U-Pb Geochronology II
High spatial resolution studies

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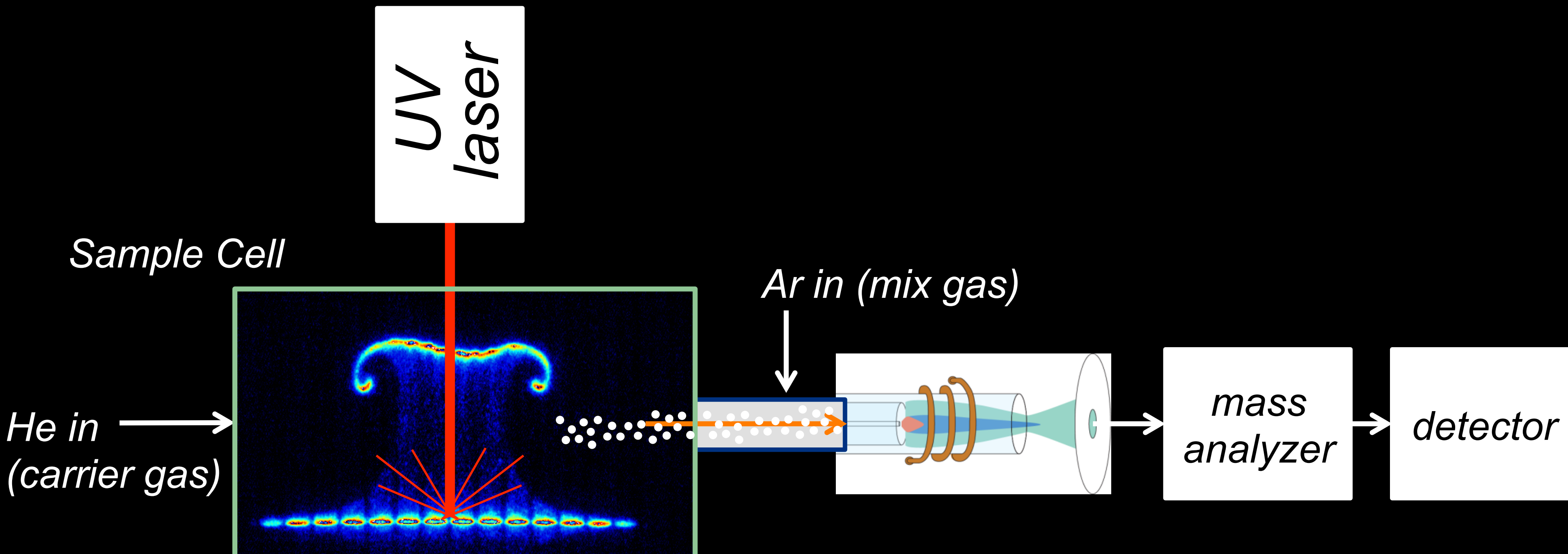
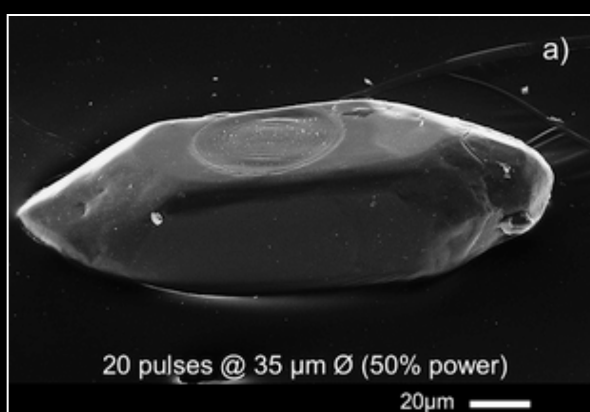
laser-ablation split-stream petrochronology

Geochronologists are people, too…

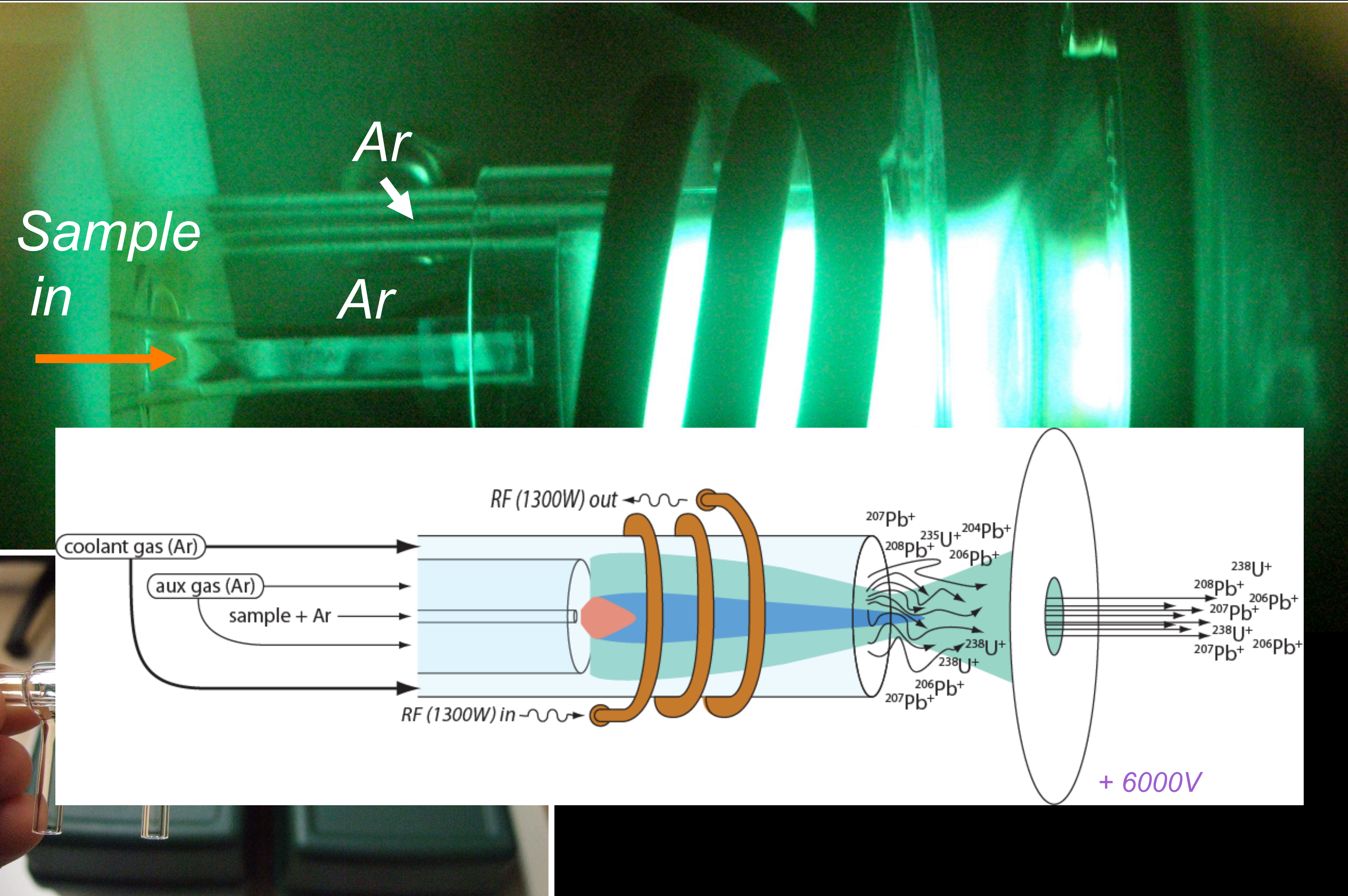
Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) systems





ion sources: inductively coupled plasma (ICP)

good: v. high efficiency; bad: large energy dispersion



Application of LA-ICPMS geochronology

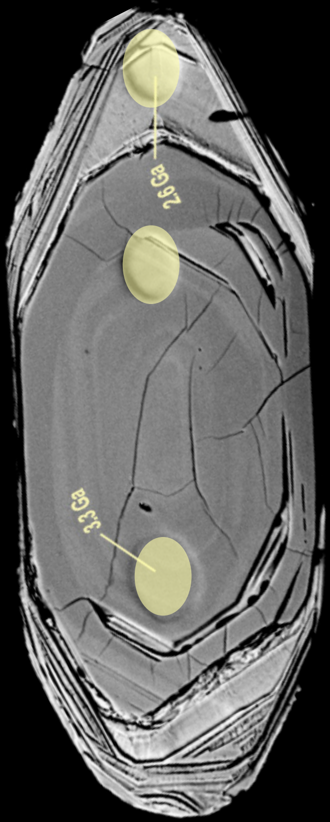
Key attributes:

- High spatial resolution

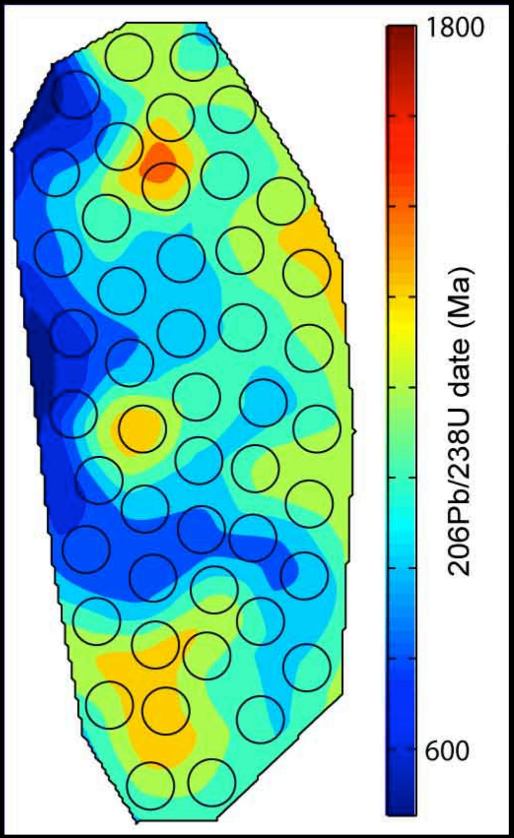
- Rapid data acquisition

- Petrochronology (e.g., Ti, REE, Hf, Nd)

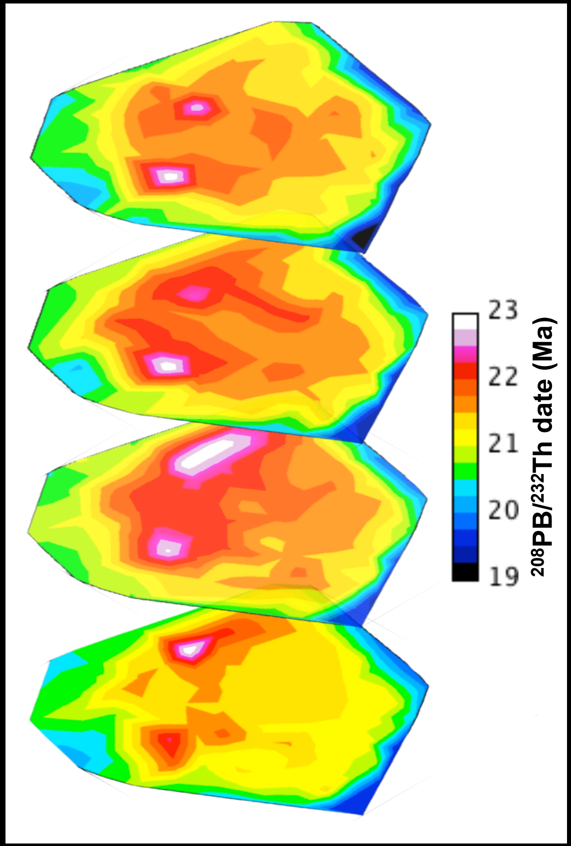
Unprecedented Spatial Information



zircon SIMS



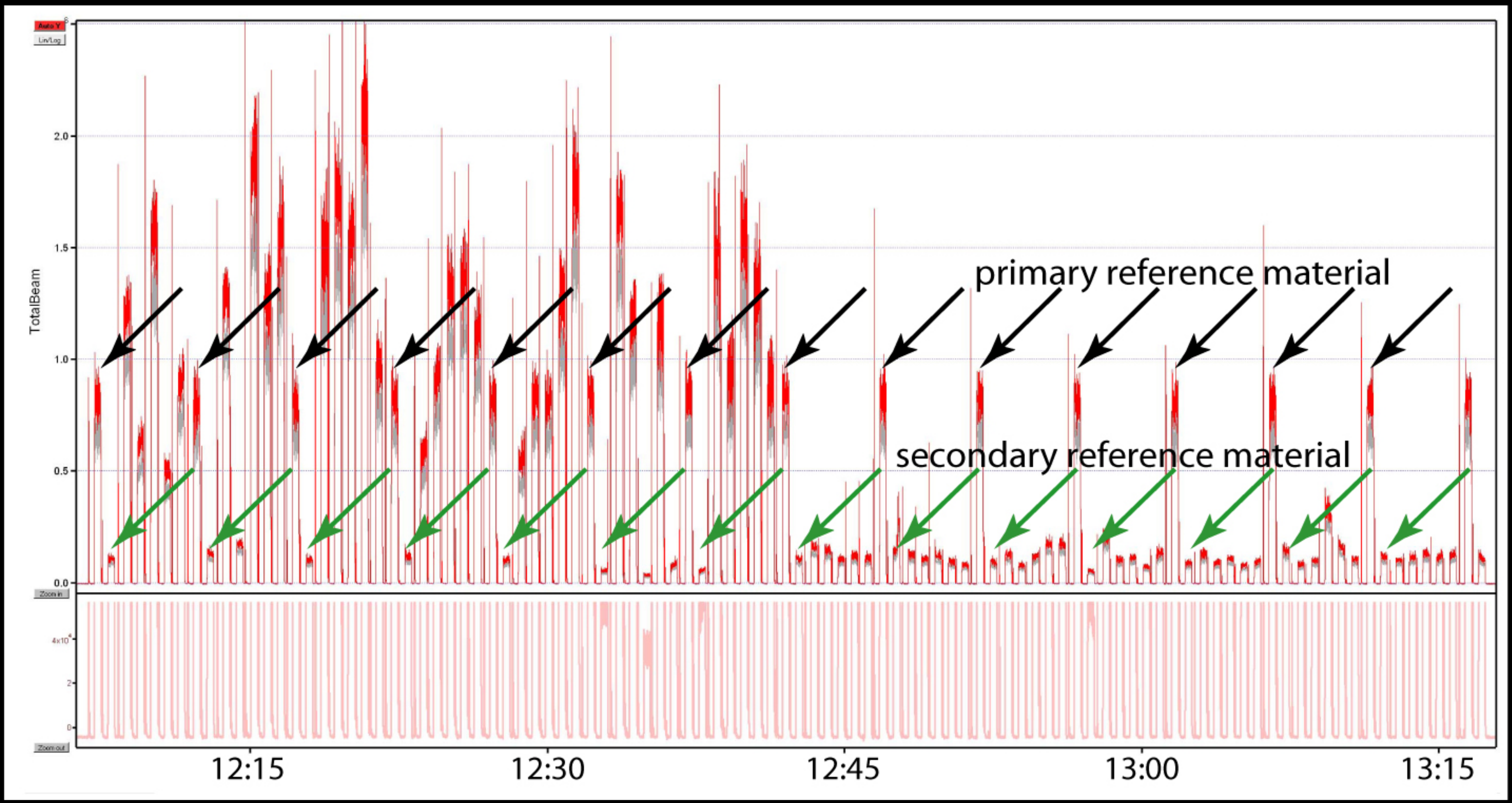
zircon ICP



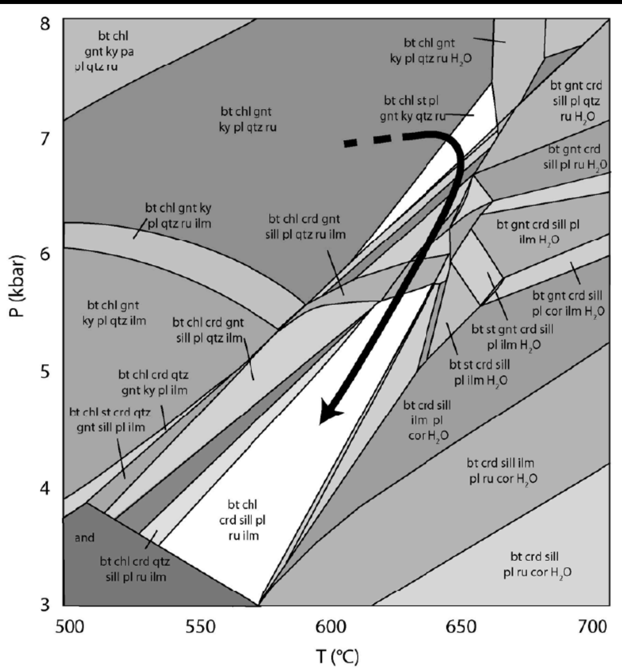
monazite ICP

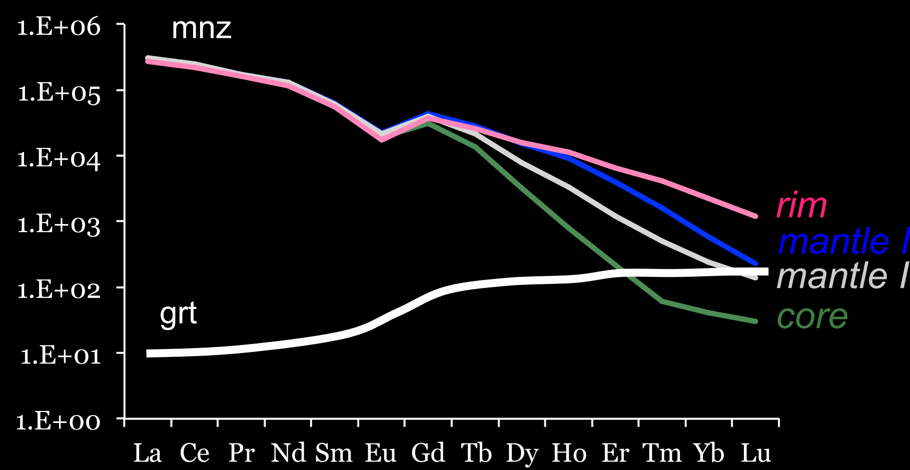
Rapid Acquisition

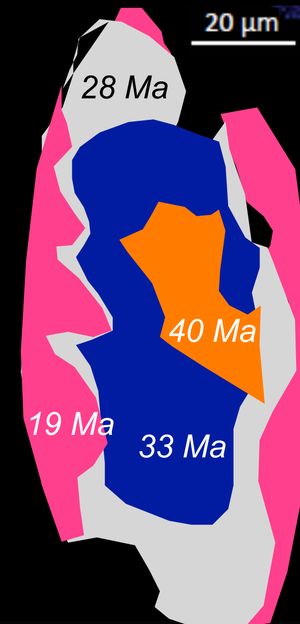
75 min of LA-ICPMS data, including 15 I° standards, 15 II° standards, 70 unknowns

