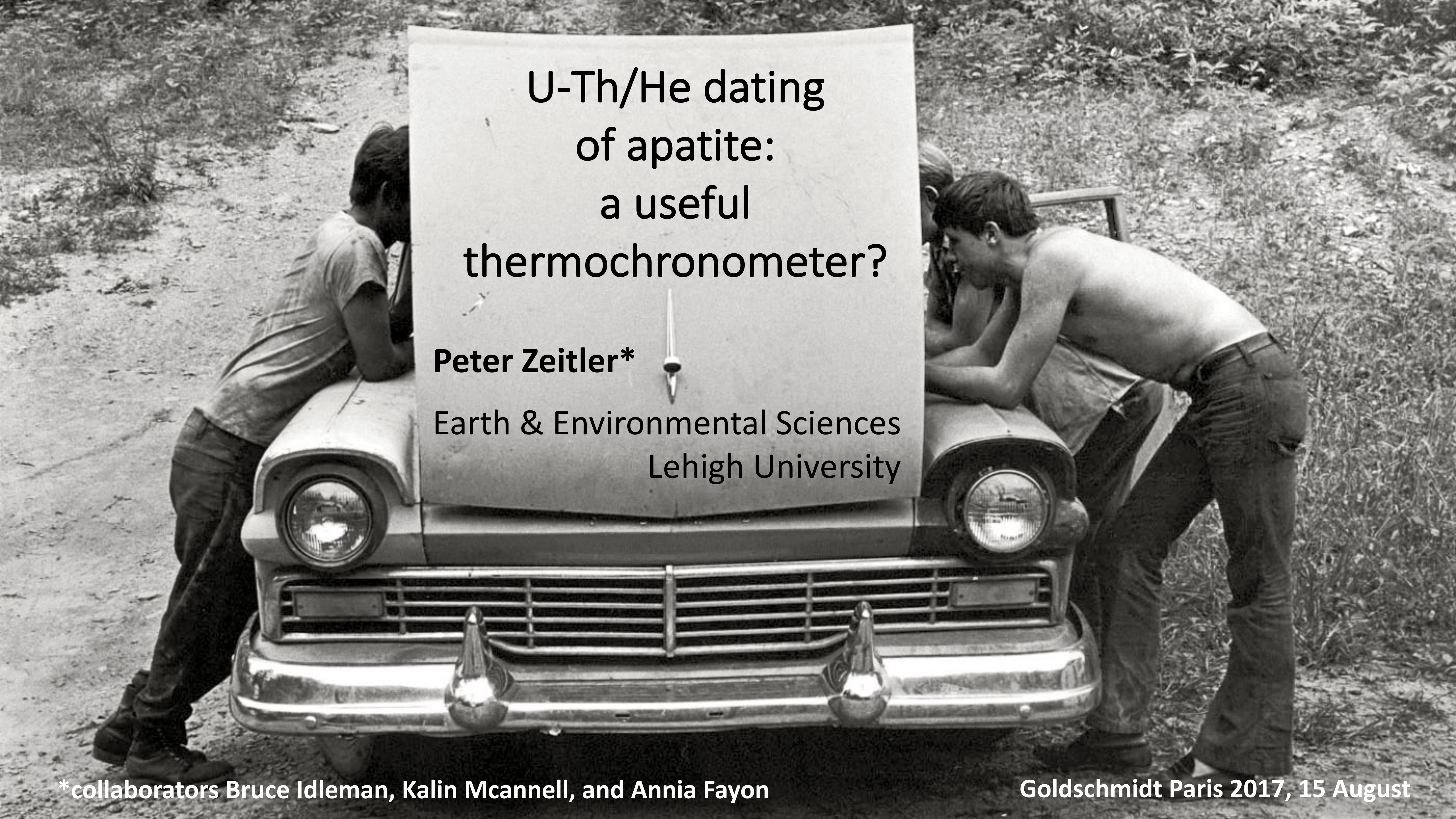
U-Th/He dating of apatite: a useful thermochronometer?

Peter Zeitler*

Earth & Environmental Sciences
Lehigh University



*collaborators Bruce Idleman, Kalin Mcannell, and Annia Fayon

Goldschmidt Paris 2017, 15 August

Where we've been

70's and 80's: Fundamentals

90's and 00's: Technical advances

U-Th/He community exceptional

- cooperation
- systematic development of tools

Not always been true in geochemistry and geochronology!

Thermochron and U-Th/He methods now an important mainstream tool in geosciences

Where we stand

Powerful models for geologic applications

Good understanding of kinetics and systematics (size, shape, kinetics, alpha-ejection, radiation damage, composition, zoning, grain integrity, anisotropy…)

Everything is for the best in this best of all possible worlds!

But…

Dispersion

Where we stand

After accounting for all the beautiful factors, significant “excess” dispersion too often remains

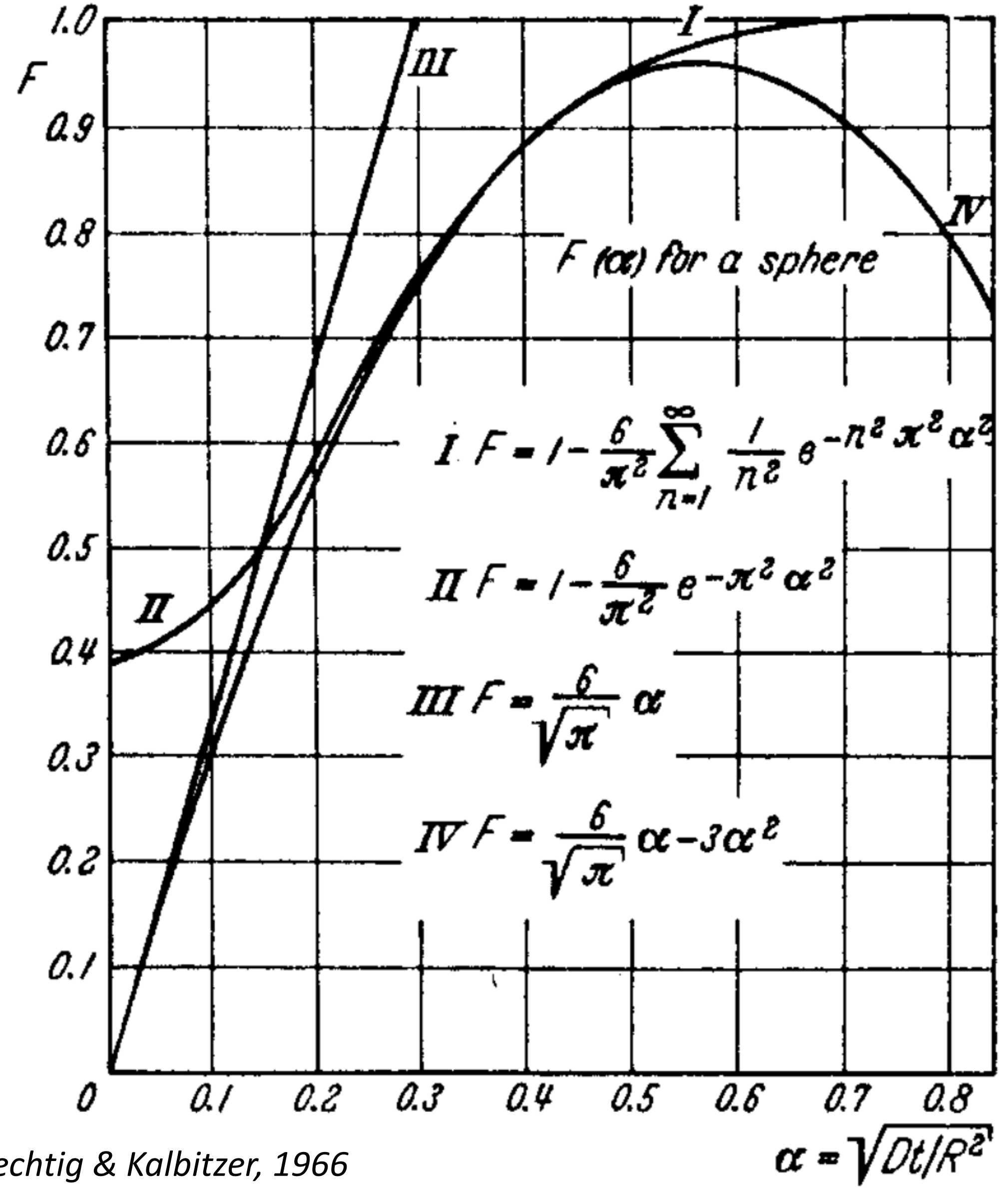
Are we facing up to this? Or just pressing ahead with Pecube and HeFTy and QTQt, hoping statistics and modest *n* will help?

There are rumblings out there, about U-Th/He “not working”

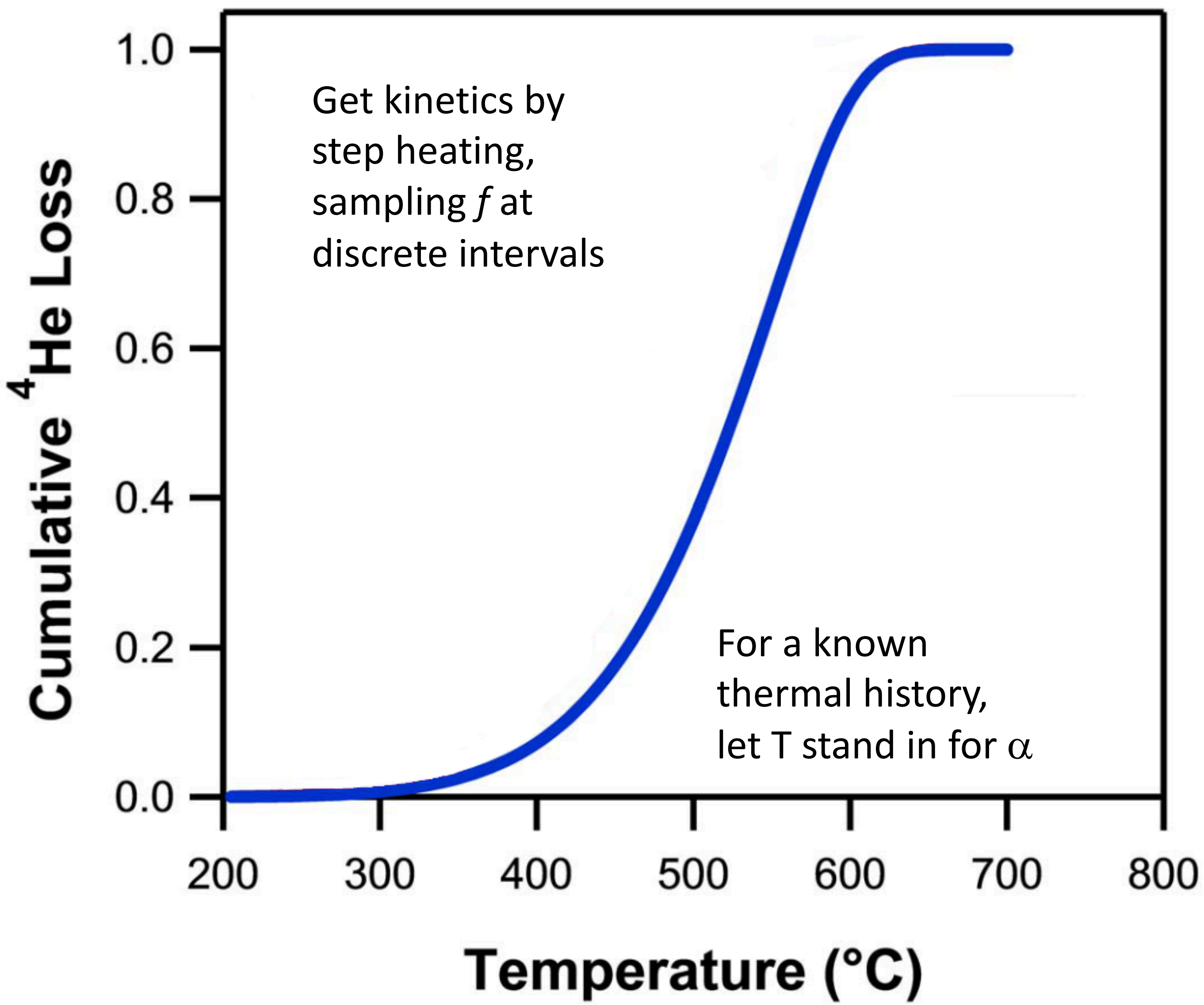
A major conclusion at the Maresias meeting was that dispersion needs to be addressed and understood

