Monazite fission-track dating of the Catalina metamorphic core complex, AZ, USA

Gilby Jepson[1], Barbara Carrapa[1], Sean Jones[2], Andrew Gleadow[2], and Barry Kohn[2]

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Abstract

Monazite fission-track presents itself as a novel, low-temperature thermochronometer with annealing studies placing its closure temperature between ˜45 and 25 °C. Previously, monazite has been unsuitable for fission-track dating due to high abundance of gadolinium and insufficient investigation of the etching protocol. Gadolinium causes self-shielding via thermal neutron capture and substantial associated nuclear heating during irradiation which prevented robust monazite fission-track dating using the traditional external detector method. Further, early etching studies were found to be extremely corrosive to monazite grains. However, developments in LA-ICP-MS fission-track analysis allow for measurement of 238U and improvements in monazite fission-track etching protocols mean that dating monazite through the fission-track method is now viable. In this study, we present monazite fission-track data from an elevation profile (2260 m, 2000 m, 1600 m, and 1200 m) from the Catalina metamorphic core complex (Catalina MCC), in southern AZ, USA. We follow the etching protocol described in Jones et al. (2019), etching the monazites in 6 M HCl for 90 minutes at 90 °C. We measure the 238U concentration via LA-ICP-MS and compare the dates to other multi-method thermochronology from the same rocks. Traditional low-temperature thermochronology (apatite and zircon fission-track, apatite and zircon (U-Th-Sm)/He) from the Catalina MCC reveals cooling at 25-20 Ma and 18-10 Ma. Preliminary monazite fission-track analysis yields a date of 6.1 $\pm$ 0.4 Ma, far younger than all the traditional thermochronometric data, in-line its far lower closure temperature. The 6 Ma monazite fission-track date is consistent with the youngest phase of hematite (U-Th)/He dates observed in the nearby Rincon metamorphic core complex and suggest that these dates correspond to the latest phase of exhumation in response to Basin and Range extension and/or climate enhanced erosion. These preliminary results show that monazite fission-track can reveal shallow crustal processes and contribute to constraining thermal histories below ˜60 oC, which are traditionally difficult to resolve.

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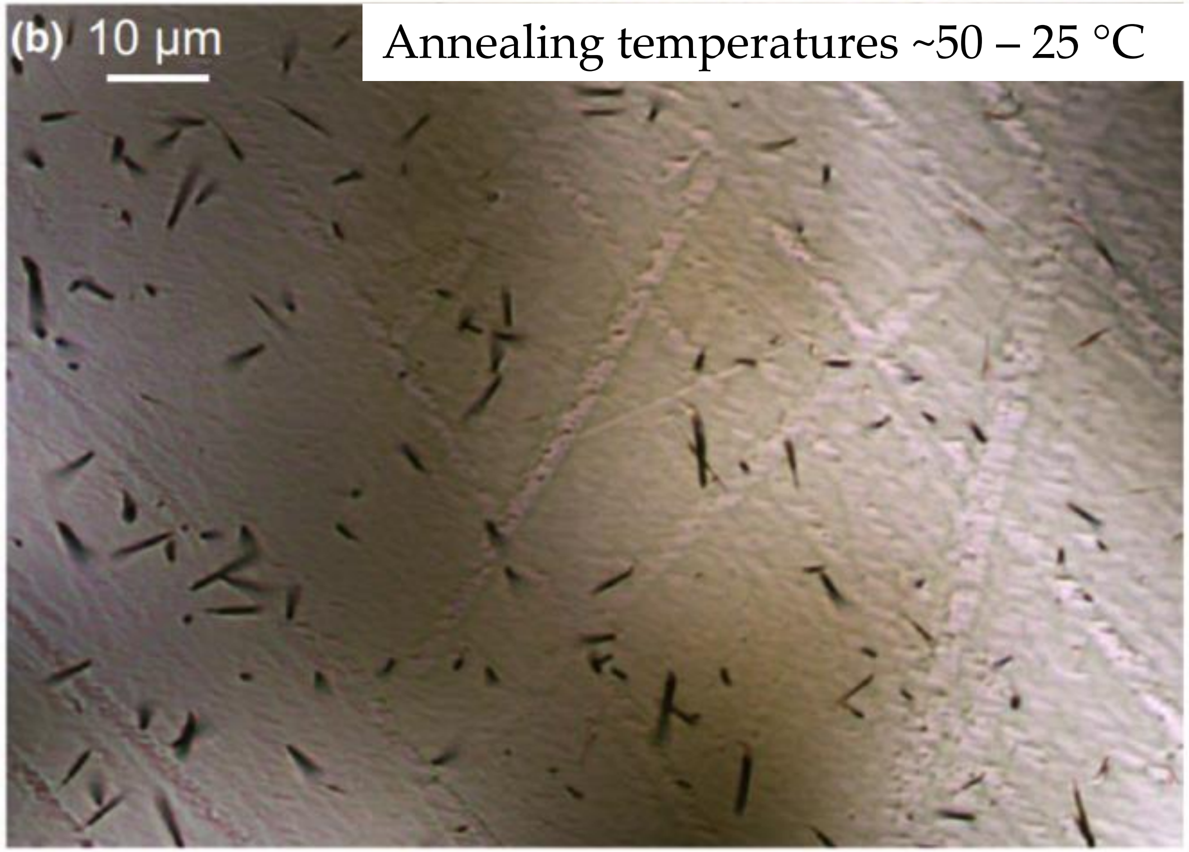
If we can etch monazite, we should be able to date it!*

Madagascar Monazite: Weise et al. 2009

Harcourt monazite: Jones et al. 2019

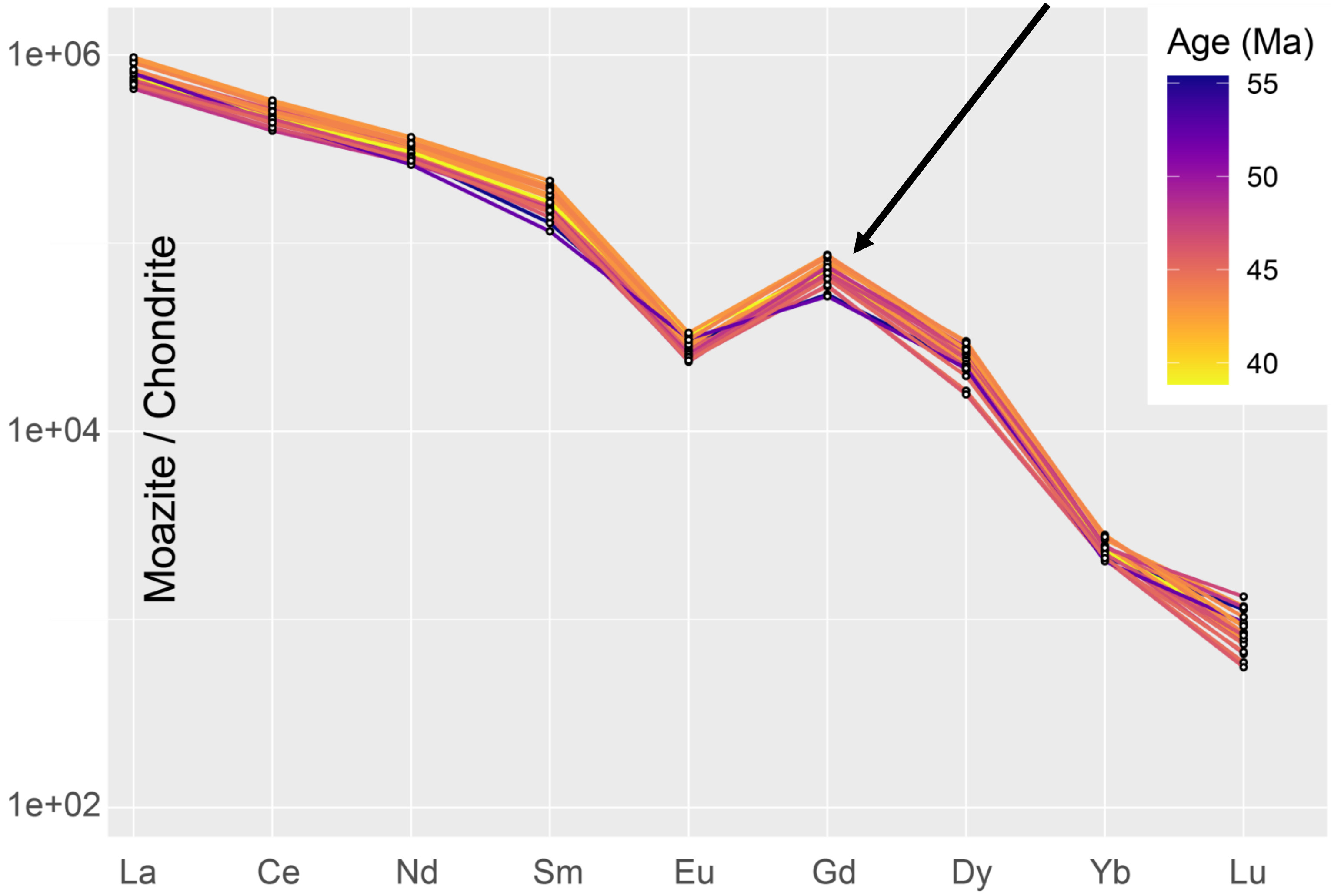


*But not with EDM

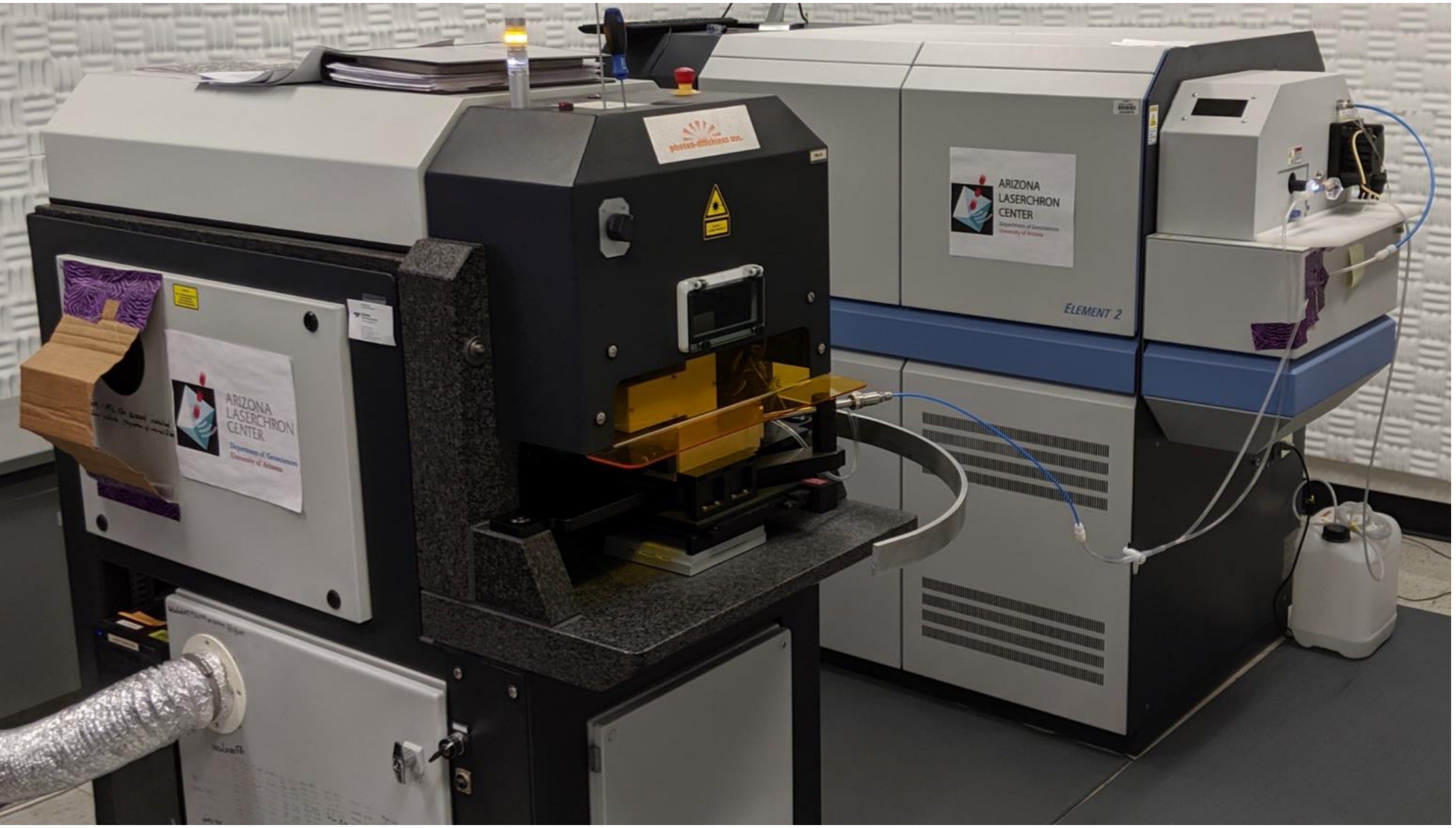
Monazite: a REE phosphate
(Ce,La,Nd,Th) (PO_4,SiO_4)

