Significance of micropores and low noble-gas solubilities for thermochronology

Peter Zeitler (Lehigh University)

In collaboration with Eva Enkelmann, Lenny Ancuta, Bruce Watson, and Jay Thomas

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A fundamental assumption, untested

$$t = \frac{1}{\lambda} \ln\left(\frac{{}^{4}He_{meas} - {}^{4}He_{init}}{8 \cdot {}^{238}U} + 1 \right)$$

Arguments for ignoring $^{4}He_{init}$:

- $^{4}He_{init}$ is difficult to assess
- low atmospheric ^{4}He abundance
- high He mobility – (de)sorption, diffusion…
- U-Th/He method "works"

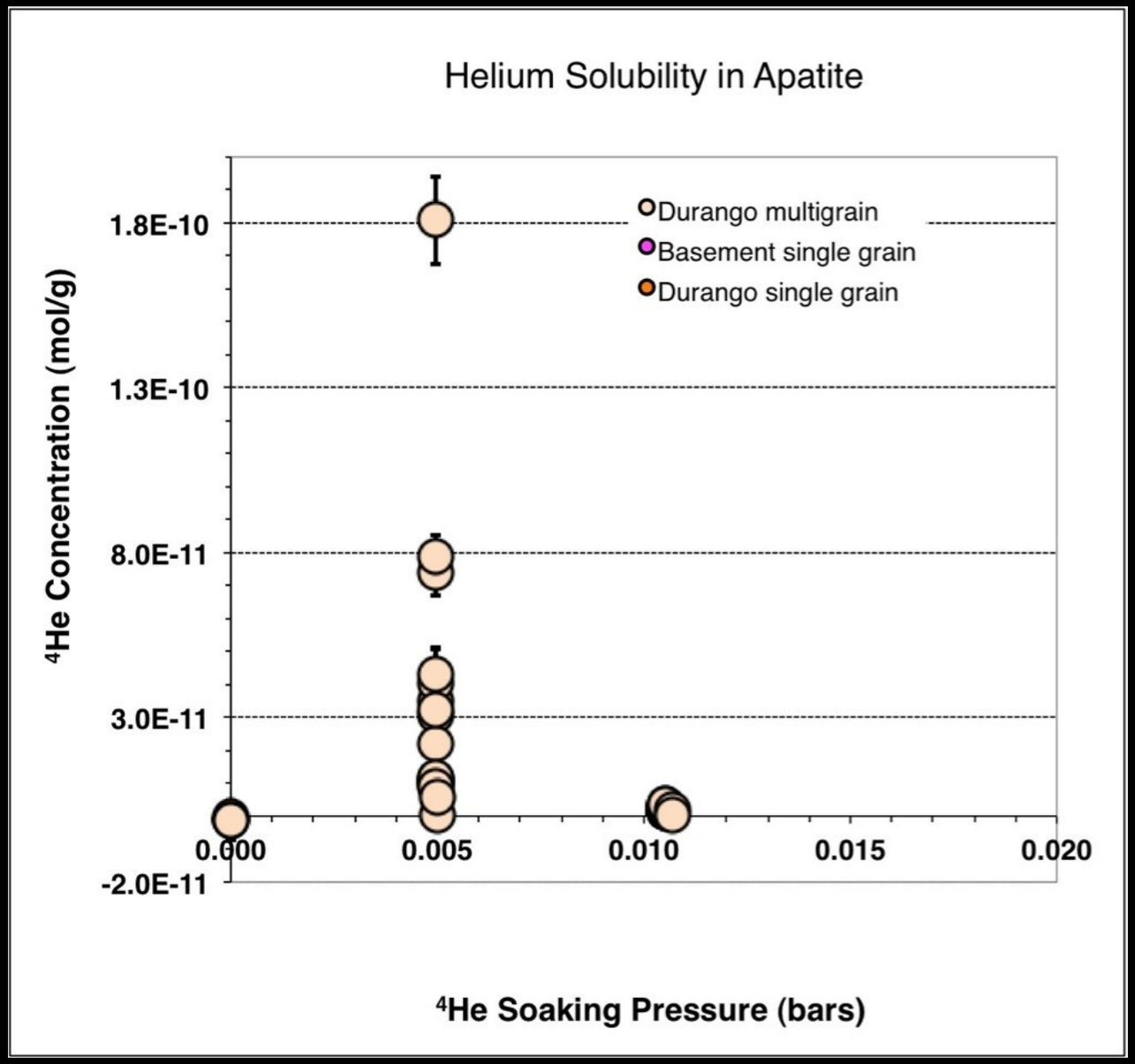
So what <u>is</u> the solubility of He in apatite?

