Temperature, strain rates, and rheology: the key parameters controling strength variations in the Australian lithosphere

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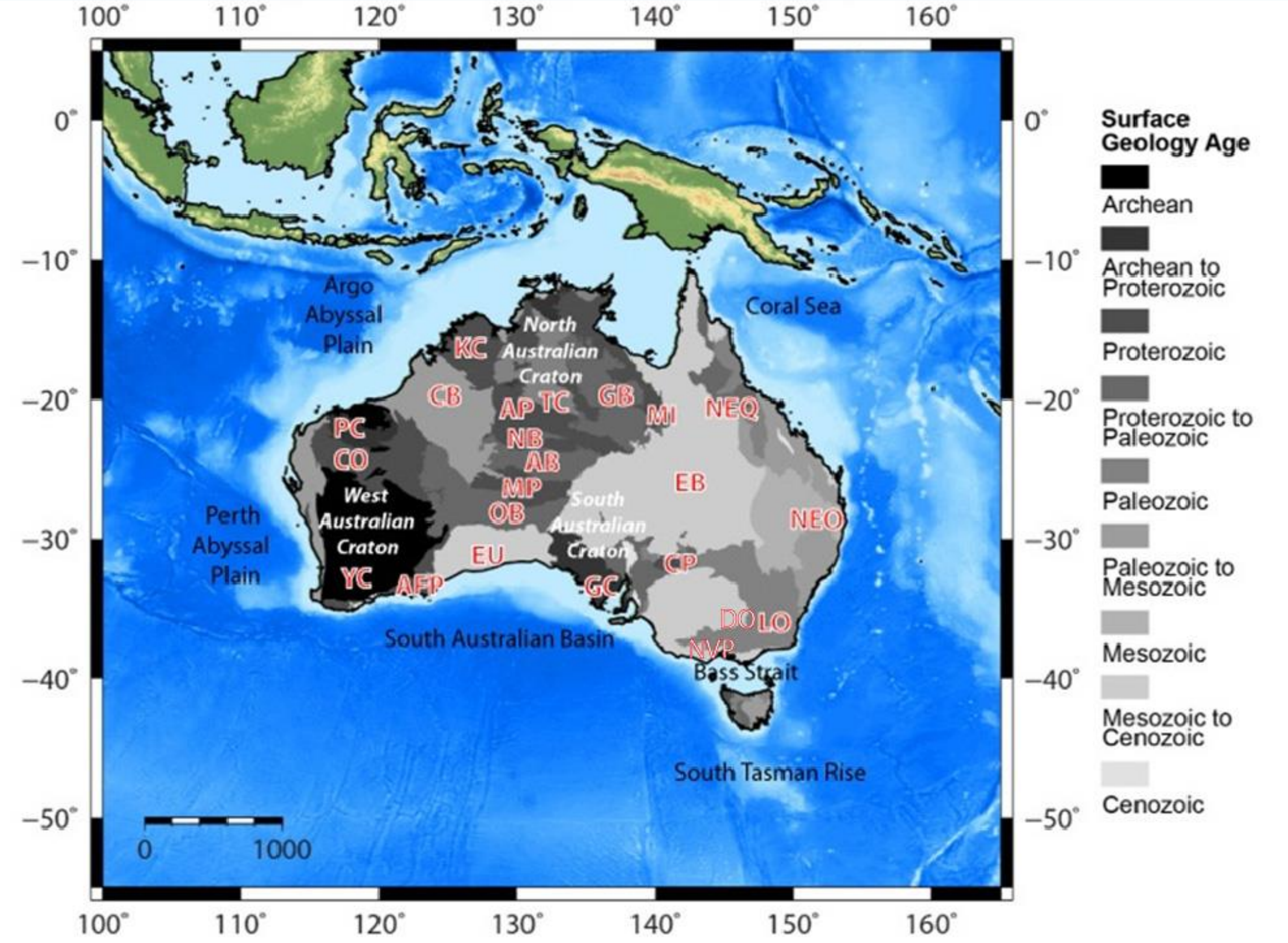
Australian Continent

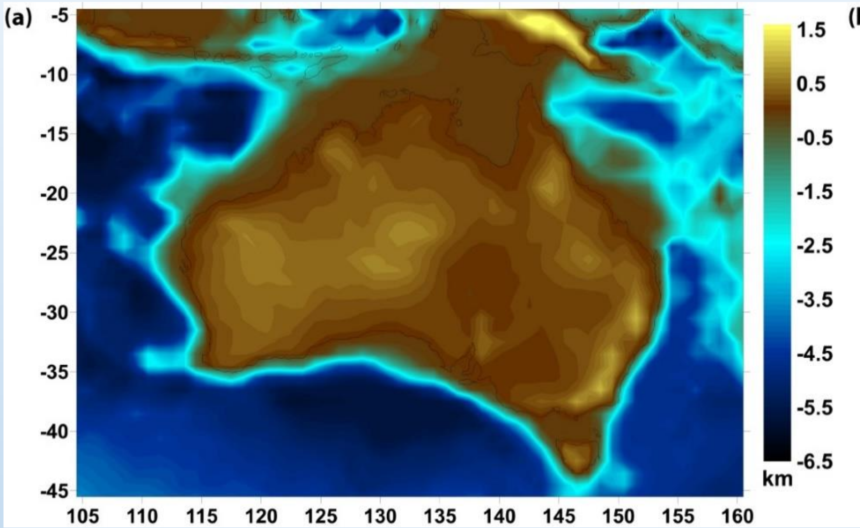


West-Australian Craton: **PC**—Pilbara Craton, **YC**—Yilgarn Craton, **CO**—Capricorn Orogen. *South Australian Craton*: **CP**—Curnamona Province, **GC**—Gawler Craton. *North Australian Craton*: **AP**—Arunta Province, **KC**—Kimberley Craton, **MI**—Mt Isa Inlier. *Proterozoic Orogens*: **AFP**—Albany–Fraser Province, **MP**—Musgrave Province; **TC**—Tennant Creek. *Phanerozoic Orogens*: **LO**—Lachlan Orogen, **NEO**—New England Orogen, **NEQ**—North East Queensland. *Major Sedimentary Basins*: **EU**—Eucla Basin, **OB**—Officer Basin, **AB**—Amadeus Basin, **CB**—Canning Basin, **NB**—Ngalia Basin, **GB**—Georgina Basin, **EB**—Eromanga Basin.

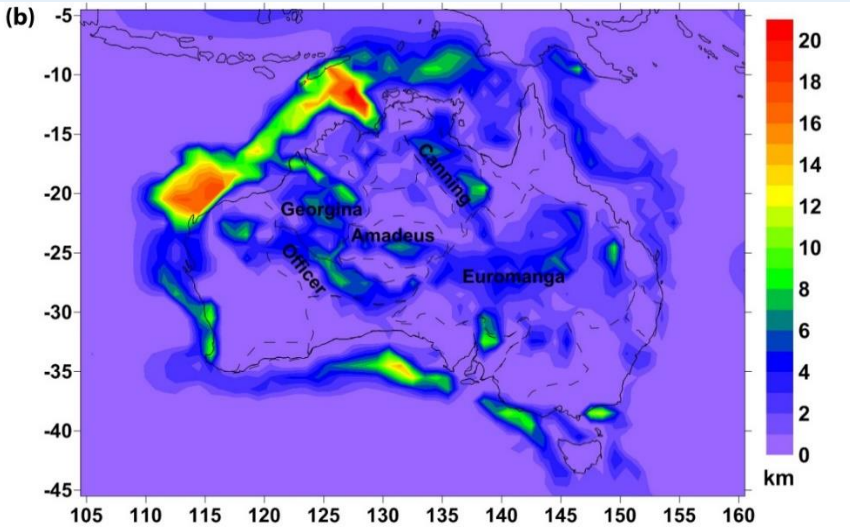
Crustal Structure

AuSREM model provides the main boundaries and velocity of the crust and upper mantle of Australia