Blocks slow thermal neutron bombardment (Weise et al. 2009)

https://www.mineralatlas.eu

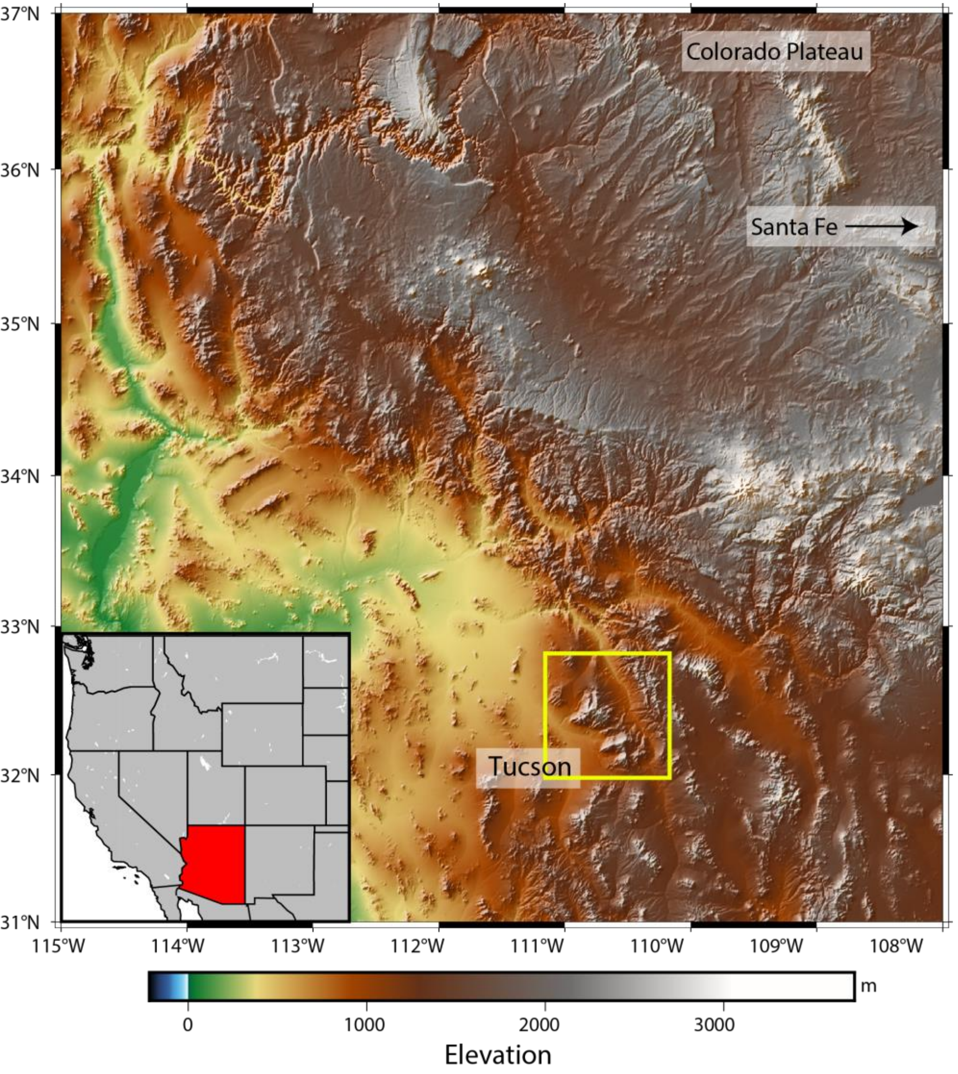


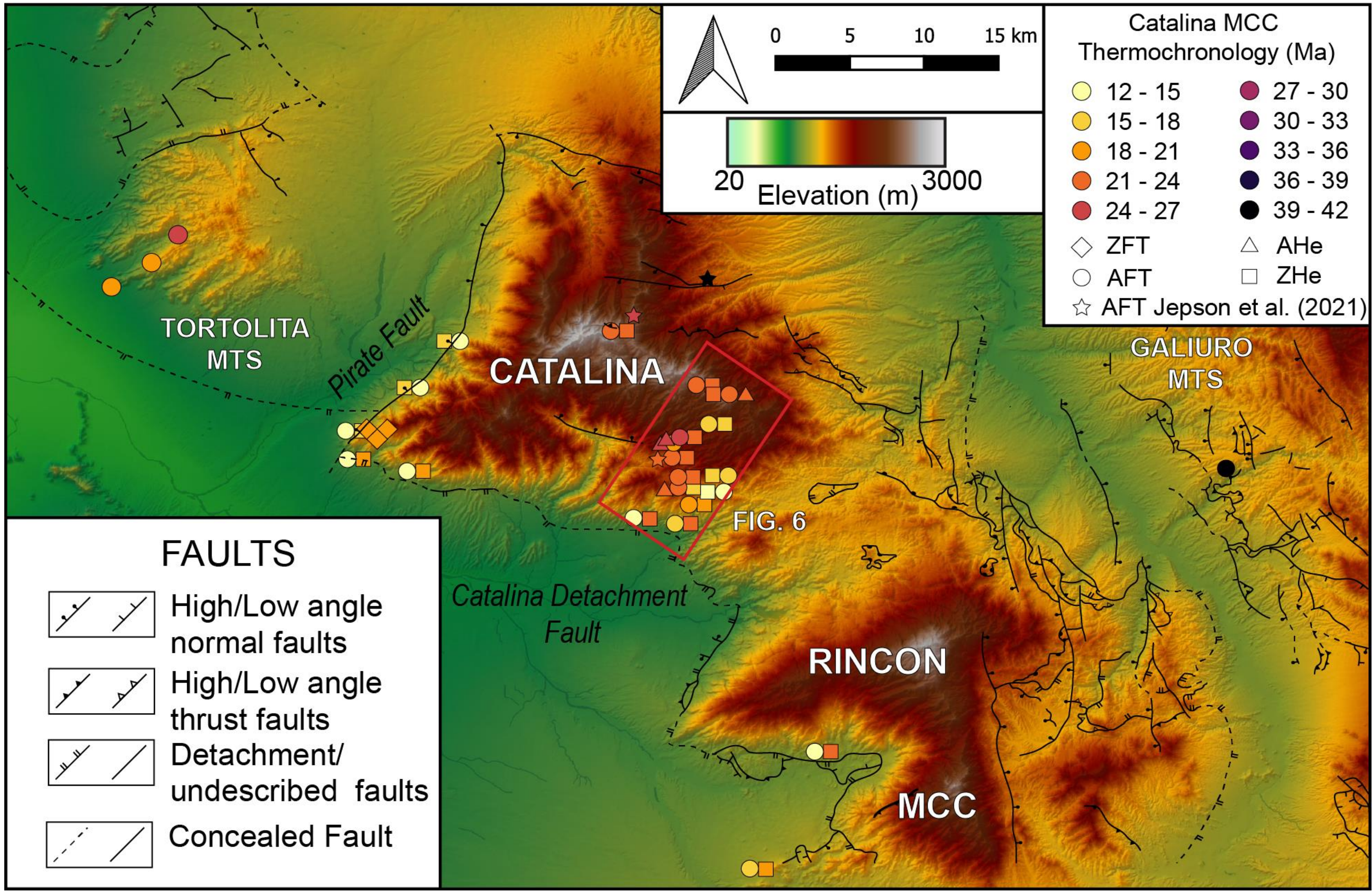
Approach: Laser Ablation FT



LA-ICP-MS set-up allows for single-grain monazite U-Pb and ^{238}U determination (Fayon, 2008).

Location: Catalina metamorphic core complex

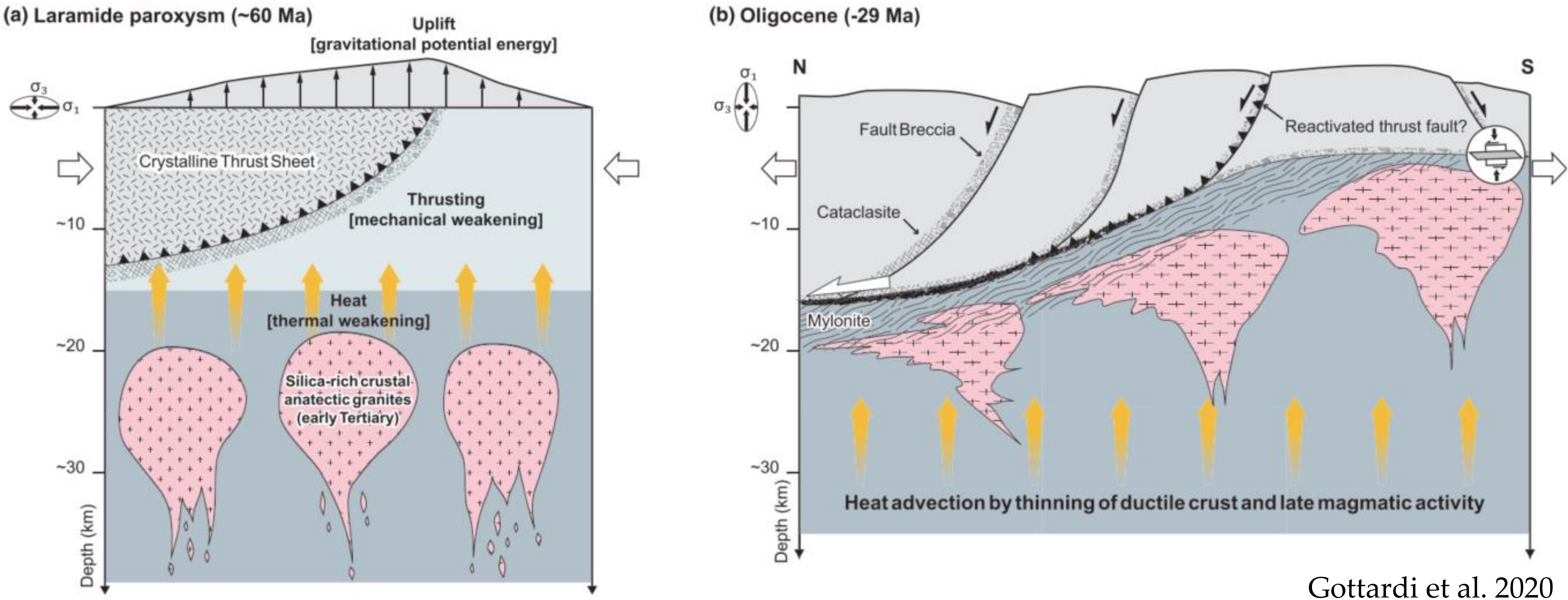




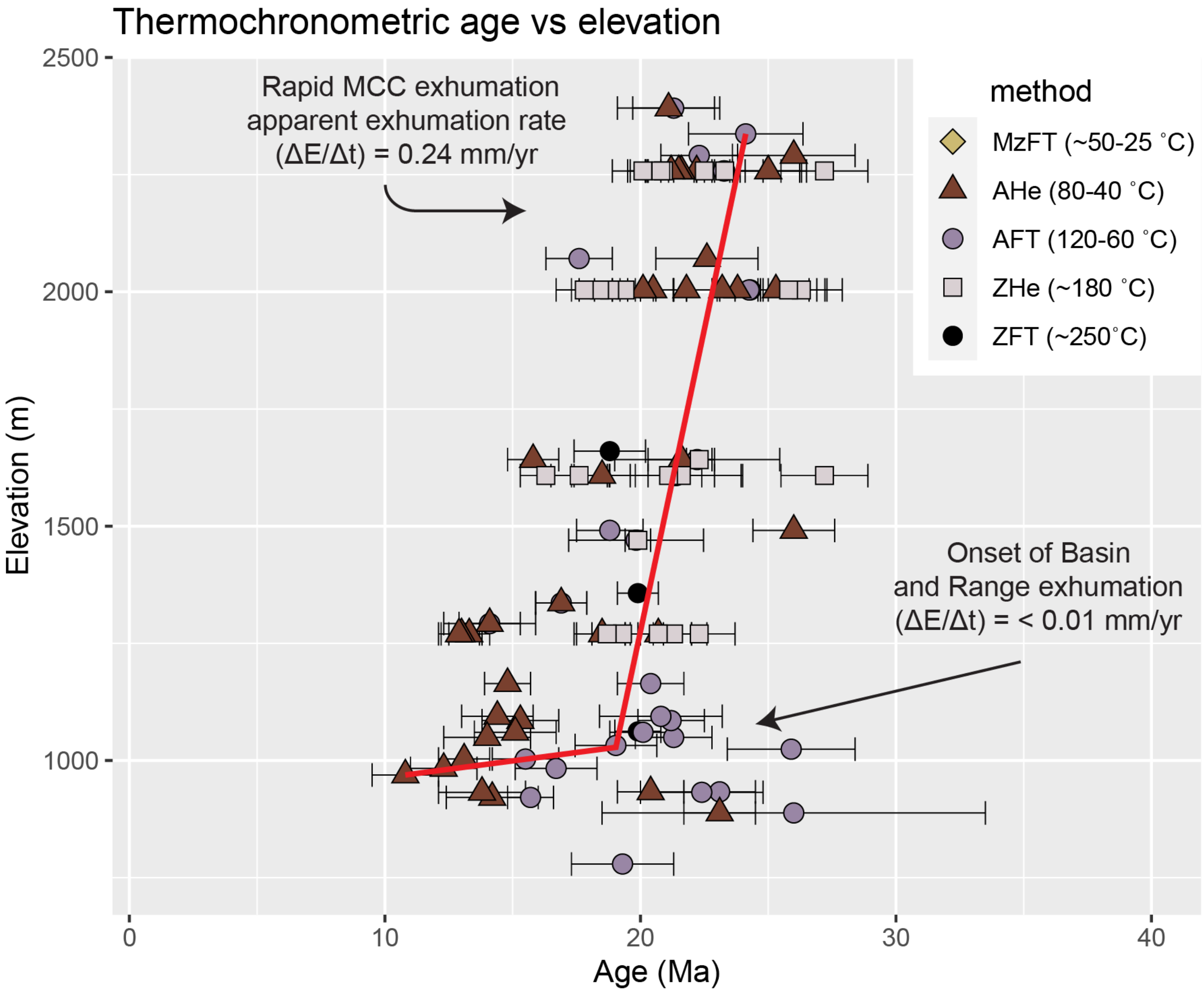
High-relief, geologically young, and covered with thermochronometric dates!*

*also nice and close for all the re-sampling required..