Study using "soaking" experiments with ^{4}He:

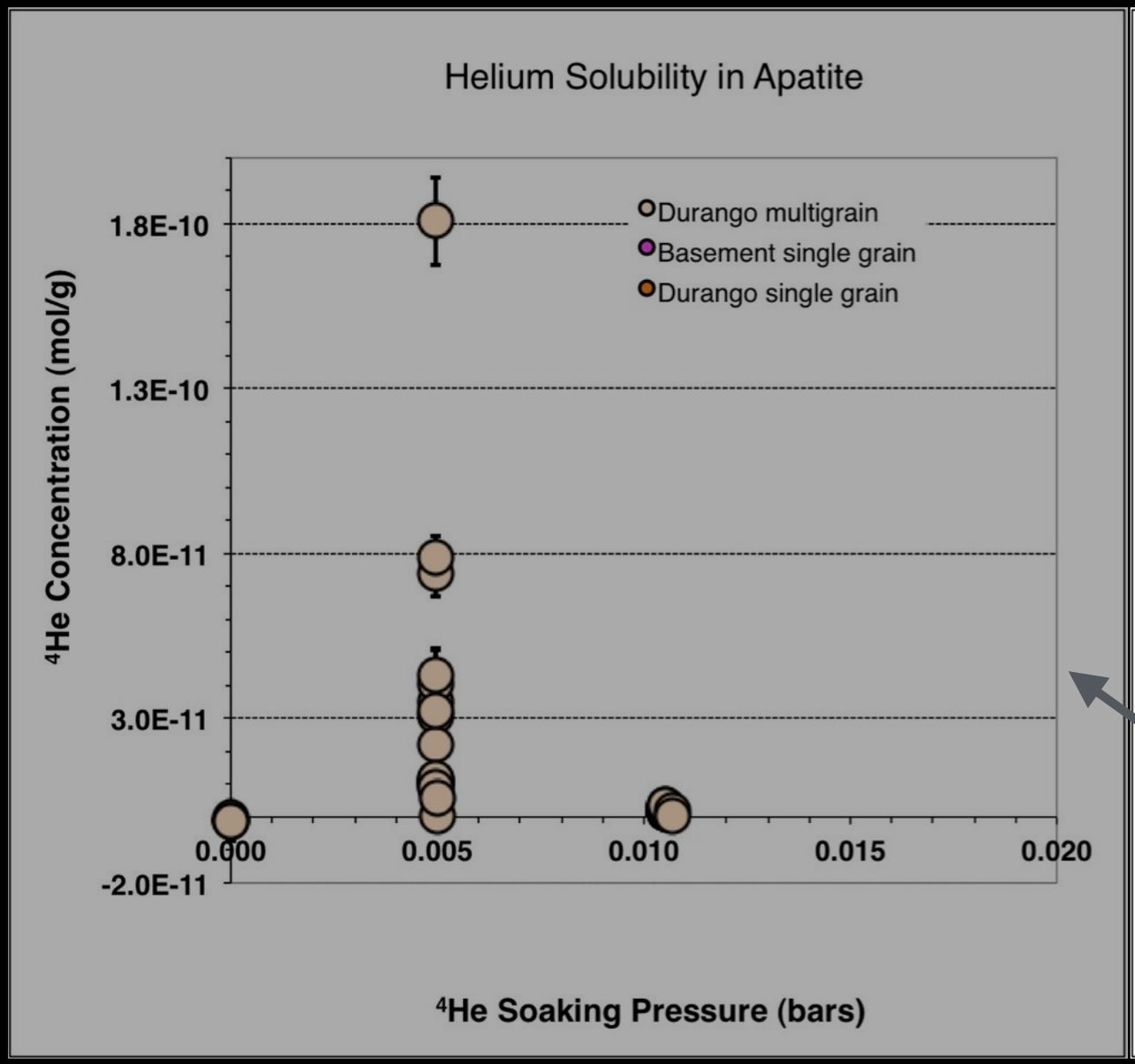
<u>low-P</u>: pressurize extraction line to 5-10 mbar; sample in furnace at 200-900°C; up to 24 hours

