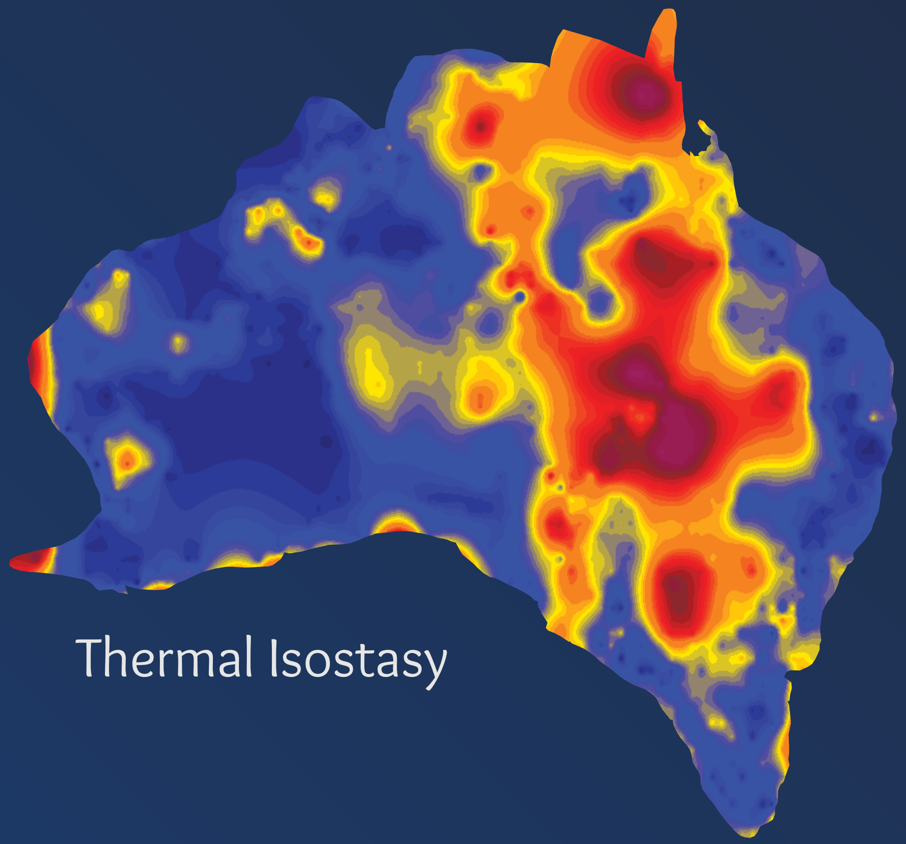
Towards a Global Heat Production Model: Geochemical and Seismological Perspective



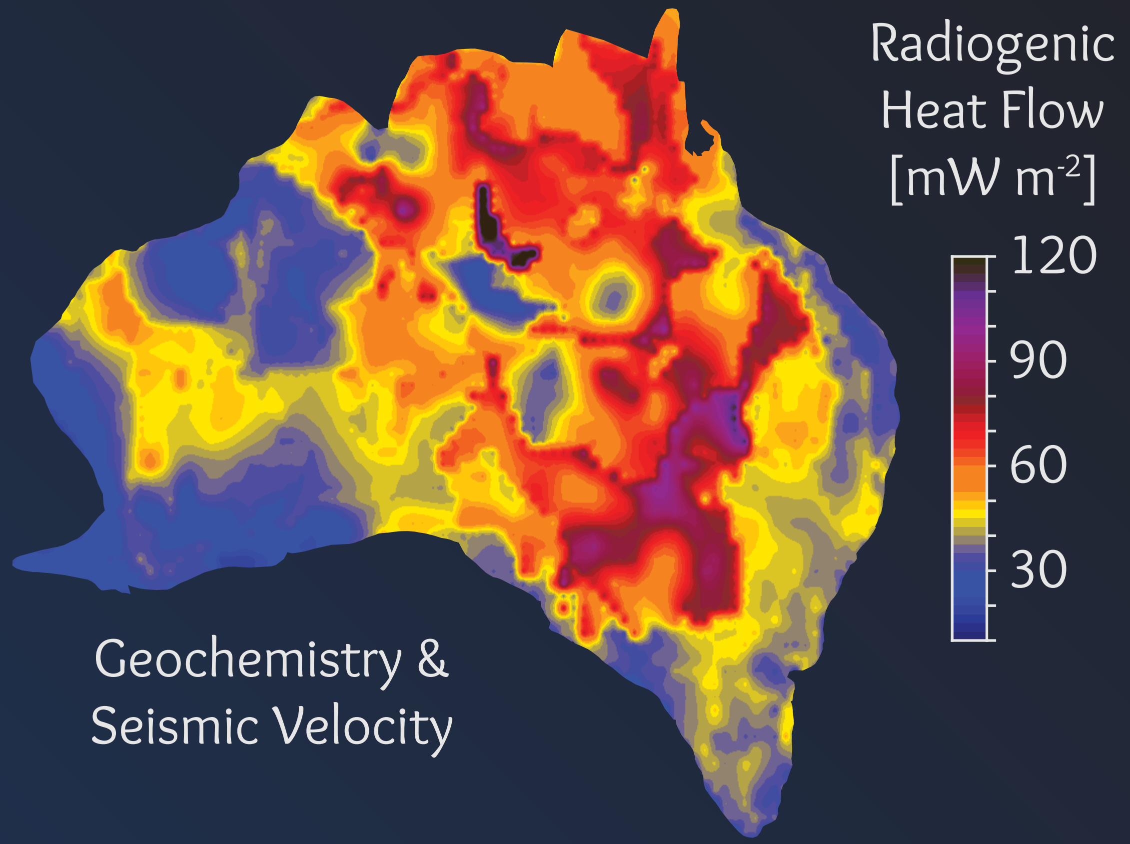
Thermal Isostasy

THE UNIVERSITY
of ADELAIDE

SUB CRUCE LUMEN

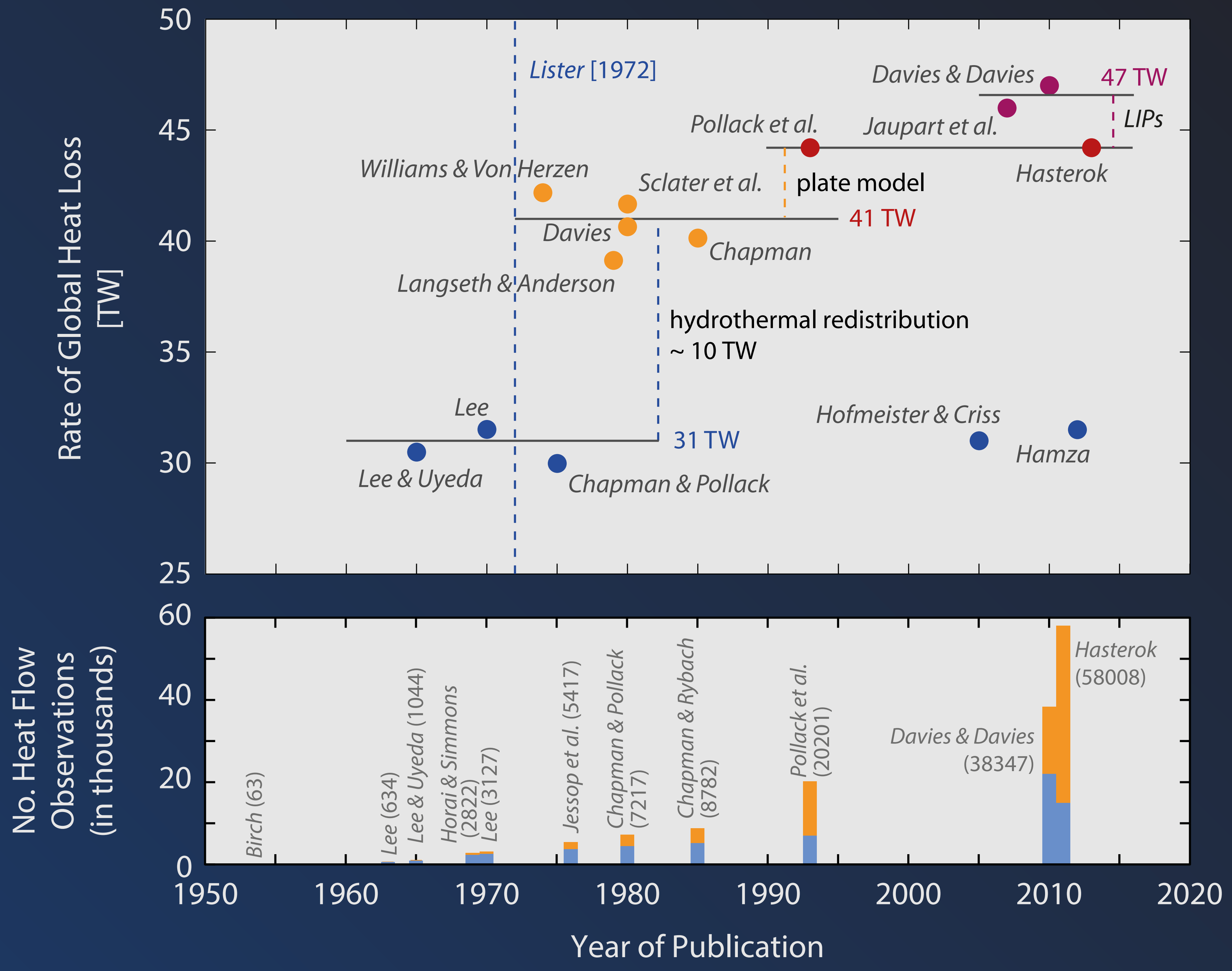
Derrick Hasterok

Matthew Gard
Jessica Webb
& Sam Jennings



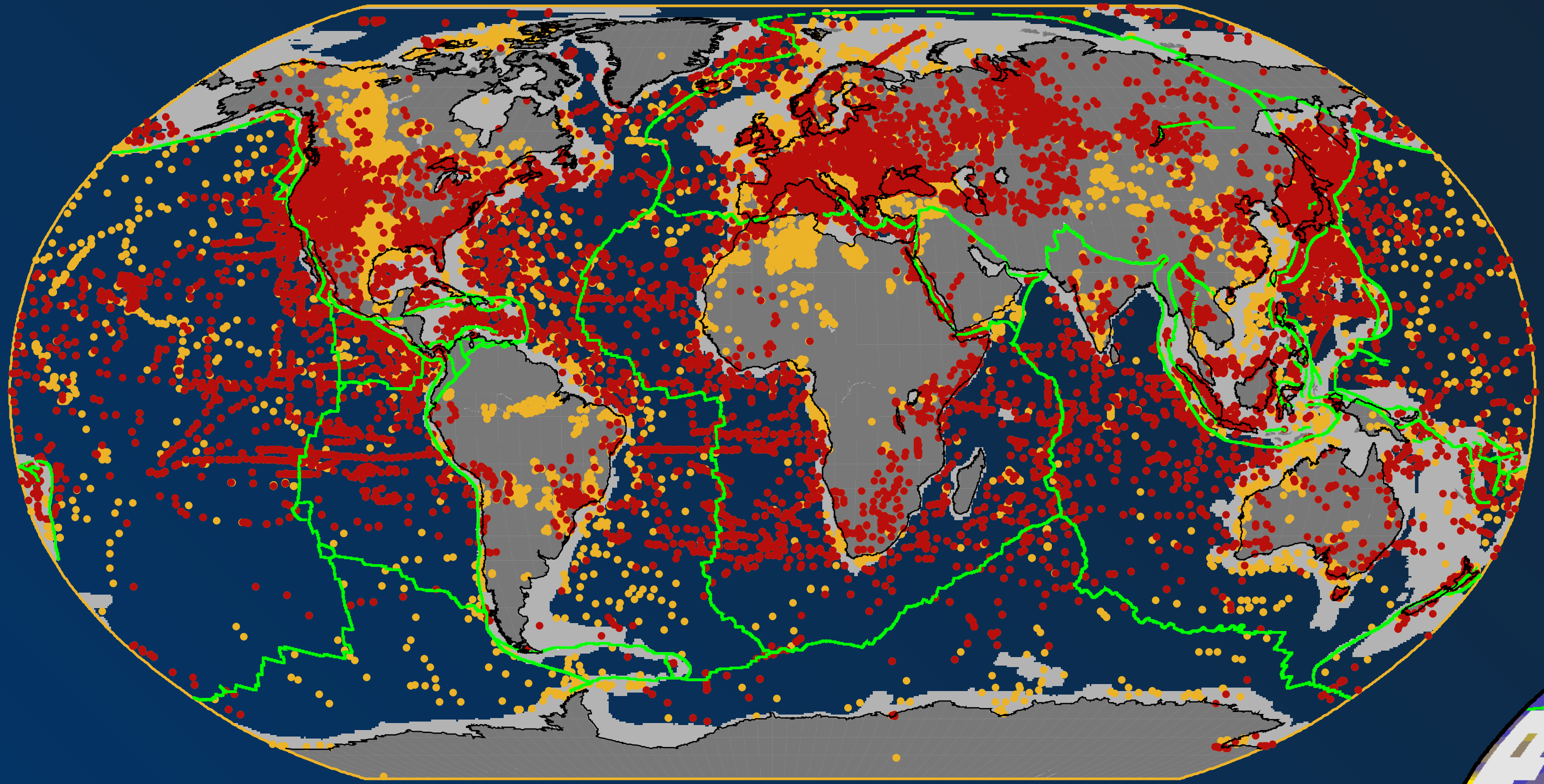
Geochemistry &
Seismic Velocity

Global Power Loss



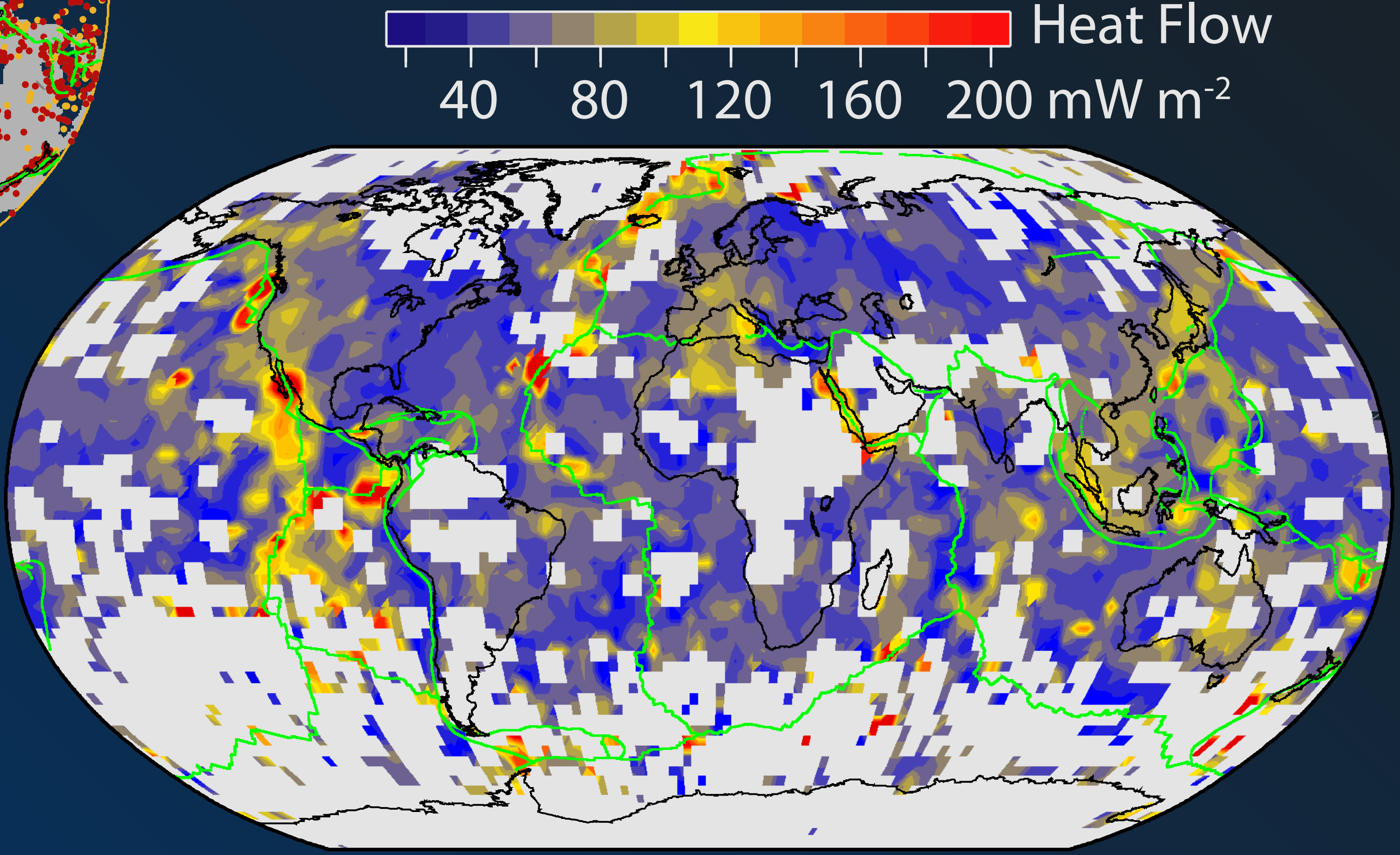
Global Heat Flow

Global Heat Flow Database

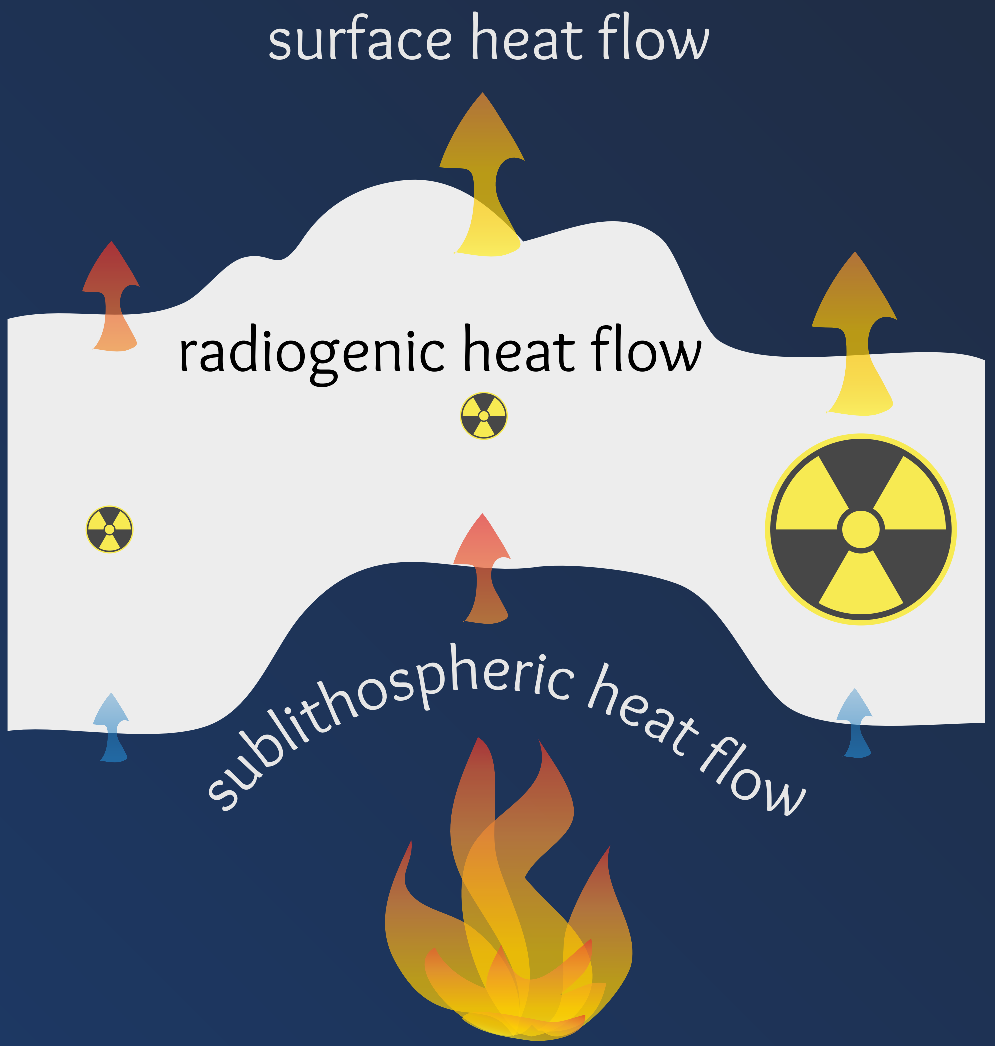


- ● 20,201: Pollack et al. [Rev. Geophys., 1993]
- ● 58,008: Hasterok [2010]

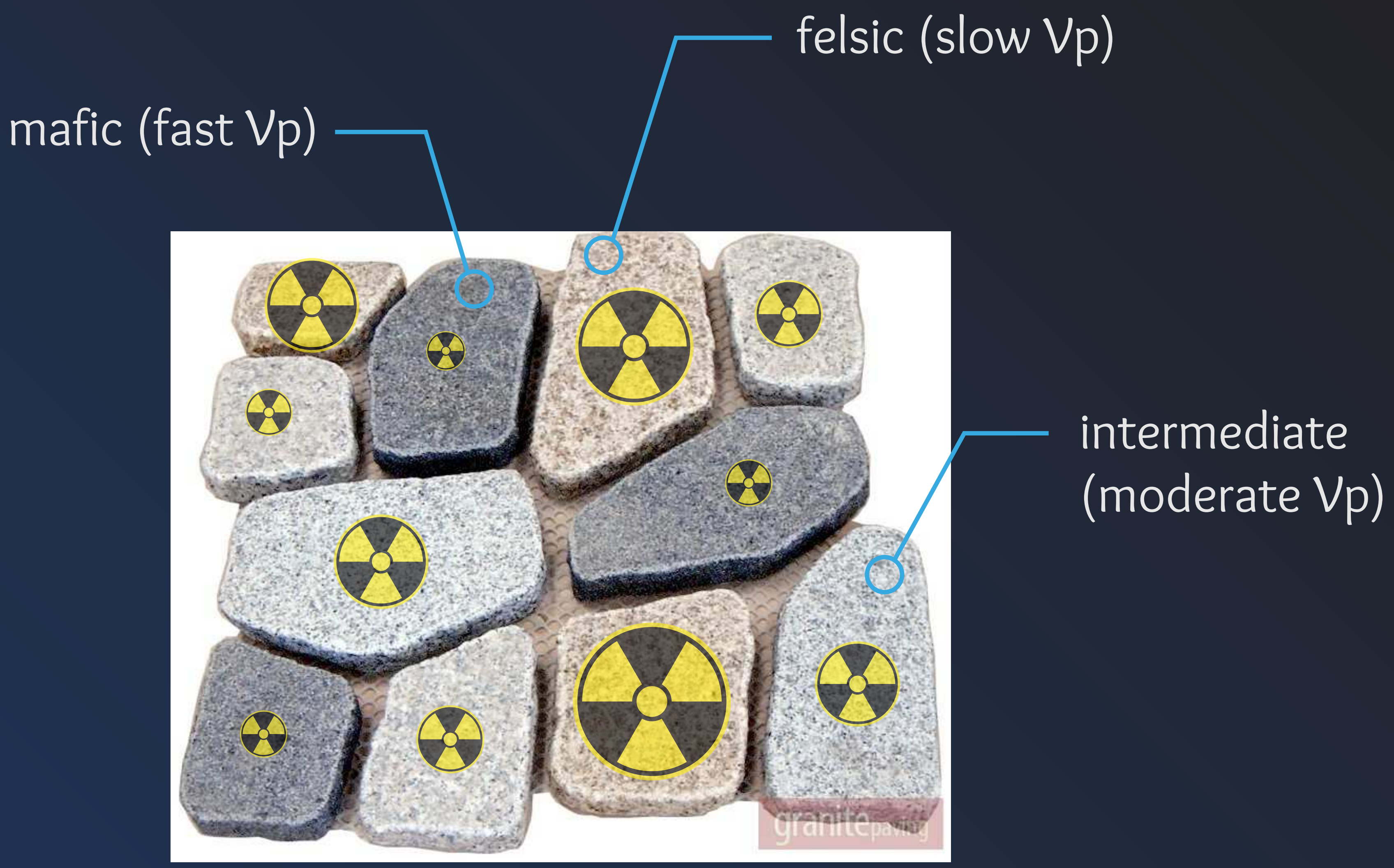
Raw Global Heat Flow



Radiogenic Heat Production (2 perpectives)



thermal isostasy



chemistry <—> physical properties

Thermal Isostasy Theory

Oceans

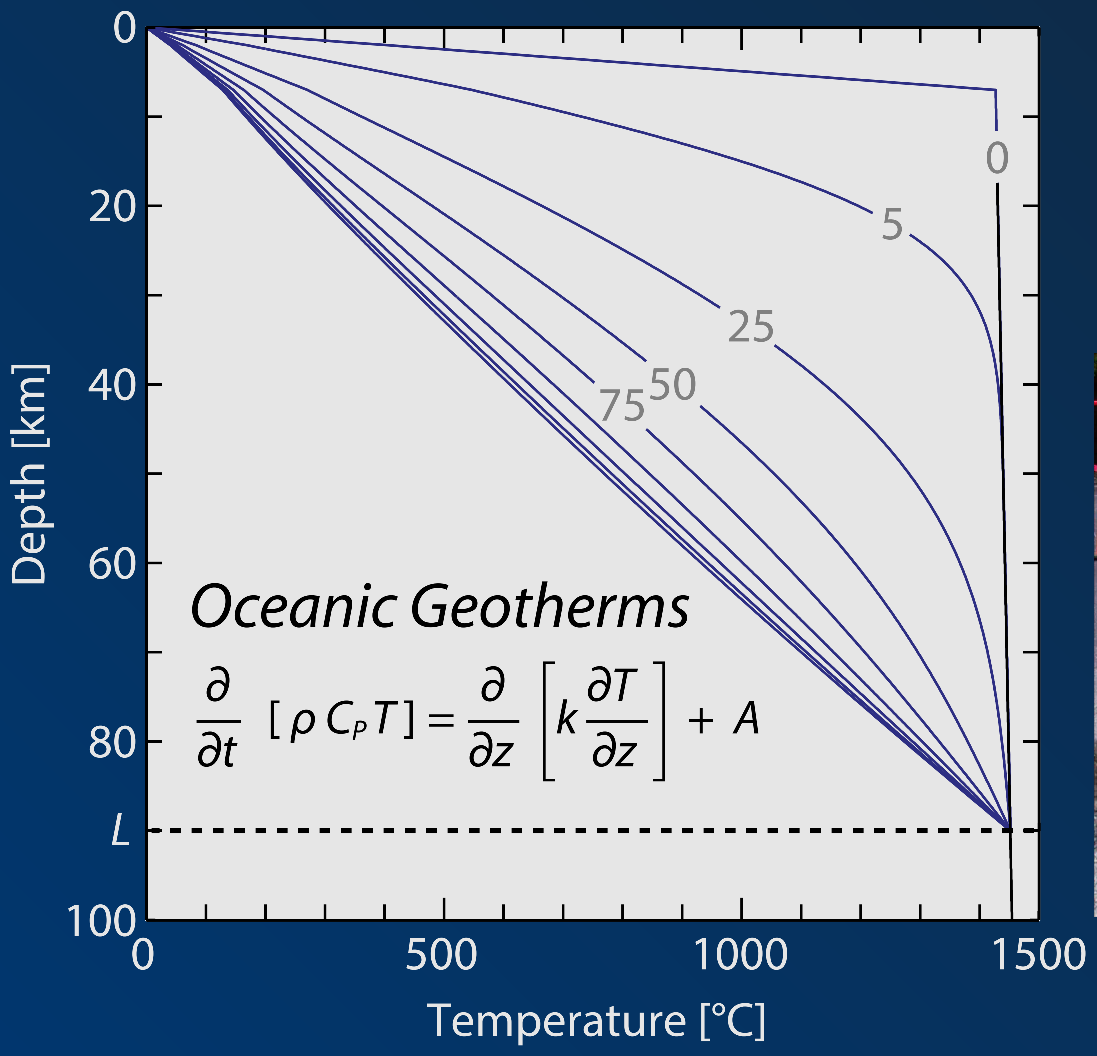
Geotherms → Elevation

$$s = \frac{\rho_0}{\rho_a - \rho_w}\,\alpha \int_0^L [T_t(z) - T_0(z)]\, dz$$

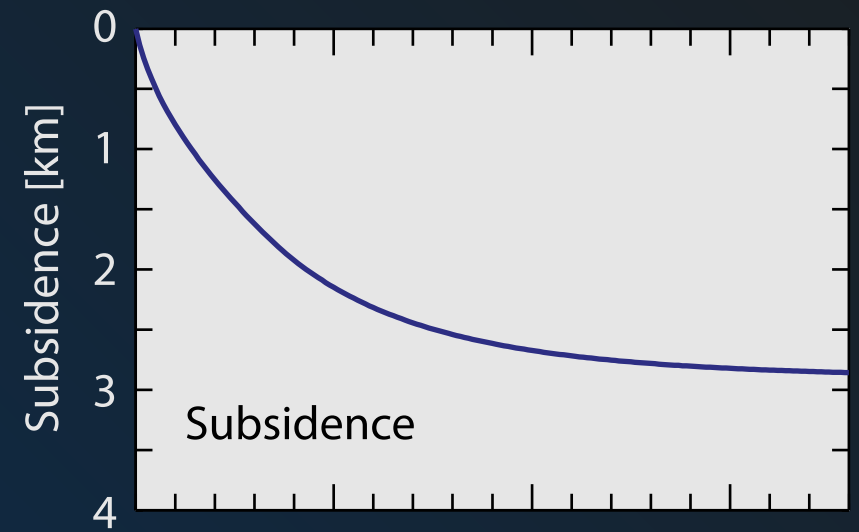
density scaling

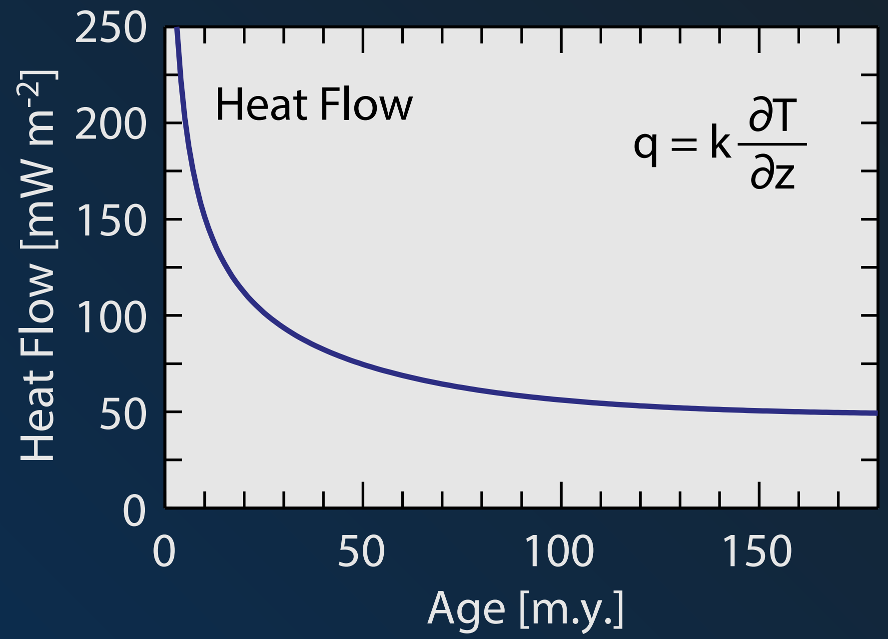
thermal expansion

geotherms



$$\frac{\partial}{\partial t}[\rho C_P T] = \frac{\partial}{\partial z}\left[k\frac{\partial T}{\partial z}\right] + A$$