We might need to look deeper under the hood to see what’s really there…

Volume diffusion in laboratory



Fechtig & Kalbitzer, 1966

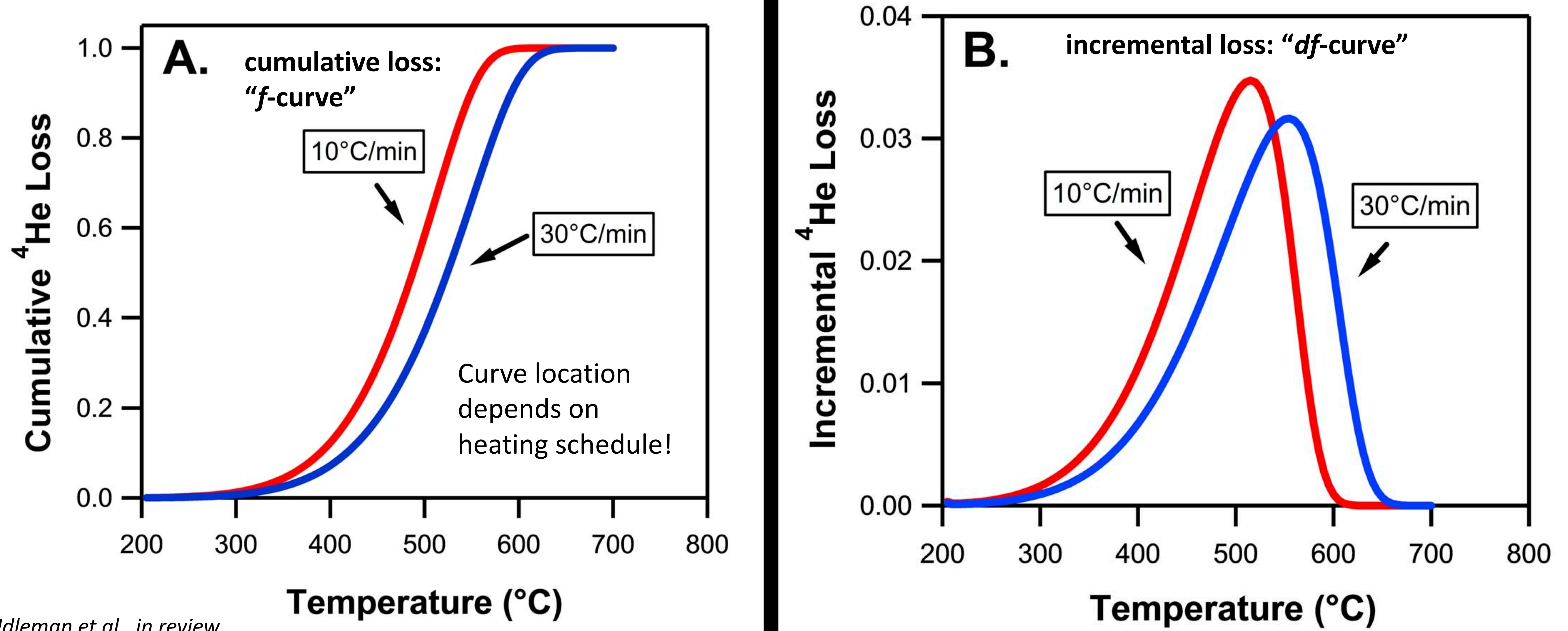


Continuous Ramped Heating (CRH) analysis

Continuous static-mode gas analysis

Continuous linear temperature ramp

df-curve is first derivative of *f*-curve



Idleman et al., in review

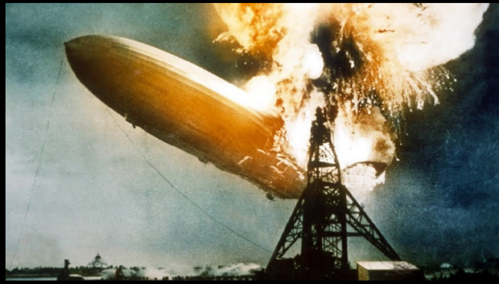
CRH analytical considerations

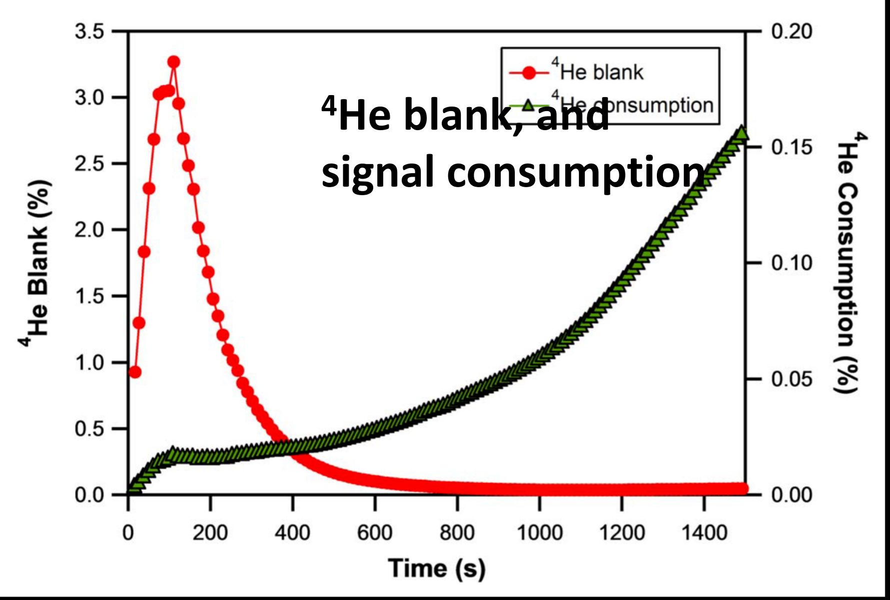
Furnace open to mass spec!

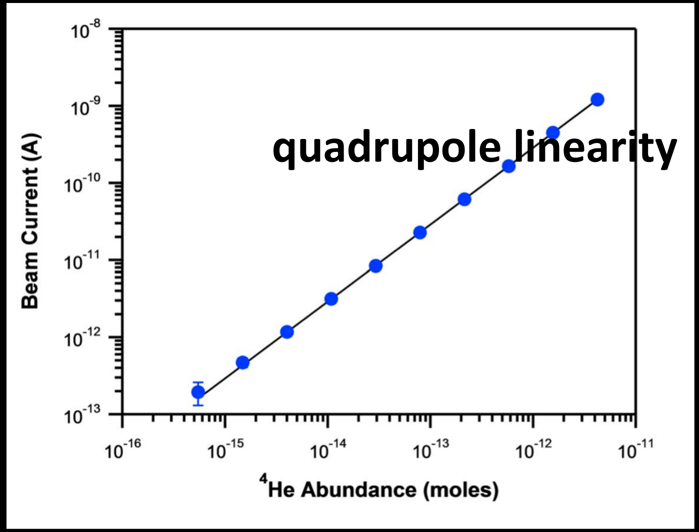
High H with resistance furnace (laser better)

with furnace, at times, some sensitivity changes

<u>Please</u> use quadrupole, not sector machine!