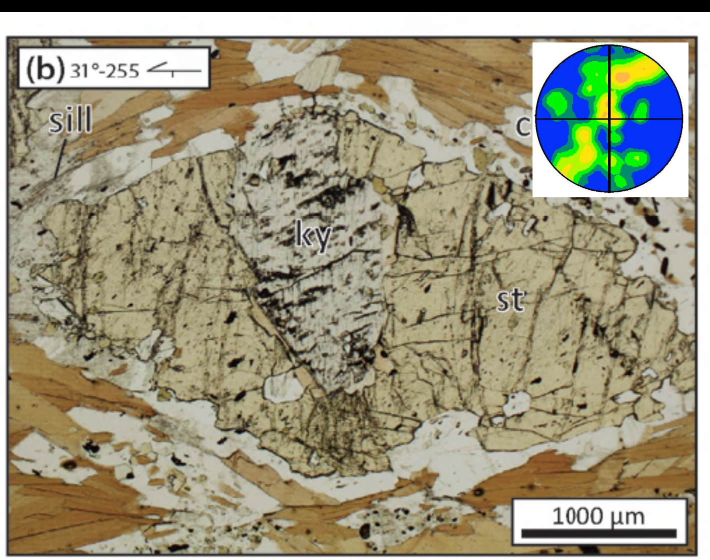


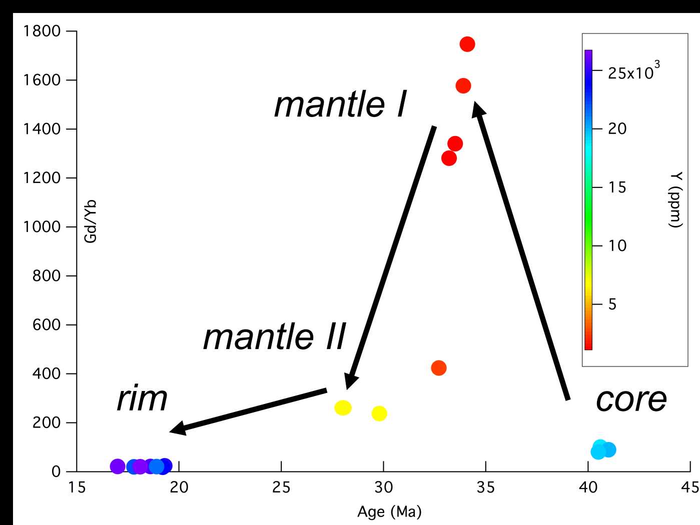
Petrochronology linking P, T, t, & D

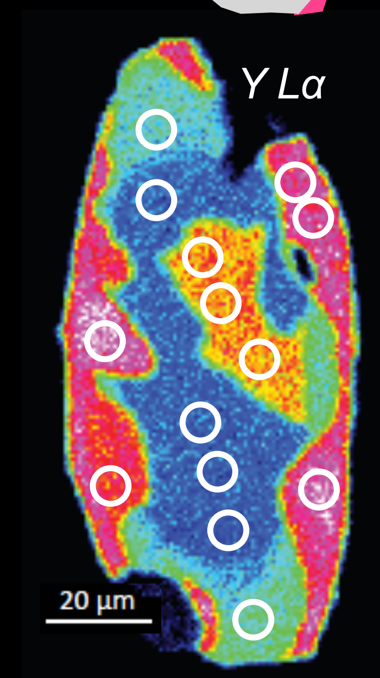




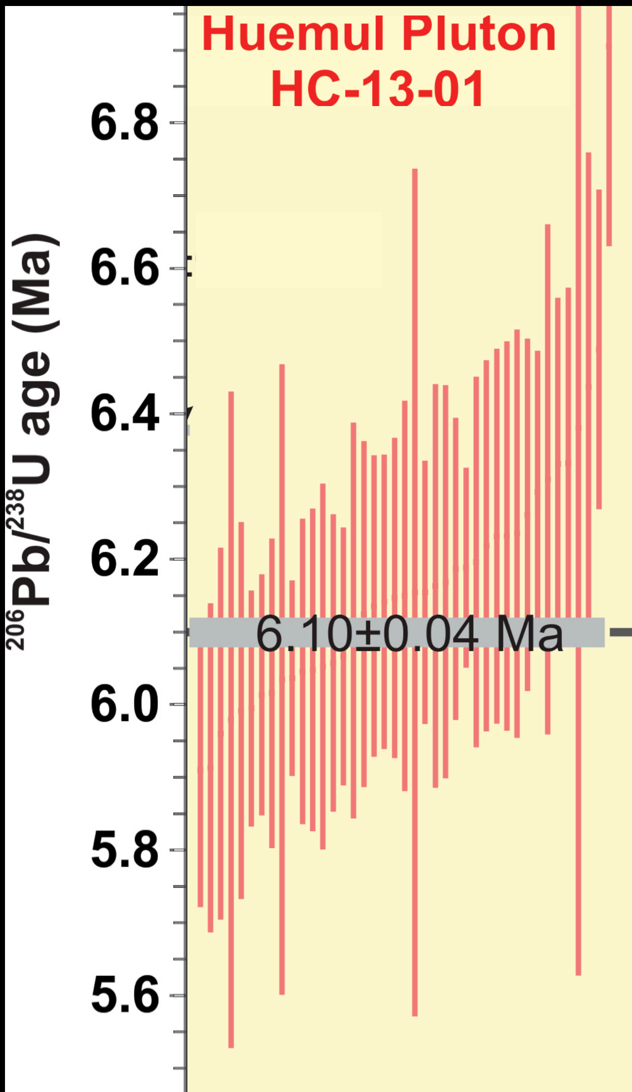


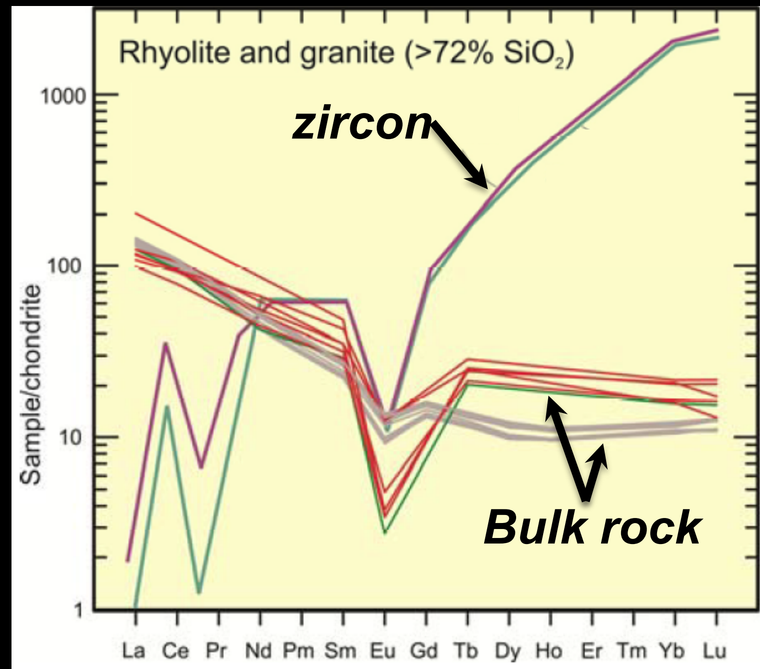


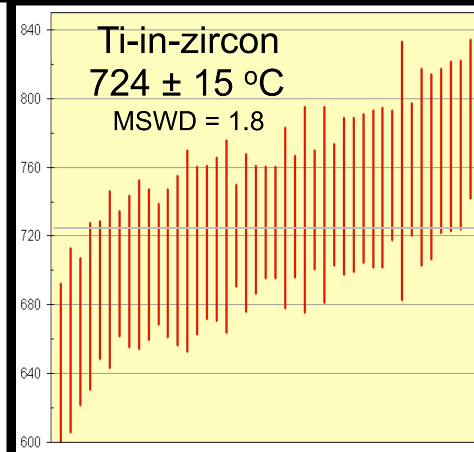


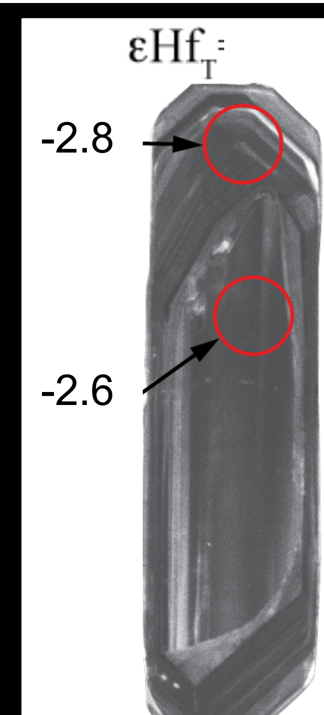


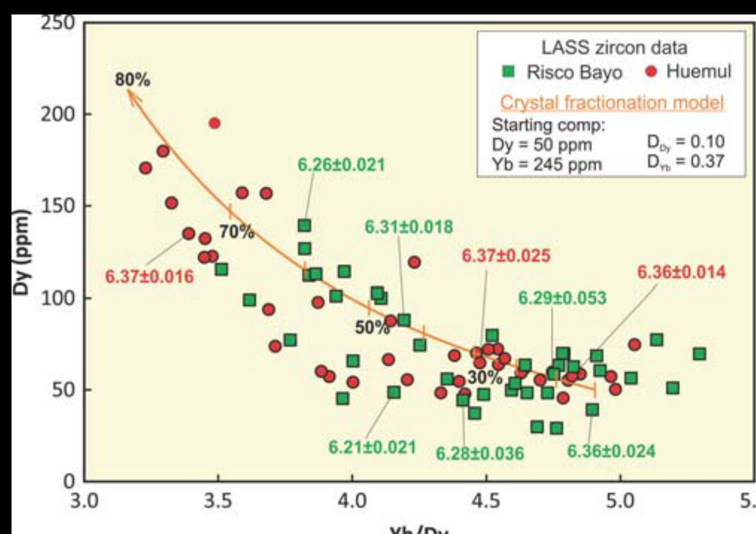
Petrochronology linking date to P-T-X evolution











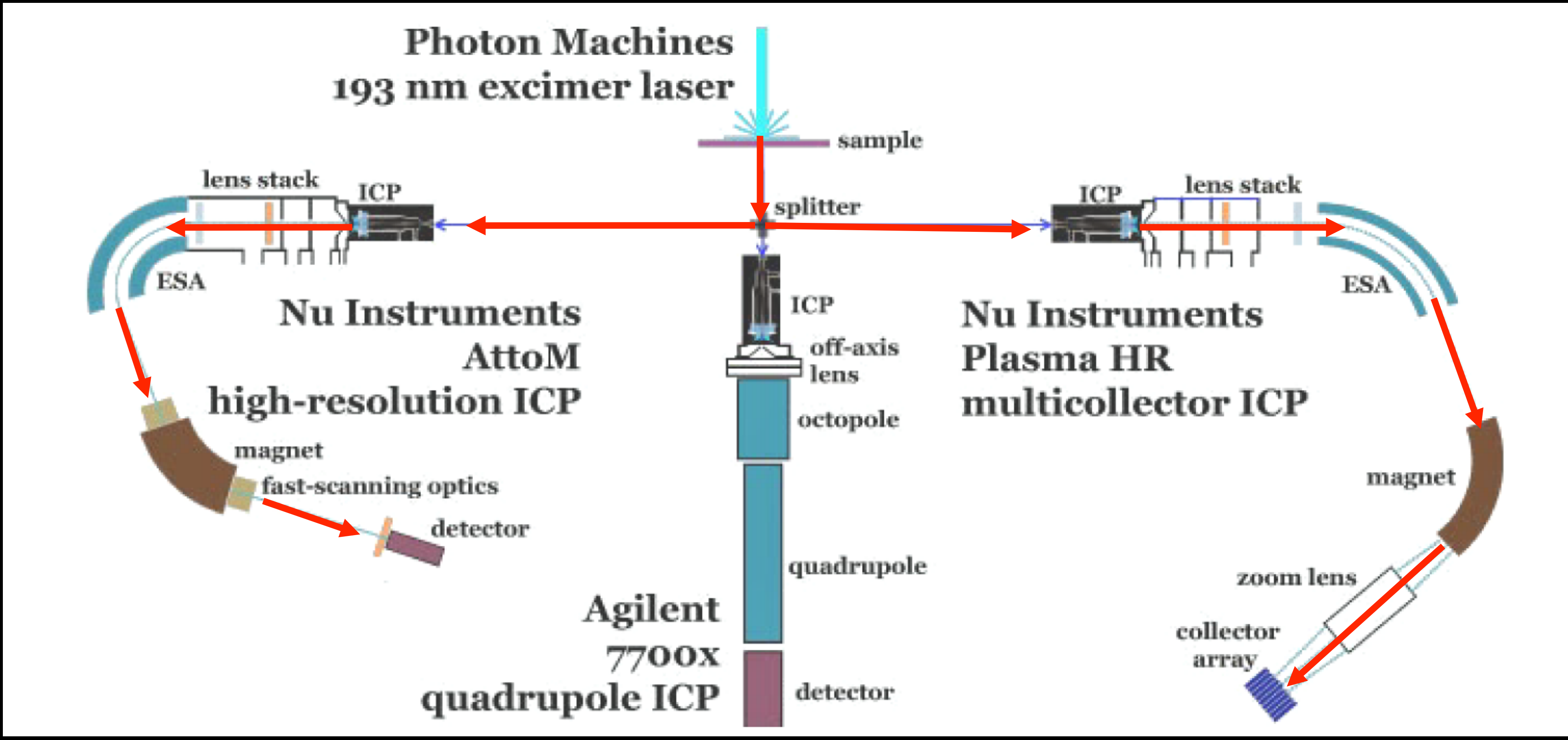
Singer, Schoene & Cottle unpubl.

Instrumentation

Laser Ablation Split Stream Analysis (LASS) at UCSB

AttoM / Agilent Quad
(REEs or U-Th/Pb)

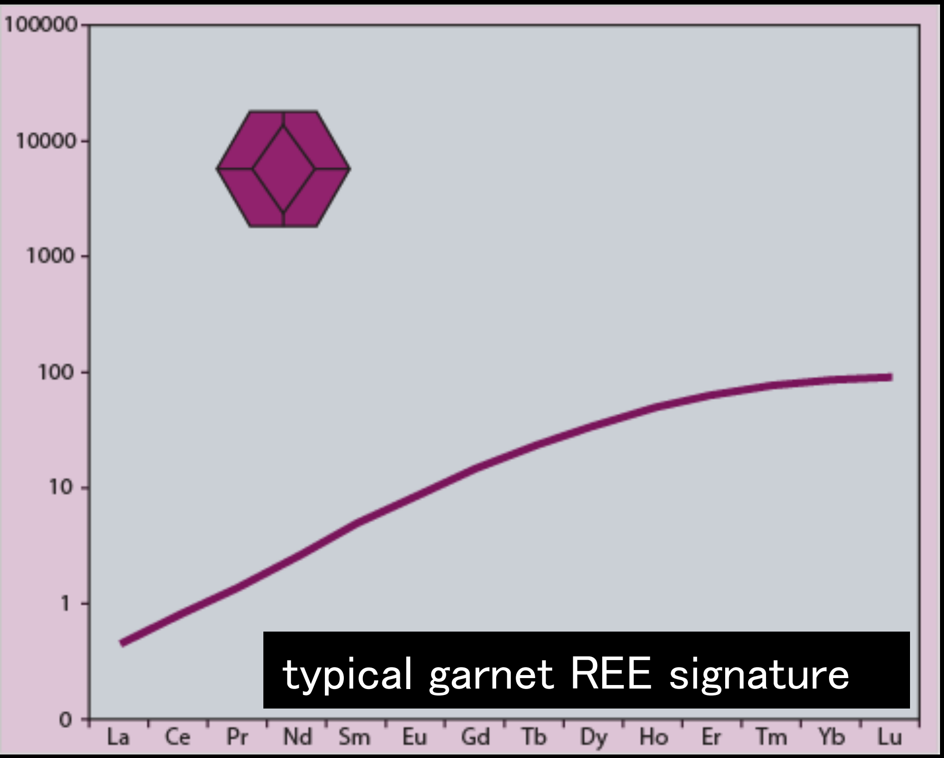
Nu Plasma
(U-Th/Pb, Nd, Hf, Sr, Li etc.)

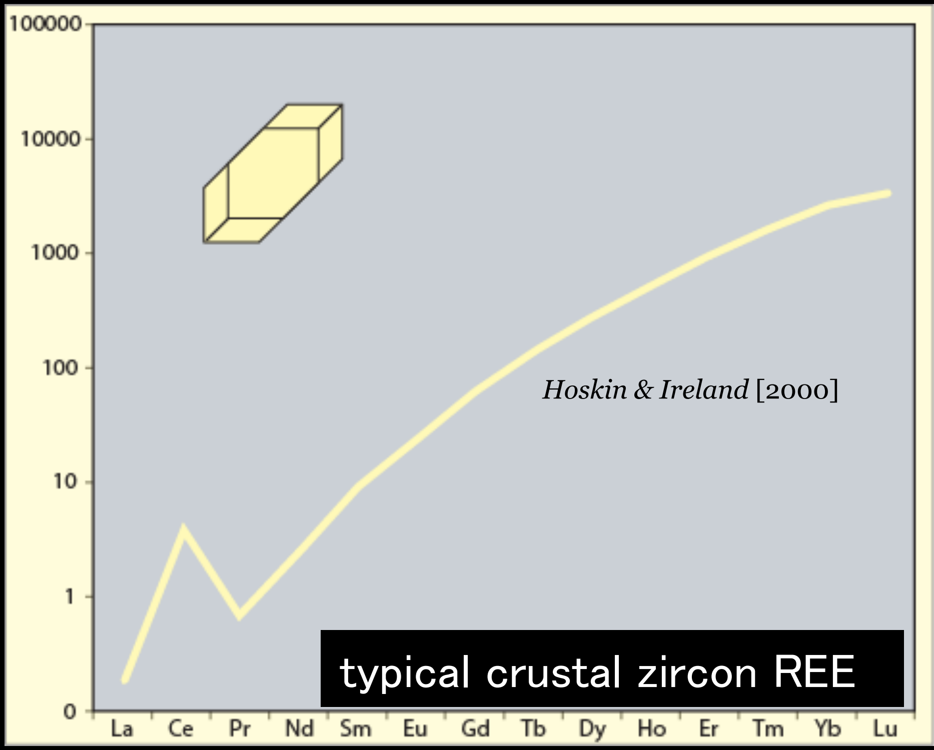


Petrochronology: Underlying Principles

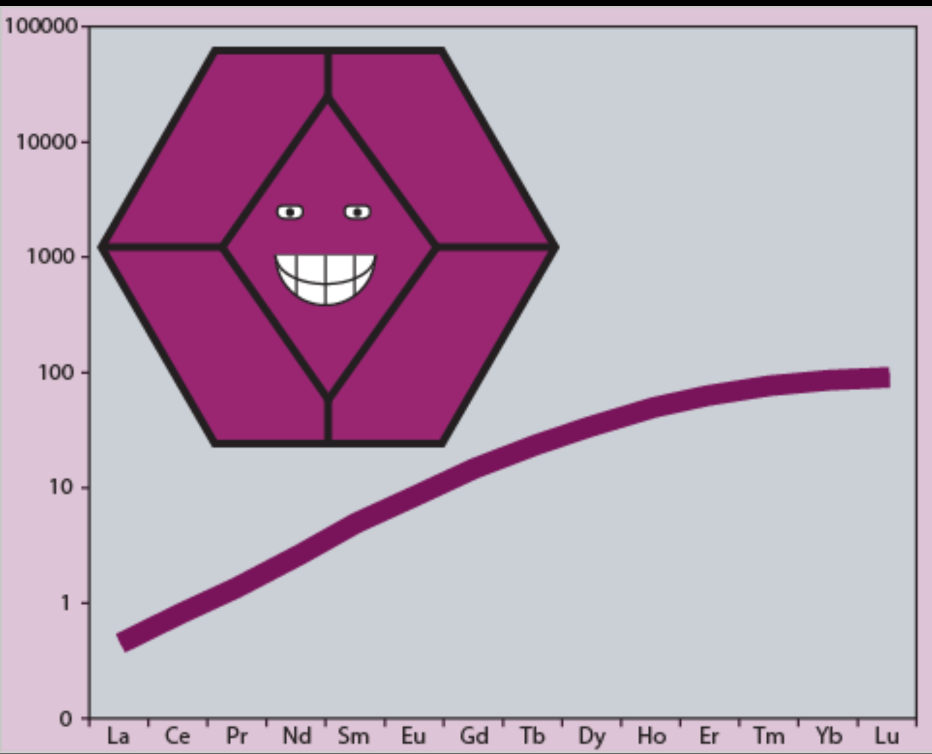
- Fuse Petrology + Chronology
- chronometer of interest contains particular elements (e.g., zircon contains Lu, but not La)
- element—or group of elements—provides signature of another phase (e.g., Eu anomaly from feldspar)
- changes in trace elements driven by (dis)appearance of phases & dT & dP
- want fast grain-boundary diffusion & slow volume diffusion

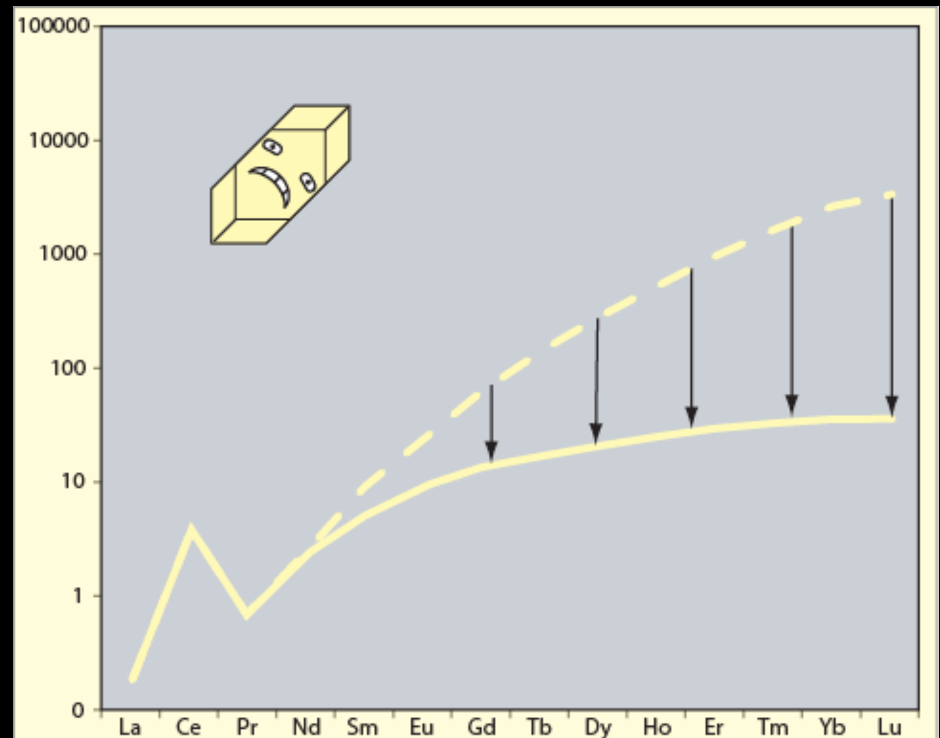
Zircon Petrochronology: REE Signature of Garnet