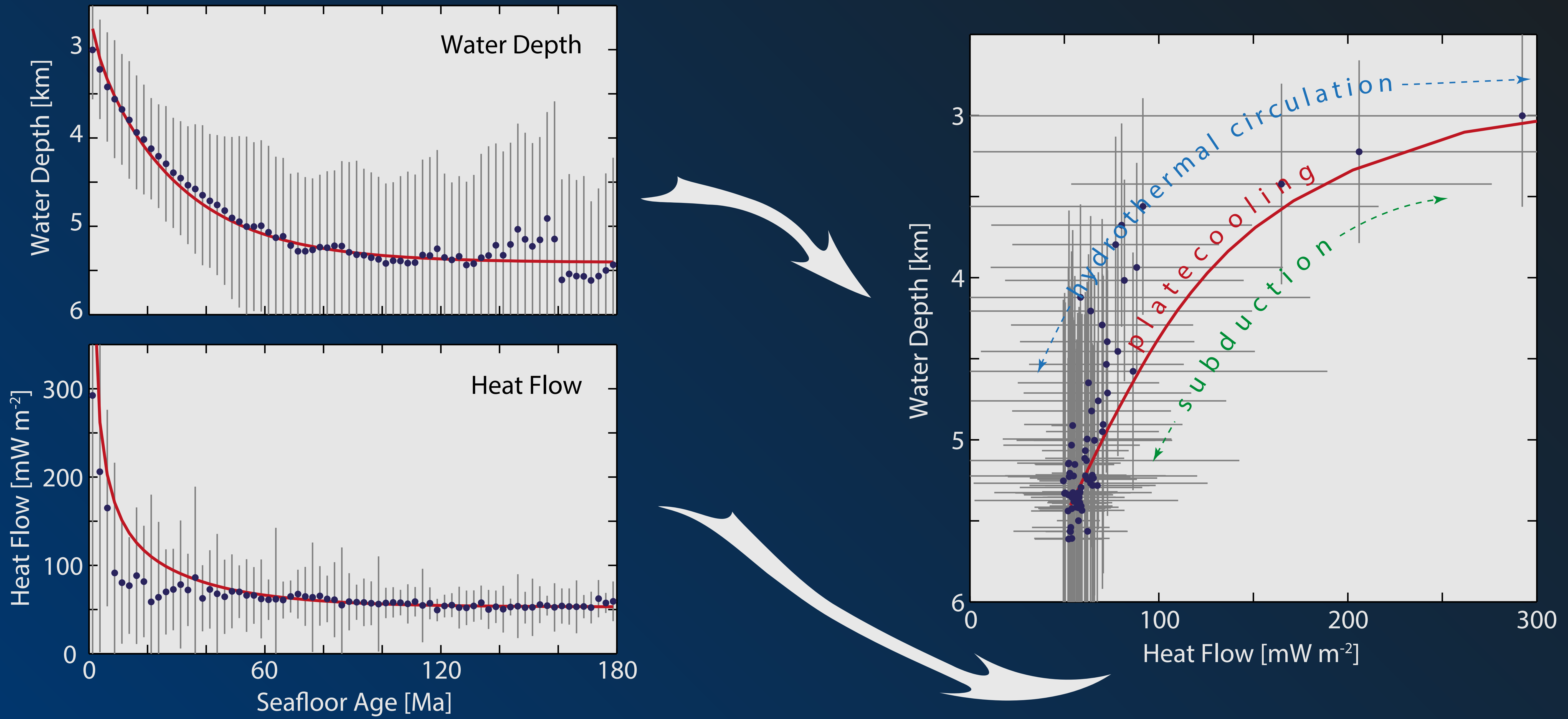




$$q = k\frac{\partial T}{\partial z}$$

Thermal Isostasy

Oceans



Thermal Isostasy Theory

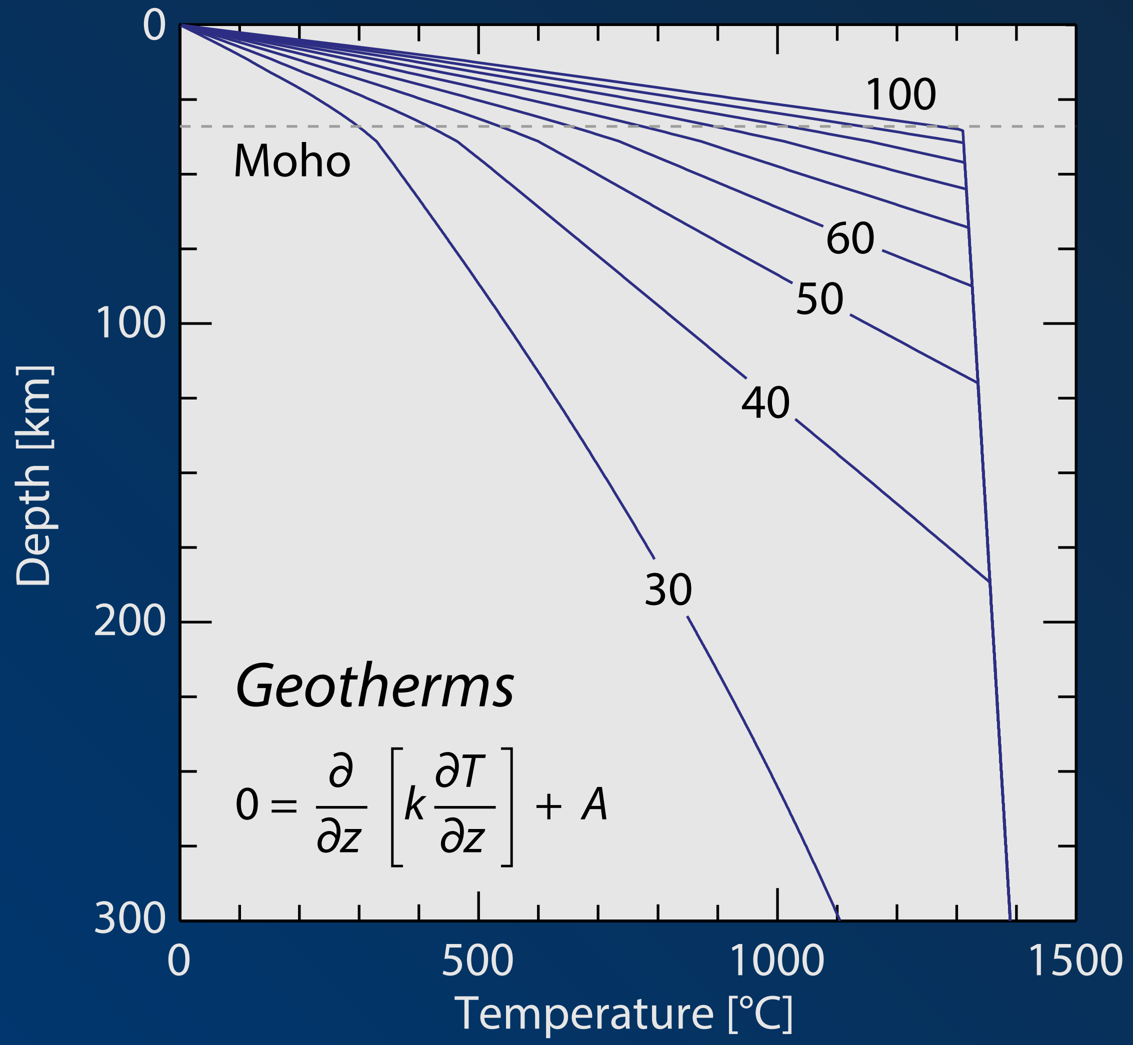
Continents

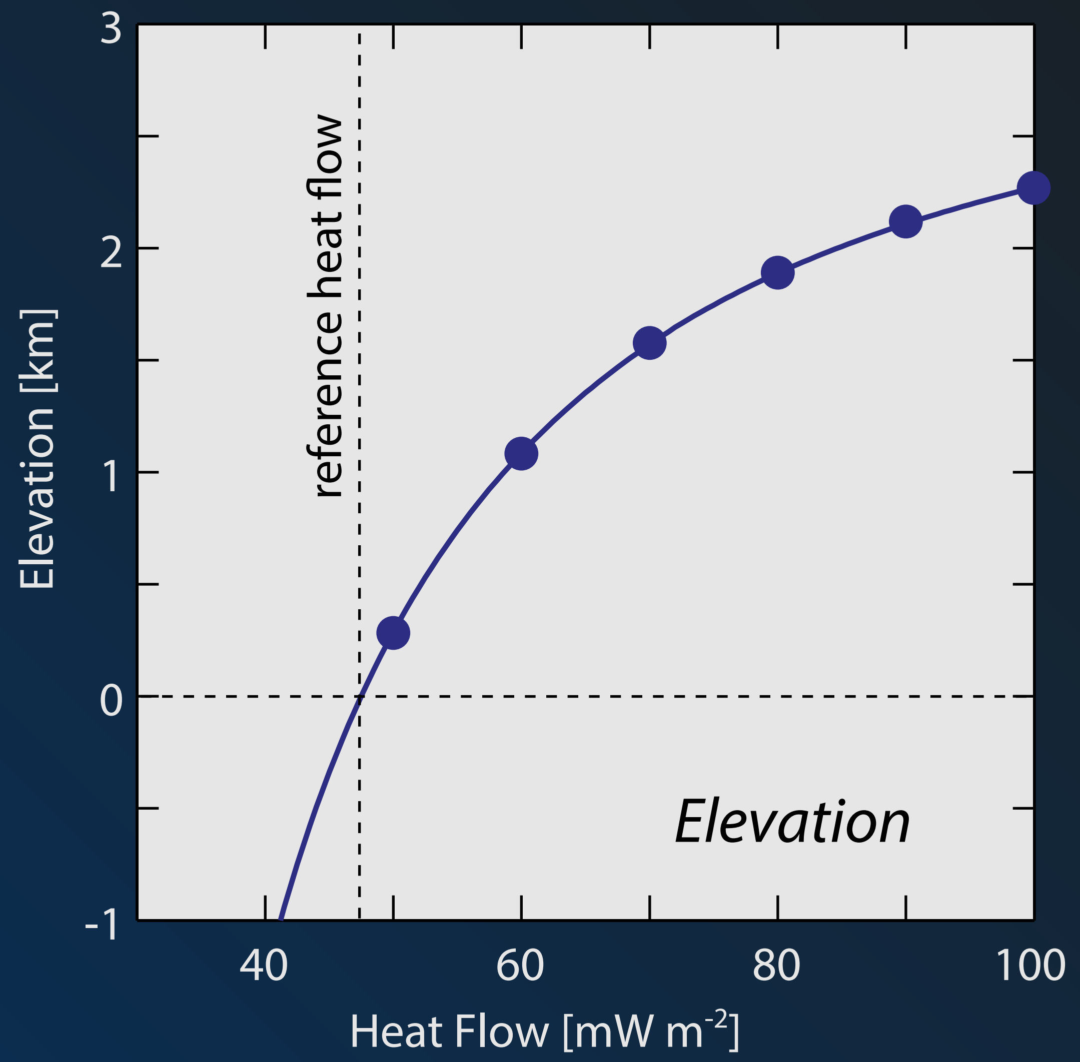
Geotherms → Elevation

$$\varepsilon = \alpha \int_{0}^{z_{max}} [T_q(z) - T_{ref}(z)]\, dz$$

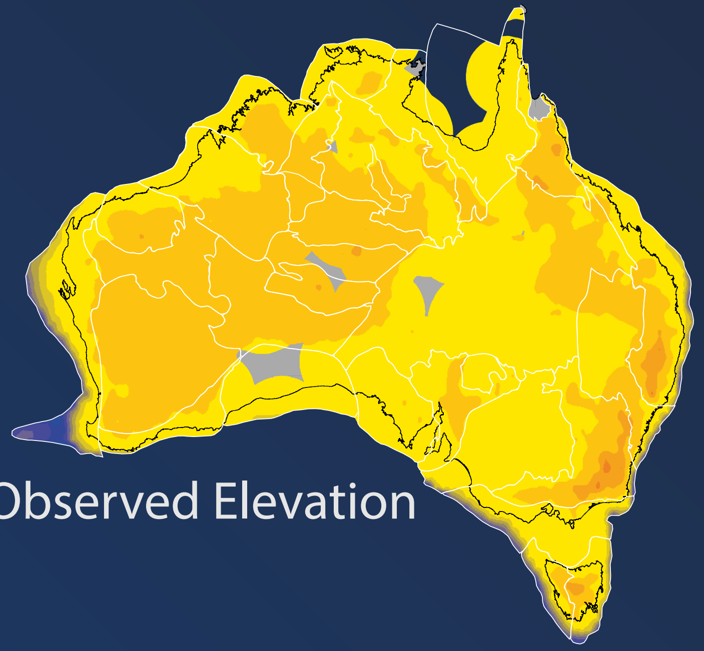
thermal expansion

geotherms

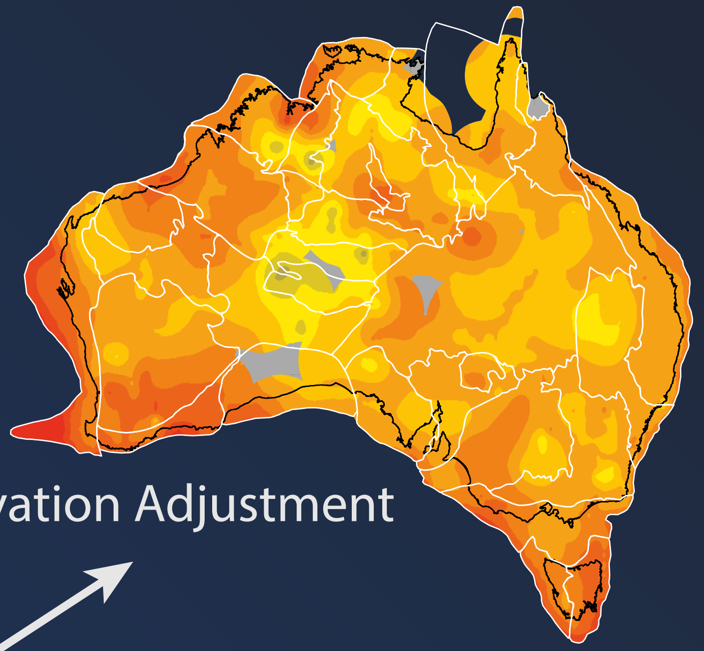




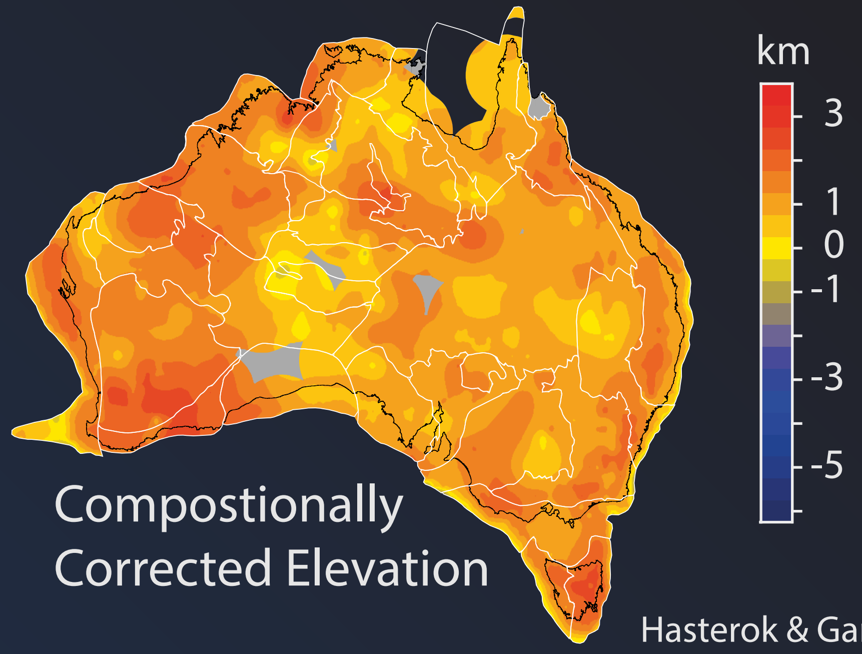
Before using elevation, must normalize compositional buoyancy


Observed Elevation

+


Elevation Adjustment

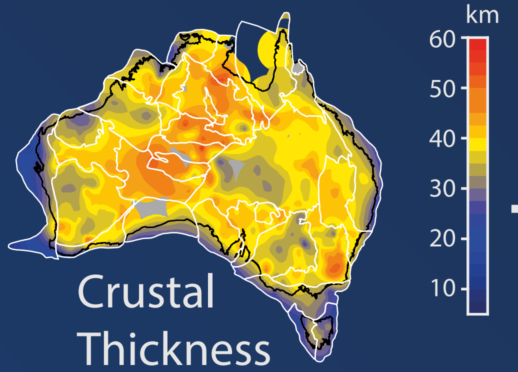
=



Compostionally Corrected Elevation

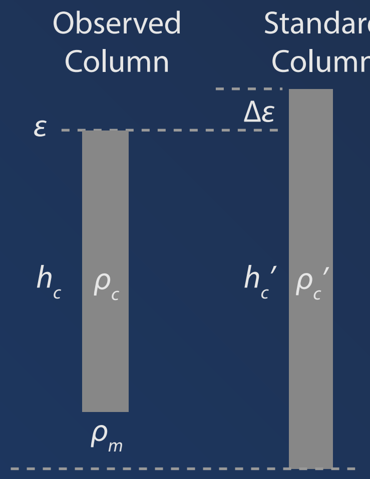
Hasterok & Gard (EPSL, accepted)

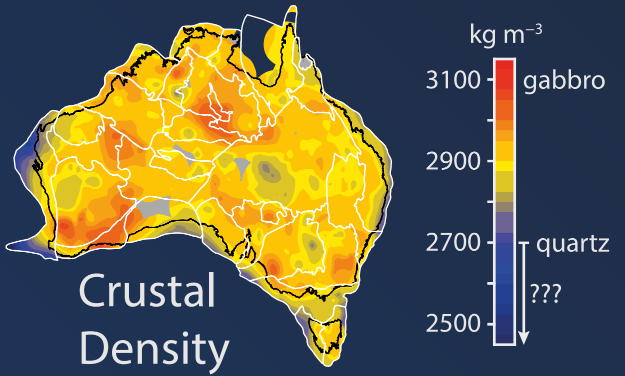
Isostatic Correction



Crustal Thickness

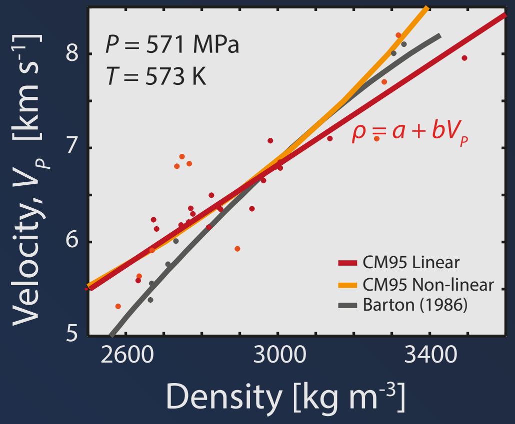
AusREM (Salmon, GJI, 2013)





Crustal Density

Velocity to Density Conversion

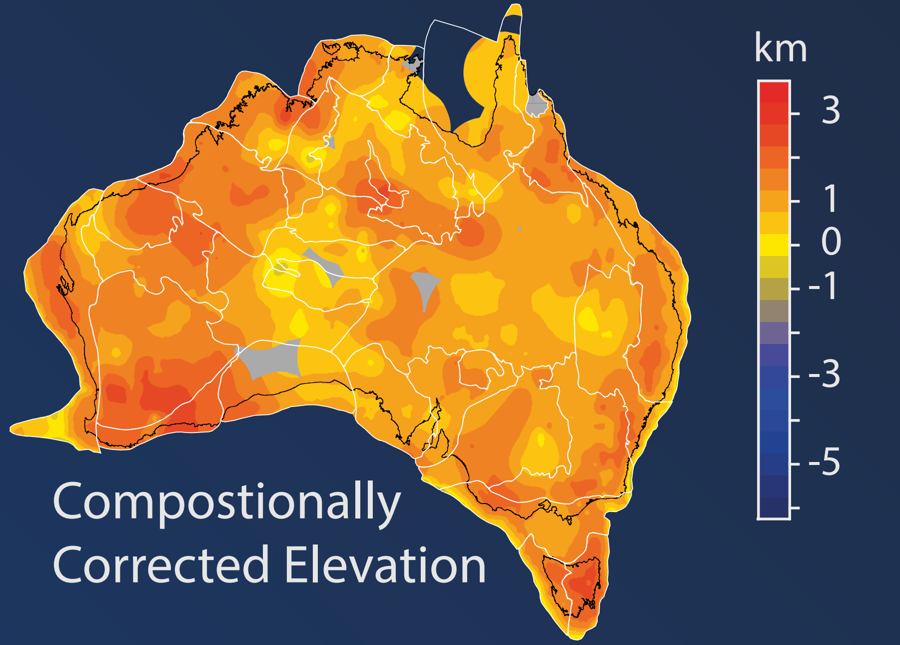


Christensen & Mooney (JRG, 1995)

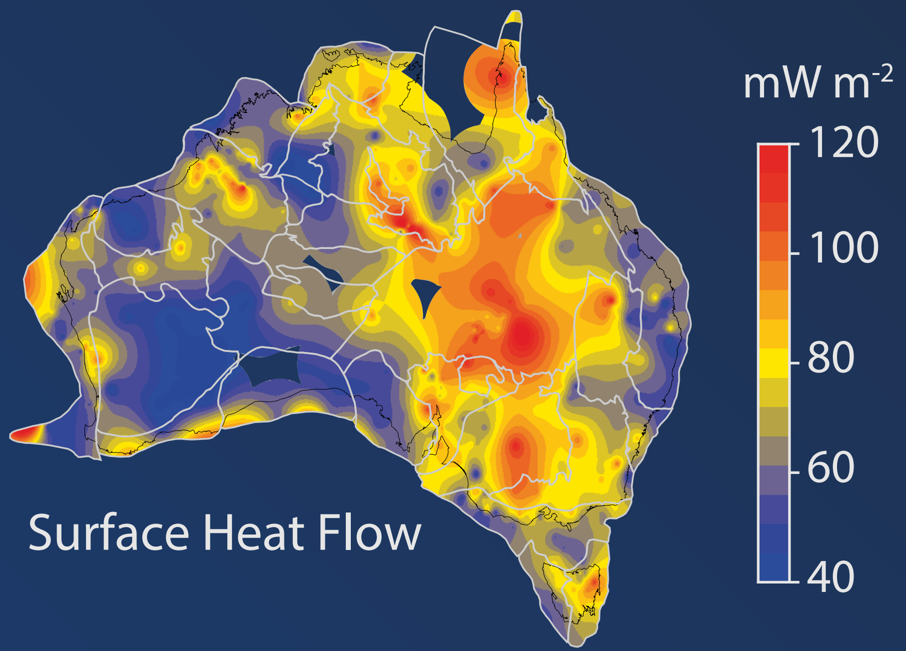
Crustal P-Wave Velocity Model

AusREM (Salmon et al., GJI, 2013)

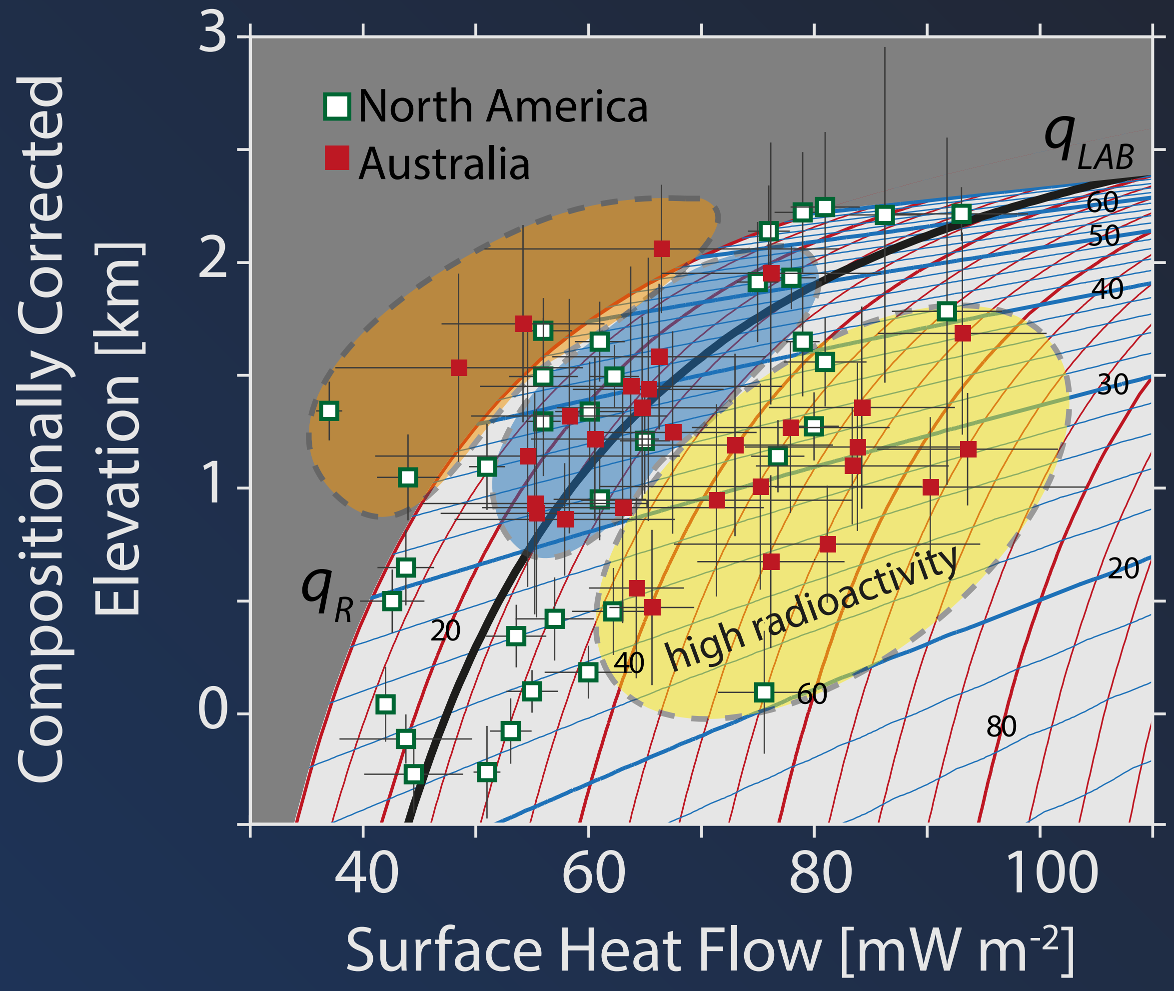
Thermoisostatic analysis identifies three major contributions to thermal elevation