A metamorphic core complex

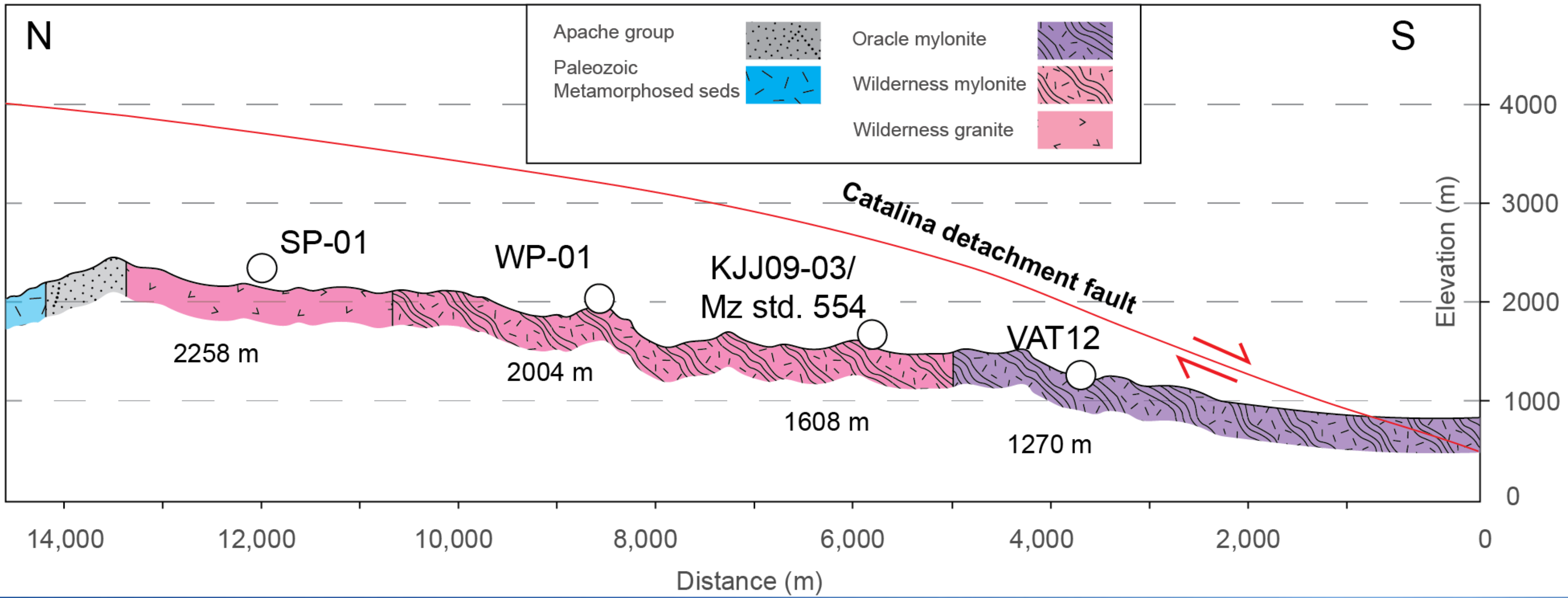


Gottardi et al. 2020



1) 26-19 Ma phase of rapid cooling observed in higher temperature thermochronometers and at higher elevations.

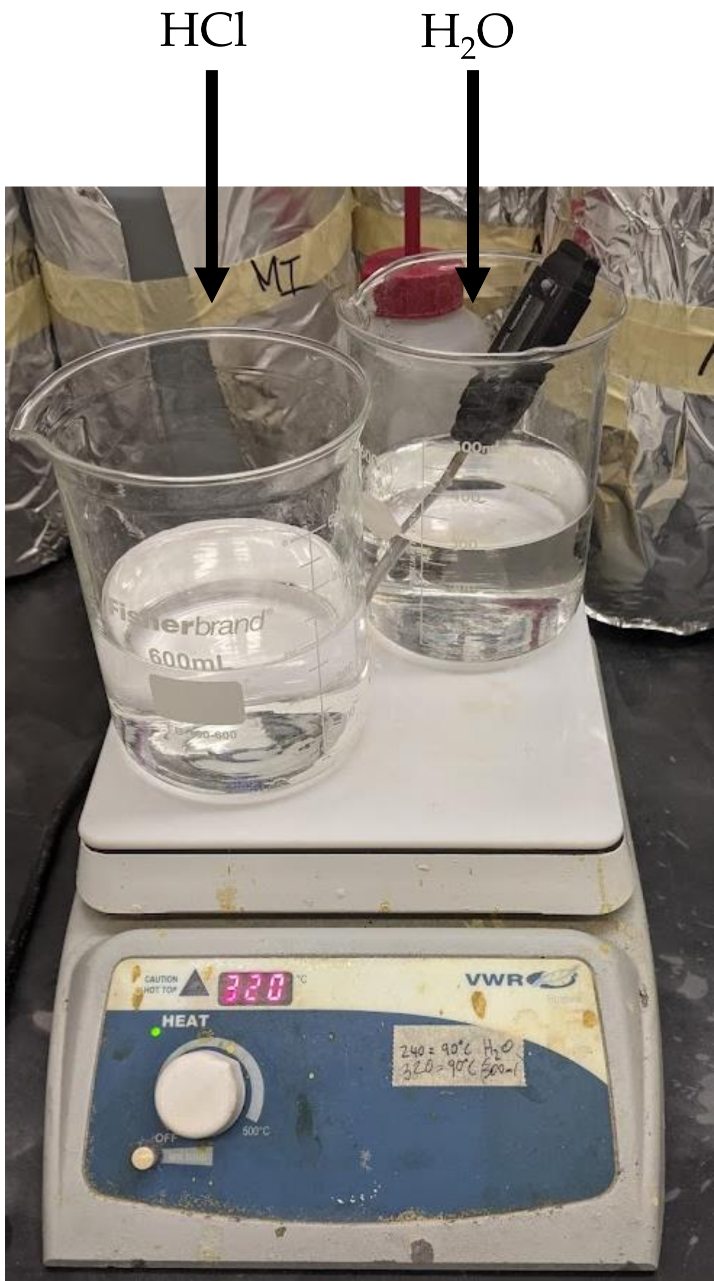
2) 19-11 Ma phase of slower cooling observed in lower temperature thermochronometers and at lower elevations


N
S
Apache group
Paleozoic
Metamorphosed seds
Oracle mylonite
Wilderness mylonite
Wilderness granite
Catalina detachment fault
SP-01
WP-01
KJJ09-03/
Mz std. 554
VAT12
2258 m
2004 m
1608 m
1270 m
4000
3000
2000
1000
0
Elevation (m)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Distance (m)

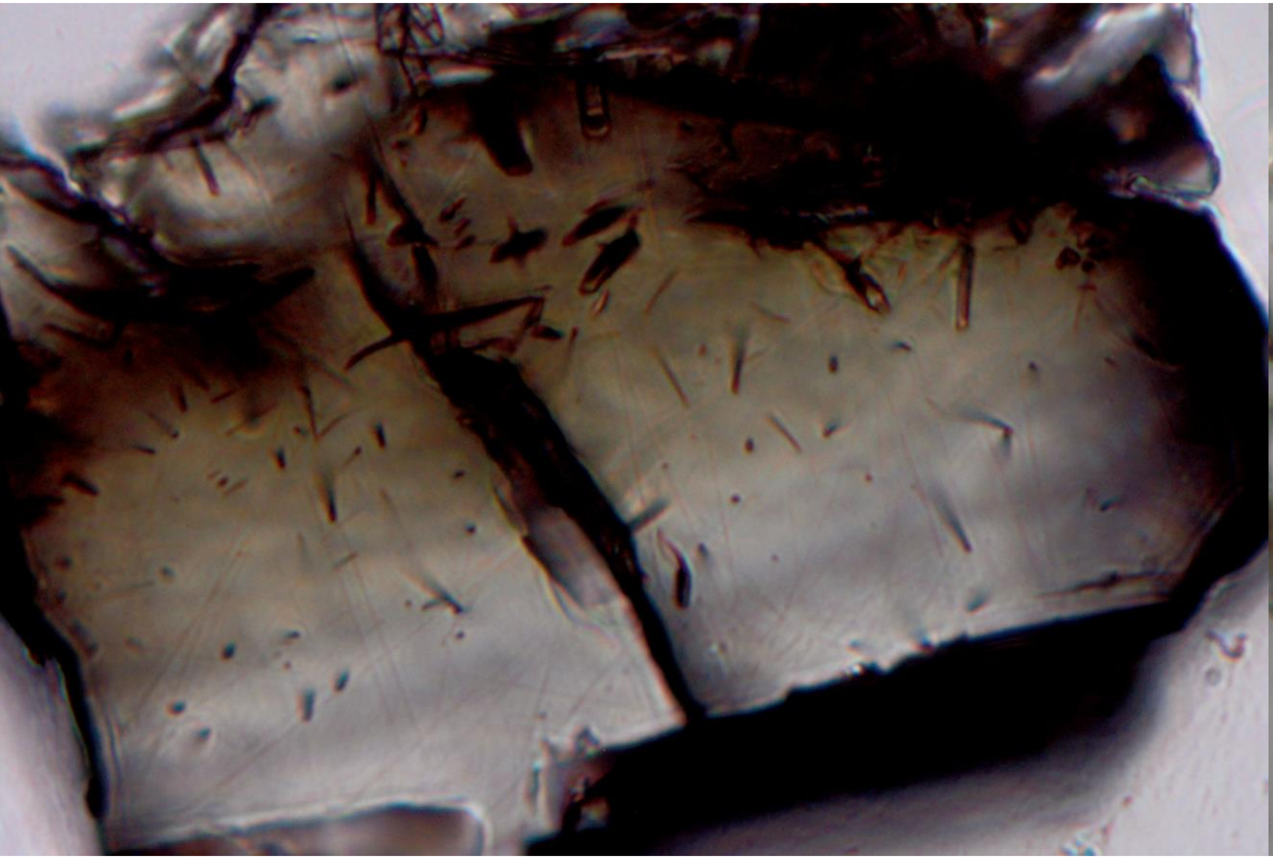

S
N

Etching:

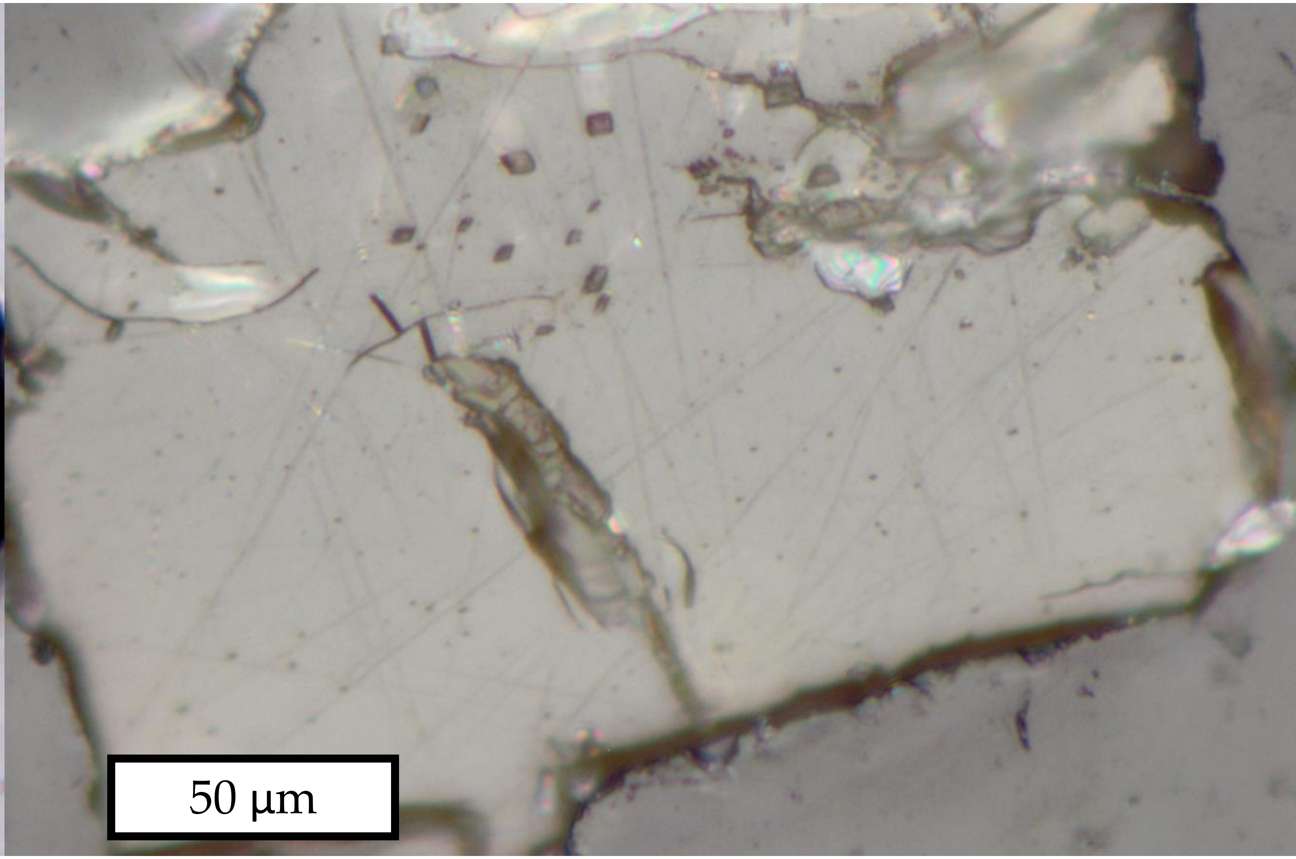
- Used 1 inch plastic ring form – reduces the expansion of epoxy
- Etched for 30 – 60 minutes in 6M HCl at 90 °C



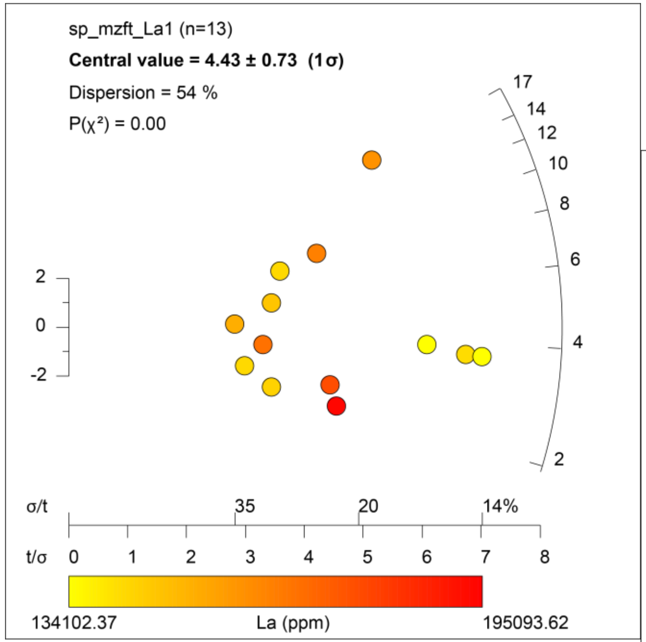
Etching:



Monazite transmitted light

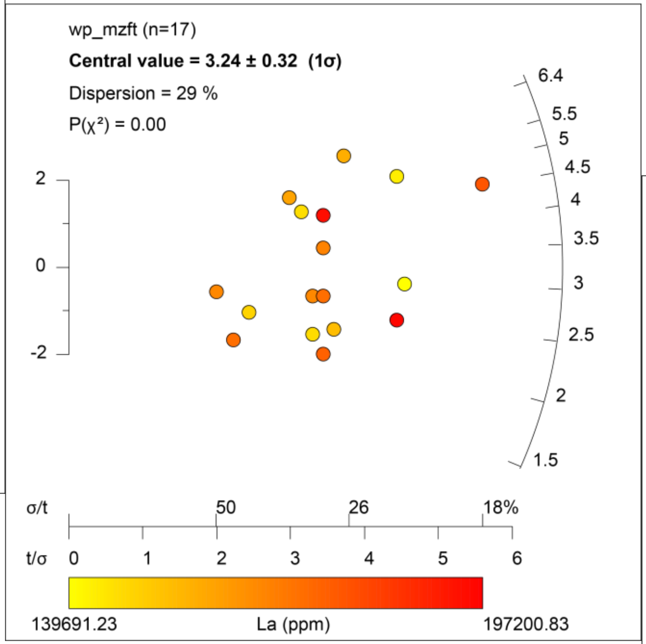


Monazite reflected light



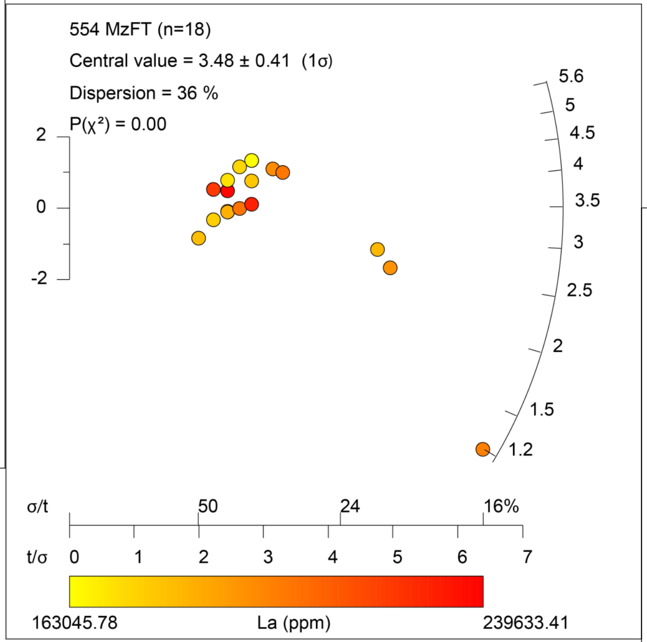
Mz FT date: 4.4 ± 0.7 Ma

Elevation: 2,258 m



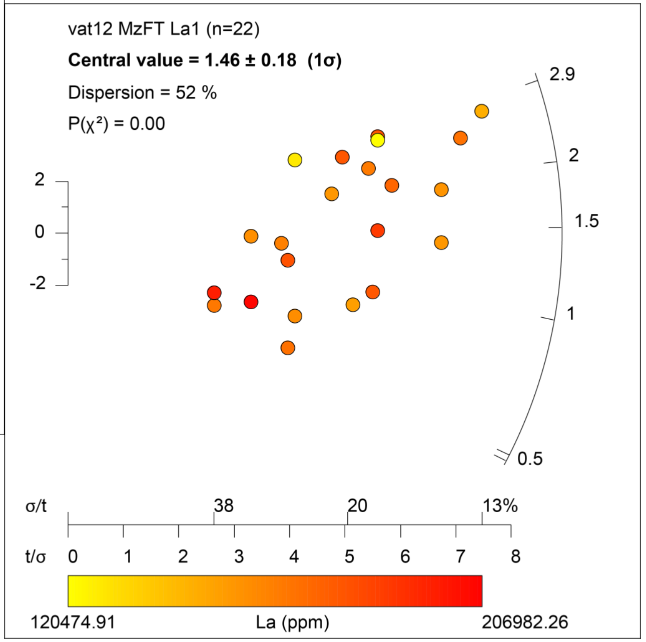
Mz FT 3.2 ± 0.3 Ma

Elevation: 2,004 m



Mz FT 3.5 ± 0.4 Ma

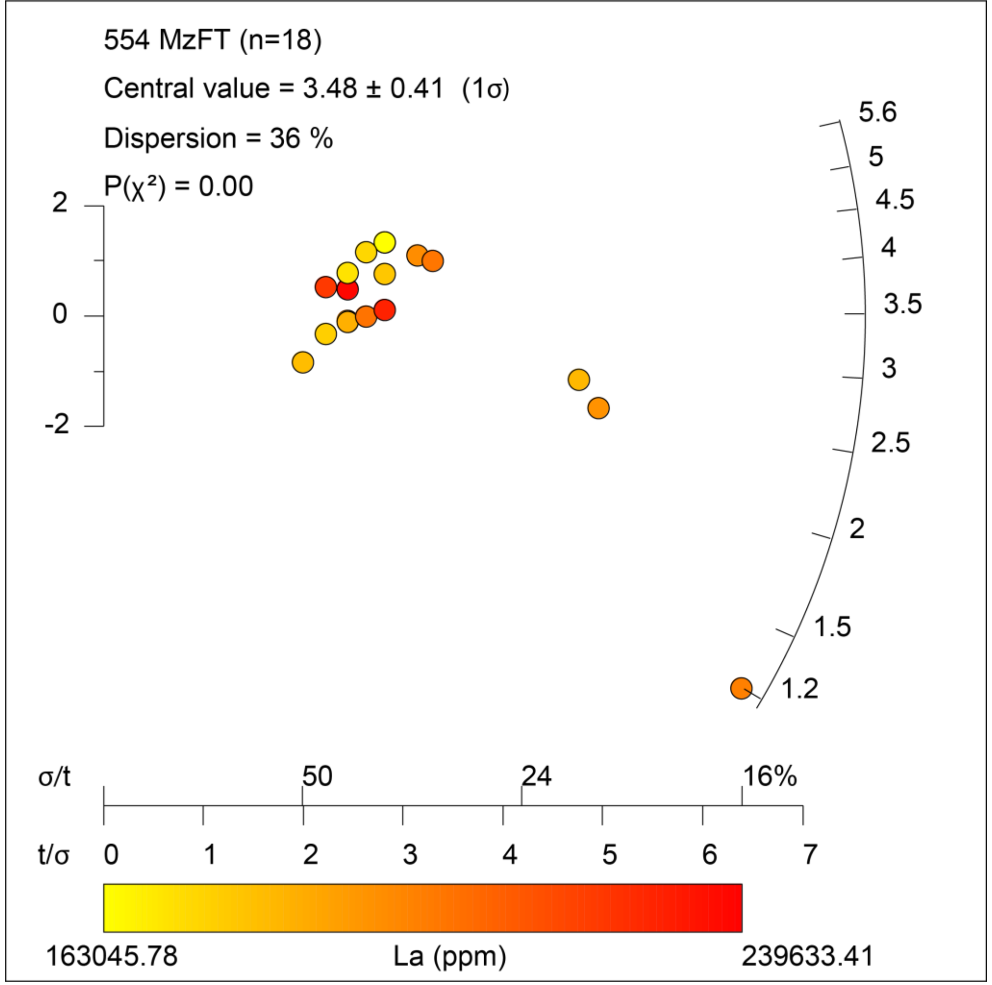
Elevation: 1,608 m



Mz FT 1.5 ± 0.2 Ma

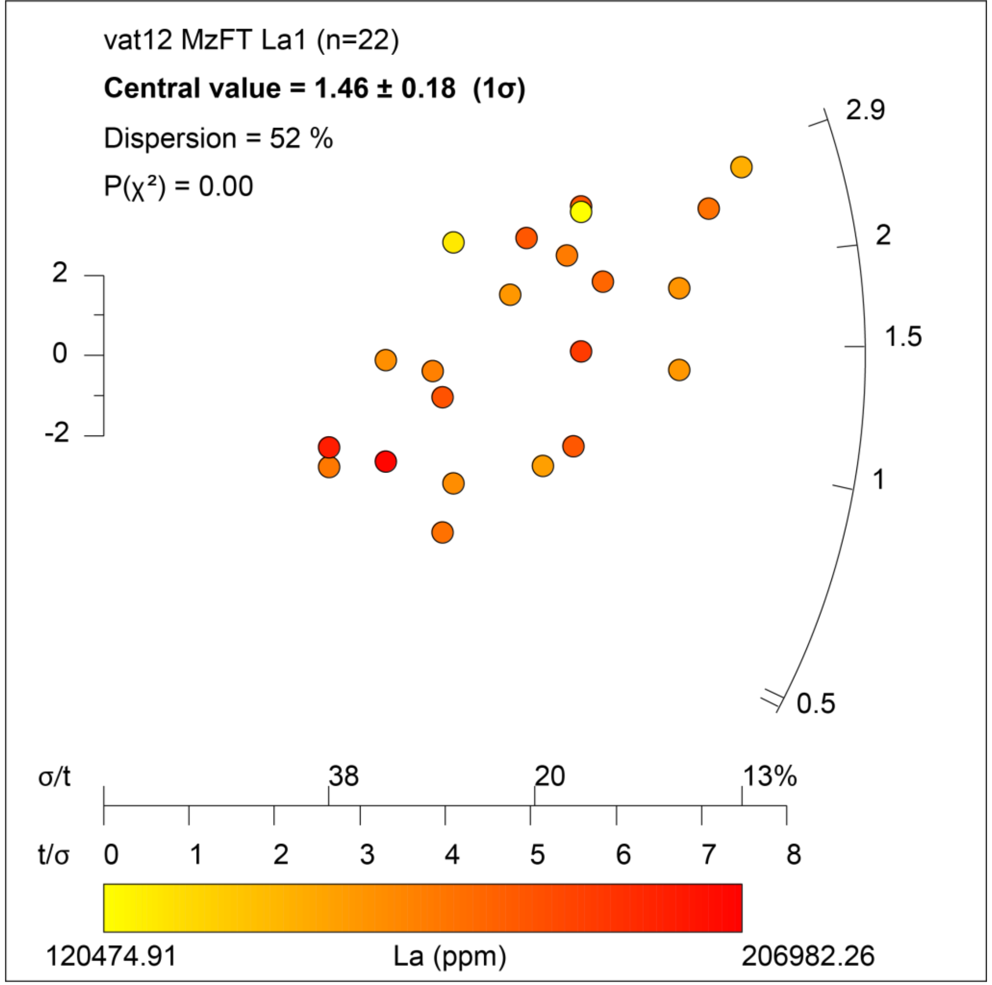
Elevation: 1,270 m

Calculated using an initial track length of 10.6 um (Weise et al. 2009, Jones et al. 2020)