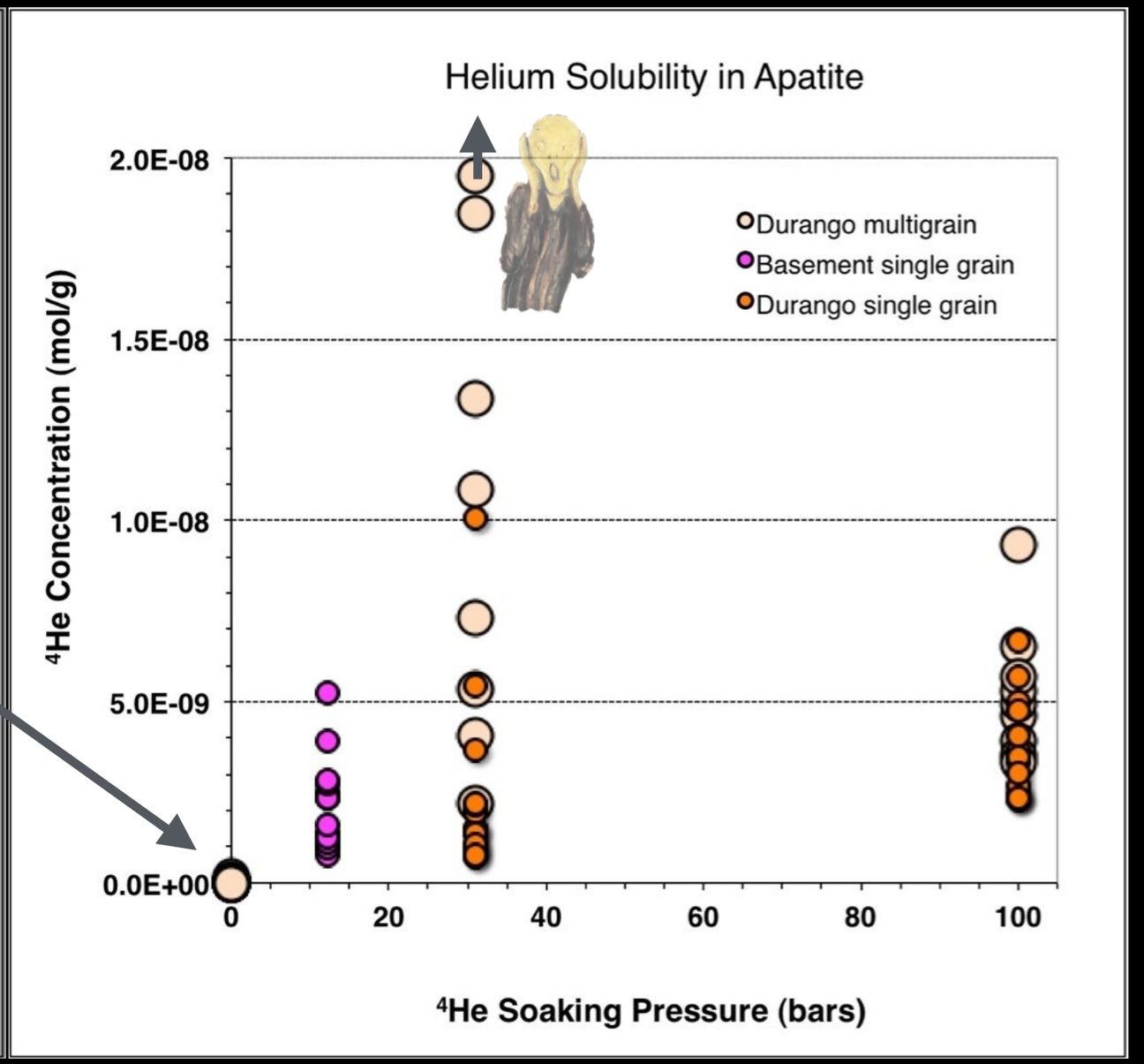
<u>high-P</u>: pressures of 12 to 100 *bars*; samples in heated boats at 530-650°C; 900 to 1400 hours

Solubility results



Solubility results





What's going on?

Watson and Cherniak (2003):

Micropores (née fluid inclusions) control Ar uptake and apparent solubility in quartz

What about fluid inclusions in apatite?

- we know that they exist (including in Durango)
- small inclusions avoid decrepitation?
- at bars p_{He}, don't need large volume (~50 ppm_v explains uptake)
- what's their size distribution?
- could miss flincs under optical inspection

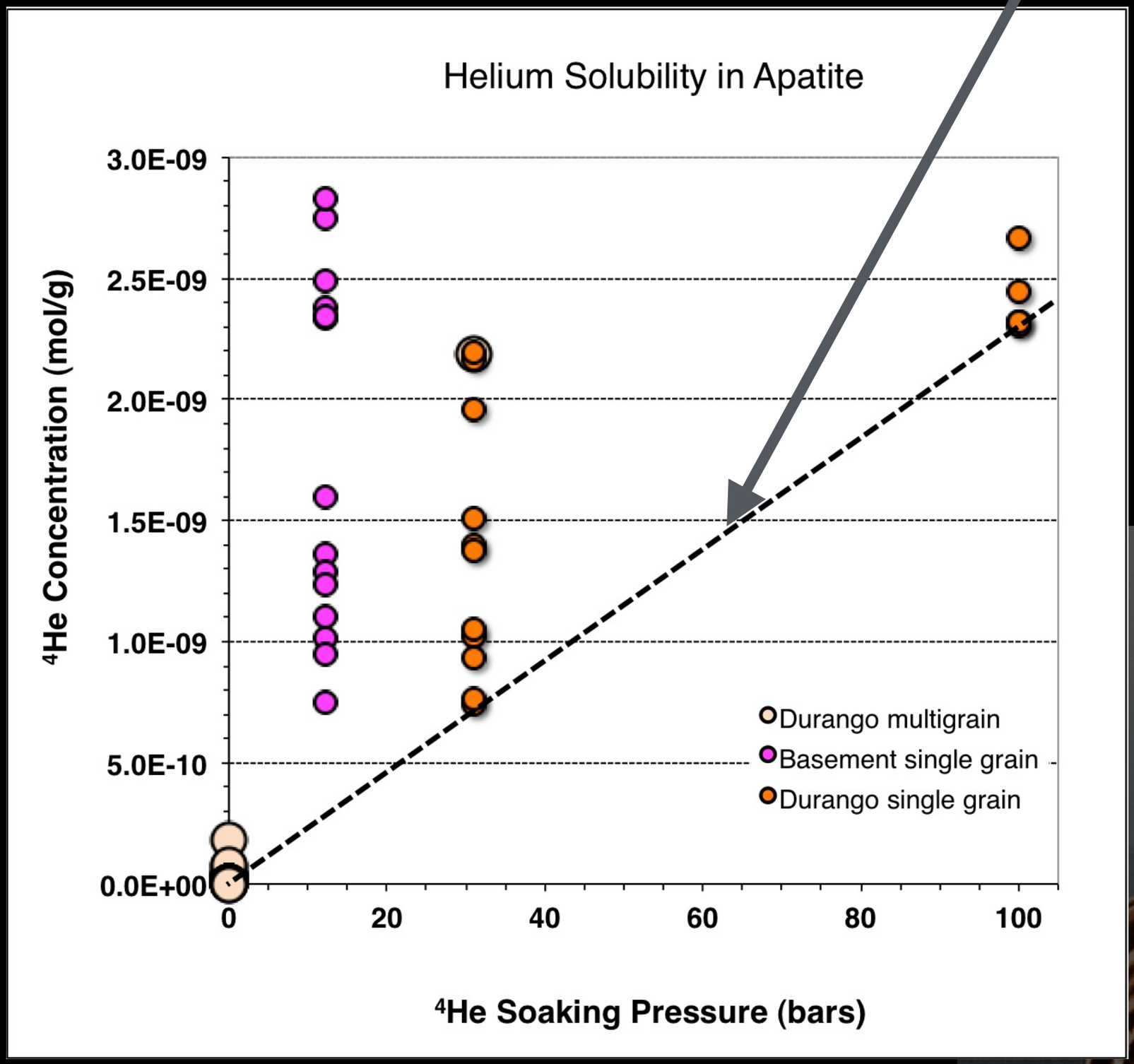
In vacuo crushing experiments: soaked samples