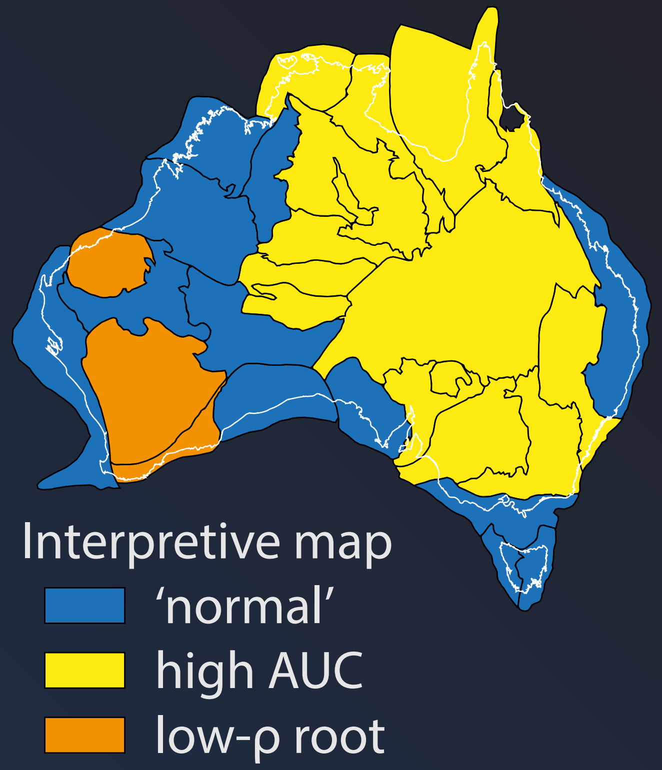


Compostionally Corrected Elevation



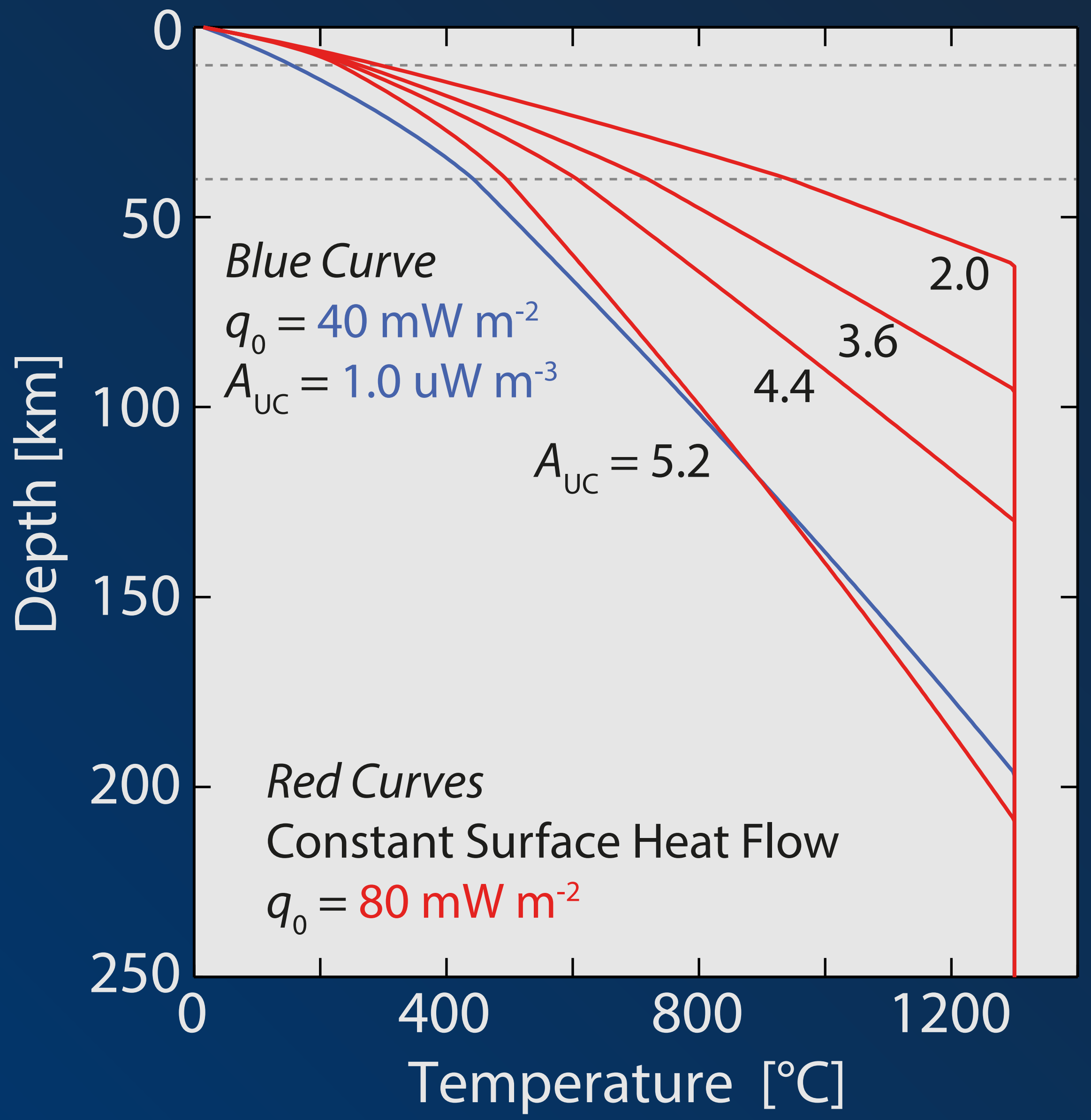
Surface Heat Flow

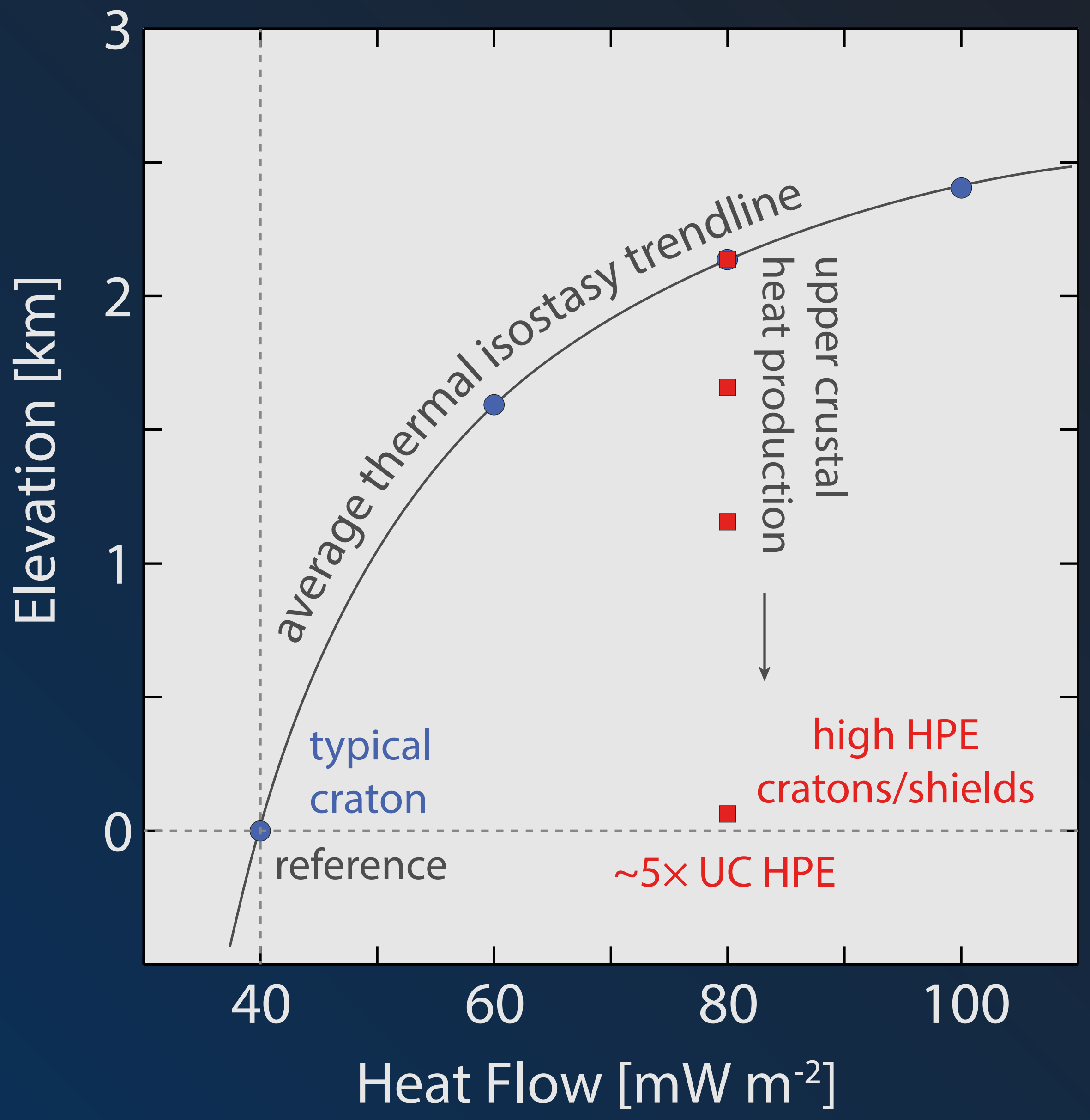




Hasterok & Gard (EPSL, accepted)

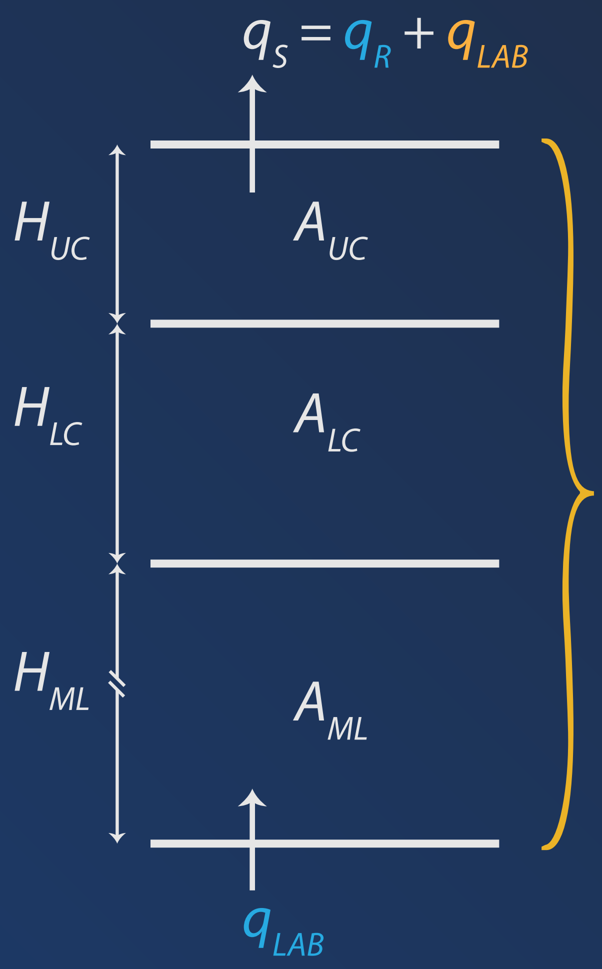
Elevation can be used to estimate heat production





Hasterok & Gard (EPSL, accepted)

3-Layered Radioactivity & Sublithospheric Heat-flow (3L-RASH) Model

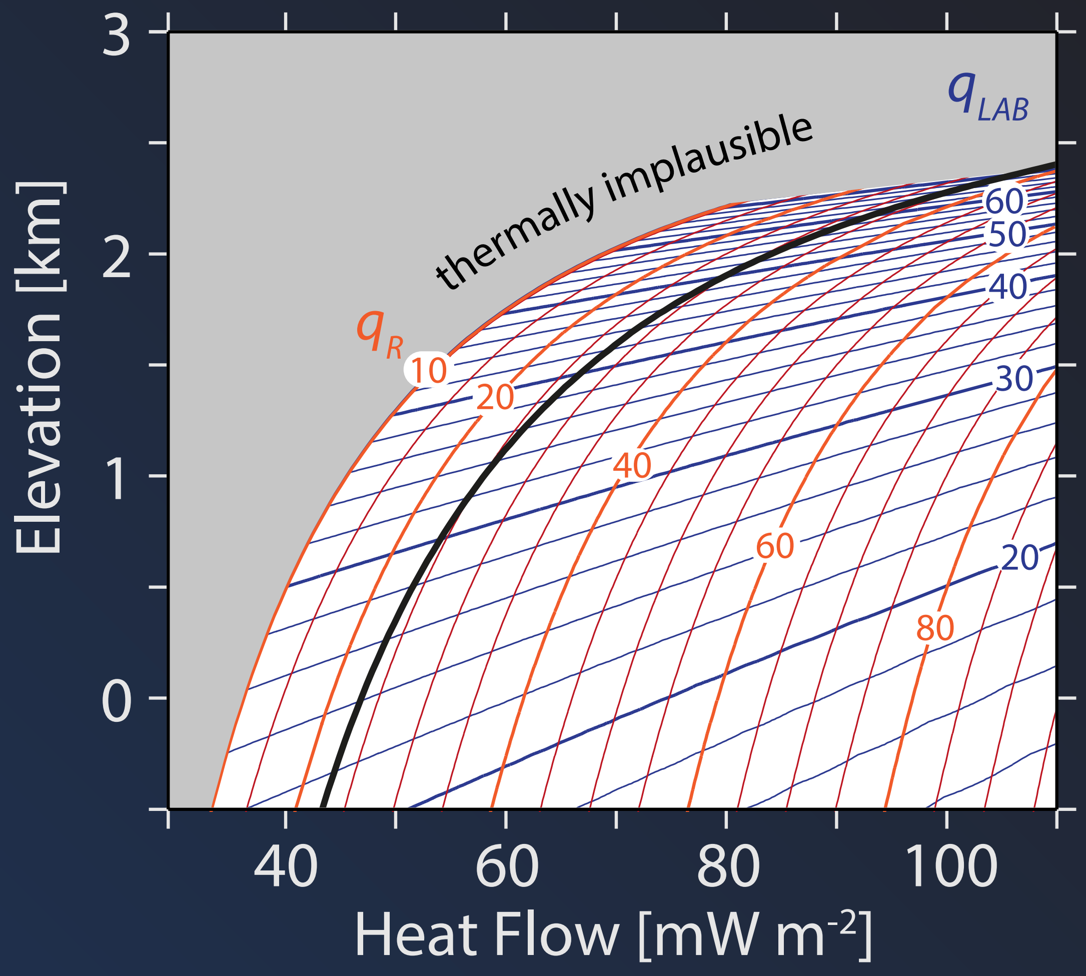


Heat Flow out top =

Heat Flow Produced within

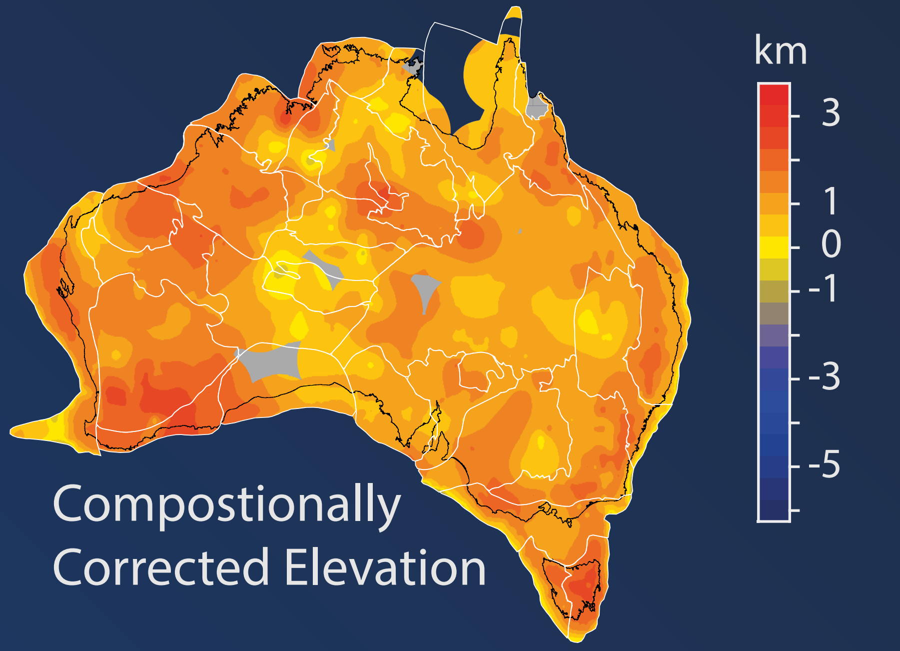
$$q_R = \underbrace{A_{UC} H_{UC}}_{\text{upper crust}} + \underbrace{A_{LC} H_{LC}}_{\text{lower crust}} + \underbrace{A_{ML} H_{ML}}_{\text{mantle lithosphere}}$$

+ Heat Flow in bottom

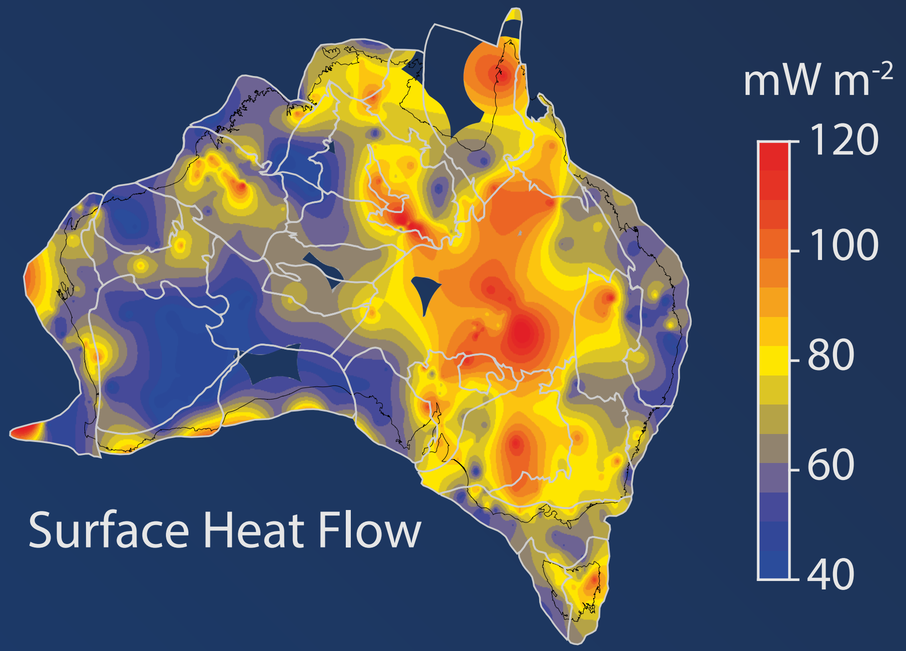


Hasterok & Gard (EPSL, accepted)

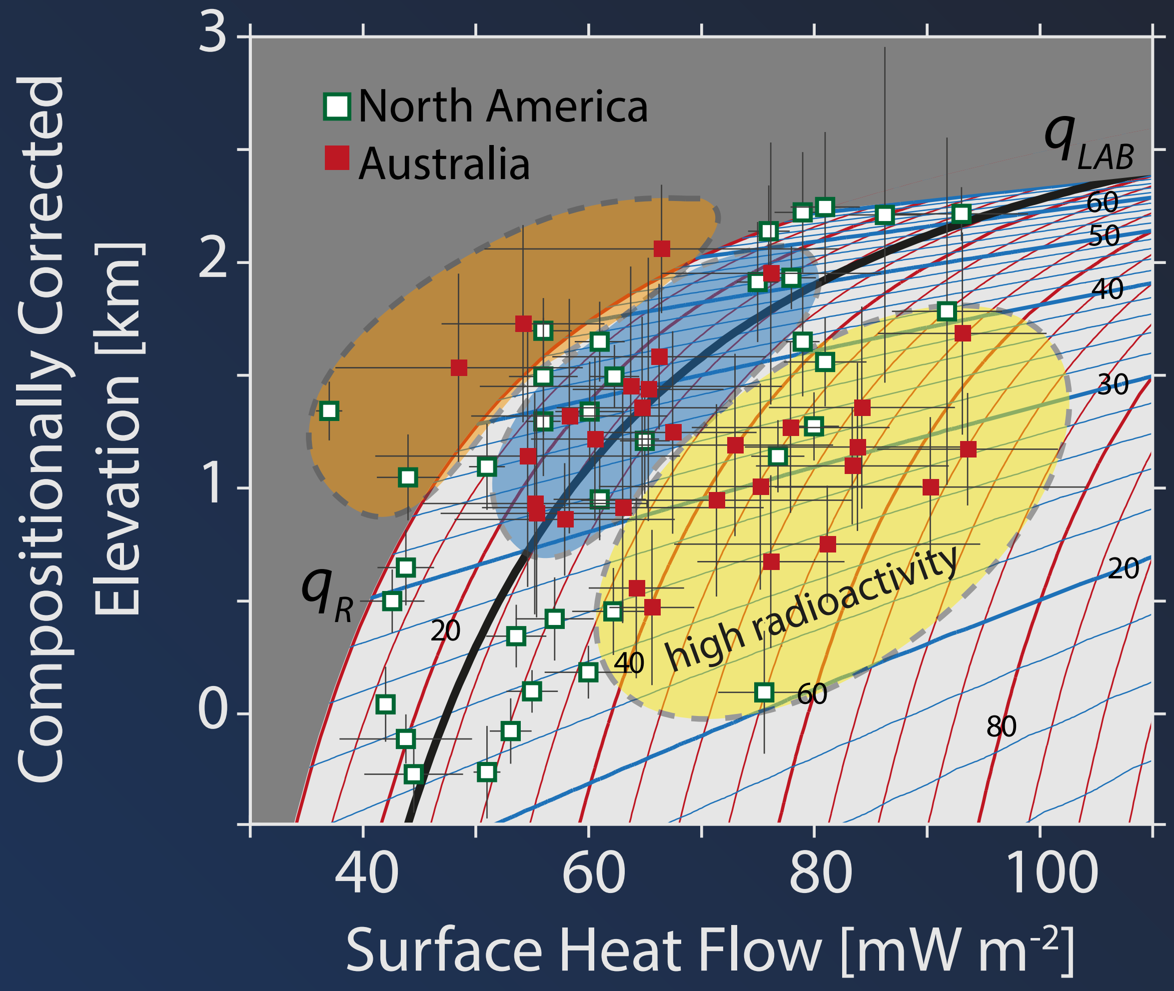
Thermoisostatic analysis identifies three major contributions to thermal elevation

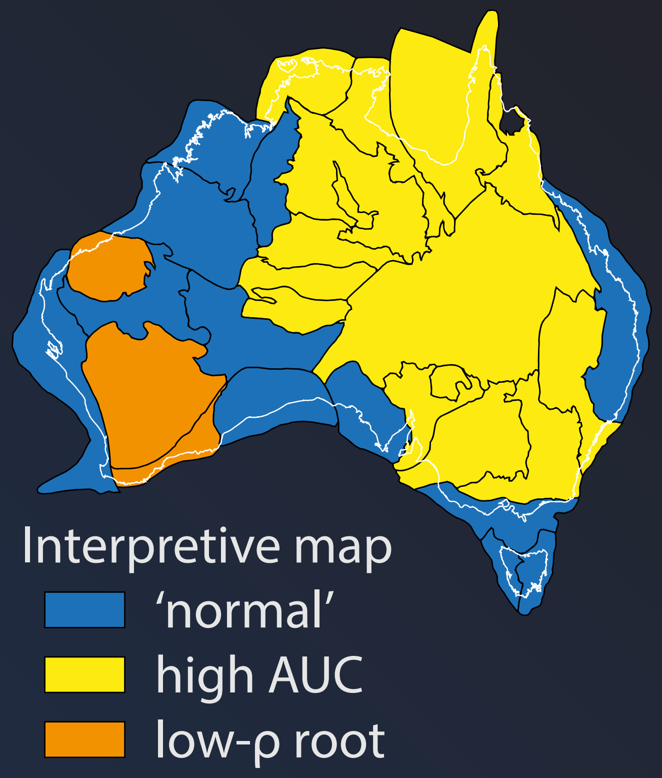


Compostionally Corrected Elevation



Surface Heat Flow

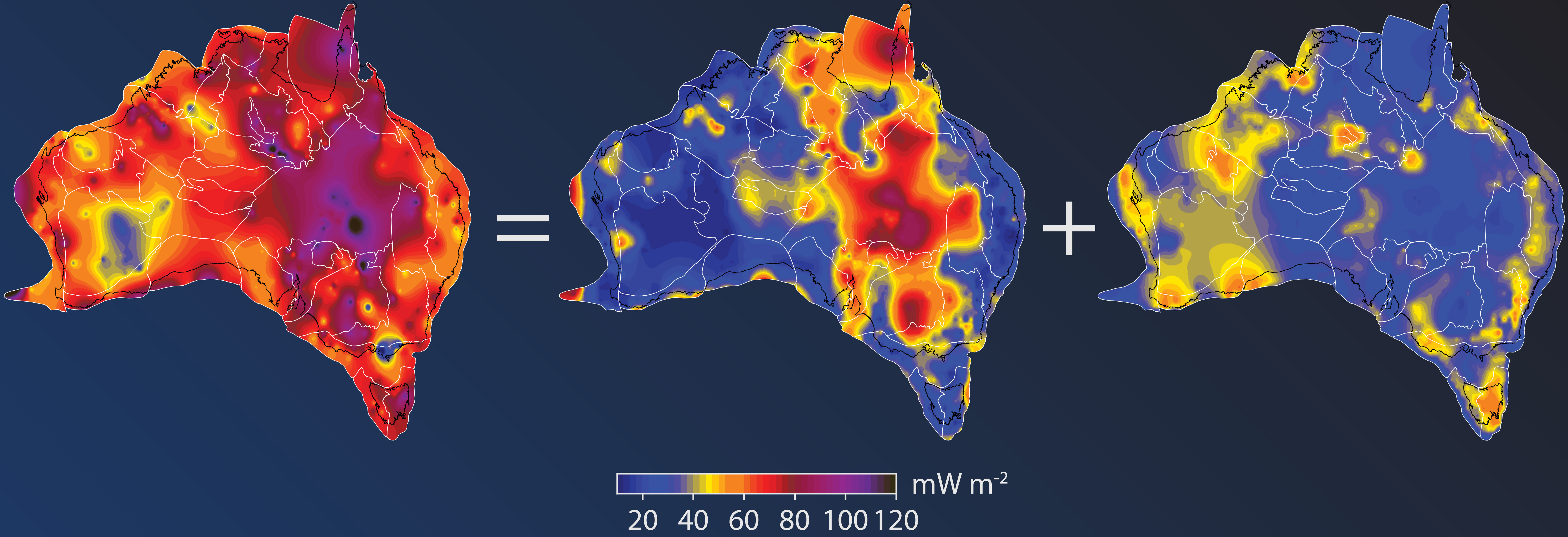




Hasterok & Gard (EPSL, accepted)

Decomposition of Surface Heat Flow

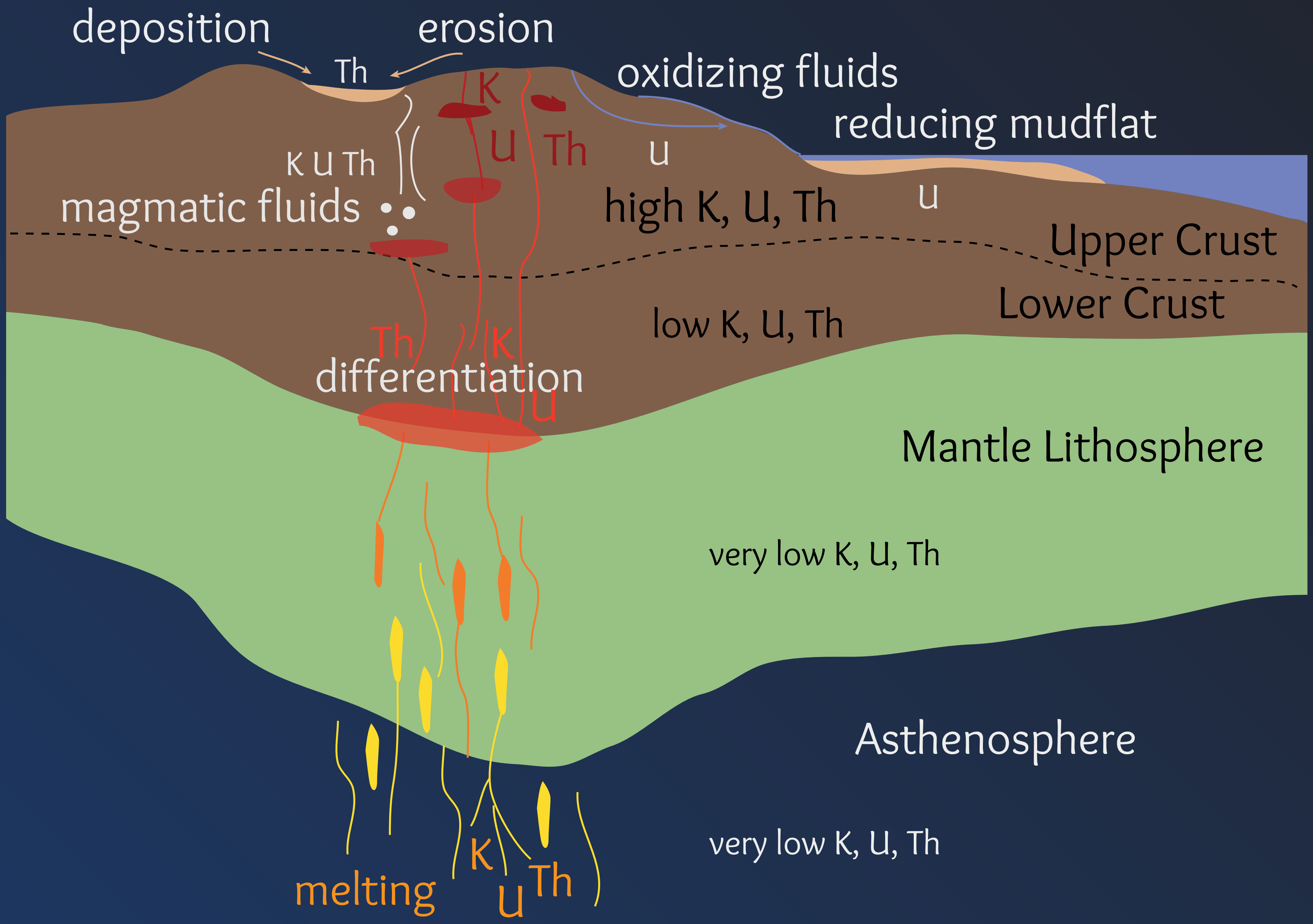
(thermal isostasy)



$$q_S = q_R + q_{LAB}$$

Hasterok & Gard (EPSL, accepted)