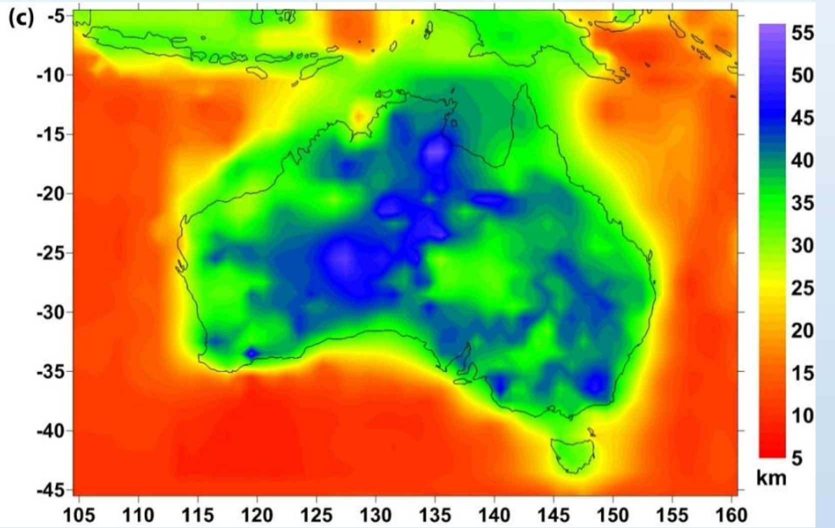
Topography



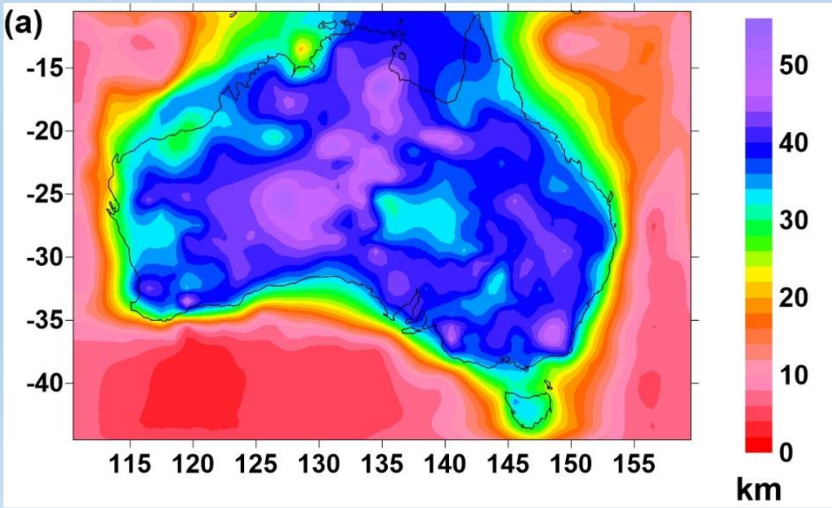
Depth of the Basement



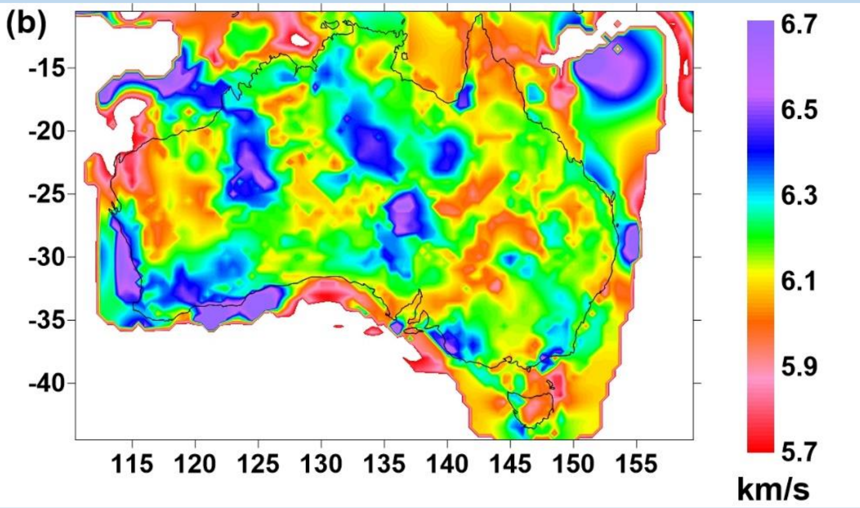
Moho Depth



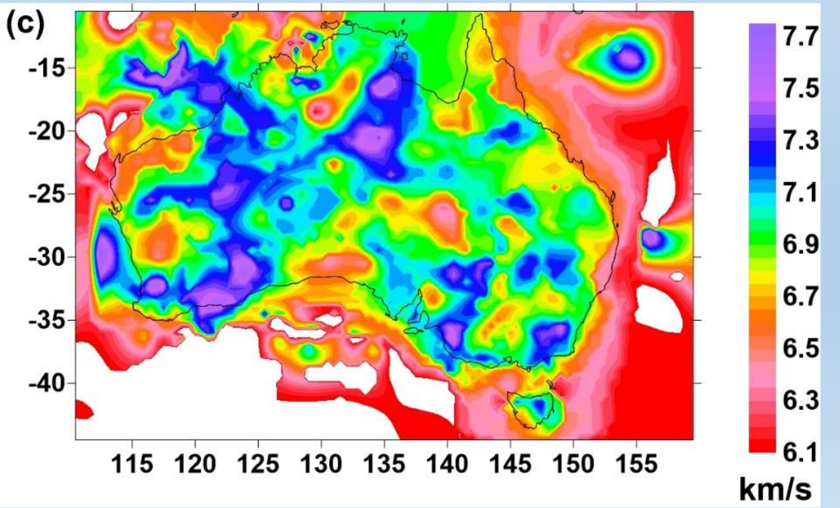
Crustal Thickness



Mean Velocity UC

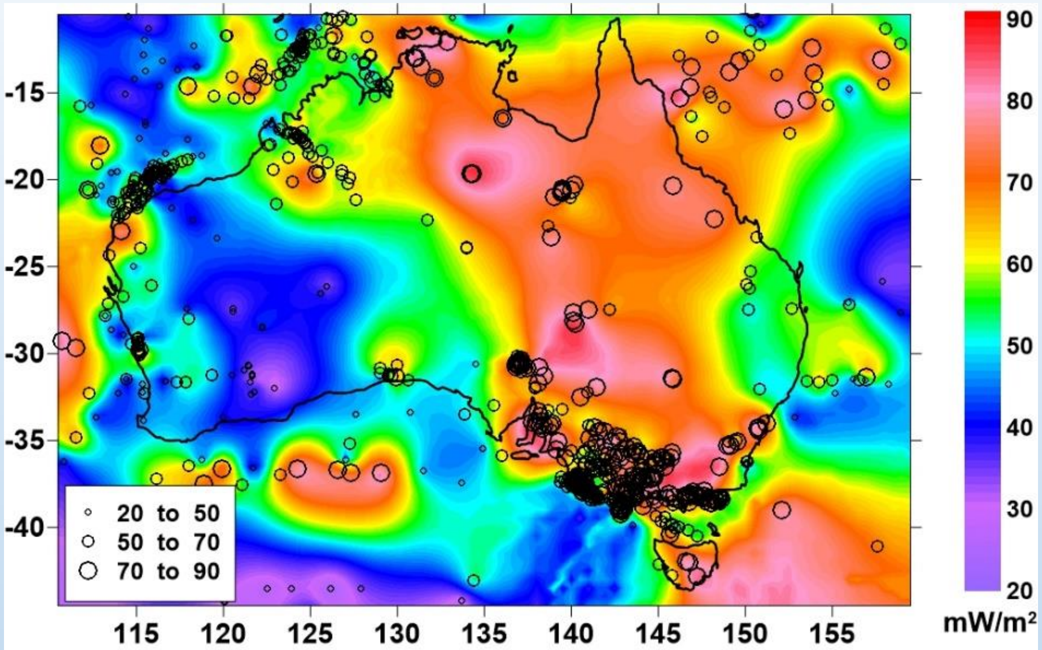


Mean Velocity LC



Crustal Thermal Model

Surface Heat Flow



A=Heat Generation

λ or k=Thermal Conductivity (T,z)

