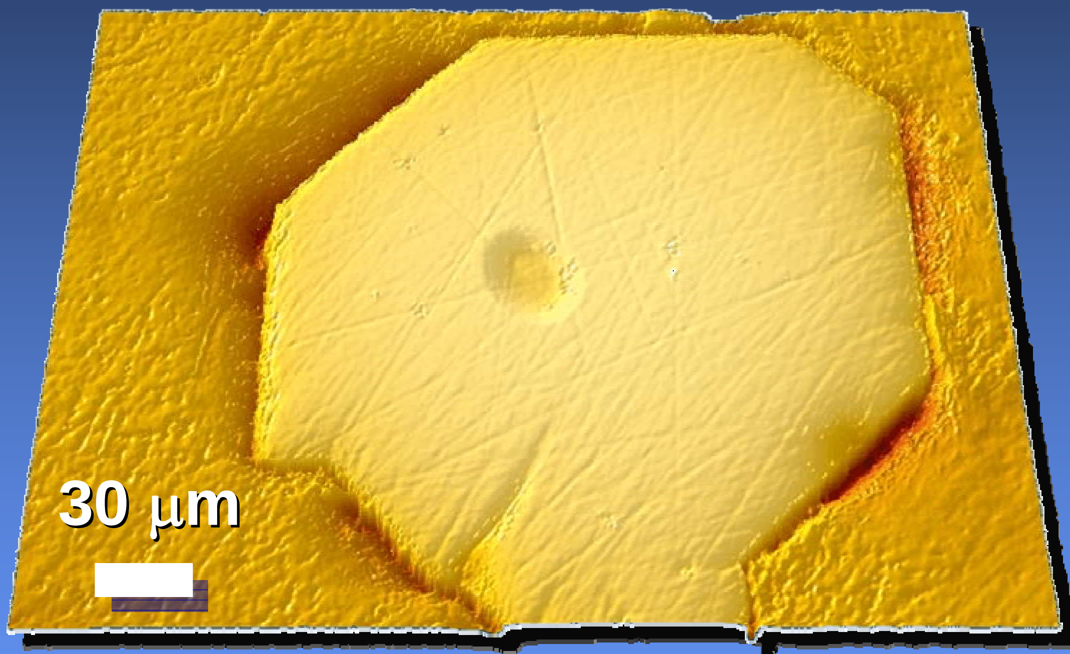
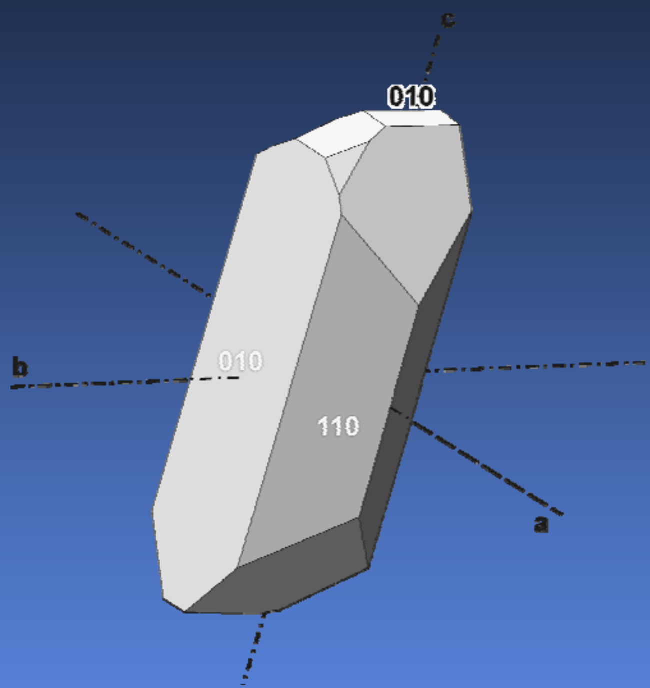
U-Pb (and U-Th) dating of micro-baddeleyite

