



# Pressure-temperature & temporal constraints on regional metamorphism near Big Thompson Canyon, CO (USA)

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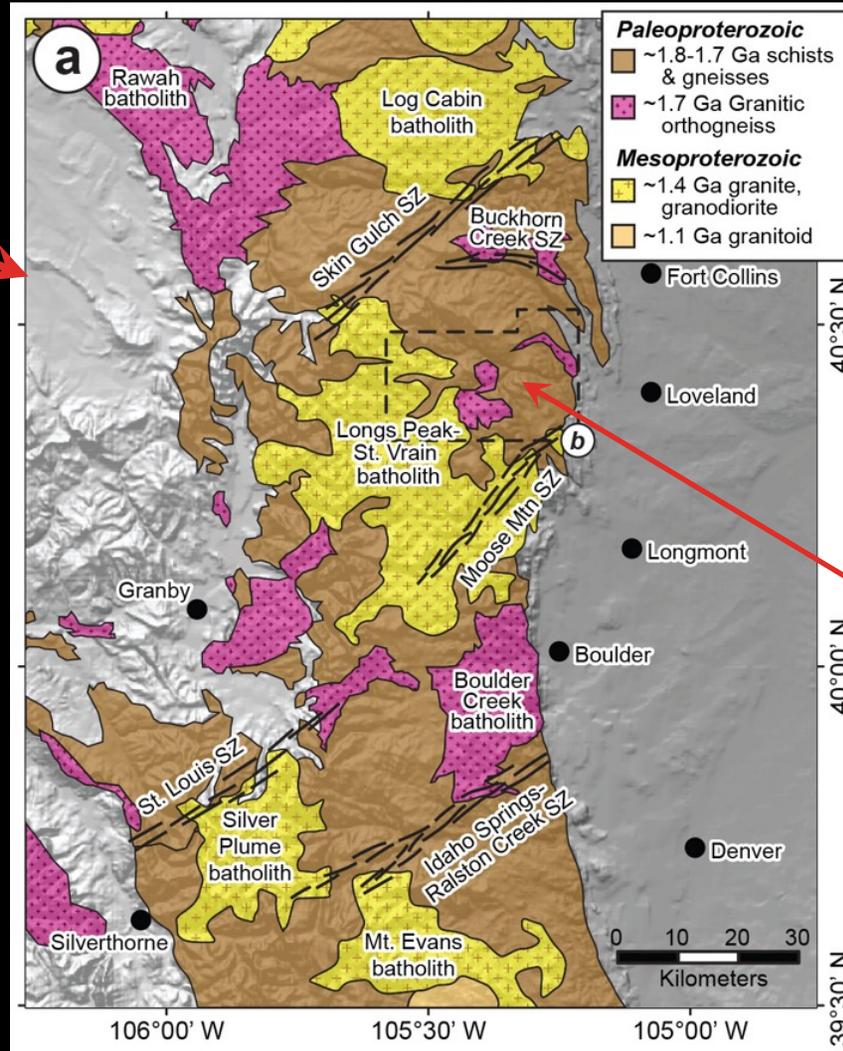
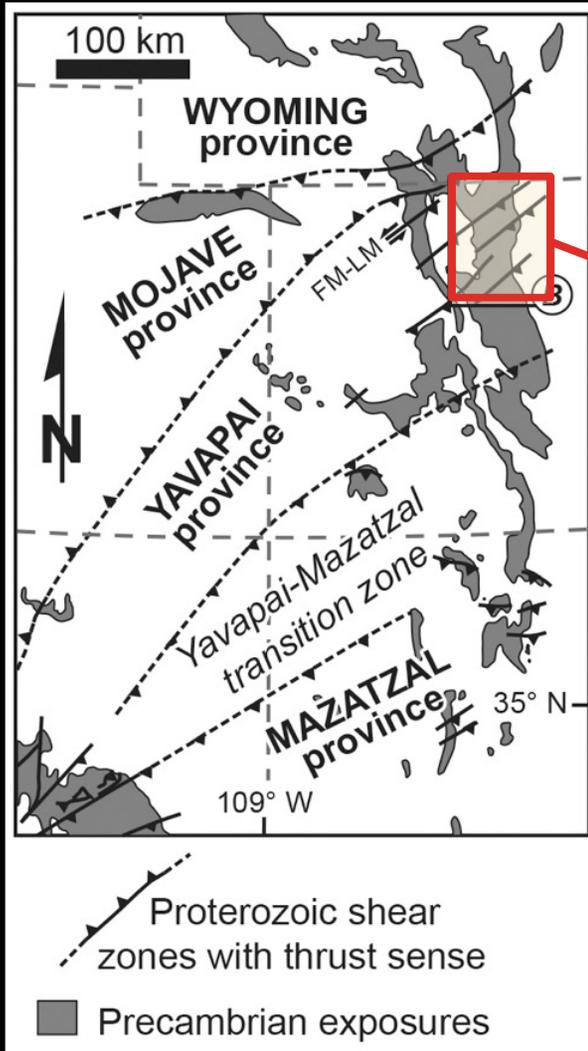
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COLORADO



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# Studied area



What?  
Paleo-proterozoic supracrustal rocks

Where?  
Big Thompson Canyon  
(Front Range, North CO).

