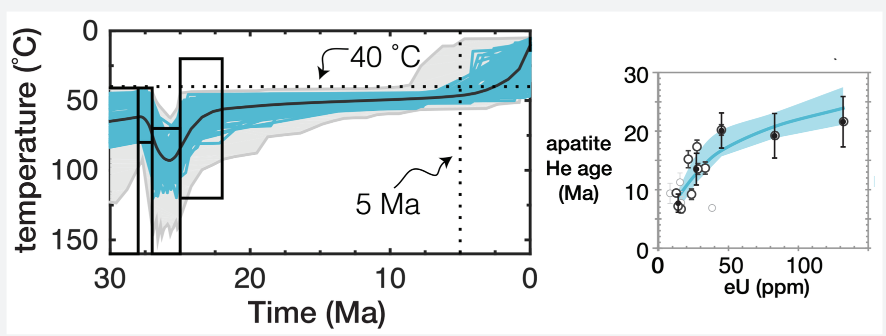
Know (all!) your assumptions, investigate the sensitivities: Towards more rigorous thermal history modeling practices

Kendra E. Murray
Department of Geosciences, Idaho State University
Nathan A. Niemi
Department of Earth and Environmental Sciences, University of Michigan—Ann Arbor

Thermo2020 Santa Fe, NM

THE THERMOCHRONOLOGY COMMUNITY NEEDS BETTER STANDARDS FOR MODELING BEST PRACTICES

Currently, and through no fault of any one study or modeling program, published models are a patchwork of modeling philosophies, assumptions, and auxiliary hypotheses that are rarely sufficiently explored—to the frustration of authors, readers, and reviewers.



Congratuations! you have a distinctive thermal history. But...why? You need to investigate how robust this signal is, but there are no clear standards for what this means in practice. Example model result from Murray et al., 2016.

our community needs to both embrace a diversity of modeling approaches and collectively discuss and set broad expectations for thermal history modeling

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this requires an ongoing conversation

How do you answer these questions?

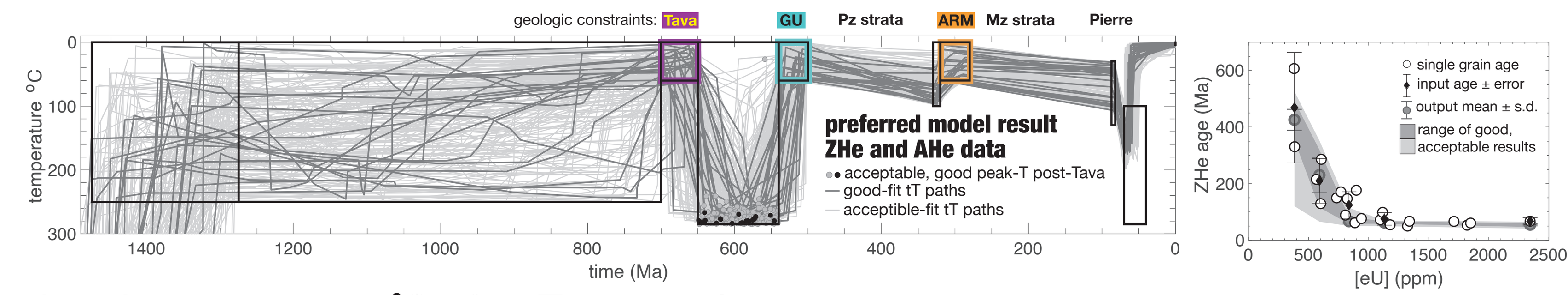
- What characterizes a “robust” thermal history model result?
- How can and should a model result’s rigor be demonstrated?
- How should one communicate the layers of interpretation that produce a preferred thermal history result, and the geologic interpretation of that result?

Here, we argue that the fundamental characteristic of any robust thermal history model result is that it is accompanied by a clear articulation of “THE WHY”.

THE WHY: the reason(s) that a model produces a distinctive history, be it the power of a geologic constraint or assumption, a grain’s age, a spatial relationship between samples, the choice of kinetic model, etc.

OUR EXAMPLE RESOLVES A DISTINCTIVE NEOPROTEROZOIC HISTORY

But why? How robust is this result?



- heating to 235-285°C after Tava emplacement
- cooling to surface conditions before Paleozoic deposition on the Great Unconformity

interpretation: 3-10 km burial in Neoproterozoic rift basin related to break-up of Rodinian supercontinent

Additional modeling reveals 3 main reasons for this distinctive result.

