Widespread enigmatic continental exhumation revealed by deep-time thermochronology

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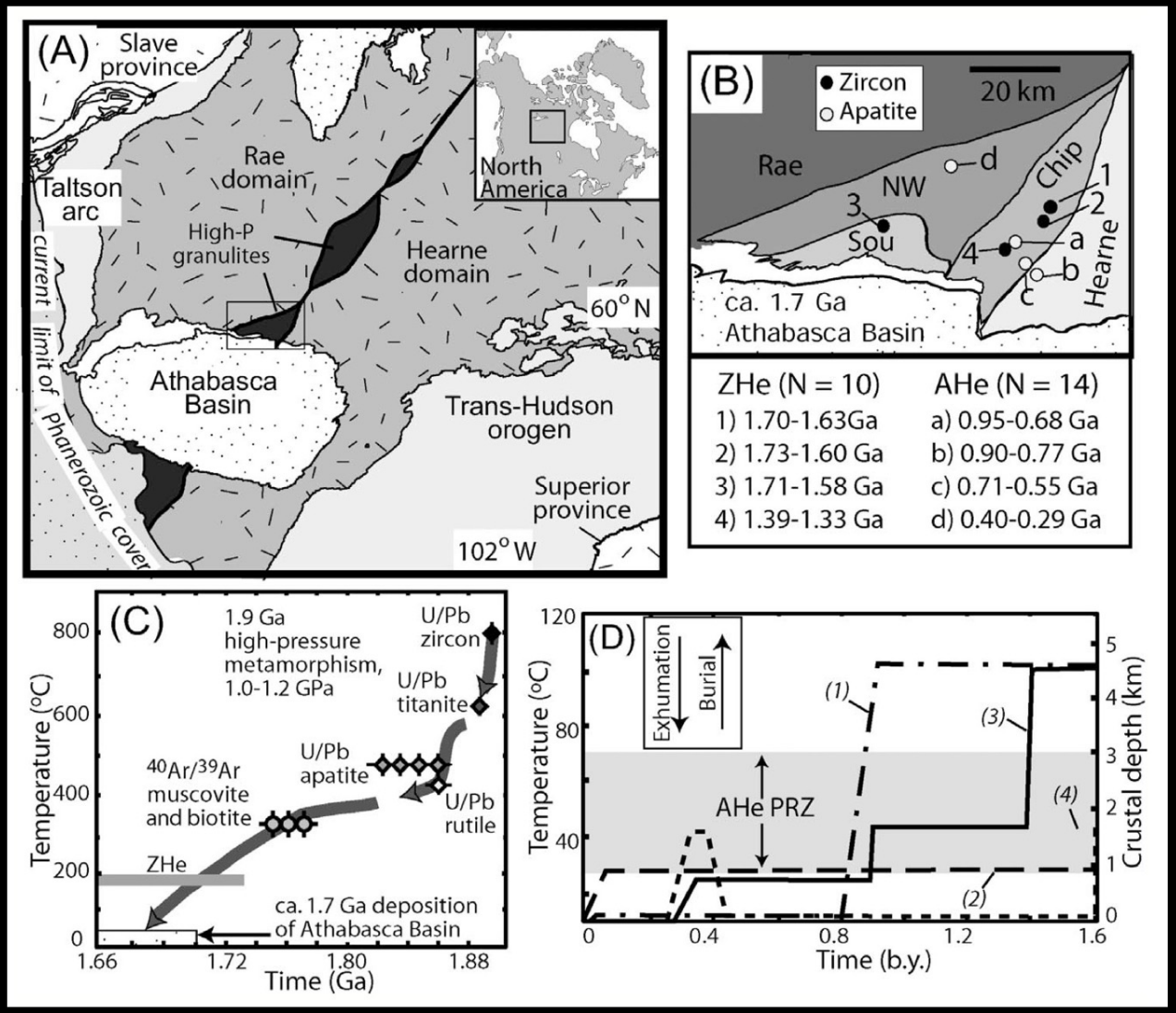
Thermo2018

Why deep-time thermochronology?

Deep-time thermochronology



Flowers et al., 2006, Geology, 34: 925-928

AHe age of 500 to 900 Ma

Exciting: stability!

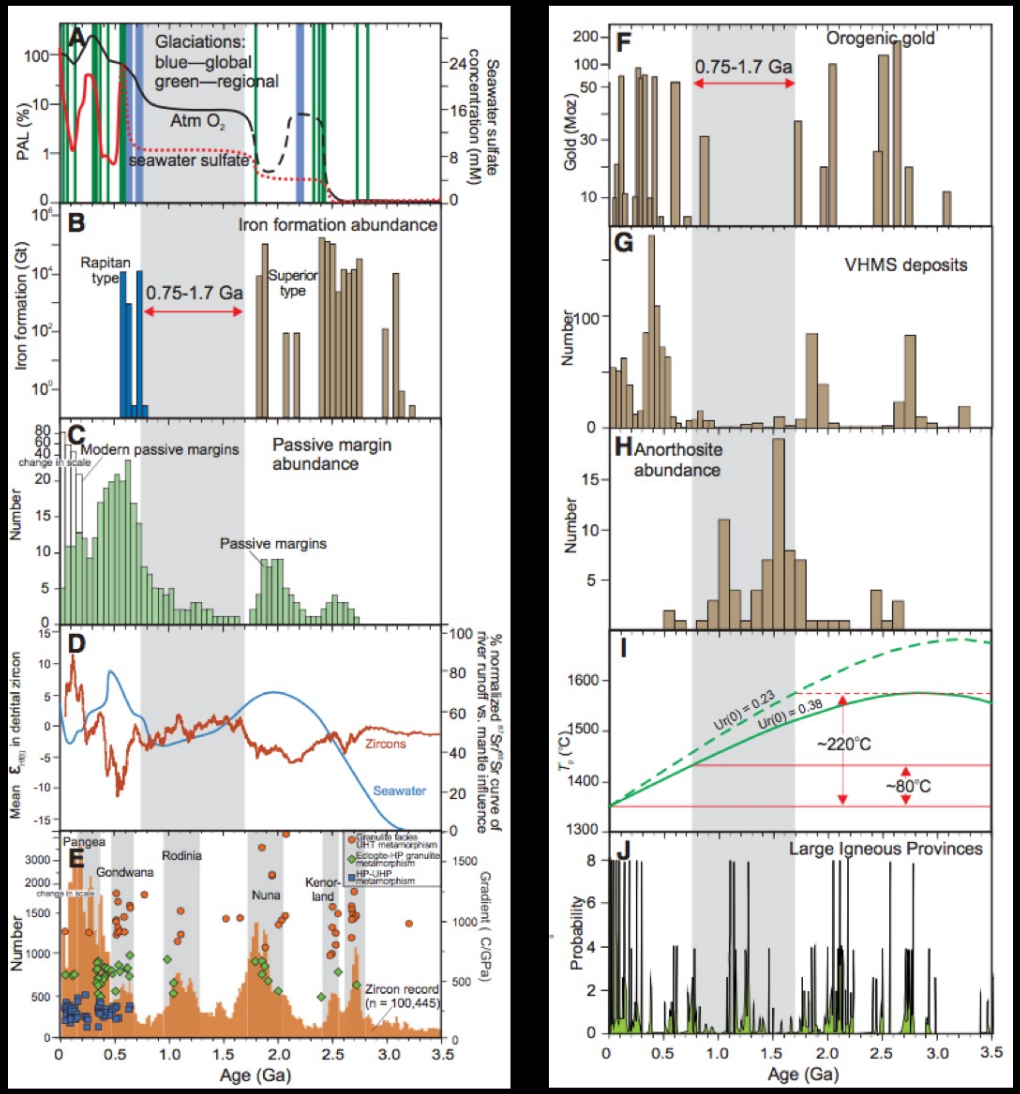
< 50°C and < 2 km burial for past 500 to 1000 m.y.

Ages would not survive greater burial or erosion

Boring Billion…Dullest Time on Earth…Barren Billion…Earth's Middle Age

Was much of the Proterozoic inherently dull, a time of environmental, evolutionary, and lithospheric stability?