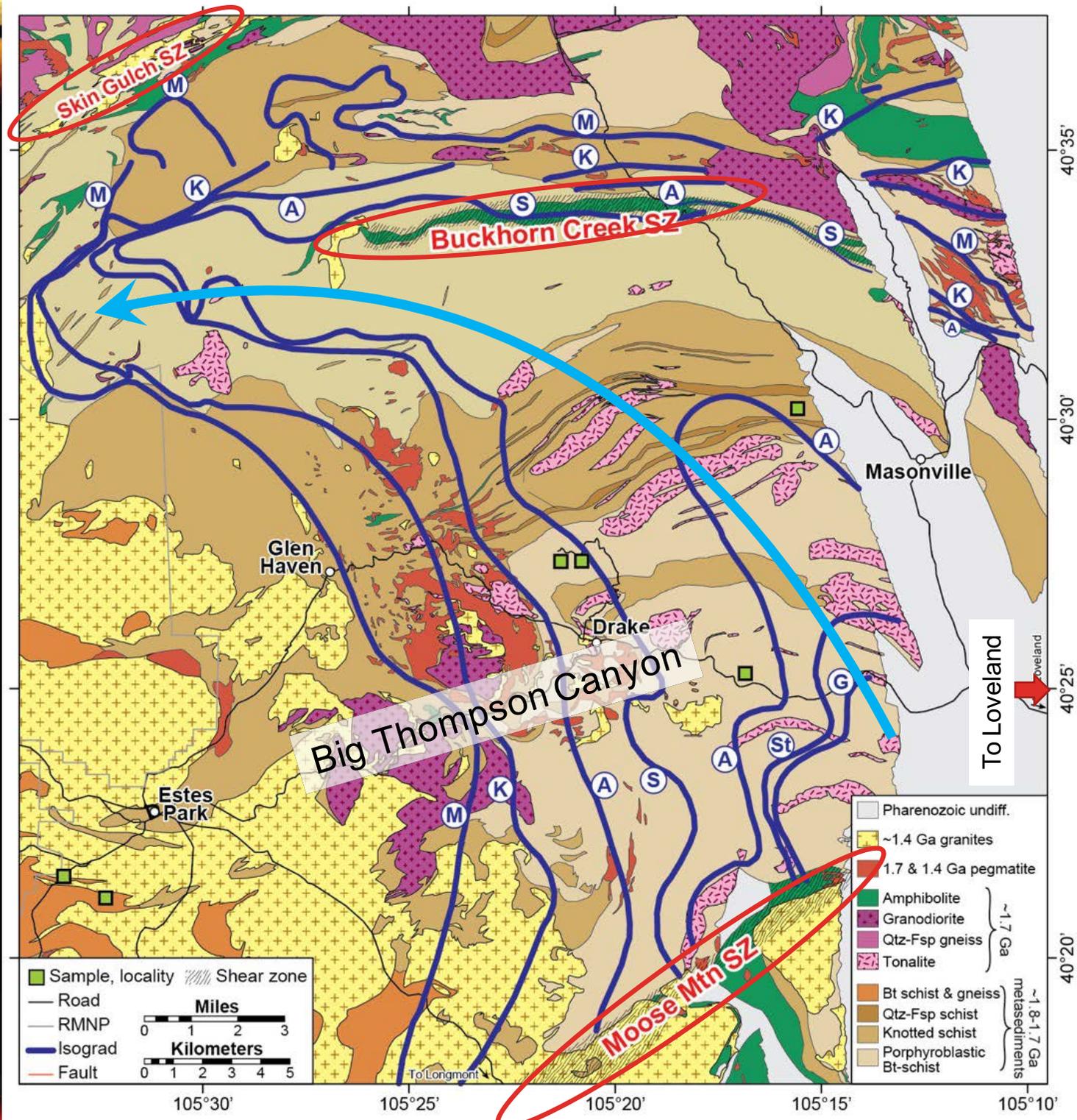


# Geological map

(Cole & Braddock, 2009)

Mineral zones from biotite- to migmatite-zone (unique in Front Range).

Surrounded by three **shear zones**.



# Problematic & approach

- **Why and when?** Complex tectonometamorphic history spanning from ~1.8 to 1.4 Ga...
  - Single (main) metamorphic cycle at ~1.7-1.65 Ga (Yavapai) with minor effect from 1.4 Ga event?
  - ...or multiple events at 1.7, 1.6 and 1.4 Ga (Yavapai, Mazatzal and “Berthoud” orogenies)?
  - Tectonic origin of the event(s)? (*not discussed here...*)

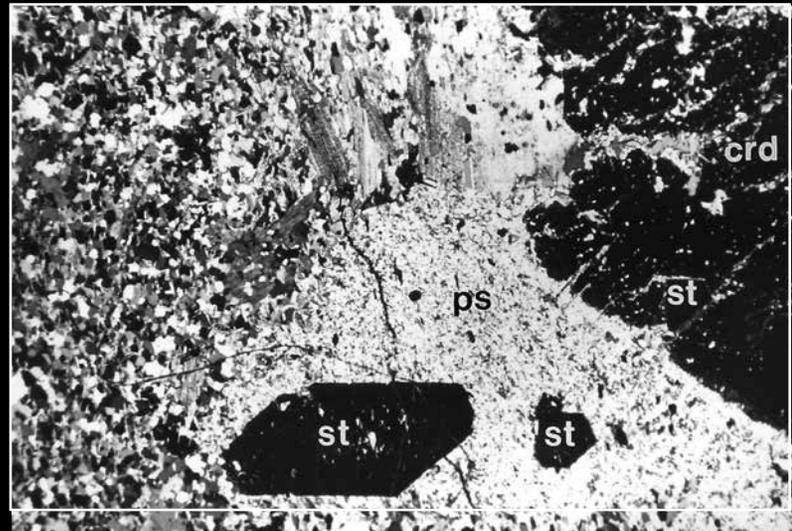
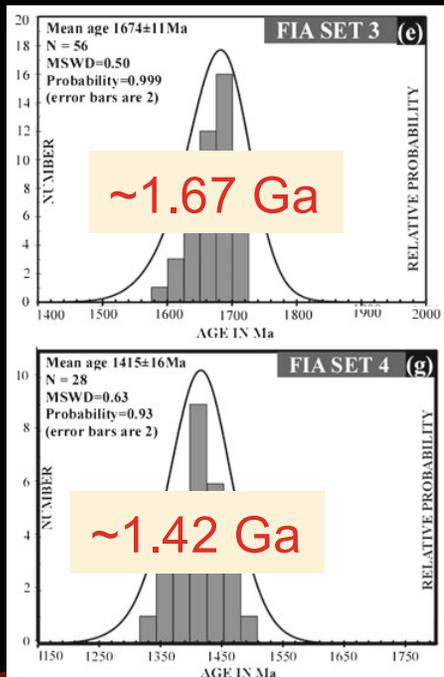
## **Preliminary study (this talk):**

- Detailed petrographic analysis
- Multi-equilibrium thermobarometry & PT-pseudosections
- Electron microprobe U-Th-Pb dating of monazite & xenotime

# Evidence for multiple events?

Monazite  
ages at both  
1.65 Ga & 1.4 Ga

*Shah & Bell (2012)*



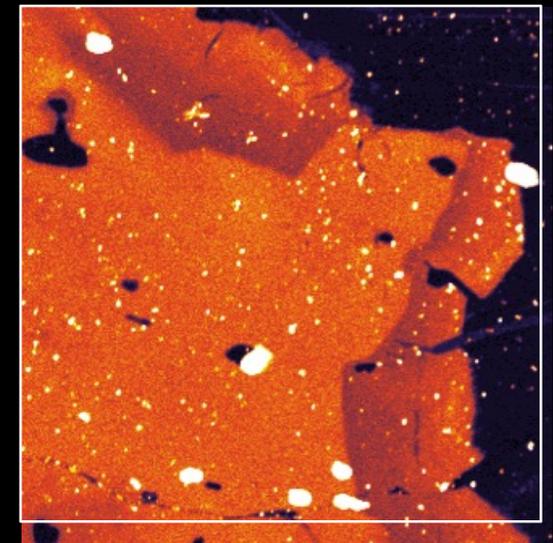
Fresh staurolite and St  
pseudomorph.

Resetting of Ar-Ar ages at 1.4 Ga  
(partial for Hbl, complete for mica)

*Shaw et al. (1999)*

Multi-stage Grt growth  
(Ca-map, FOV 1 mm).  
Multiple generations of  
other index minerals  
(St, And, Sil, Crd).