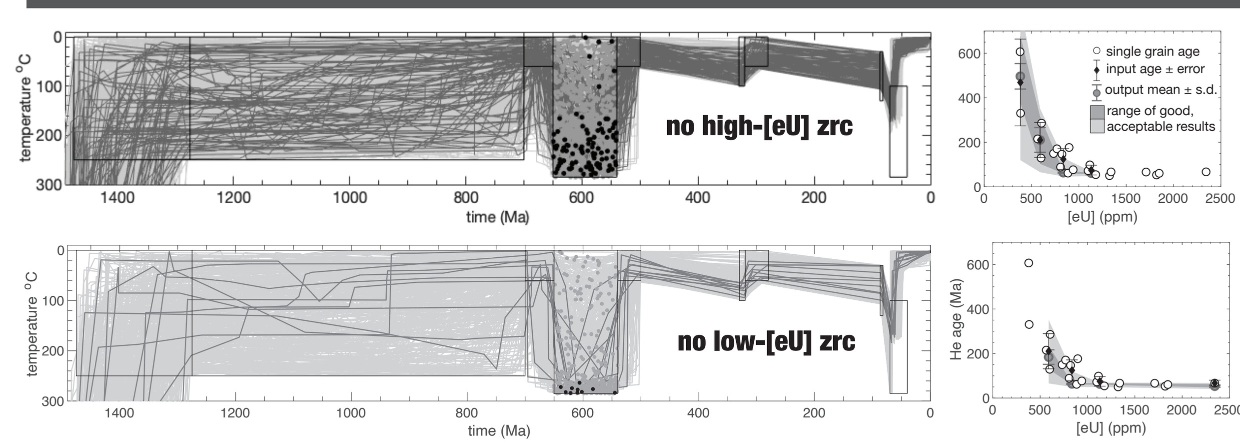
1. there is no more than 600-700 Myr of net radiation damage accumulated in the zircon crystals dated

BUT:

2. published Ar/Ar ages require basement rocks were colder than ~250°C for most of the last 1.5 Gyr
3. the geologic record places these samples at the surface before 650 Ma and for most of the Phanerozoic

We also find that the temperature of heating is well constrained, but the timing is not. (4)

TEST: REMOVE HIGH- OR LOW-[EU] GRAINS



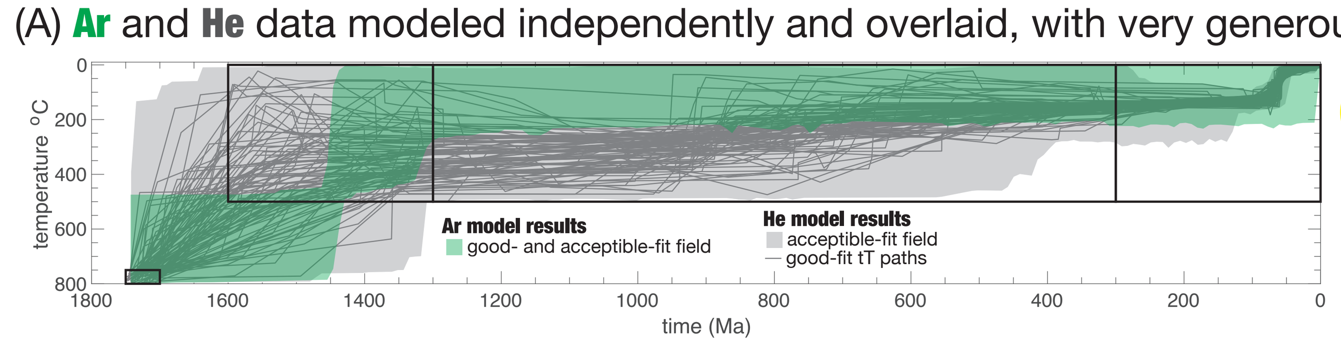
Does our result depend entirely on a single age?

the result is most sensitive to the most damaged, highest [eU] zircon crystals (top panel), not the oldest grains (bottom panel) (1)