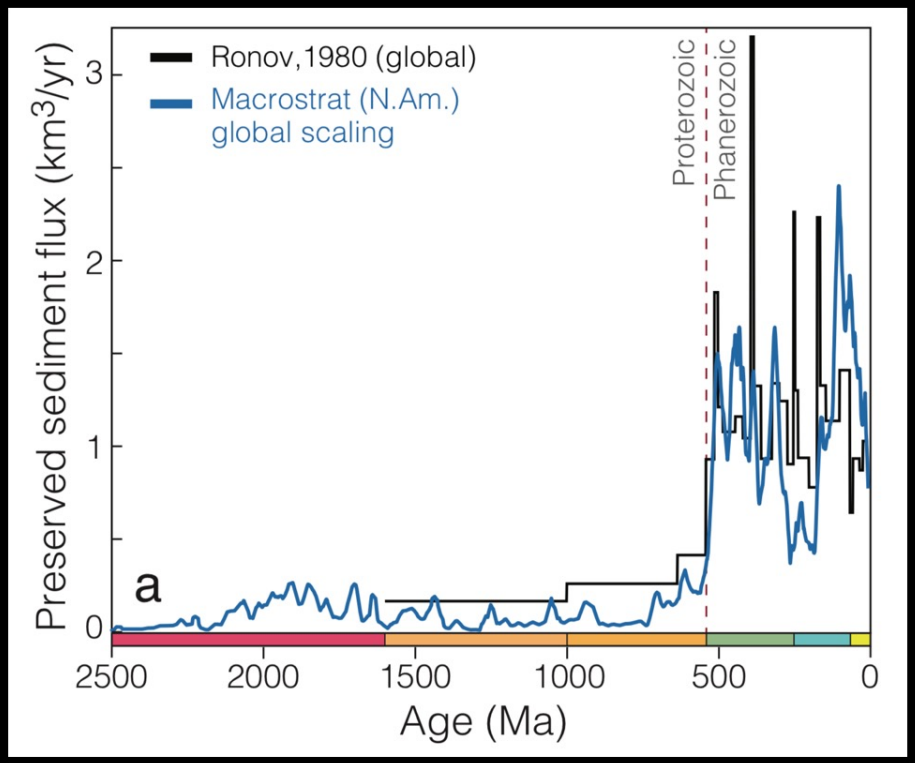
Or was it more dynamic than realized, and we're just not reading the right records?