*Mahan et al. (2013)*





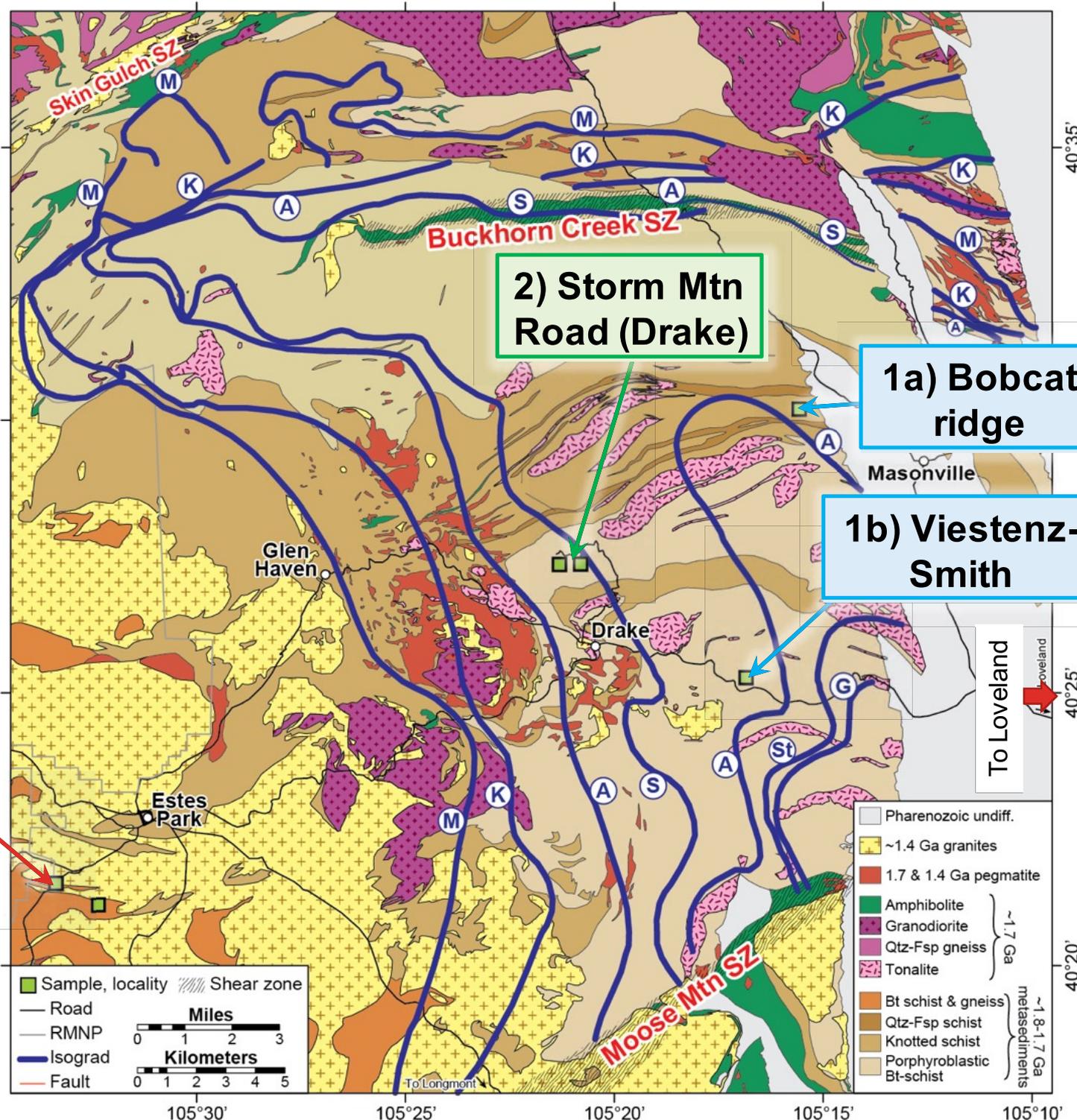
# Geological map

(Cole & Braddock, 2009)

Three zones investigated:

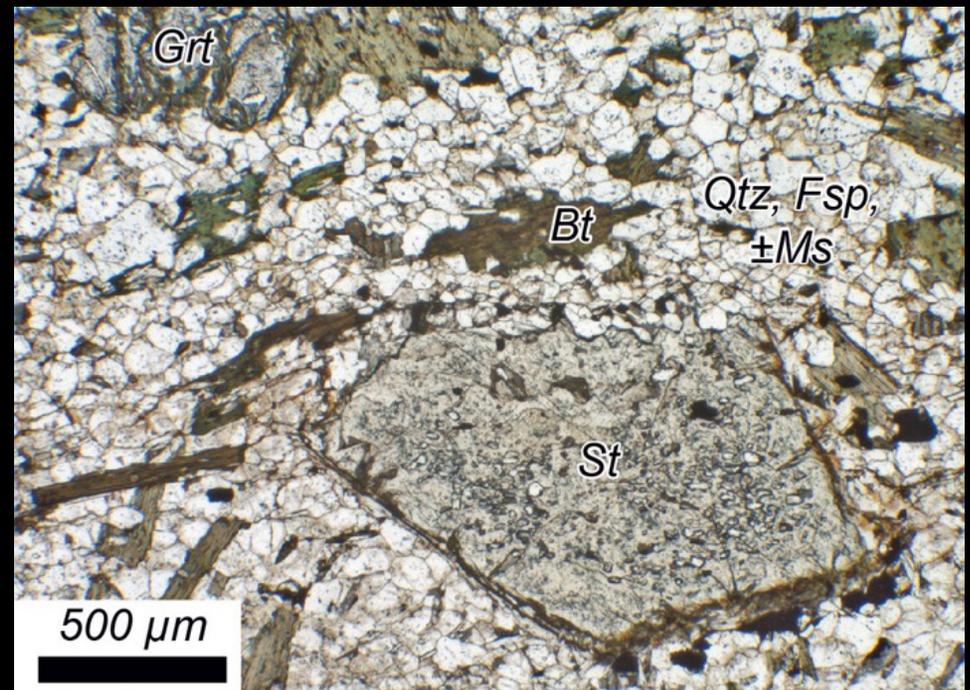
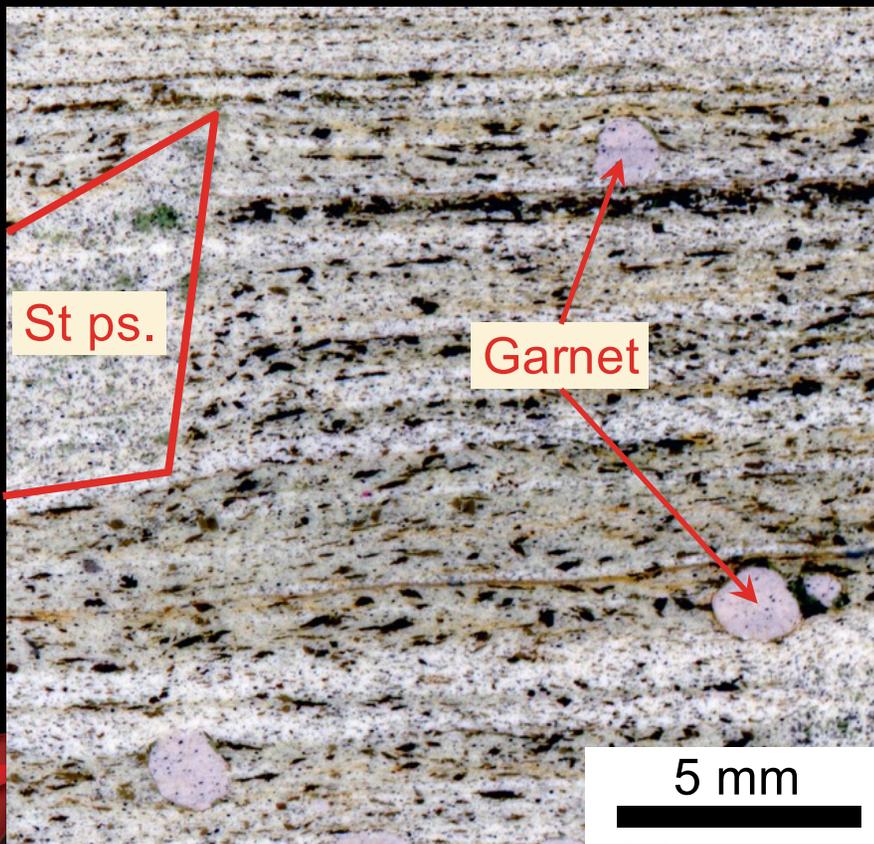
- And/St-zone,
- And → Sil,
- Migmatite.