TEST: START WITH GENERIC MODELS, SYSTEMATICALLY ADD CONSTRAINTS

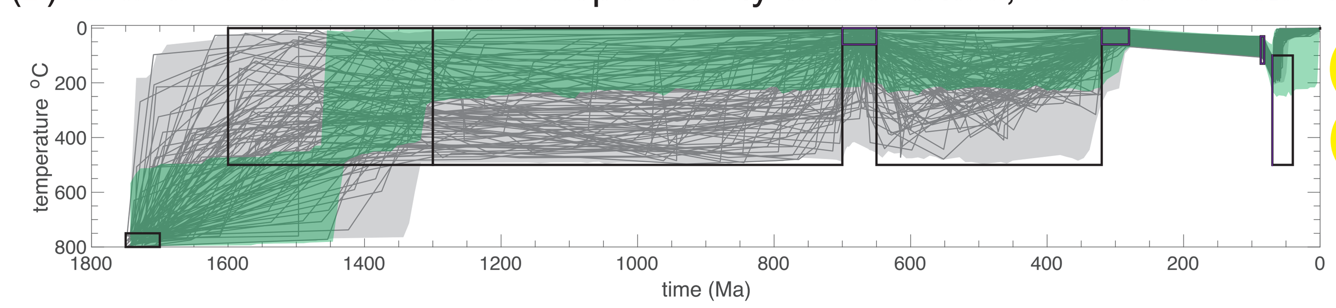
Which information are our results most sensitivte to?

(A) **Ar** and **He** data modeled independently and overlaid, with very generous exploration boxes



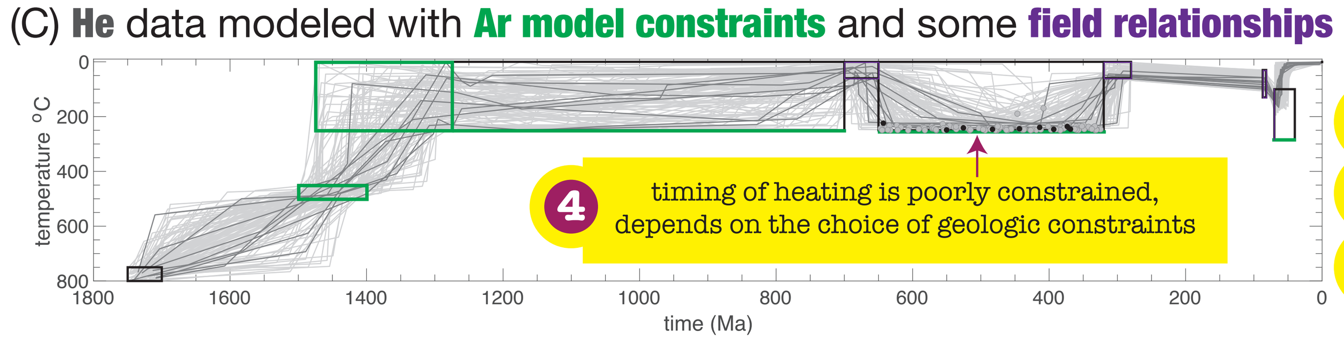
(2) Mesoproterozoic hornblende and biotite Ar/Ar ages require T<~250-280°C since ca. 1300 Ma • He ages on their own are insensitvie to the Proterozoic history

(B) **Ar** and **He** data modeled independently and overlaid, with some **field relationships**



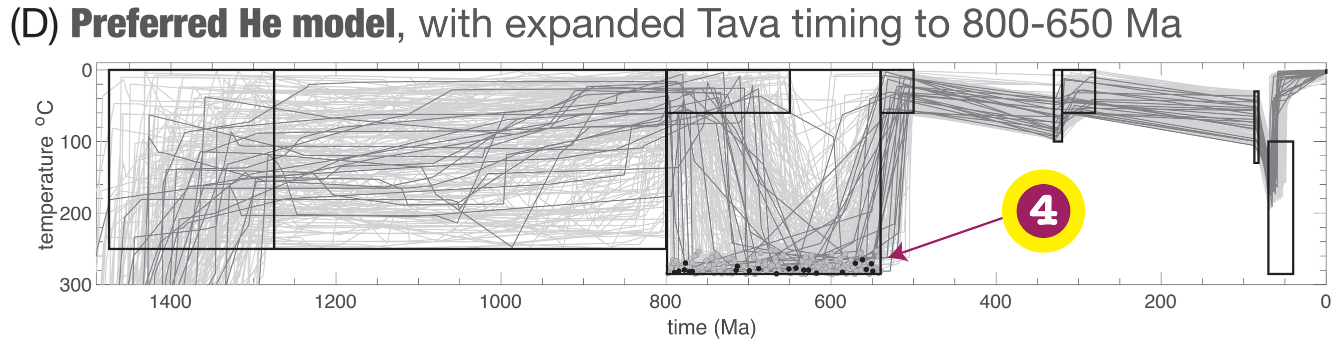
(1) (2) If rocks are permitted to be as hot as 500 °C before 650 Ma, then our Neoproterozoic heating event is not required • Ar ages are insensitive to the Phanerozoic geologic constraints (2)