Zircon Petrochronology: REE Signature of Garnet

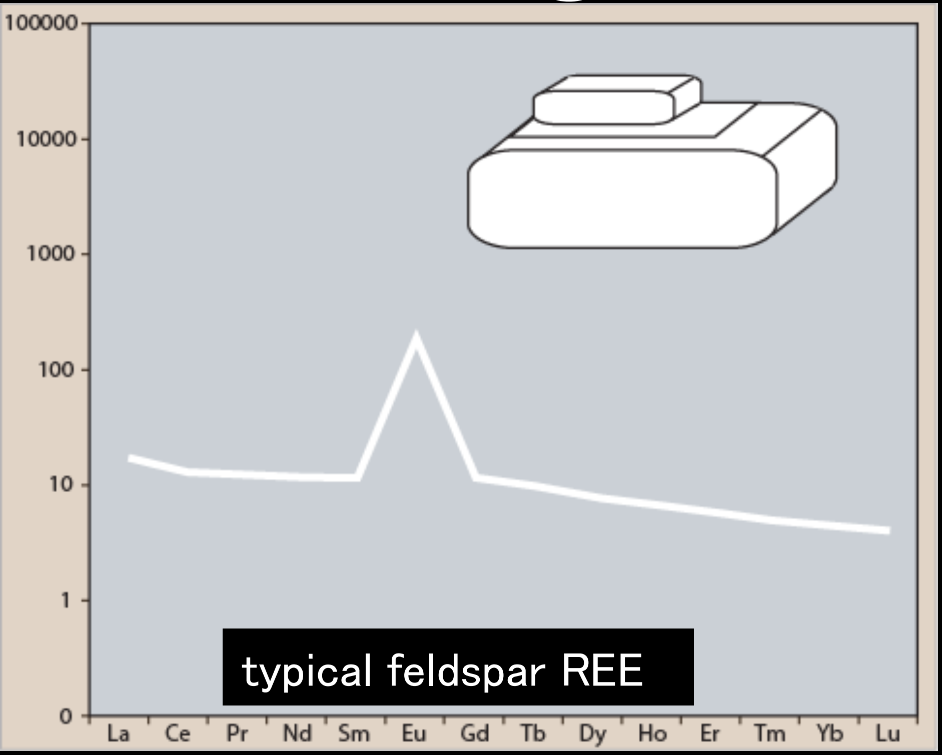


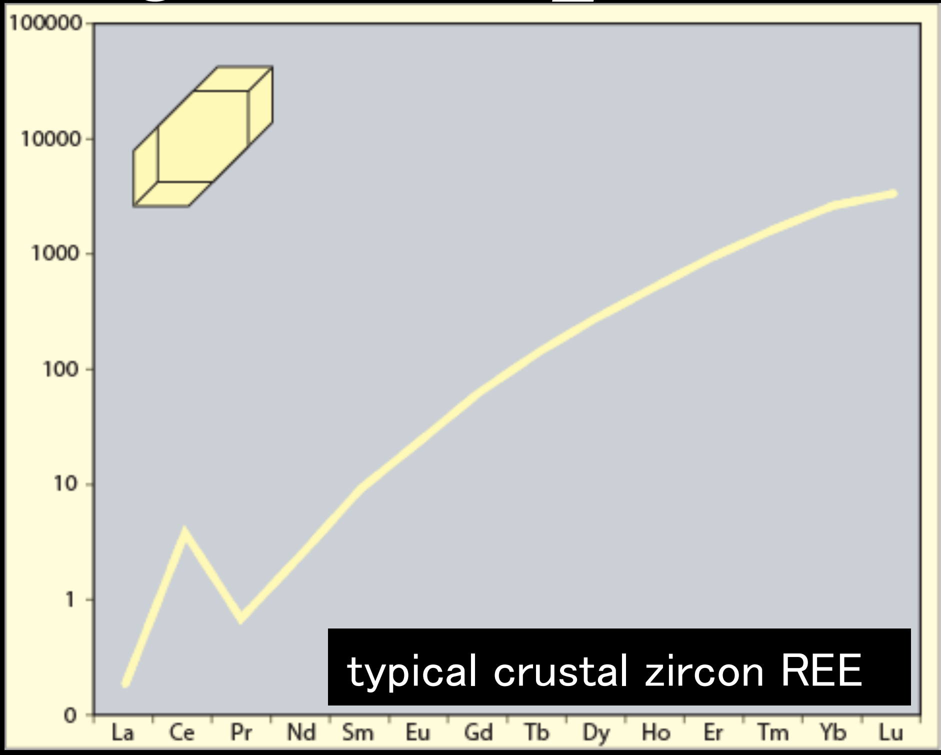


↑ P, T

↑ Garnet

Zircon Petrochronology: REE Signature of Feldspar

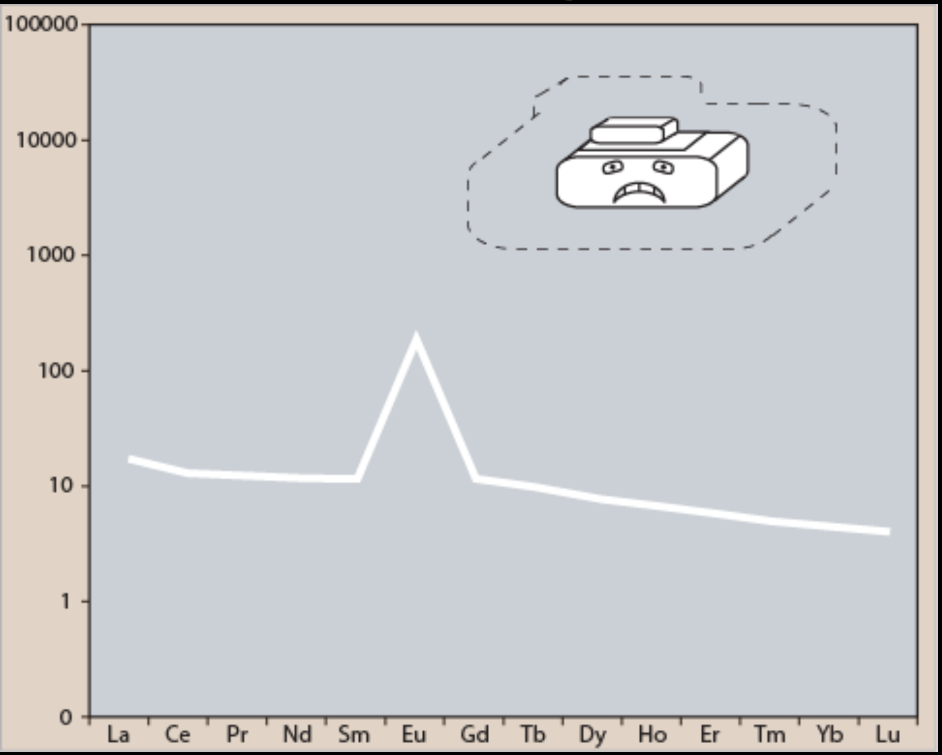


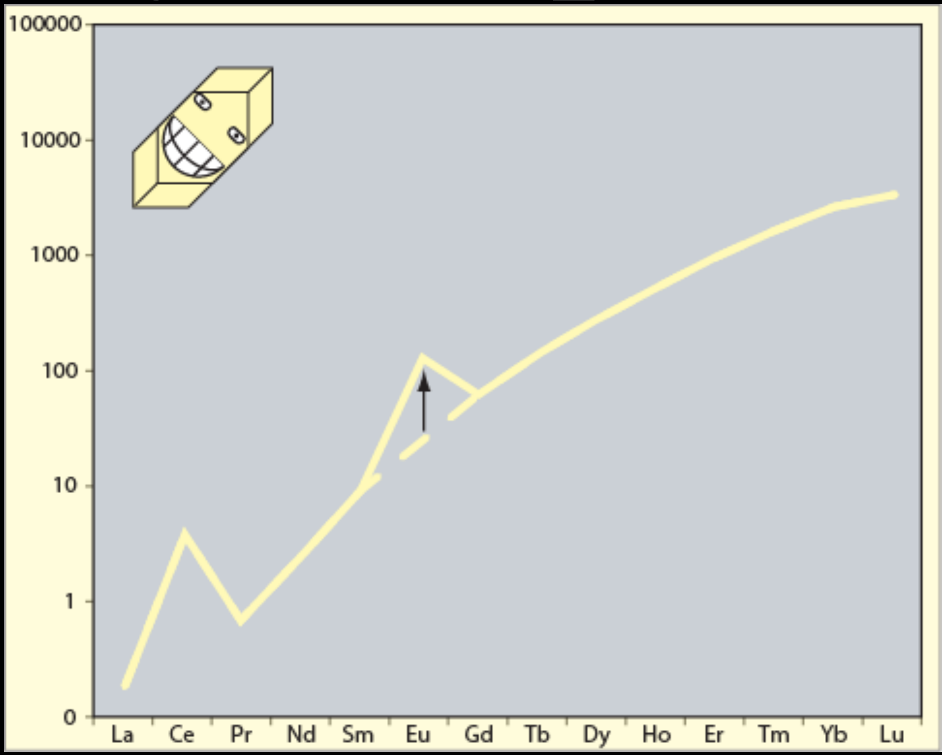


↓ P/T

↑ Plagioclase

Zircon Petrochronology: REE Signature of Feldspar





↑P/T

↓Plagioclase

Petrochronology examples

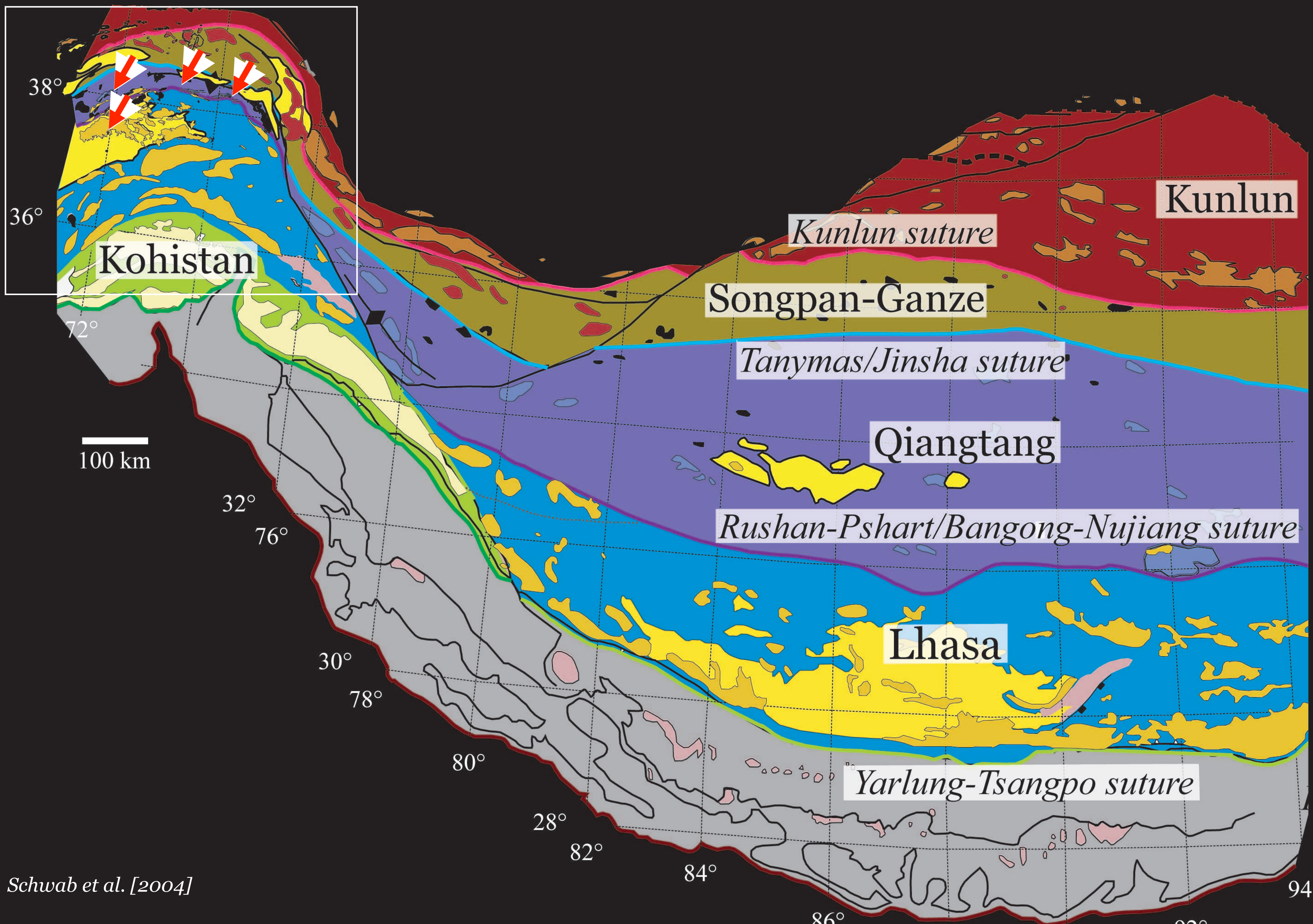
- Utilizing trace elements to understand complex metamorphic & magmatic histories

  → *Pamir/Himalaya & Norway*

- Campaign style petrochronology

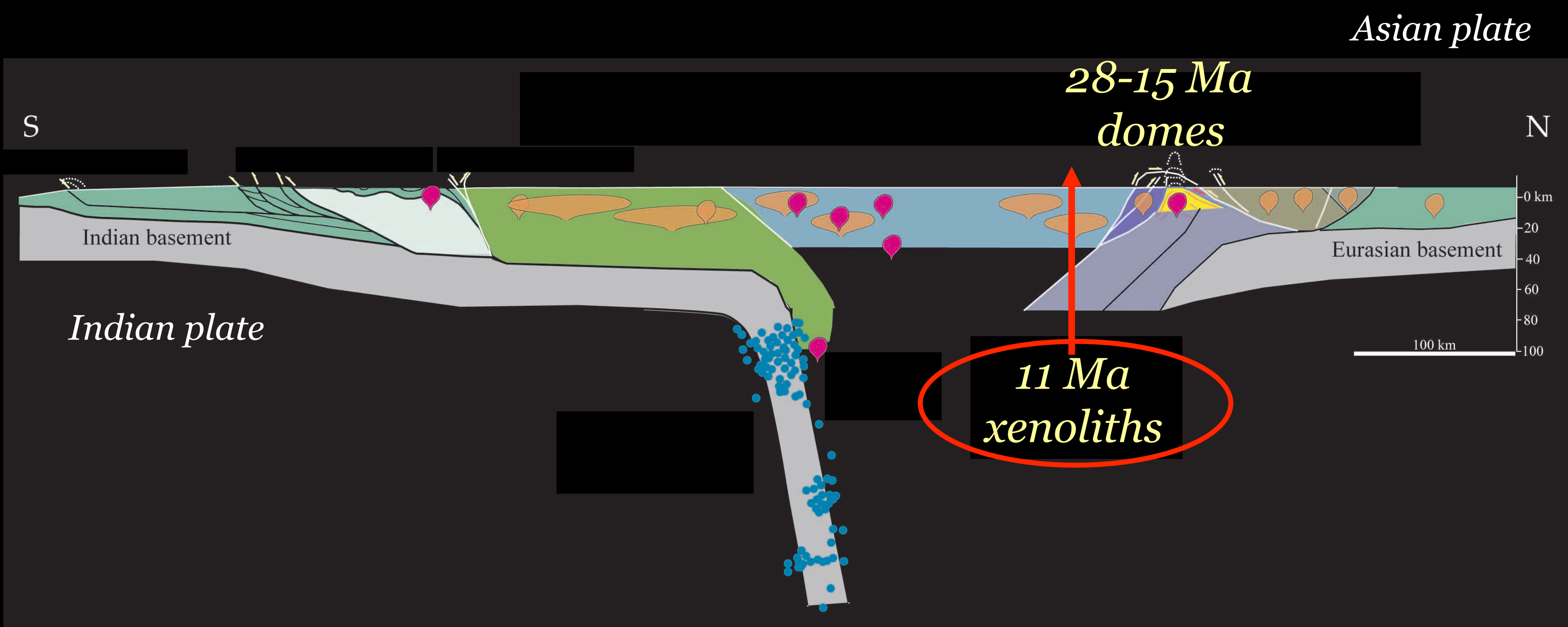
  → *grain-, outcrop-, & orogen-scale*

Pamir, Domes & Xenoliths

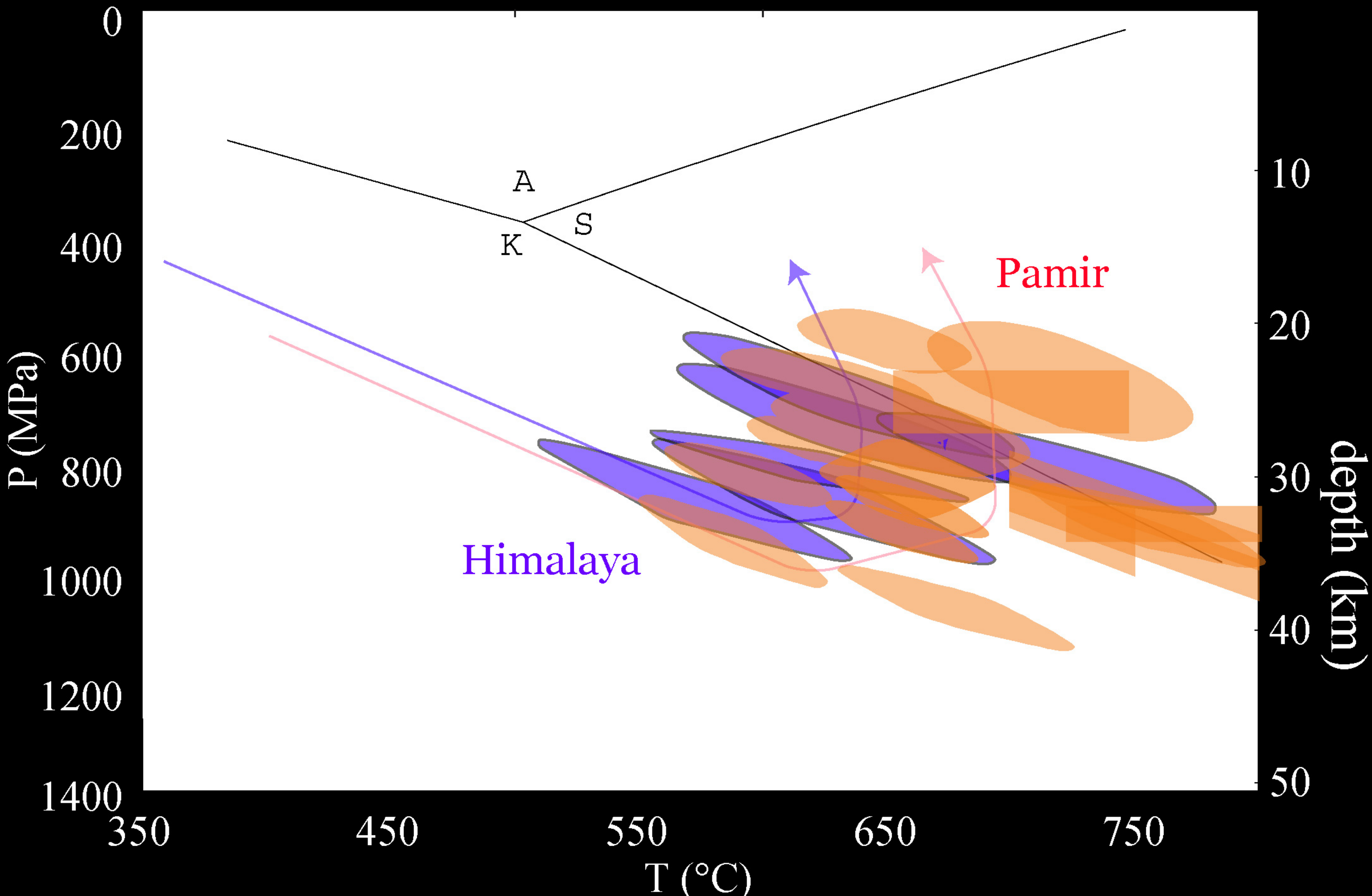


Schwab et al. [2004]

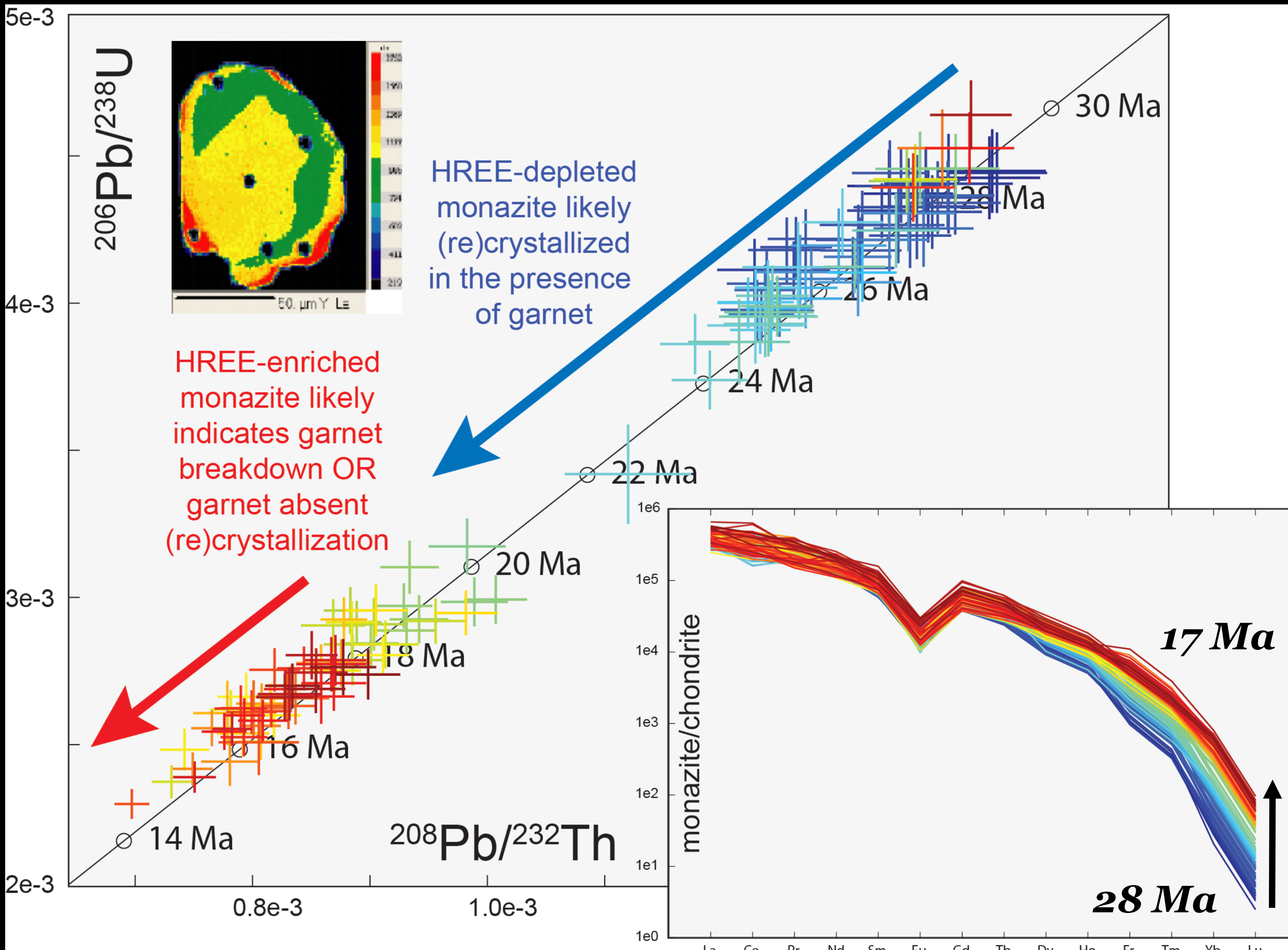
Pamir, Domes & Xenoliths



Domes from Mid–Deep Crust



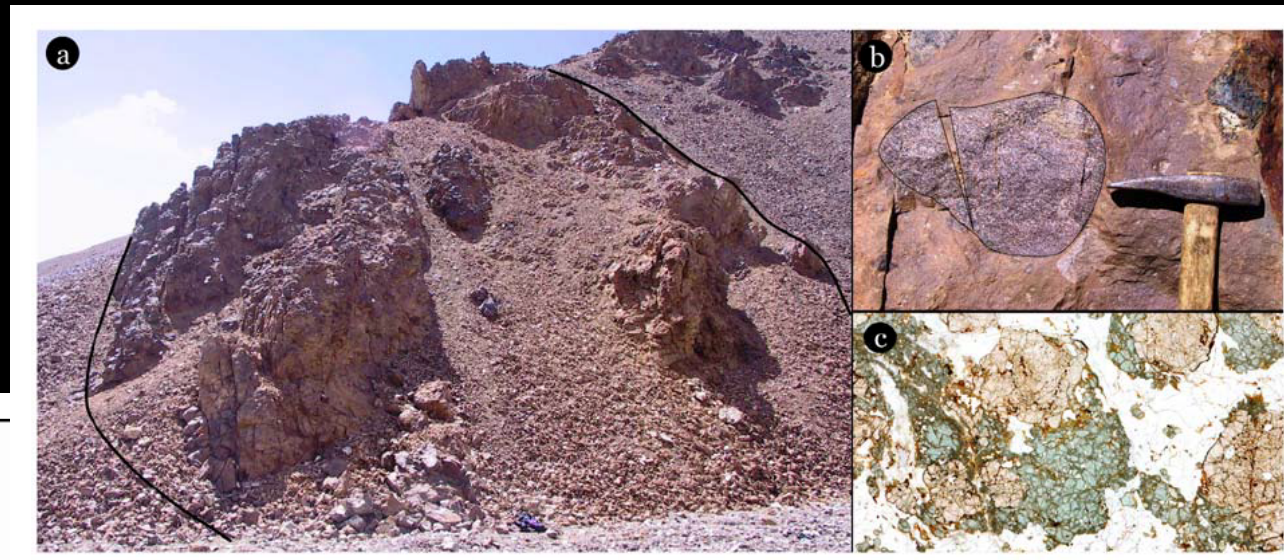
Pamir Domes: monazite

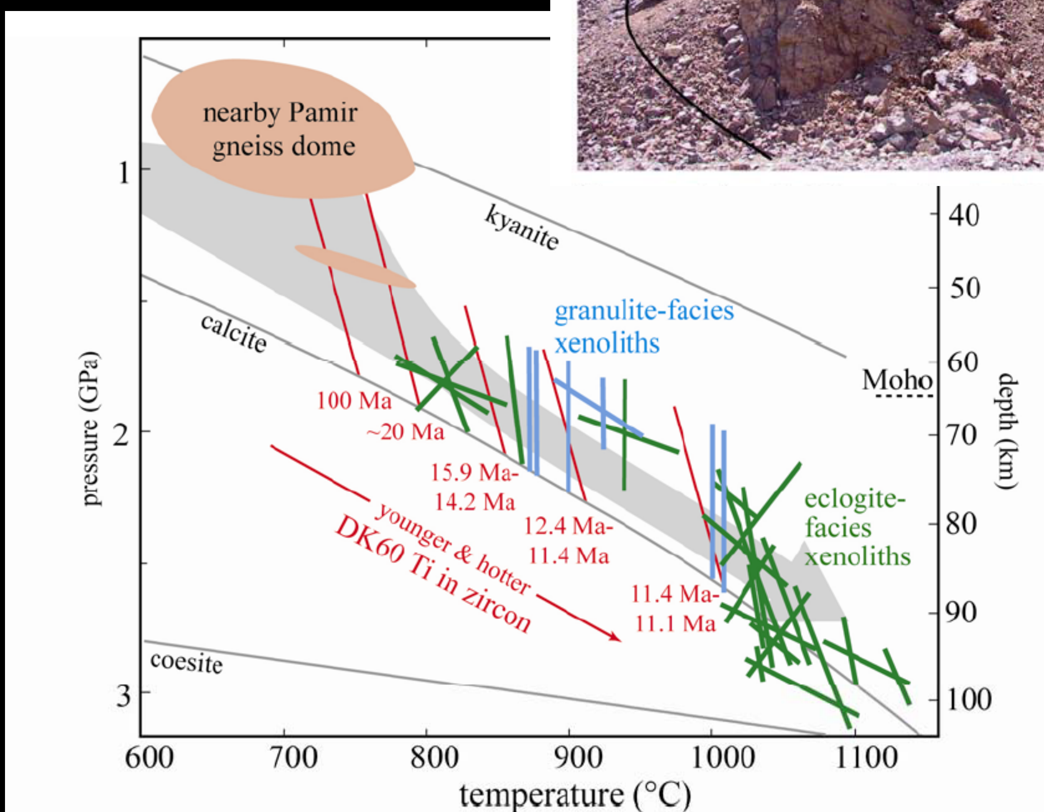


Stearns et al., (2013)

Pamir xenoliths

- pieces of continental crust that reached UHT at mantle depths

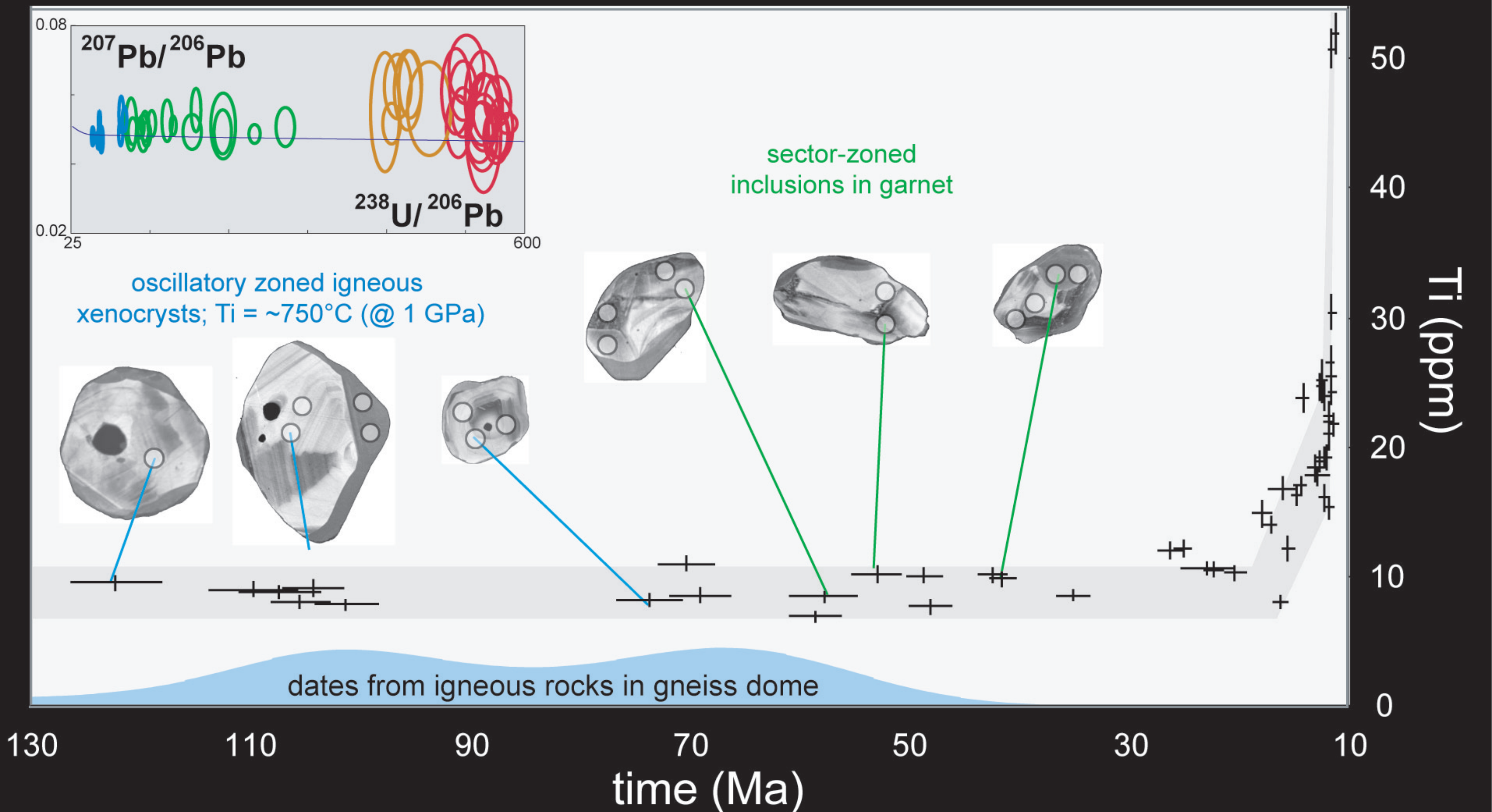




- Implications for behavior of continental crust during collisional orogensis

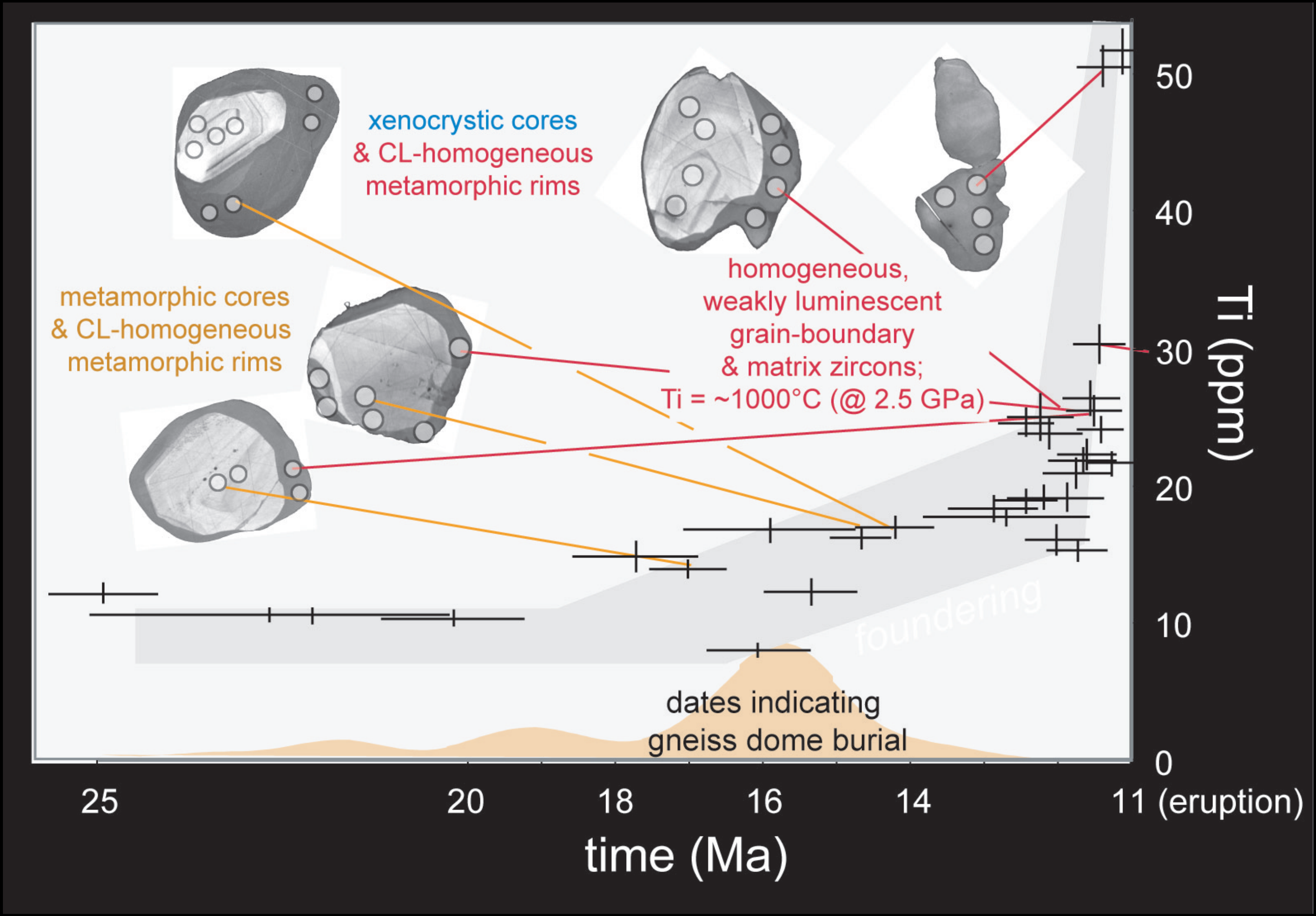
Hacker et al., (2005)