3) Estes Park



# Staurolite grade samples

- Rare fresh staurolite, mostly pseudomorphed.
- Two Grt-bearing metapelite samples: M08-16 (St pseudomorph) and M13-11 (fresh and pseudomorphed St)
- Ms, Bt, Pl, Qtz, Grt,  $\pm$ St,  $\pm$ Chl ( $\pm$ And in Al-rich sample)

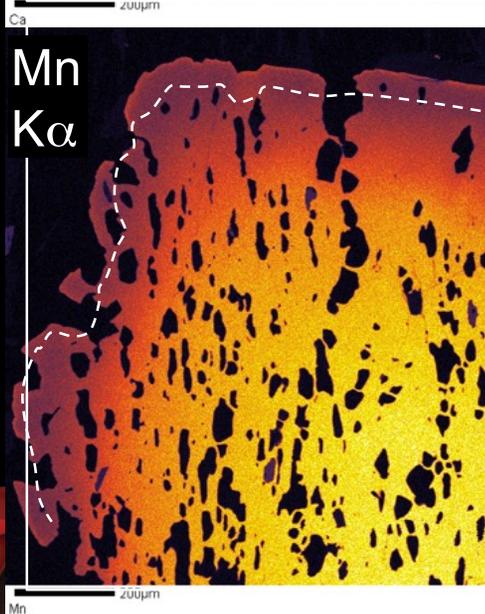
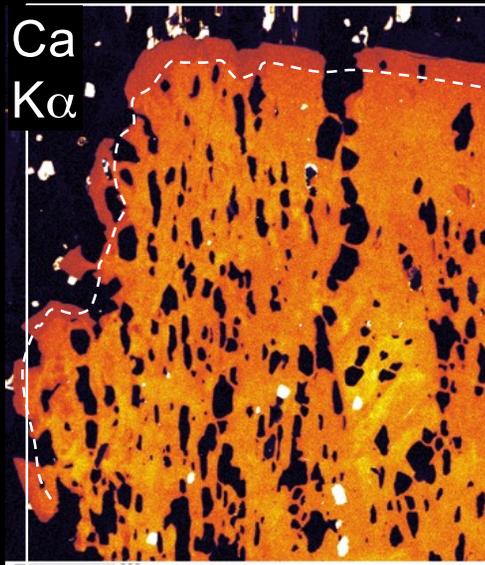


Viestenz-Smith (M13-11)

Bobcat ridge (M08-16)

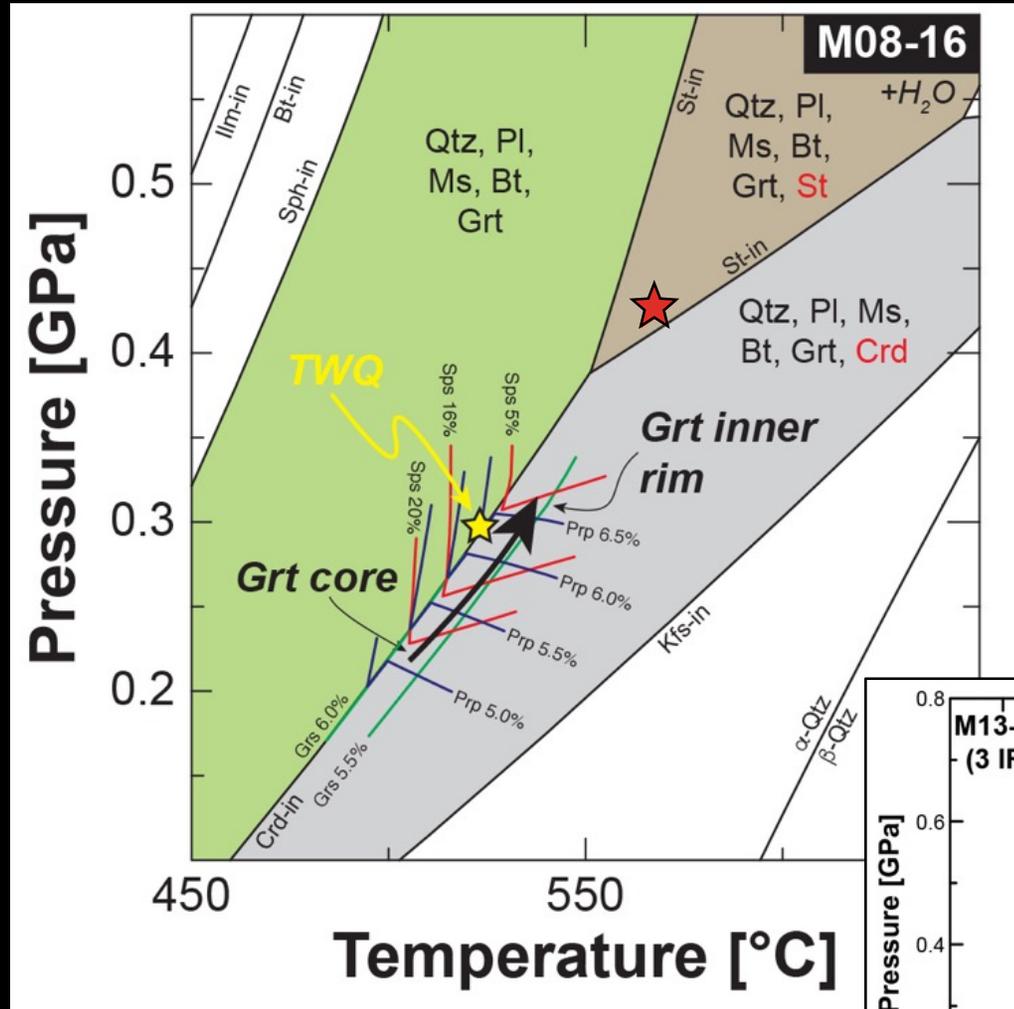
Prograde zoning  
 Ca-poor overgrowths  
 No late re-equilibration