Geochemical Constraints on Heat Production

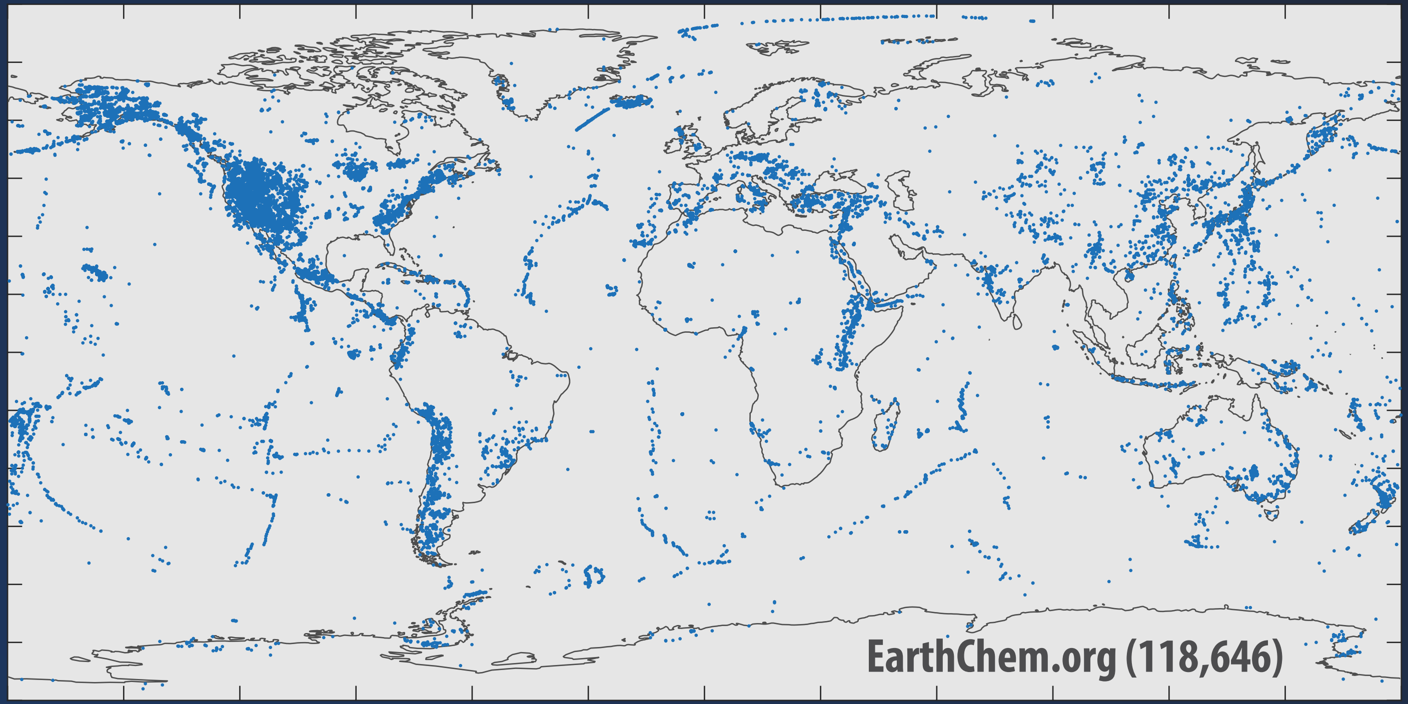


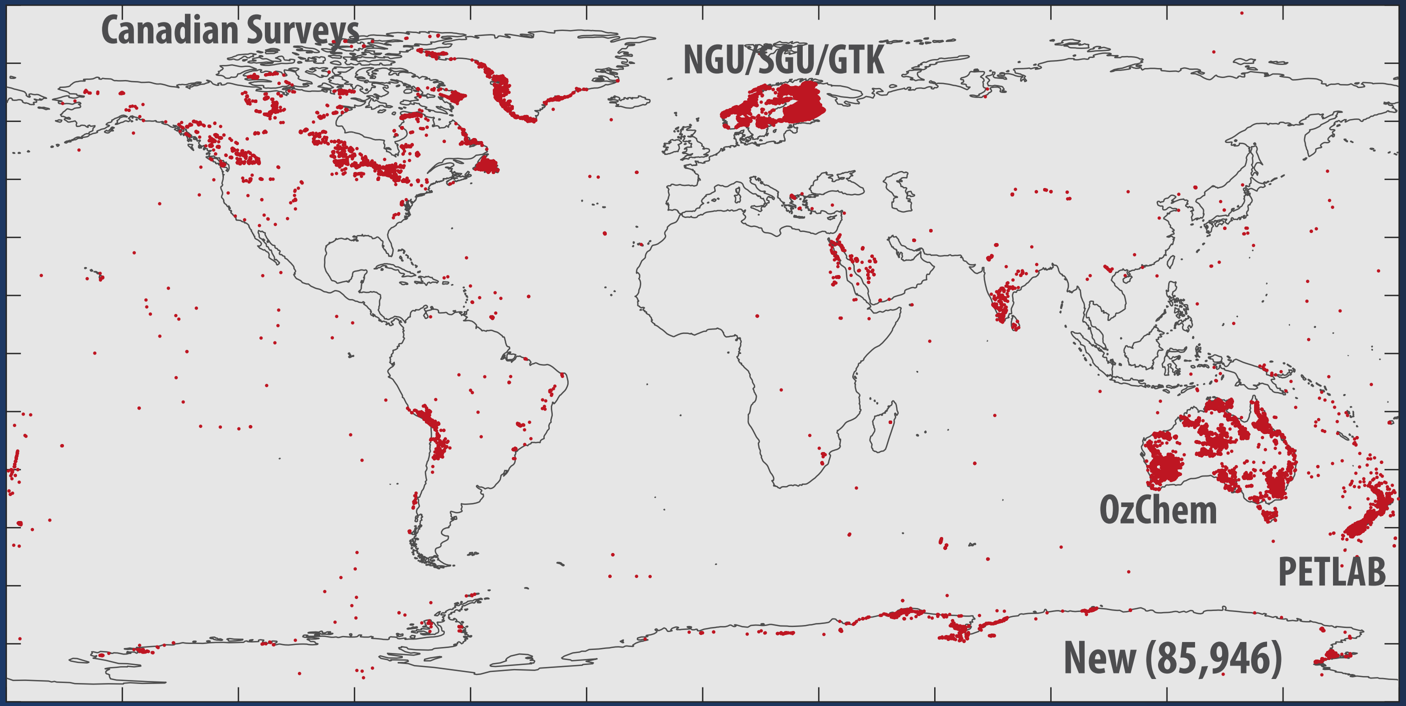
Computing Heat Production

$$\underbrace{A_{\mu W\ m^{-3}}}_{\text{heat production}} = \overset{\text{density}}{\rho}\ [\underbrace{9.52\ U_{ppm} + 2.56\ Th_{ppm} + 2.89\ K_2O_{wt.\%}}_{\text{heat producing elements}}] \times 10^{-5}$$

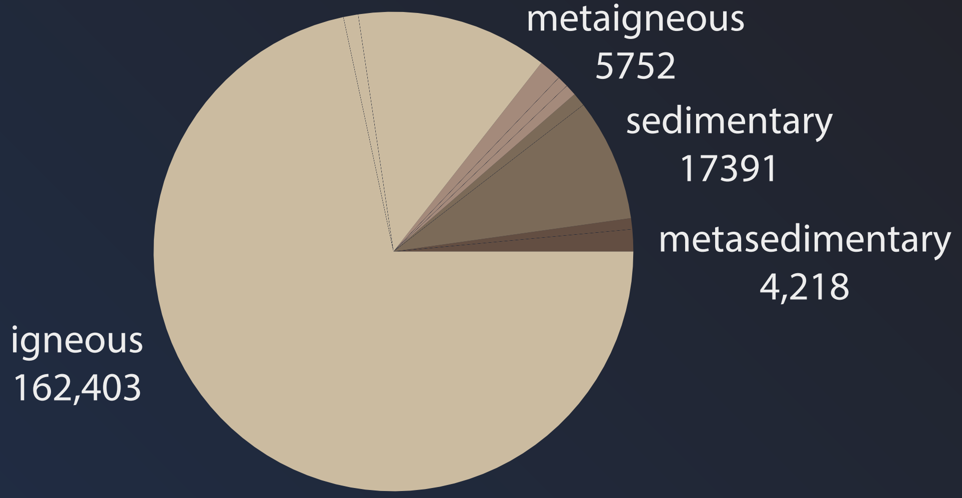
Rybach (1988)

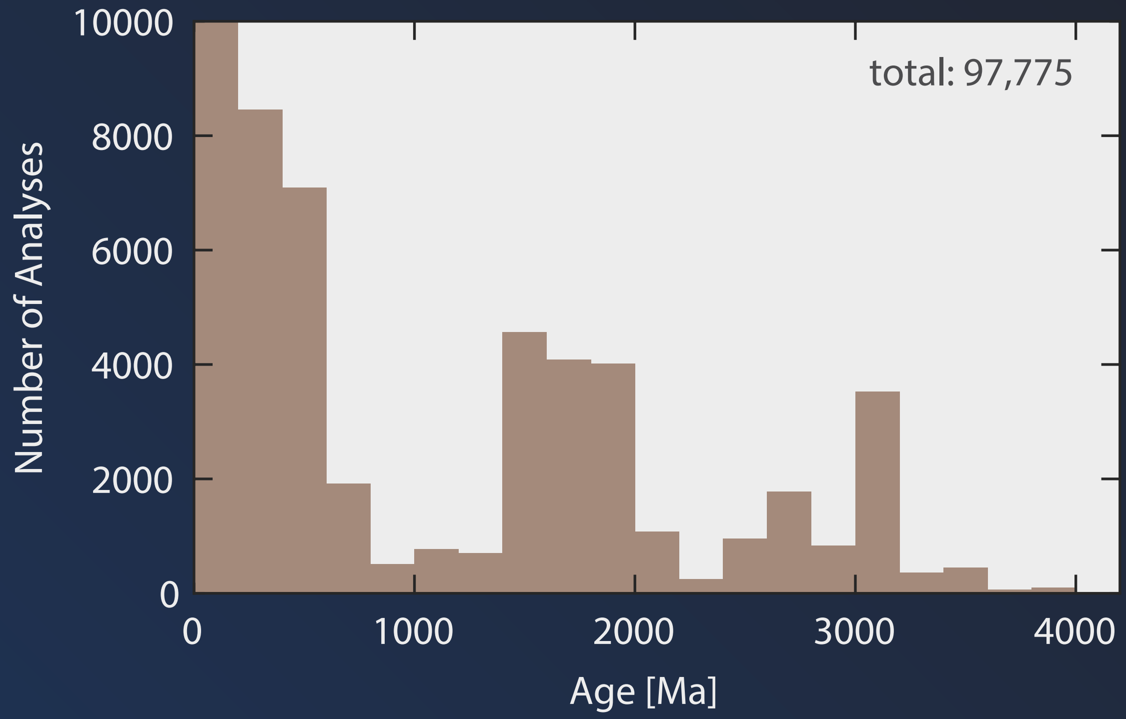
Global Geochemical Data



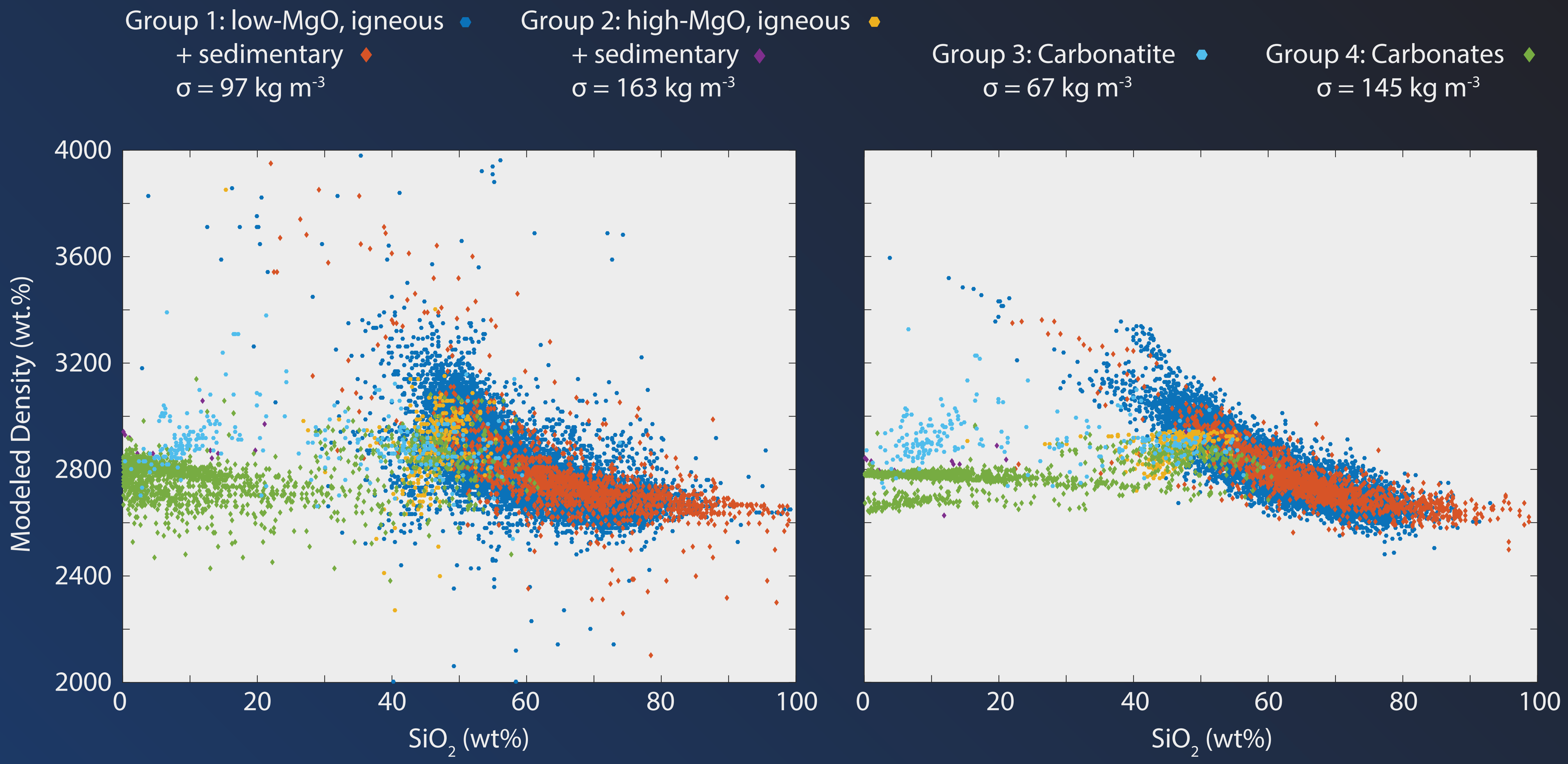


New data from >500 additional sources and a few geological surveys

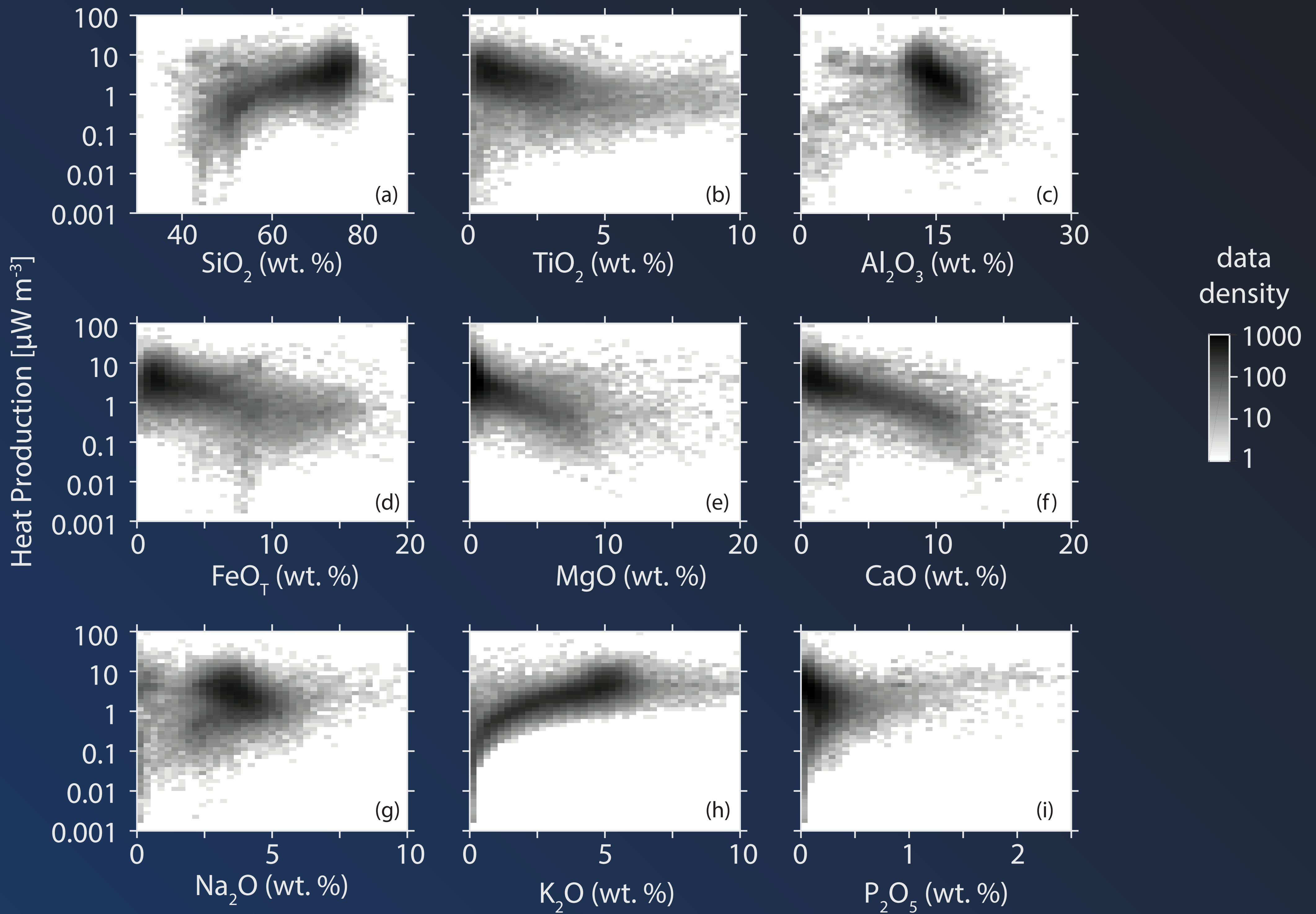




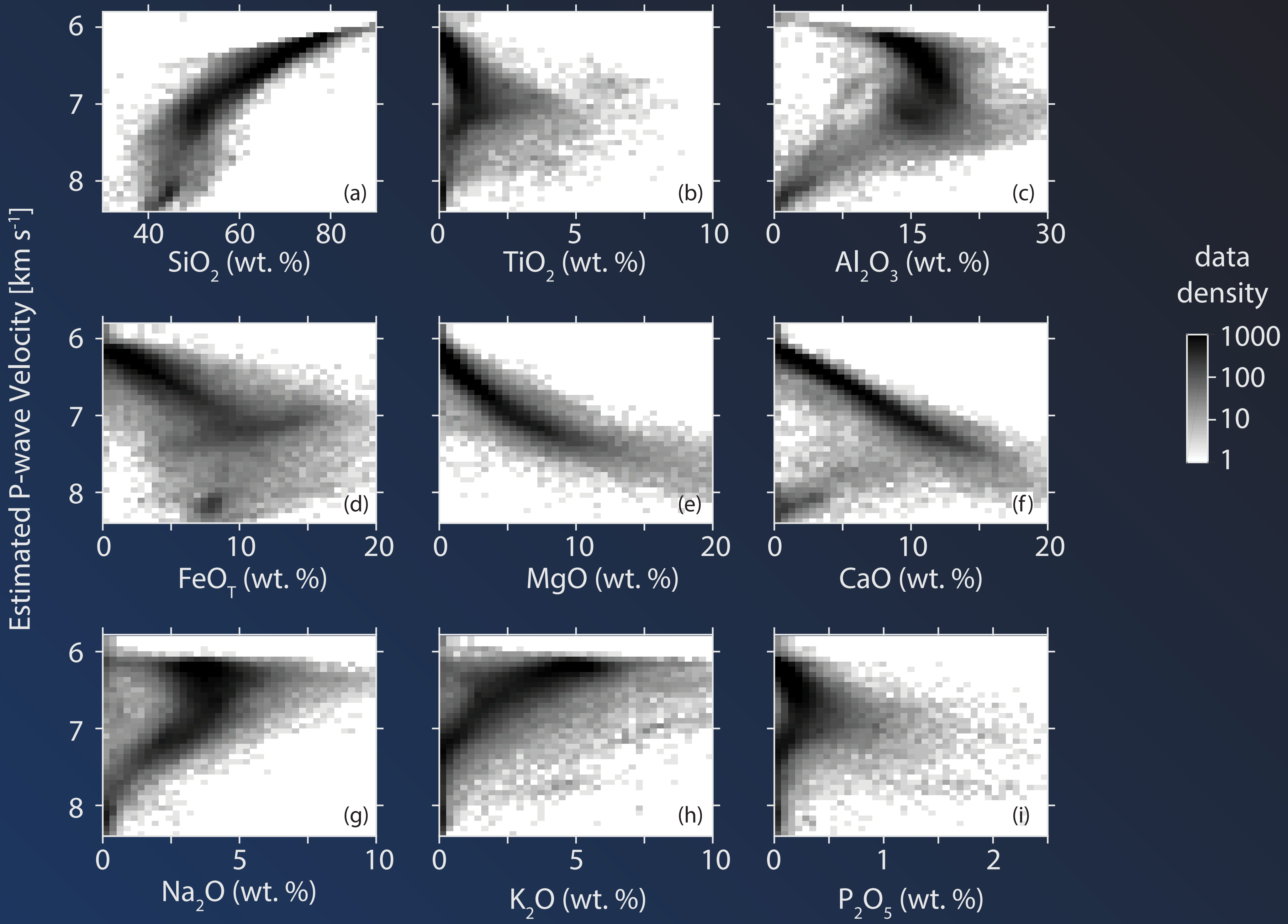
Modelling Density



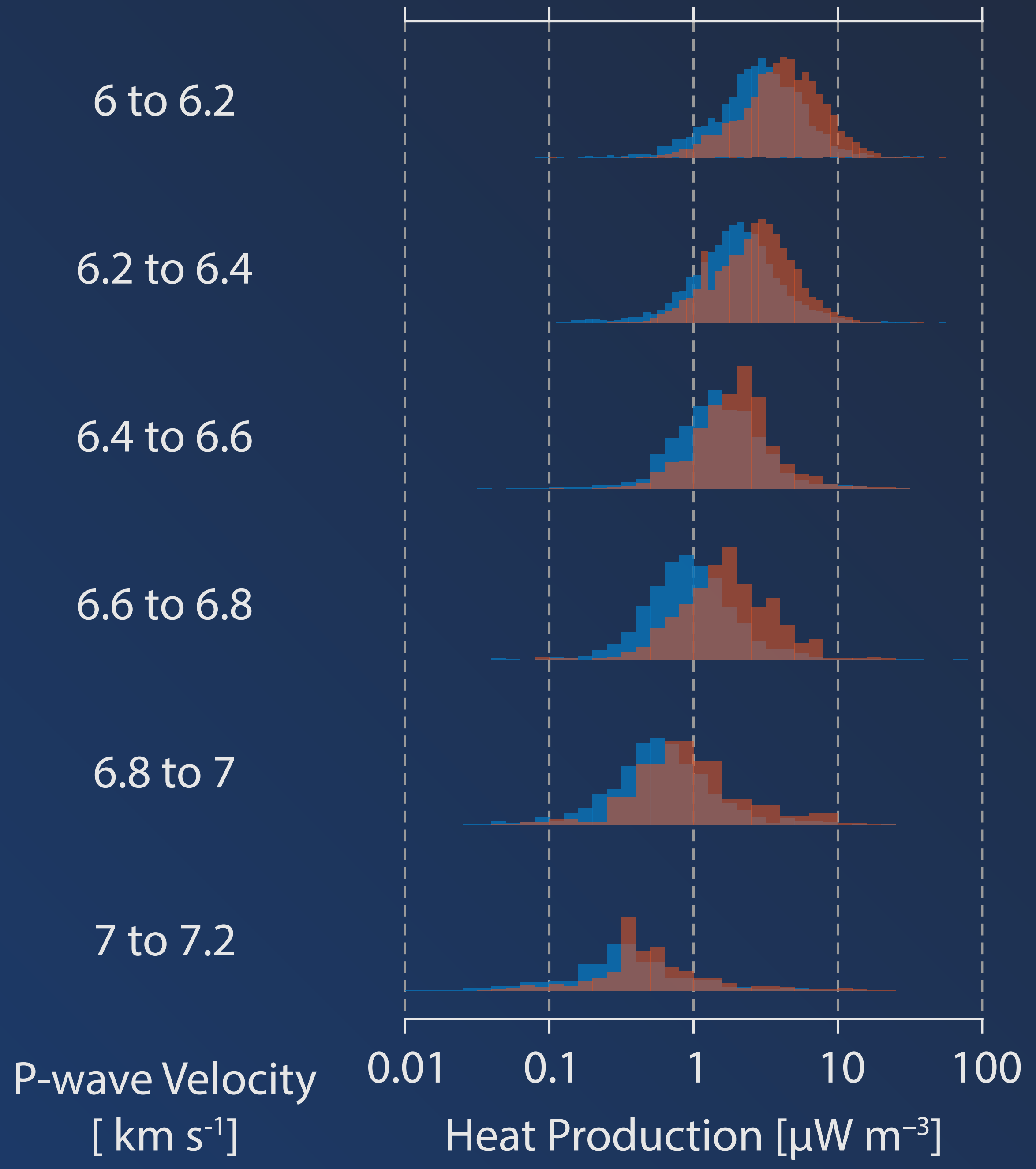
Systematic Variations with Major Elements