Ti vs. U-Pb date



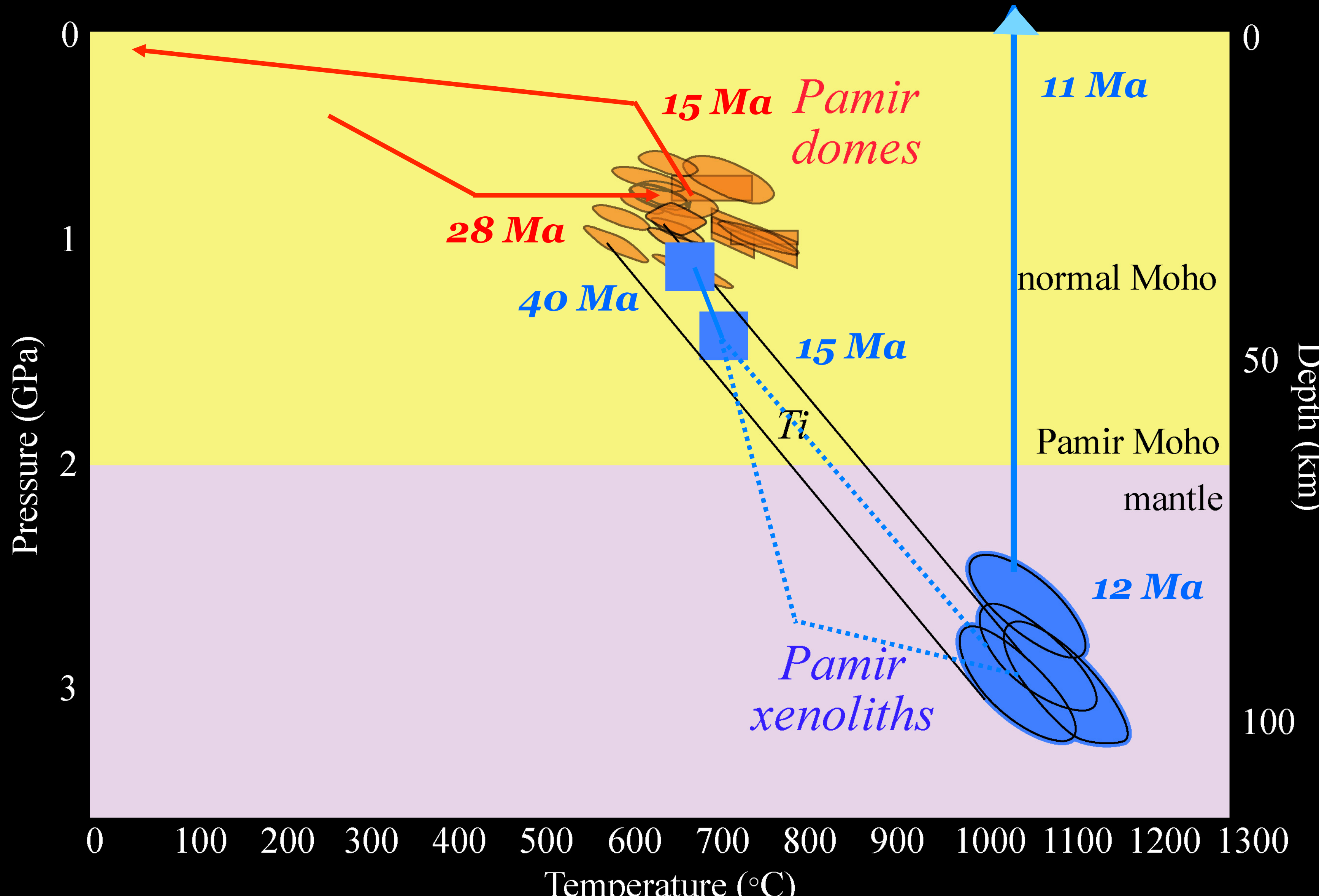
Pamir UHT, near-UHP xenoliths

Ti vs. U-Pb date

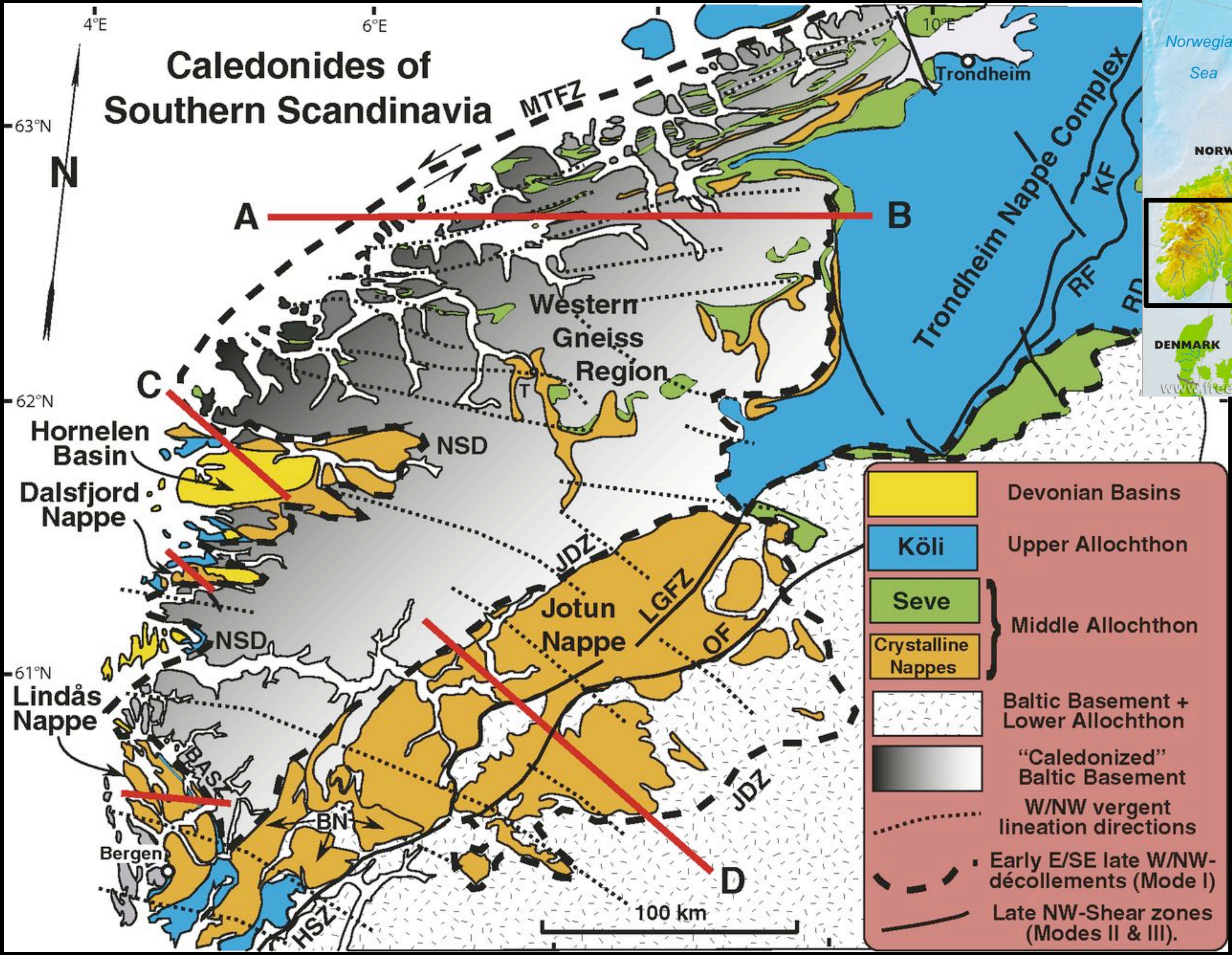


Pamir UHT, near-UHP xenoliths

Crust Went Up and *Down*

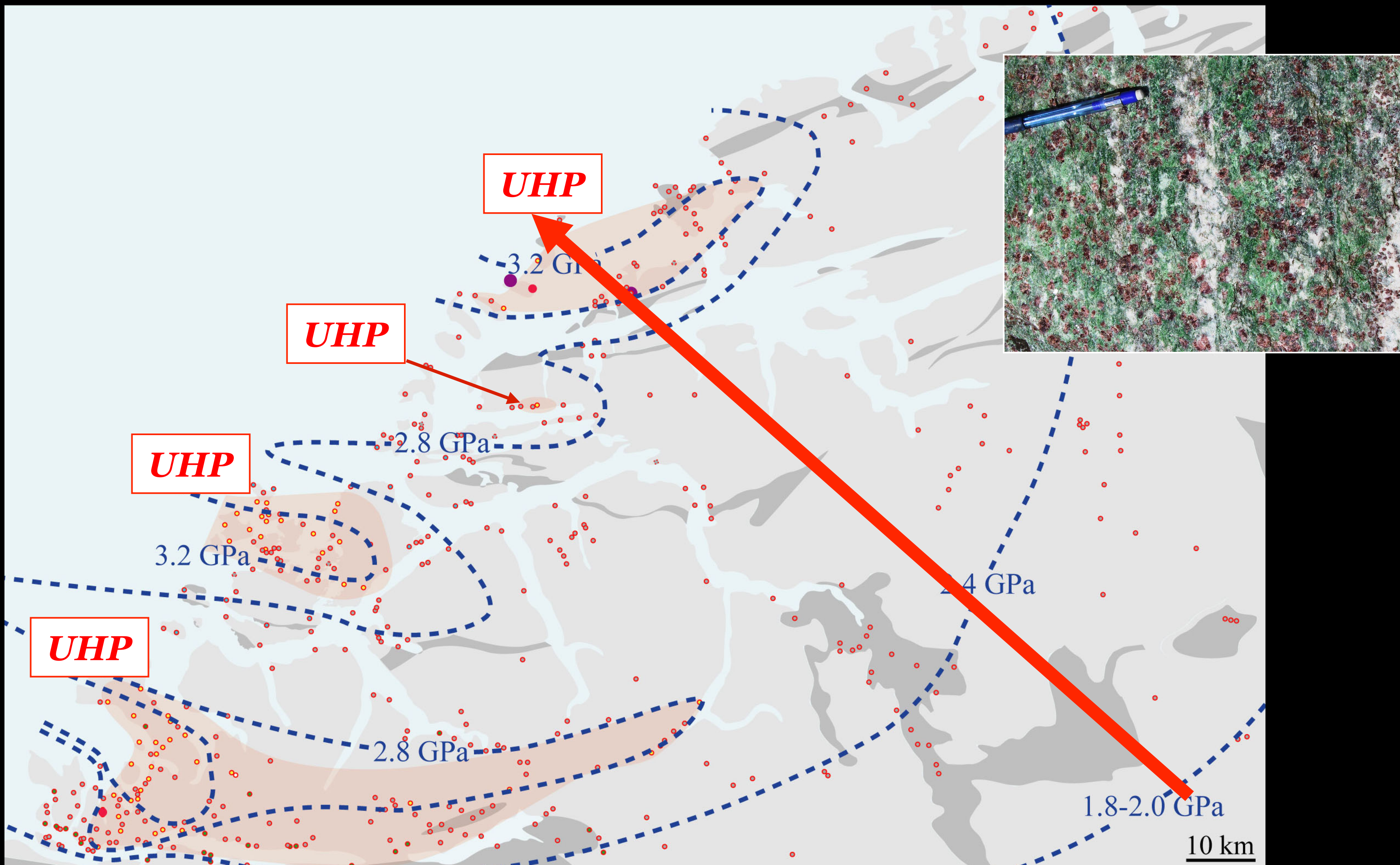


Giant *Norwegian UHP Terrane*



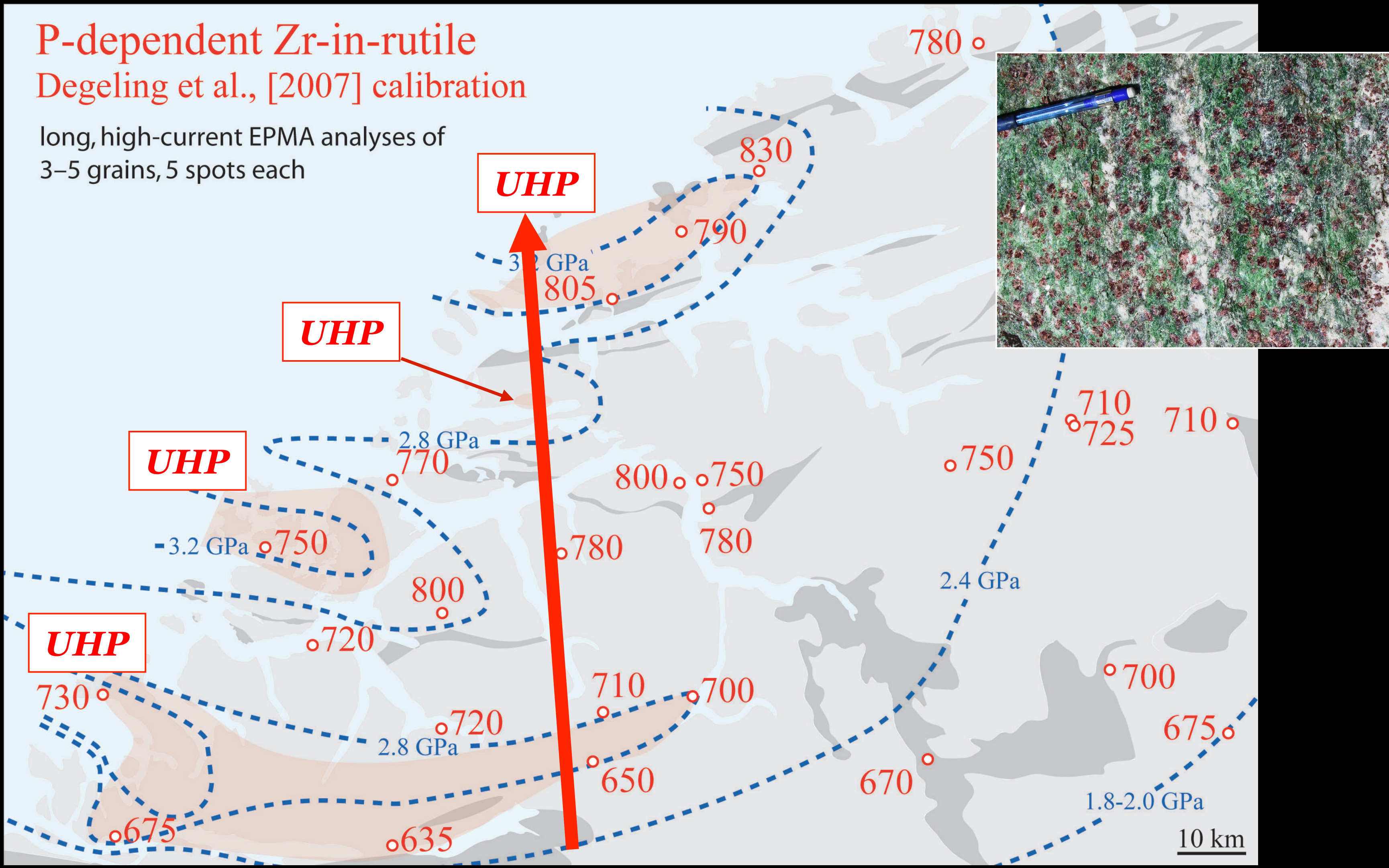
Eclogite ∇P: 1.8–3.6 GPa (65–135 km)

1–2% eclogite & peridotite exposed over 30,000 km²



Cuthbert et al. [2000]; Terry et al. [2000]; Wain et al. [2000]; Schärer & Labrousse [2002]; Carswell et al. [2003, 2006]; Labrousse et al. [2004]; Walsh & Hacker [2004]; Ravna & Terry [2004]; Root et al. [2005]; Young et al. [2007]; Butler et al. [2012]

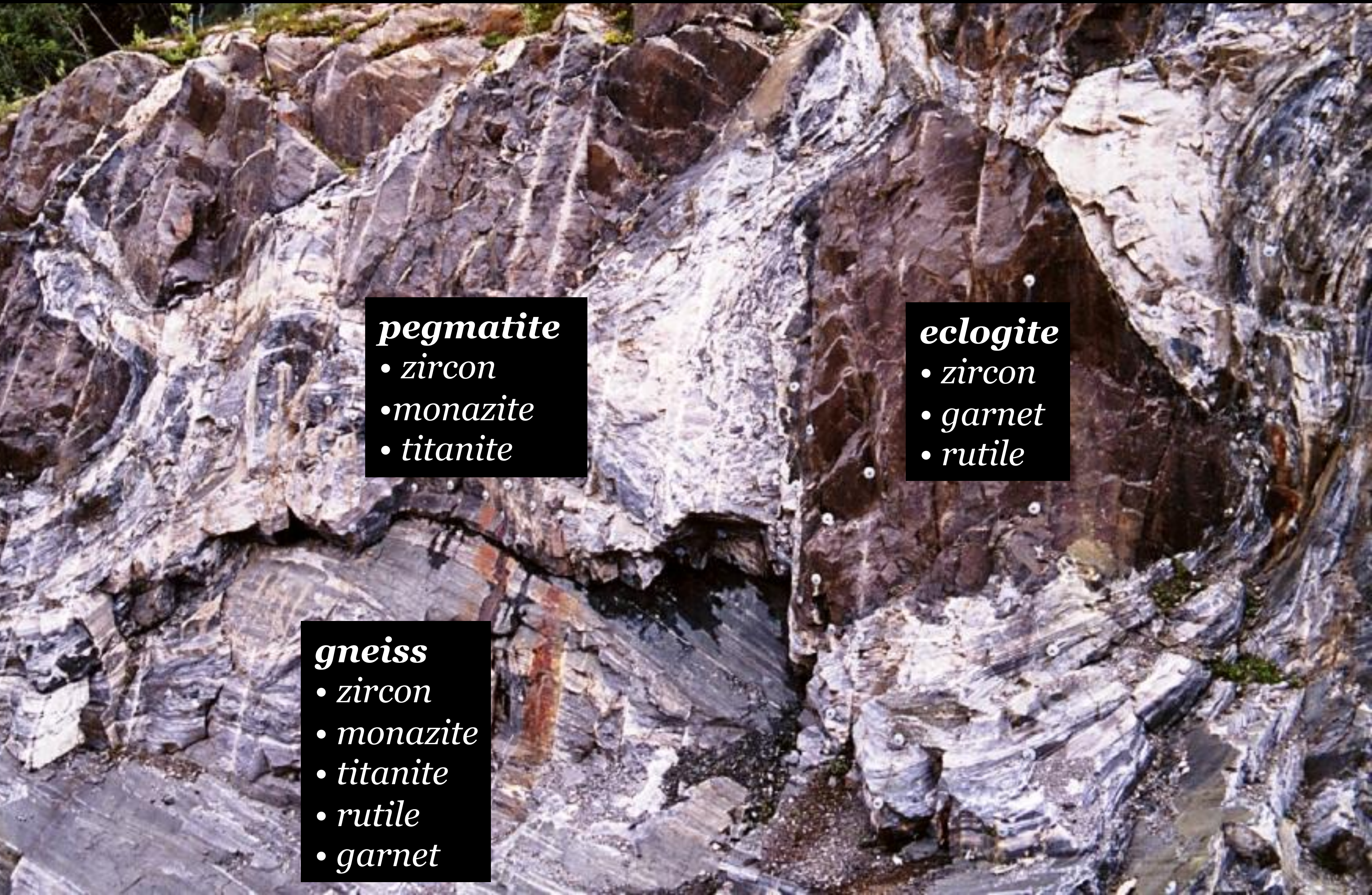
Eclogite ∇T: 650–825 °C



Giant *Norwegian UHP Terrane*

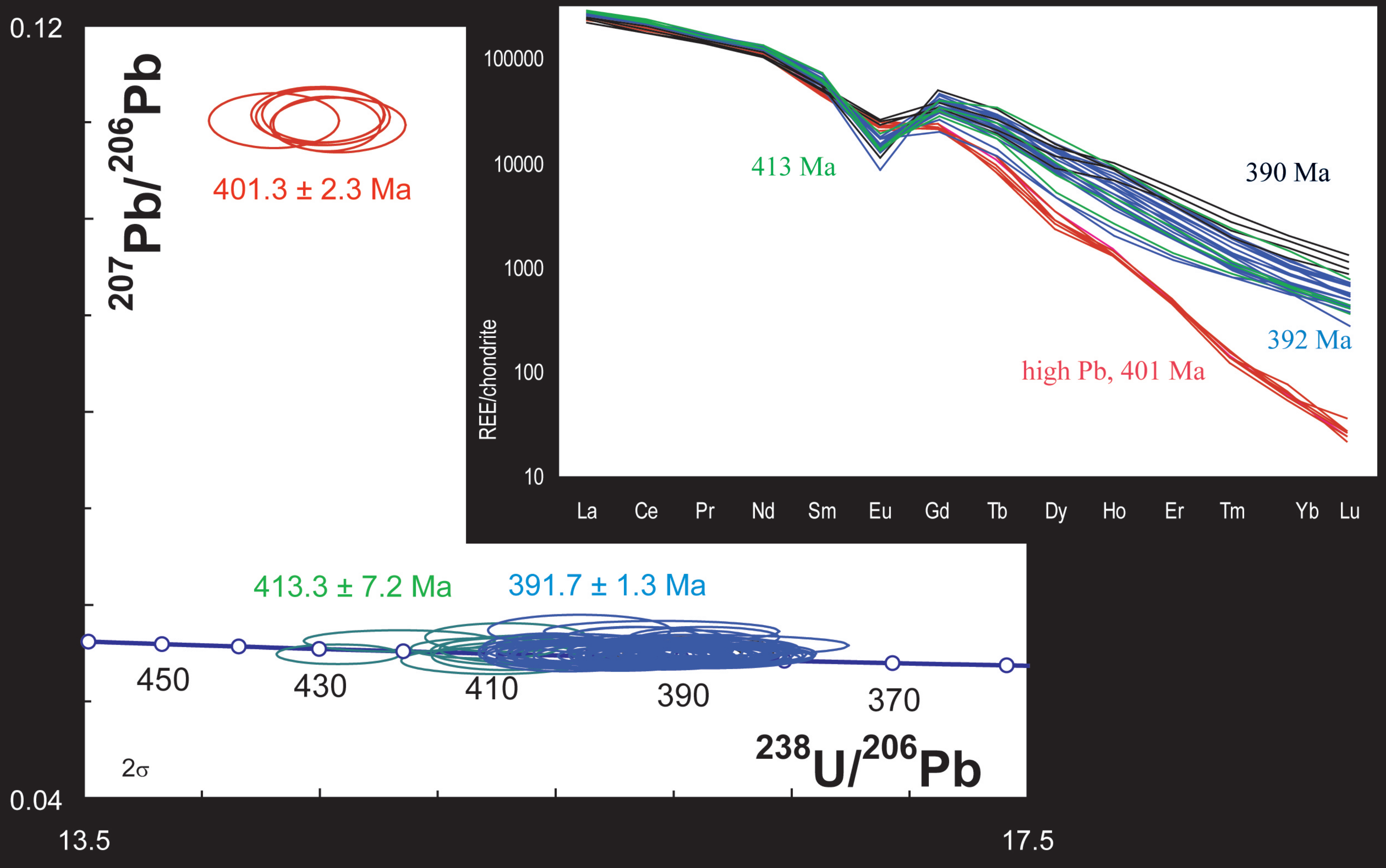
- What is the timing and duration of UHP metamorphism?
- Were burial and exhumation rapid, or slow?
- Are UHP rocks within discrete blocks or are they a uniform package?