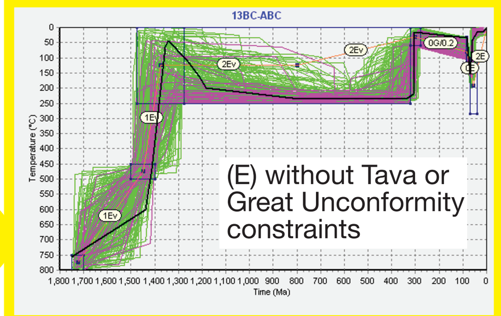
(C) **He** data modeled with **Ar model constraints** and some **field relationships**



(1) (2) (4) These rocks had to get hot enough for long enough in to fully reset both He content and radiation damage in zircon but not perturb the mica Ar/Ar systems. • Heating cannot happen after Ancestral Rockies (or Cambrian time, in our preferred model). (3)

(D) **Preferred He model**, with expanded Tava timing to 800-650 Ma





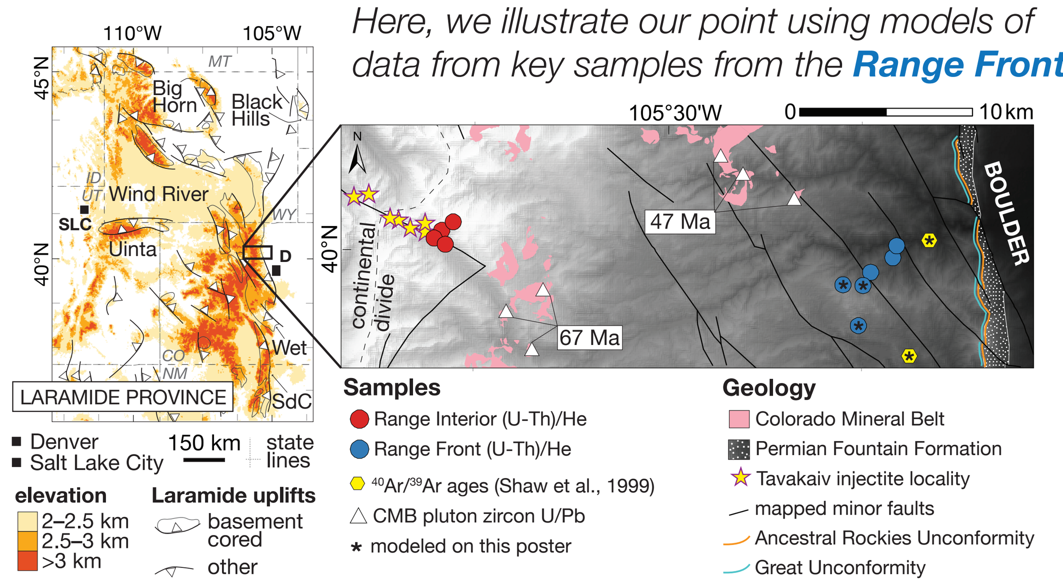
(E) without Tava or Great Unconformity constraints