*Bobcat ridge (M08-16)*

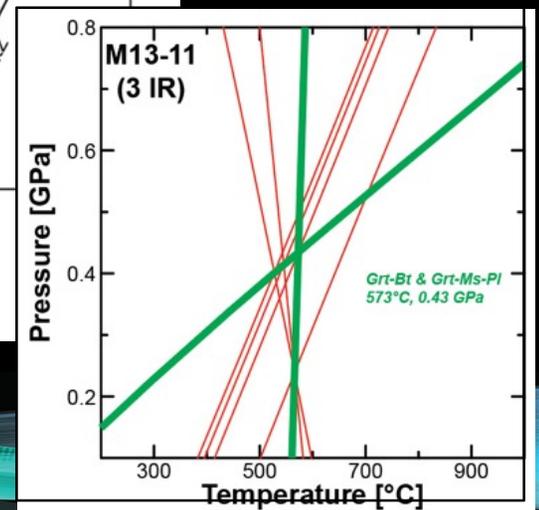


# Staurolite grade samples

★ M08-16 Multi-equilibrium PT (TWQ): ~0.3 GPa, 540 °C



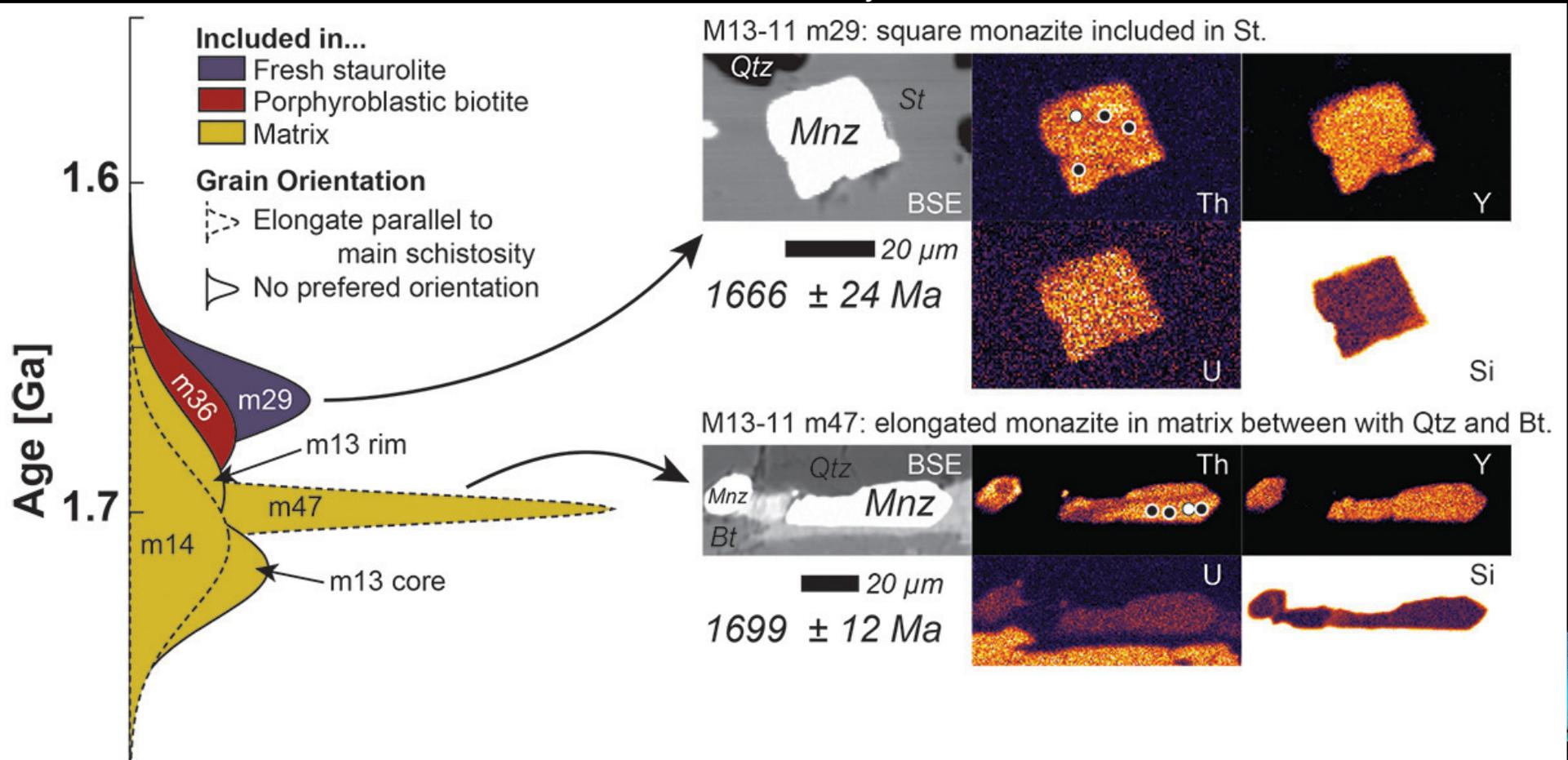
★ M13-11:  
 slightly  
 higher  
 pressure  
 (~0.43 GPa,  
 570 °C)



# First monazite U-Th-Pb

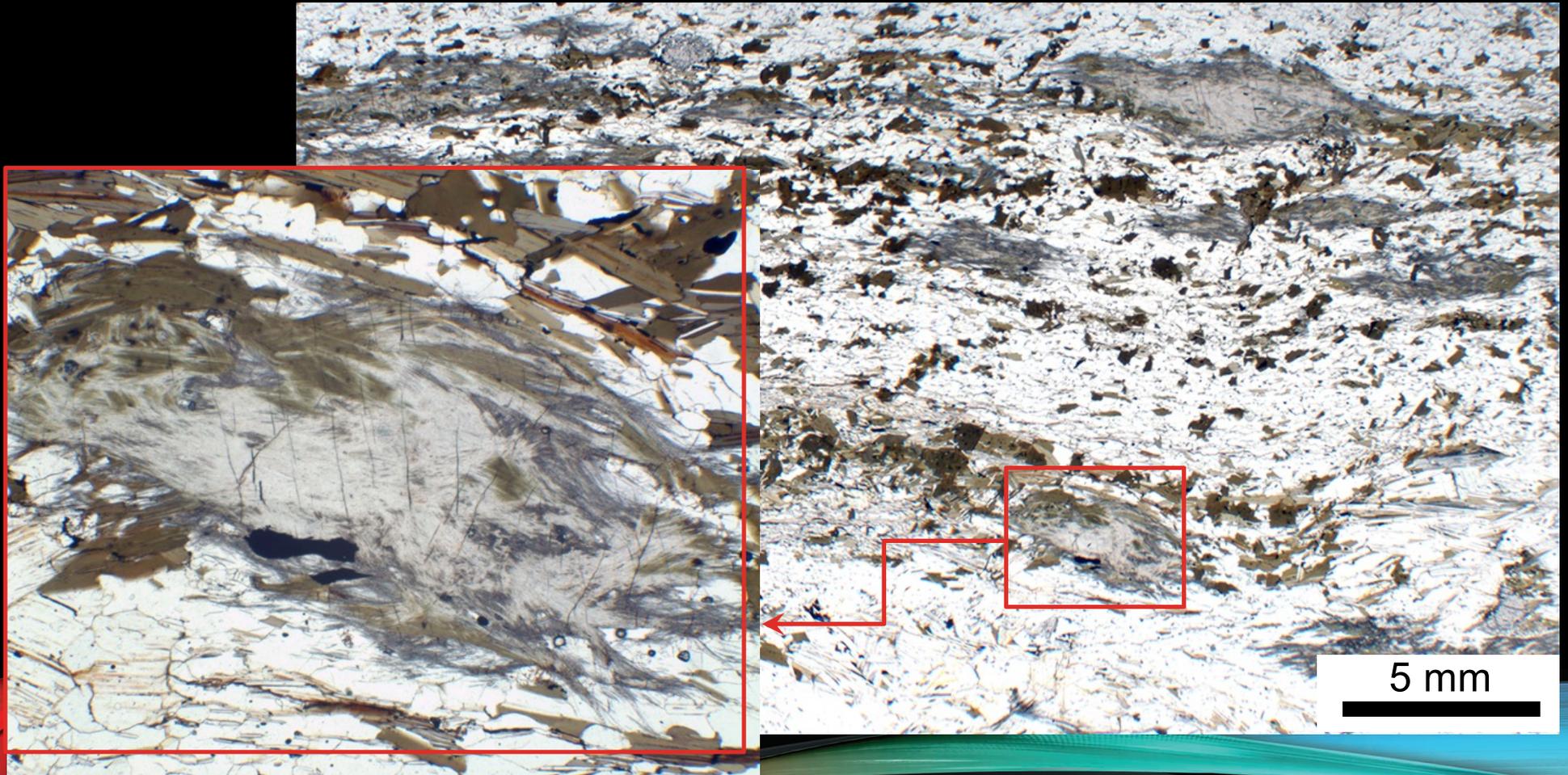
- First results in St-bearing sample (M13-11) obtained on Cameca SX-100 “Ultrachron” (University of Massachusetts, Amherst)
- Mnz included in St = 1.67 Ga (max. age for 2<sup>nd</sup> St-growth)