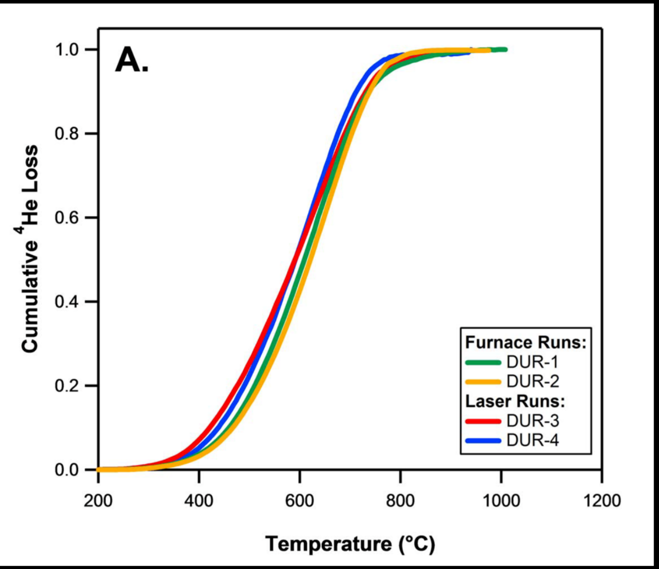


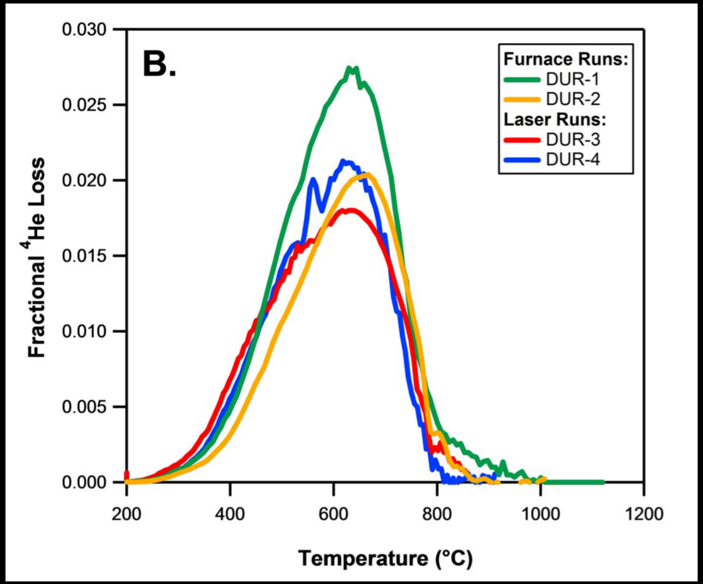


CRH analysis: Durango trials

Furnace and laser

df-peak shifted due to rollover in kinetics





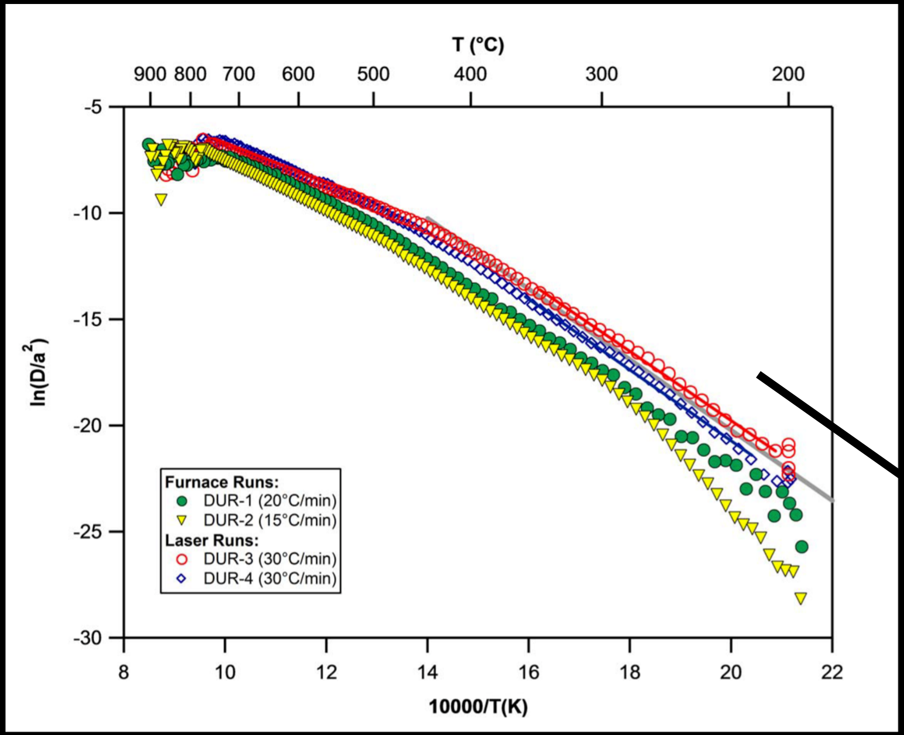
CRH analysis:
Durango apatite kinetics

Detailed Arrhenius plot in < 45 minutes

Same math as step heating

Laser CRH: same as conventional results

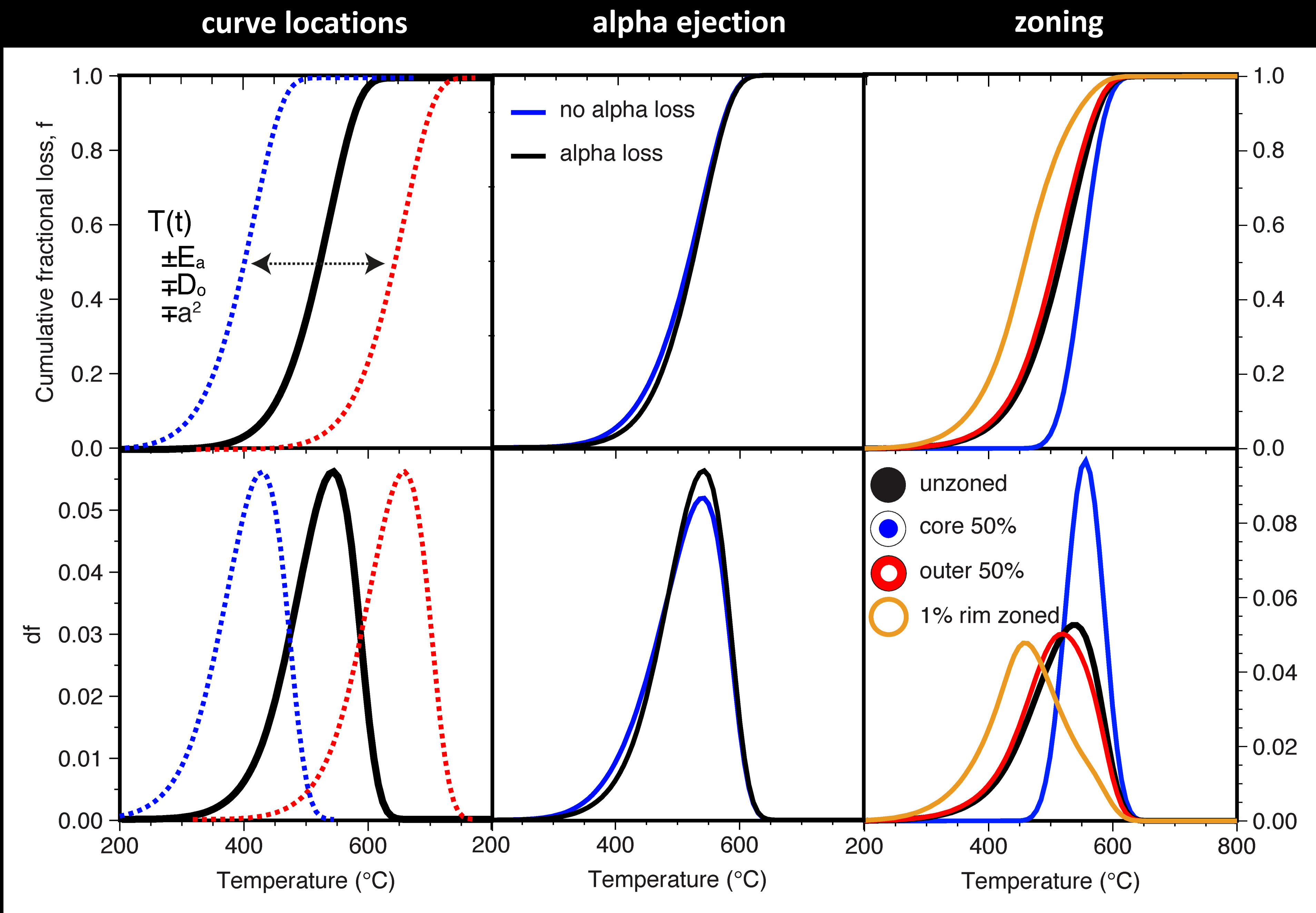
Note: rollover deferred for faster heating schedule



CRH systematics

Curve locations can vary

Concentration profiles have minor impact: curves remain simple



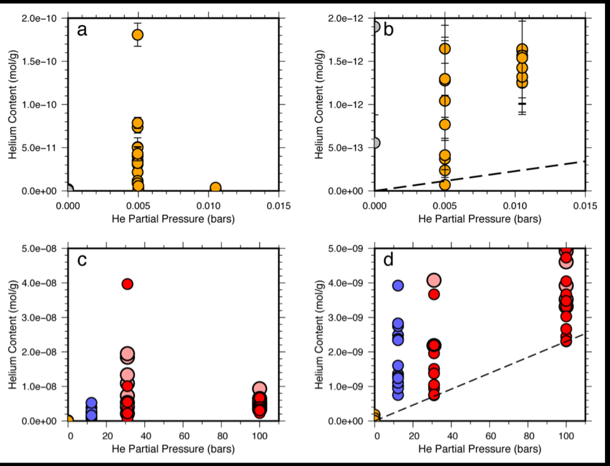
McDannell et al., in review

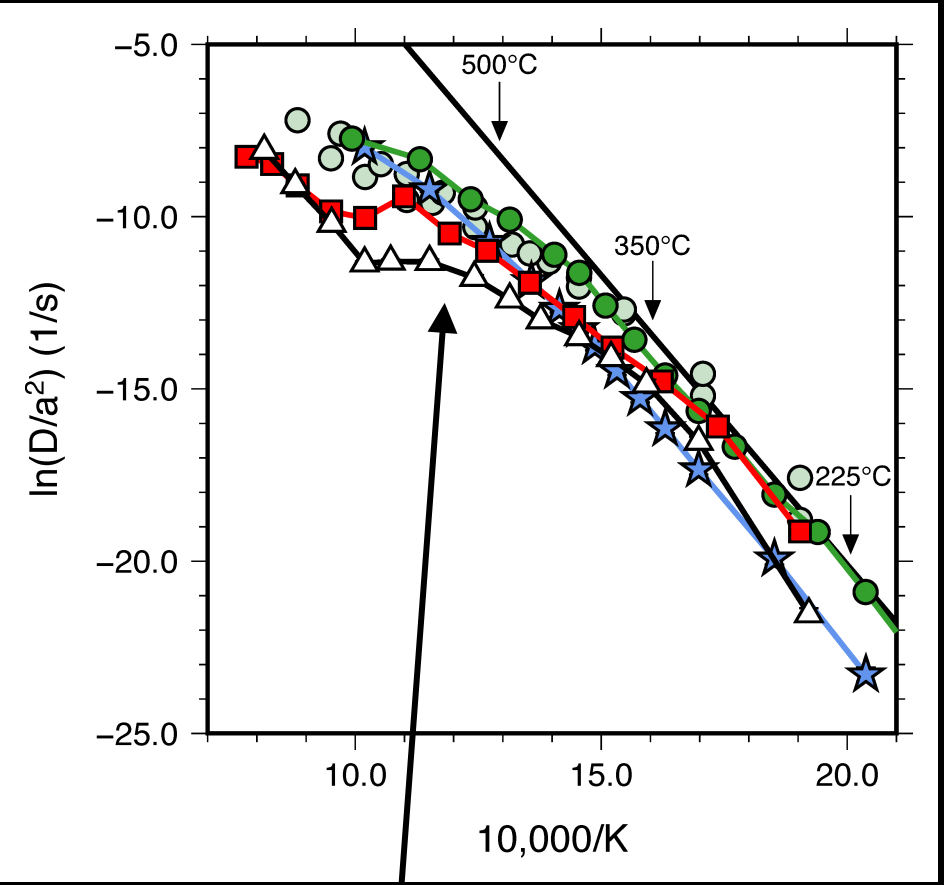
Apatite misbehaviour

Clear grains of standard: vast range in solubilities

“Bad-actor” grains give complex Arrhenius plot

Soaked samples and bad actors yield over 50% ^{4}He on crushing





Zeitler et al., 2017

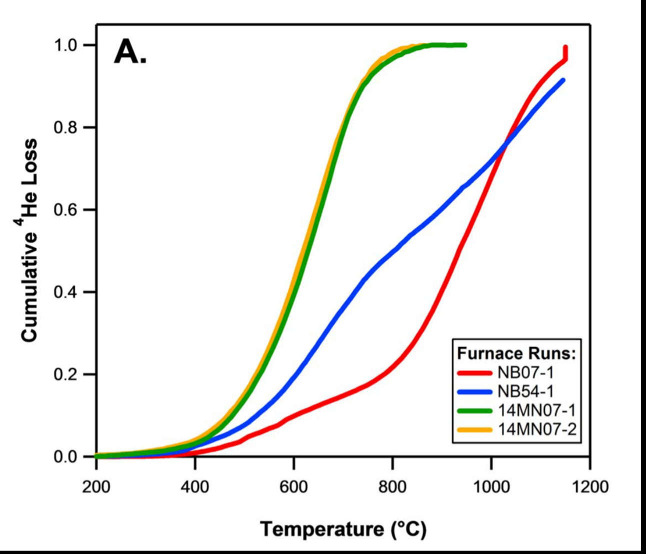
Setting	^{4}He released on crushing
Fast-cooled, no age dispersion	0.5% (Dur.); 2.6 - 3.4%
Slow-cooled, variable age dispersion	6 – 9 %
Fast-cooled, large age dispersion (NB07)	53%
Soaked at high ^{4}He pressure	17 – 64%