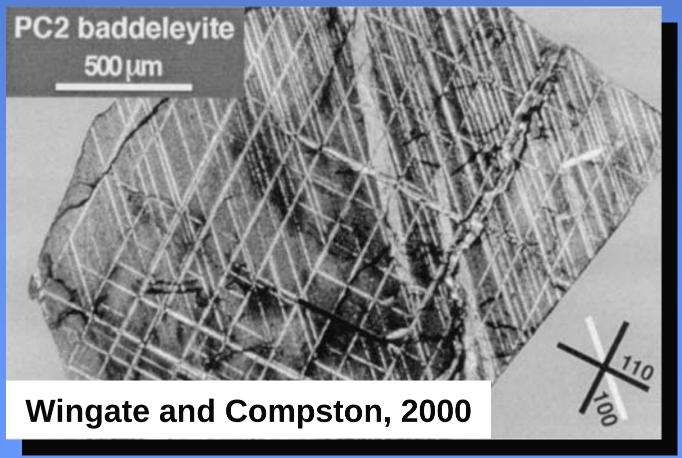


Axel K. Schmitt
UCLA SIMS, NSF National Ion Microprobe Facility

Collaborators: T. Mark Harrison (UCLA)
Kevin Chamberlain (University of Wyoming)

Baddeleyite (BAD-ü-LĒ-ite)* basics





Wingate and Compston, 2000

- chemical formula: ZrO_2
- monoclinic (commonly twinned)
- minor HfO_2, TiO_2, FeO, SiO_2
- U between ~200 – 1000 ppm
- low common Pb, Th/U <<0.2
- wide range of occurrences (terrestrial and extraterrestrial)
  - mafic and ultramafic rocks (basalt, gabbro, diabase)
  - alkali rocks (carbonatite, syenite)
  - mantle xenoliths (from kimberlites)
  - metacarbonates
  - impact-related rocks (tektites)

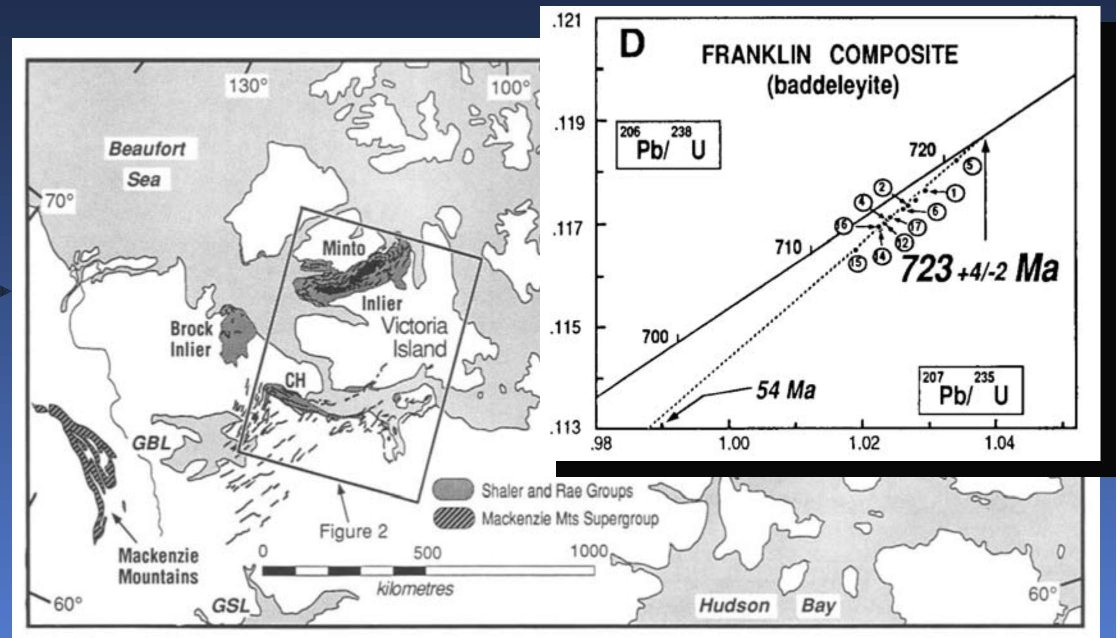
*National Library Service for the Blind and Physically Handicapped (NLS), Library of Congress