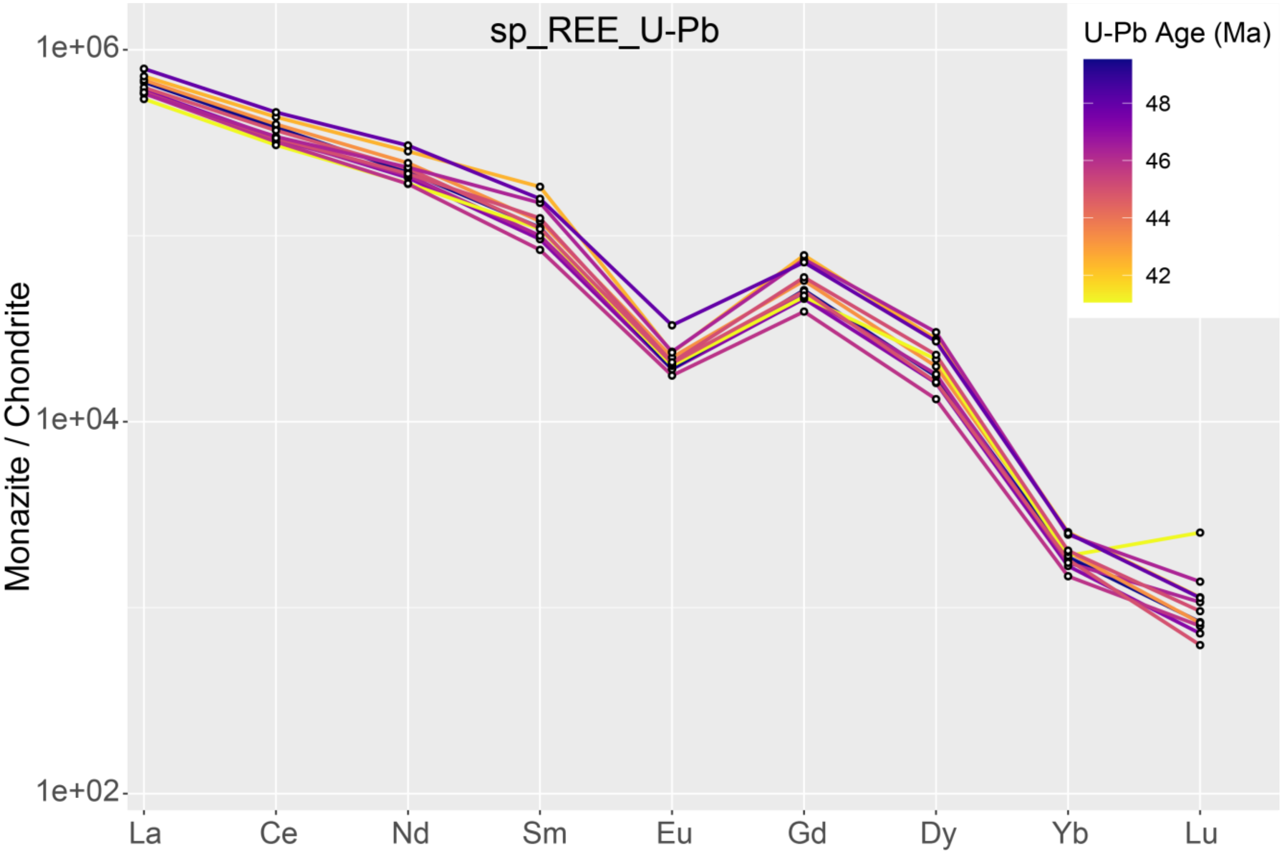
Mz FT 3.5 ± 0.4 Ma

Elevation: 1,608 m

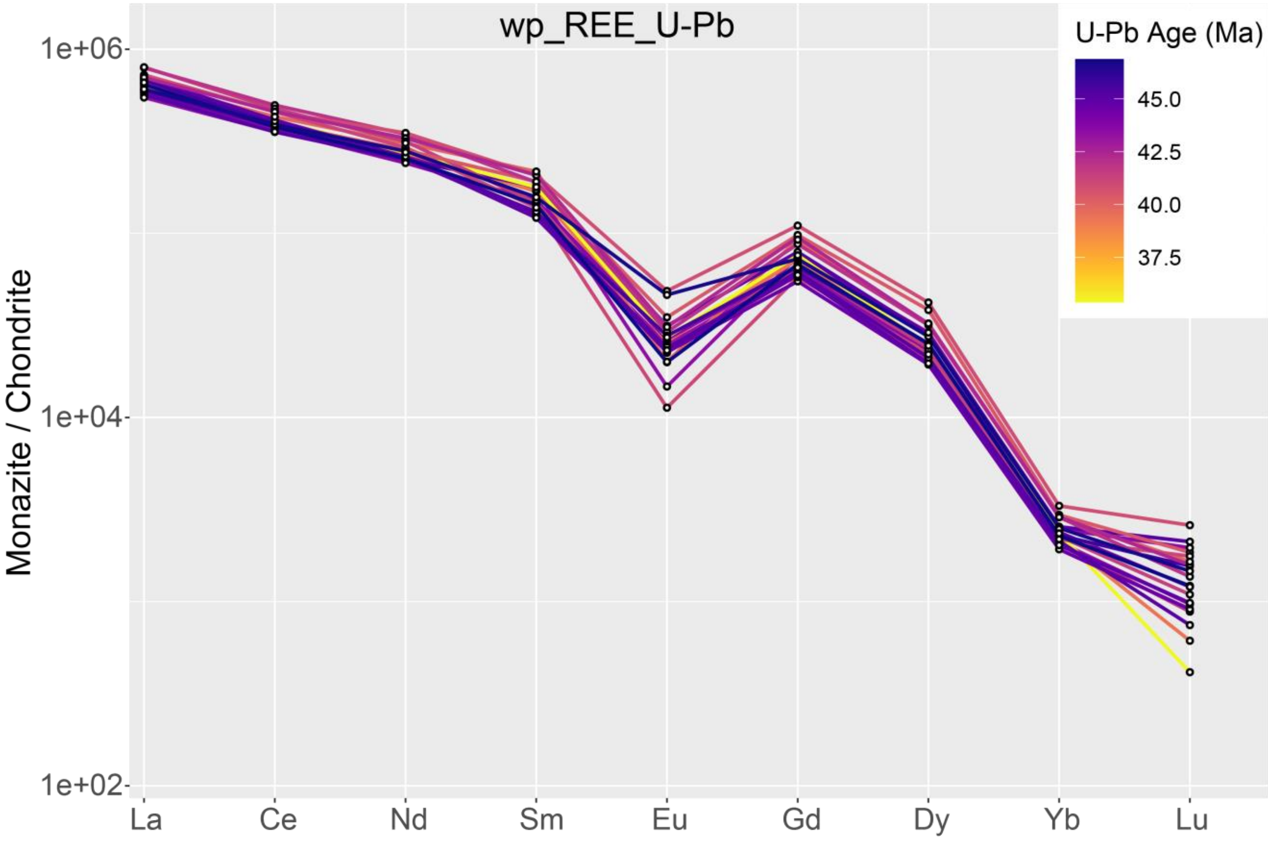


Mz FT 1.5 ± 0.2 Ma

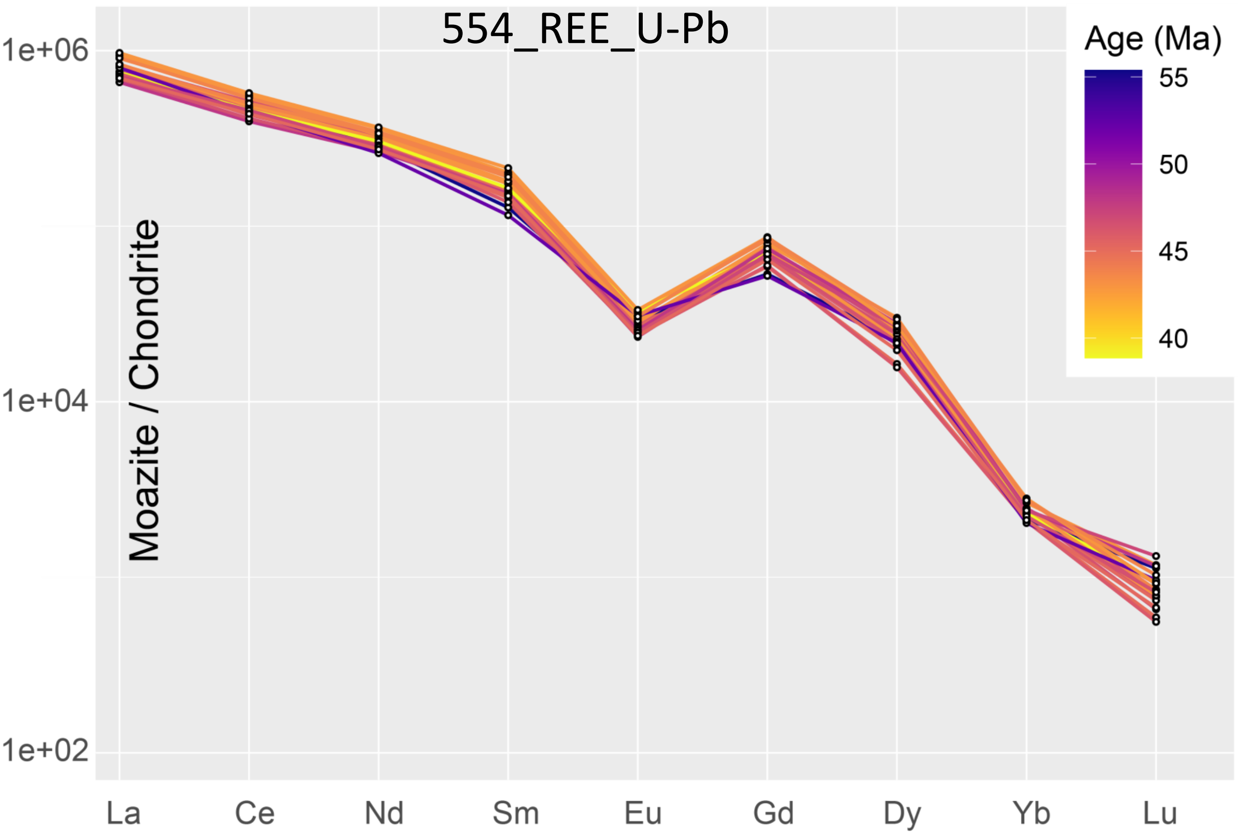
Elevation: 1,270 m



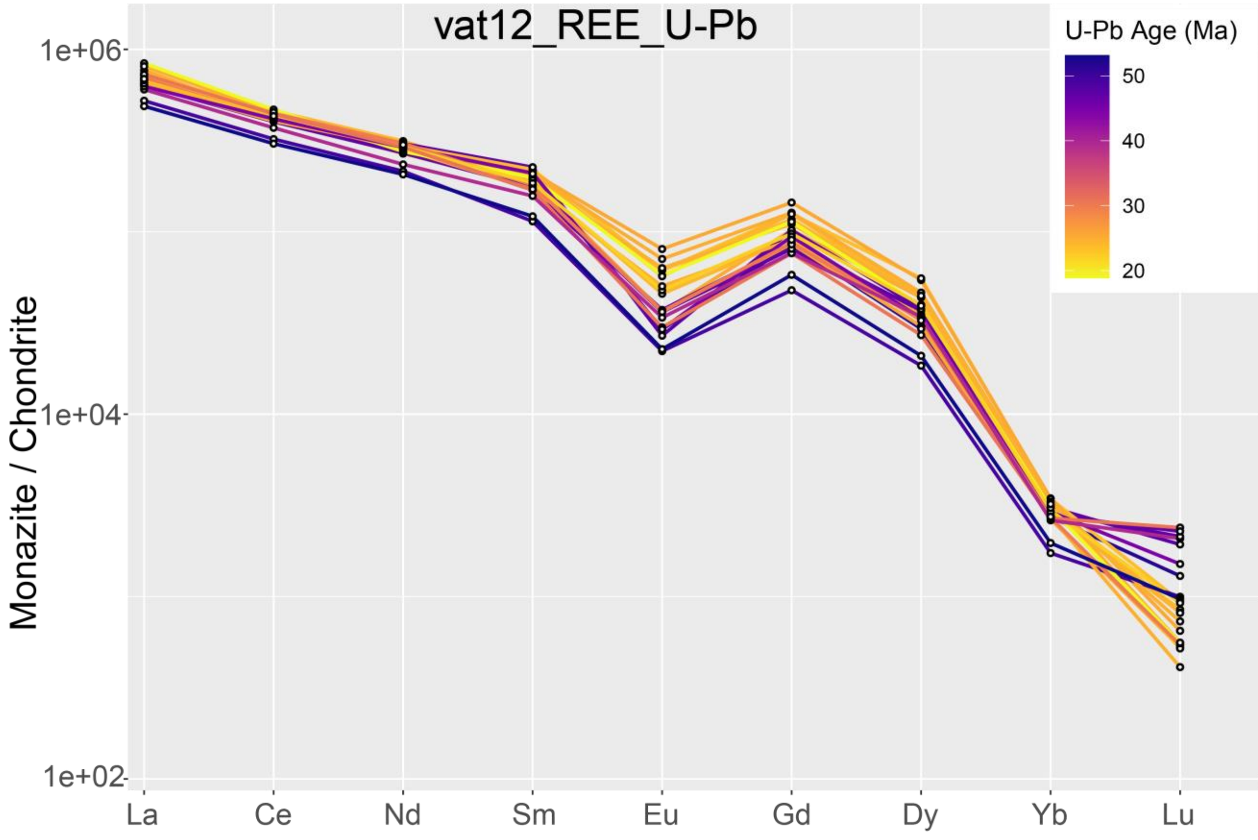
Elevation: 2,258 m



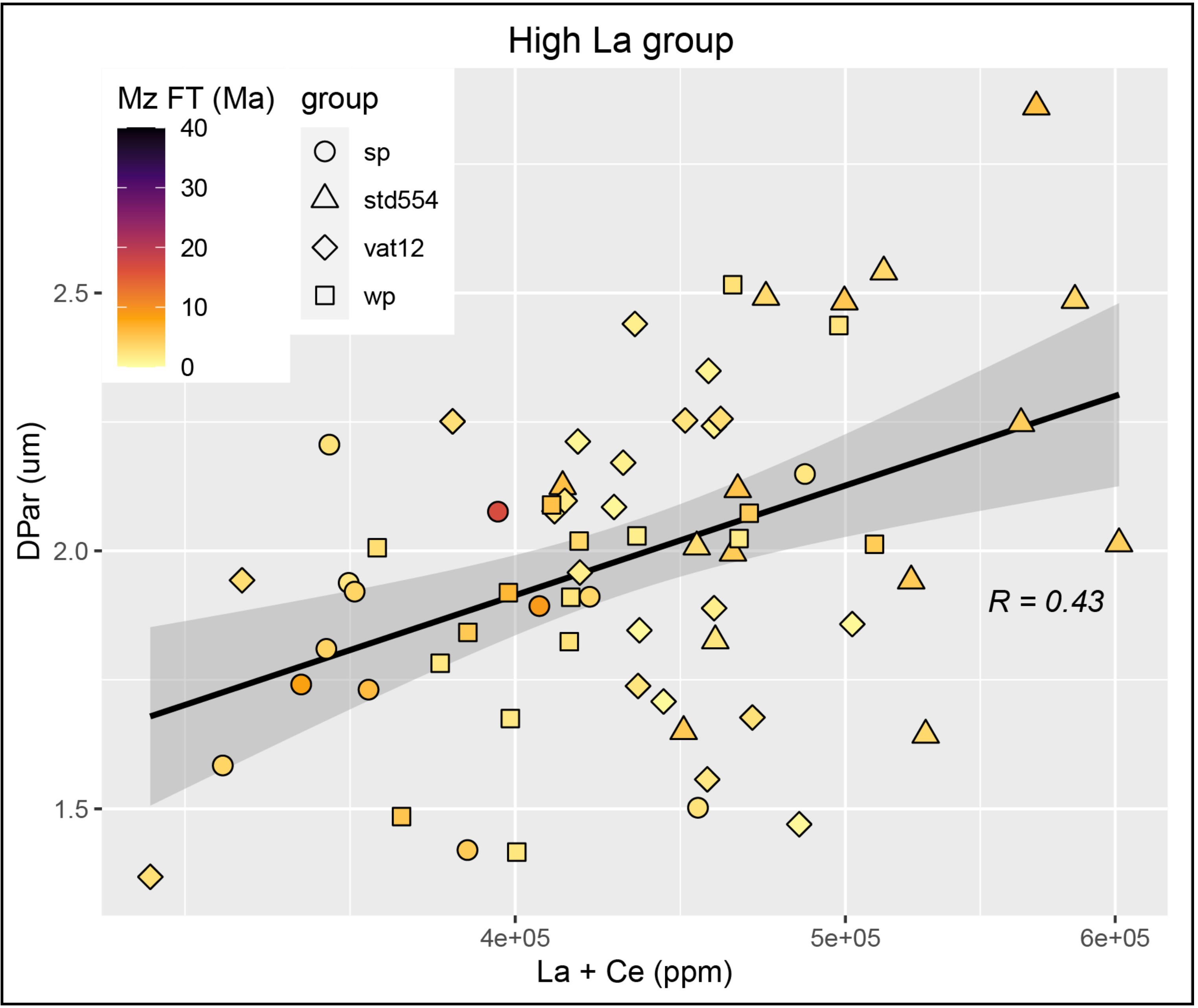
Elevation: 2,004 m



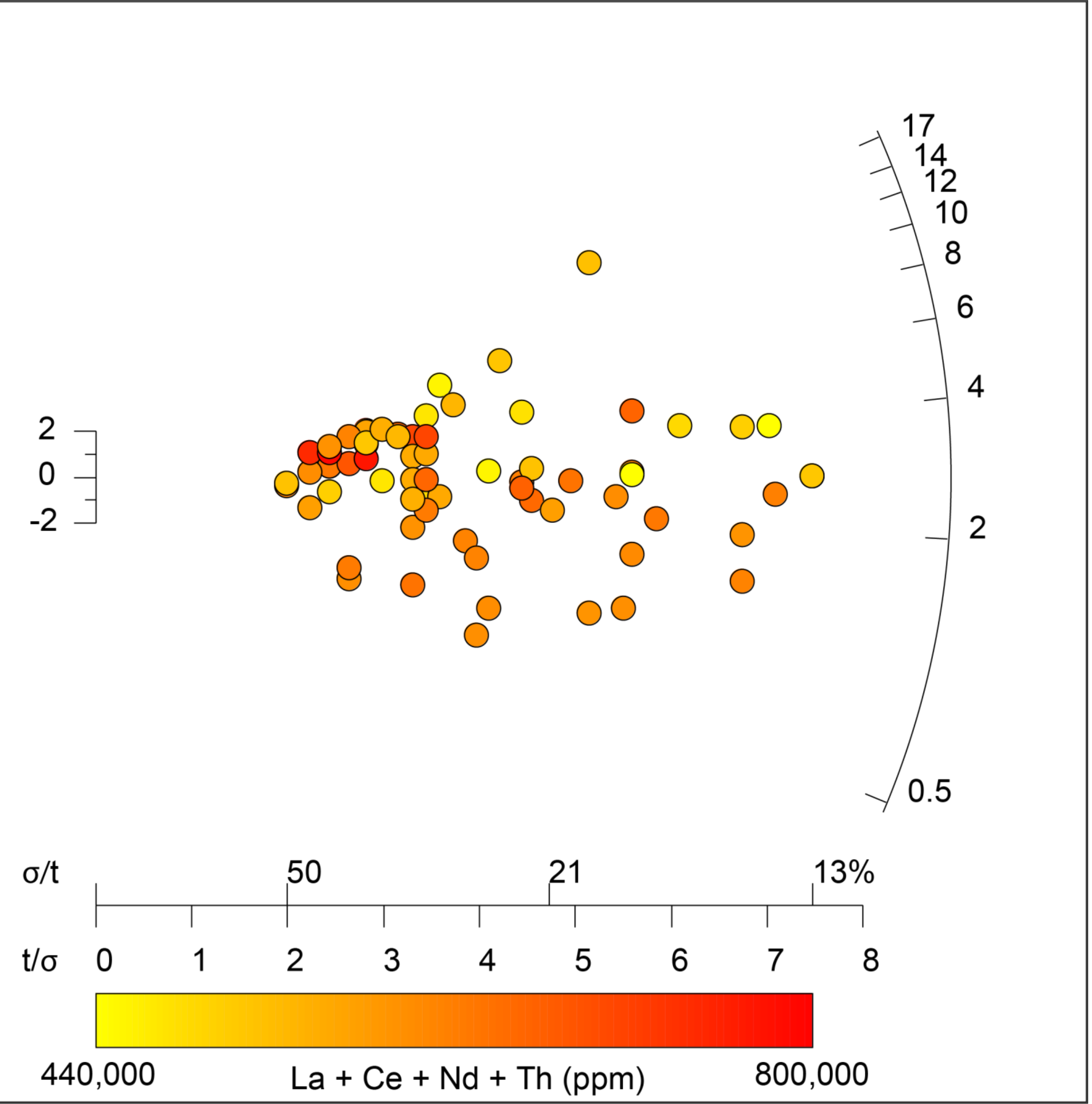
Elevation: 1,608 m



Elevation: 1,270 m