Outcrop Relations



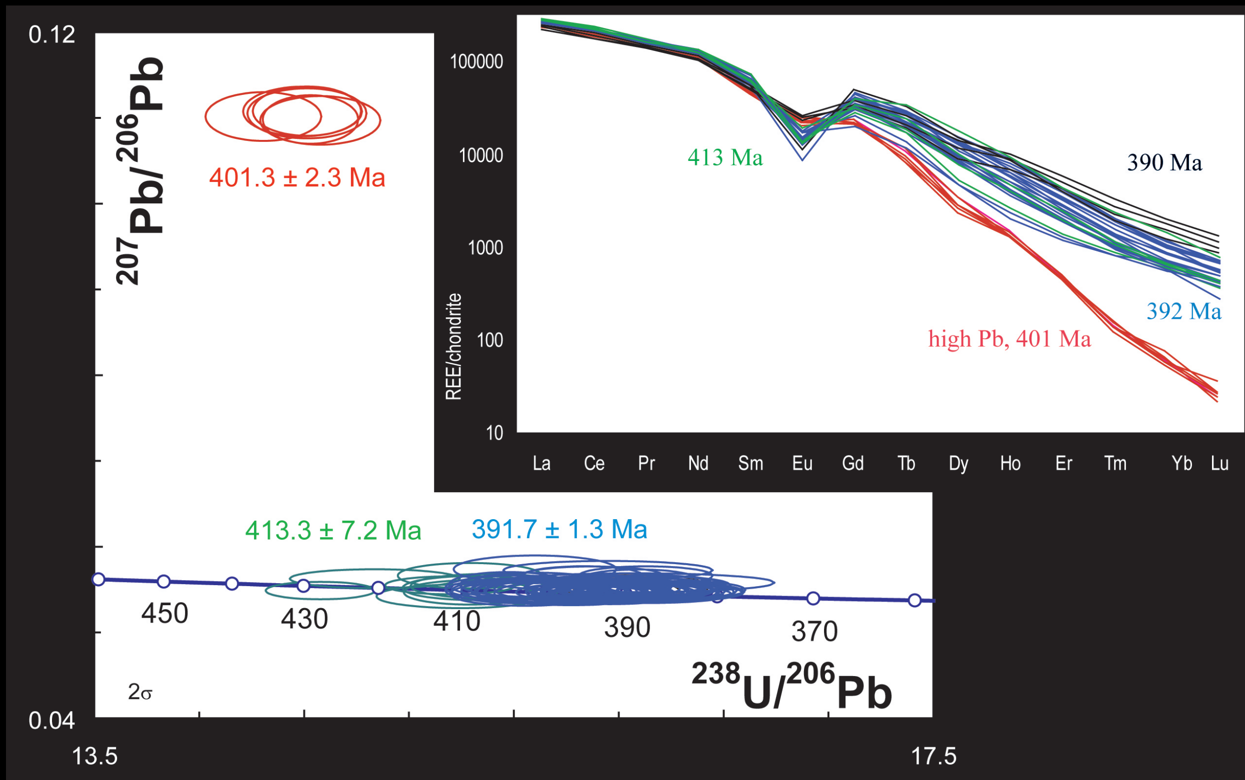
Gneiss Into & Out of Eclogite Facies

Monazite High Pressure gneiss, Norway



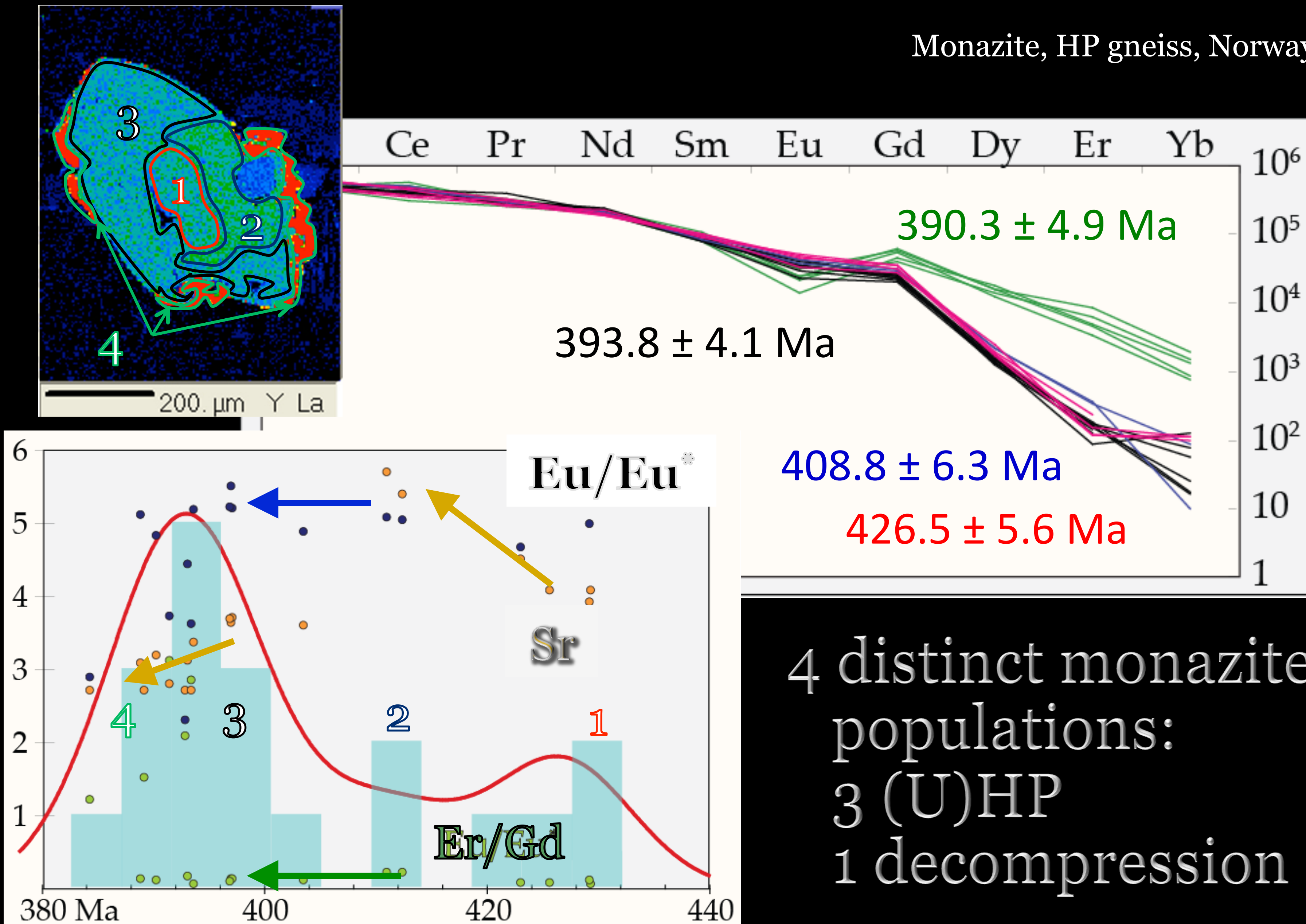
Gneiss Into & Out of Eclogite Facies

HP gneiss, Norway



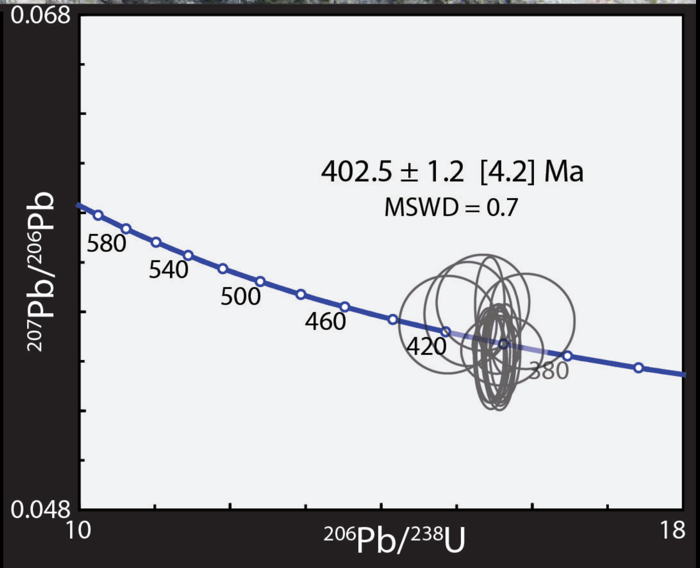
	Eu/Eu*	HREE content	cm-Pb
413 Ma:	-ve	high	low
401 Ma:	none	low	high
392-390:	-ve	high	low

Gneiss Exhuming from UHP

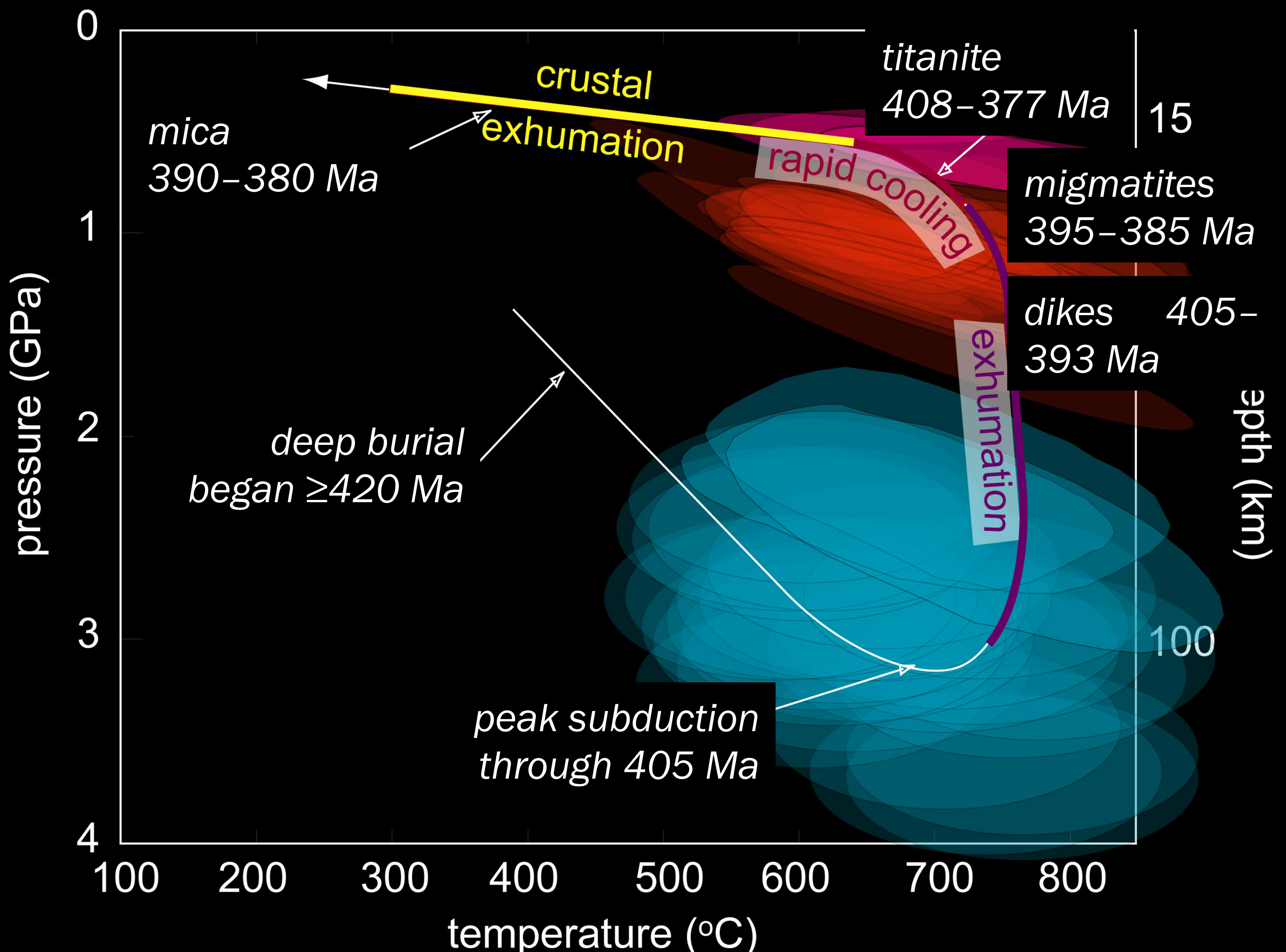


4 distinct monazite populations:
3 (U)HP
1 decompression

Did melting occur at UHP?