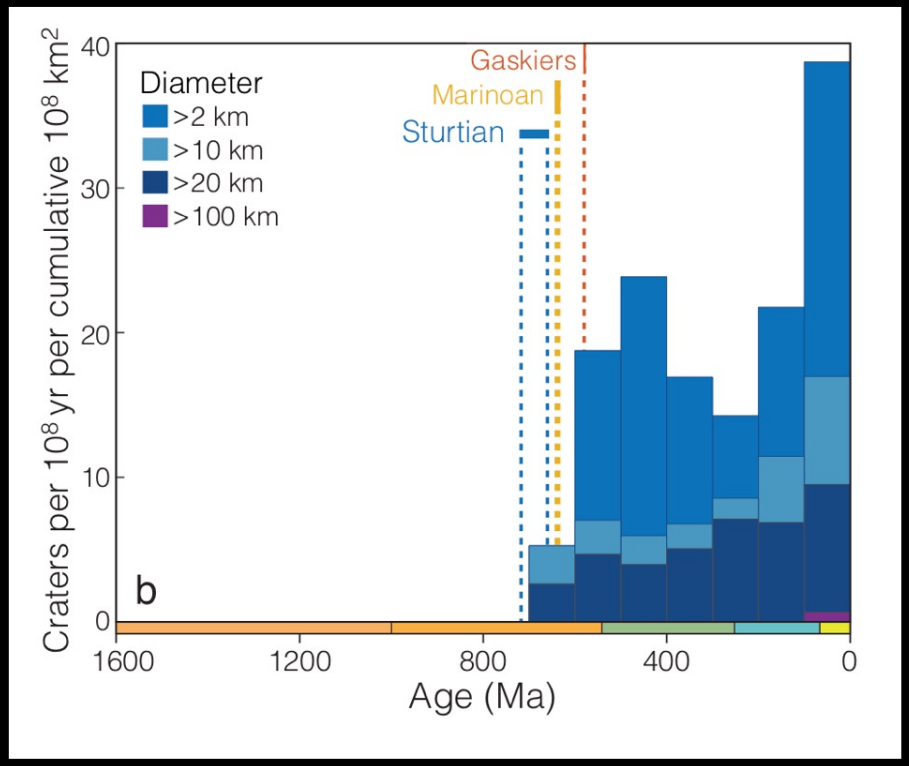
Cawood and Hawkesworth, 2014

Issues with the geologic record

Brenhin Keller et al., in revision, PNAS



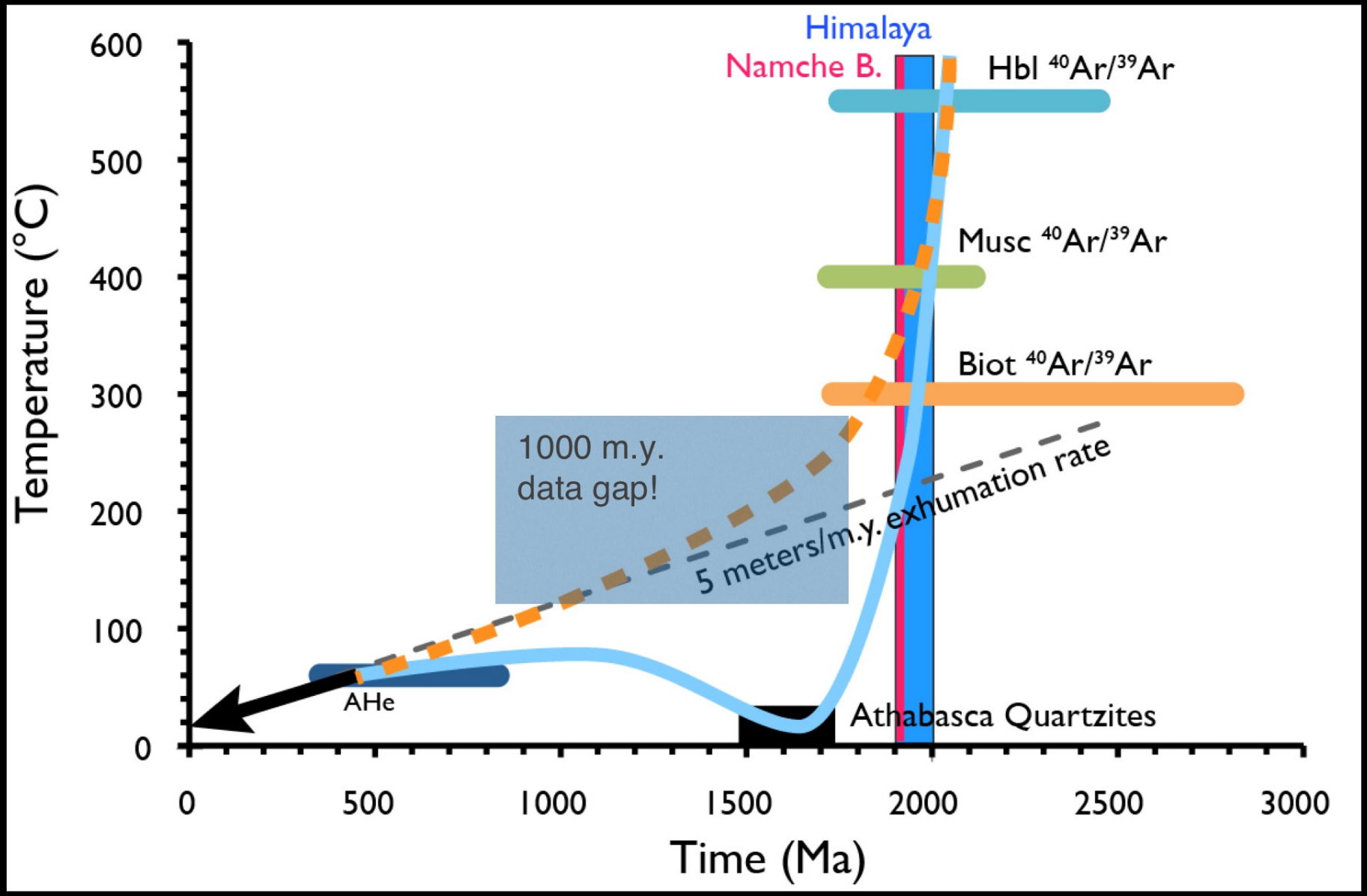
preserved record of sediment flux



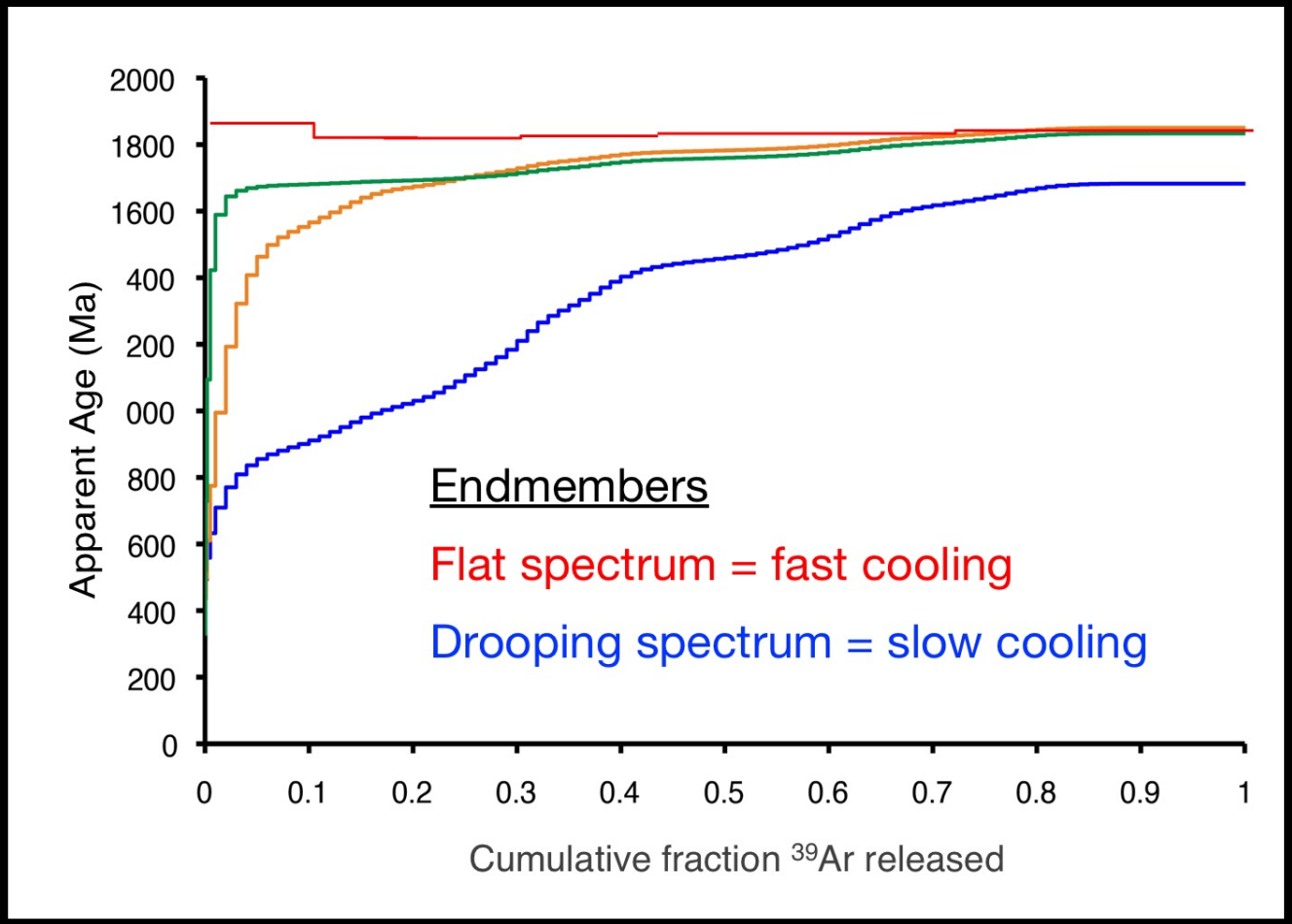
apparent impact cratering rate per unit area

For parts of many cratons, prior stability has been inferred more from a <u>lack</u> of direct stratigraphic and geochronological evidence, leaving an observational gap exceeding a billion years

A closer look at Proterozoic age patterns



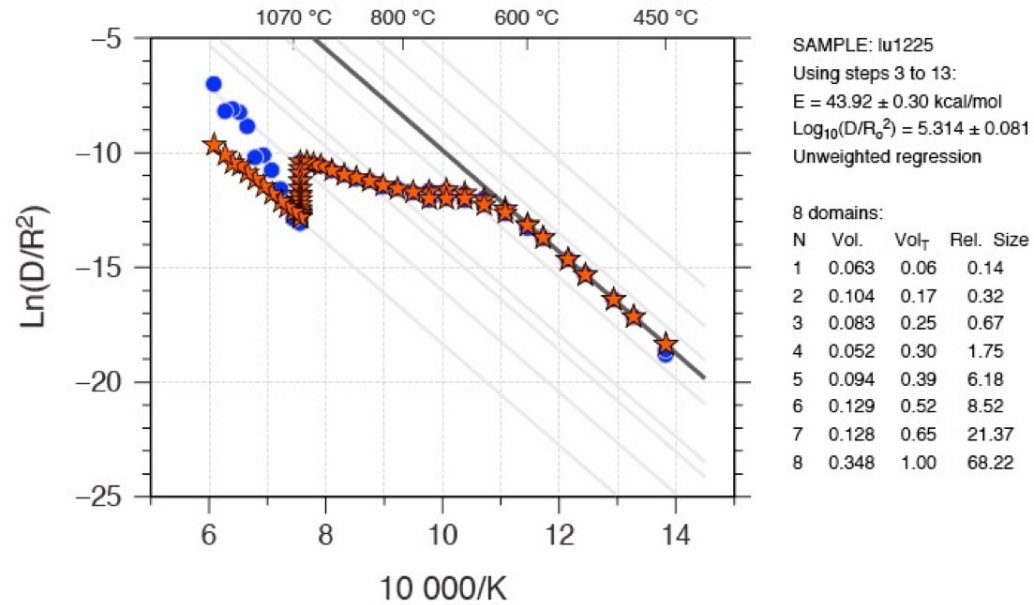
$^{40}Ar/^{39}Ar$ basics – K-feldspar age spectra

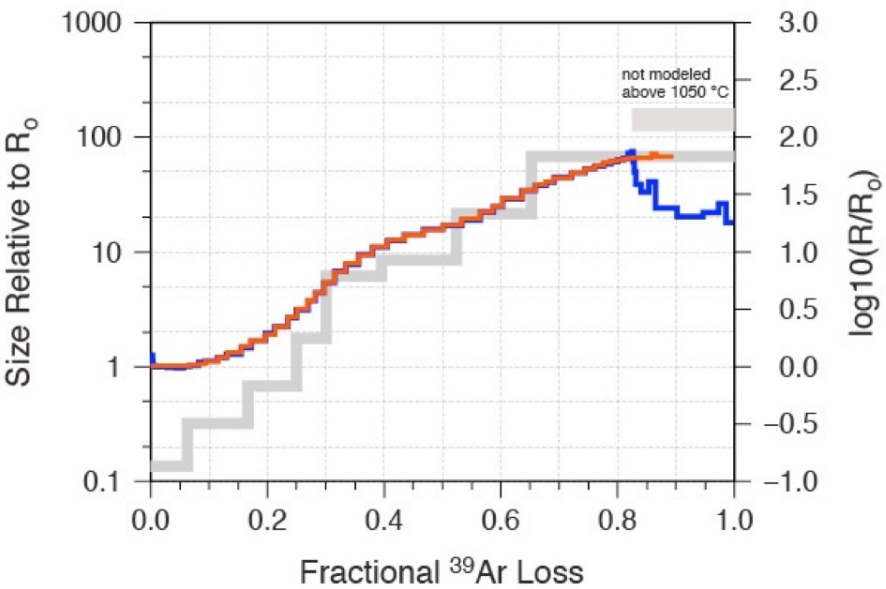


Age-spectrum shape can qualitatively distinguish between different cooling histories

This can also be quantified.