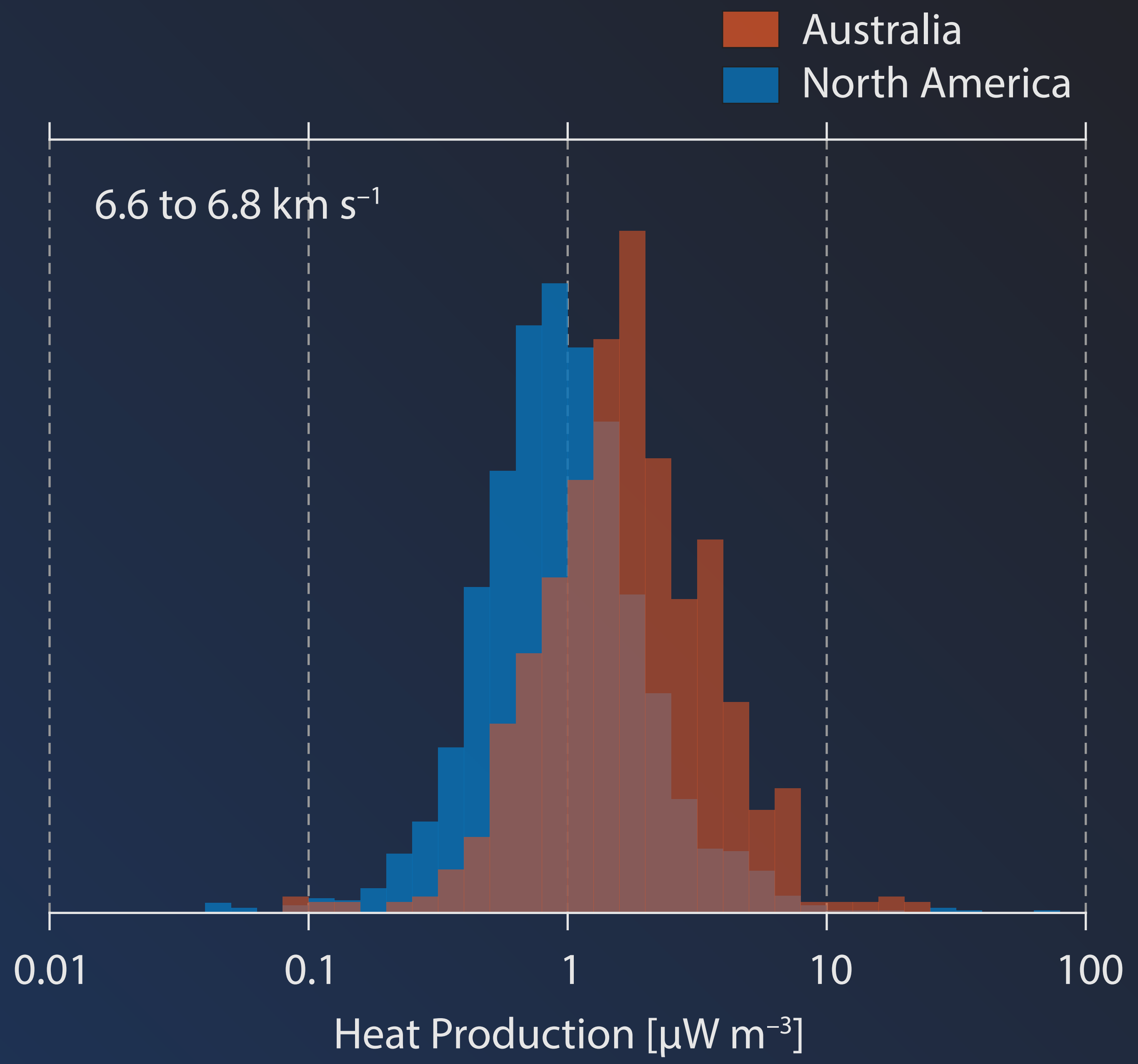


Systematic Variations with Major Elements

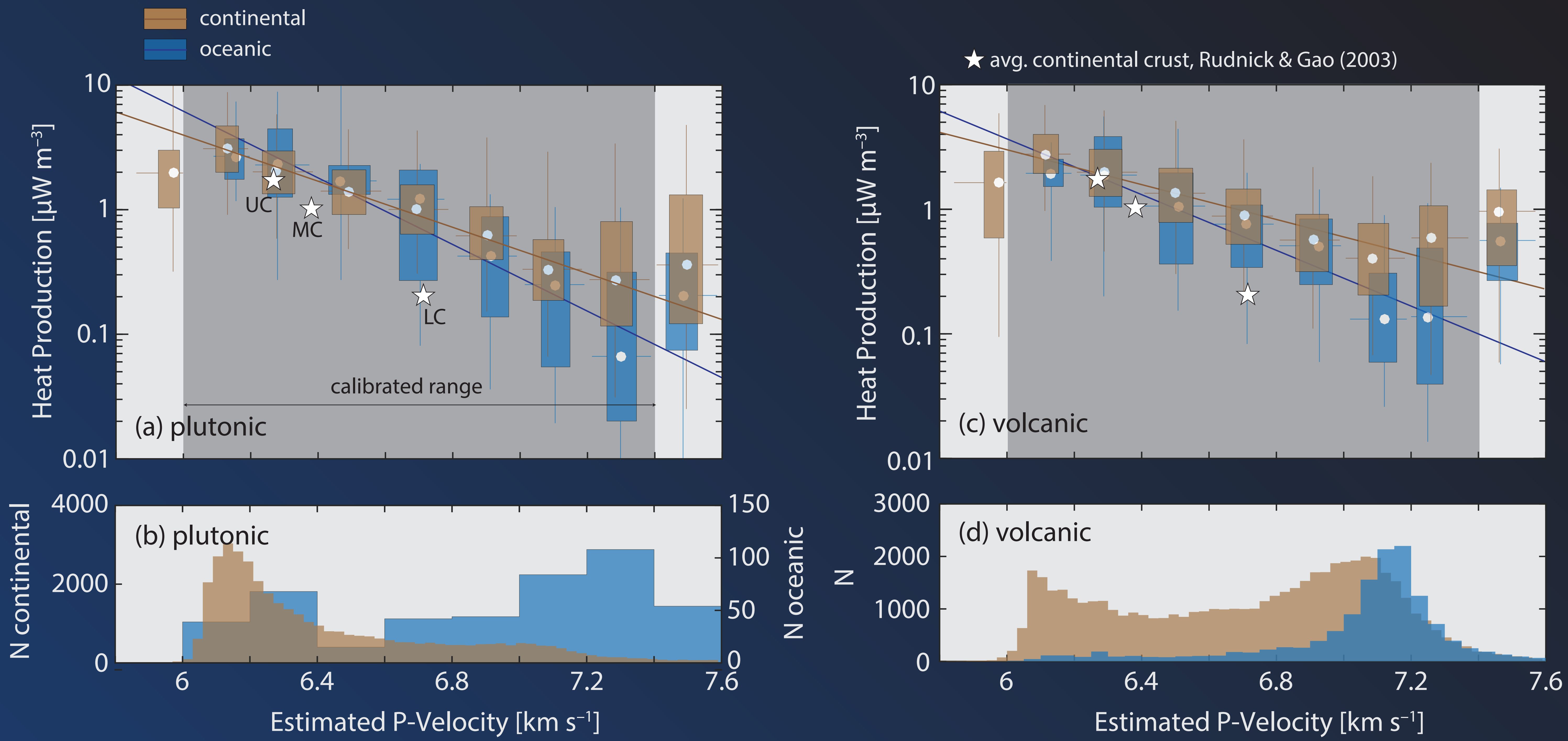


Broad distributions across continent allow room for regional variations



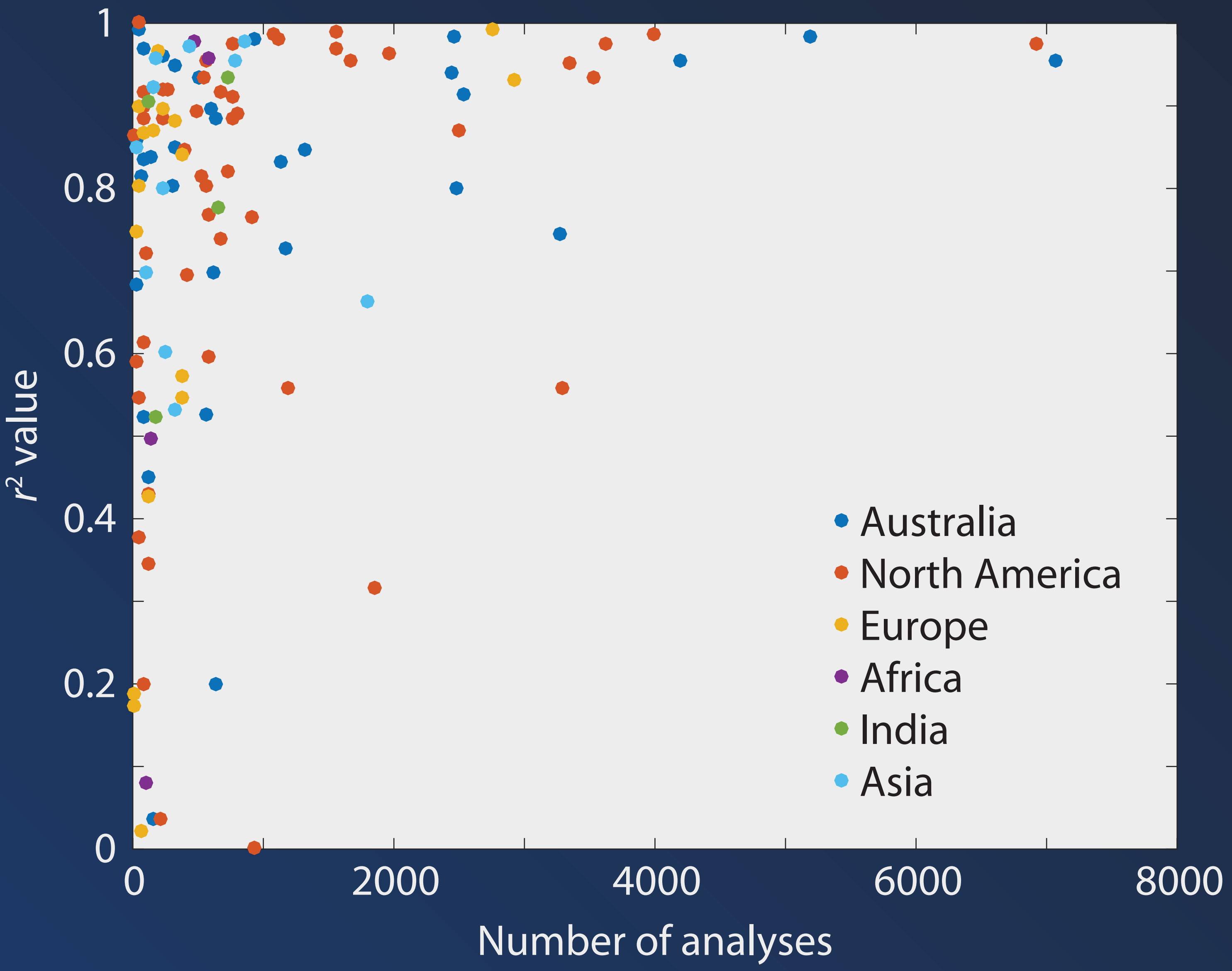


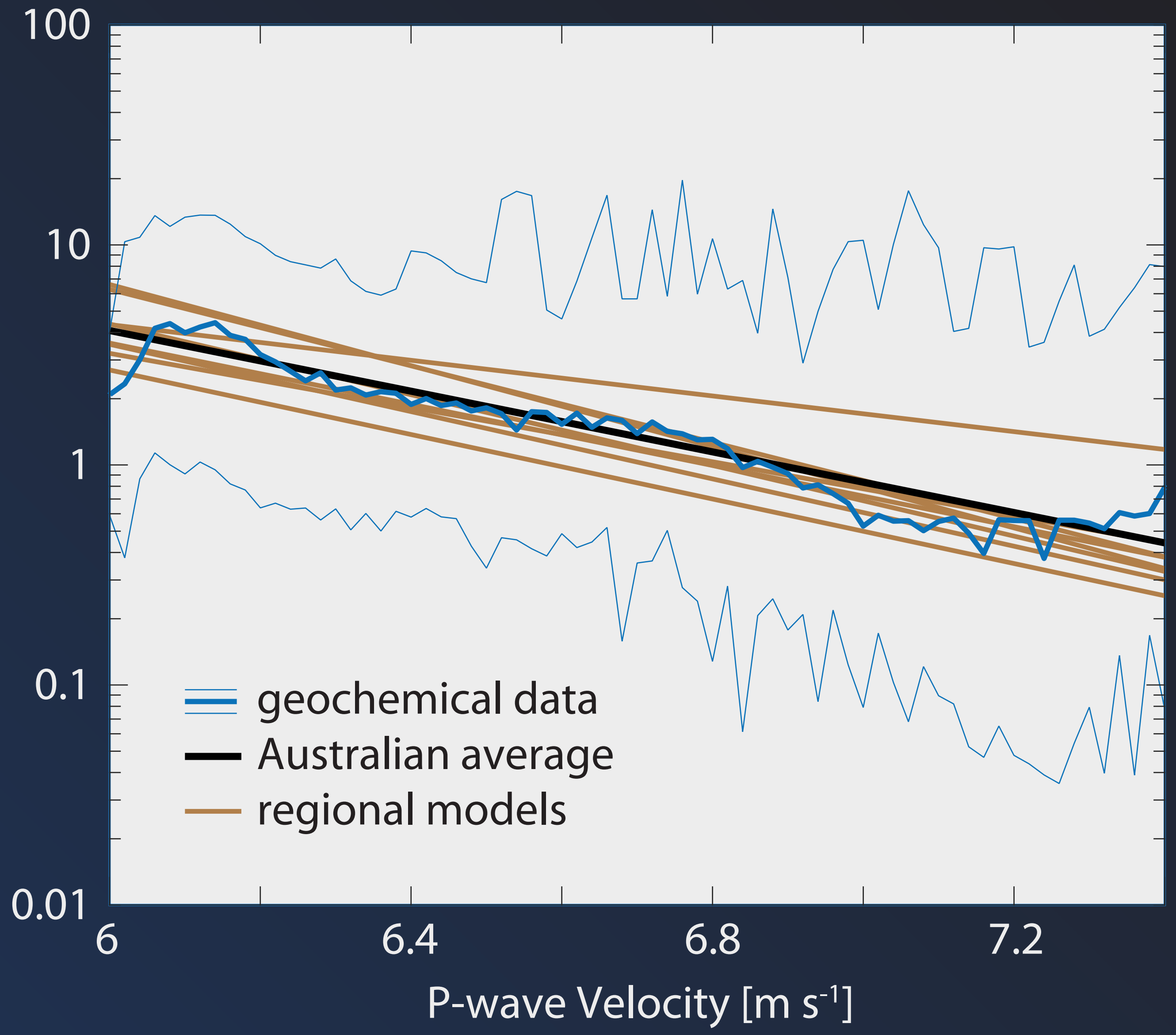
Continental versus Oceanic Heat Production



Hasterok & Webb (2017)

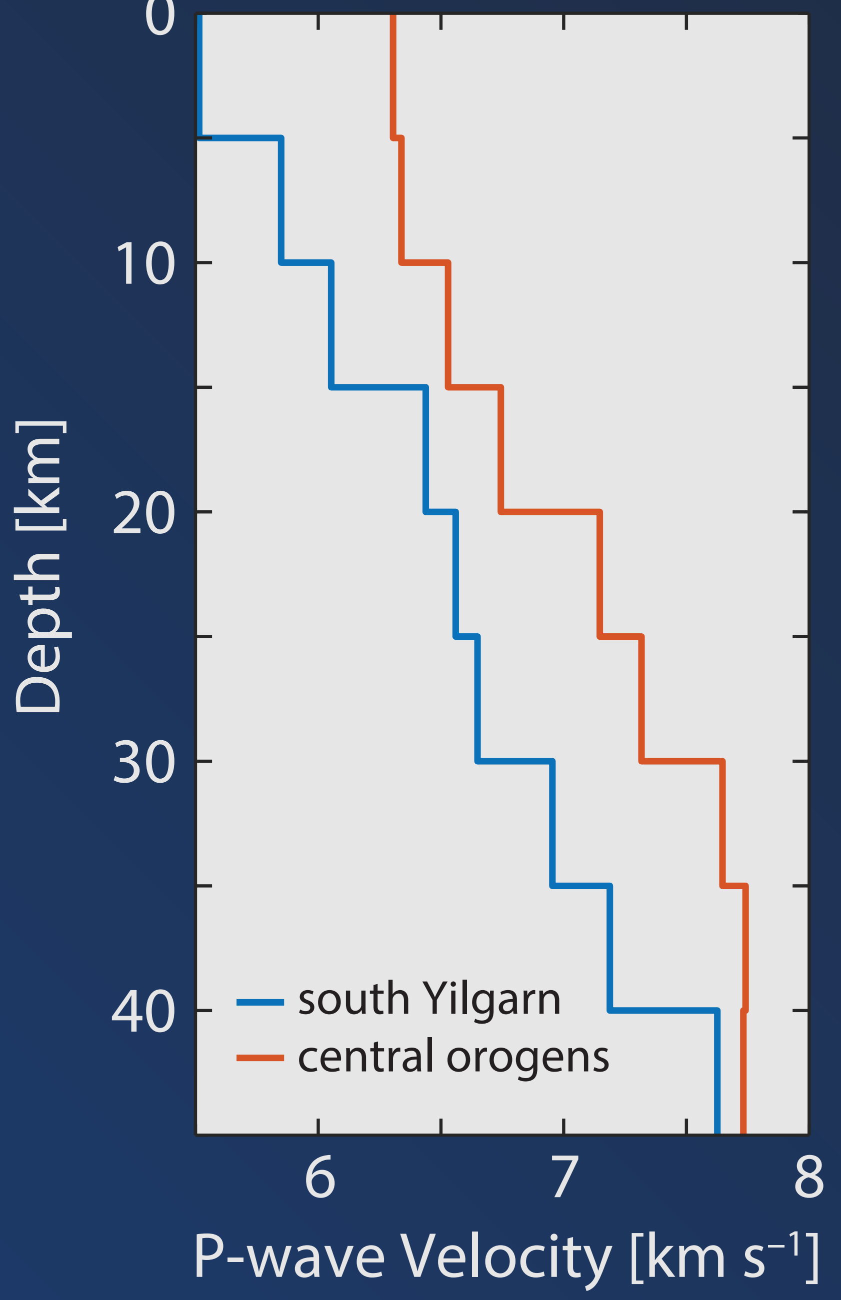
Performance and Variations in log-Linear Models



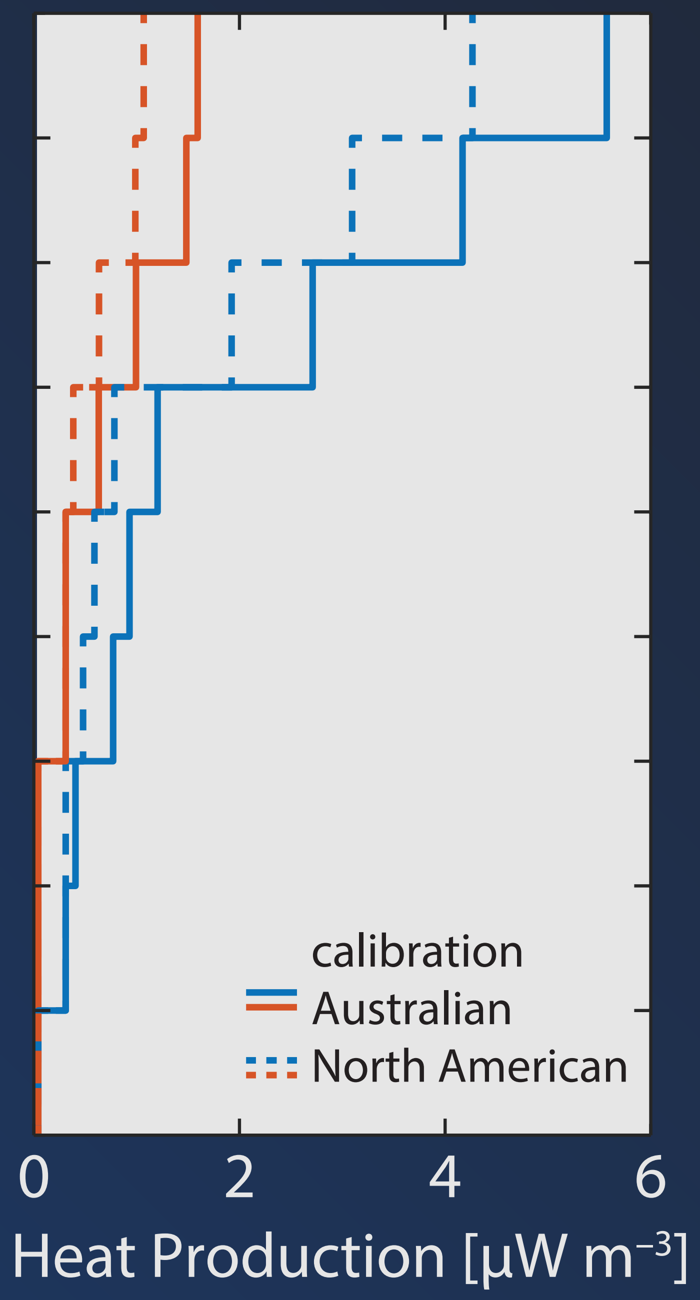


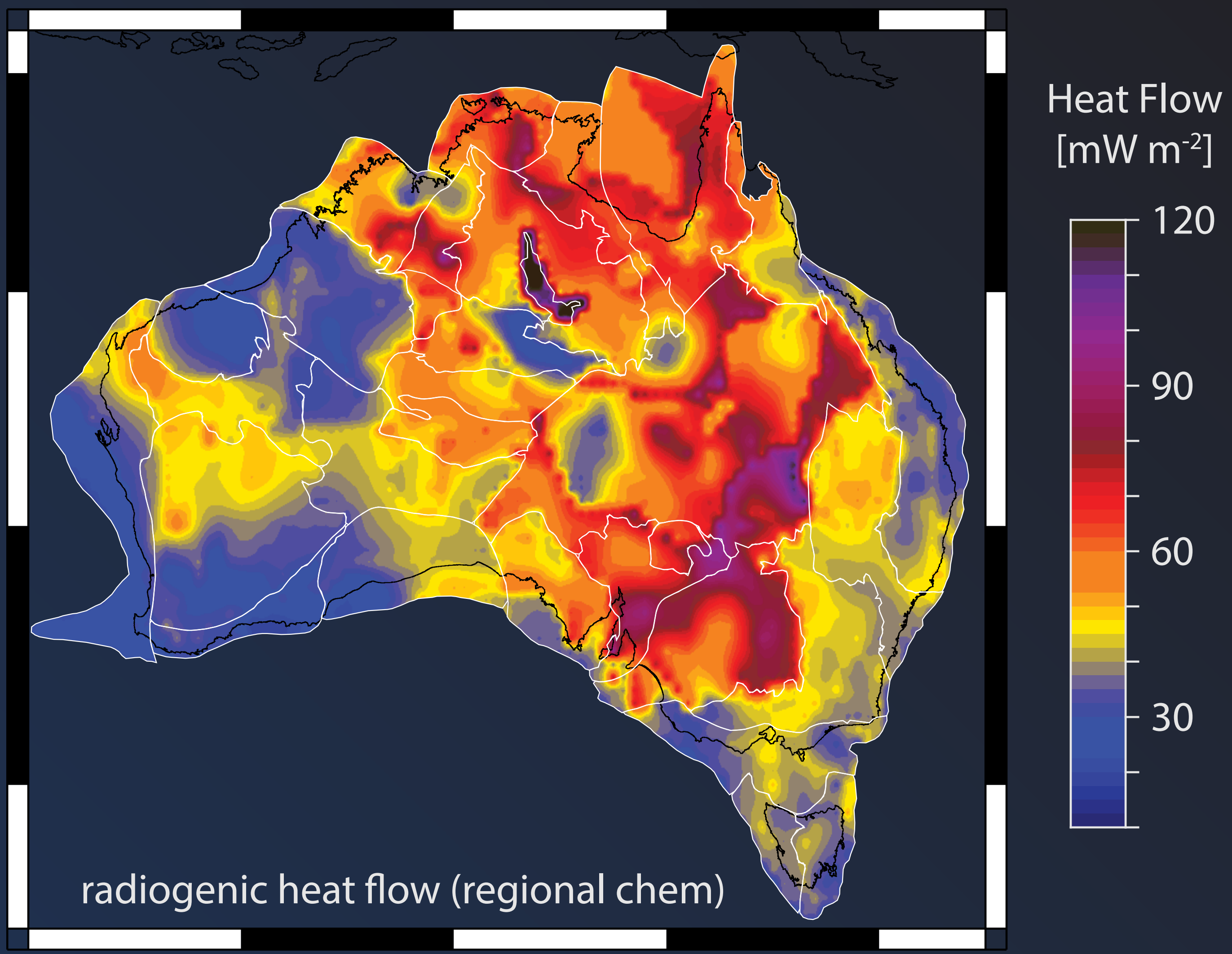
Converting Seismic Velocity to Heat Production

Velocities from AusREM (Salmon et al., GJI, 2013)



$$\text{radiogenic heat flow} = \sum\left(\text{heat production}\right)\left(\text{layer thickness}\right)$$

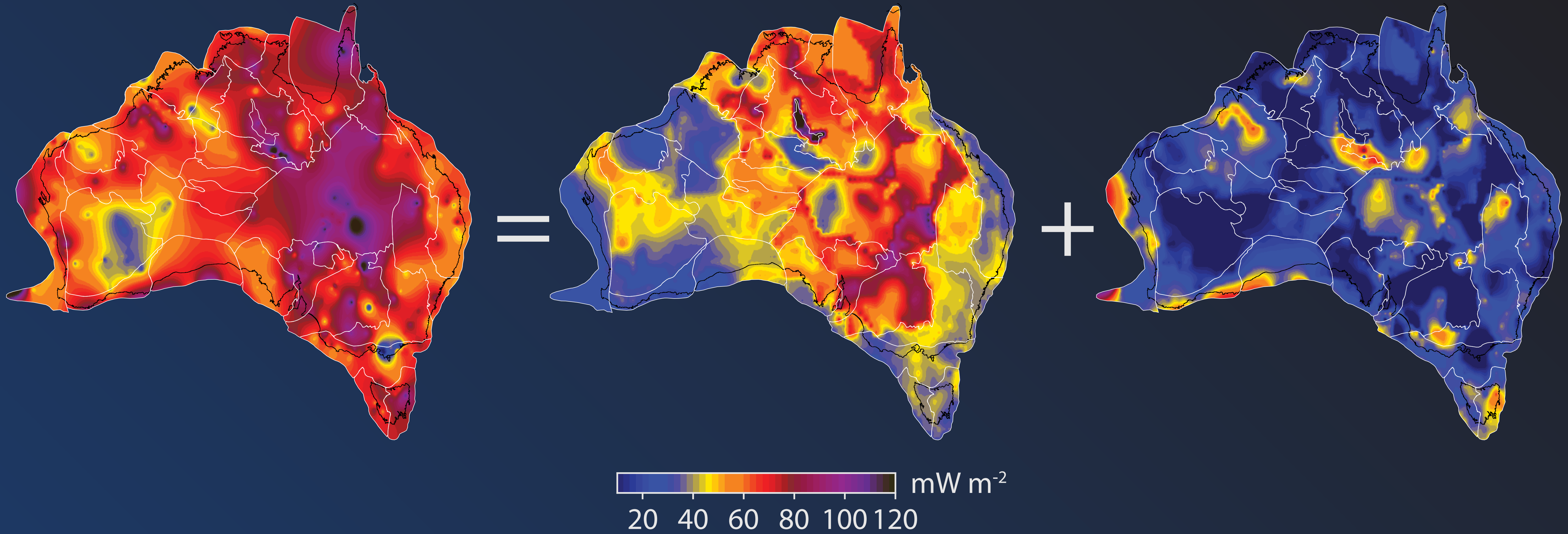




radiogenic heat flow (regional chem)

Decomposition of Surface Heat Flow

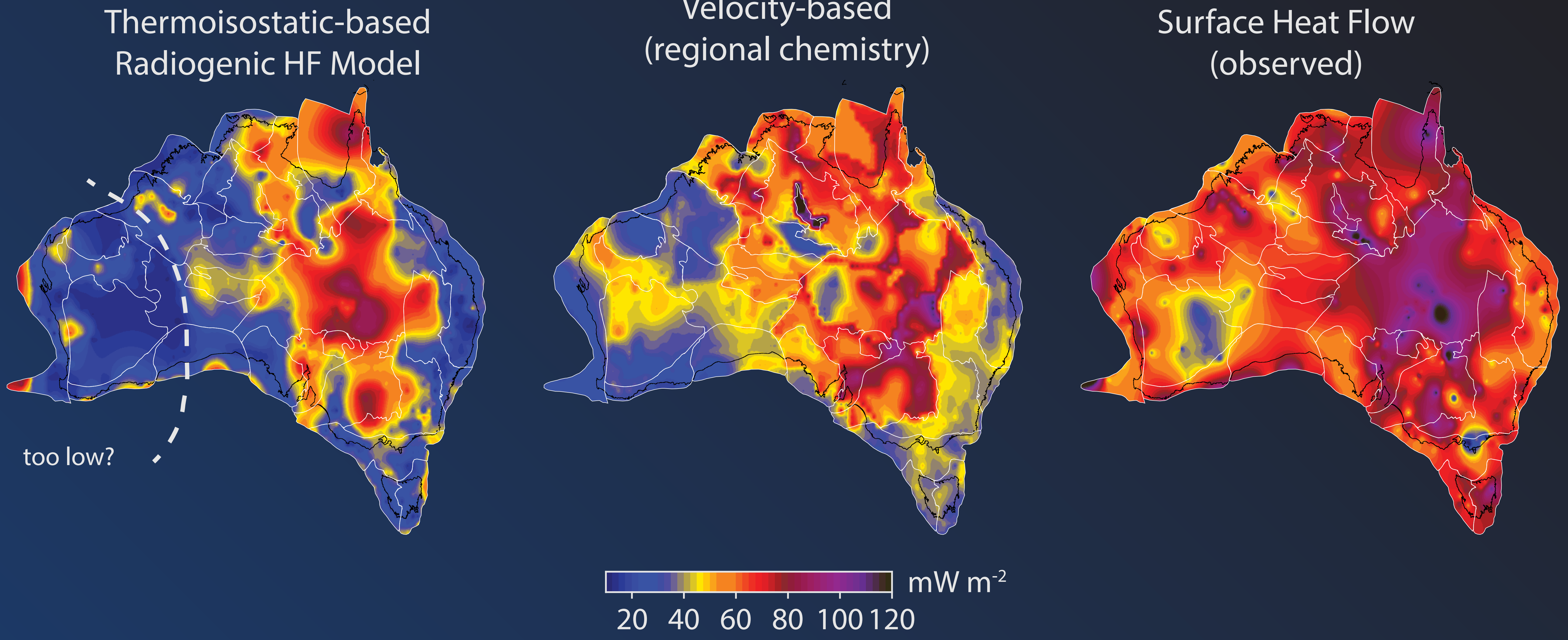
(chemistry-velocity)



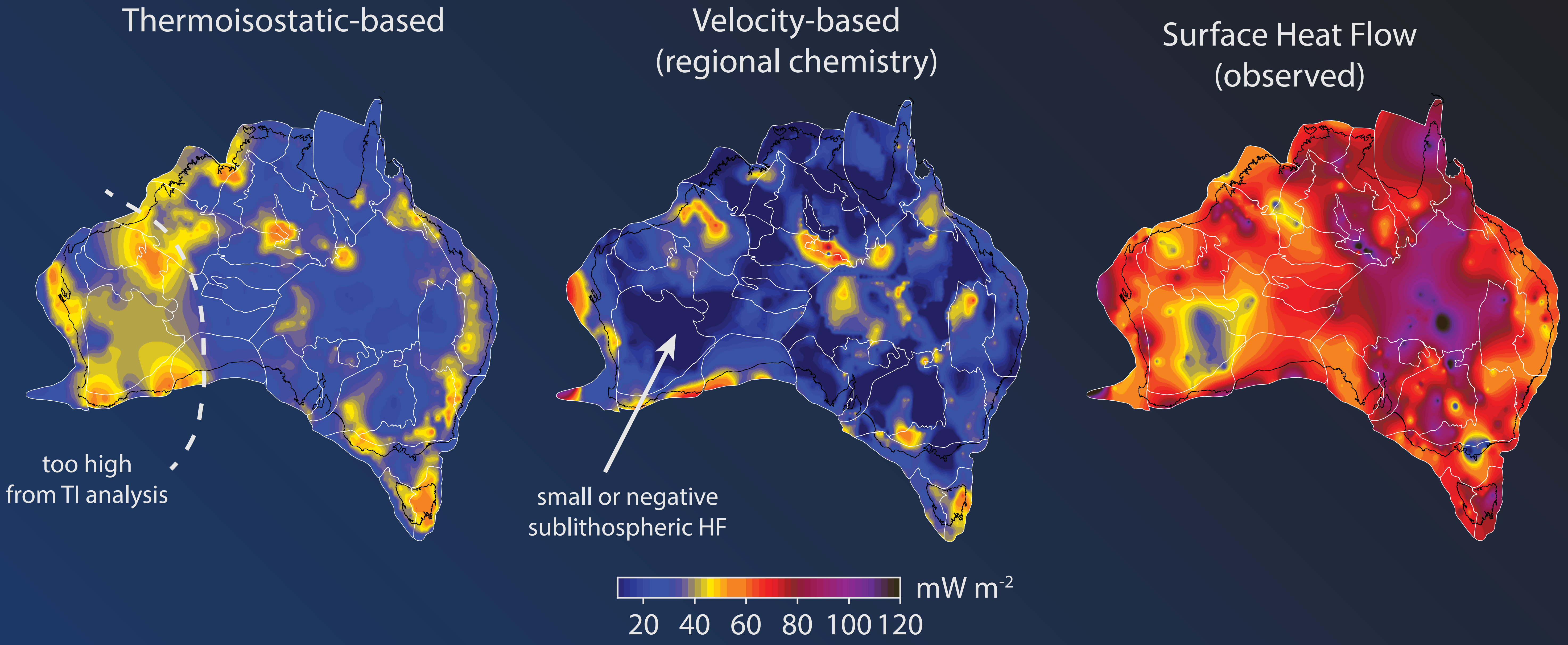
$$q_S = q_R + q_{LAB}$$

Hasterok & Gard (EPSL, accepted)