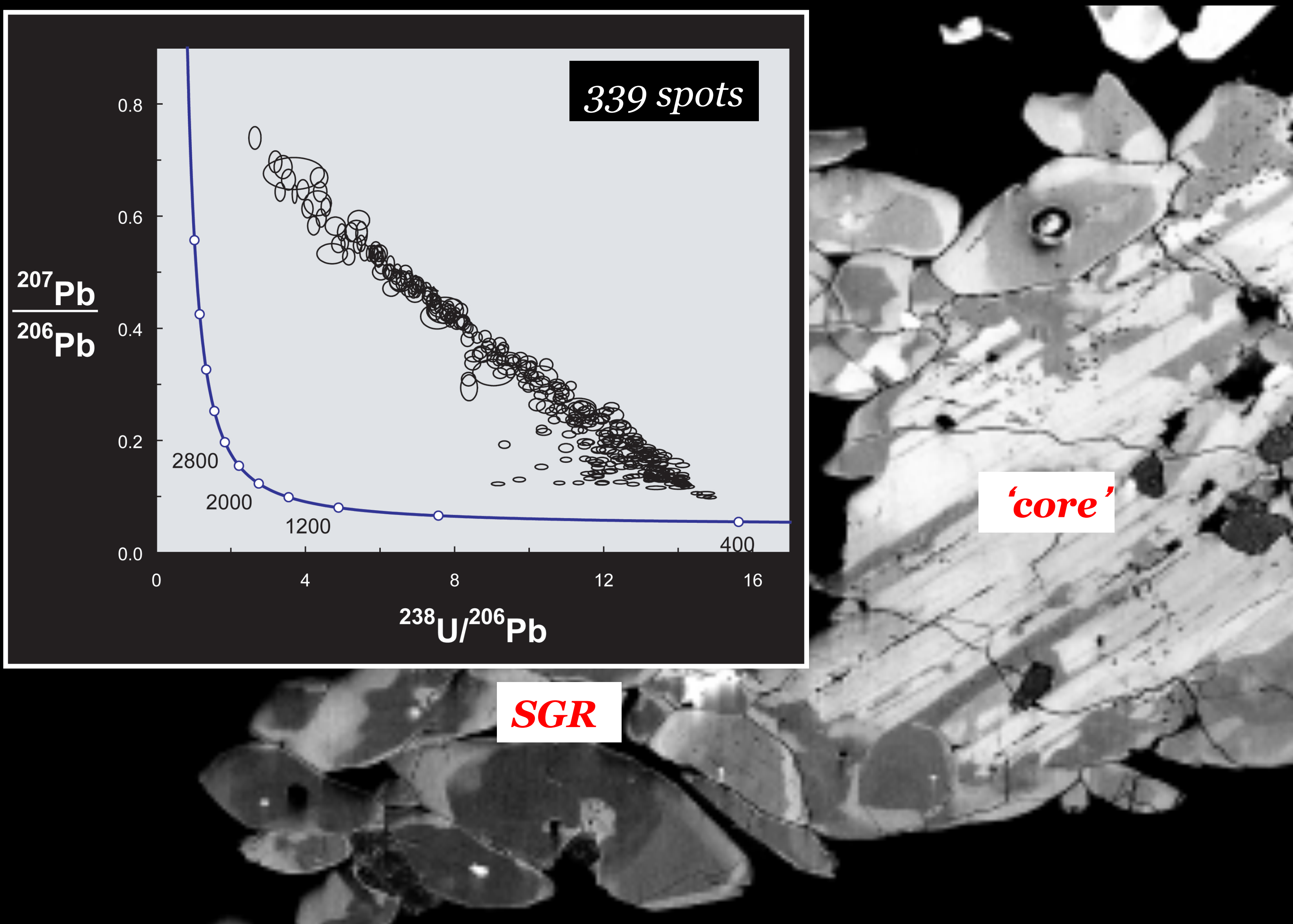


≥15 Myr Subduction, 15–25 Myr Exhumation

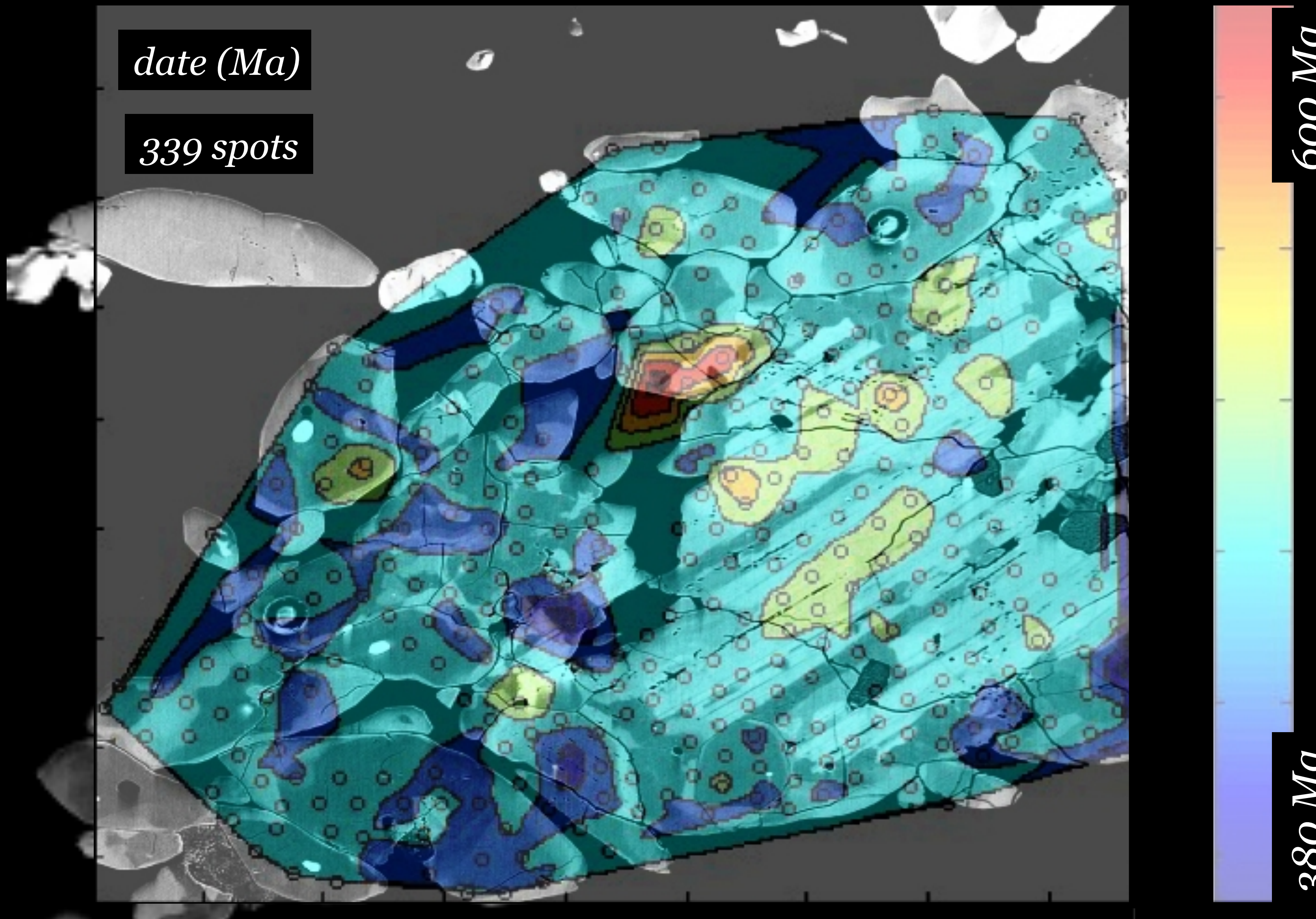


Campaign-style petrochronology #1
grain-scale

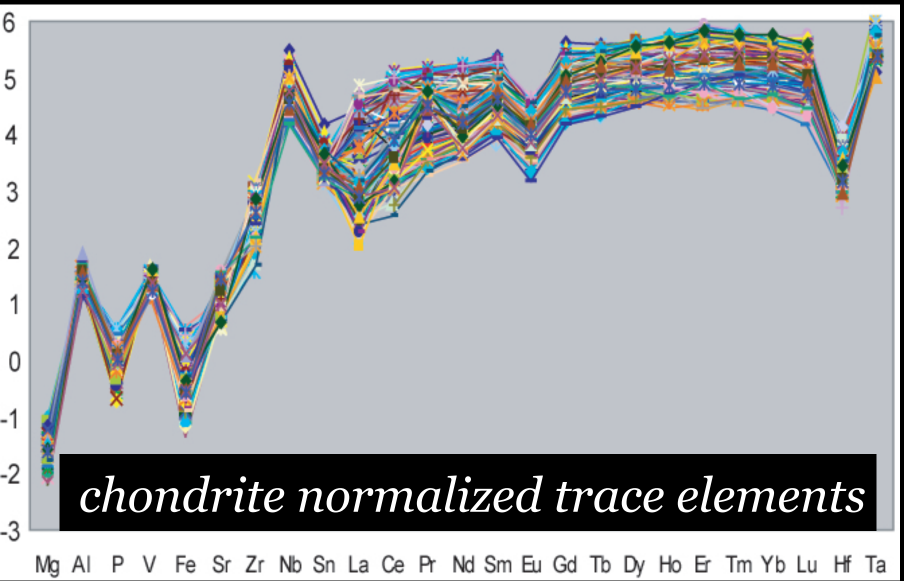
LASS Titanite analysis

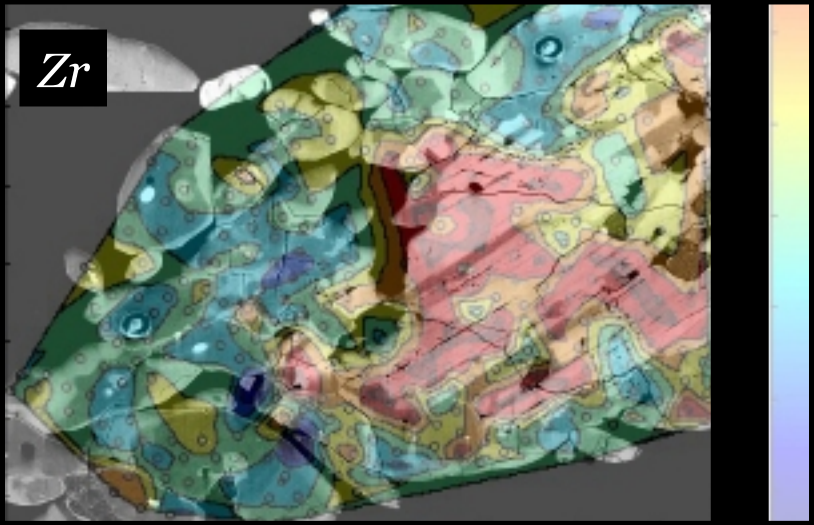


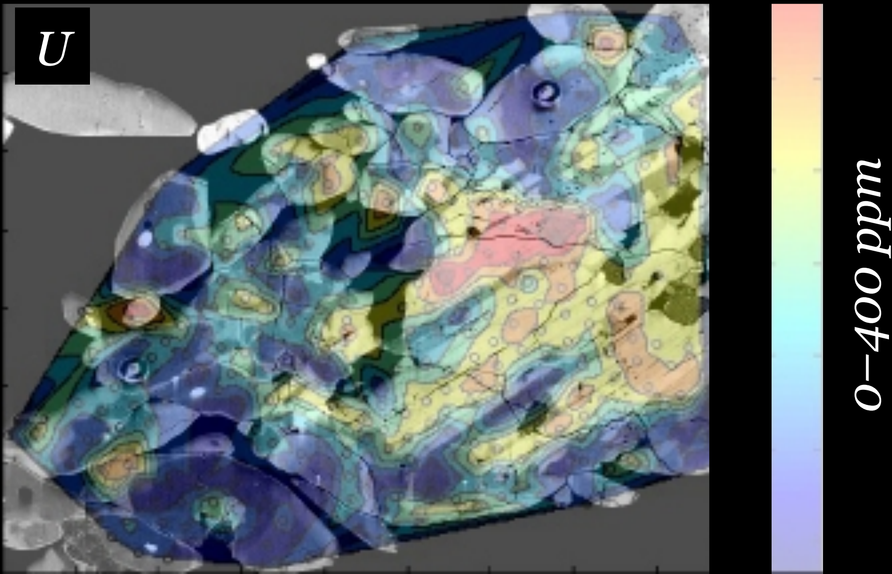
LASS Titanite Date Map

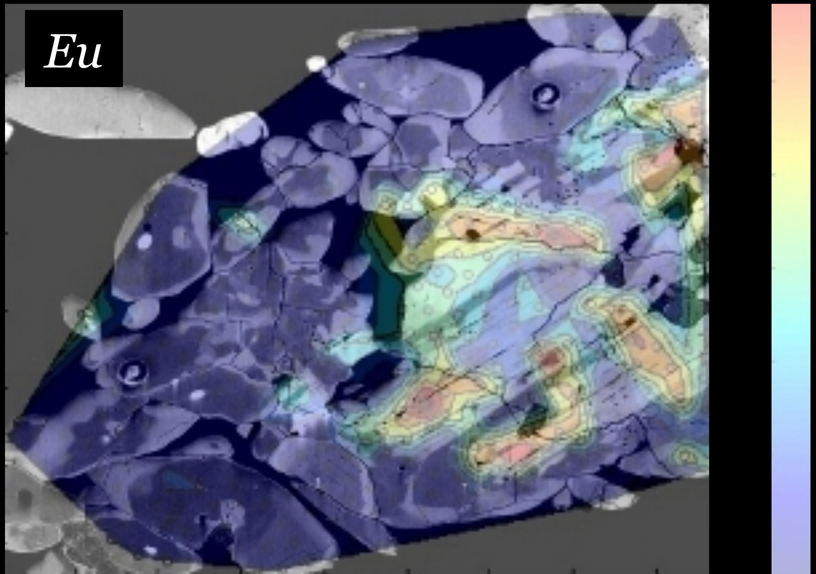


LASS Titanite Elemental Maps

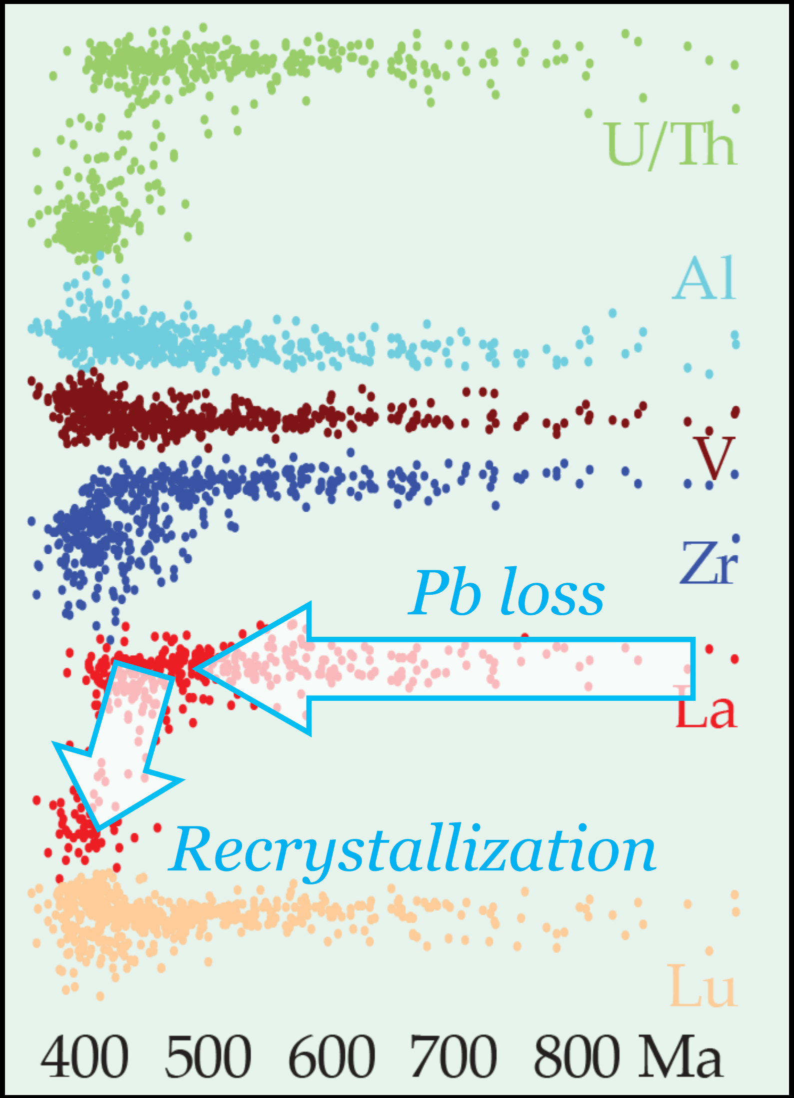


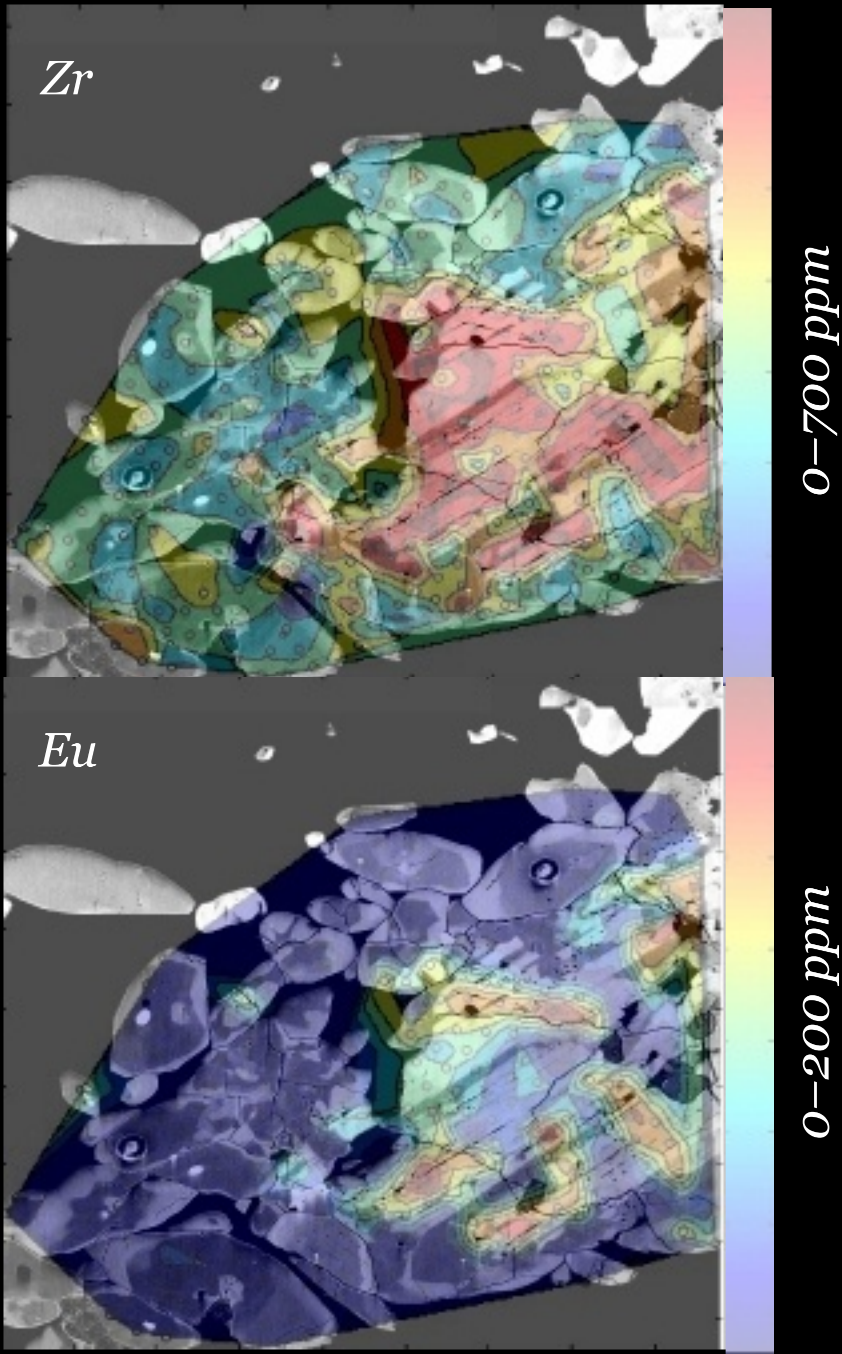






Trace element vs. apparent age



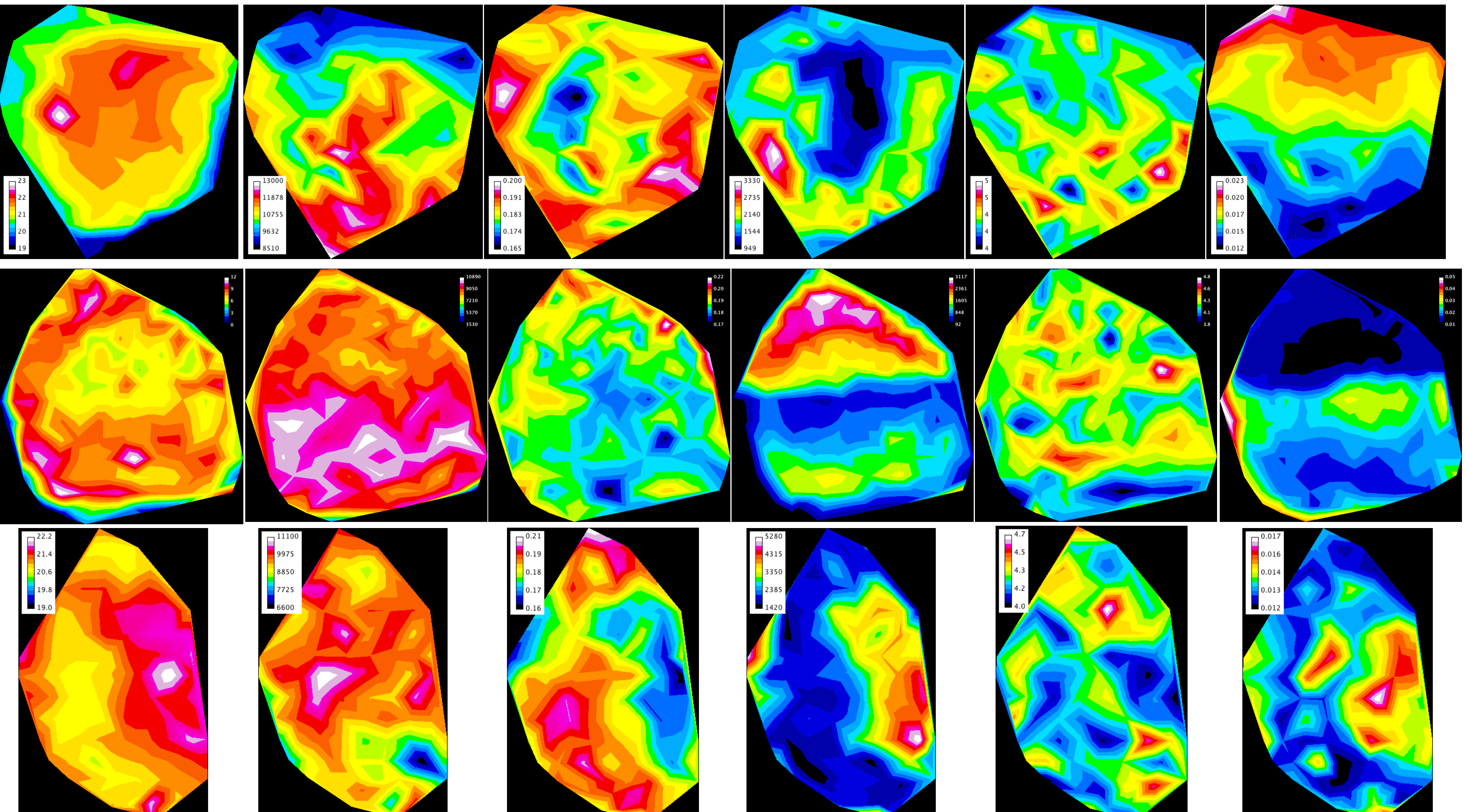


Monazite U/Th-Pb + Trace-Element Maps

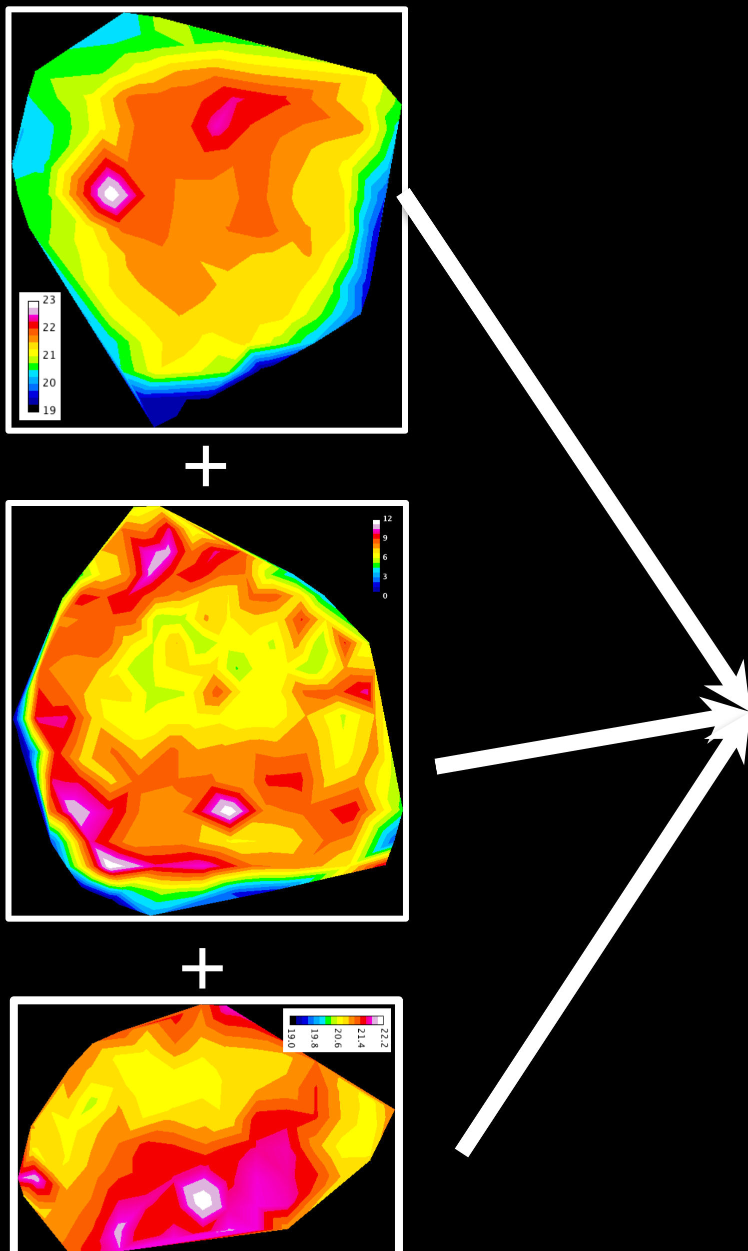
~1 hr/grain; 270 analyses

Himalayan migmatite

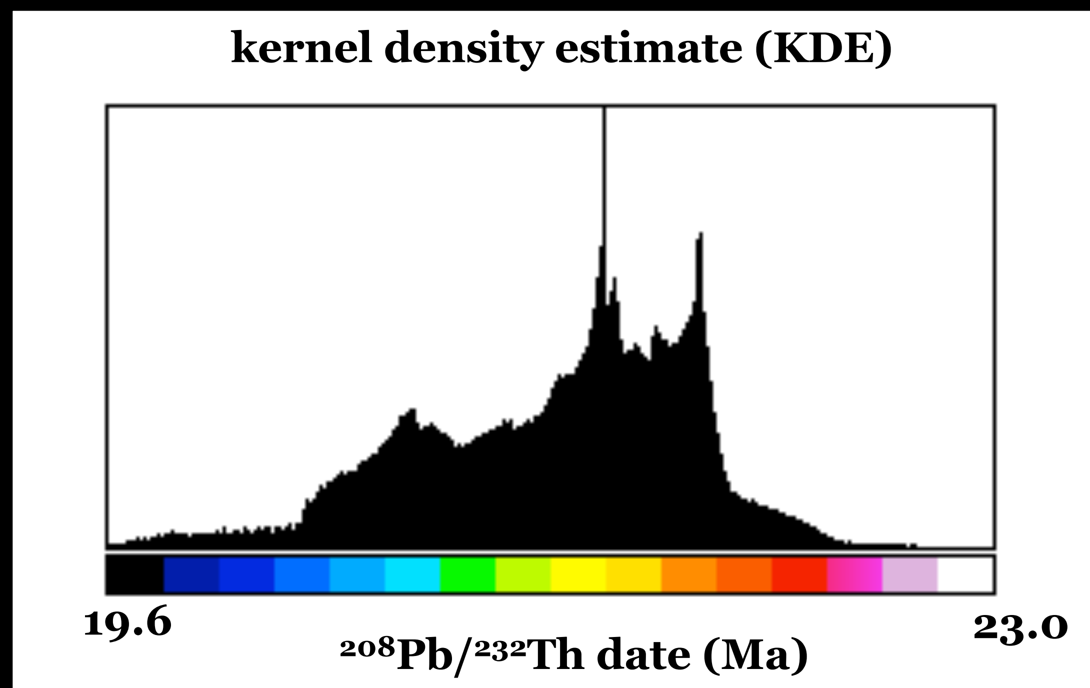
Pb/Th date (Ma)	Ca	Sm/Nd	La/Yb	Ce^*_n/Ce_n	Eu^*_n/Eu_n



Generate KDE directly from grain maps



accurate representation
of relative age proportions
in multiple grains

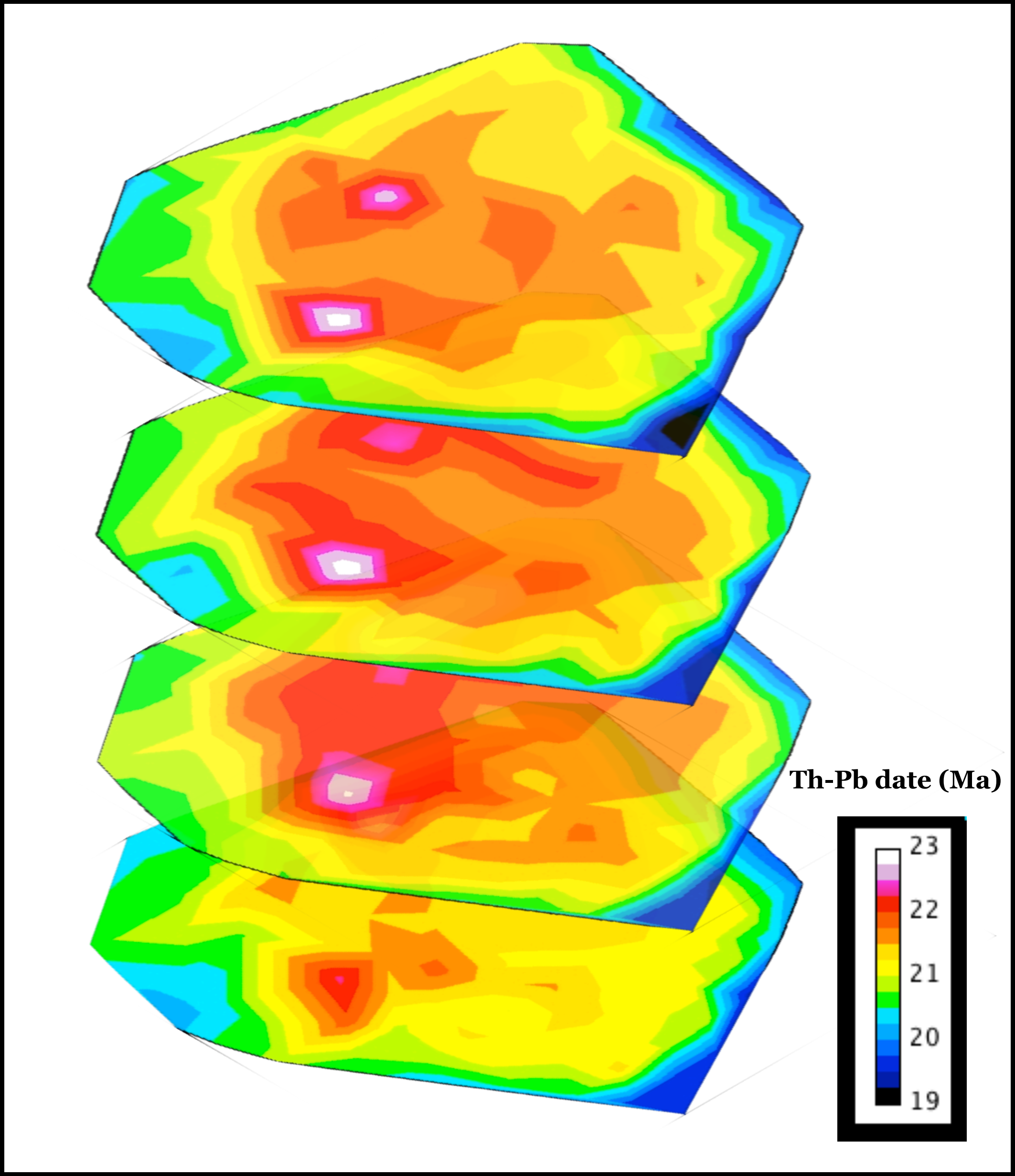


Even 3D Maps: Himalayan monazite

rapidly obtain depth profiles

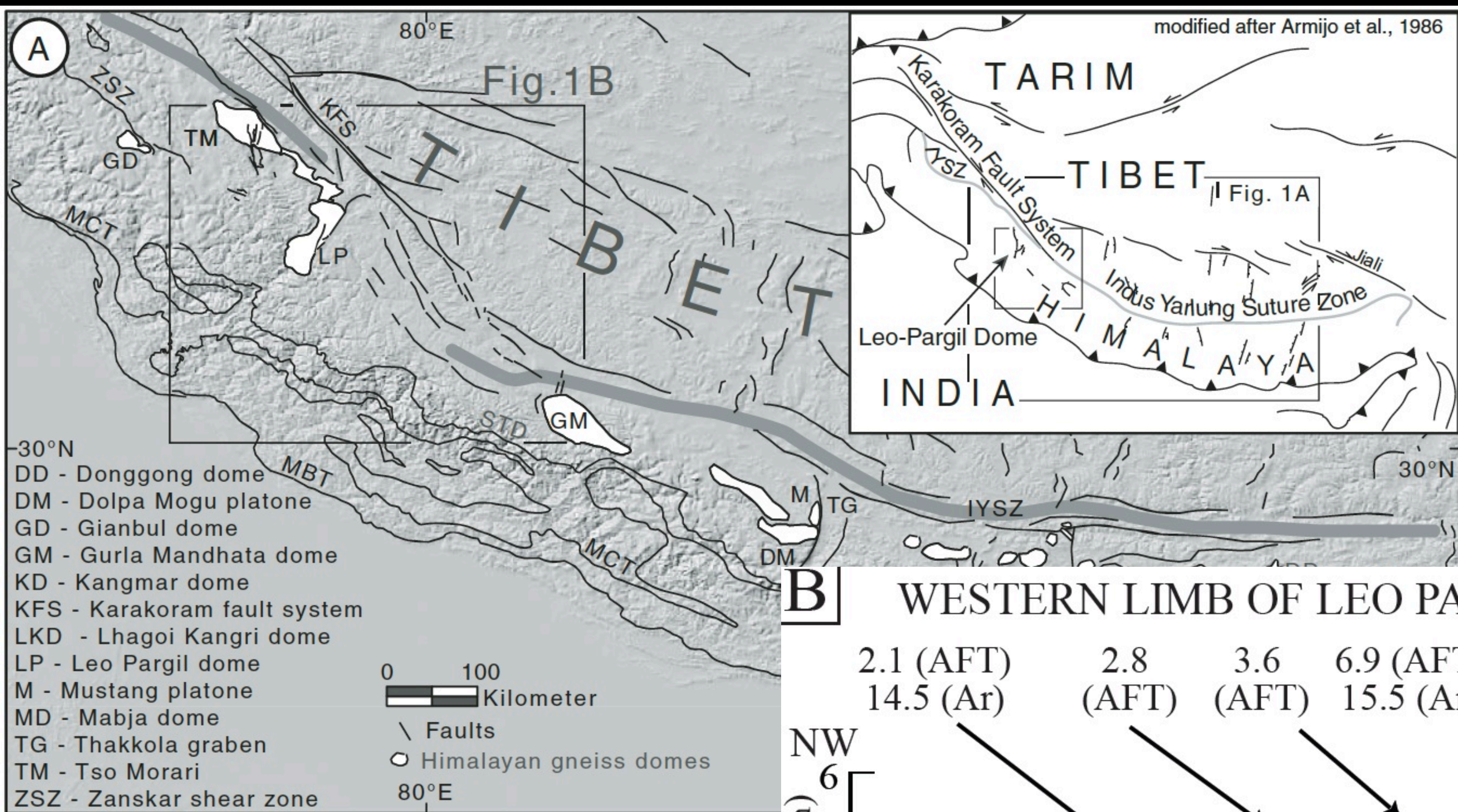
~1hr / map (date + REE)