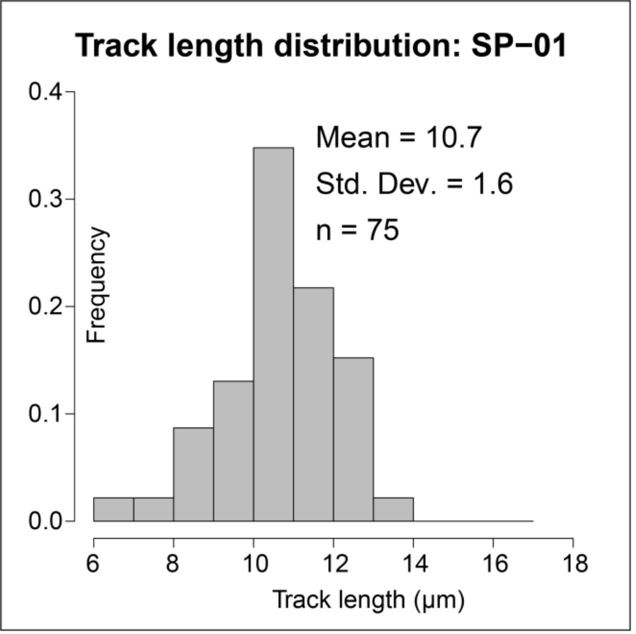


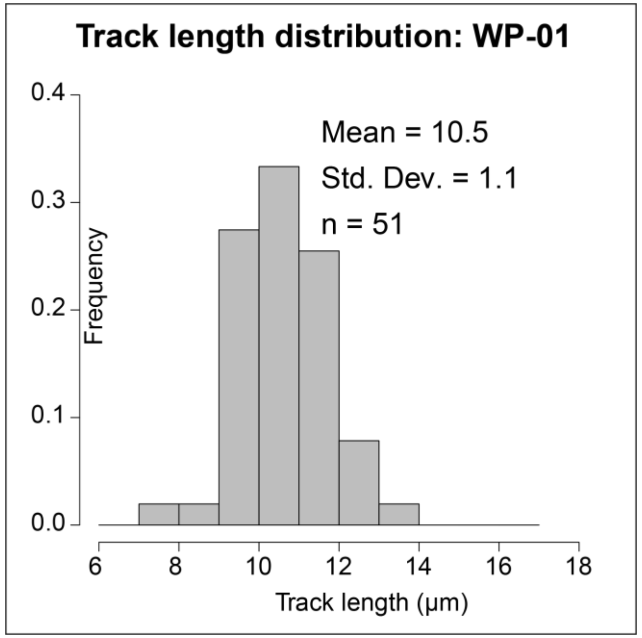
At high La and Ce concentrations, DPar loosely correlates with light REEs

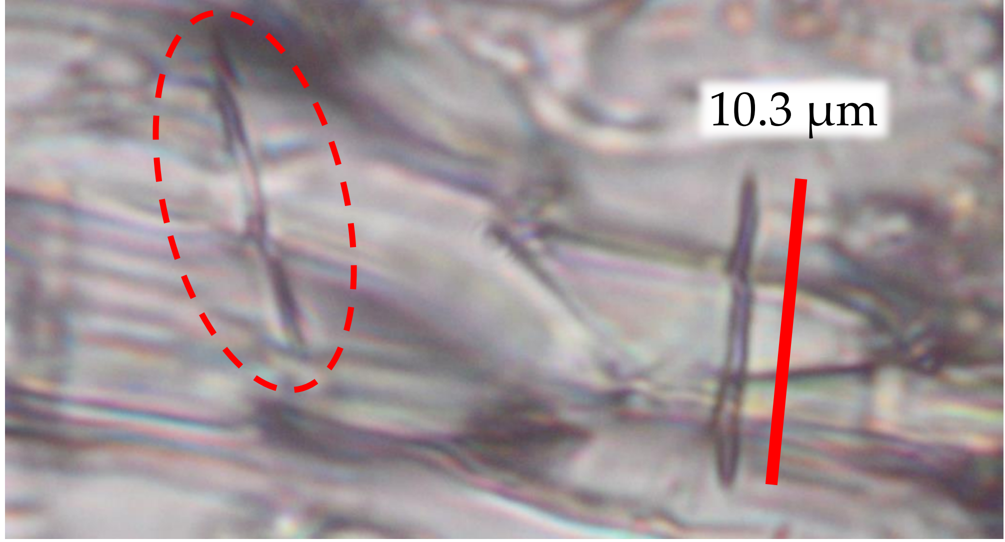


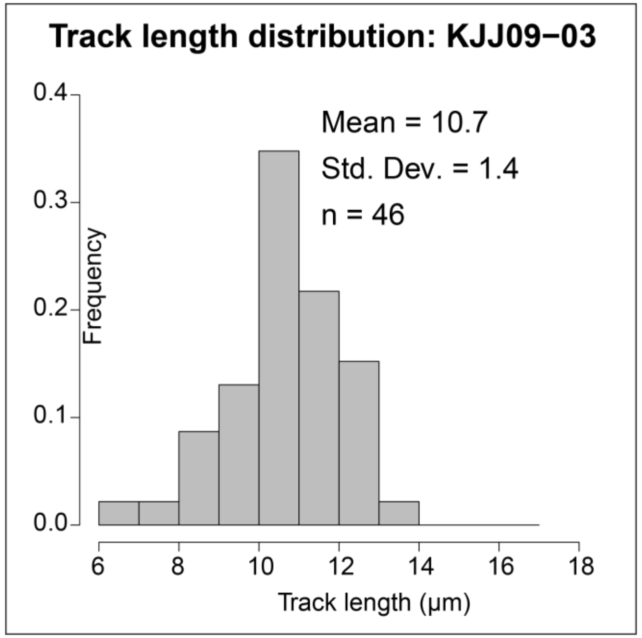
Monazite: a REE phosphate
(Ce,La,Nd,Th) (PO_4,SiO_4)

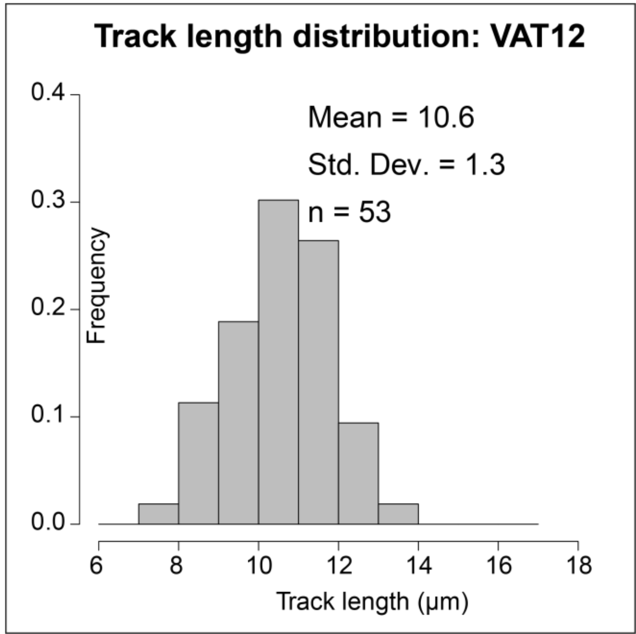
Weak trend of younger dates with high REE + Th concentrations.