K_0= 3W/m K

q= Heat flow

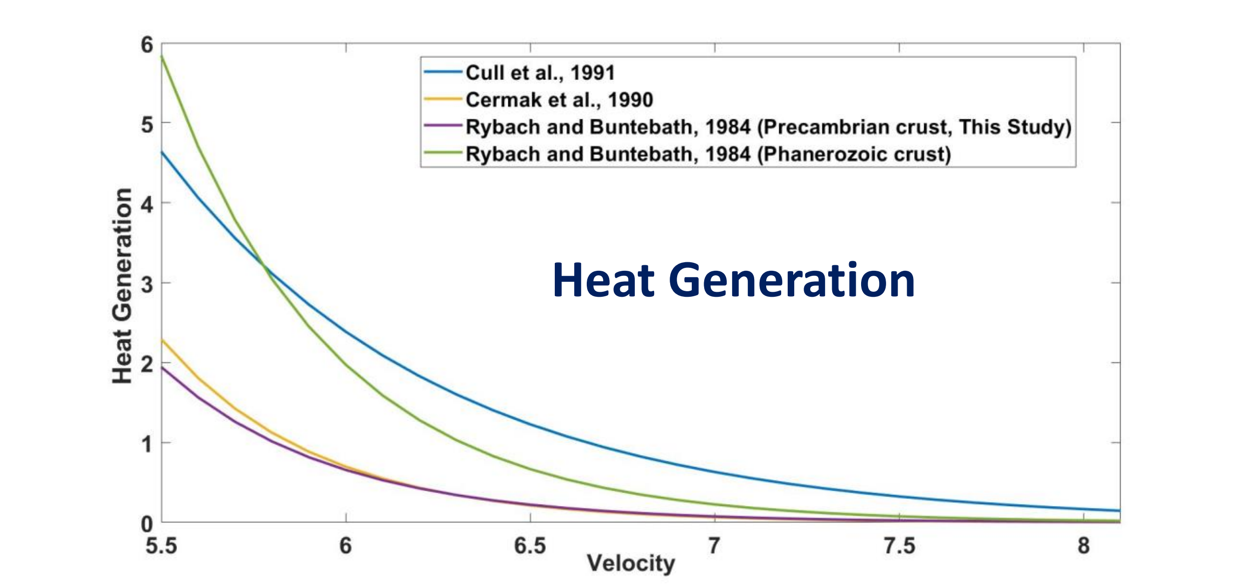
Vp= P-wave velocity

$A=e^{(12.6-2.17Vp)}$ Cull et al., 1991

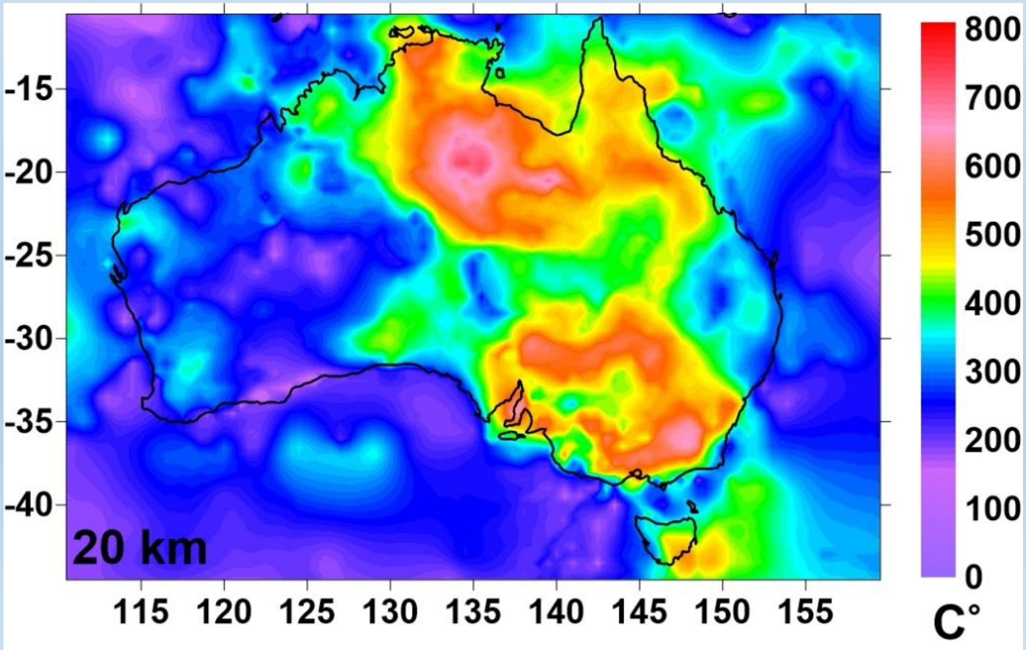
$$k(T,z) = k_0\,(1+c\,z)/(1+bT)$$

$$T_{i+1} = T_i + \frac{q_i}{\lambda_i}\Delta z_i - \frac{A_i}{2\lambda_i}\Delta z_i^2$$