Work by C. Condit and RESESS student D. Rattanasith



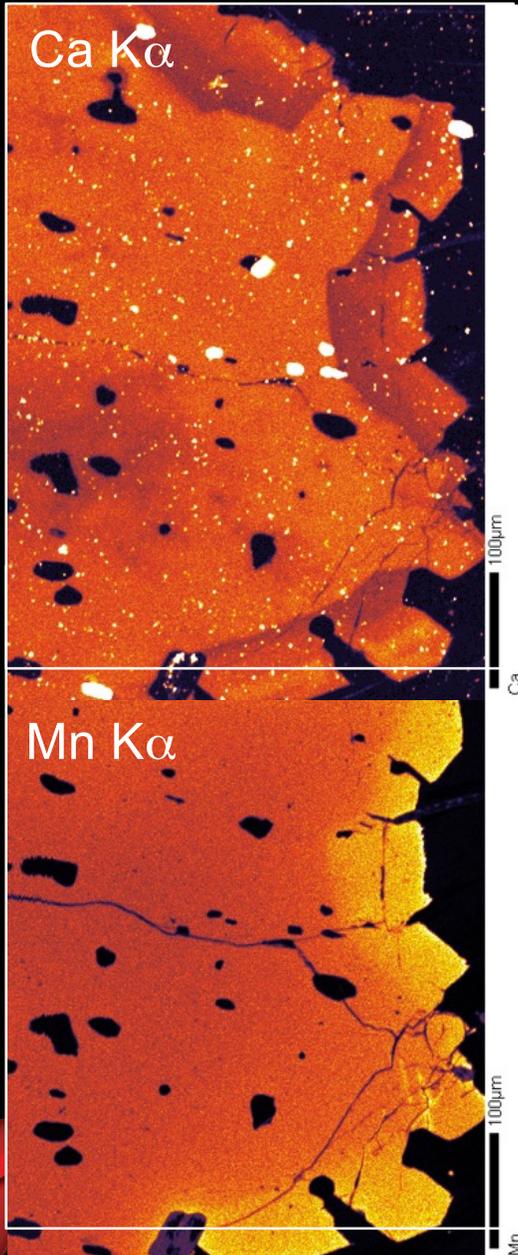
# Transition And → Sil

- Grt-bearing metapelite, transition And (M09-24) → Sil (M09-22)
- Bt, Ms, Pl, Qtz, Grt, Sil (or And)
- *PT results uncertain (Grt resorption), ~0.4 GPa, 550-600 °C?*

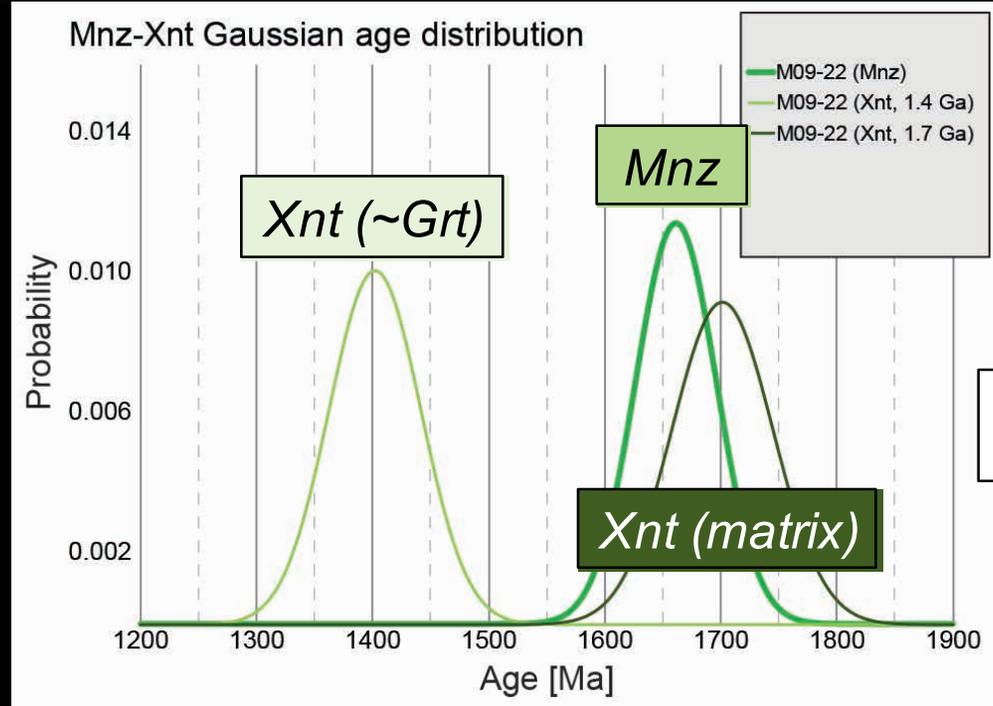


Minor zoning in core  
Ca-poor overgrowths  
Late re-equilibration

# Transition And → Sil

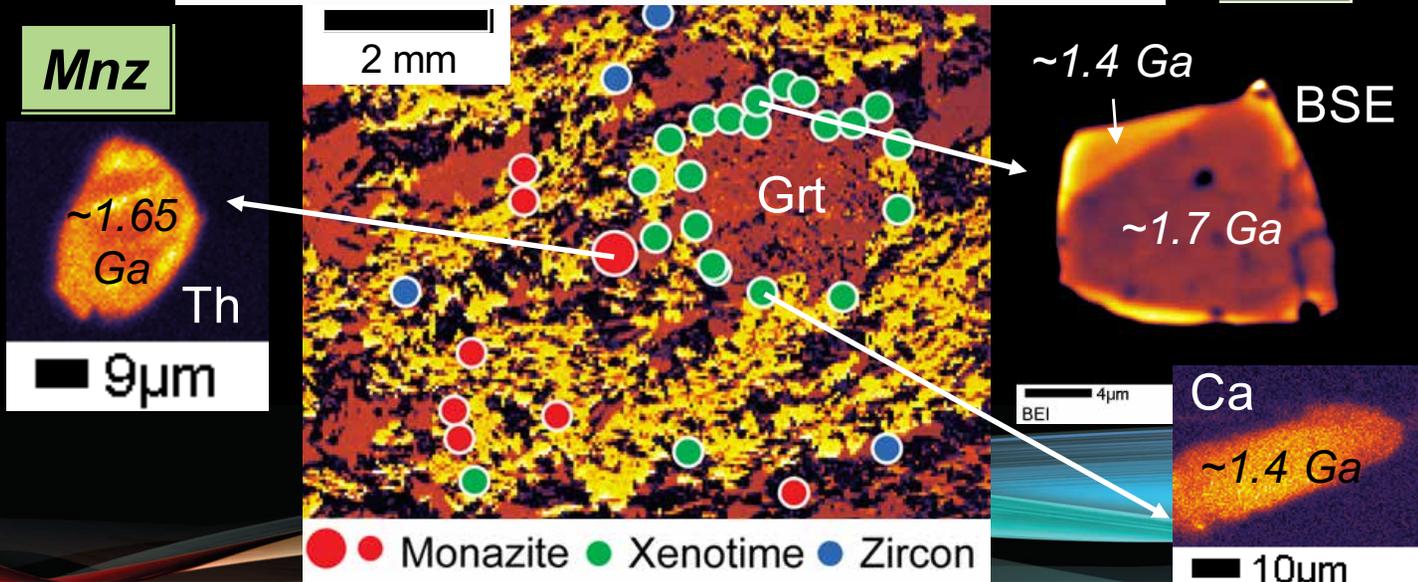


Drake,  
Storm  
Mtn Rd  
(M09-22)