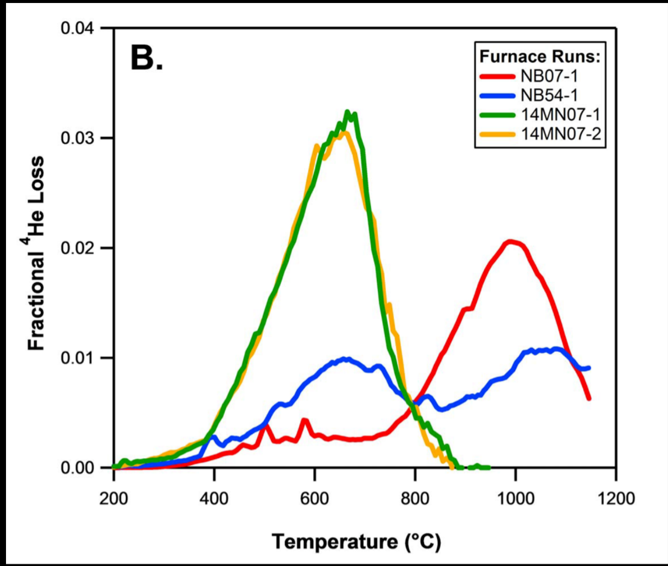
CRH analysis: good vs. bad actors

Bad-actor ages:

NB07: 11, 14, 25 (should be ~5-7 Ma)

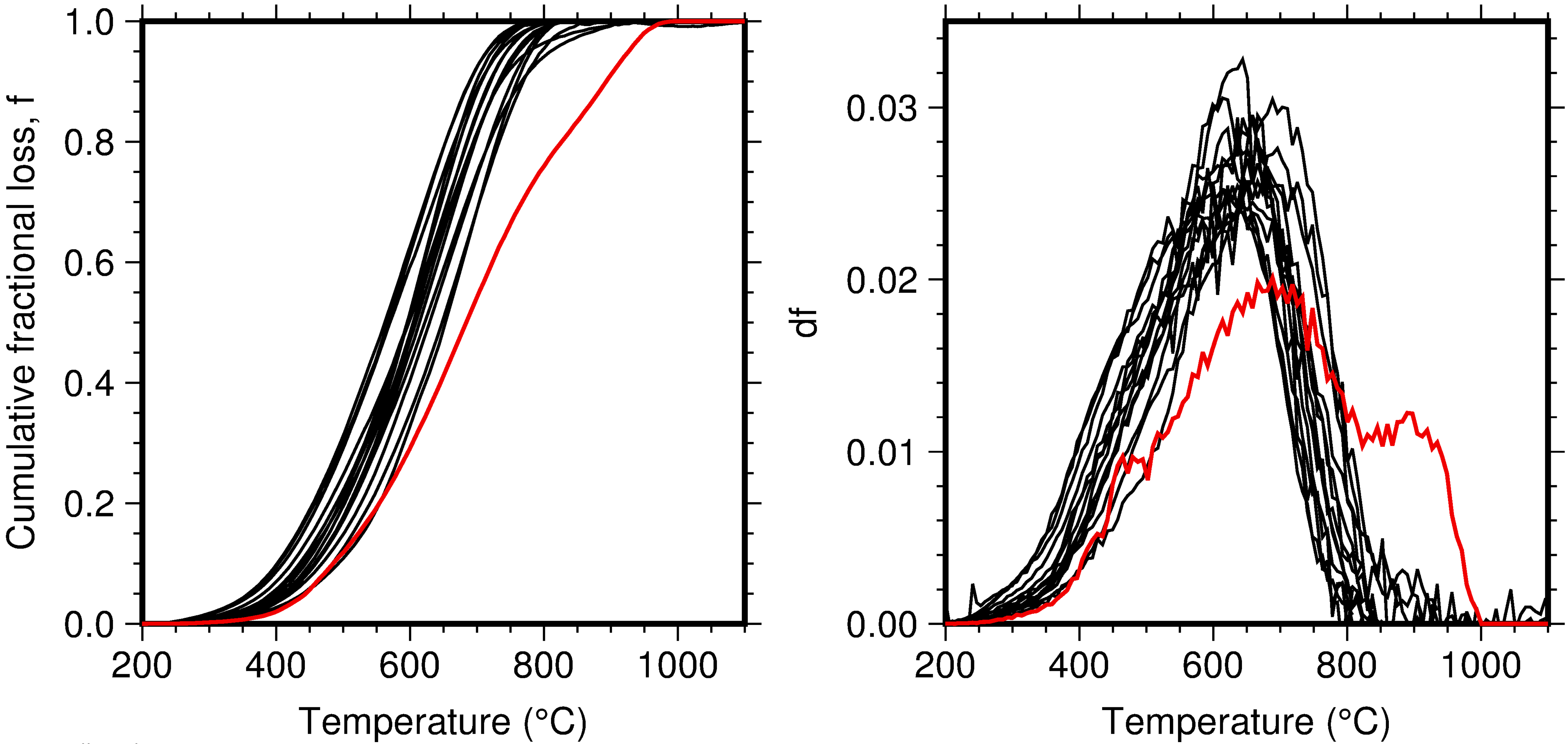
NB54: 13, 56, 204 (should be <15 Ma)