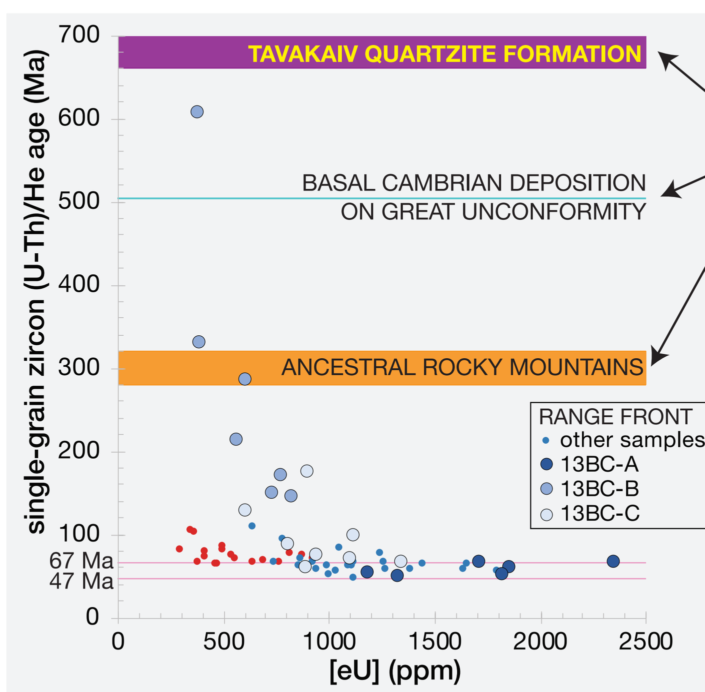
Even without the Tava and Great Unconformity near-surface constraints, the basement rocks needed to be hot, but not too hot, (~200-250°C) for 10s-100s of Myr in Proterozoic time. Exactly when is poorly constrained by the data. (1) (3) (4)

FINDING THE WHY: AN EXAMPLE FROM DEEP-TIME THERMOCHRONOLOGY

1.7 Ga crystalline basement rocks, central Front Range, Colorado USA

*Here, we illustrate our point using models of data from key samples from the **Range Front**.*





Zircon (U-Th)/He data

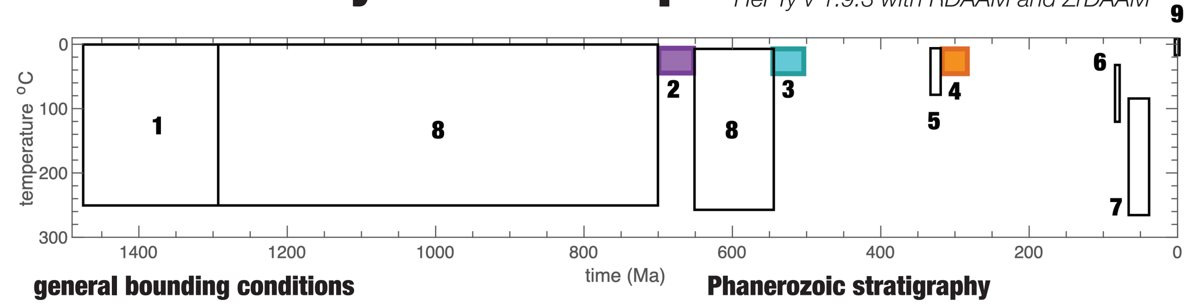
basement rocks were in the near-surface 3 times prior to the Cretaceous Laramide Orogeny

Qualititative Data Assessment

- Zircon He ages 607-50 Ma
- negative-slope age-[eU] pattern suggests that a pre-Cretaceous history is preserved in these rocks

Thermal history model set-up

run to find 100 good-fit paths or 1 mil attempts
HeFTy v 1.9.3 with RDAAM and ZrDAAM



general bounding conditions

0. 1.7 Ga crystallization of Boulder Creek batholith (not shown) Premo et al., 2000
1. Bt and Hbl Ar/Ar data: T<280-250°C after 1300 Ma (data from Shaw et al., 1999 modeled separately in HeFTy)
9. surface T today

near-surface conditions

2. Tavakaiv quartzite injectites by ca. 700-650 Ma Siddoway and Gehrels, 2014; Jensen et al., 2018
3. deposition on the Great Unconformity ca. 500 Ma (not preserved everywhere) Siddoway et al., 2013
4. Ancestral Rockies unconformity ca. 320-280 Ma Kluth and Coney, 1981; Leary et al. 2017

Phanerozoic stratigraphy

5. <1 km thick regional Paleozoic strata *Siddoway et al. 2013; Tewto, 1979*
6. <1 km thick local Mesozoic strata by 83 Ma Wruke and Wilson, 1969
7. 2.5 km thick Pierre Shale deposited 1.5 km deposited 70-68 Ma Scott & Cobban, 1965; Kauffman, 1977

exploration

8. where no geologic constraints

Different geologists translate these geologic constraints into tT space in different ways (cf. Flowers et al., 2020 & Ricketts et al., 2021)

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