Comparison of Radiogenic Estimates



Comparison of Sublithospheric HF Estimates

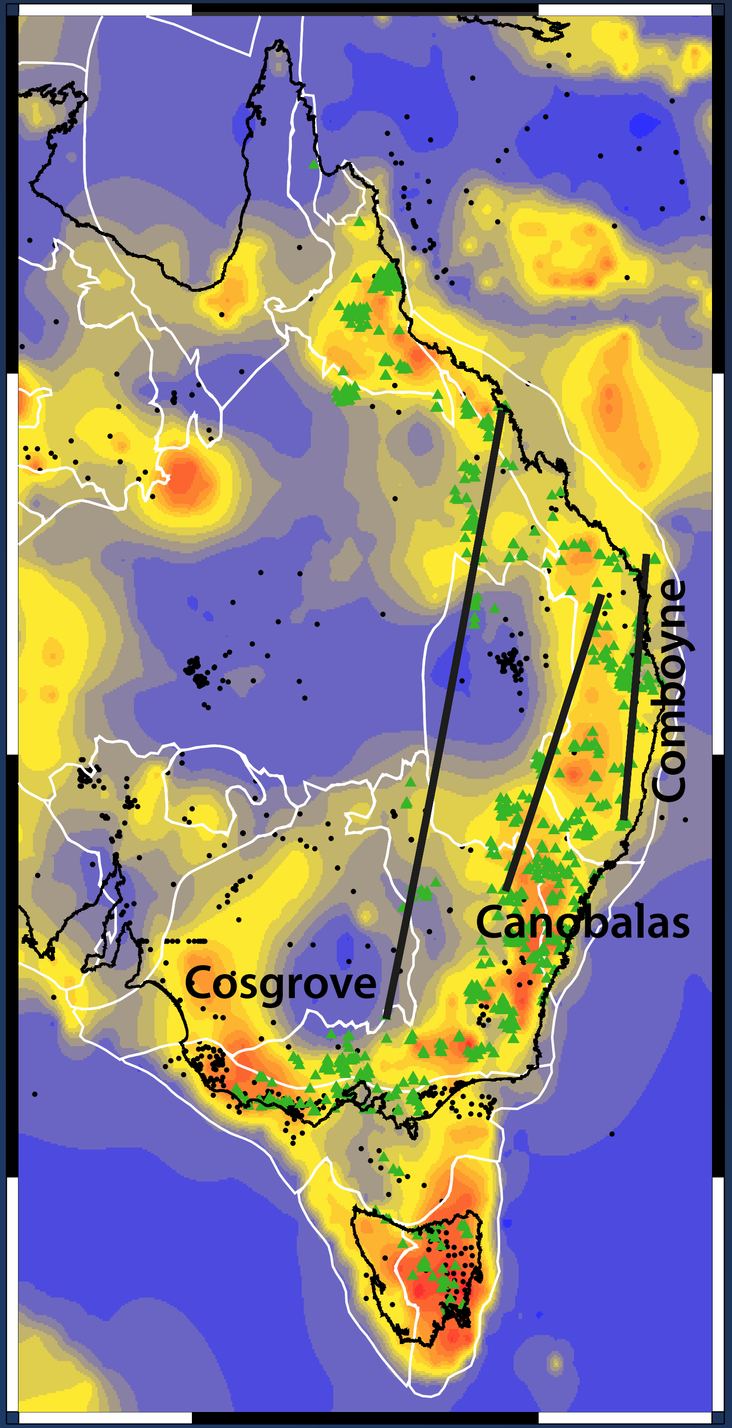


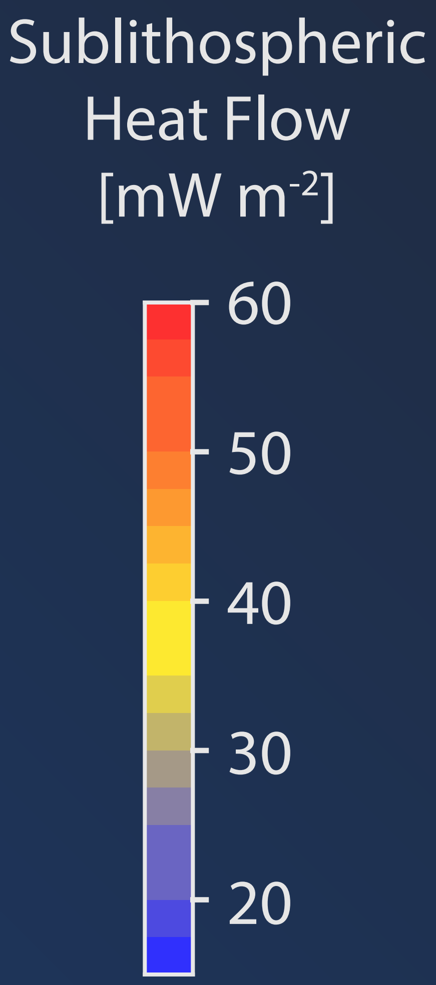
Thermoisostatic-based

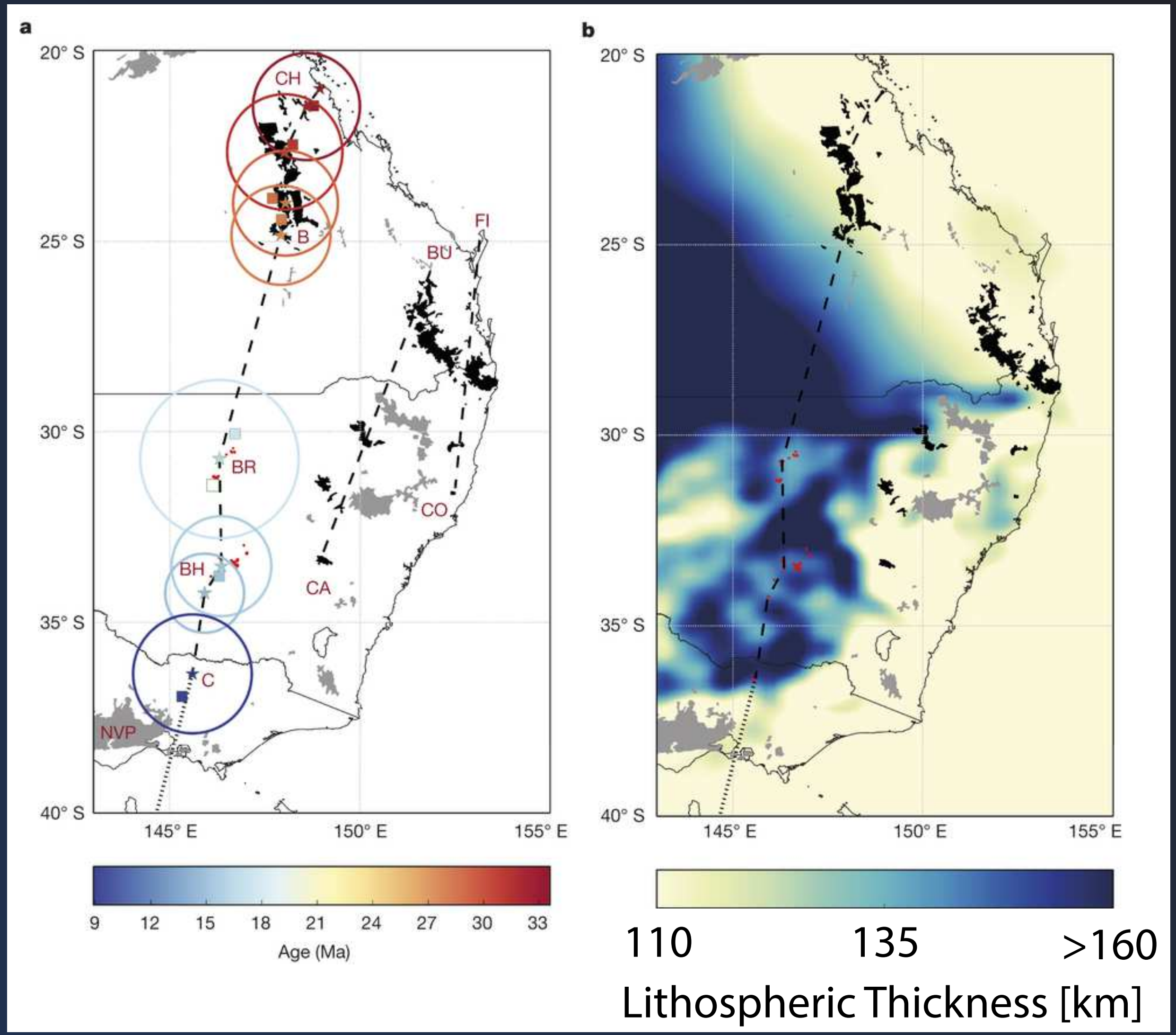
Velocity-based
(regional chemistry)

Surface Heat Flow
(observed)

High mantle heat flow along Australia's east/southeast coast







Davies et al. (Nature, 2015)

Conclusions

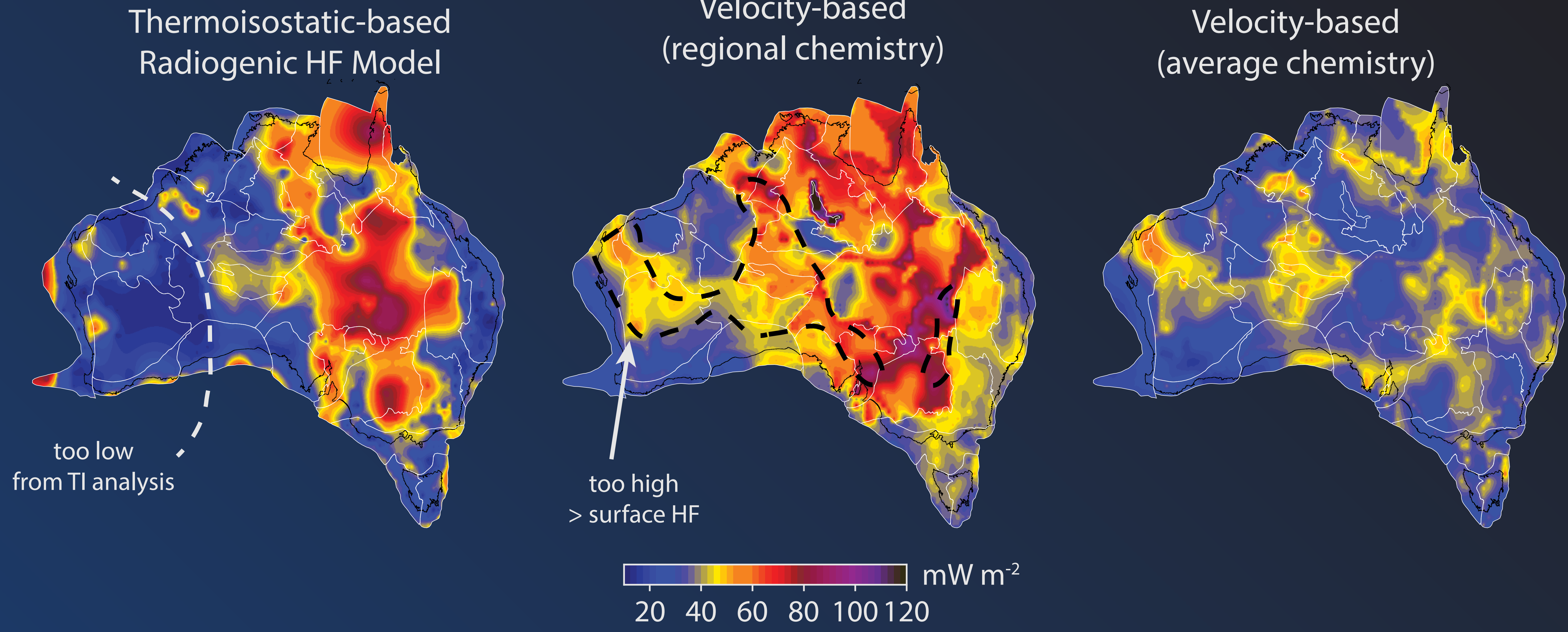
some similarities in both heat production models

both models have advantages and disadvantages

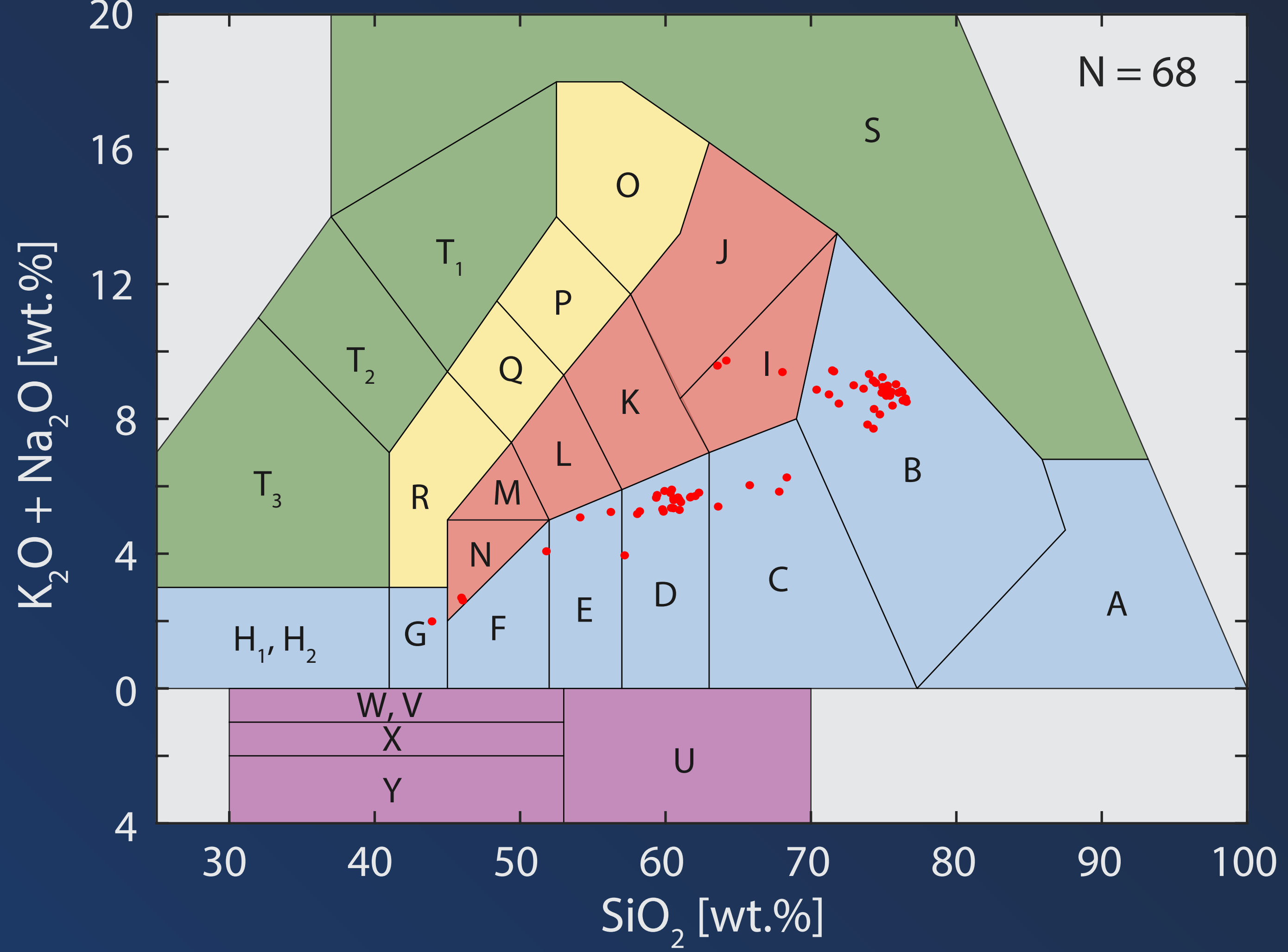
future improvements:
- velocity-based:
    - better models of crustal structure/composition (incorporate seds)
- thermoisostatic based:
    - better thermal conductivity and mantle density models (gravity)
- joint (Bayesian?) inversion

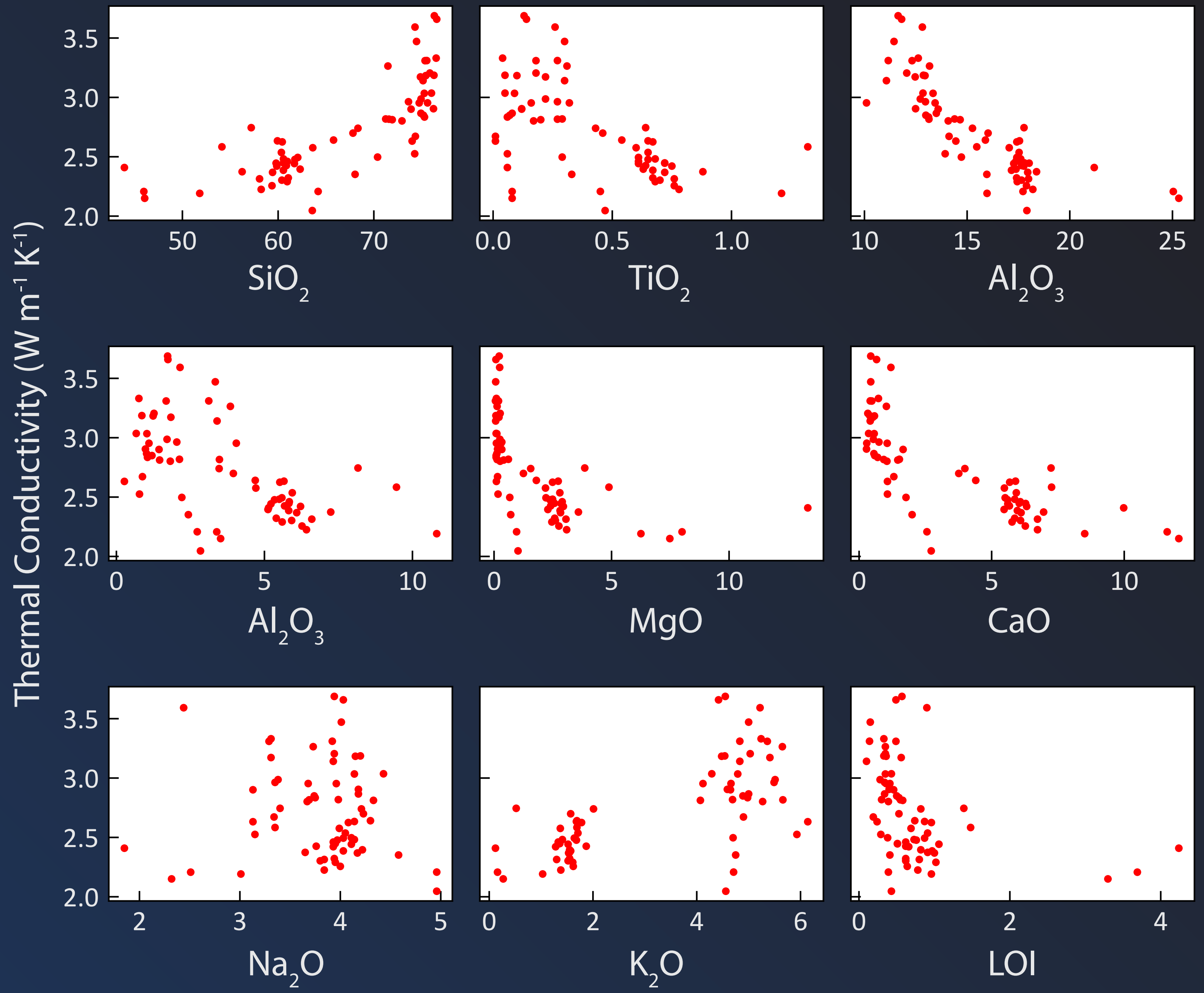
Geoneutrinos!!!

Comparison of Radiogenic Estimates



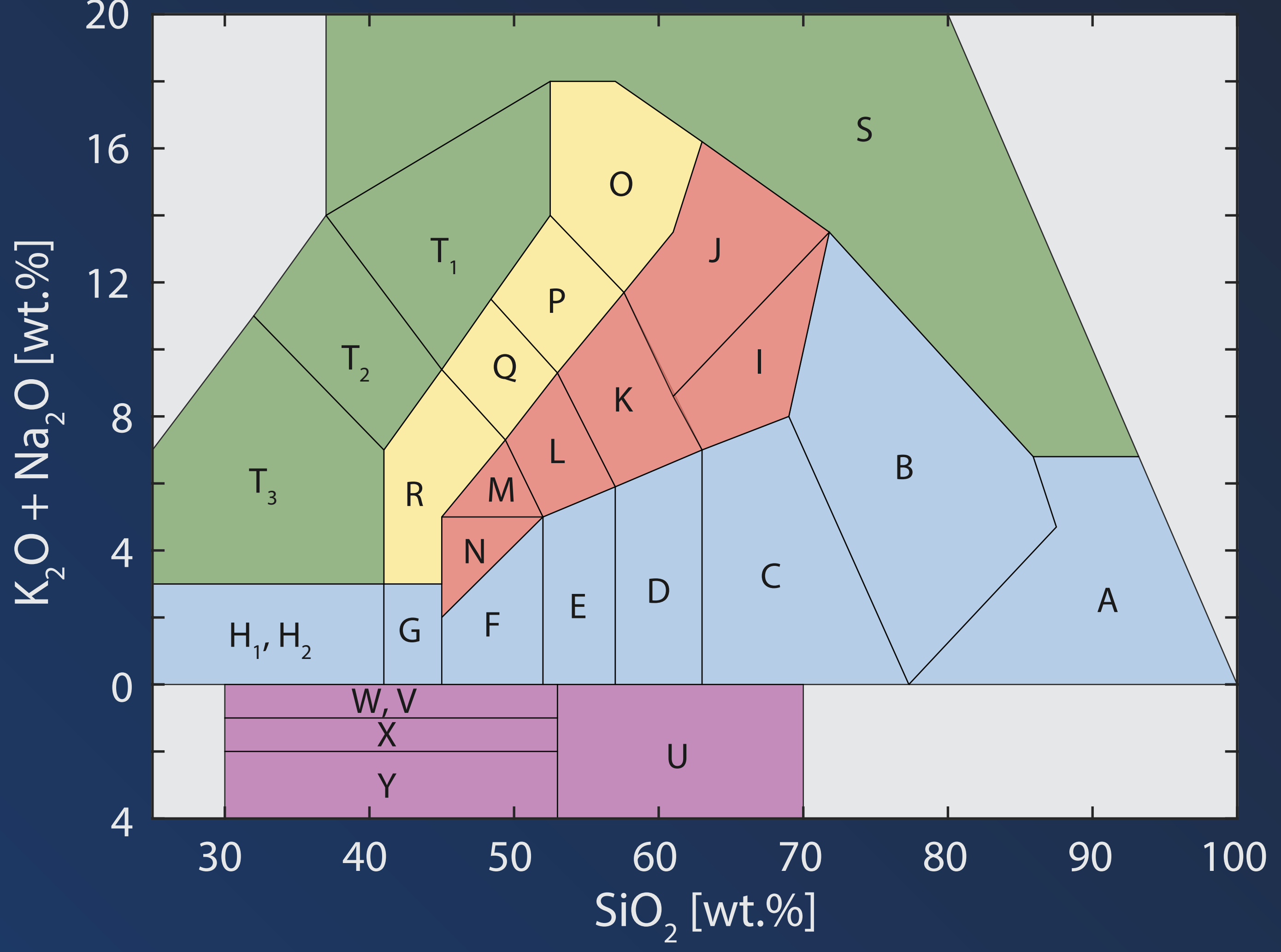
Heat Production Plutonic Rocks

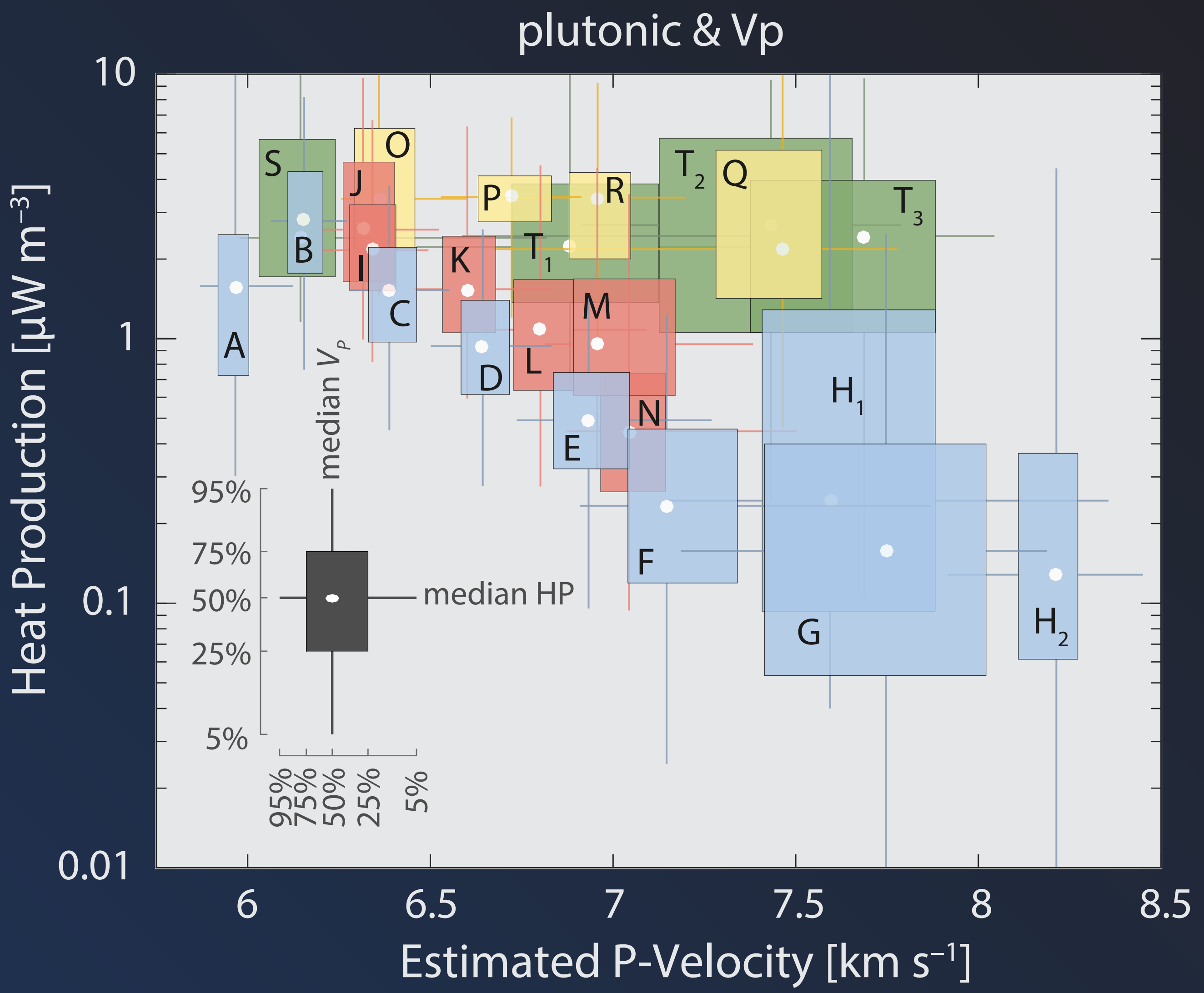




S. Jenning (in progress)

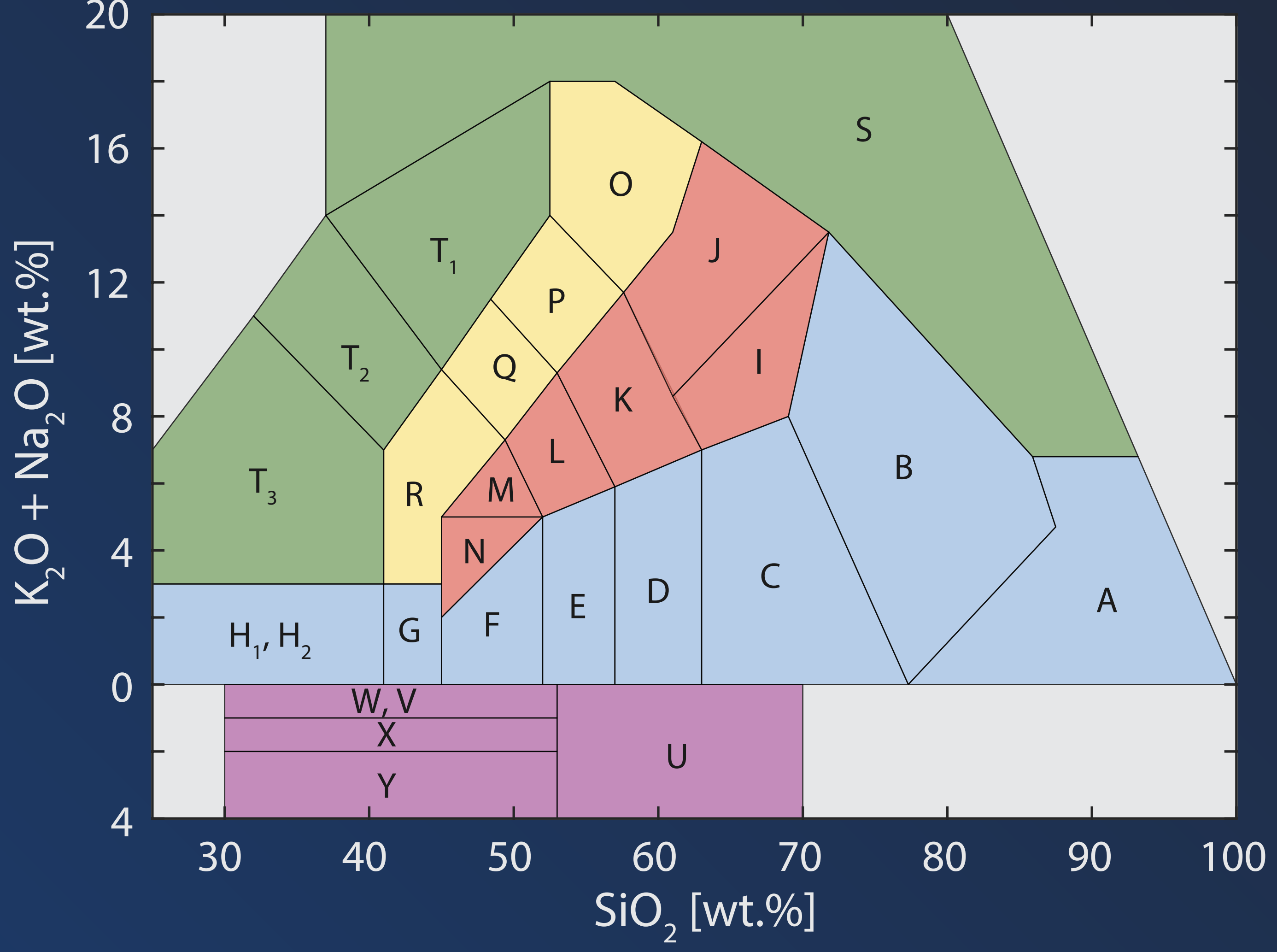
Heat Production Plutonic Rocks

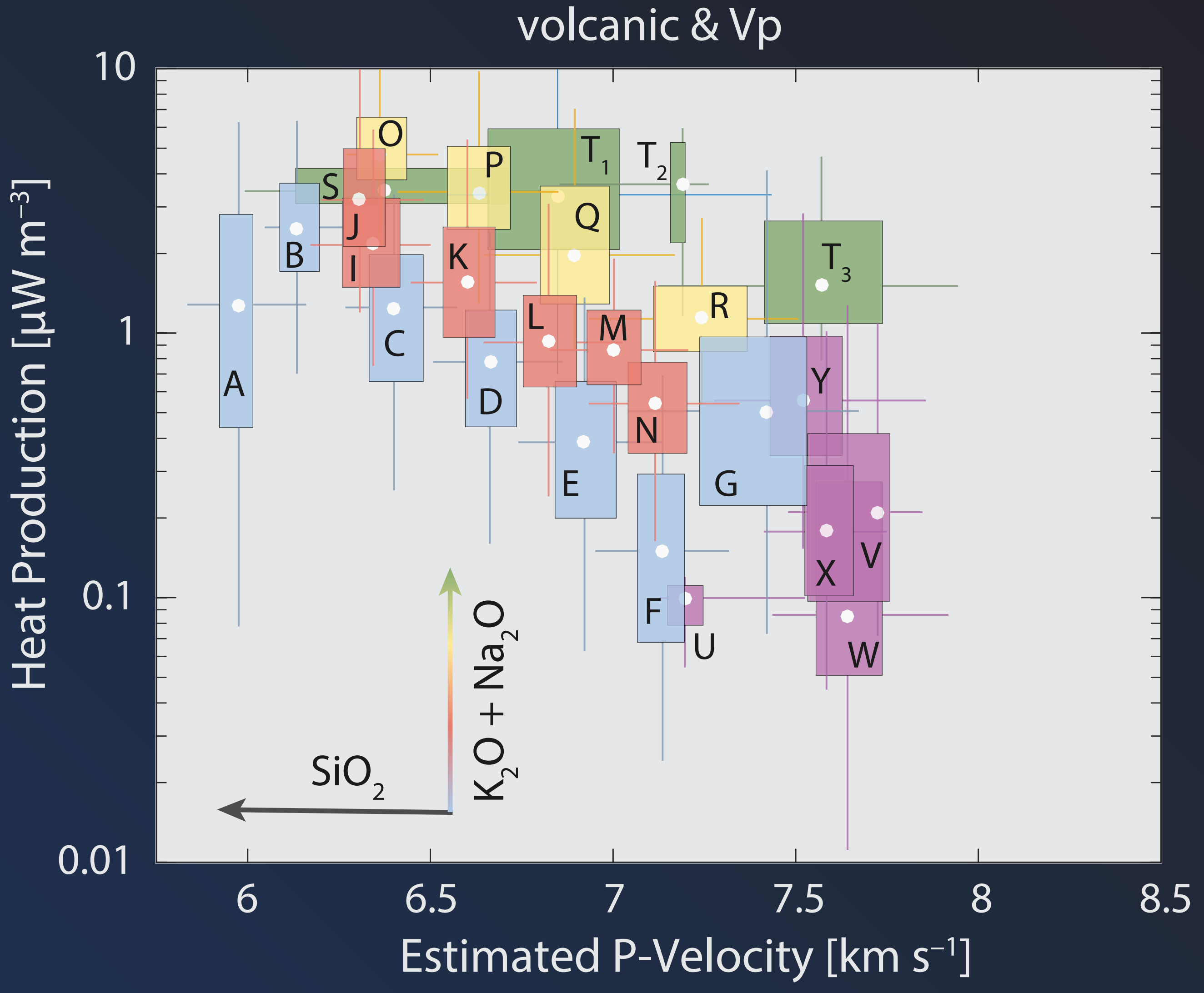




Hasterok & Webb (accepted)