$$q_{i+1} = q_i - A_i \Delta z_i,$$

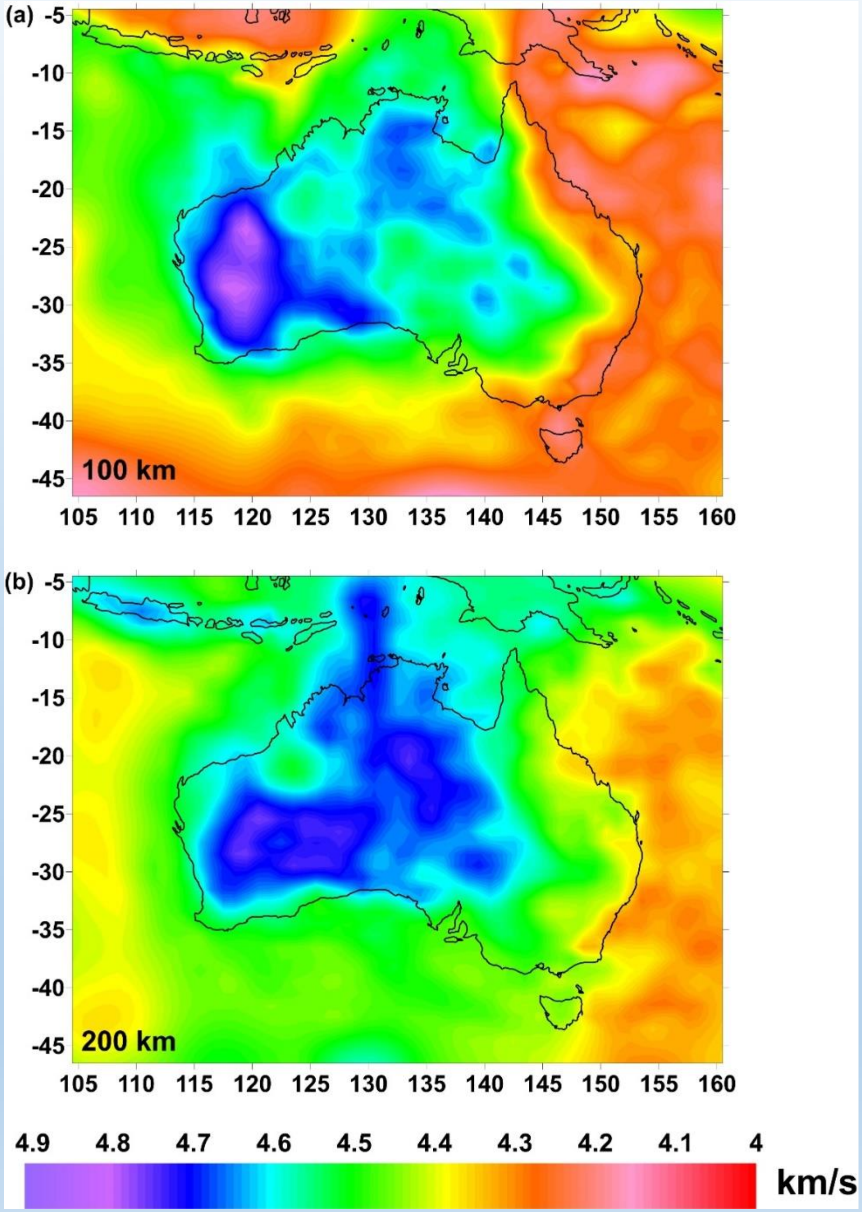


Crustal Temperature



Seismic Velocity in the Upper Mantle

AuSREM Velocity Model



Seismic velocity inversion
(composition, water, partial melt, anelasticity, anharmonicity)

$$T^{n+1} = T^{n} + F_{damp}\left\{\left[V_{obs} - V_{syn}(T^{n})\right] / \left[\left(\frac{\partial V}{\partial T}\right)_{syn}\left(T^{n}\right)\right]\right\}$$

$$V_{syn}(P,T,X,\omega) = V_{anh}(P,T,X)V_{anel}(P,T,\omega)$$

VRH
averaging scheme

Anelasticity model
(homologous temperature scaling)

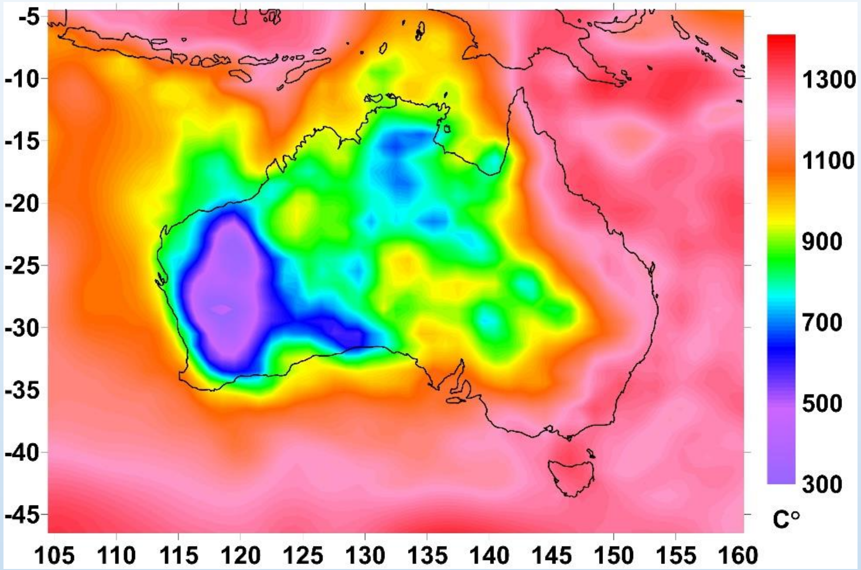
Fertile Upper Mantle

Ol	OPX	CPX	Gr	Mg#
58.5	15	11.5	15	89

Depleted Mantle

Ol	OPX	CPX	Gr	Mg#
69.5	21	4	5.5	94

Initial Thermal Model

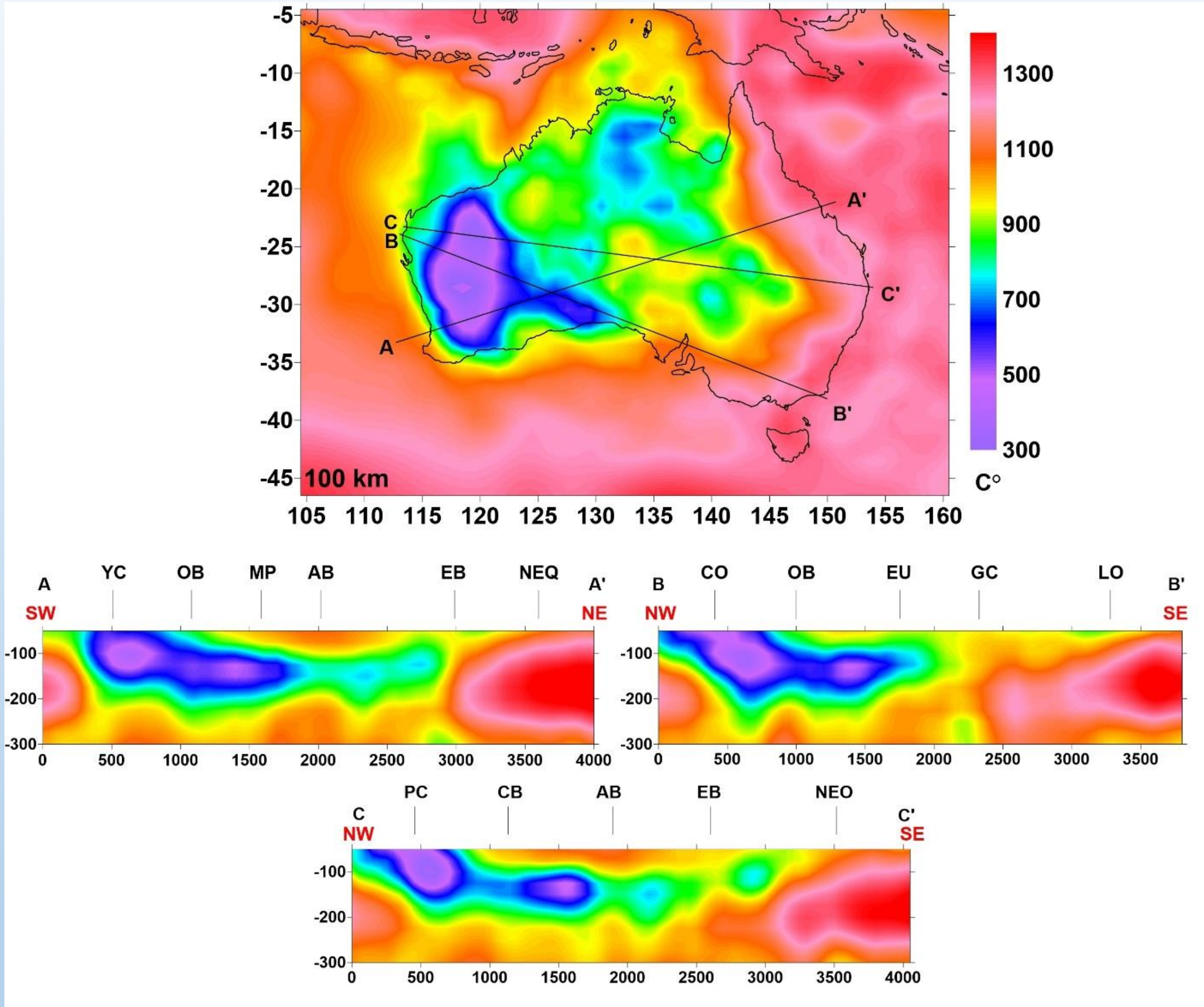


Mantle thermal Model → **Gravity residual anomalies** → **Mantle density variations** → **Predicted compositional changes** → **Mantle thermal Model**