Sample	Comment	"Mechanical"
Durango	standard; 31 bars	48%
Durango	standard; 100 bars	16%
NC/MM4a	Appalachian slow-cooled; 12 bars	64%
NC/SY2AB	Appalachian slow-cooled; 12 bars	52%

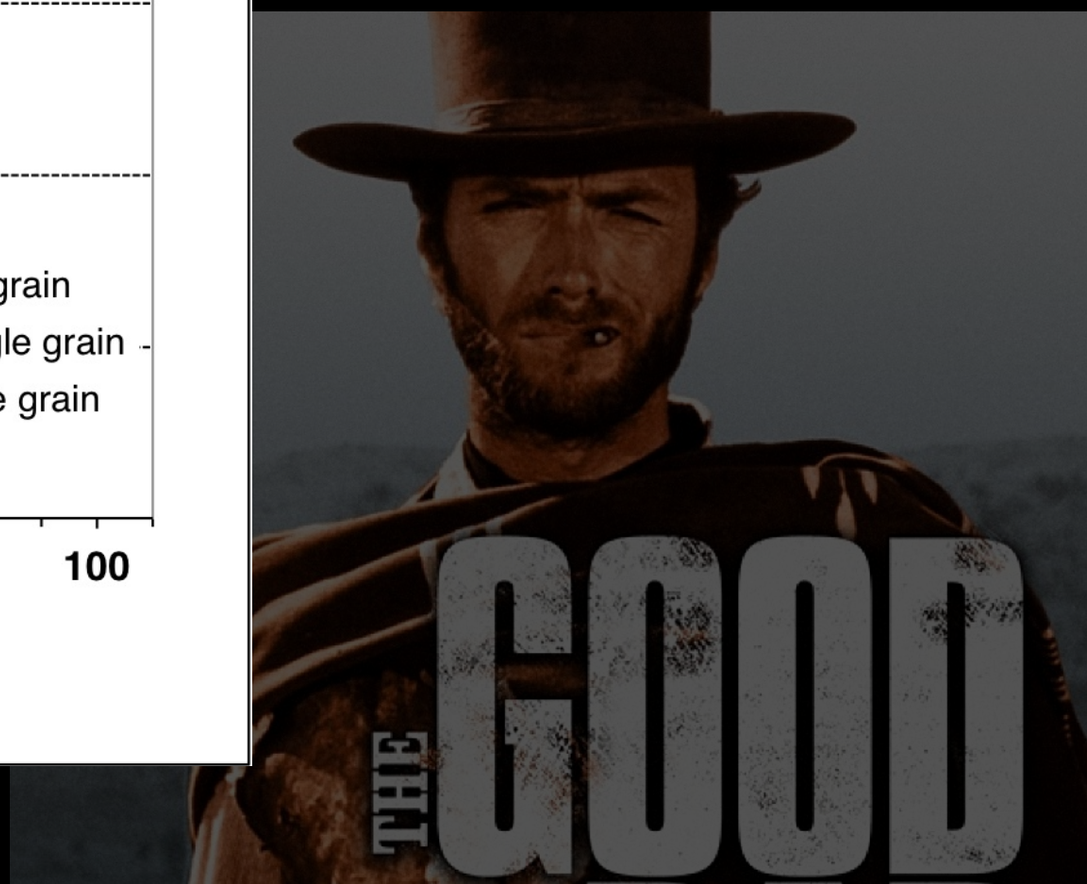
Micropores could explain scatter in solubility data