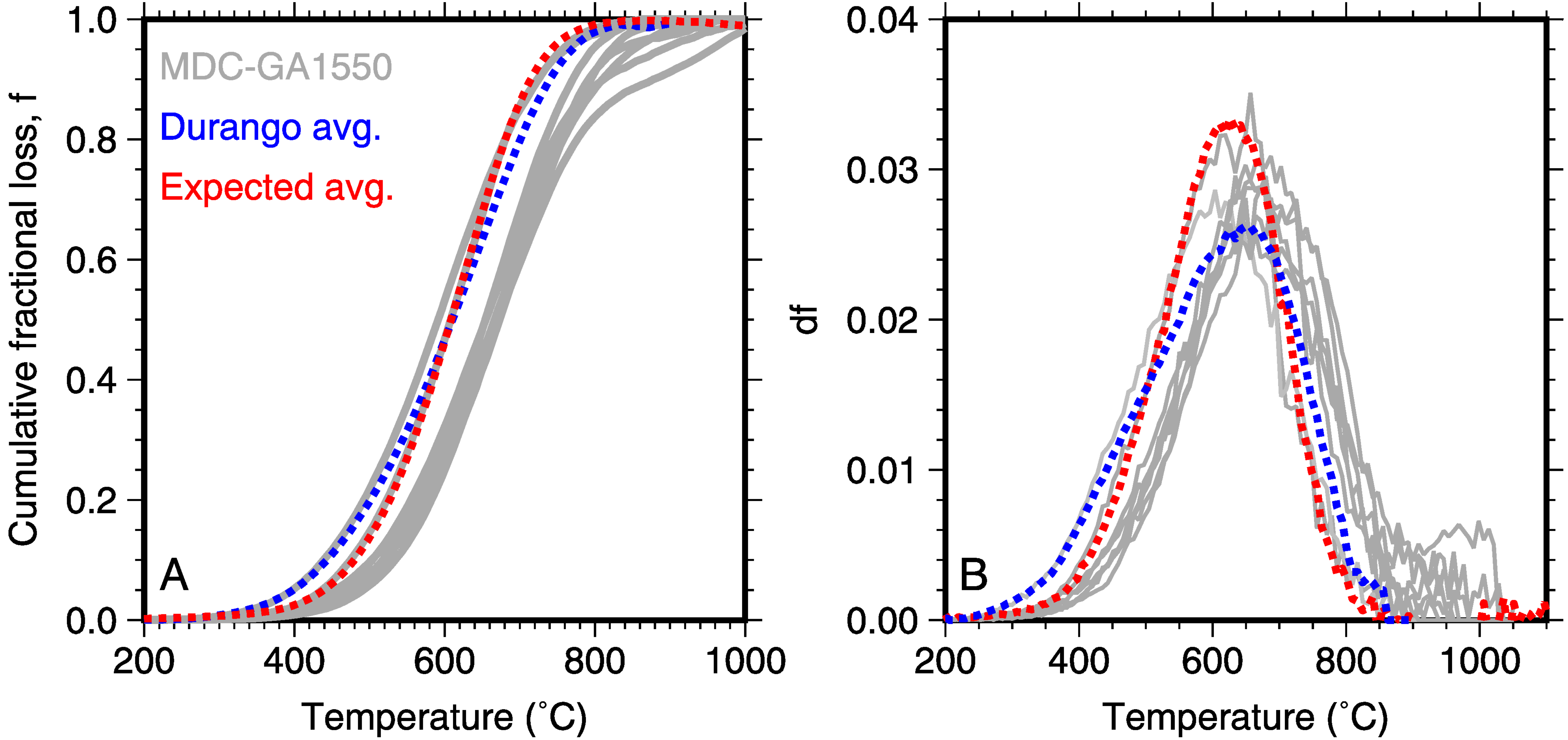
CRH analysis: Durango apatite

Furnace, n = 17, unfiltered



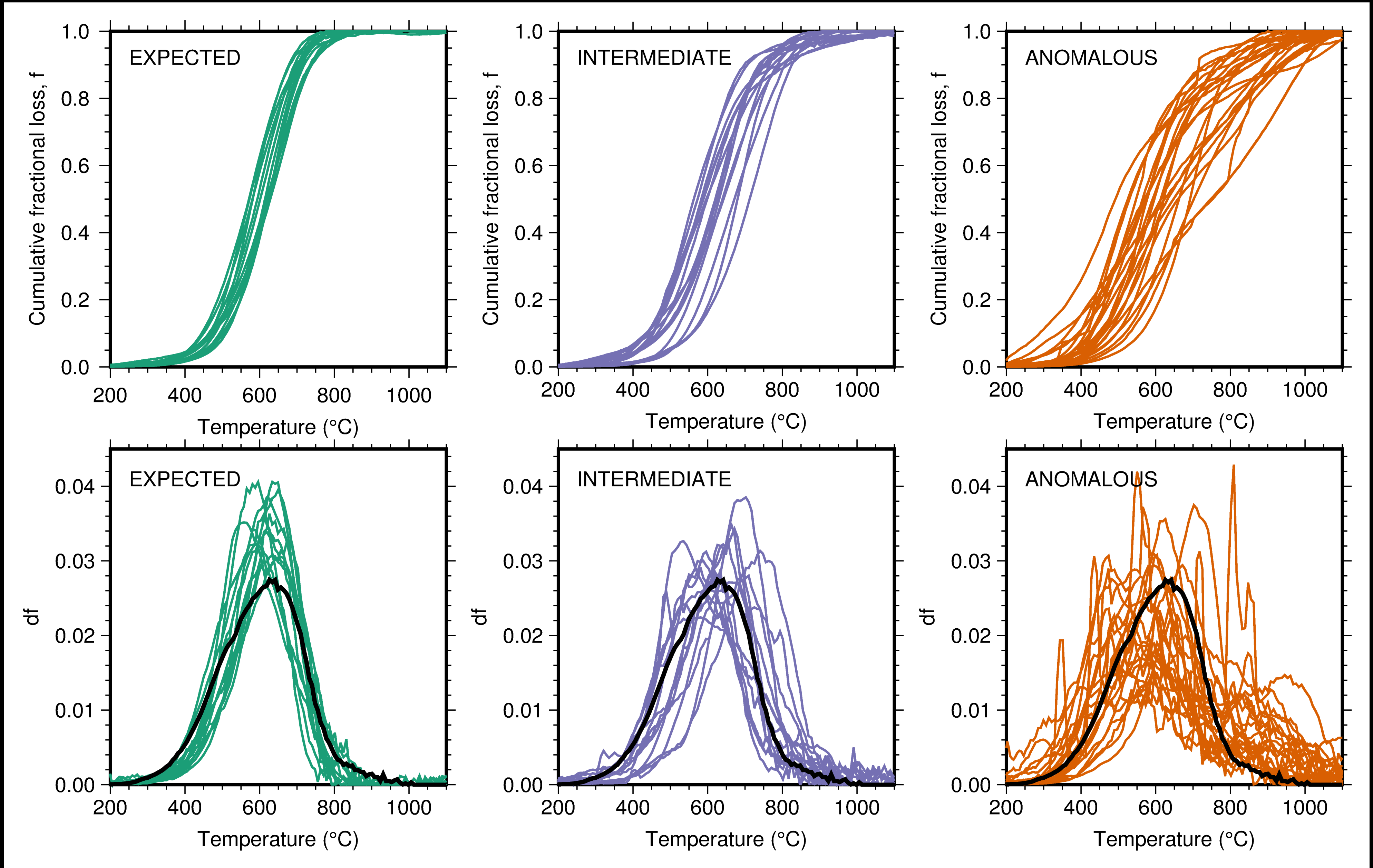
McDannell et al., in review

CRH analysis: Mt. Dromedary (GA1550 site)