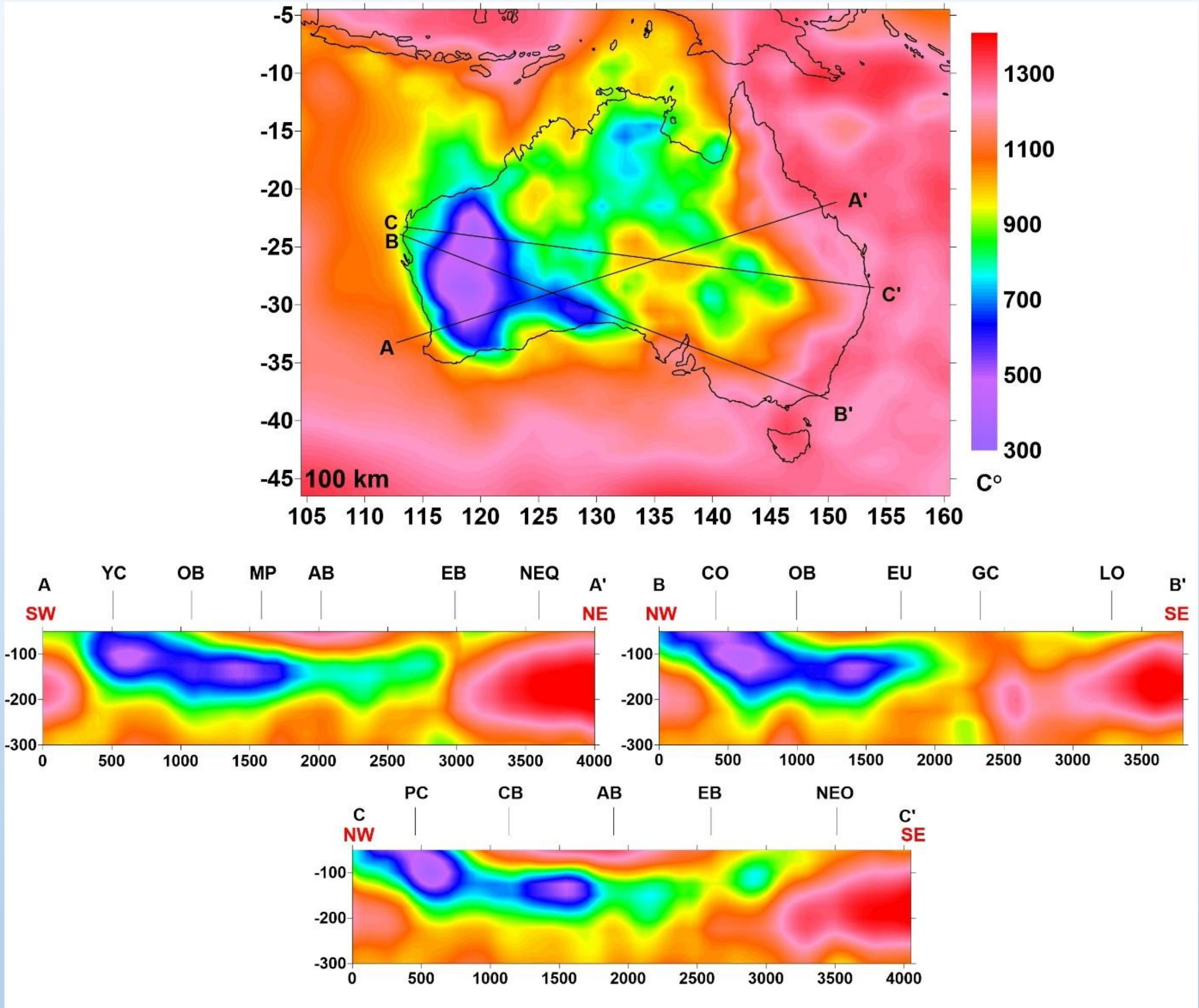
Iterative process

Upper Mantle Thermal Model

Initial Temperature



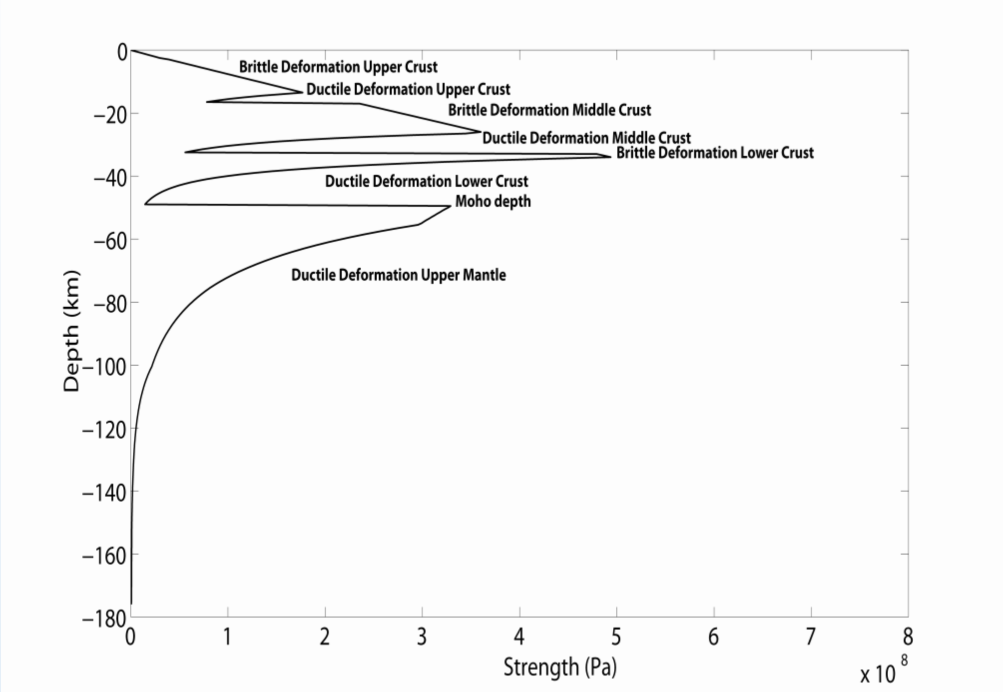
Final Temperature



YC—Yilgarn Craton, **OB**—Officer Basin, **MP**—Musgrave Province, **AB**—Amadeus Basin, **EB**—Eromanga Basin, **NEQ**—North East Queensland, **CO**—Capricorn Orogen, **EU**—Eucla Basin, **GC**—Gawler Craton, **LO**—Lachlan Orogen, **CB**—Canning Basin, **NEO**—New England Orogen.