^{4}He solubility in apatite

$$< \frac{2.4 \times 10^{-11} mol}{g - atm}$$

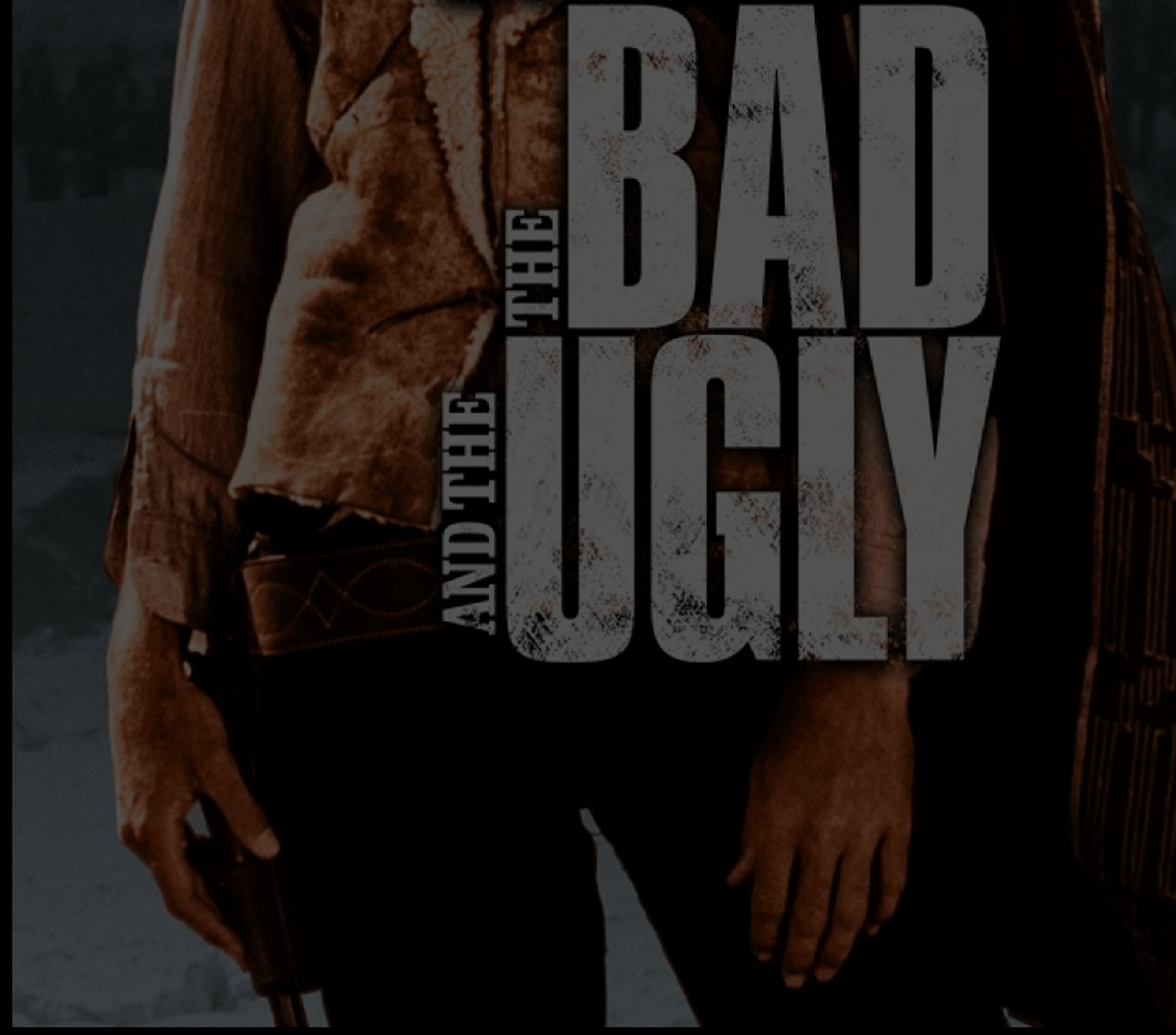


At this low solubility, p_{He} at closure depths is unlikely to ever cause problems