$^{40}Ar/^{39}Ar$ basics – K-feldspar kinetics

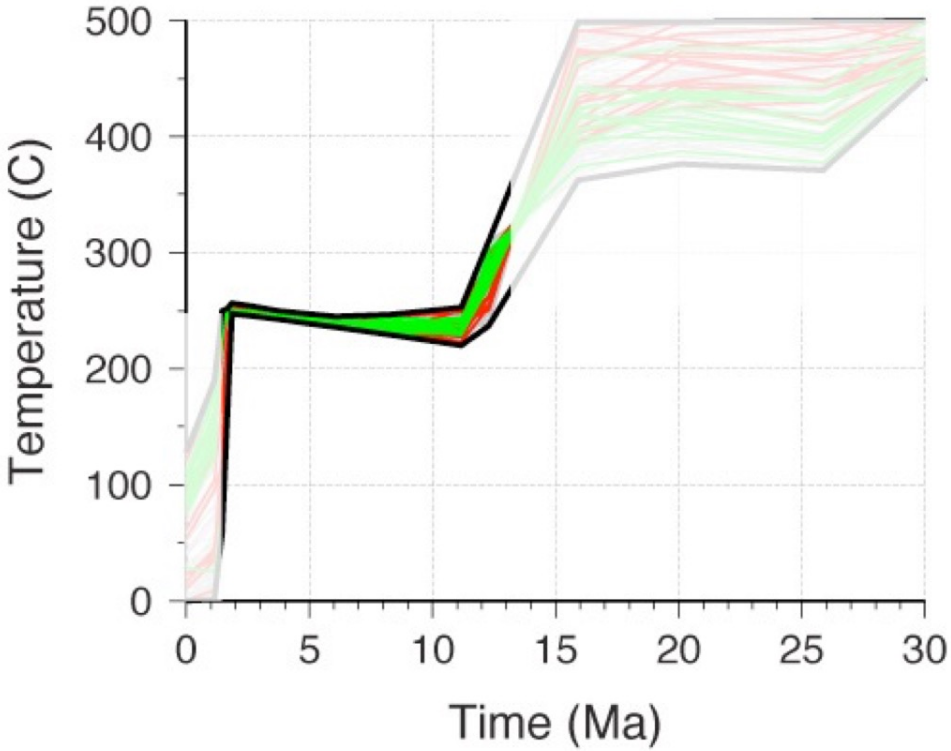


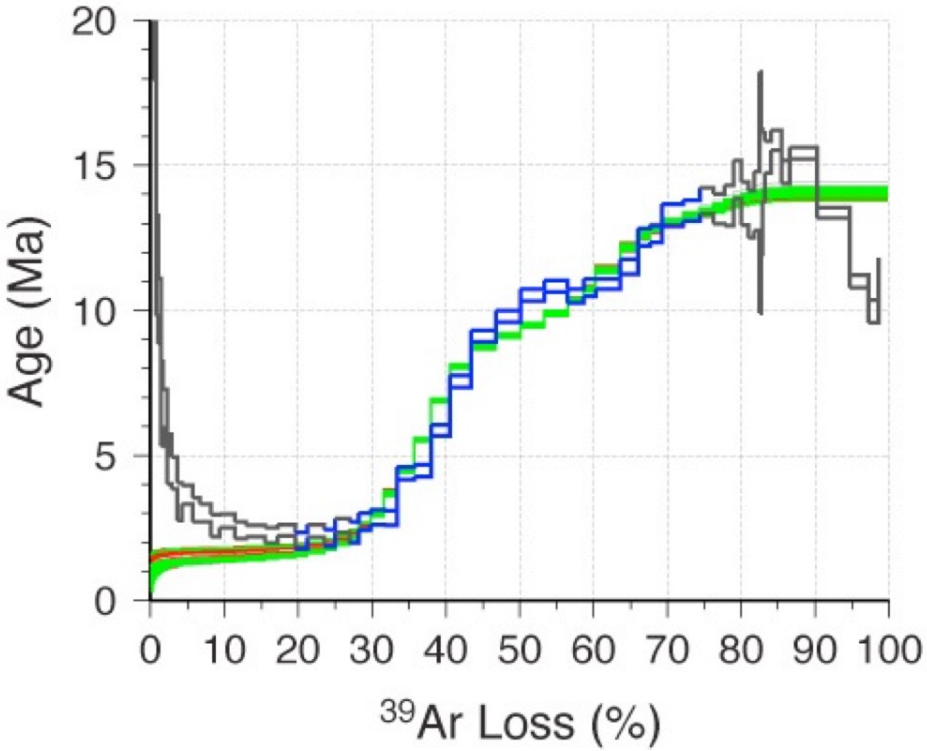


Release of ^{39}Ar during step-heating permits us to measure both:

- diffusion kinetics
- diffusion-domain structure
- this is essence of the MDD model

Finally, inversion for continuous thermal history



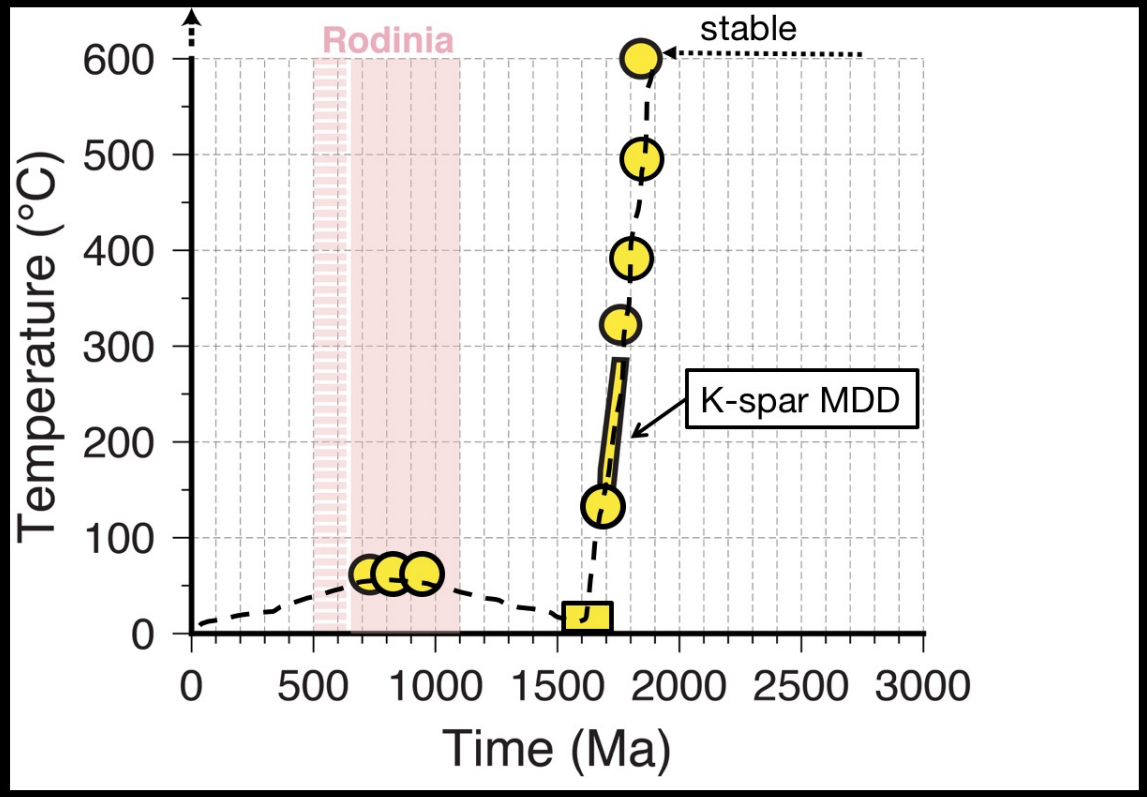


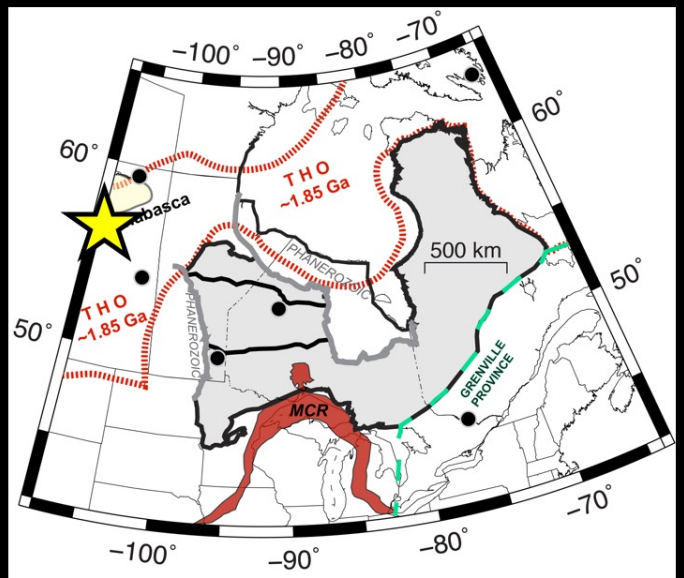
Only unknown is thermal history, so we can invert for this using **sample-specific** kinetics

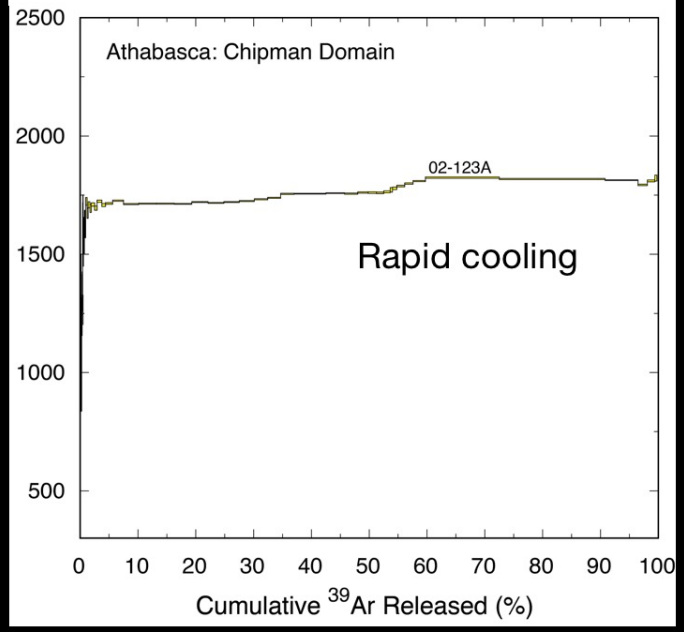
100 to 200˚C recorded, from ~150 to 300˚C, depending on sample