- **The final thermal model shows an increase of temperature in the shallow upper mantle of about 100-150°C in both the Archean and Proterozoic cratons.**

Strength model of the lithosphere



Brittle Deformation (Byerlee Law)

$$\sigma = f\rho g z(1-\lambda)$$

Ductile Deformation (Power Law crust/Mantle)

$$\sigma = \left[\frac{\dot{\varepsilon}}{A_P}\right]^{\frac{1}{n}}.\exp\left[\frac{E_P}{nRT}\right]$$

Ductile Deformation (Dorn Law mantle)

$$\sigma_{DL} = \sigma_D(1-[-\frac{RT}{E_D}ln(\frac{\dot{\varepsilon}}{A_D})]^{\frac{1}{2}})^2$$

ρ	Density
z	Layer depth
f	Friction coefficient (0.75/3)
λ	Pore fluid factor (0.36)
g	Acceleration of gravity (9.8 m/s^2)
$\dot{\varepsilon}$	Strain rate (10e^{-15}s^{-1})
R	Gas constant (8.31JK^{-1}mol^{-1})
n	Power law exponent
E_P	Power law activation energy
A_P	Power law strain-rate
E_D	Dorn law activation energy
A_D	Dorn law strain-rate
σ_D	Dorn law stress
T	Temperature

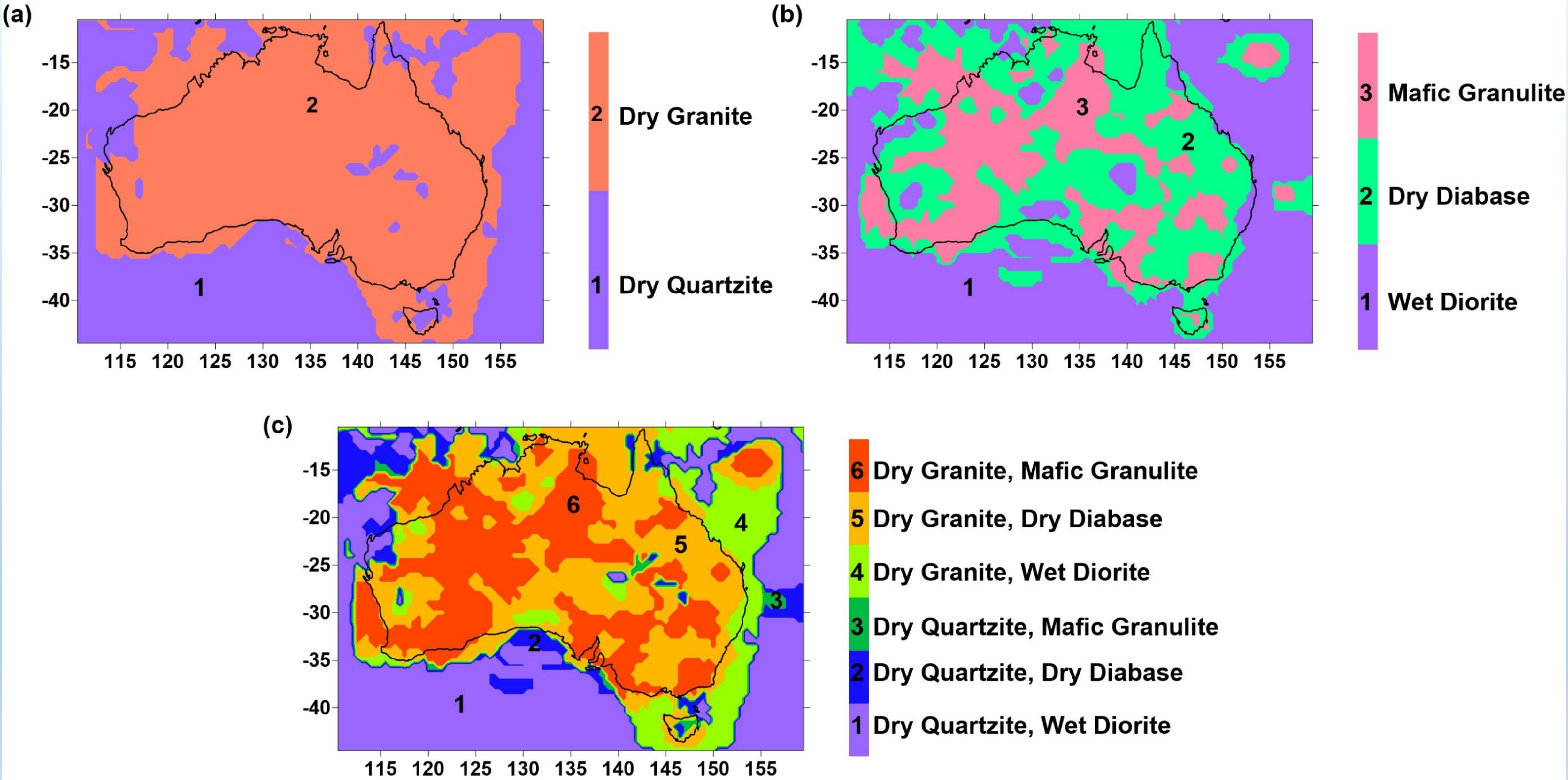
AuSREM Crustal Model

Rheology:

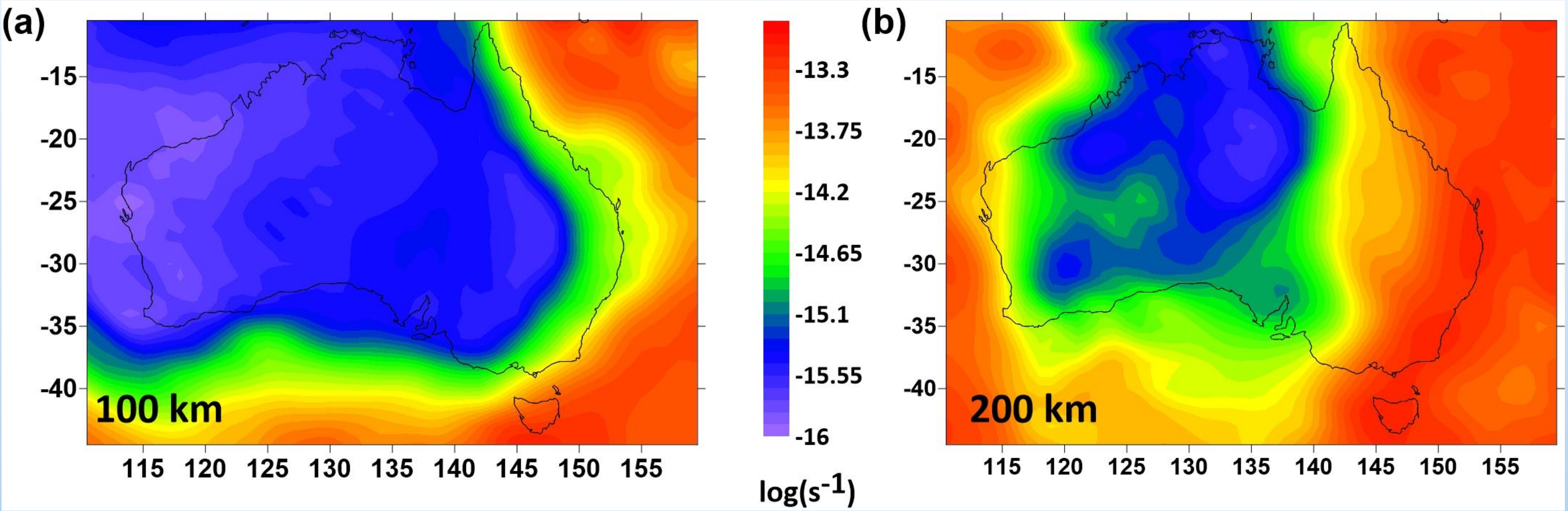
Crust: Variable on the base of seismic velocity; **Upper Mantle**: Dry Peridotite