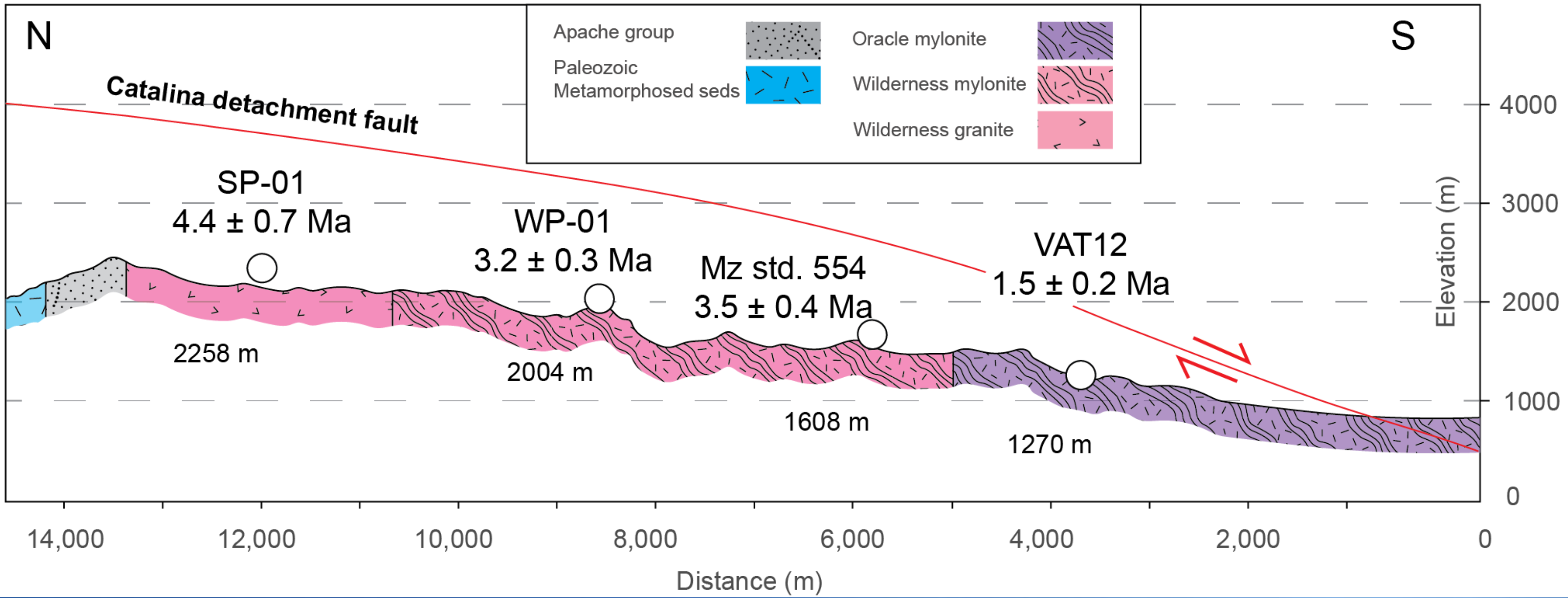






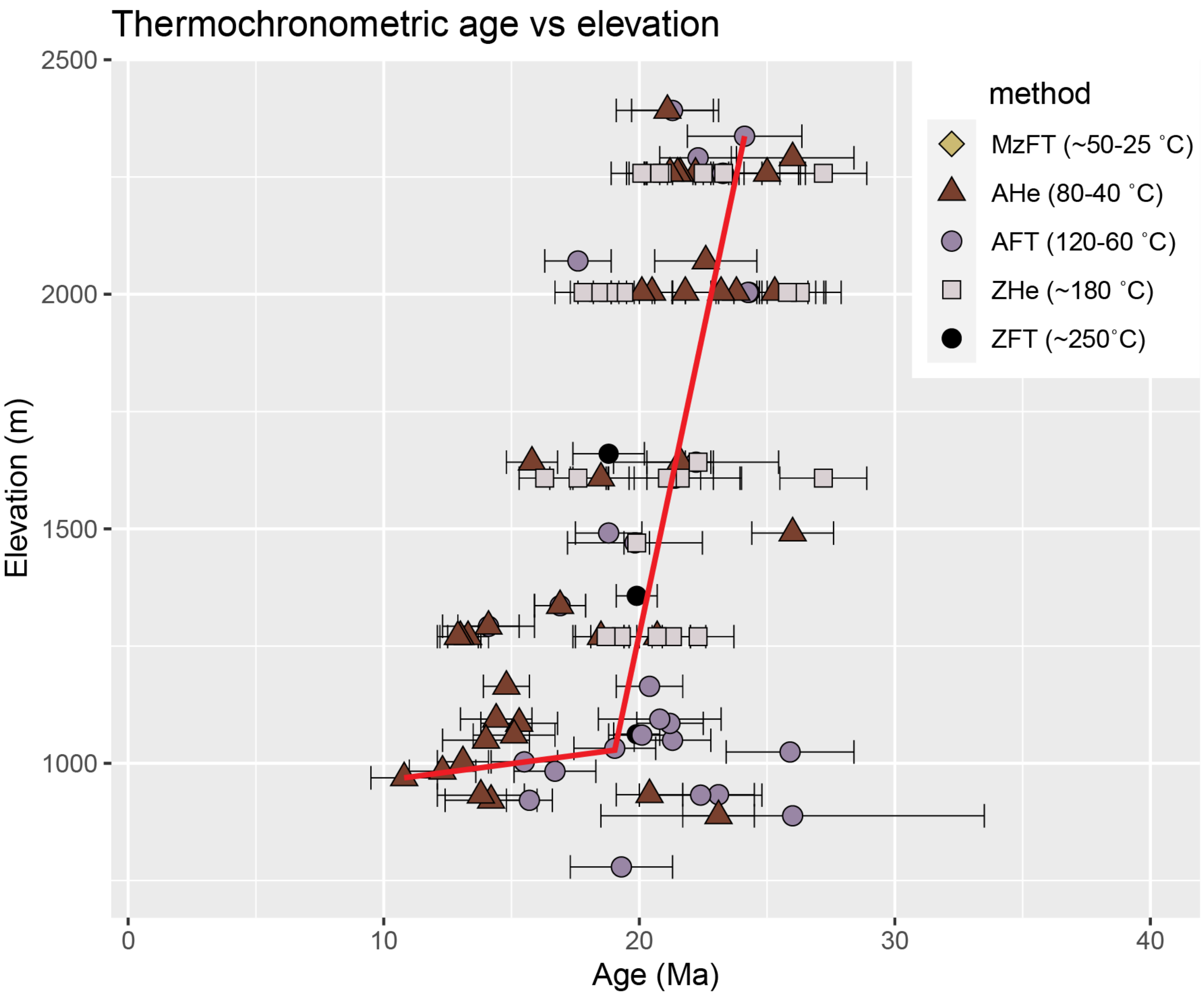


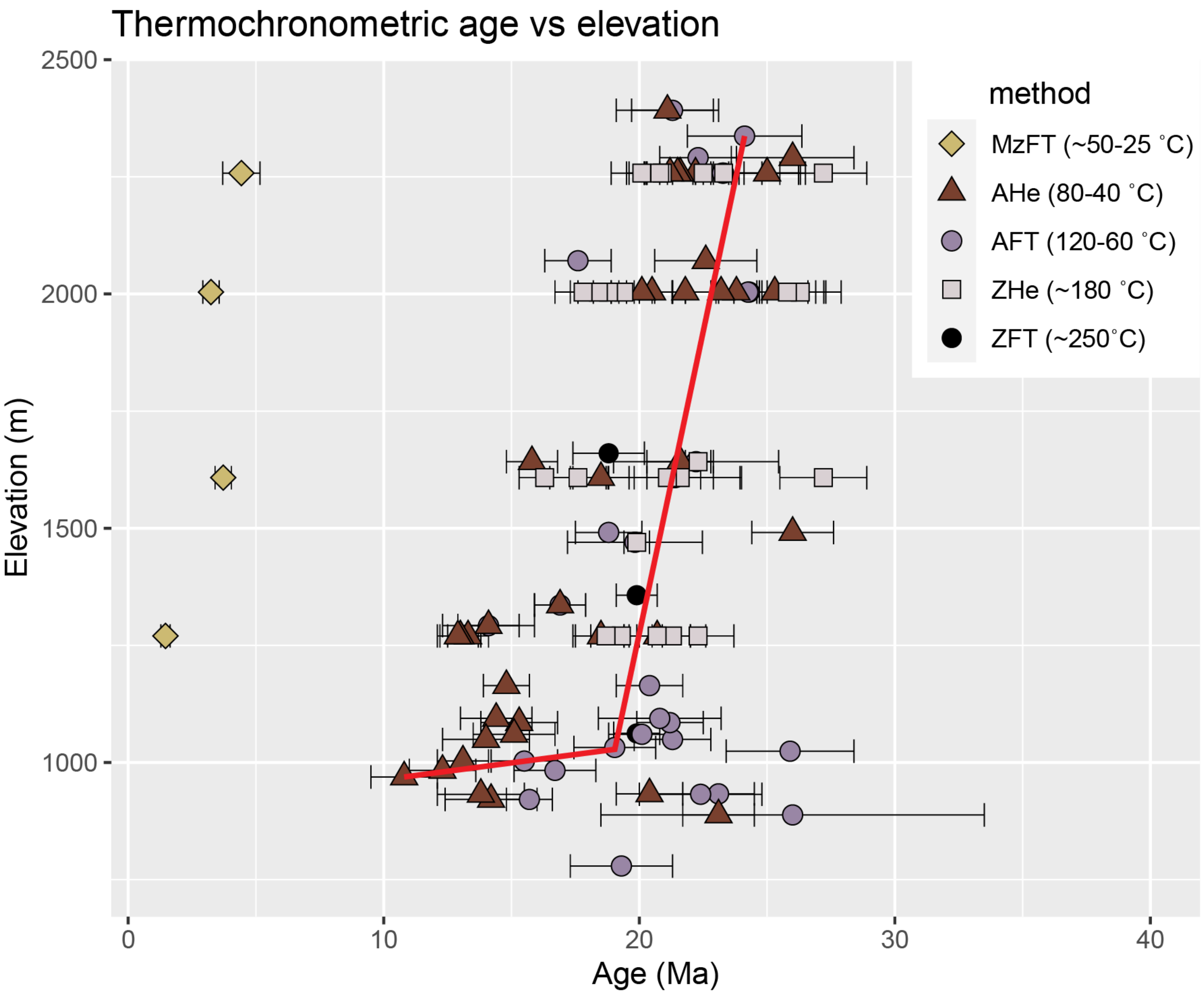
Consistent with the measured length of ~ 10 μm fossil confined tracks (Weise et al. 2009)


N
S
Apache group
Paleozoic
Metamorphosed seds
Oracle mylonite
Wilderness mylonite
Wilderness granite
Catalina detachment fault
SP-01
4.4 ± 0.7 Ma
WP-01
3.2 ± 0.3 Ma
Mz std. 554
3.5 ± 0.4 Ma
VAT12
1.5 ± 0.2 Ma
2258 m
2004 m
1608 m
1270 m
Elevation (m)
4000
3000
2000
1000
0
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Distance (m)

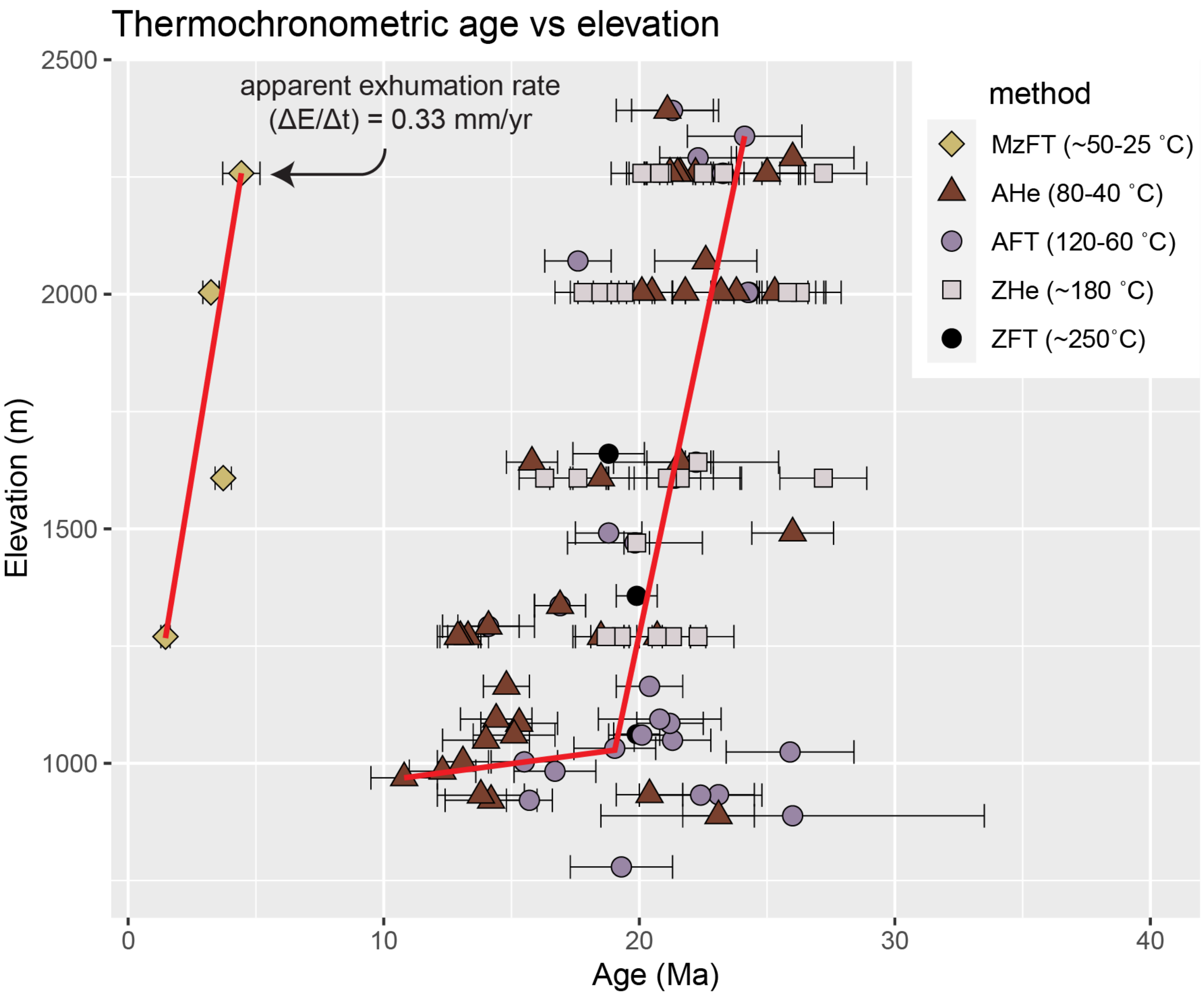

S
N

Interpreting the results: closure temperature





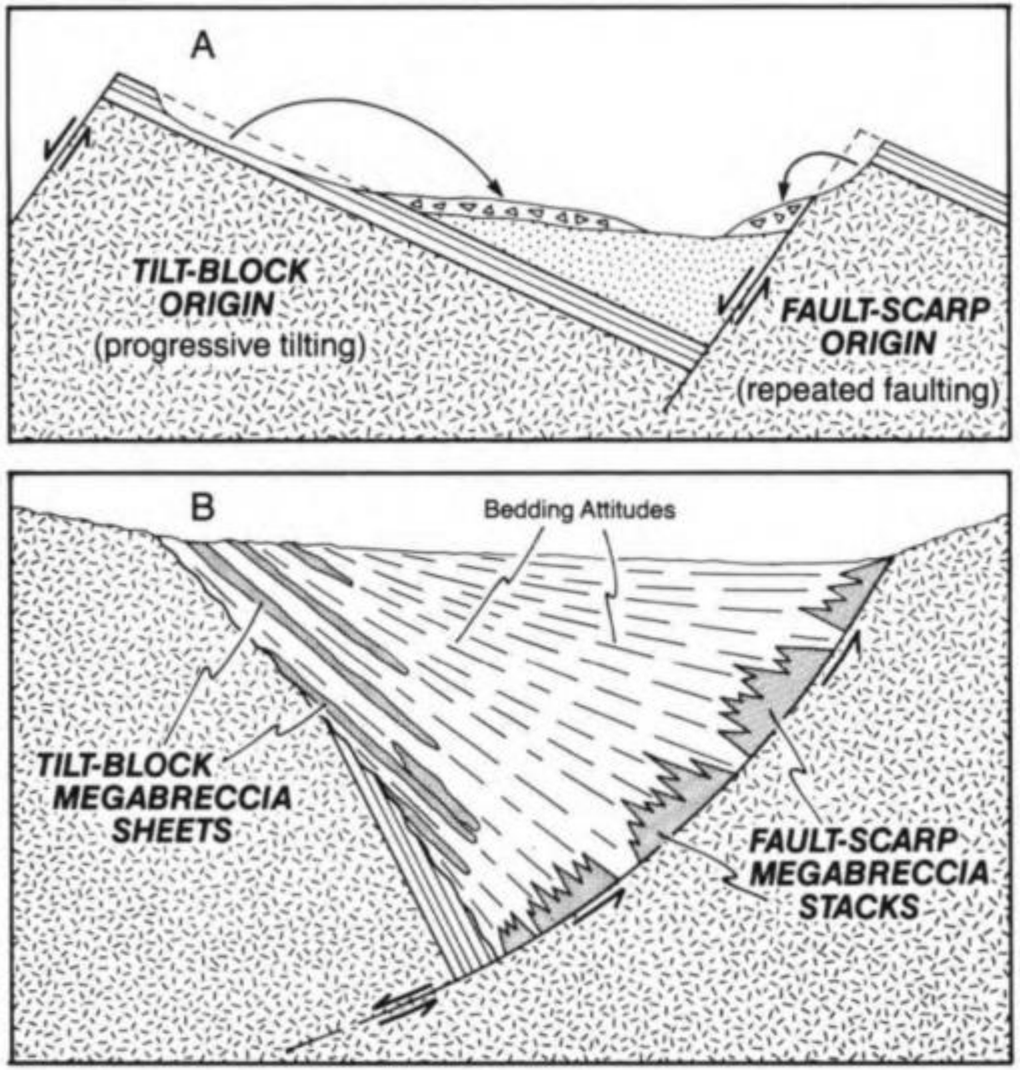
- Monazite FT (~2-5 Ma) dates are younger than all traditional thermochronometric dates observed in the Catalina Rincon (~10 – 26 Ma).
- As a result, the MzFT thermochronometer must sensitive to lower temperatures (< 40 °C, Jones et al 2020).



- Extremely rapid apparent exhumation rate. Faster than what is observed for the MCC detachment faulting.

What's driving Plio-Plistocene thermochronometric dates?