K-feldspar MDD data, Canadian craton: Athabasca test – old rocks work

Inversion of K-feldspar data matches constraints from other thermochronometers

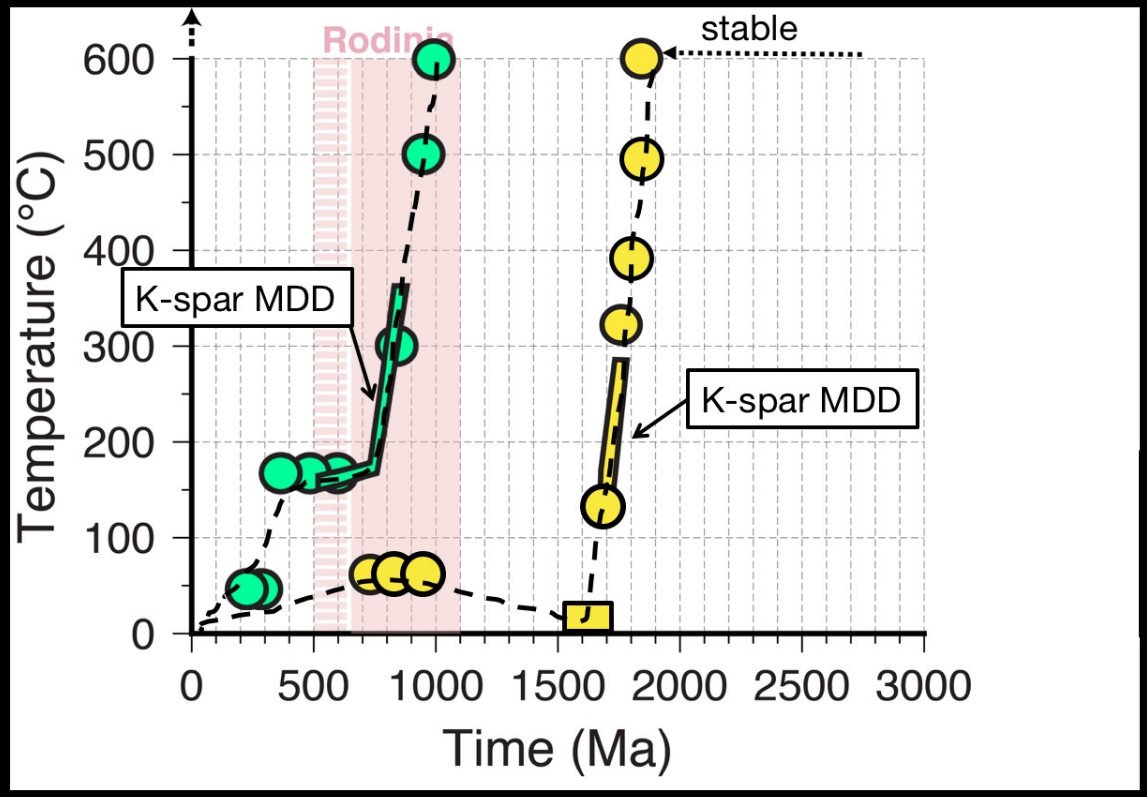


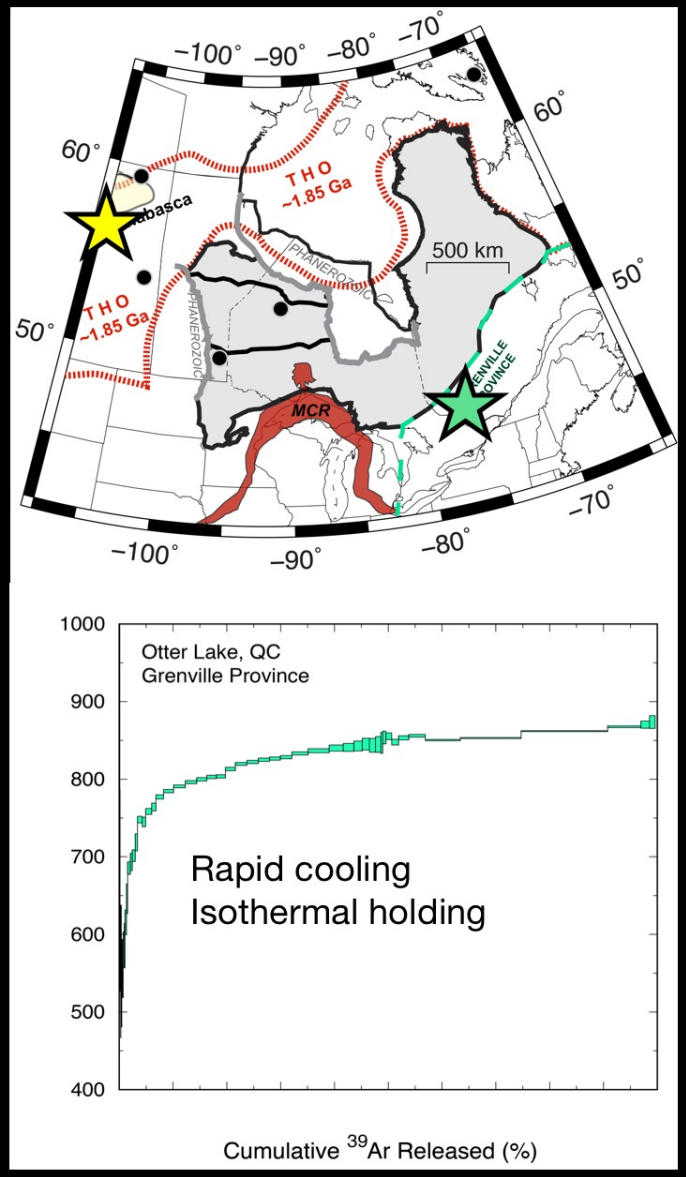




K-feldspar MDD data, Canadian craton: Grenville test – old rocks work

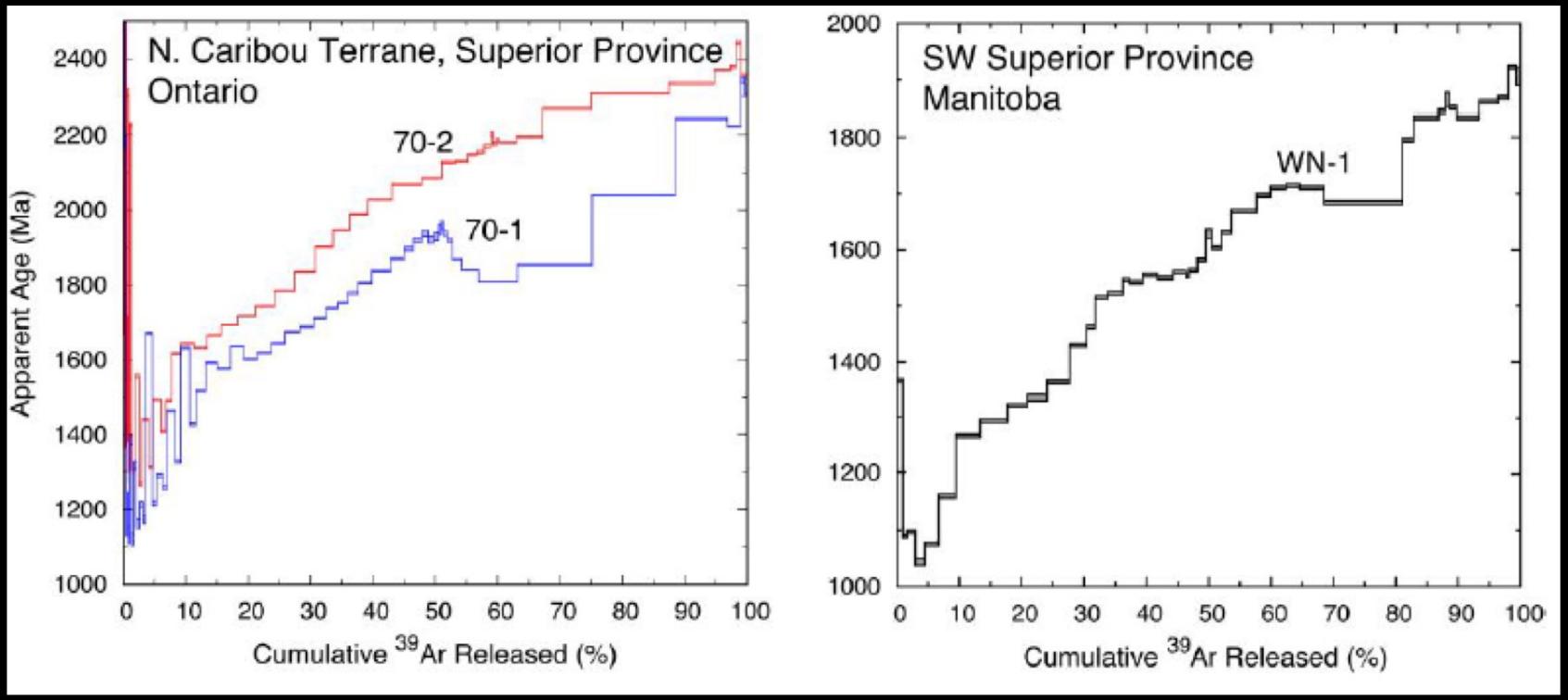
Inversion of K-feldspar data matches constraints from other thermochronometers