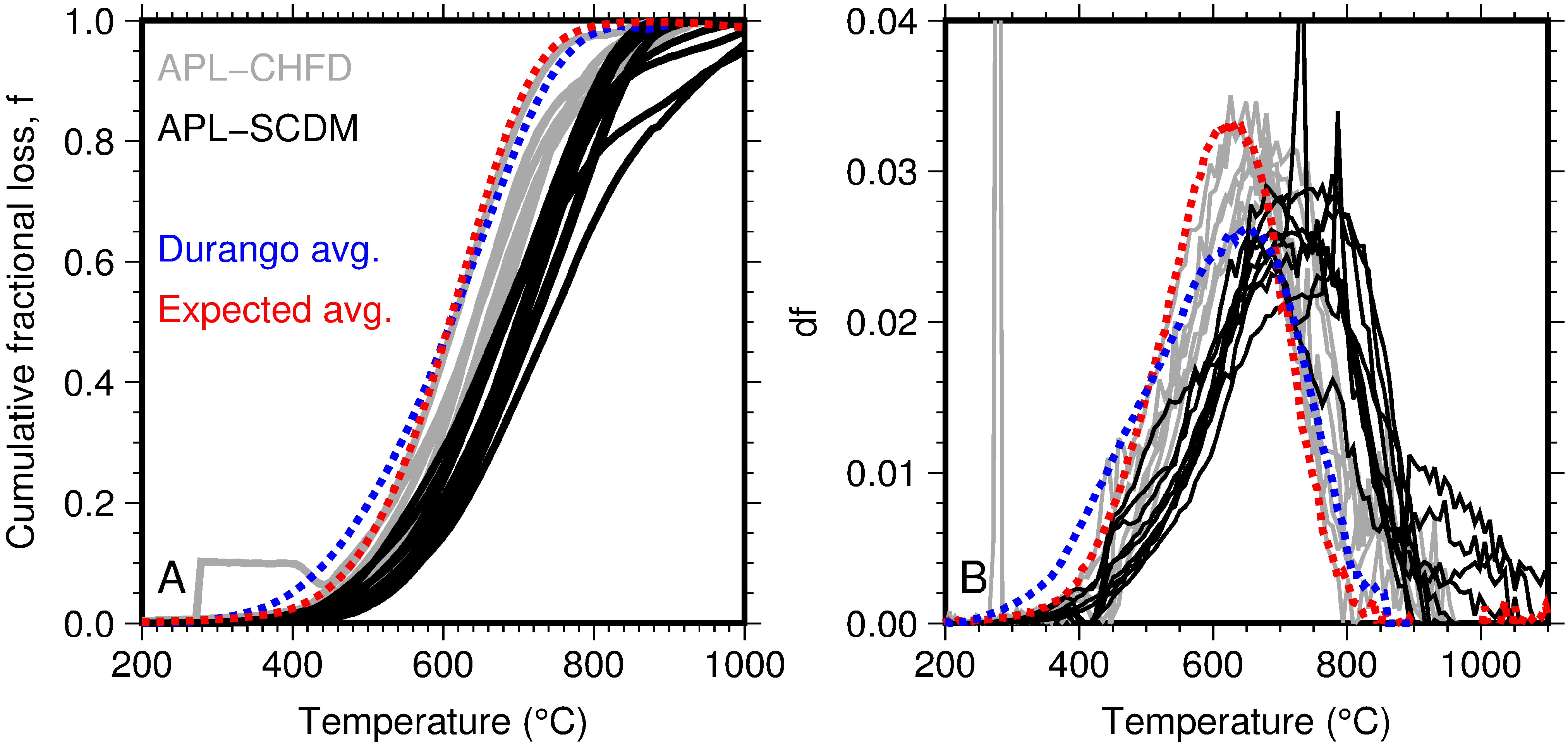
McDannell et al., in review

CRH analysis: Mongolia slow cooling



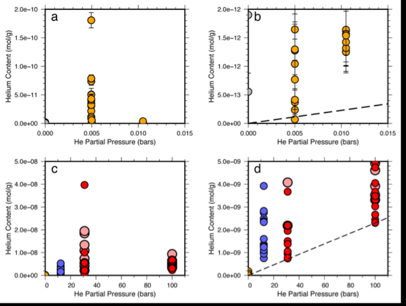
McDannell et al., in review

CRH analysis: Appalachians

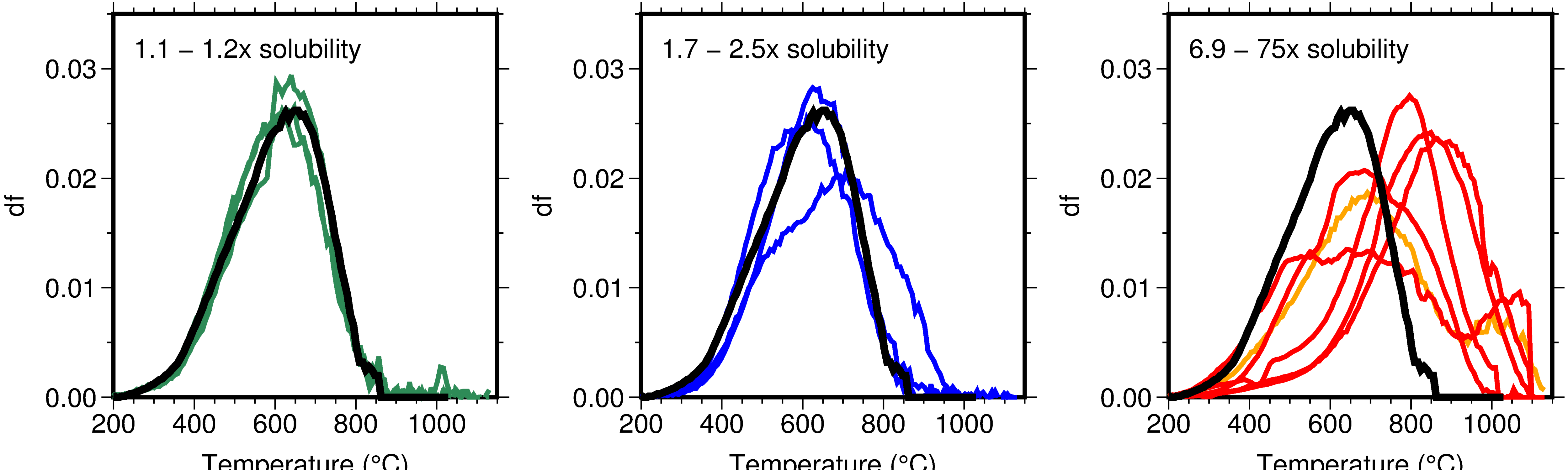


McDannell et al., in review

CRH analysis: solubility samples

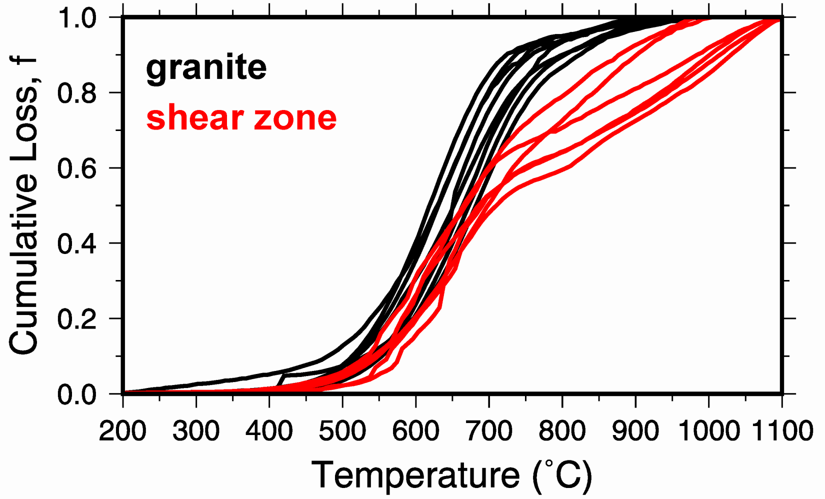


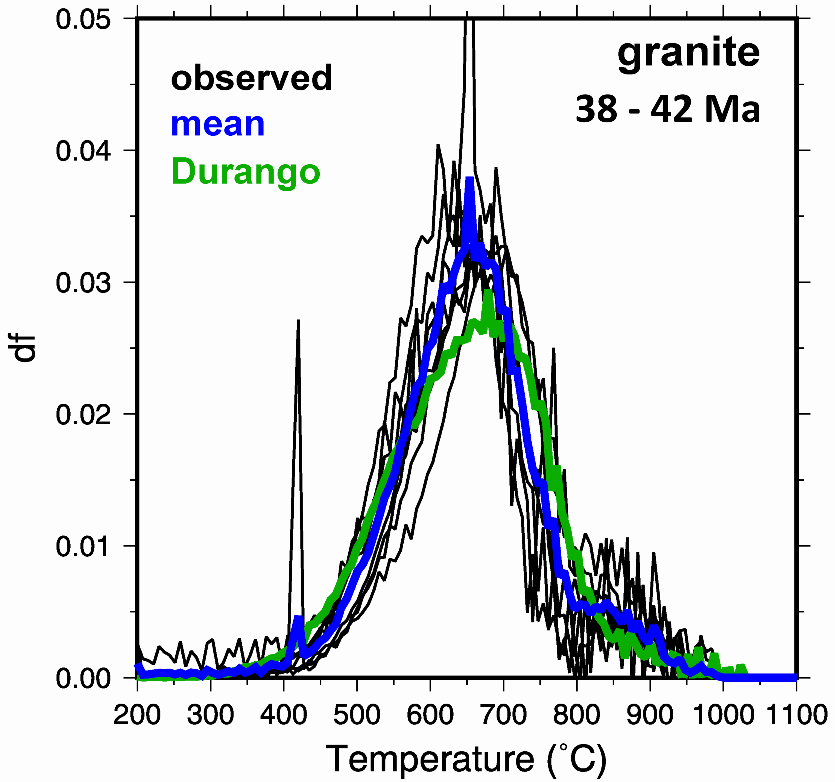
Durango, Appalachian grains soaked at 12-100 bars p_{He}

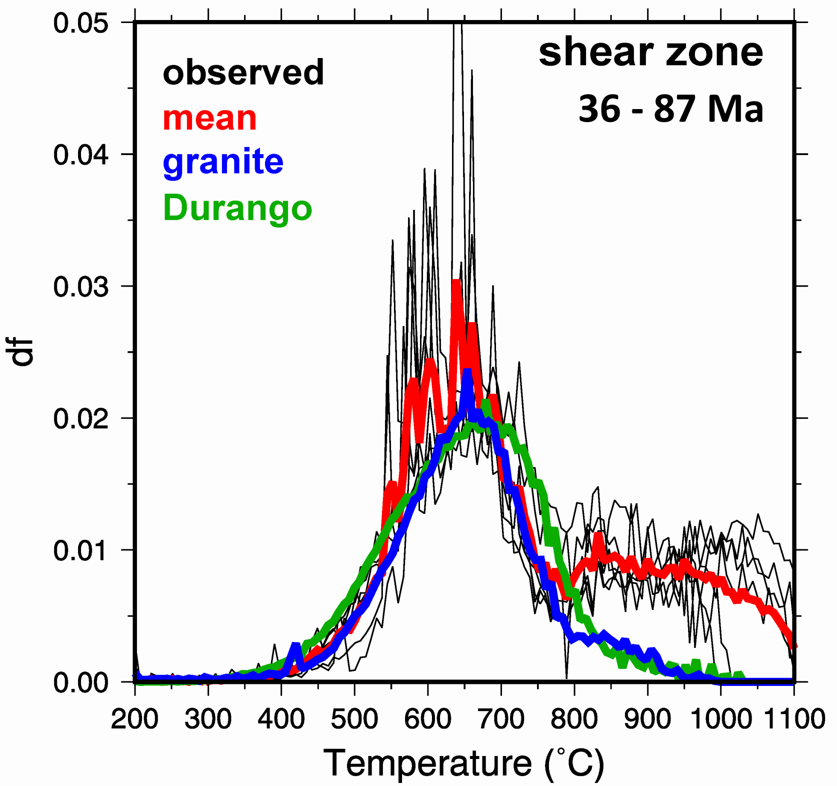


McDannell et al., in review

CRH analysis:
Sierra Nevada shear zone

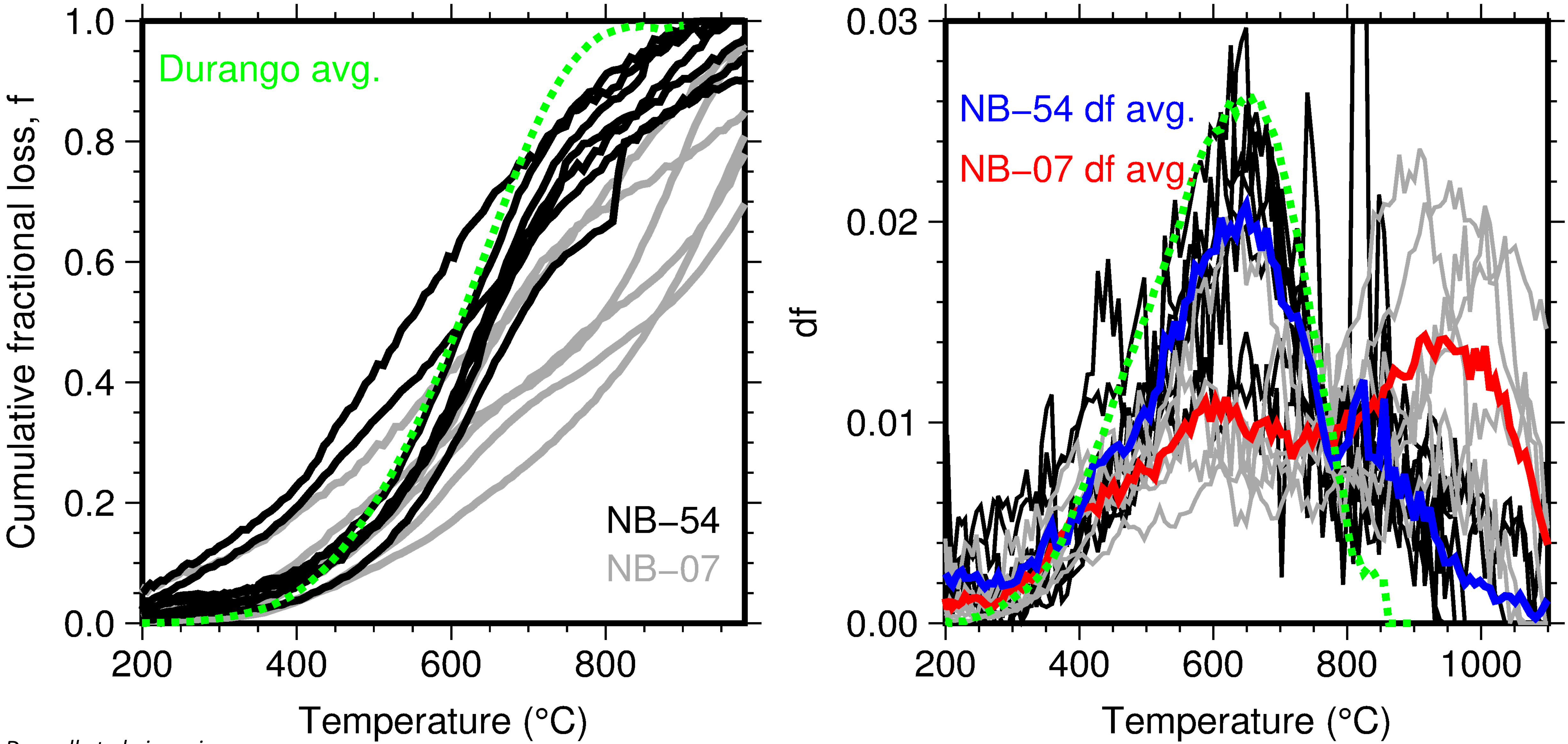






McDannell et al., in review; Fayon and Hansen, 2015

CRH analysis: Tibet bad actors



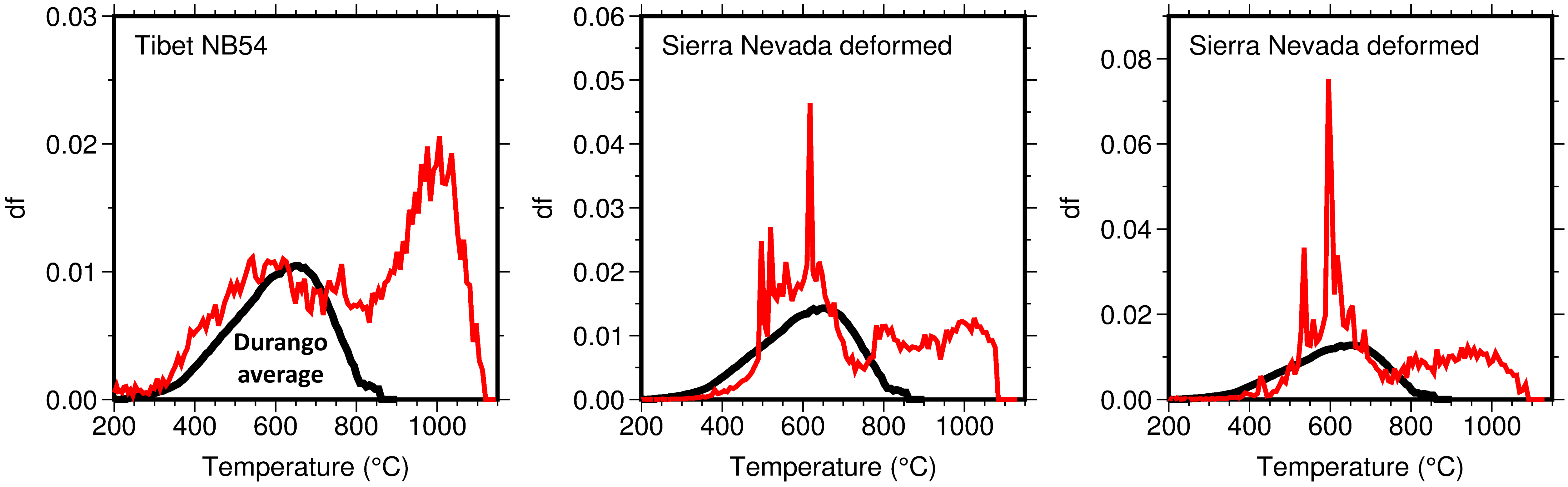
McDannell et al., in review

CRH analysis: age correction?