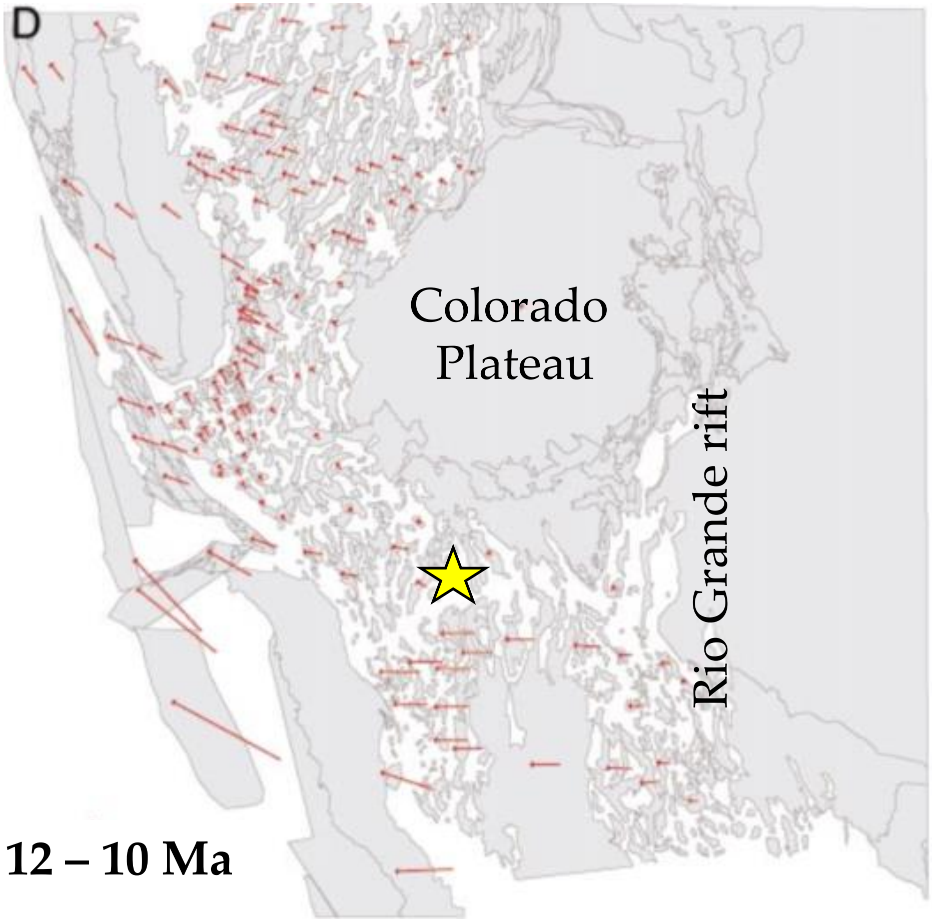
Interpreting the results: ~6 Ma



Dickinson 1991

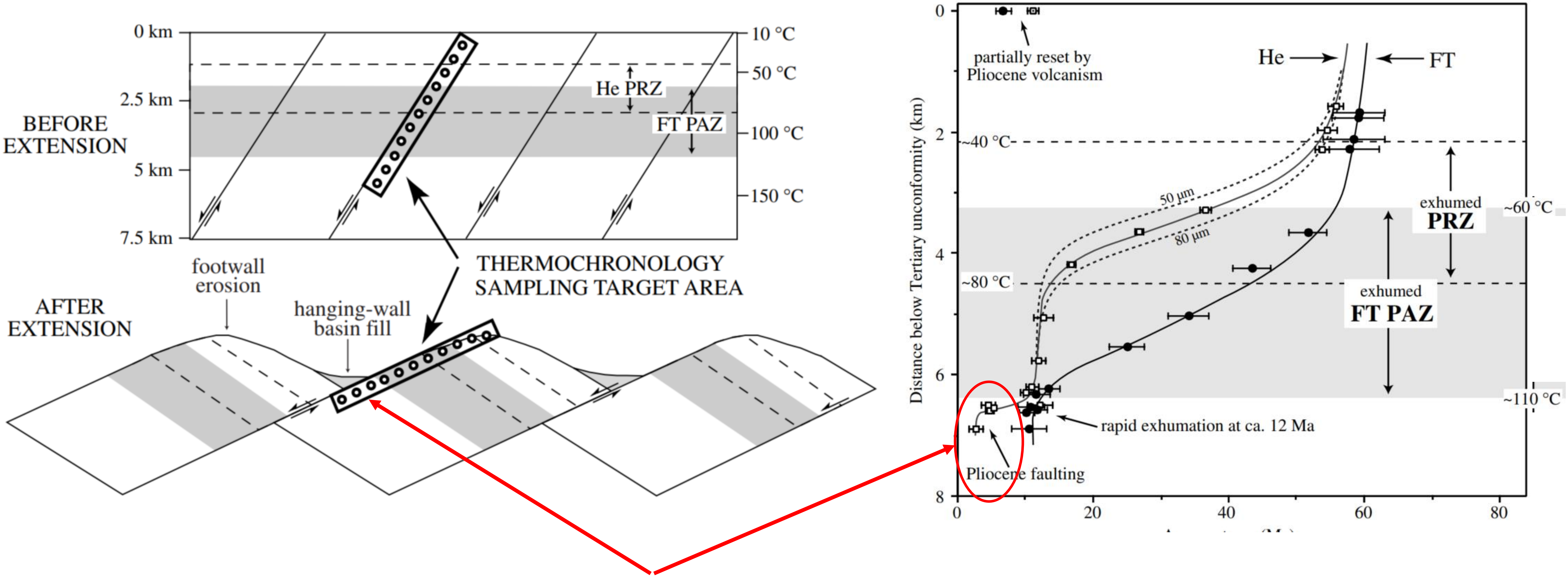
- Major Basin and Range extension occurs at ~ 18-12 Ma across southwestern North America.

McQuarrie and Wernicke, 2005



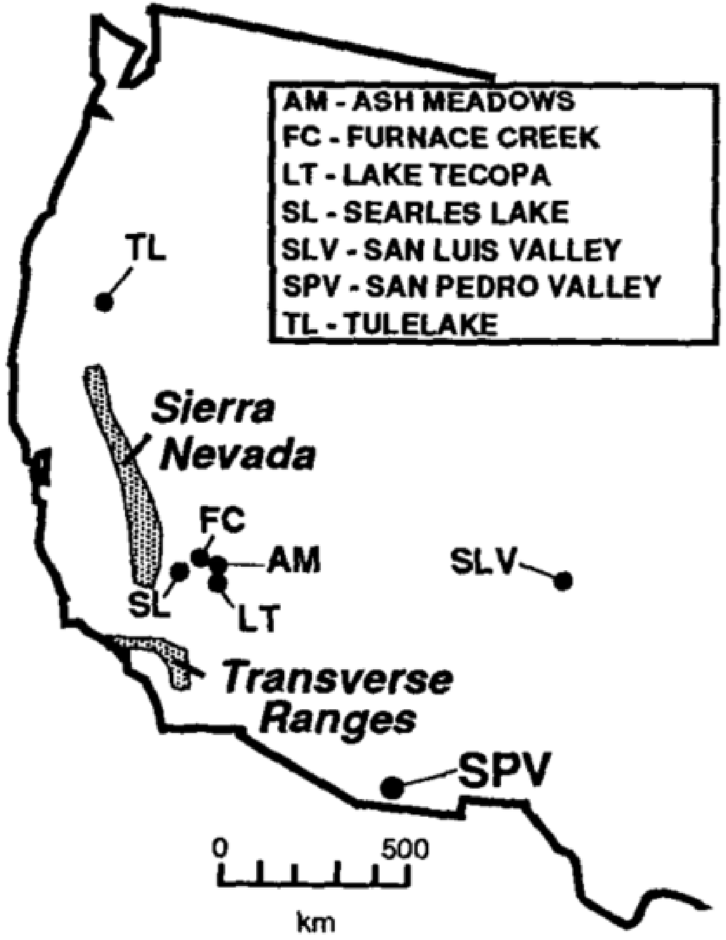
12 – 10 Ma

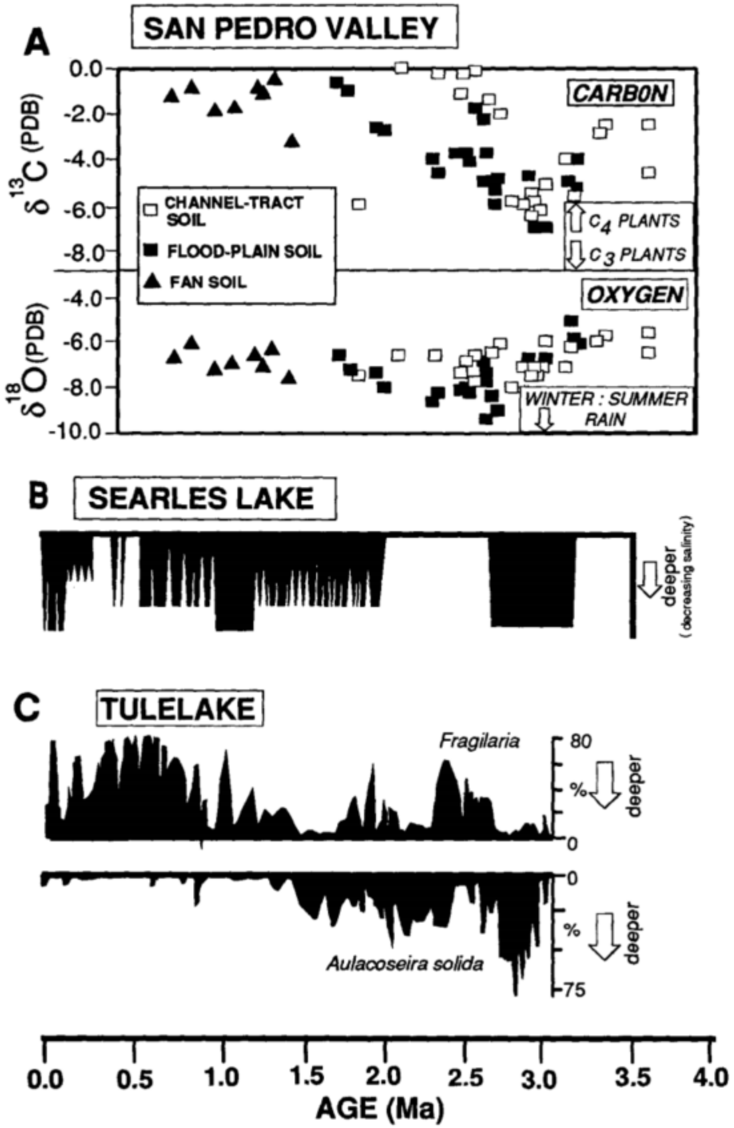
Interpreting the results, tectonics: Stockli et al 2000 (White Mountains, California)



~ 5 Ma AHe dates suggesting more recent extensional events

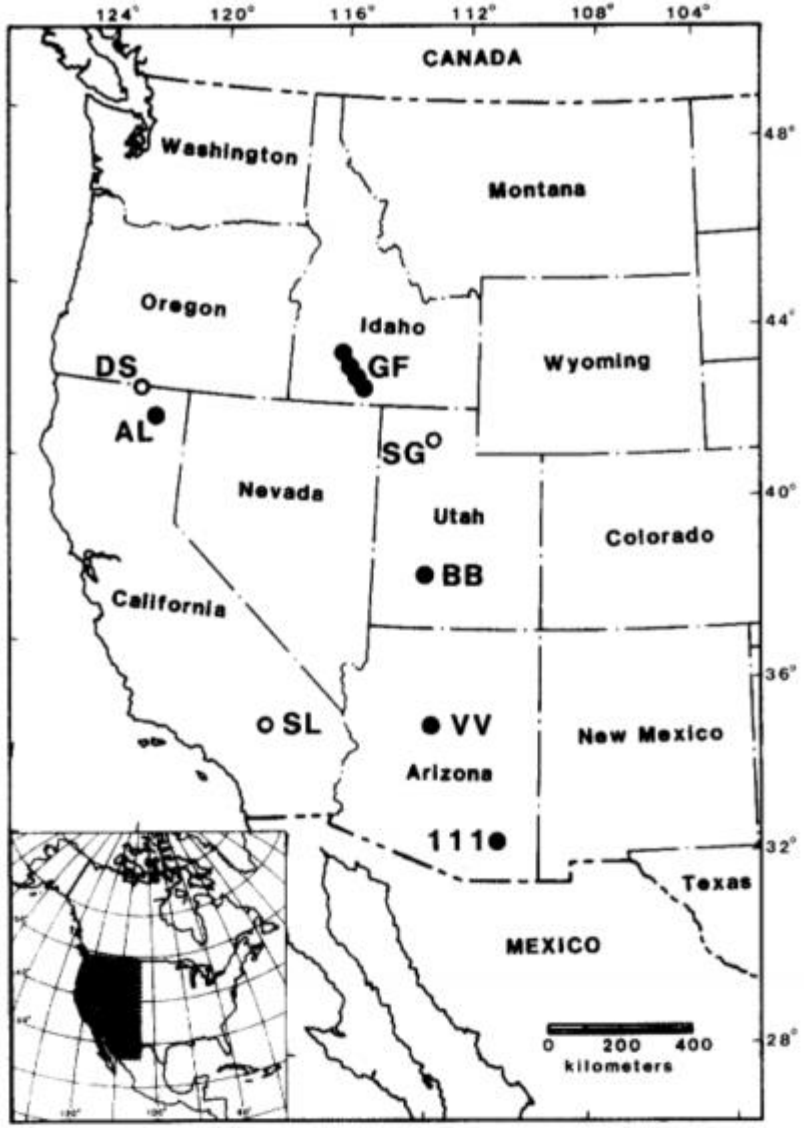
Interpreting the results, climate: Smith et al. 1993





Cool, wet conditions between 3.2 and 2.8 Ma

Interpreting the results, climate: Forester, 1991



Evidence from lacustrine ostracodes:

- Increased precipitation from 4.5-3.5 Ma
- High precipitation/low evaporation at 3.5-2.5 Ma
- Return to a more modern hydroclimate at 2.5 Ma

Take home points

- Monazite fission-track dates are (mostly) far younger than traditional thermochronometers. Supporting closure temperatures ~25-50 °C

- Monazite chemistry (specifically La/Ce/Nd/Ce concentrations) impacts monazite DPar and perhaps annealing.

- Monazite fission-track dates correspond to a young exhumational event, highlighting applicability for dating geomorphological and geologically young tectonic processes

- Watch out for titanite….