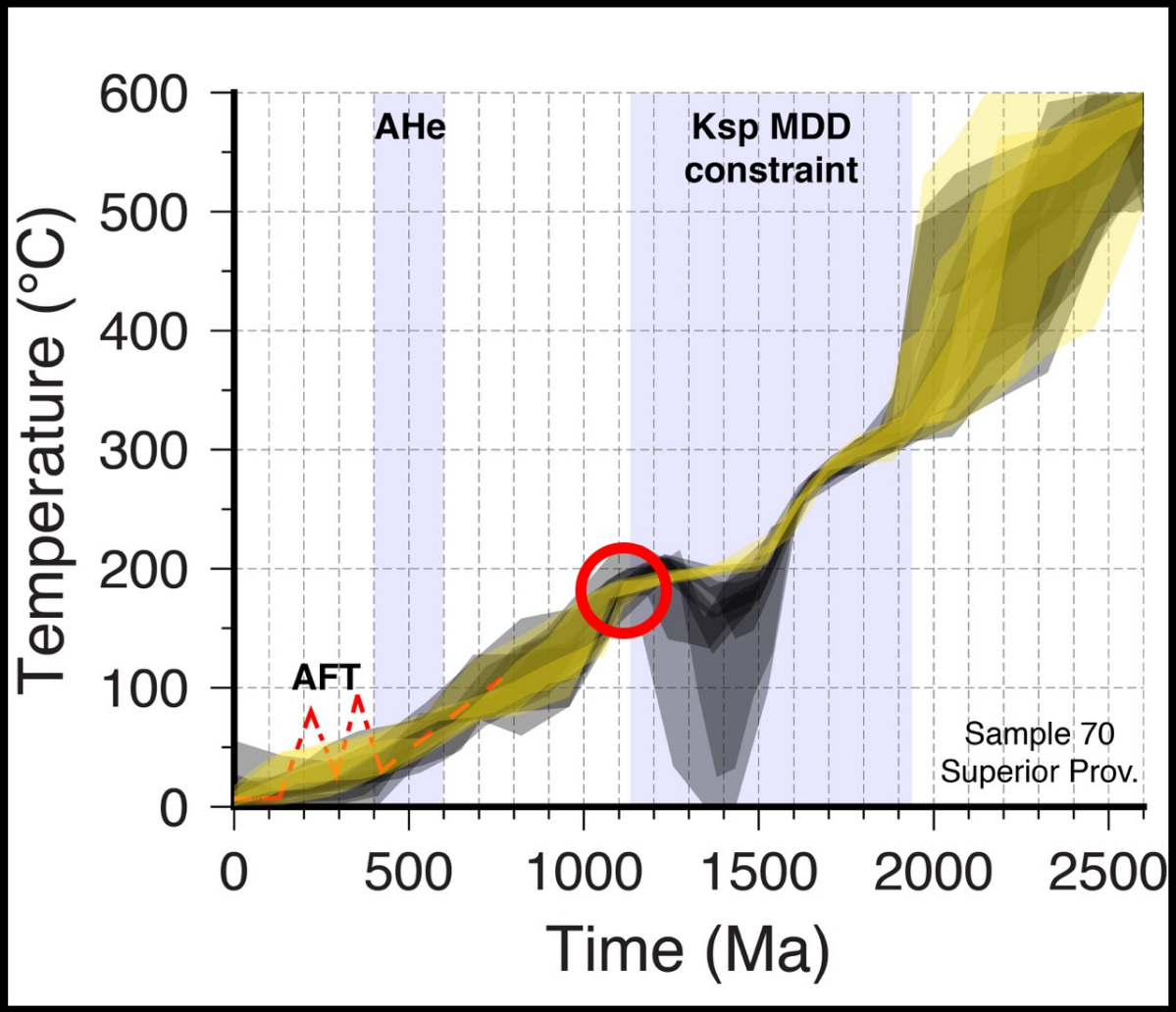
K-feldspar MDD data, Canadian craton: western Superior Province

Age gradients of 800 to 1000 Ma!

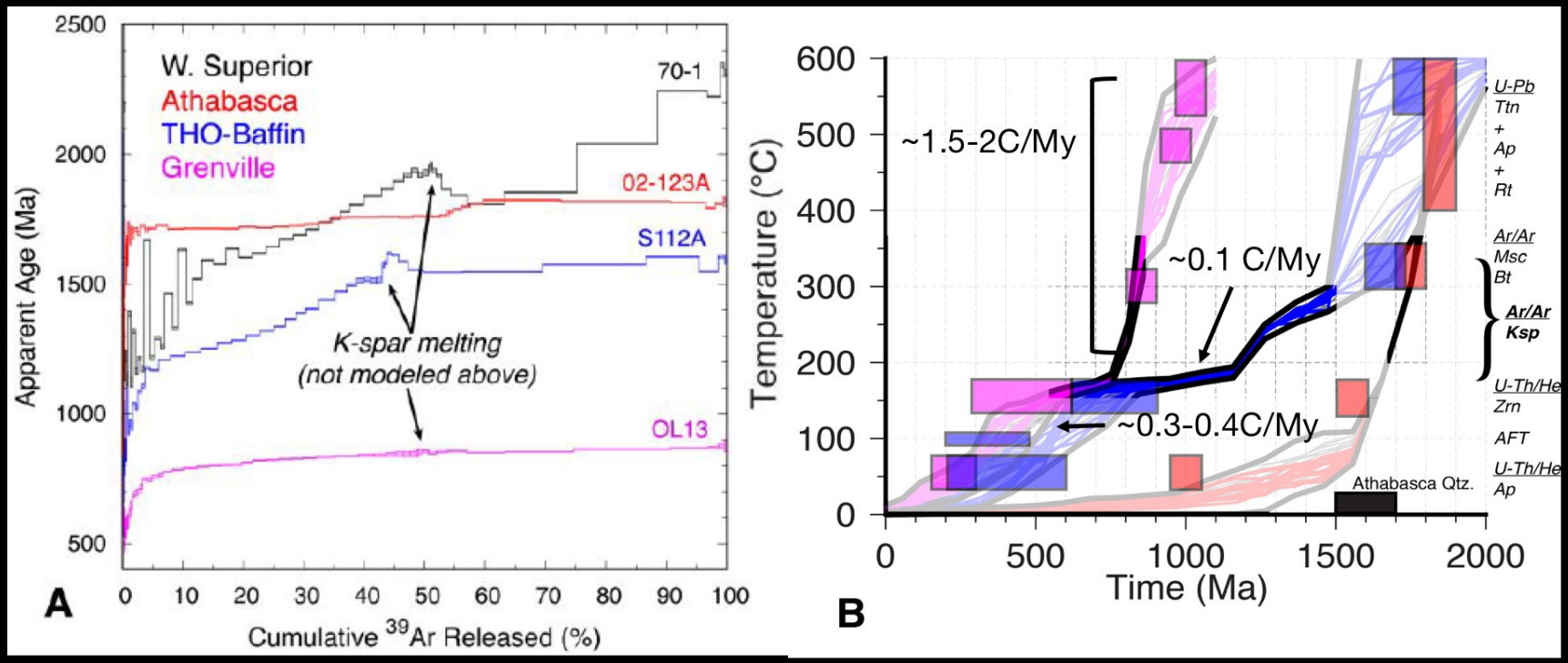


K-feldspar MDD data, Canadian craton: alternative models

~200˚C at 1000 Ma, reheating or monotonic scenarios



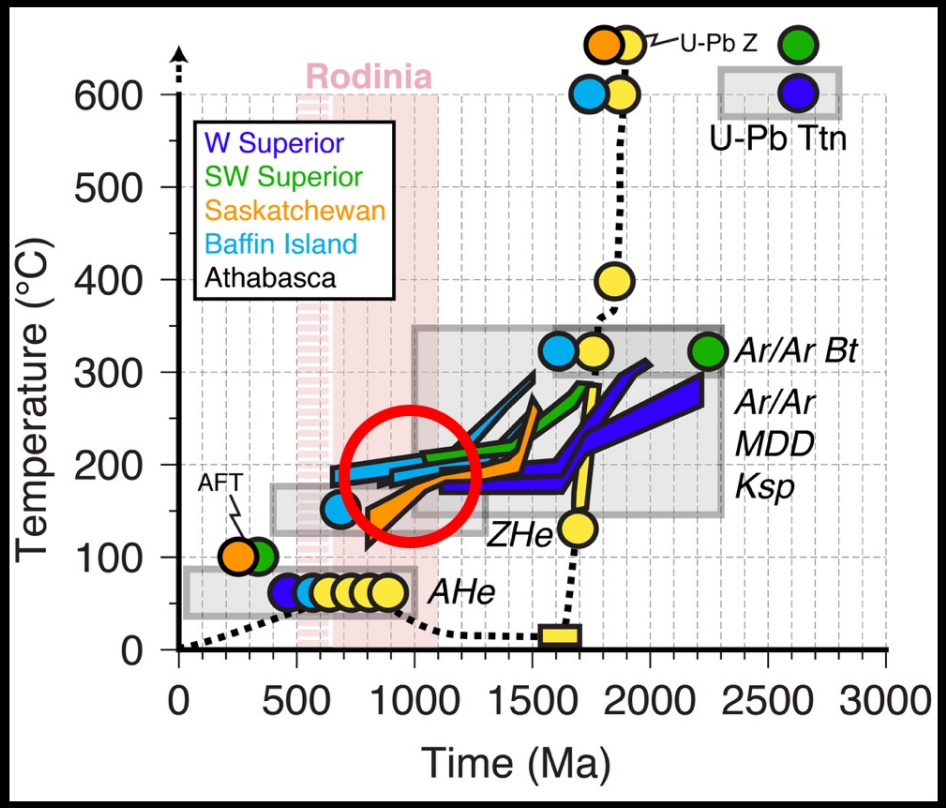
K-feldspar MDD data, Canadian craton: western Superior Province tT