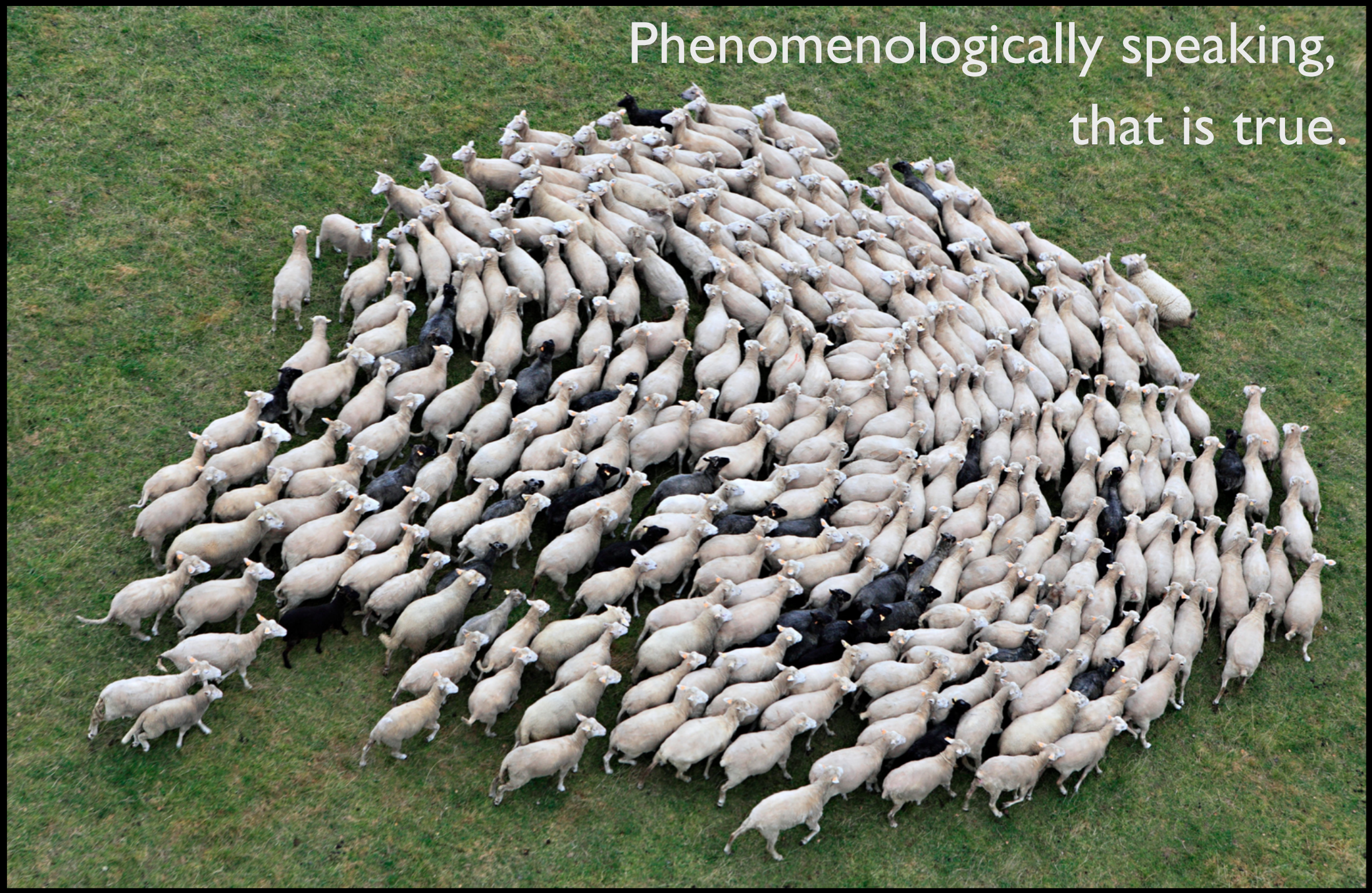


Nagging thoughts

So how <u>did</u> all that "mechanical" ^{4}He get into chips of clean, 'inclusion-free' Durango standard?



We all know that diffusion runs smoothly down the concentration gradient, right?