Thermal Model of the Crust and Upper Mantle

Crustal Rheology

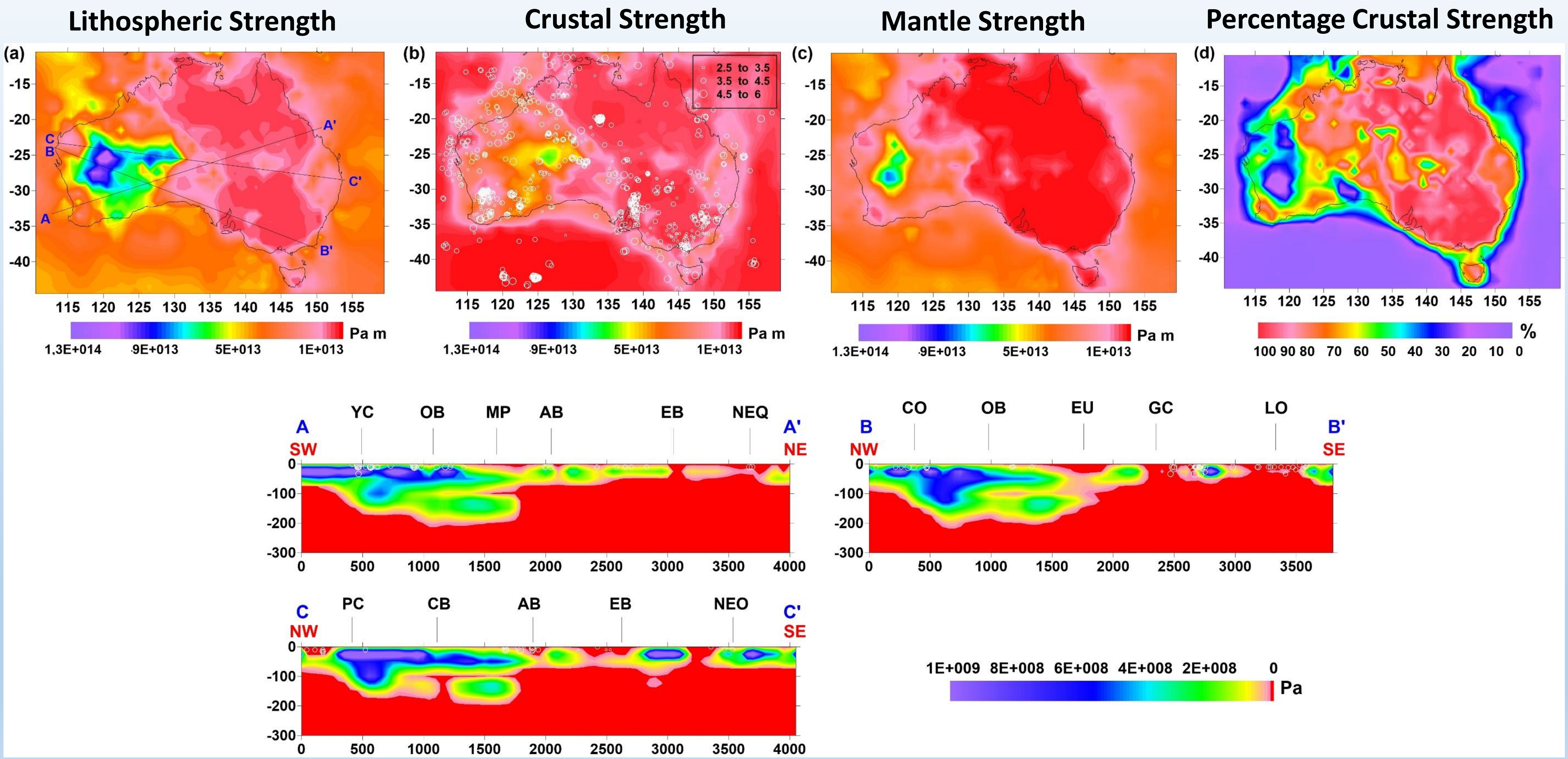


Strain Rate Variations



- **Strain rate variation is calculated from a mantle flow model constrained by gravity and seismic tomography.**
- **There is a distinct difference in the rate of deformation between the western and central part of Australia (slow strain rate) and eastern parts (fast strain rate) of Australia.**

