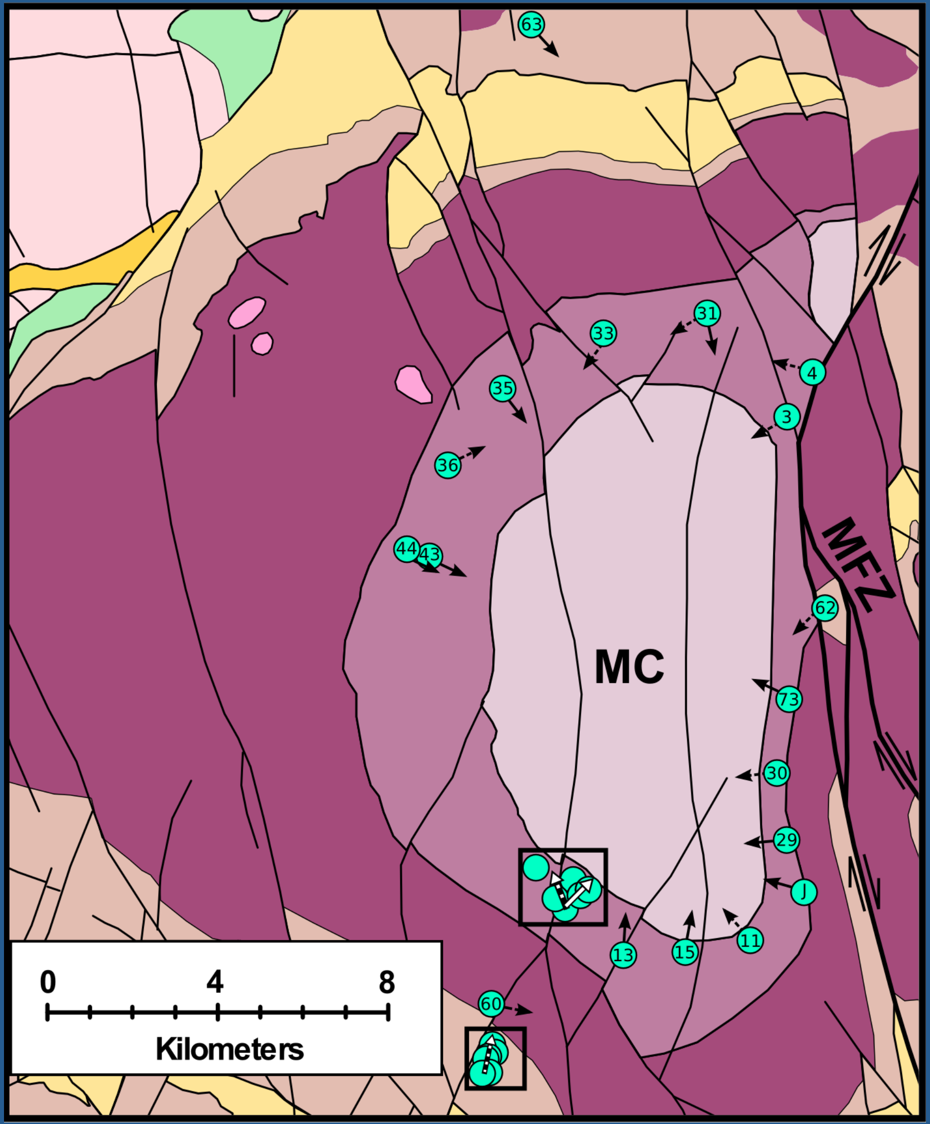


Williams & Bagas (2007)