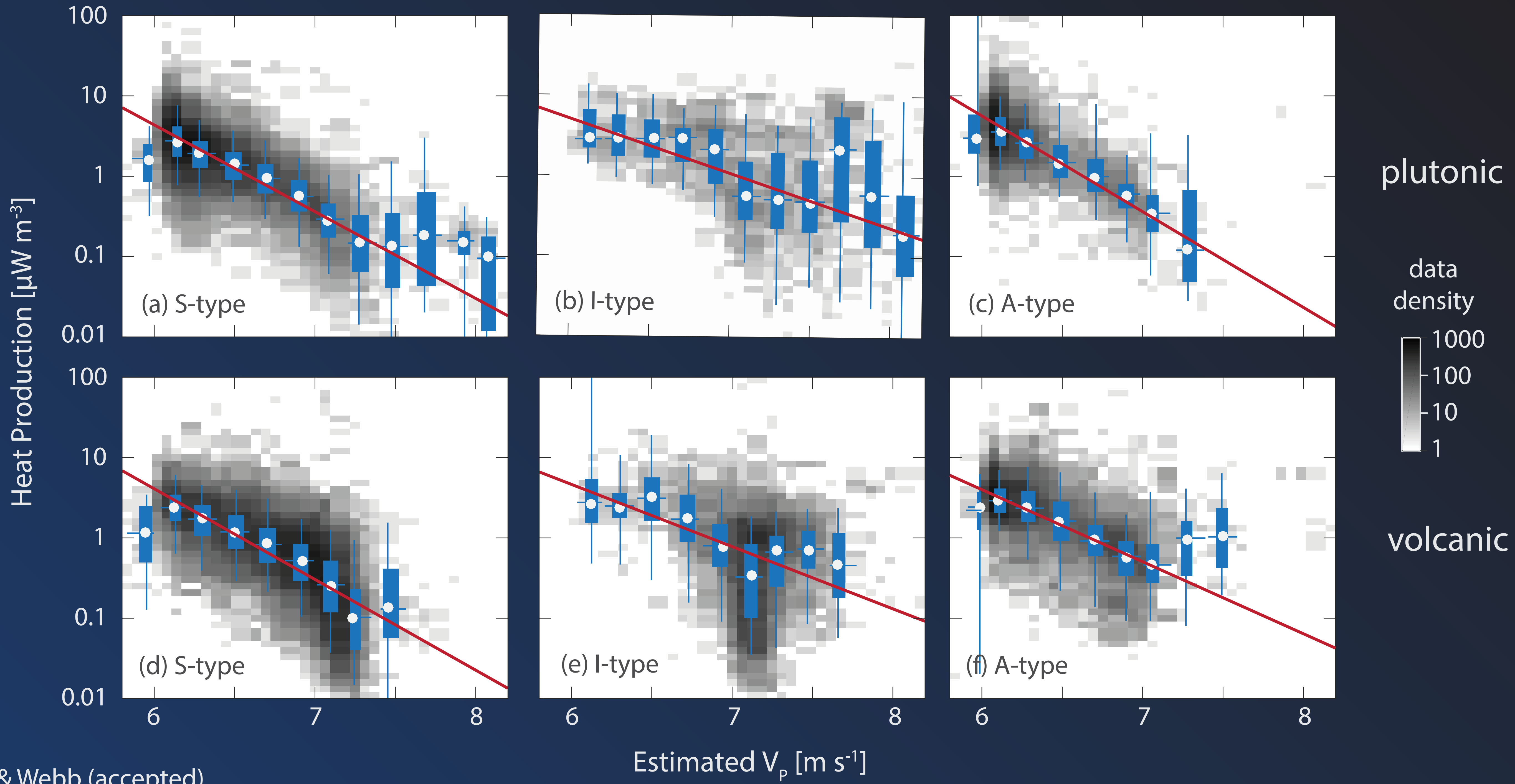
Heat Production Volcanic Rocks





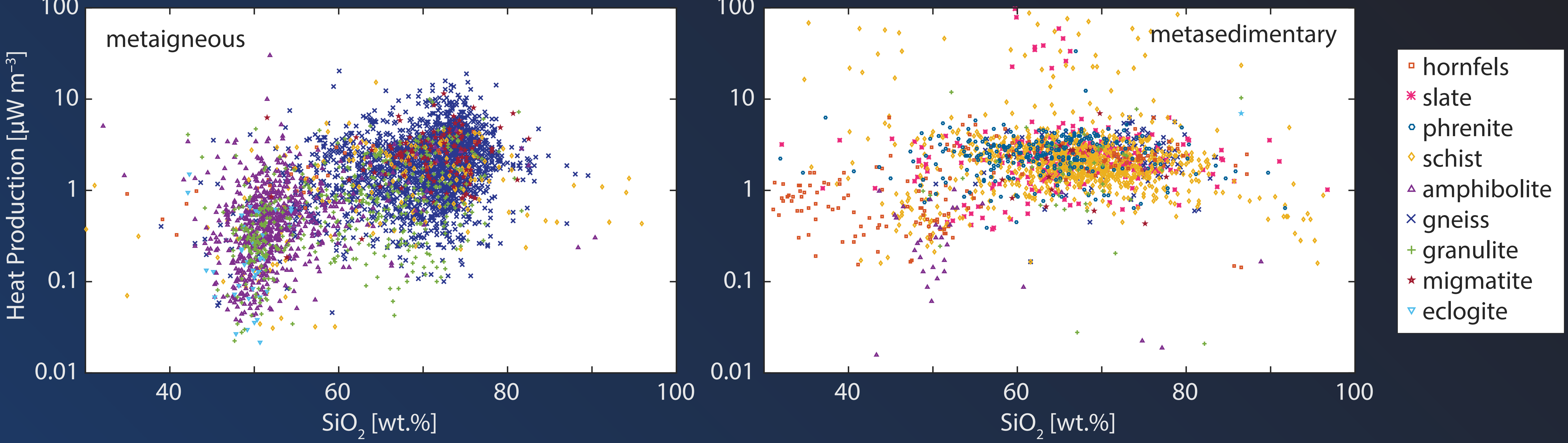
Hasterok & Webb (accepted)

Heat Production Varies by Igneous Type



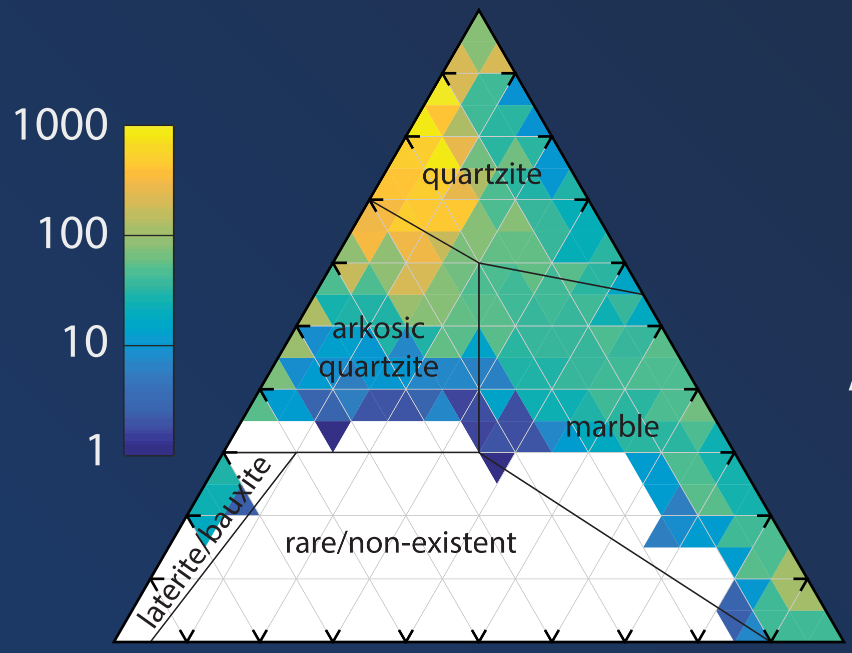
Hasterok & Webb (accepted)

No clear effect of metamorphic grade

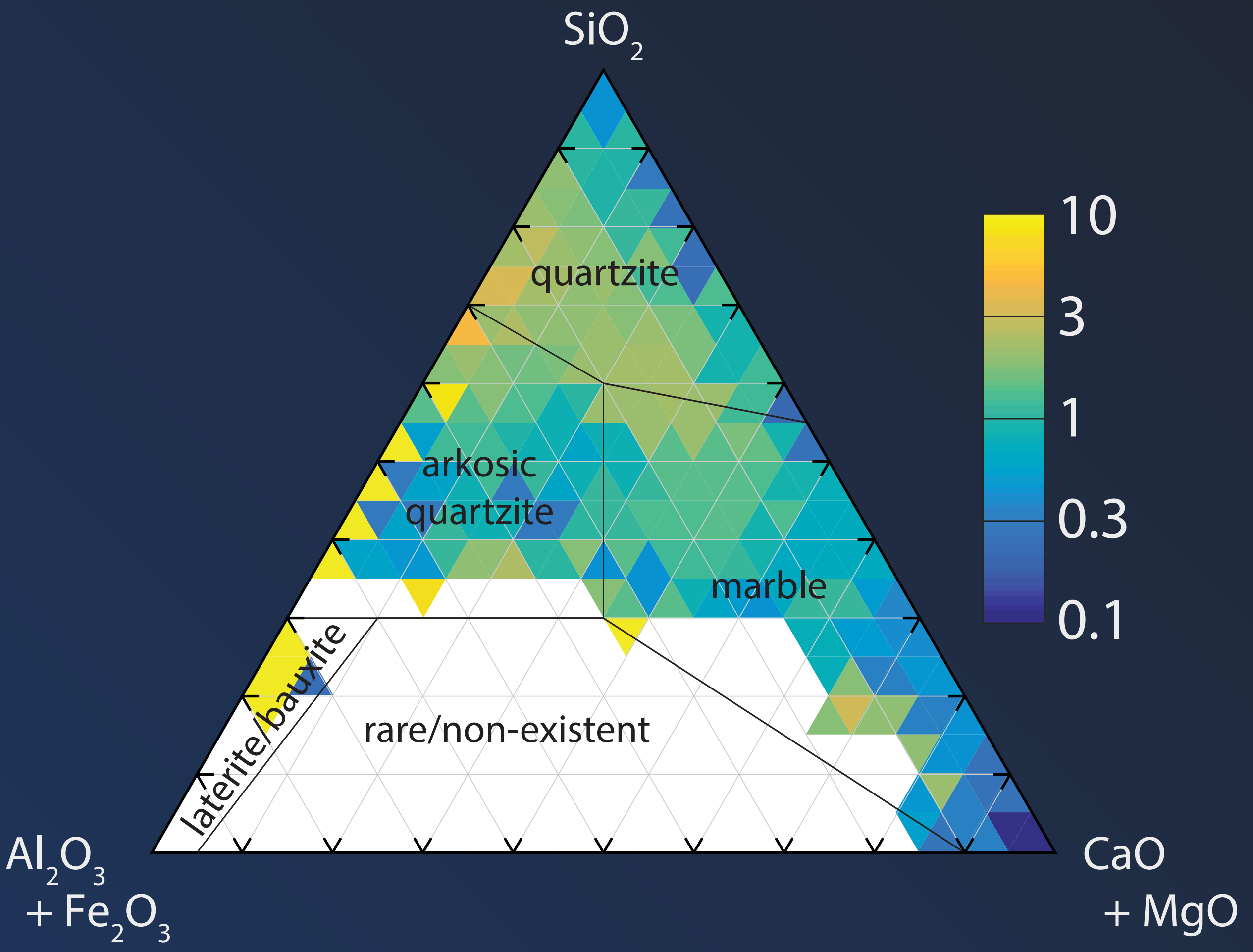


Heat Production of (Meta-)sedimentary Rocks

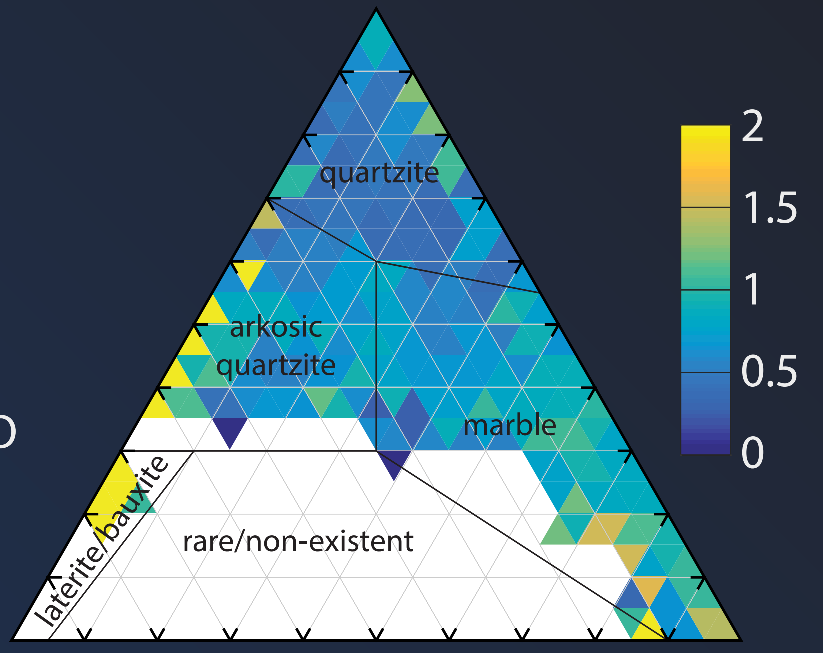
Number of analyses



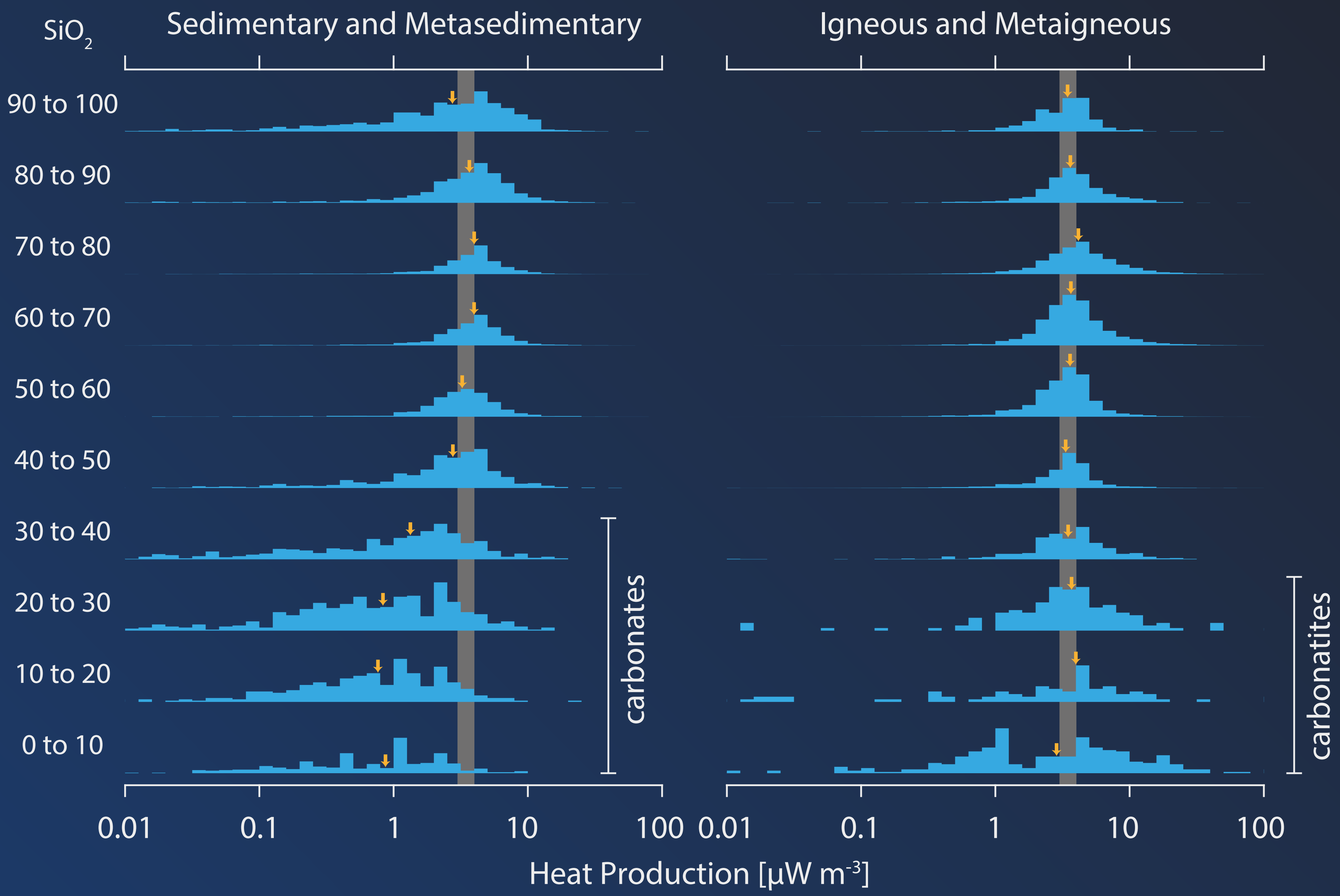
Median Heat Production [μW m^{-3}]



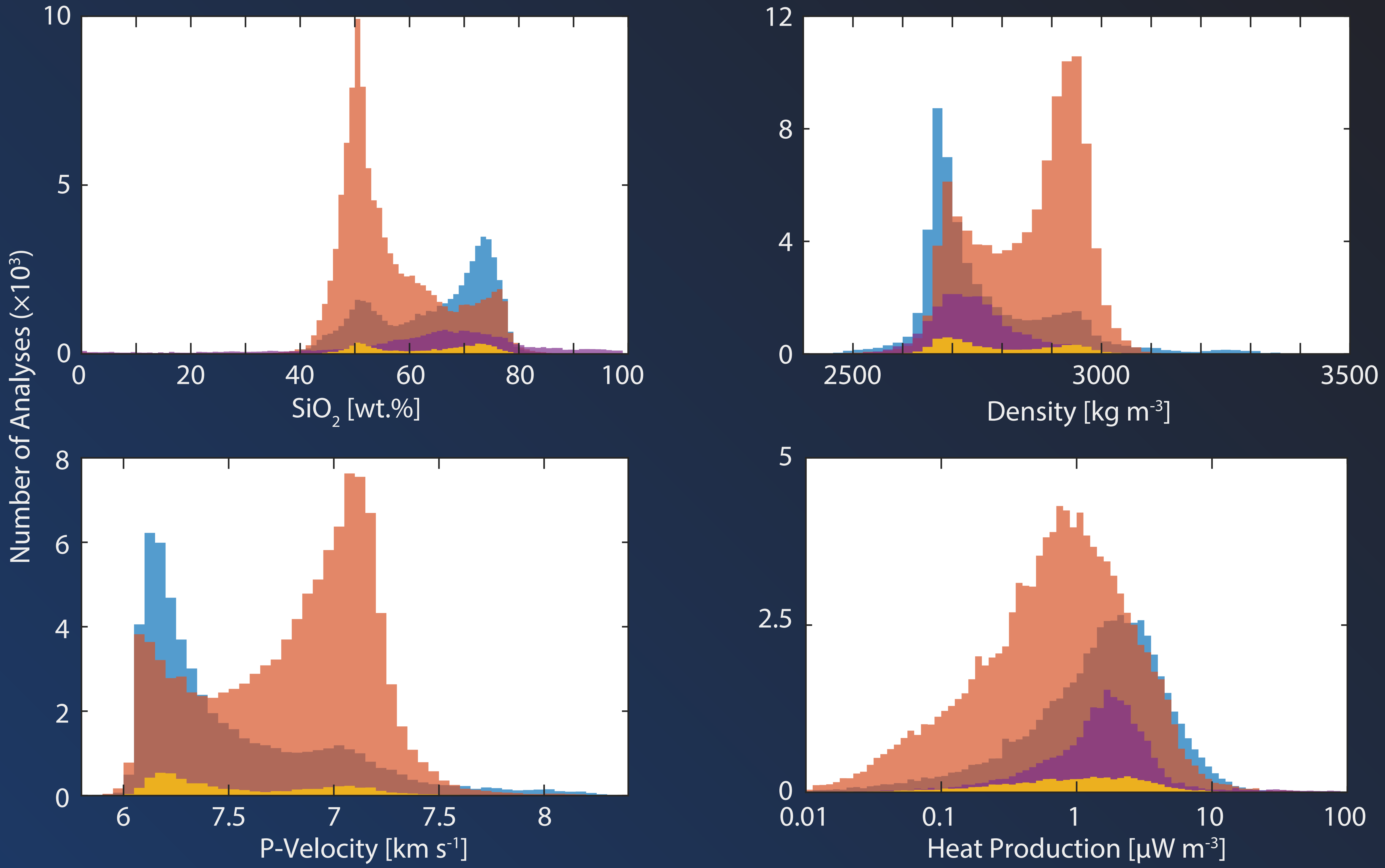
Standard Deviation (log units)