Move beyond just screening?

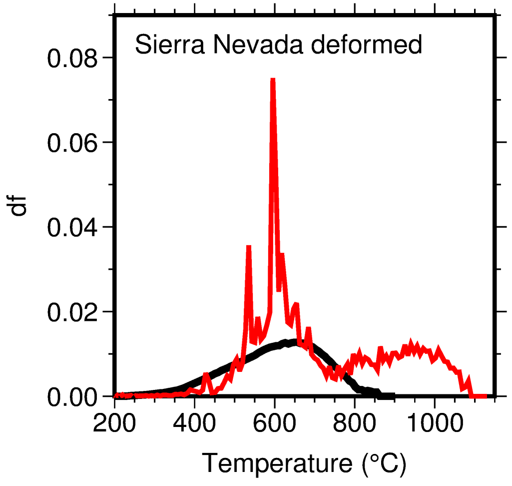
Even ratty samples show some “expected” release

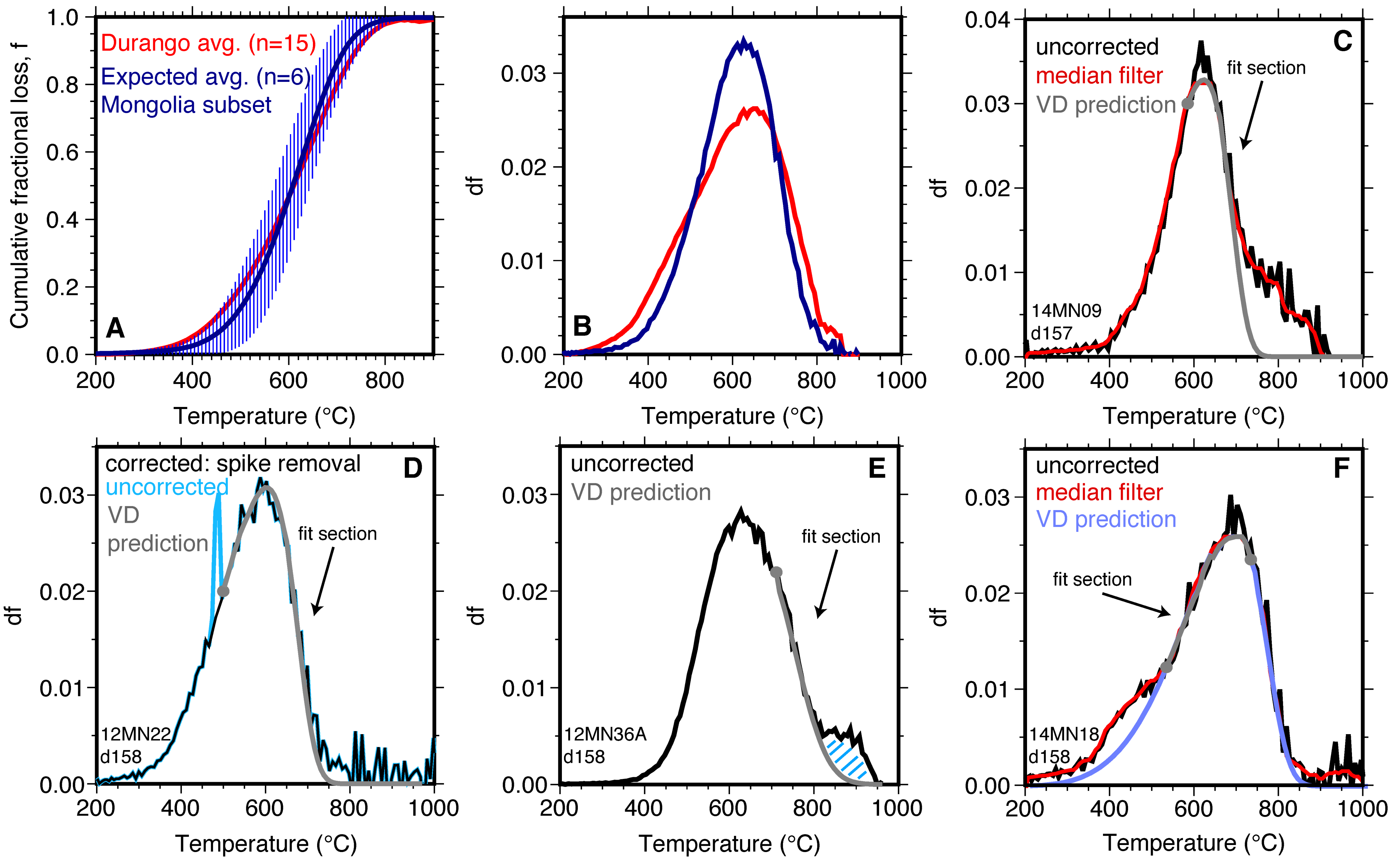
Eliminate spikes; use area of lower-T peak?



McDannell et al., in review

CRH analysis: age-correction challenges

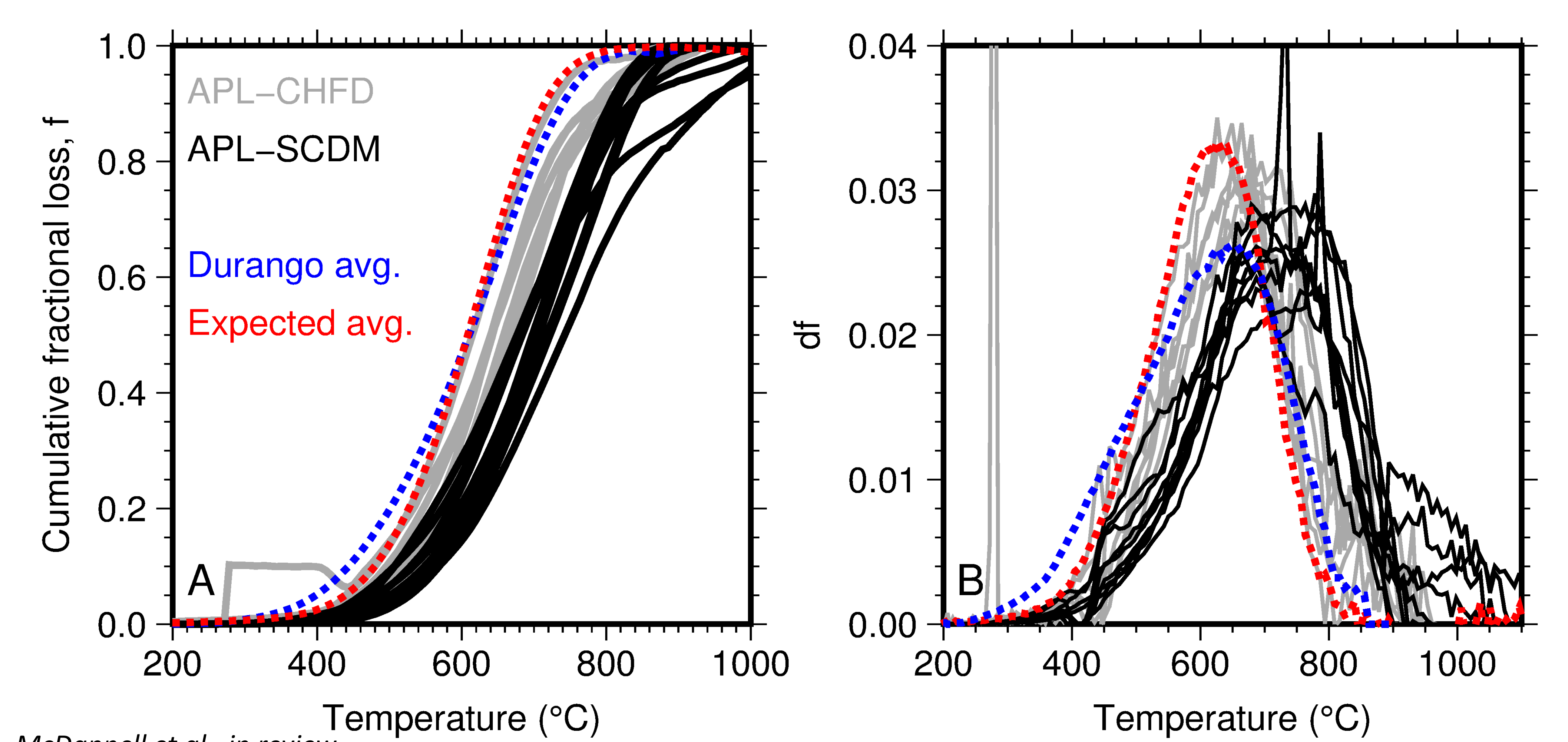




McDannell et al., in review

CRH age correction: Appalachians

	SCDM (n = 9)	**CHFD** (n = 7)
<u>Observed</u>:	60 – 444 Ma, 218 ± 117	170 – 240 Ma, 199 ± 27
<u>Corrected</u>:	45 – 302 Ma, 167 ± 84	130 – 215 Ma, 168 ± 27



McDannell et al., in review

CRH age correction: Sierra Nevada shear zone

Granite (40 ± 2 Ma) (n = 6)