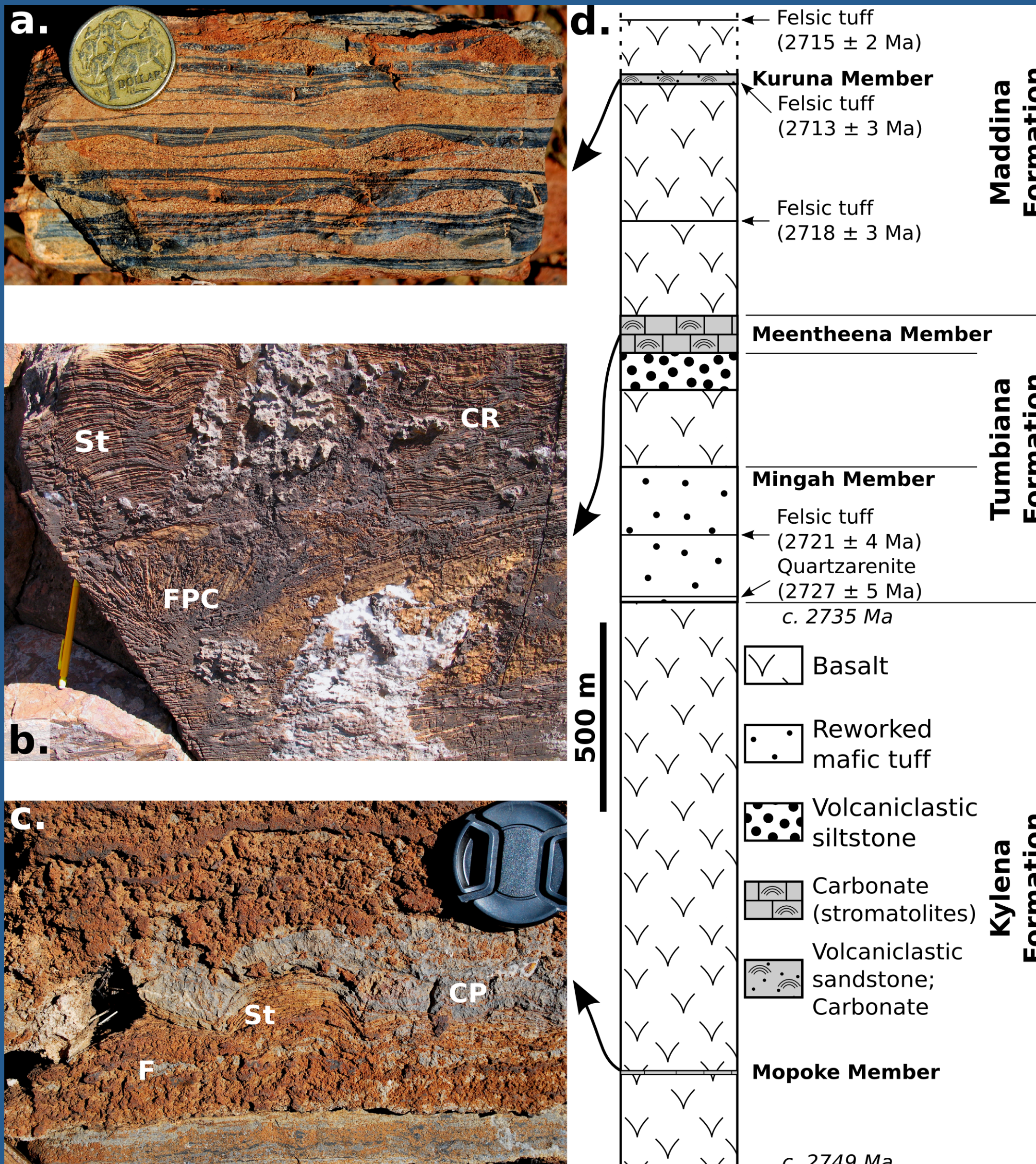
- Emplaced on top of a dome and basin structure
- Absence of syn-depositional deformation
- Structure consistent with accommodation by gravitational subsidence