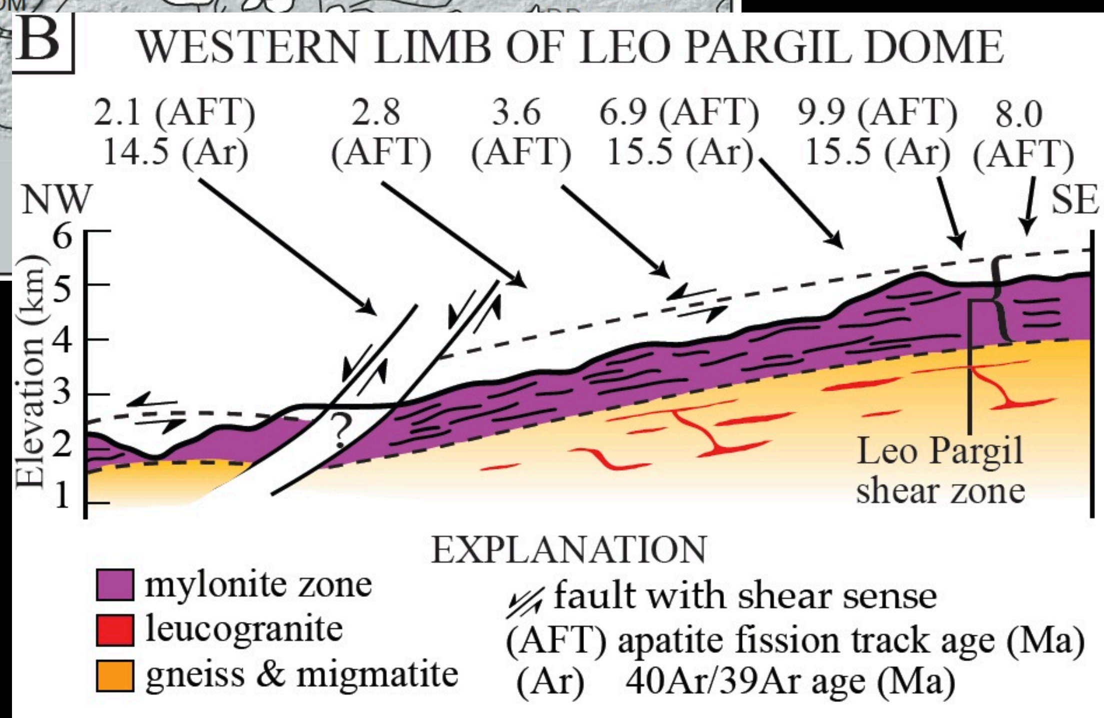
estimate volume 'age' proportions



Campaign-style petrochronology #2
outcrop-scale

Leo Pargil Dome





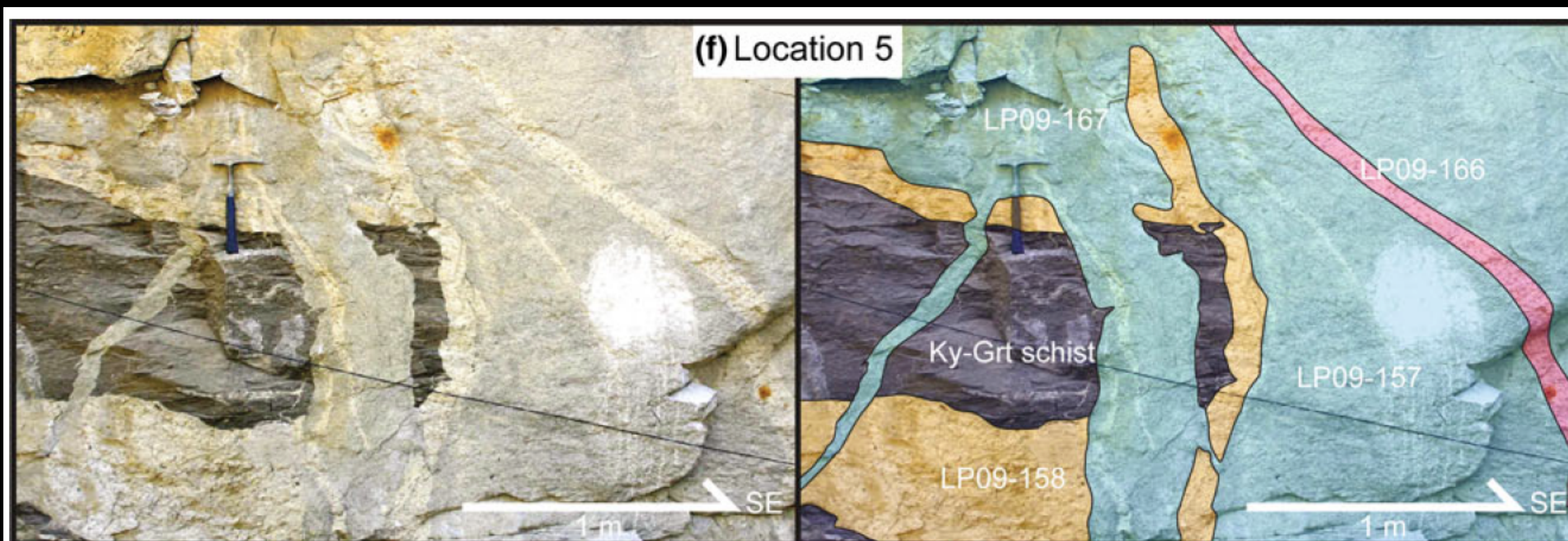
Lederer et al., (2013)

Campaign-Style 'Outcrop' Dating

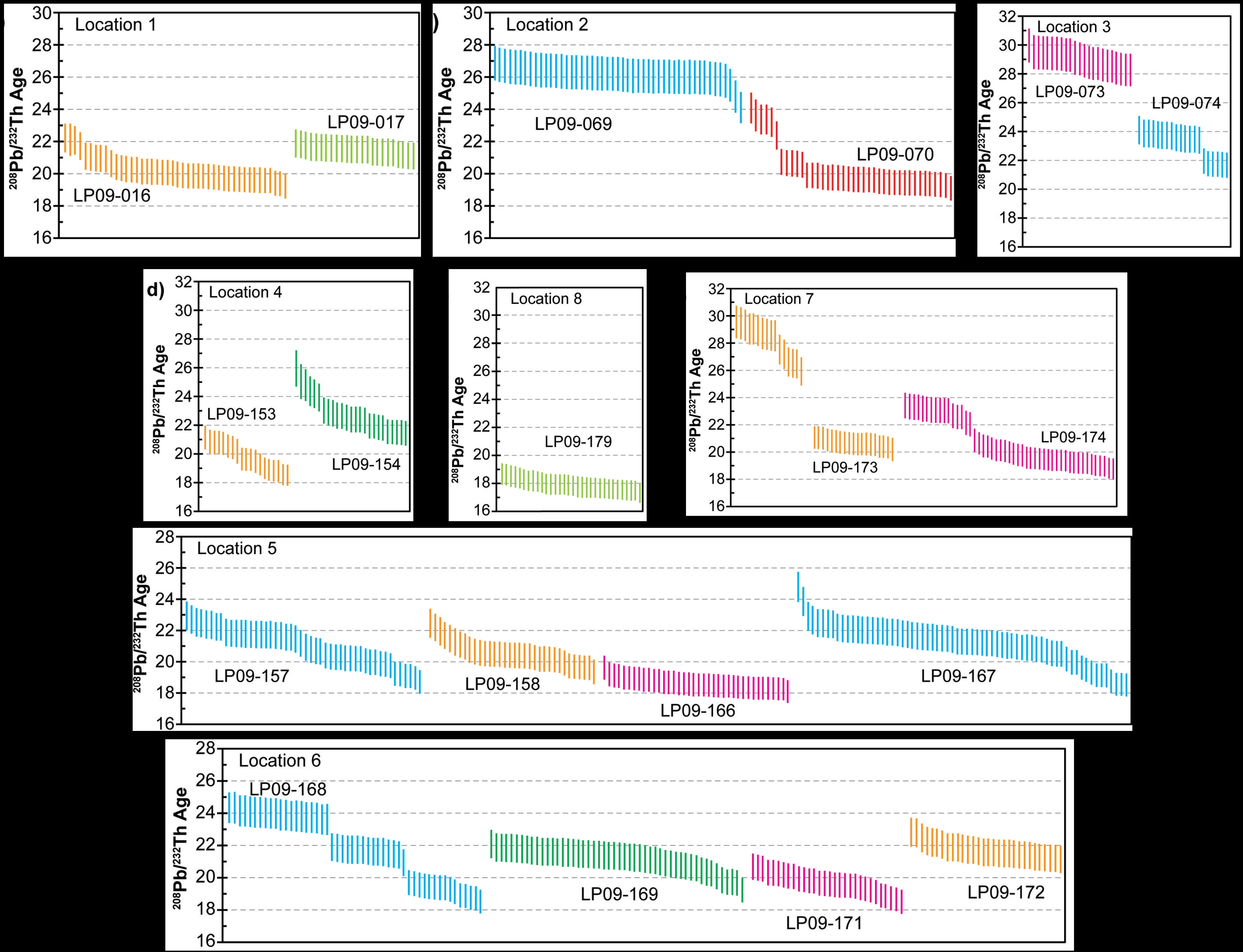
Leo Pargil Dome, NW India

~1200 spot analyses from 25 leucogranites

detailed, protracted melting history



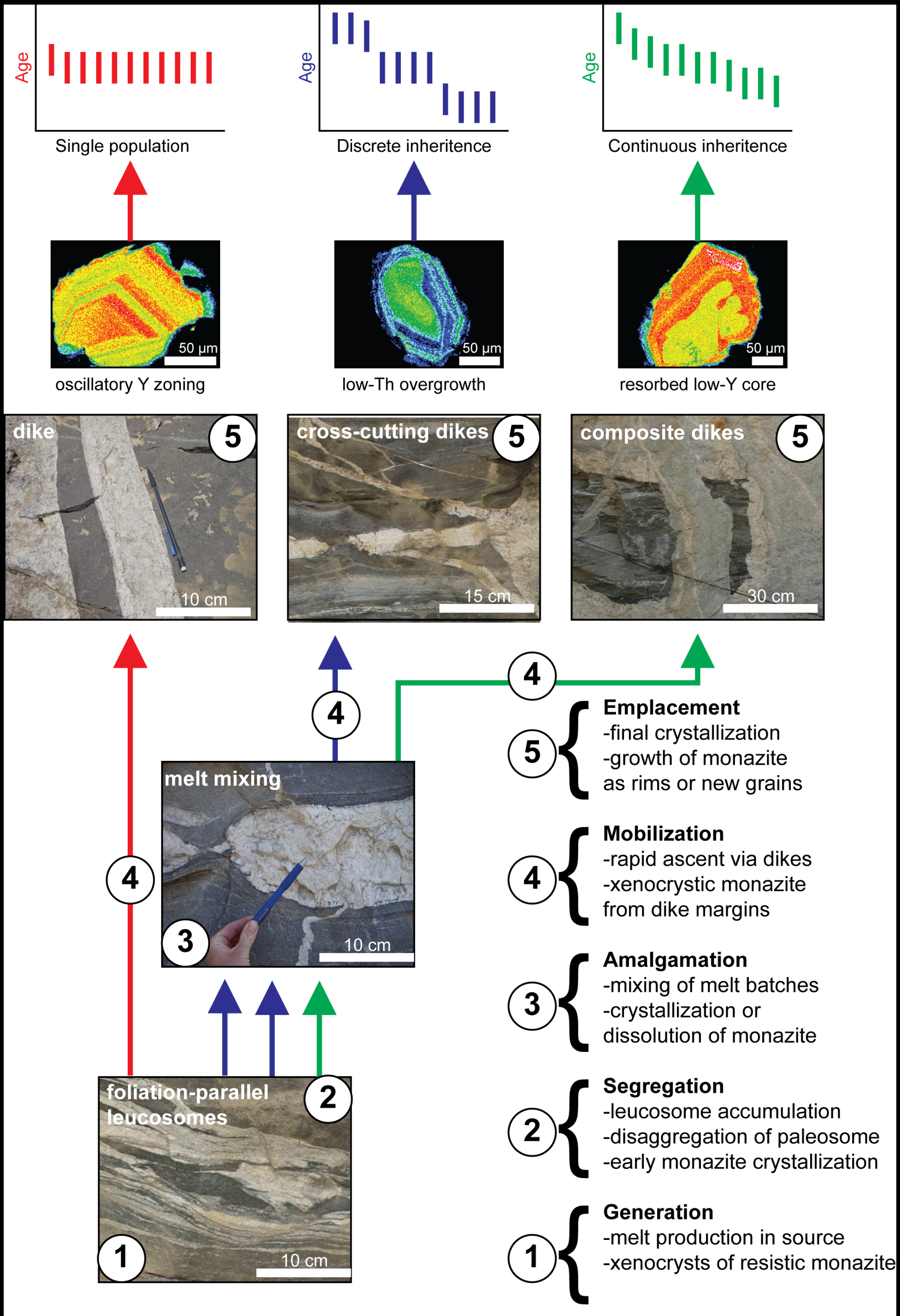
Lederer et al., (2013)



Location 1
LP09-016
LP09-017
Location 2
LP09-069
LP09-070
Location 3
LP09-073
LP09-074
d)
Location 4
LP09-153
LP09-154
Location 8
LP09-179
Location 7
LP09-173
LP09-174
Location 5
LP09-157
LP09-158
LP09-166
LP09-167
Location 6
LP09-168
LP09-169
LP09-171
LP09-172
^{208}Pb/^{232}Th Age

reveals timing & duration of melting

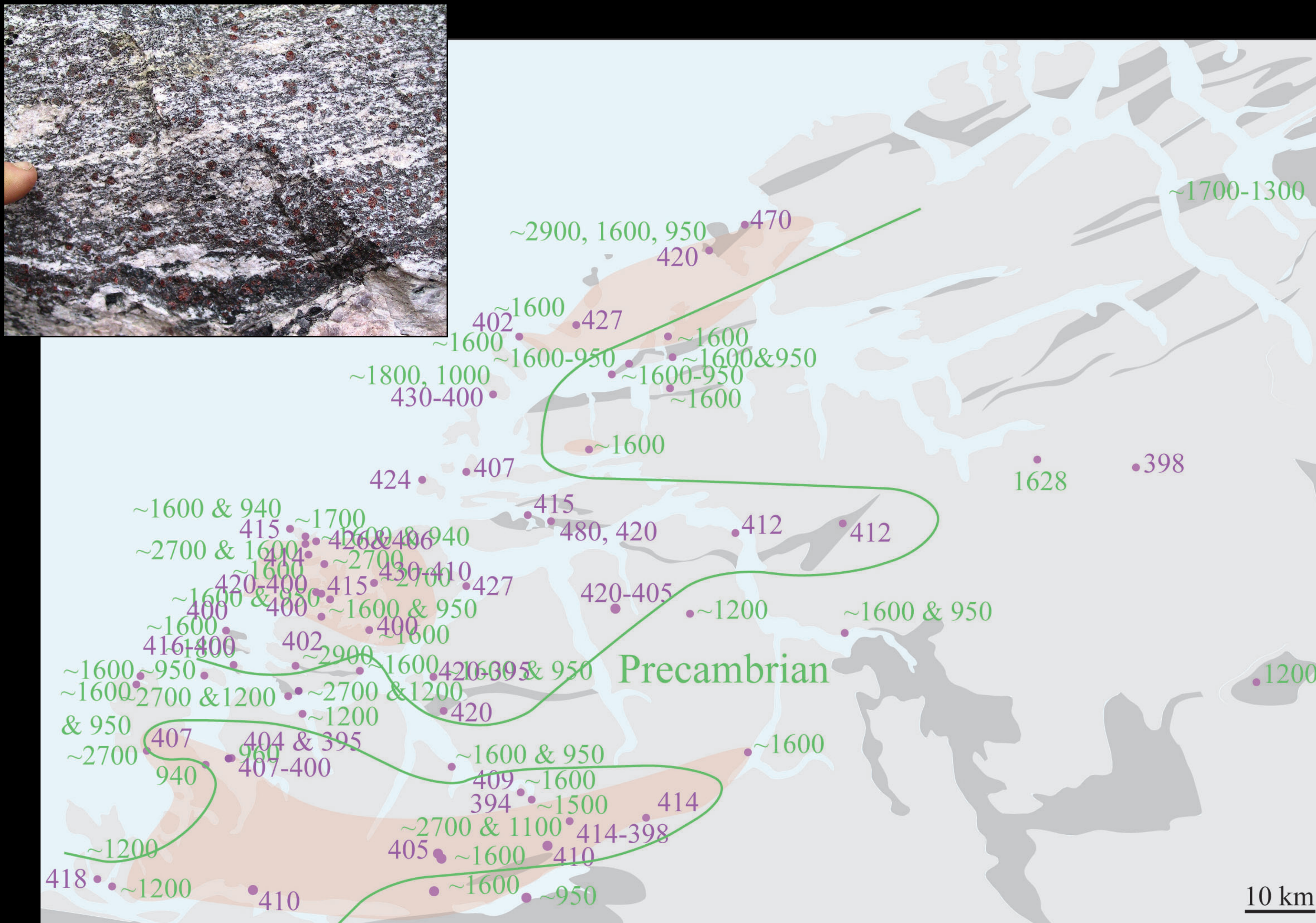
resolves complex age patterns, within & among samples



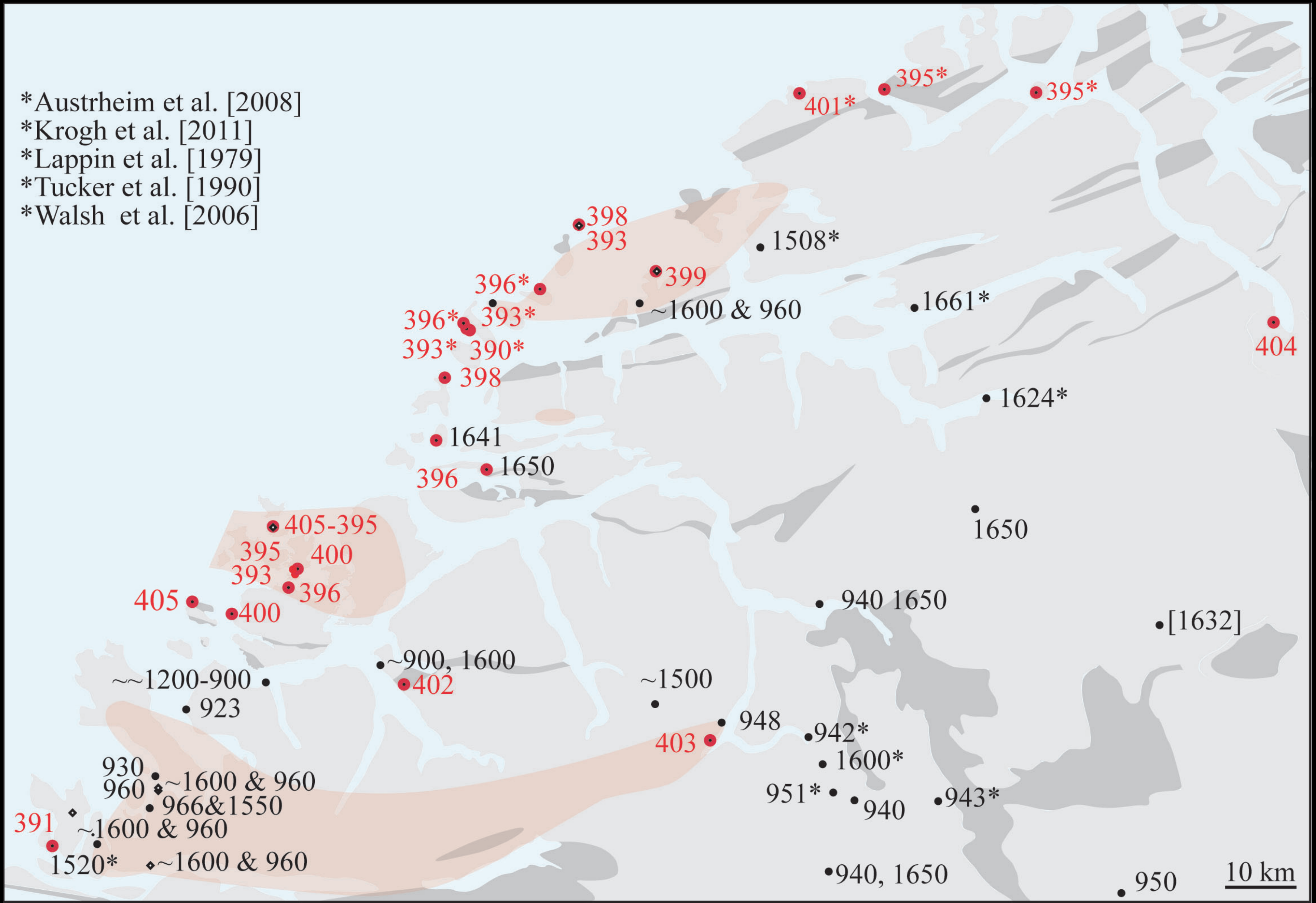
Lederer et al., (2013)

Campaign-style petrochronology #3 orogen-scale

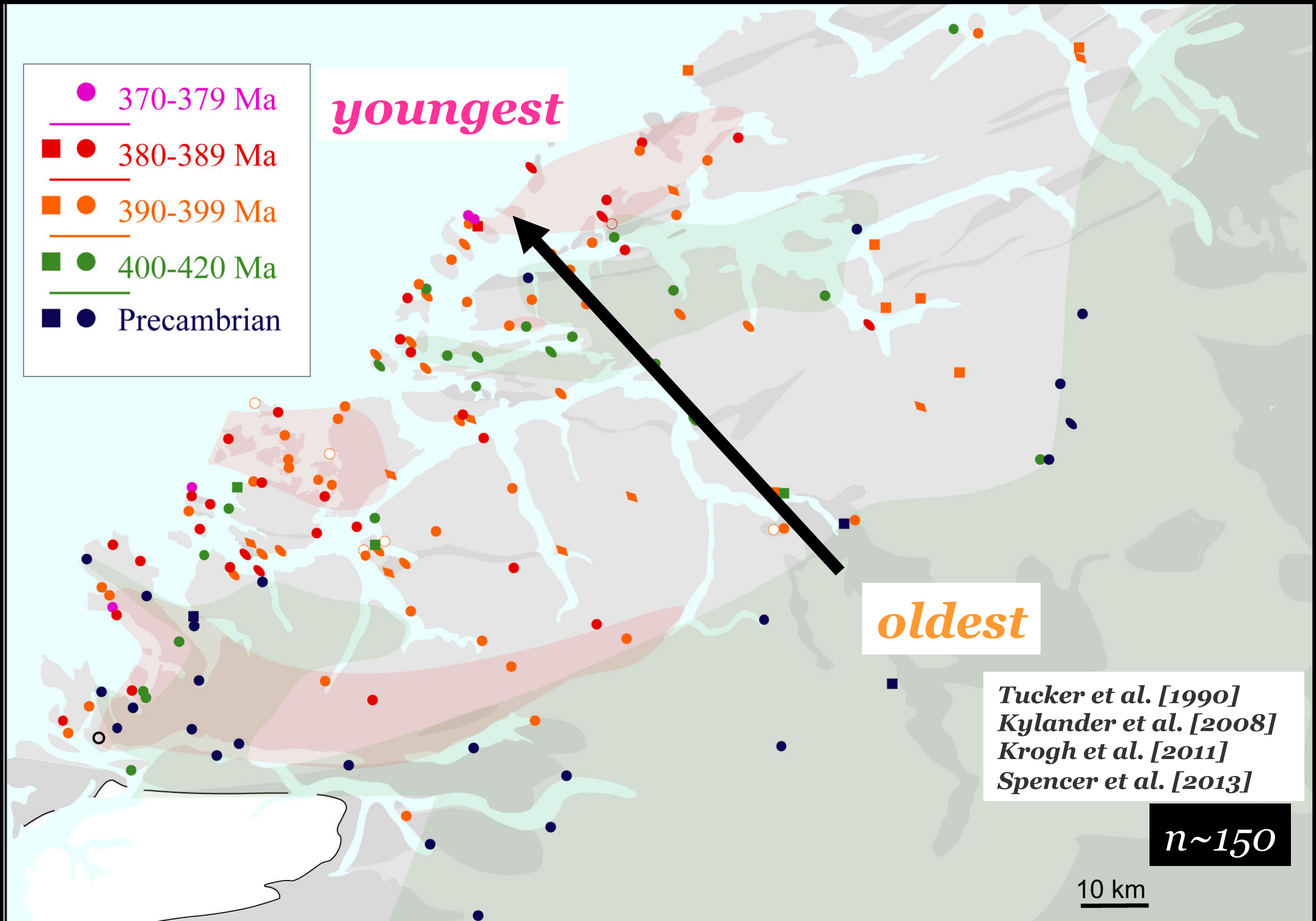
Campaign-Style Zircon Dating



Dikes; UHP Domains 405–393 Ma



Titanite U-Pb Dates: 408–377 ± 8 Ma



Rutile Date + Temperature Map

LASS Conclusions

- rapid, high throughput
- in situ spatial precision: 7–30 μm x 5 μm
- 1–2% (2σ) uncertainty U/Th-Pb dates
- can date ‘difficult’ minerals
- simultaneous dates, elements and isotope tracers, enables P-T-t-X-D