Observed: 37 – 65 Ma, 45 ± 11

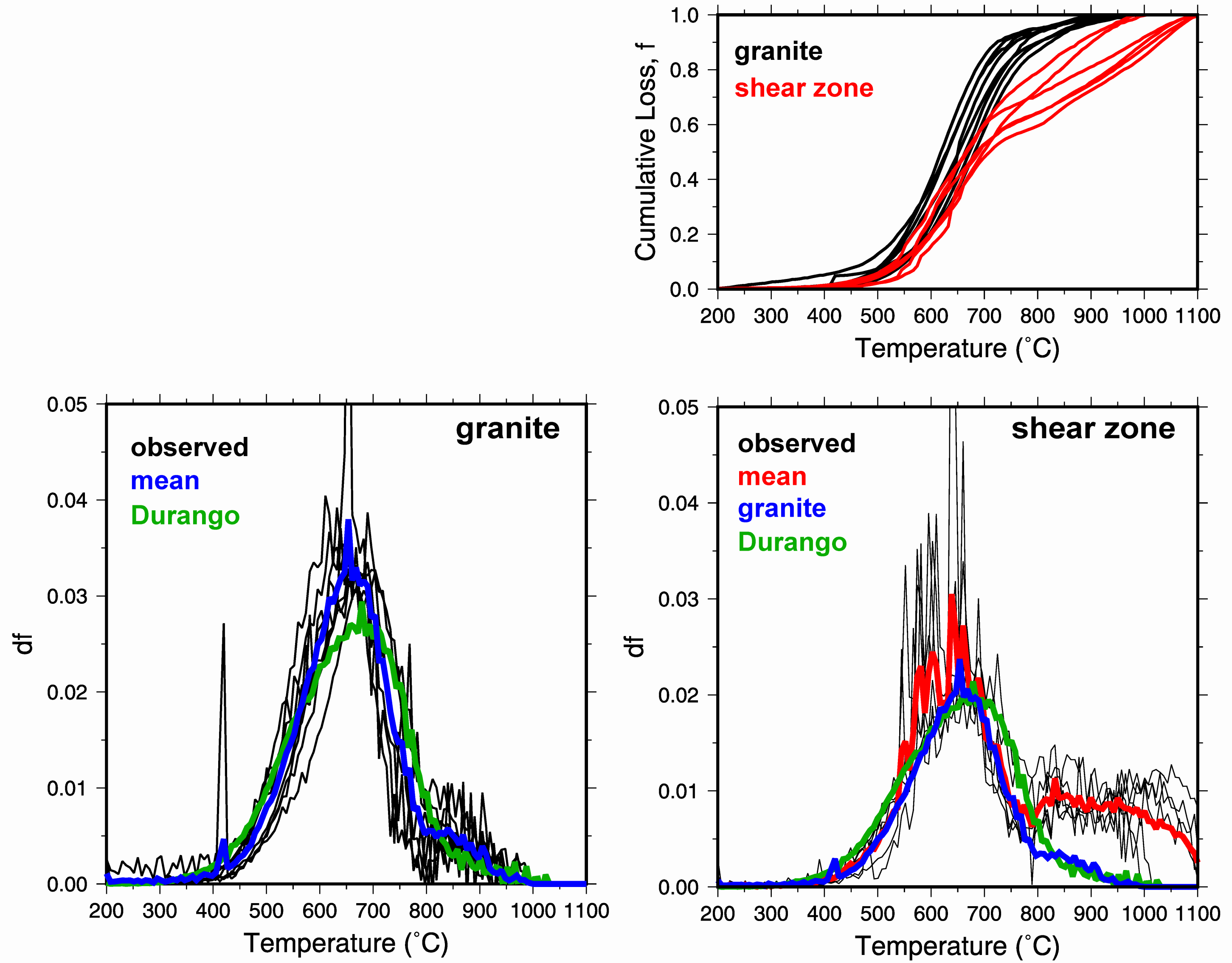
37 – 49 Ma, 41 ± 5

Corrected: 32 – 43 Ma, 36 ± 4 (39 ± 10)

Shear Zone (58 ± 20 Ma) (n = 4)

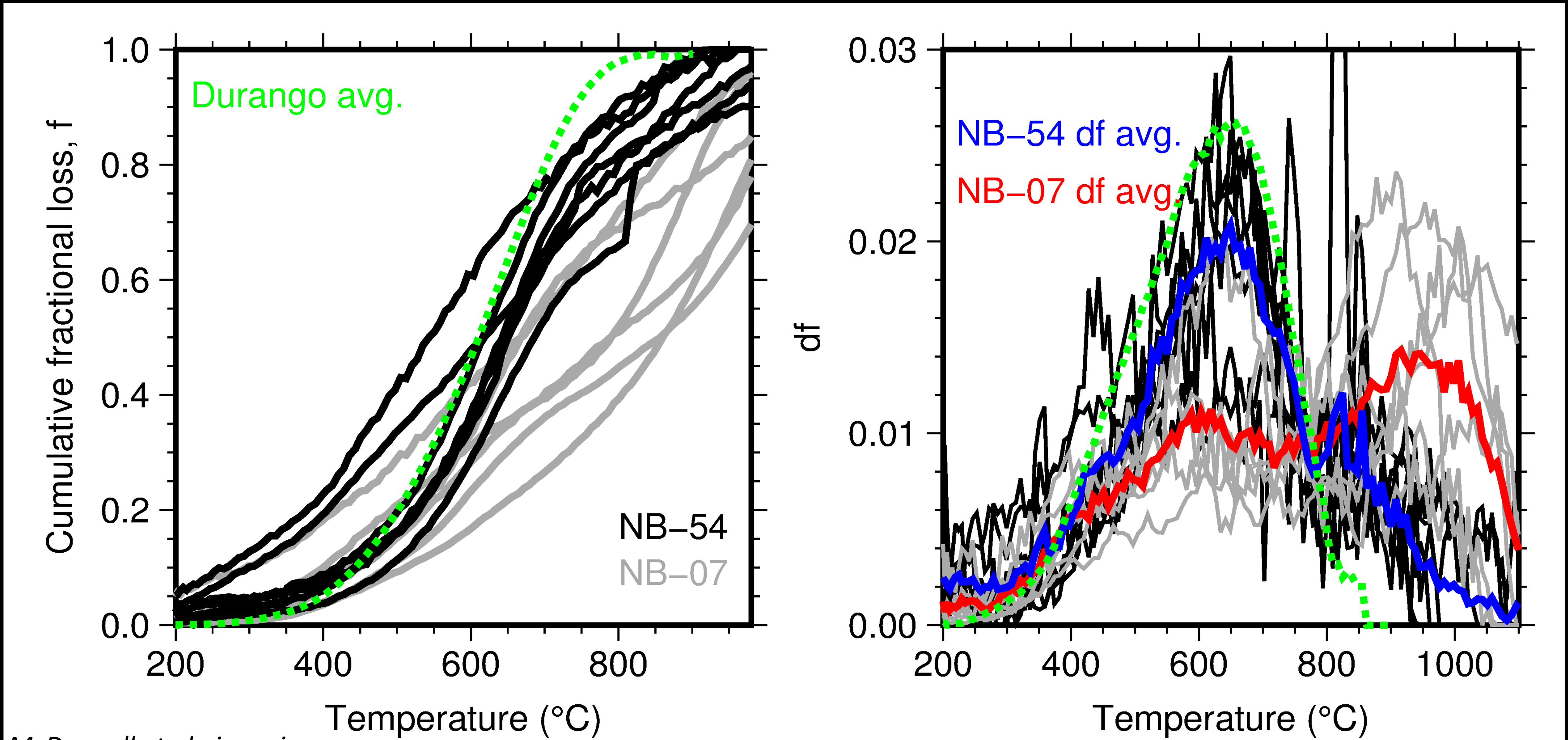
Observed: 51 – 103 Ma, 69 ± 24

Corrected: 27 – 48 Ma, 37 ± 9



CRH age correction: Tibet bad actors

	NB07 (n = 6/2) (5 – 7 Ma)	**NB54** (n = 7/5) (< 15 Ma)
Observed:	9.7 – 46 Ma, 22 ± 14	10.4 – 30 Ma, 15.4 ± 6.7
Corrected:	5.8 – 7.1 Ma, 6.4 ± 1	5.9 – 9.3 Ma, 8.2 ± 1.3



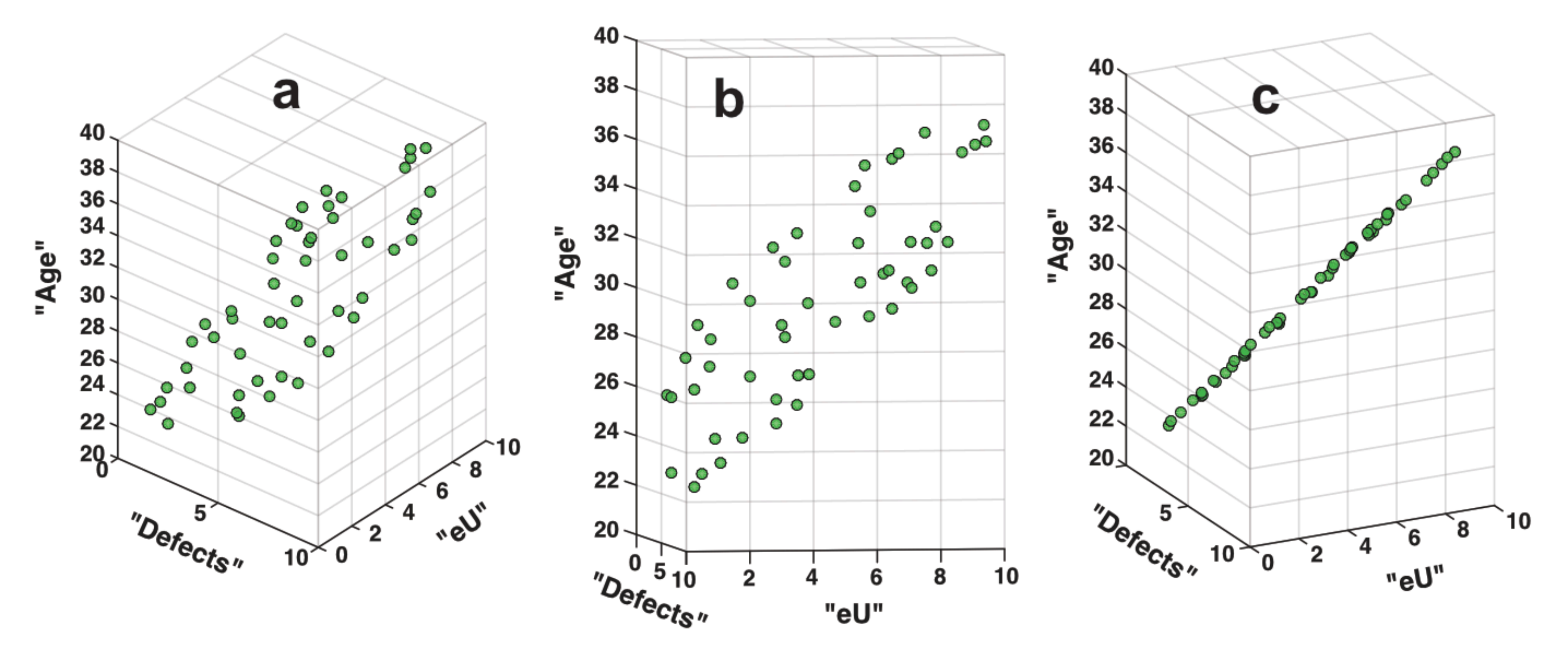
McDannell et al., in review

What's going on with "excess" dispersion?

We're looking at a lower-dimensional projection of a higher-dimensional space!

With low *n*

Some times we get luckier than others



Are defects the answer?

Regardless of model, a critical question for apatite helium thermochronometry is whether the total abundance of defects affects the helium retentivity in the low temperature regime and, if so, how and when the defects are acquired

Farley, 2000

Yes, but…

Which types of defects matter?

At what densities?

How do they form and anneal (if at all)?

What are the sources of excess ^{4}He?

- external environment?
- self-pollution with radiogenic production?

As for CRH analysis…

Continued technique development

Intensive study of well-constrained sample suites

Can age correction work reliably?

- Nature of spike and high-T components
- What's happening in lab versus nature?

Insights from ^{4}He/^{3}He analysis

Use sample kinetics rather than blanket model?

CRH analysis: zircon