Directions of palaeostress σ_H and gravitational subsidence





An exceptional stratigraphic column

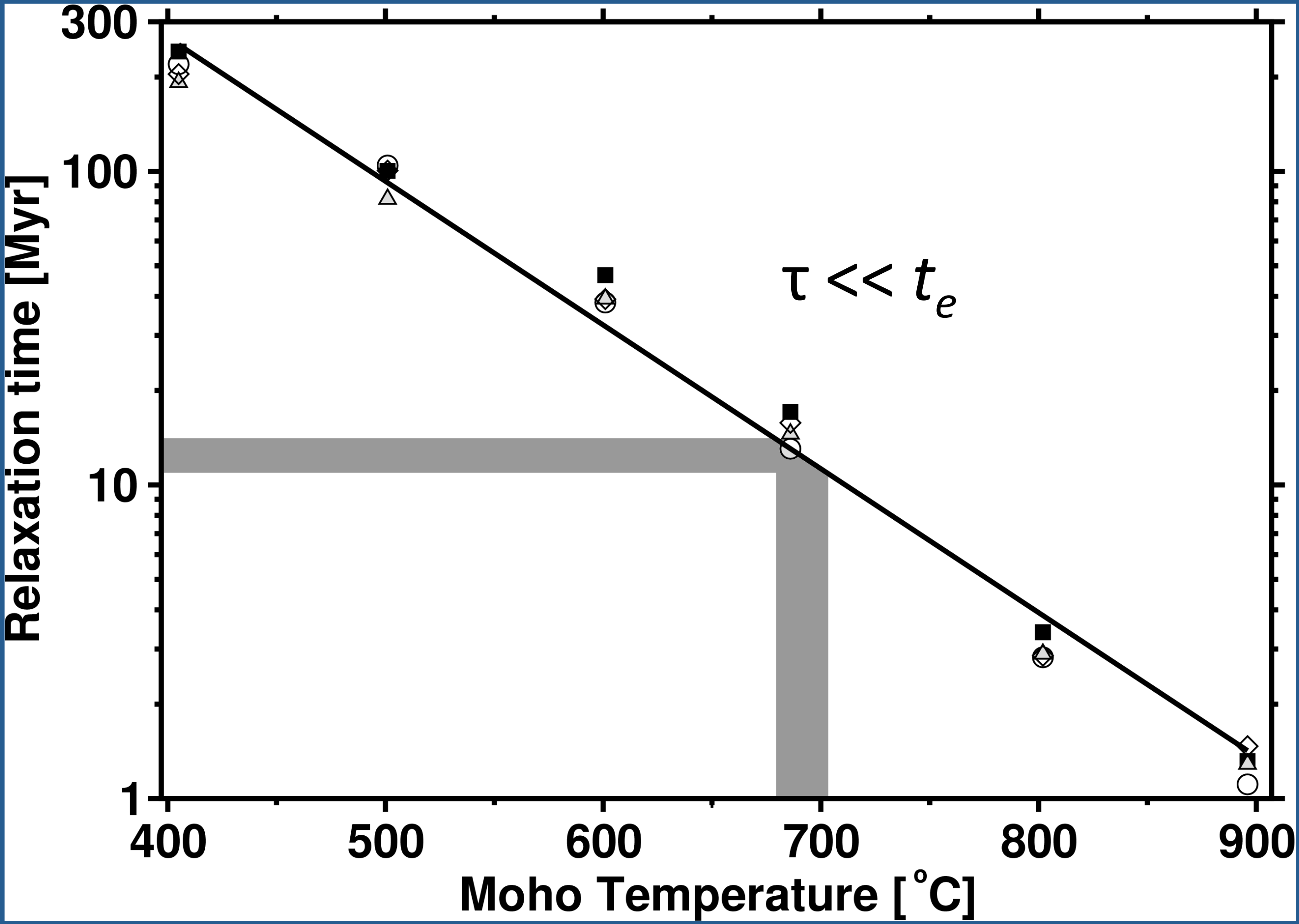


a. wavy bedding
b. climbing ripples and flat-pebble conglomerate
c. Fenestrae and carbonate precipitates

- Maddina Formation $t_e \leq 11$ Myr
- Kylena Formation $t_e < 14$ Myr

Geochronology from *Blake et al. (2004)*

Cooling of the crust in the East Pilbara



- At 2.7 Ga: $T_{Moho} \geq 670ºC$
- Present-day: $T_{Moho} \approx 480ºC$ (surface heat flow)
- Cooling by at least ~ 200ºC