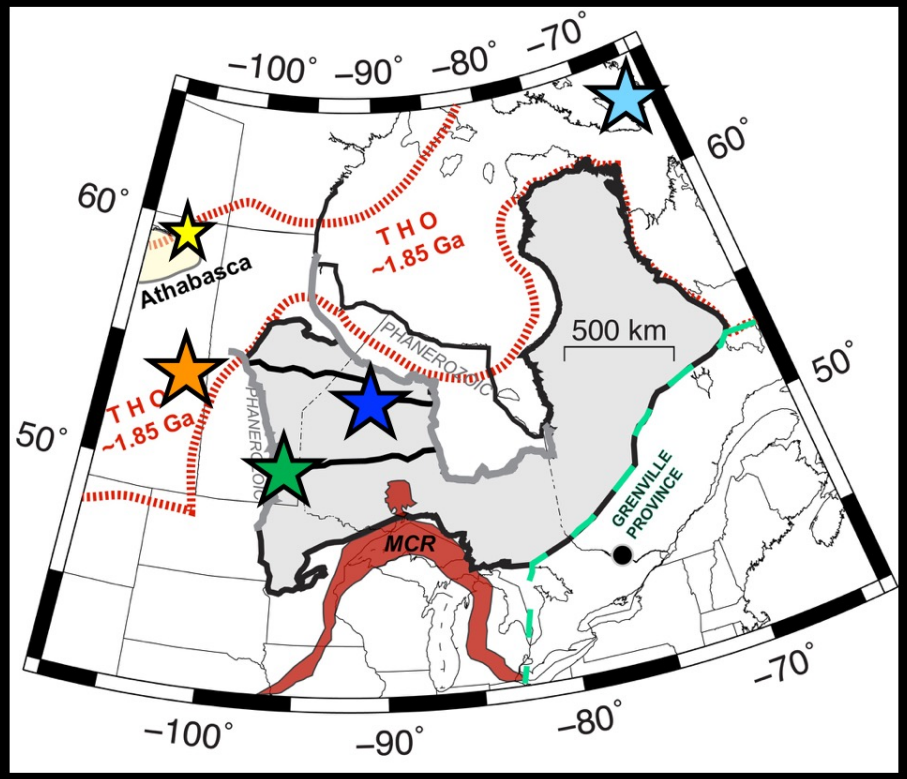


Monotonic, cooling-only models

K-feldspar MDD data, Canadian craton: cooling-only compilation

- Monotonic scenario: extreme stability for > 500 Ma
- At ~1000 Ma, samples were at ~200˚C (8-10 km!)



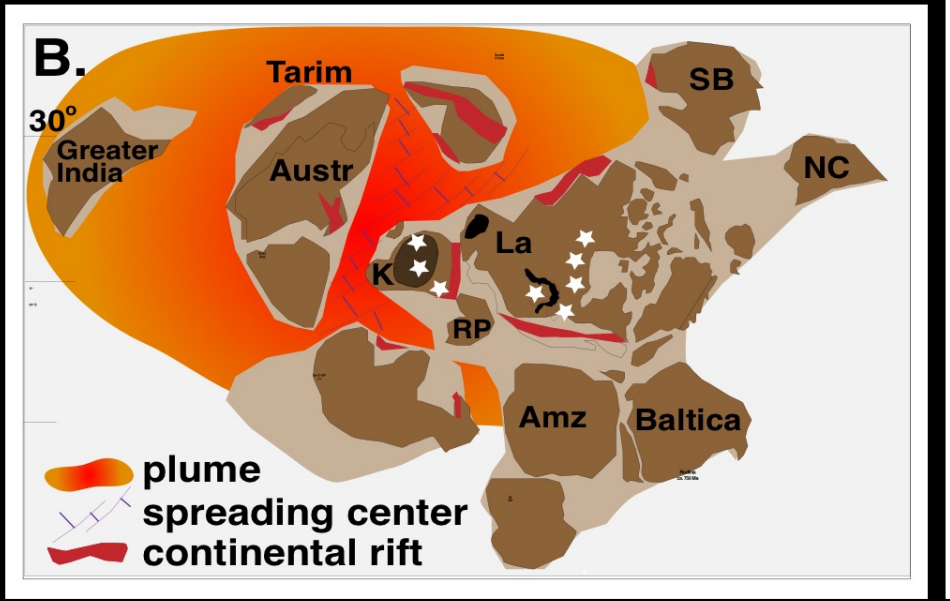


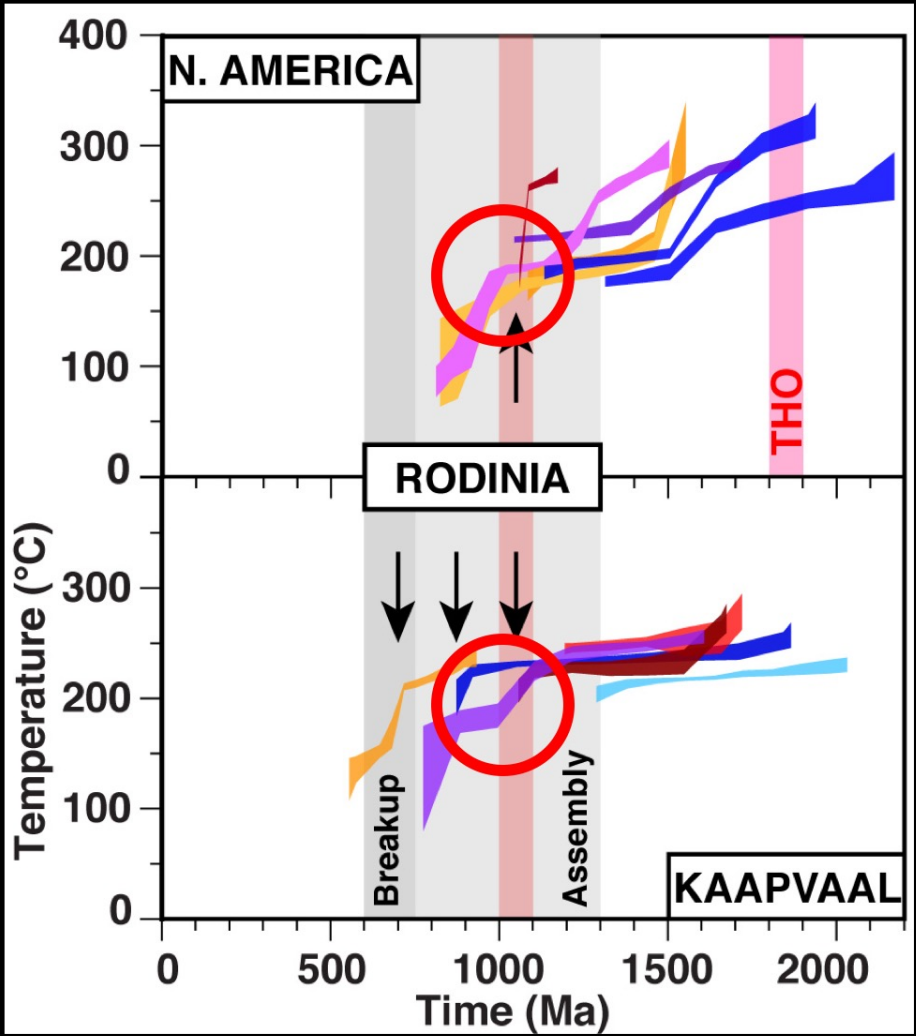
McDannell and Zeitler (2018)

K-feldspar MDD data, Kaapvaal craton: same result

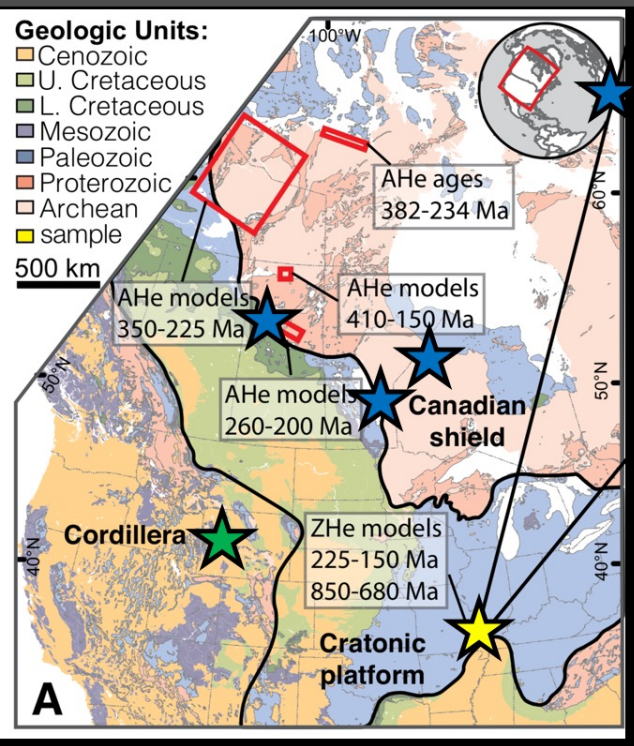
In the Kaapvaal, we also see the 200C / 1000 Ma signal

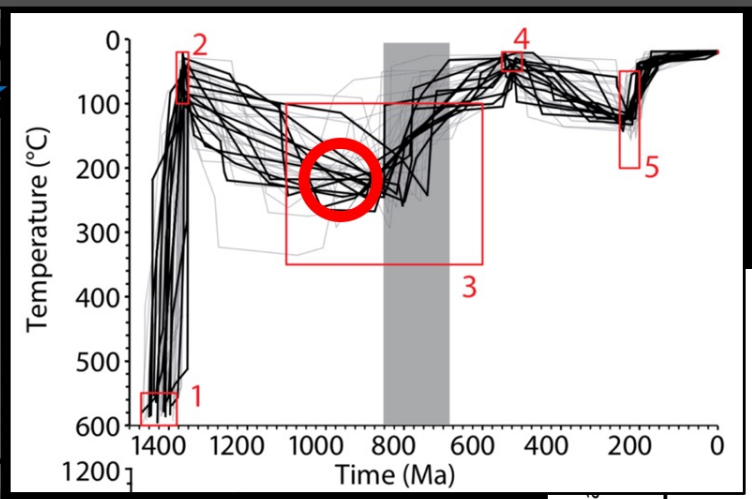
At 1000 Ma, all these samples were not so far-flung