Relic Mnz  
~2.1(4) Ga

Xnt



# Migmatite grade sample

- Possible 2-stage melting: 1<sup>st</sup> melt near Glen Haven (Ms dehydration), 2<sup>nd</sup> melt near Estes Park (Bt dehydration)?
- Assemblage @ Estes Park: Pl, Kfs, Qtz, Grt, Sil, Crd,  $\pm$ Bt ( $\pm$  spinel\*)

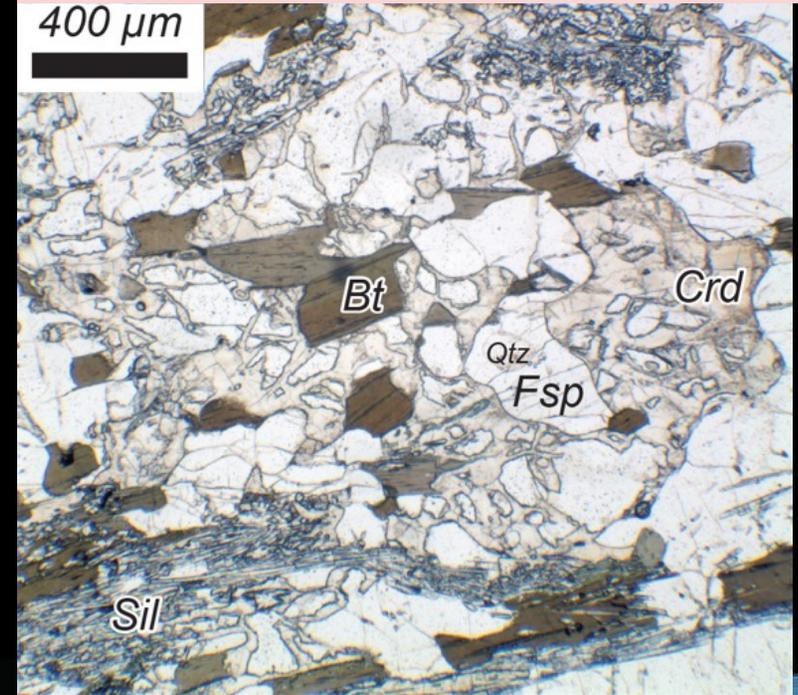
1<sup>st</sup> evidence of melting (~Glen Haven)

$Ms + Pl \pm H_2O \rightarrow Sil + Kfs + melt \pm Bt$



2<sup>nd</sup> melting (~Estes Park)

$Bt + Sil + Qtz \rightarrow Grt + Kfs + Crd + melt$



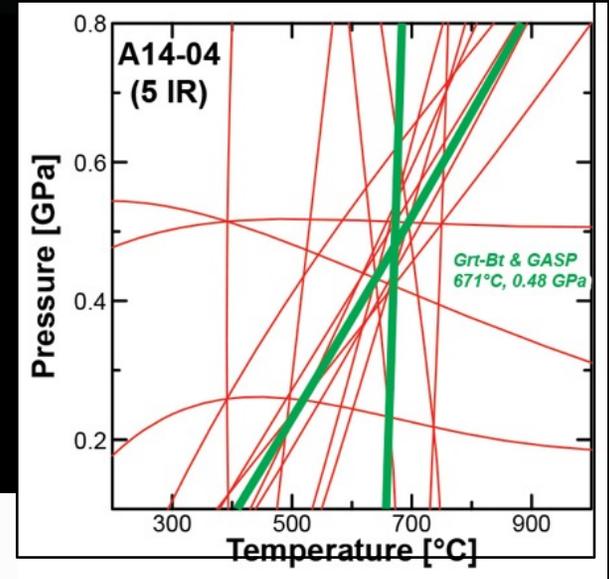
\* Zn and Cr-rich:  $(Fe_{0.64} Zn_{0.26} Mg_{0.10}) (Al_{1.90} Cr_{0.03} Fe_{0.07}) O_4$