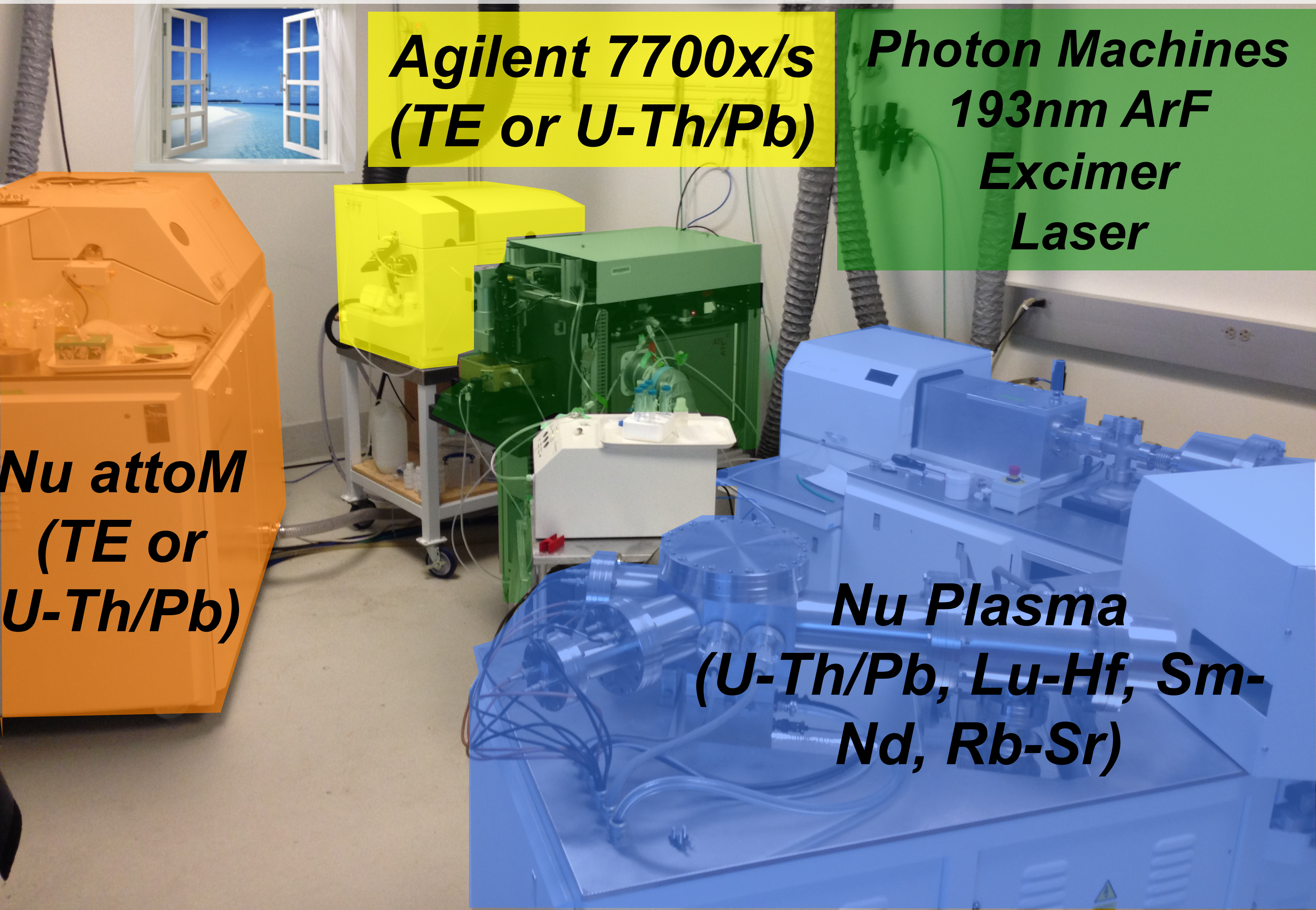
What I didn't cover…

- apply LASS method to detrital accessory phases

- U-Th/Pb + trace elements + isotope tracers (Hf, Sr, Nd, Li etc.) to evaluate igneous systems

- Use LASS to screen accessory phases prior to high precision ID-TIMS analysis

Laser Ablation Split Stream Lab (LASS) at UCSB



Linking Date to process

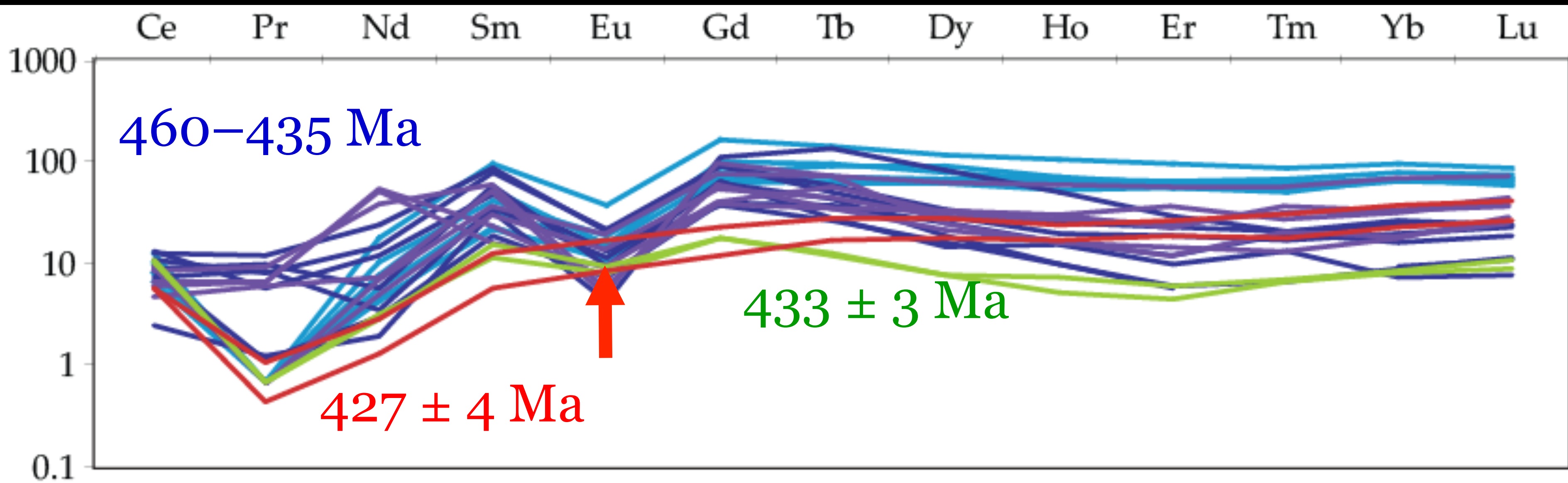
Zircon	*REE*	*Ti*	*Lu-Hf-Yb*	*O*	*Li*
Monazite	*REE*	*Y*	*Sm-Nd*	*O*	
Xenotime	*REE*	*Y*	*Sm-Nd*		
Allanite	*REE*	*Y*	*Sm-Nd*		
Apatite	*REE*	*Y*	*Sm-Nd*	*Rb-Sr*	
Titanite	*HFSE/REE*	*Zr*	*Sm-Nd*	*Rb-Sr*	
Rutile	*HFSE*	*Zr*	*Lu-Hf-Yb*		

Phase relations

Temperature ± pressure

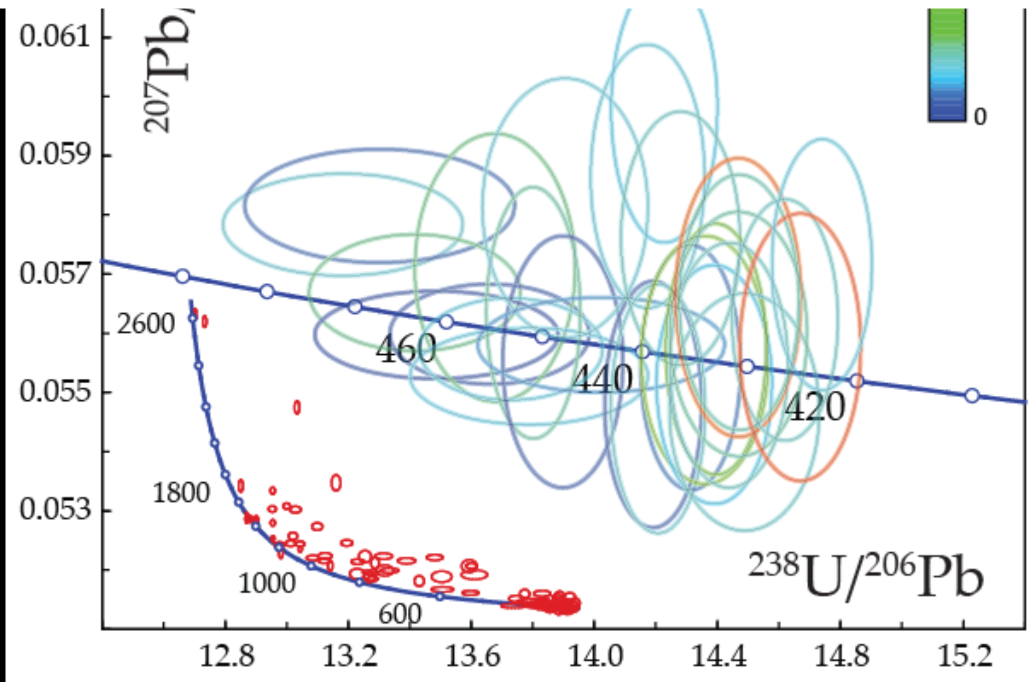
Petrogenesis and isotopic tracers

Eclogite-Facies Gneiss



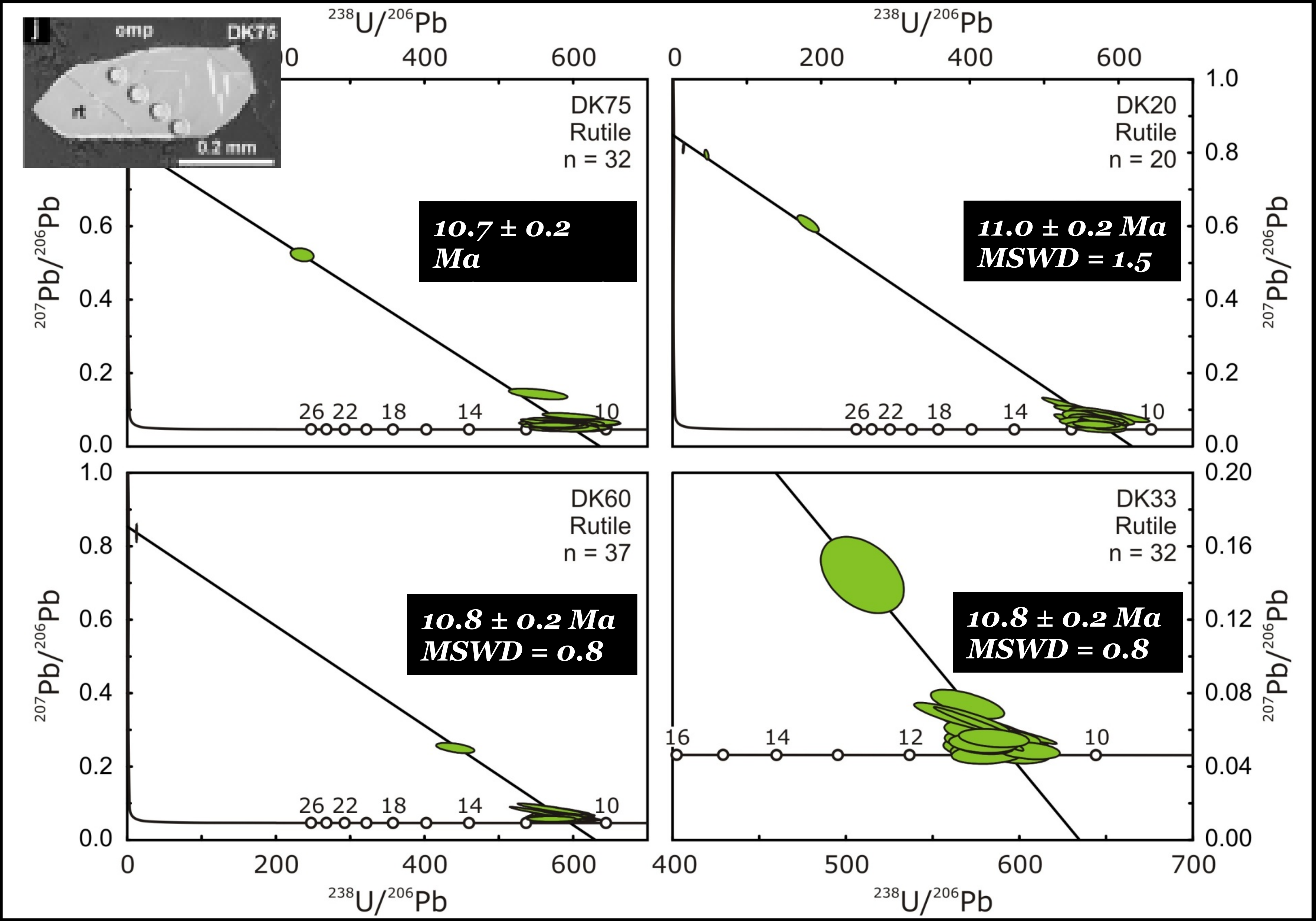
460–435 Ma +garnet
+plagioclase

433–427 Ma +garnet
–plagioclase



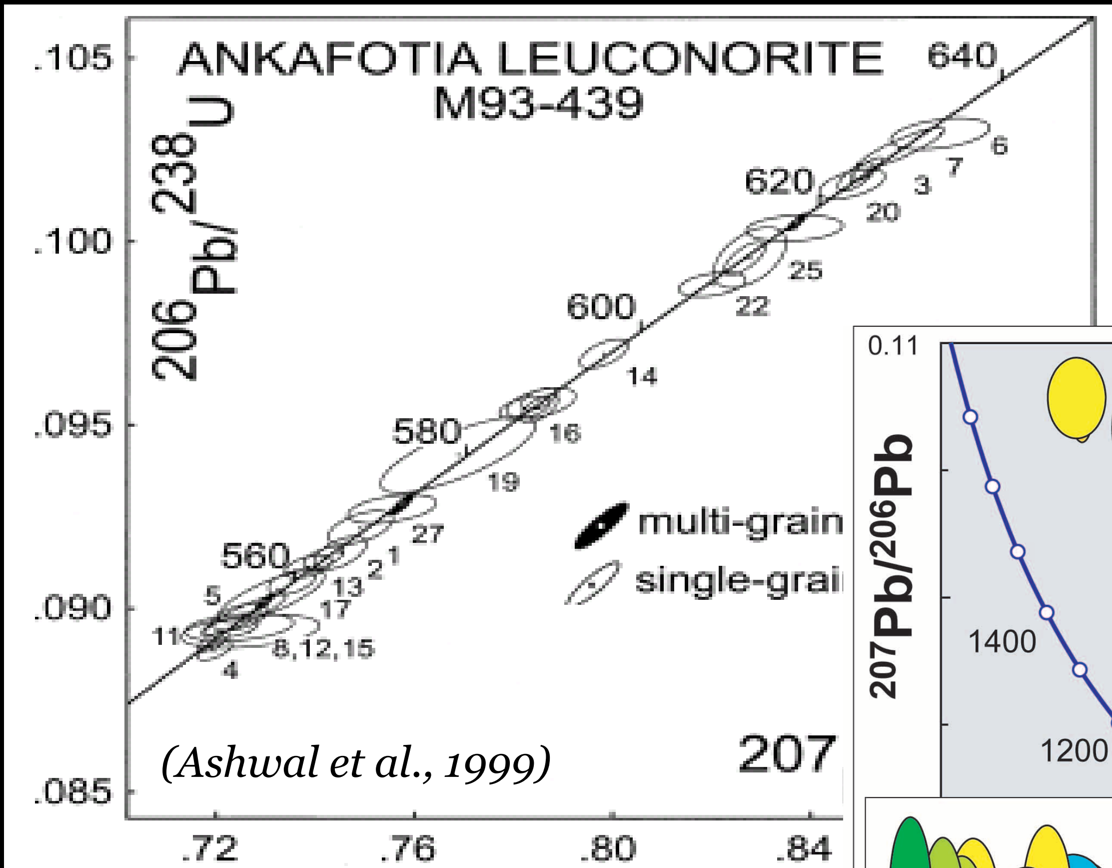
Fjørtoft Norway

Rutile Dates Eruption of Xenoliths



1 hr LASS = Heroic TIMS Work

Madagascar UHT



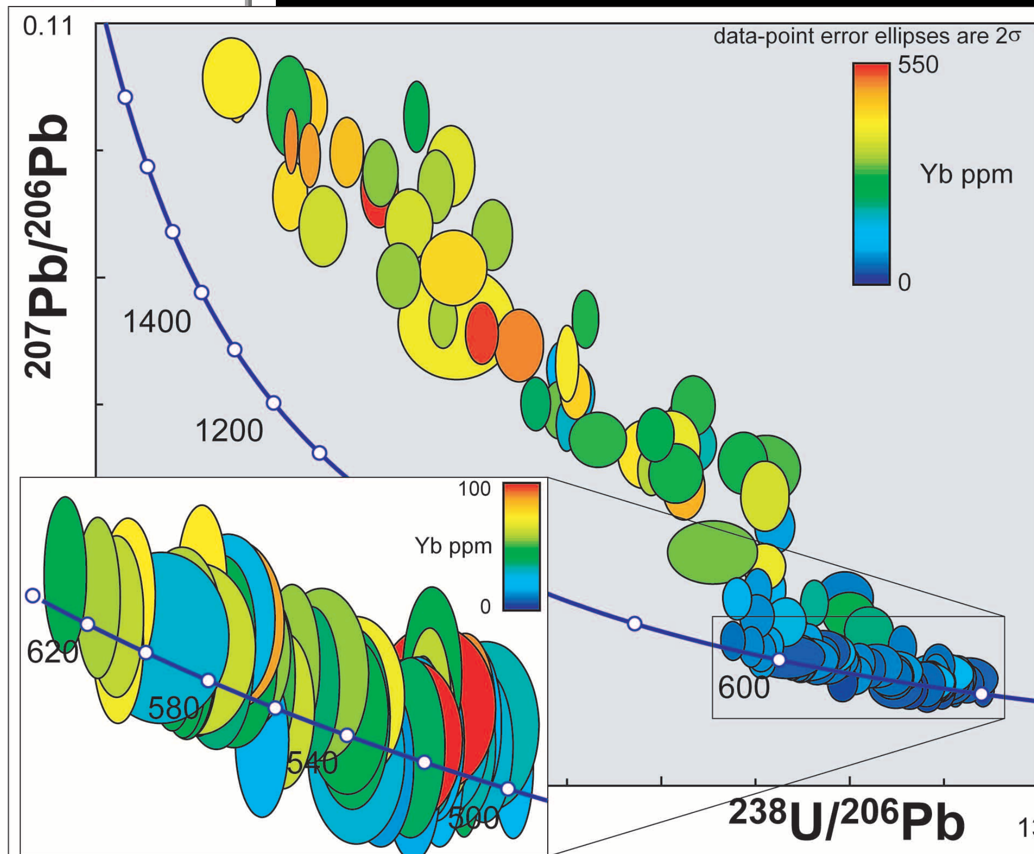
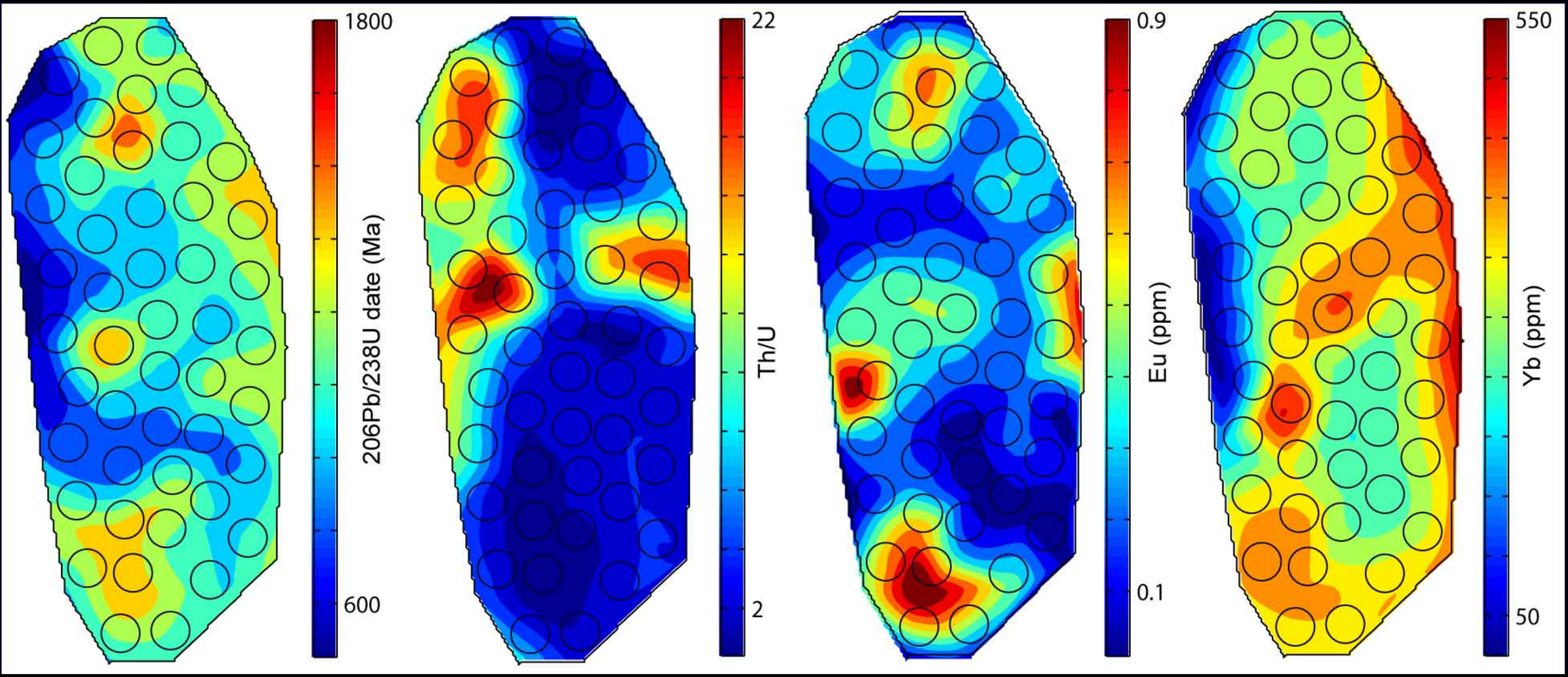


Figure x. U-Pb zircon data for Md46. 620-500 Ma metamorphic overprint of 1.9 Ga zircons.

and Grain-Scale Date Map



Single-Pulse LASS Example

- analyze single laser pulse
- integrate total signal
- split aerosol to obtain U-Th/Pb date + REE
- ~20 mins / map