Relaxation time of subaqueous Archean CFBs

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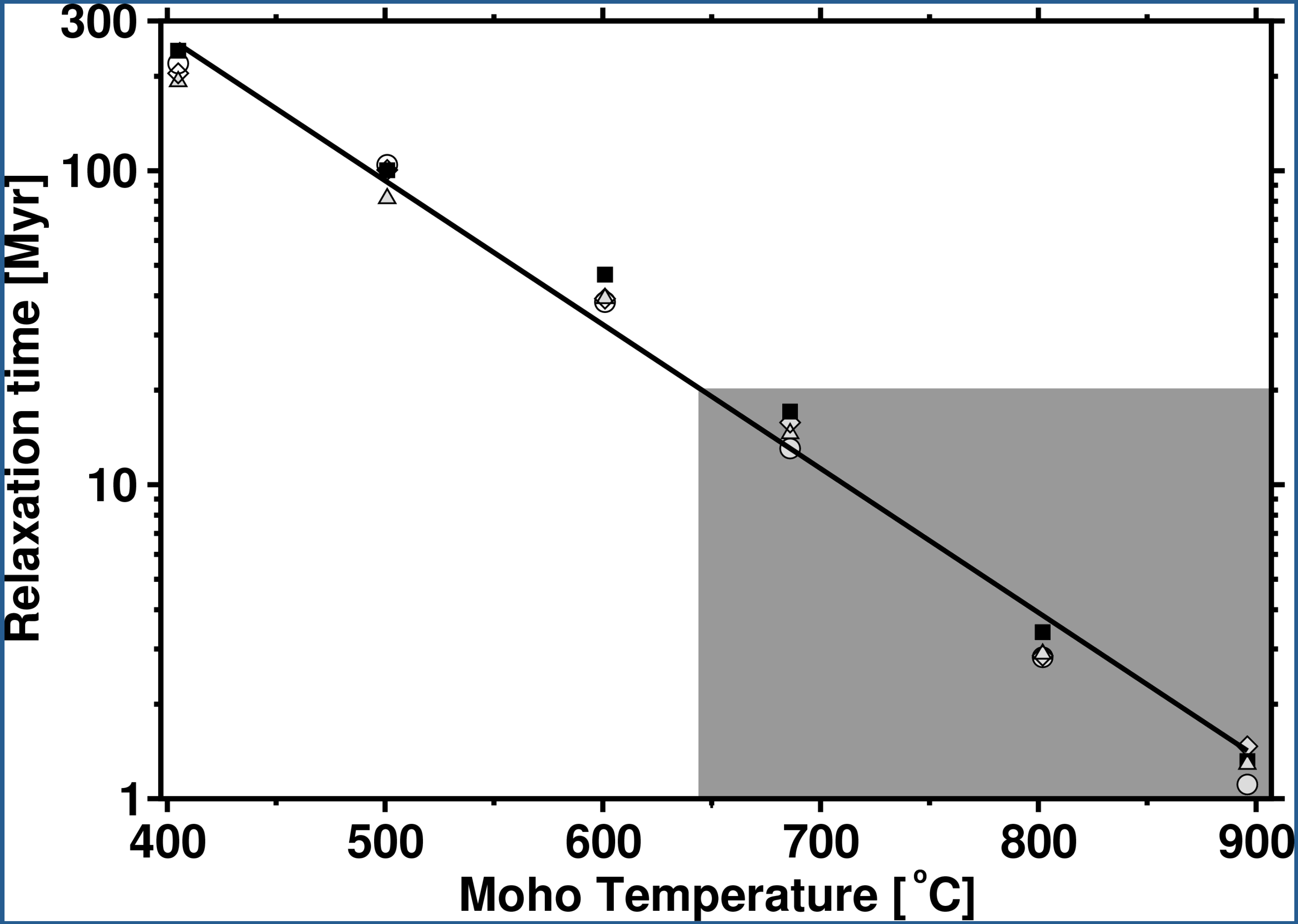
$$\tau << t_e < 20 \text{ Myr}$$

Archean geotherms were hot



➔ Eruption duration of well-constrained events implies T_{Moho} >> 650ºC

Conclusions

- The flow of hot, ductile lower continental crust was a key process that maintained Archaean CFBs below sea level
- Neoarchean cooling of the lithosphere explains the contrasted abundance of subaqueous CFBs in Archean vs. post-Archean
- The subsidence history of CFBs can be used to place broad constraints on Archean geotherms
- Well constrained (geochemistry, geology, geochronology) CBFs suggest Archean Moho temperatures >> 650ºC

Extended results