Homogeneous composition  
Inclusion rich

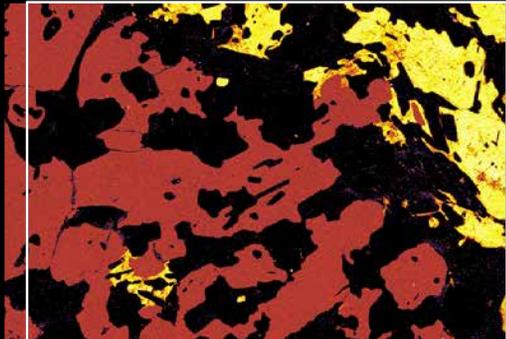
# Highest grade migmatite

A14-04

Multiequilibrium PT (TWQ):  
~0.5 Gpa, 670 °C



Ca K $\alpha$



Bt+Sil+Qtz  $\pm$ Pl

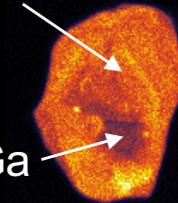
Grt+Crd+Kfs+melt



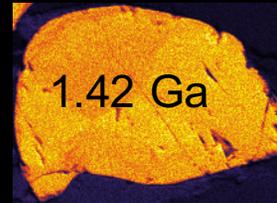
Mn K $\alpha$

1.42 Ga

1.7 Ga

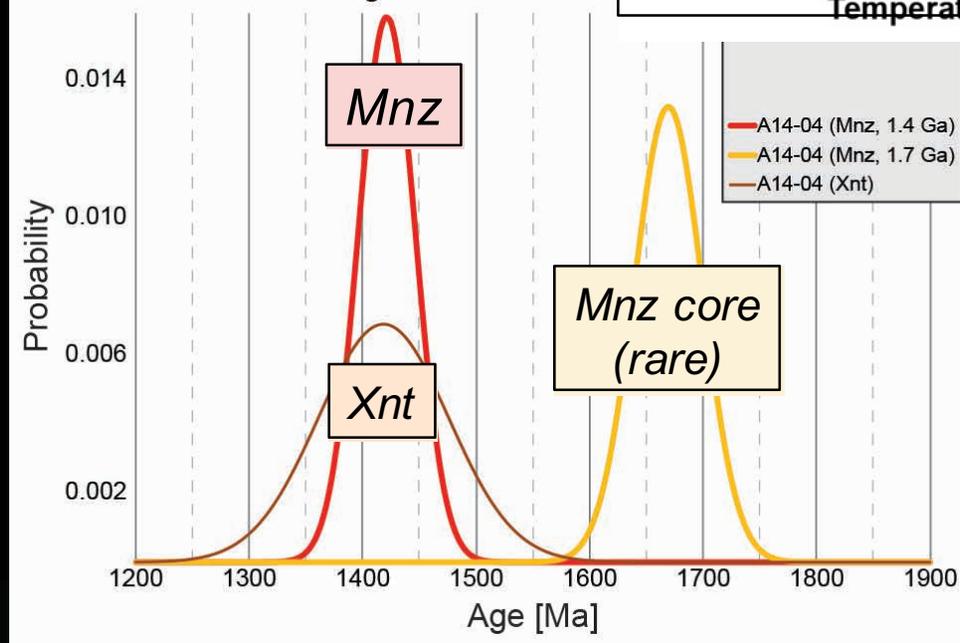


20 $\mu$ m  
Th



100 $\mu$ m  
Y

Mnz-Xnt Gaussian age distribution



*Pseudosection suggest similar conditions (work in progres...)*

# Summary PT-work & age

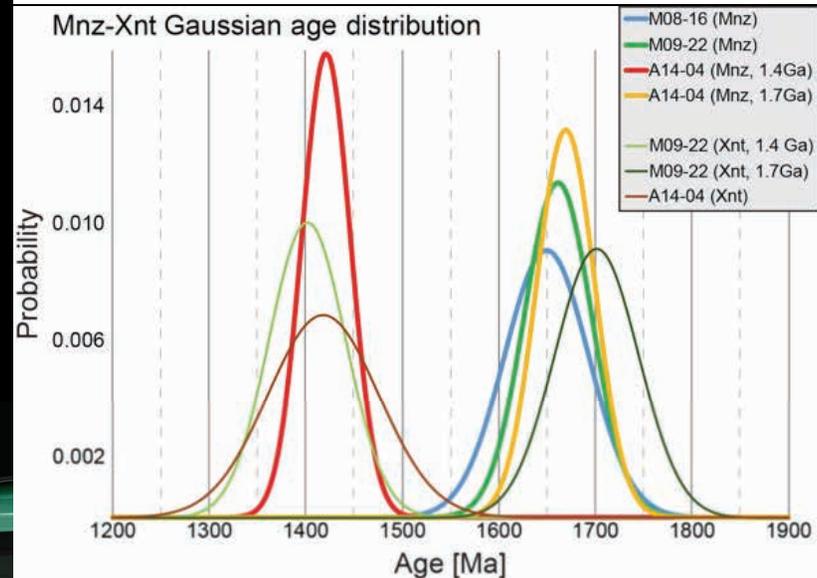
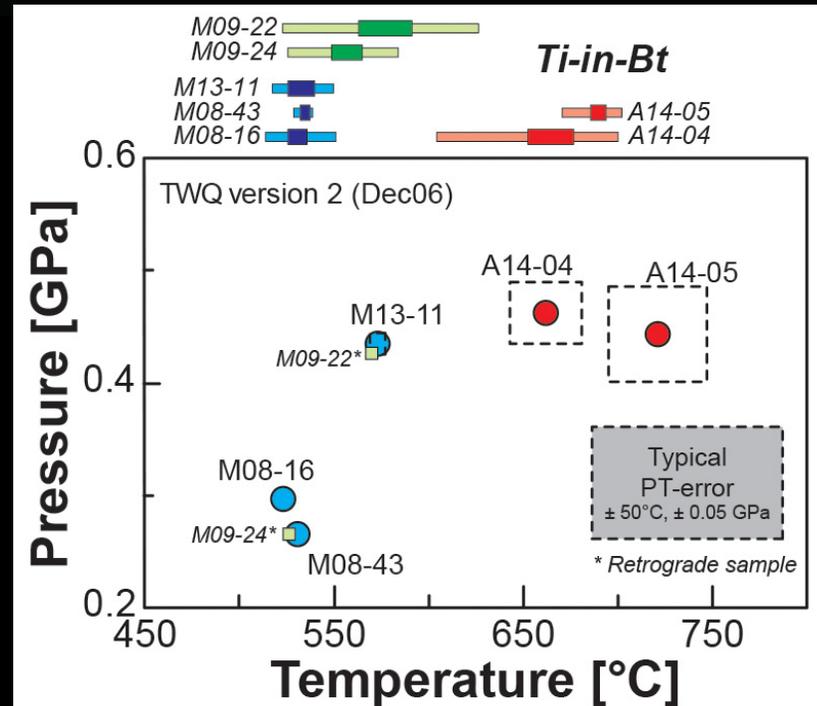
- Multiple events confirmed by Mnz & Xnt.
- All PT-work so far suggests low pressure around 0.3-0.5 GPa, from ~520 to 700°C.

## Low grade samples:

- Main metamorphism @ 1.70-1.65 Ga.
- 2<sup>nd</sup> St generation younger than 1.67 Ga
- Minor evidence for 1.4 Ga (Grt resorption).

## Highest grade migmatite:

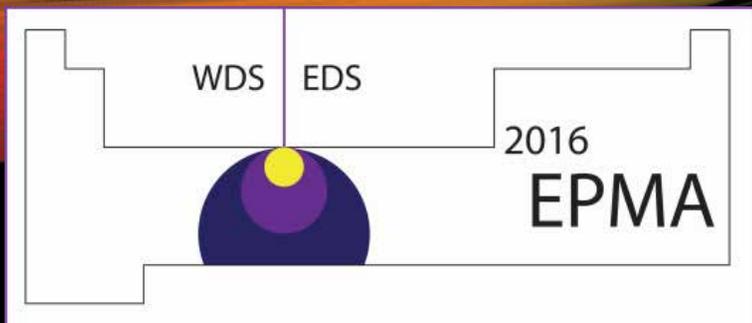
- Relic monazite ~1.67 Ga (Yavapai orogeny).
- Most Mnz & Xnt @ 1.45-1.40 Ga  
→ Bt dehydration (2<sup>nd</sup> melting?).
- Related to Longs Peak – St. Vrain intrusion (~1.45[3] Ga; Peterman & al. 1968).



# Future work

- Additional PT-work in metapelite and amphibolite, especially intermediate grade samples (Sil zone to 1<sup>st</sup> melting).
- Whole rock data for pseudosections (PT) & provenance analysis.
- Link Mnz & Xnt growth with metamorphic reactions.
- Complete dating with *in situ* zircon U-Th-Pb ages and Nd- and Hf-isotopes (origin of intrusions).
- Detailed structural geology and study of shear zones...

Combination of the above data should help deciphering these tectonometamorphic events in terms of origin and PTt.



*Organizers: Paul Carpenter, John Armstrong, John Fournelle, Raynald Gauvin, Dan Kremser, Heather Lowers, Julien Allaz, Kat Crispin, and Nicholas Ritchie*

**Electron-Probe  
MicroAnalysis 2016**  
MAS Topical Conference  
**May 16-19, 2016**  
University of Wisconsin, Madison

- User group meetings
- Tutorial on electron-probe microanalysis (EPMA)
- Quantitative microanalysis and mapping using WDS and EDS
- Correction algorithms
- FE-EPMA and FE-SEM microanalysis
- Quality control for microanalysis
- Standard reference materials
- Practical EPMA for the novice
- Problem solving and experts discussion
- Laboratory demonstrations of microanalysis