Estimating Th, U

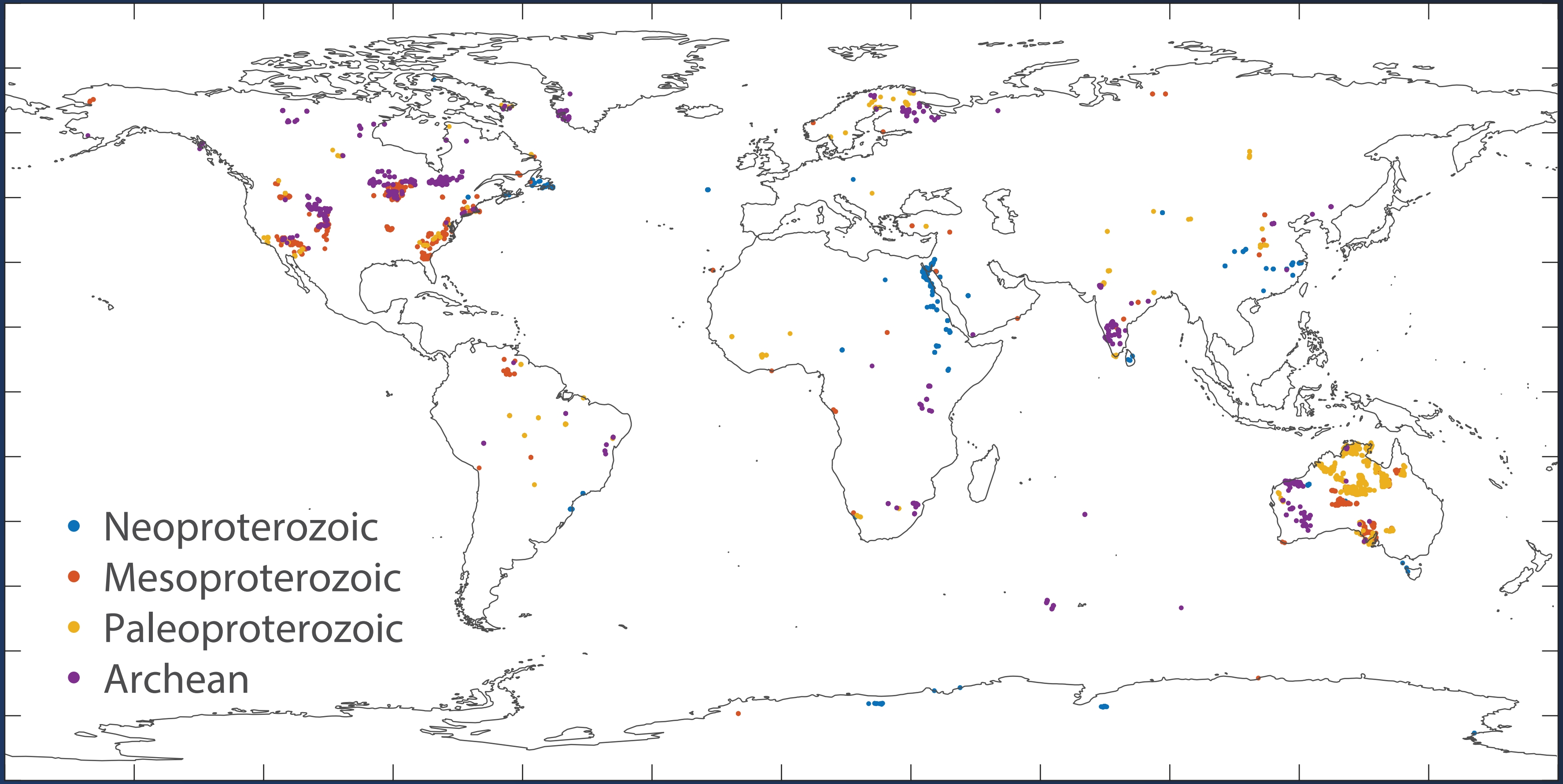


Basic Database Statistics & Derived Properties

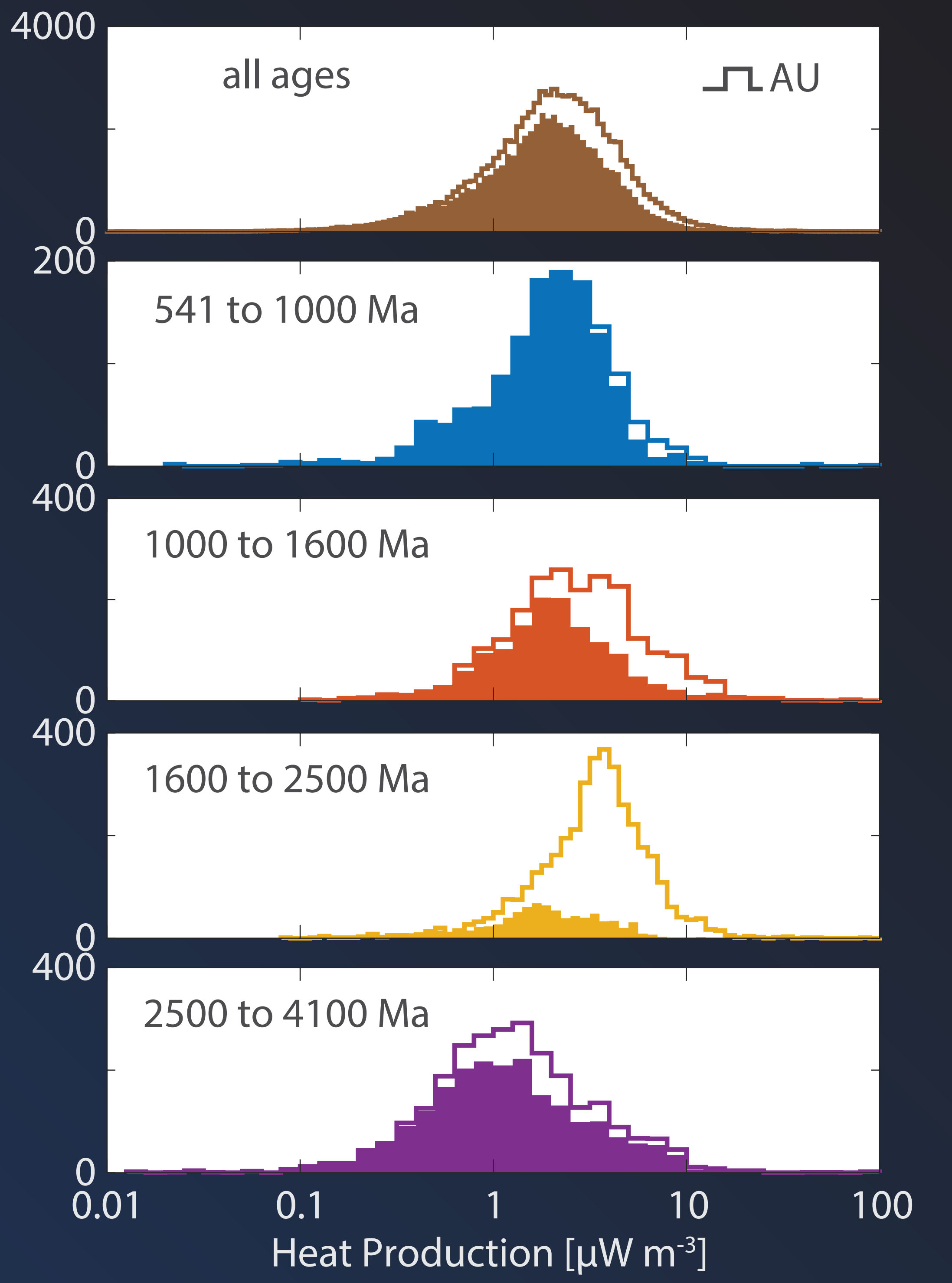


More Evidence for Anomaous Australia

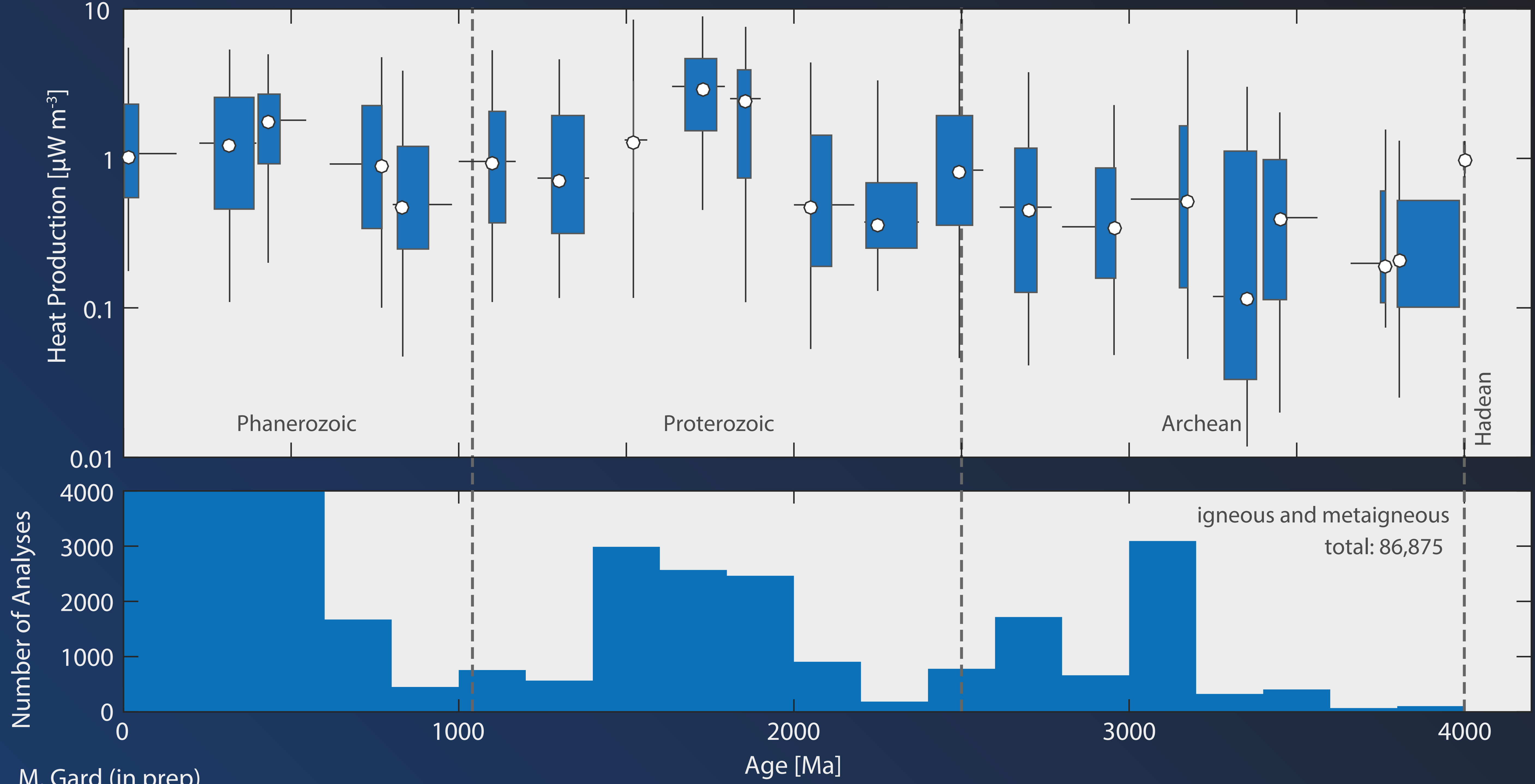
Precambrian Localities



felsic igneous + metaigneous samples, $60 \leq SiO_2 < 82$

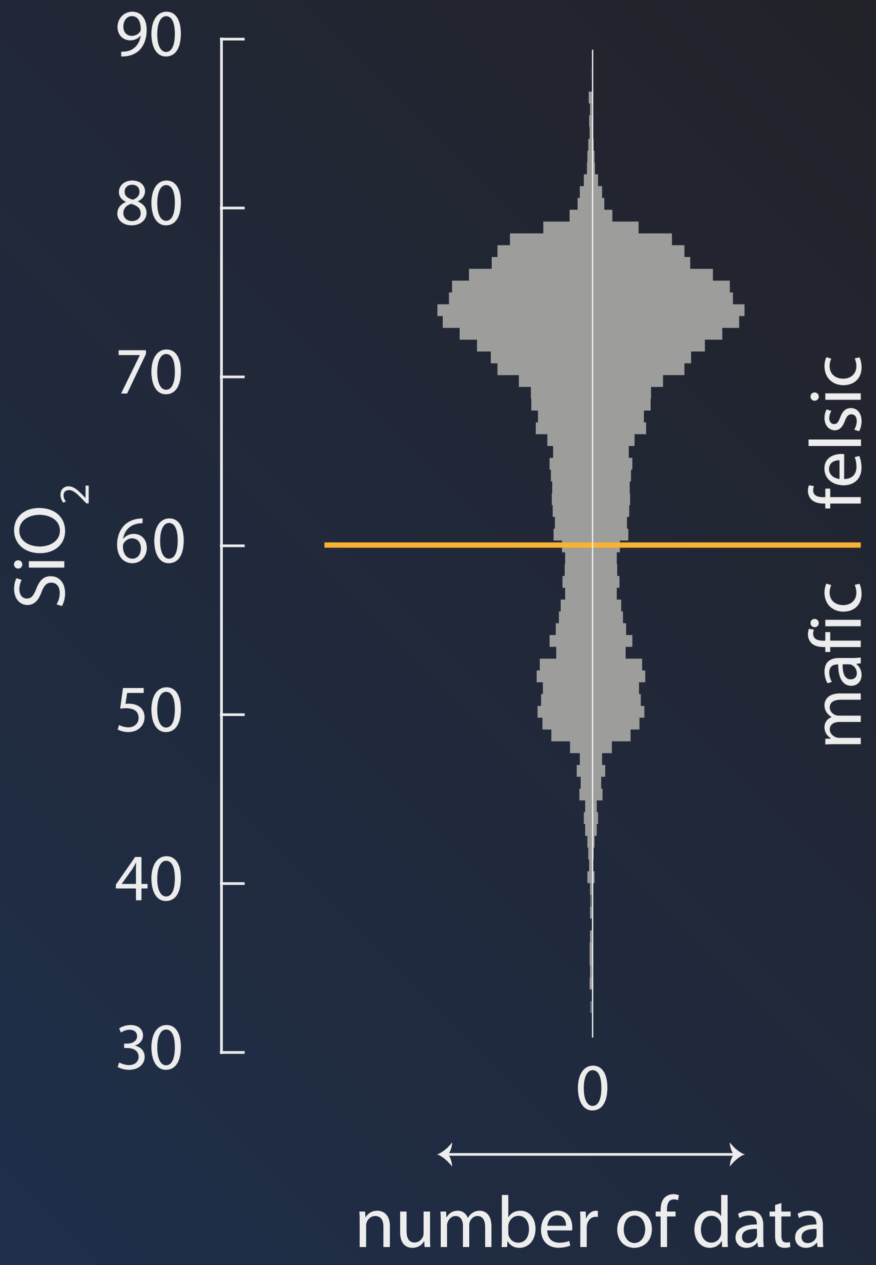


Heat Production Varies Through Time

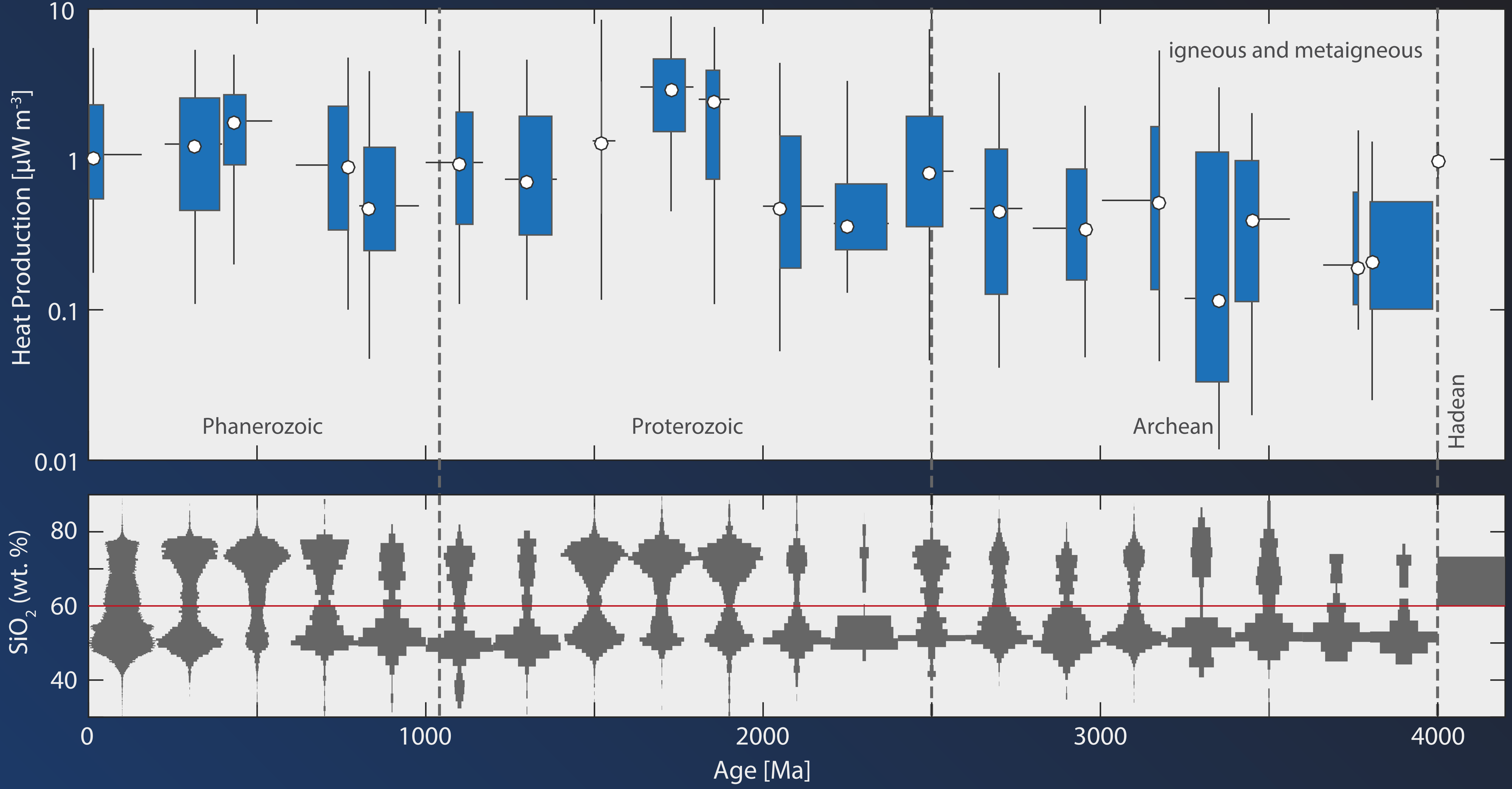


M. Gard (in prep)

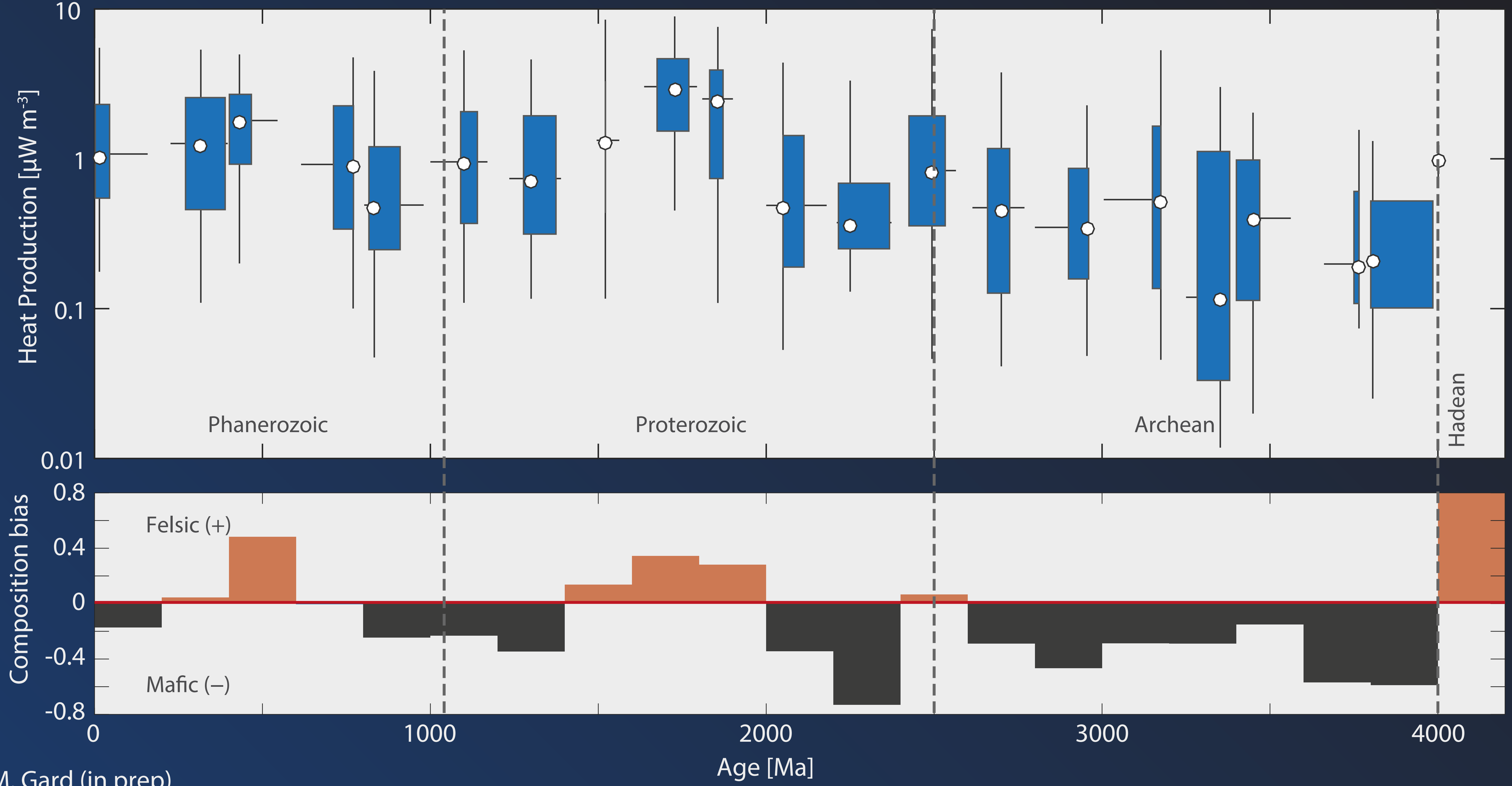
Cloud City Diagrams



A composition bias exists



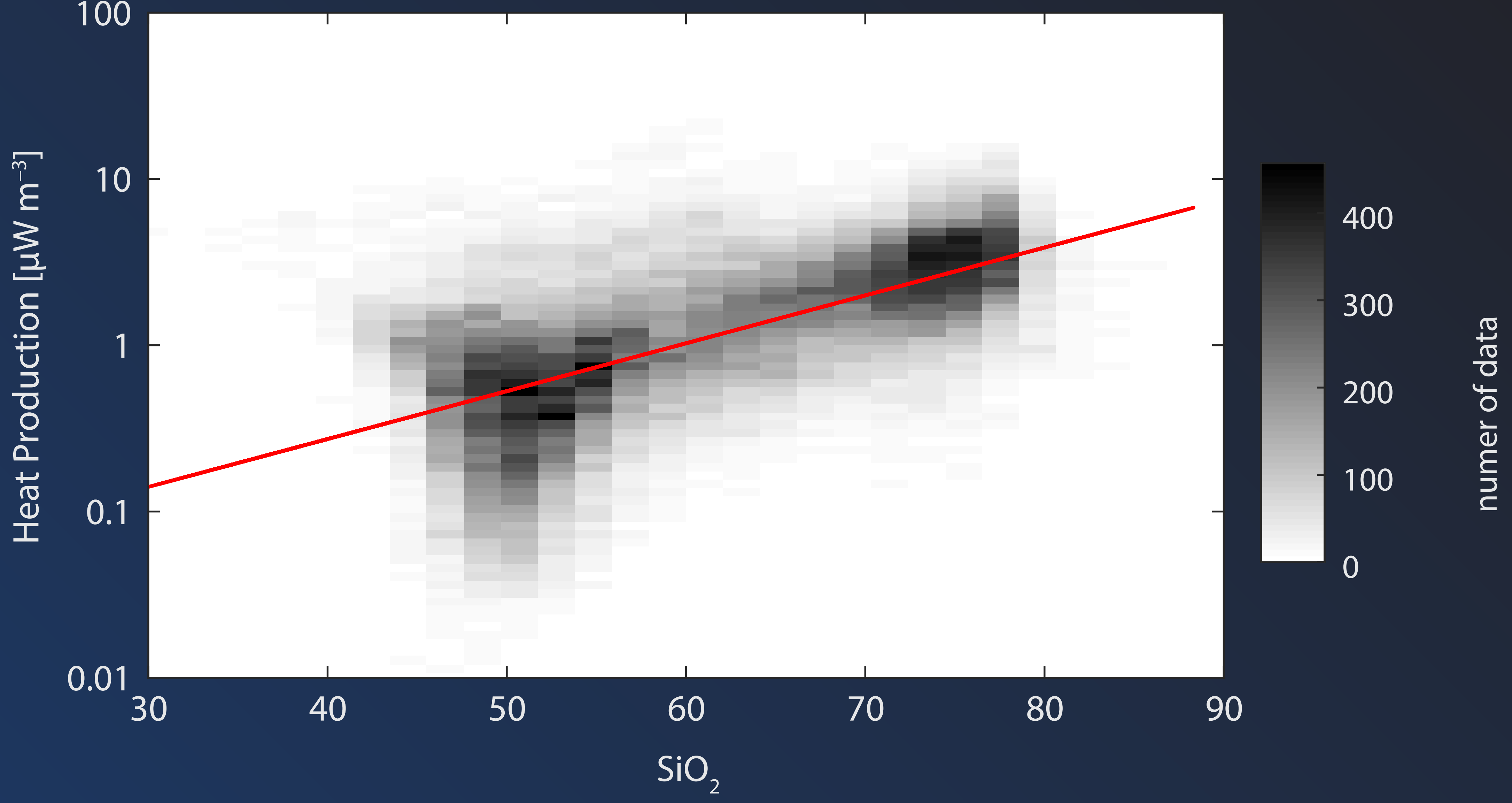
Does Felsic/Mafic Bias Influence HP?



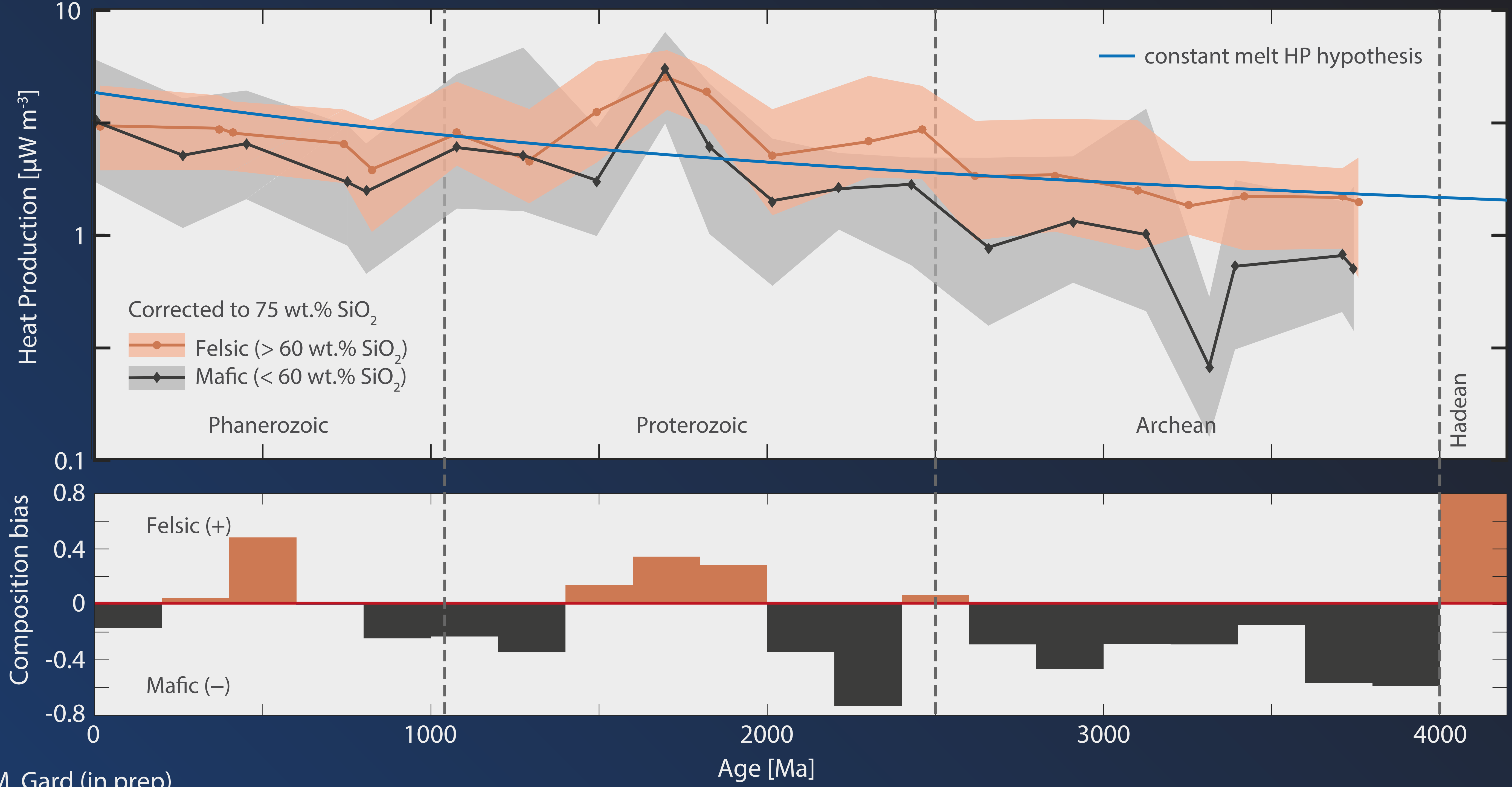
M. Gard (in prep)

SiO_2 Correction to Heat Production

$\log_{10}(A, \mu W\ m^{-3}) = 0.0288\ SiO_2(wt.\%) - 1.716$

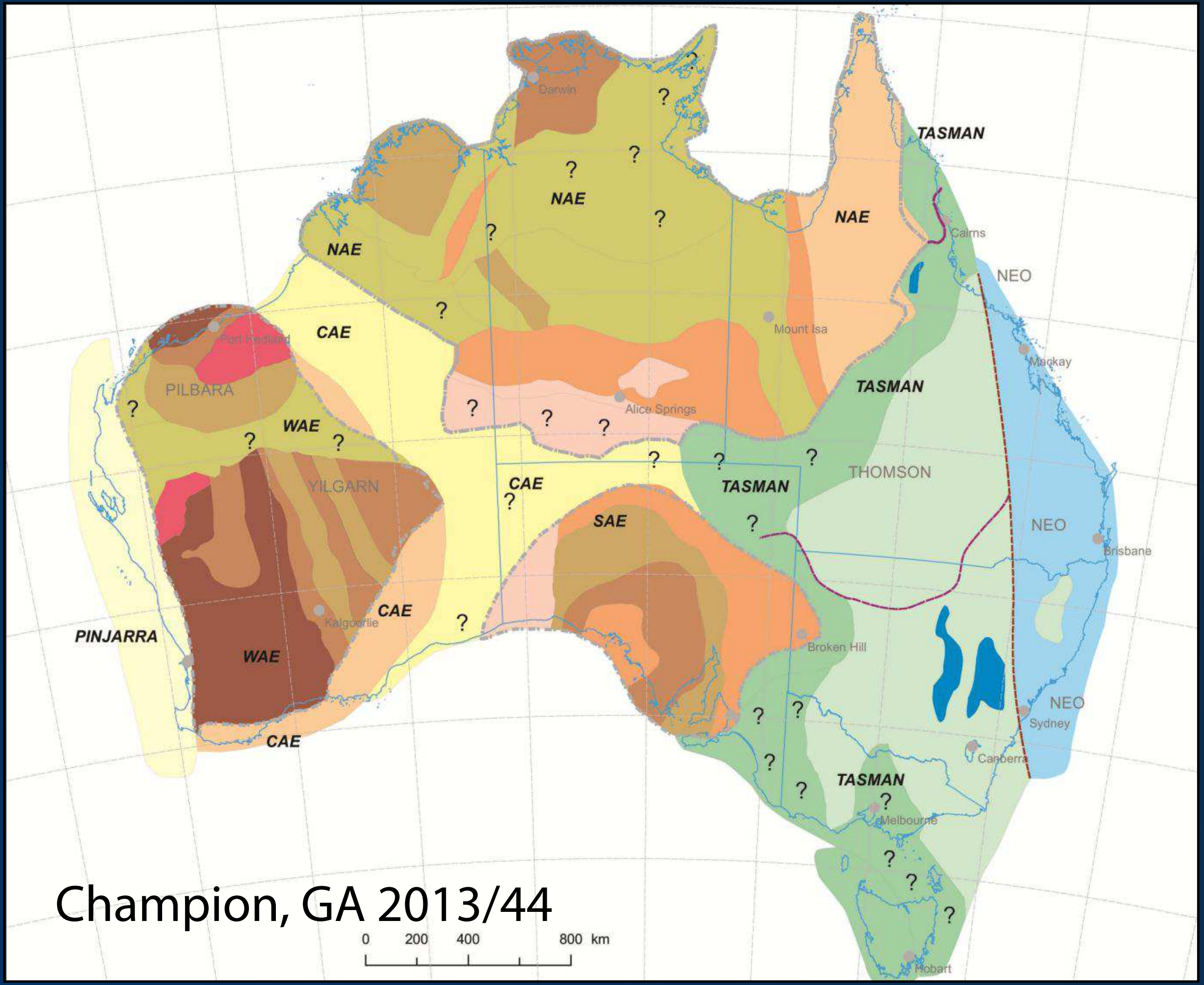


Heat Production Accounting for SiO_2 Content

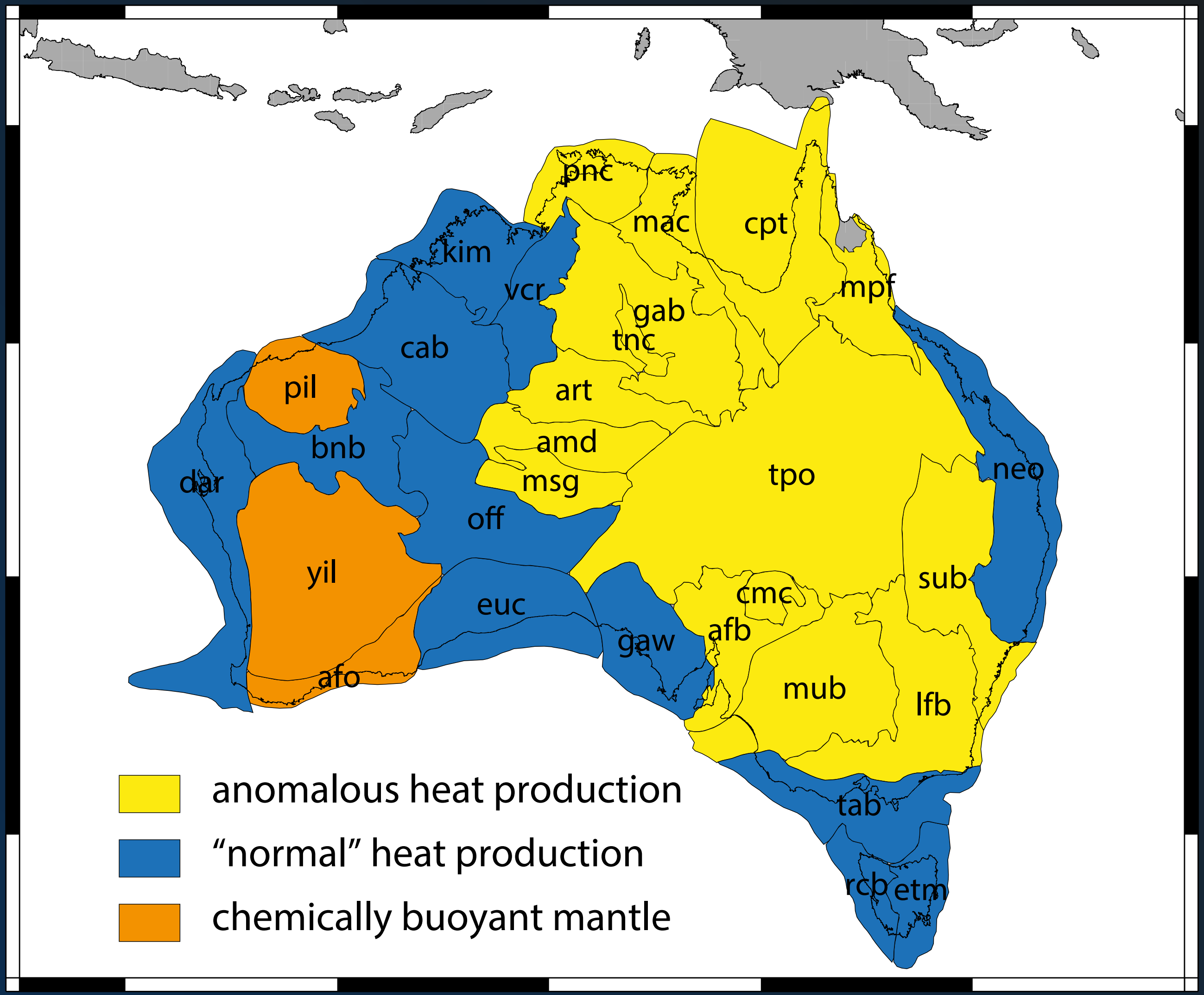


M. Gard (in prep)

Lithospheric Age



Champion, GA 2013/44



Inferred Basement
Paleozoic - Mesozoic
Ordivician (early Silurian)
(Neoproterozoic -) Paleozoic
Neoproterozoic - Paleozoic

Mesoproterozoic - Paleozoic
Meso - Neoproterozoic
Paleo - Mesoproterozoic
Archean(?) - Mesoproterozoic
Paleoproterozoic

Archean(?) - Paleoproterozoic
Neoarchean
Meso - Neoarchean
Mesoarchean
Paleo - Mesoarchean