But, for diffusing noble-gas atoms, the true path is a 3D random walk

$$\frac{R_{rms}^2}{L^2} = N$$

say L = 8e-10 m; R = 80e-6 m

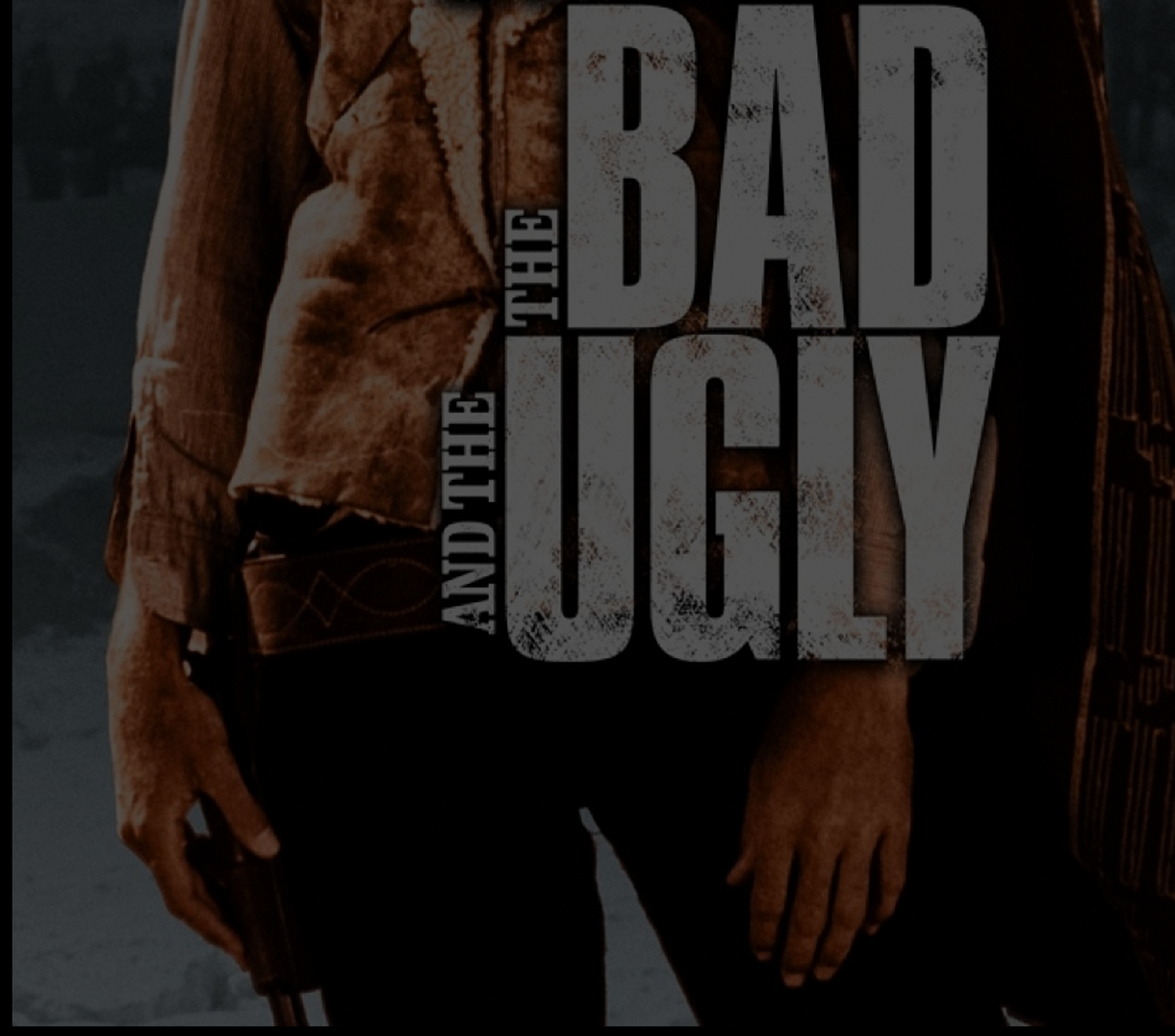
then N = 1e10

so total path = $N*L$ = 8 meters

- it takes a walk of meters to escape a grain
- total diffusion jumps is on the order of 10^{10}
- so the probability of encountering even a small void is high, even if voids occur only at ppm levels

Continued nagging thoughts

So, if even "clean"
grains can have a pores,
and if pores can trap
^{4}He, … uh-oh?



What happens to the radiogenic ^{4}He
produced during and before closure?
(that we assume just goes away)

In vacuo crushing experiments: natural samples

Sample	Comment	"Mechanical"
Durango	lab standard	0.5%
NB36-26	fast-cooled good actor	2.6%
GAM 209	fast-cooled good actor	2.6%
SN15	fast-cooled good actor	3.4%
NC/MM4a	Appalachian slow cooled	6.4%*
NC/SY2ab	Appalachian slow cooled	9.4%*
NB07-26	fast-cooled bad actor	53.1%

* Radiogenic self-pollution: another source for dispersion?

How to cope?

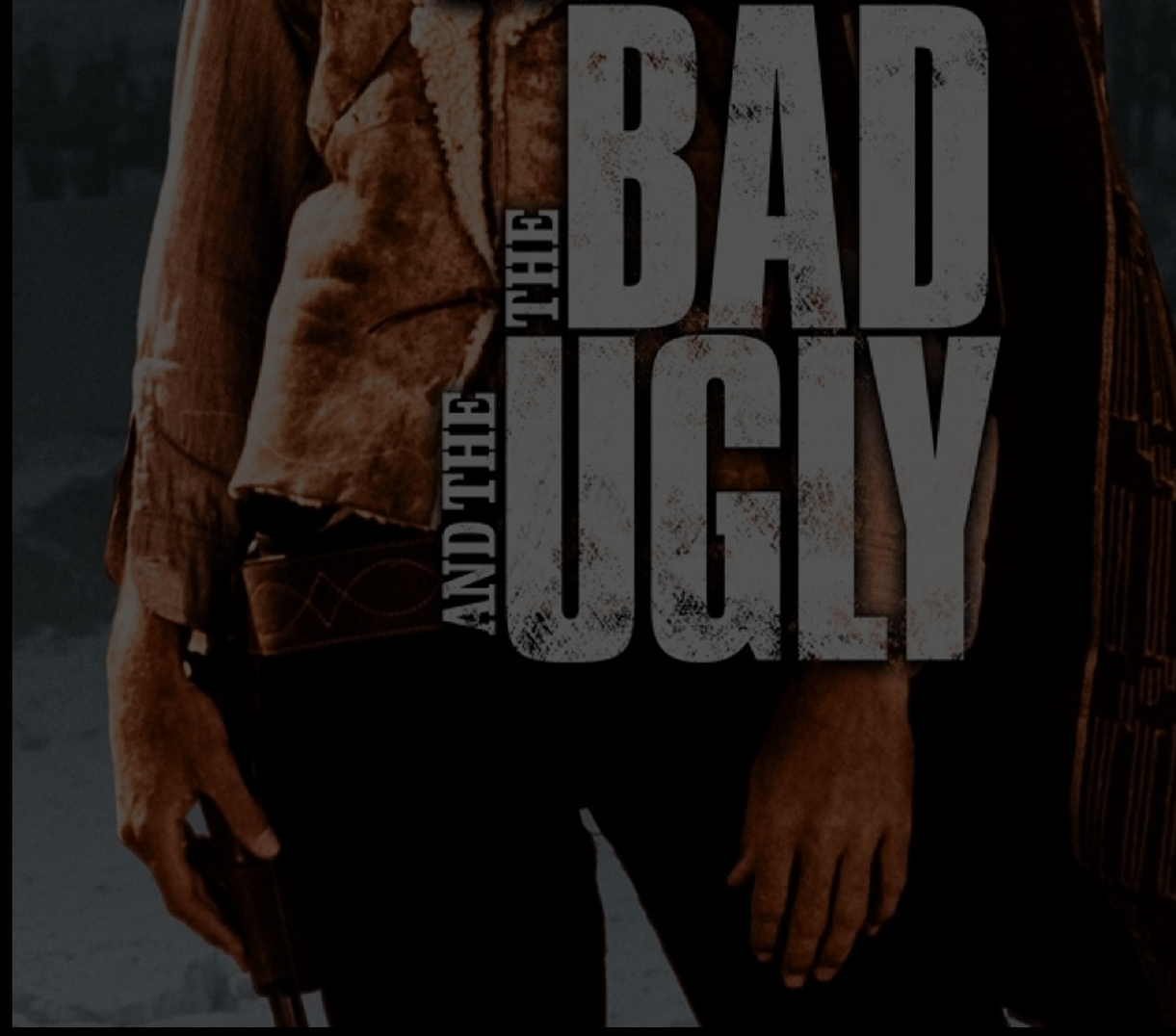
Hard to see how samples yielding mechanical ^{4}He could be used for thermochronology