Strength distribution using a variable crustal rheology and strain rate



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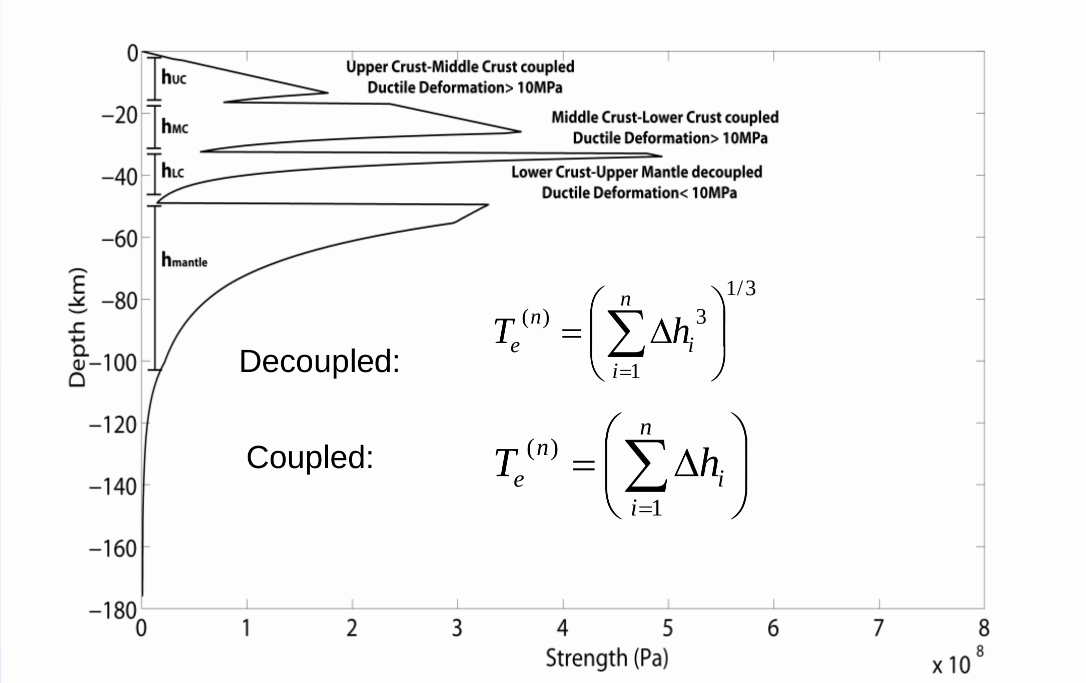
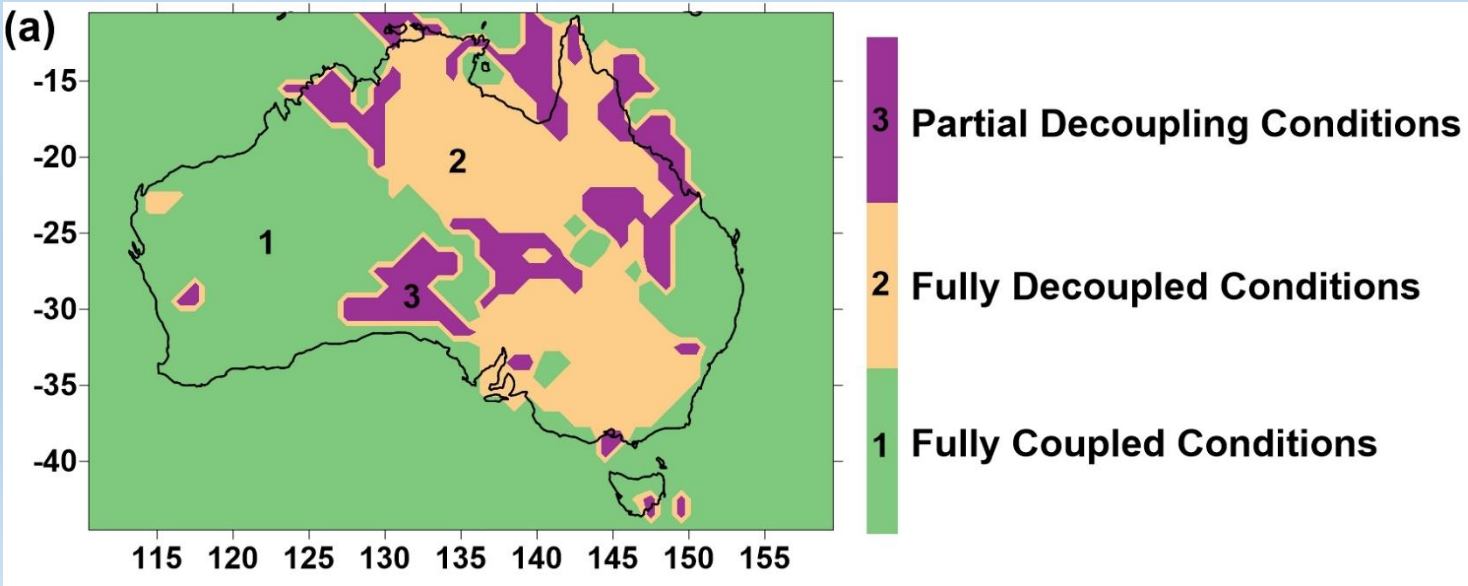
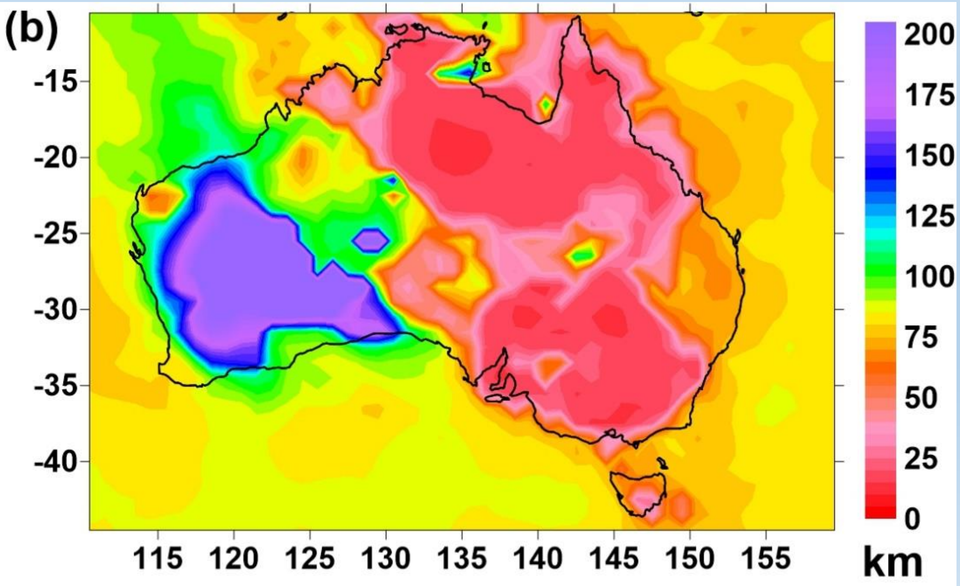
Effective Elastic Thickness (*Te*)



Coupling/Decoupling Conditions



Effective Elastic Thickness

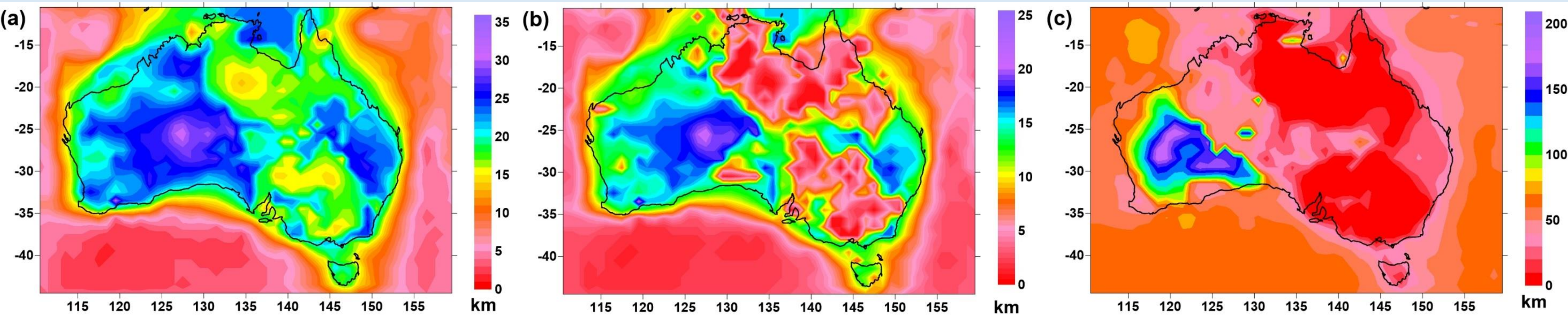


Mechanically Strong Lithosheric Layers

Mechanically Strong Upper Crust
(M_{UC})

Mechanically Strong Lower Crust
(M_{LC})

Mechanically Strong Lithospheric Mantle
(M_{mantle})



Conclusions

- The crustal temperature distribution, obtained assuming a steady state approach, and using empirical relationships between heat generation and seisimic velocity, shows thermal anomalies correlated with the surface *HF* variations. The highest temperatures are observed in the NAC, SAC, and Phanerozoic provinces, while the coldest crust underlies the geological provinces east to the WAC (e.g., Officer and Eucla basin), indicating more mafic crustal composition.

- In contrast, the patterns of the temperature variations in the upper mantle, obtained from the joint inversion of seismic velocity and gravity, are more correlated with the age of the tectonic features and less with the heat flow distributions. This can be ascribed to the different depths of the heat sources and length of the heat time diffusion.

- Using the new thermal model, we estimate the lithospheric strength and effective leastic thickness (*Te*) variations. The results show that in the WAC most of the strength is concentrated in the upper mantle, while in other parts of the continent the crust retains higher strength. The intraplate earthquakes are mostly located in the western part of Australia, where a jump in the integrated crustal strength occurs.

- The *Te* distribution shows that the most rigid area (*Te*> 100 km) corresponds to the western part of Australia, where the lithospheric layers are coupled and the mechanically strong upper mantle layer has large thickness (M_{mantle} > 50 km). Low values of *Te* (< 20 km) are found in most of the NAC, the eastern part of the SAC, and in Phanerozoic geological provinces, where the M_{lc} is strongly reduced (<1 km) and decoupling of the crust from the upper mantle occurs.

- The crustal rheological model emphasizes the influence of temperatures on the strength/*Te* distribution in some regions, such as the Officer basin, and reduces it in some others, such as the Yilgarn craton. The strain rate values, calculated using a global mantle flow model, tend to increase with the age of the tectonic features and influence the strength/*Te* variations in the opposite way with respect to temperatures.