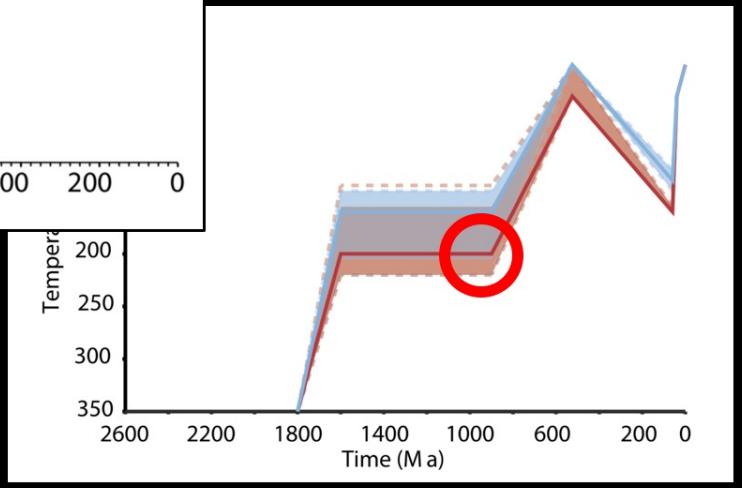
Records of early Neoproterozoic cooling are widespread across Rodinia

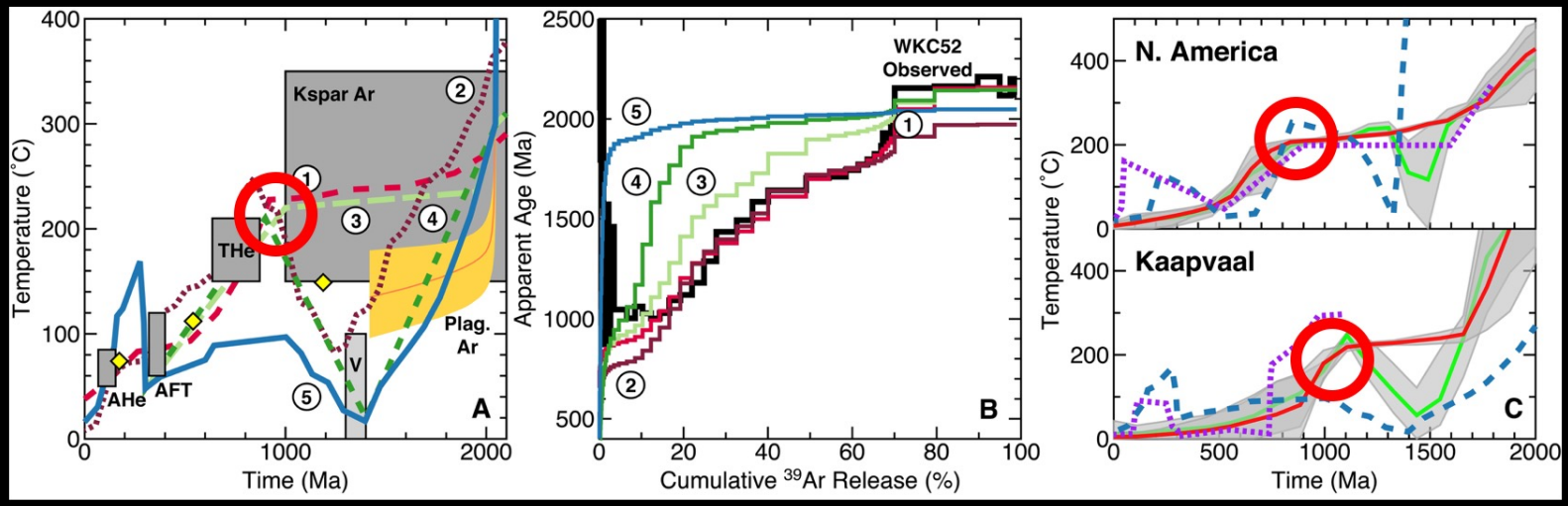




Delucia et al. (2018)

Orme et al. (2016)

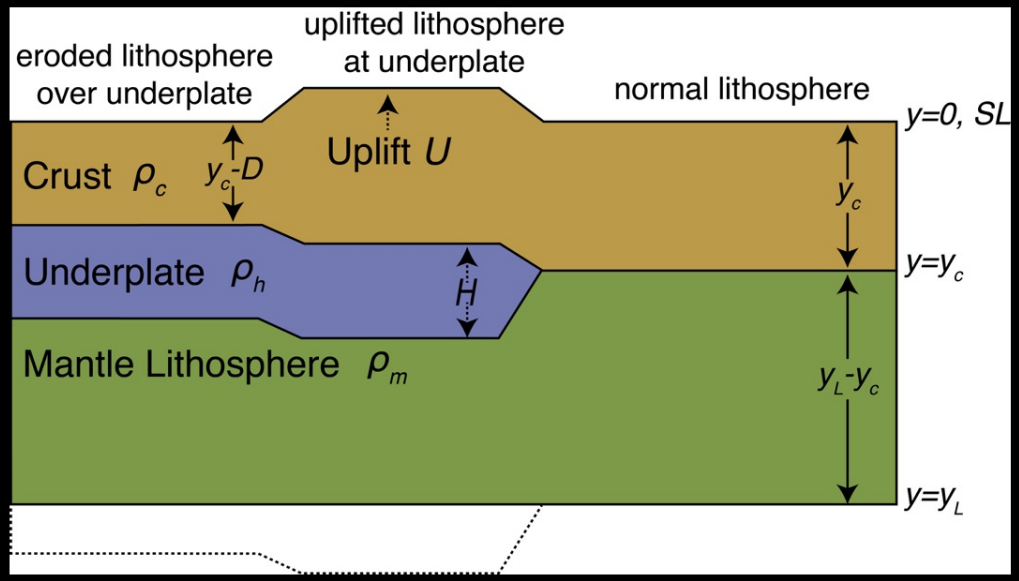




McDannell and Zeitler (in review)

Awkward! How to you exhume a stable continental interior 8 to 10 km?

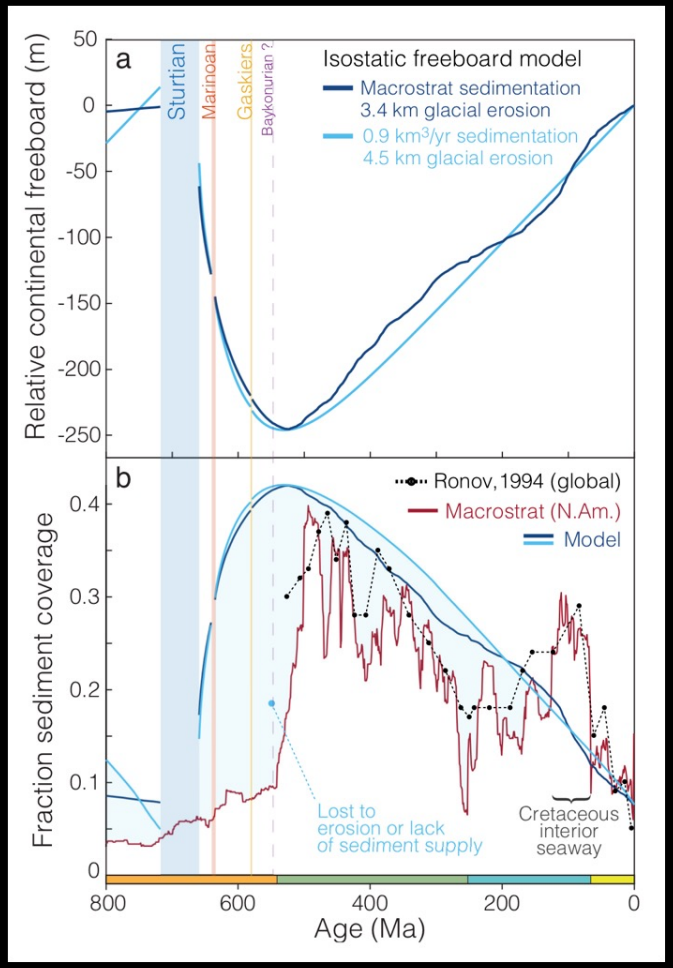
- Can't just be long slow exhumation + isostasy
- Magmatic underplating might provide the needed crustal thickness; there is evidence for this



Maybe the Proterozoic wasn't so boring:

- Growing evidence for widespread and significant exhumation
- This exhumation is enigmatic and requires a widespread driver or drivers

Broader implications: Earth-system feedbacks



Brenhin Keller et al., in revision, PNAS

Feedbacks between solid earth, surface environment, and biosphere?

- Did exhumation cause Snowball Earth or did Snowball Earth cause exhumation (or both, through feedbacks)?
- Did exhumation enhance P cycle and support diversification of life? Did this impact C cycle? More possible feedbacks here!
- Did Neoproterozoic exhumation via Snowball Earth result in early Paleozoic stratigraphic record of inundation?