Crushing is unwieldy

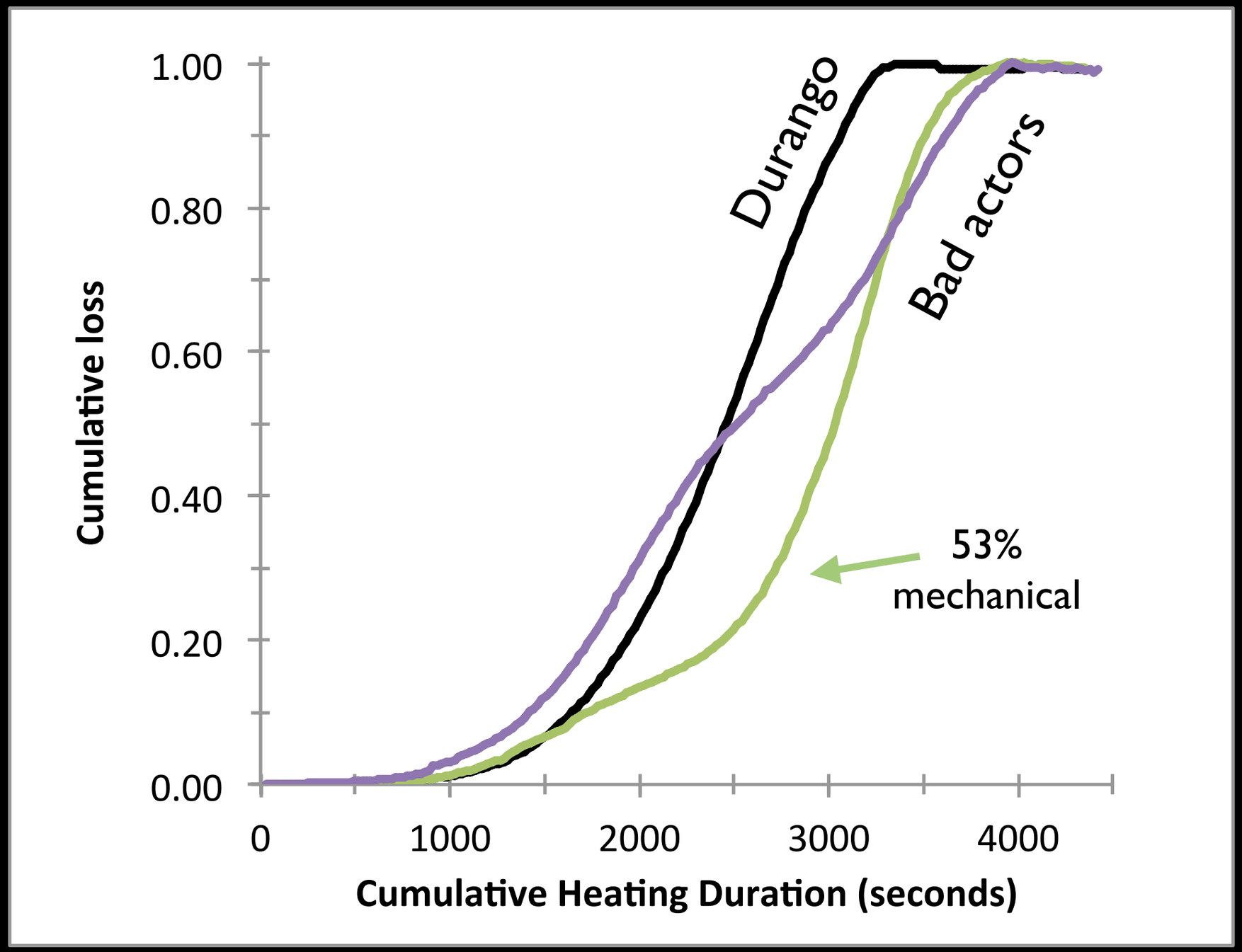
- hard for single grains
- hard to recover shards
- slow

^{4}He/^{3}He might work

- slow (requires irradiation)
- ~costly for routine screening



Screening by continuous heating/accumulation**



** Poster S1-7, Idleman and Zeitler, "Rapid characterization of noble-gas kinetics using continuous heating and gas accumulation"

Lessons

Apatite ^{4}He solubility is low: we can ignore this component

Micropores can trap helium within grains

‘Mechanical’ helium component might be ‘not uncommon’

- can slowly cooled apatites auto-contaminate themselves?
- we can screen for this by rapid step-heating

To-do: crushing, screening, characterization