Baddeleyite dating: applications and examples

Bulk analysis (TIMS)

- Mafic dikes and layered intrusions *(e.g., Heaman et al., 1992)*

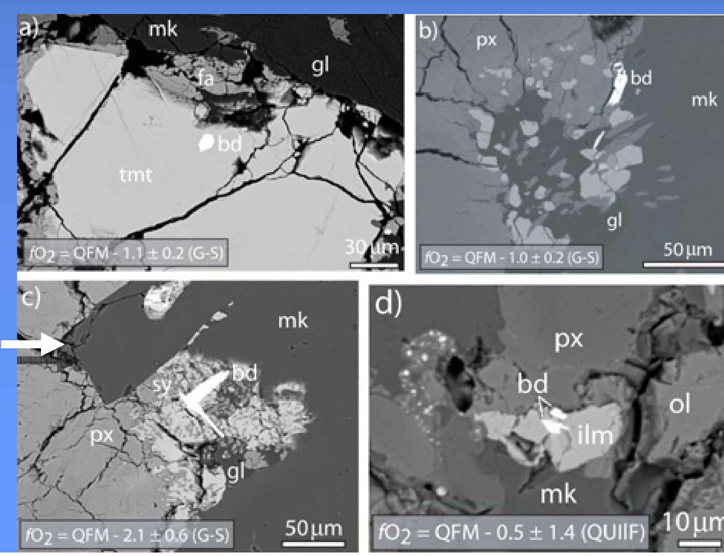
- Detrital baddeleyite *(e.g., Bodet and Schärer, 2000)*



In-situ methods (SIMS, LA ICP MS, EPMA)

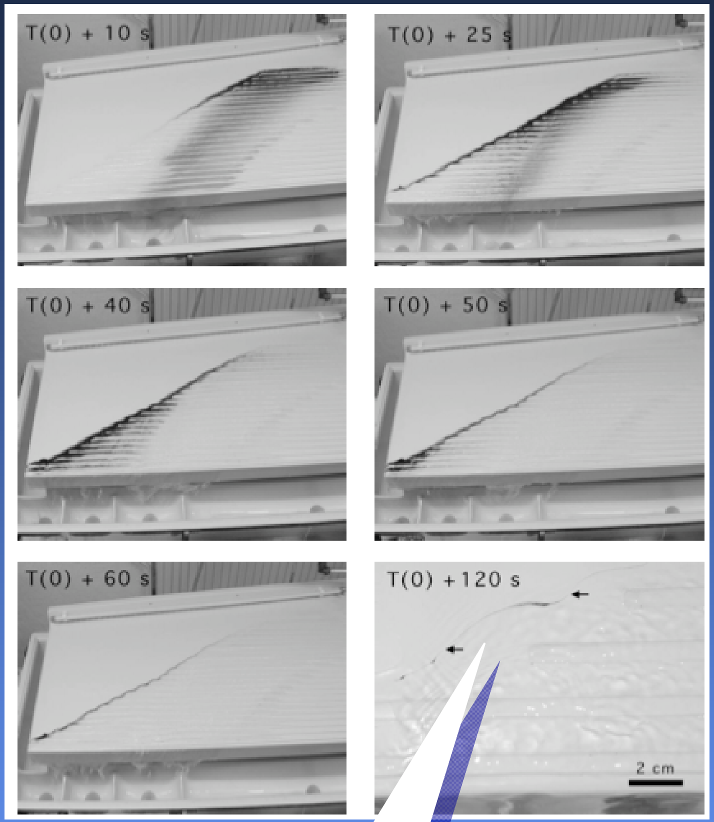
- Mafic dikes and gabbros *(e.g., Wingate et al., 1998; French et al., 2000)*

- SNC meteorites (Herd et al., 2007: 70±35 Ma and 171±35 Ma)



Micro-baddeleyite analysis: in-situ advantages

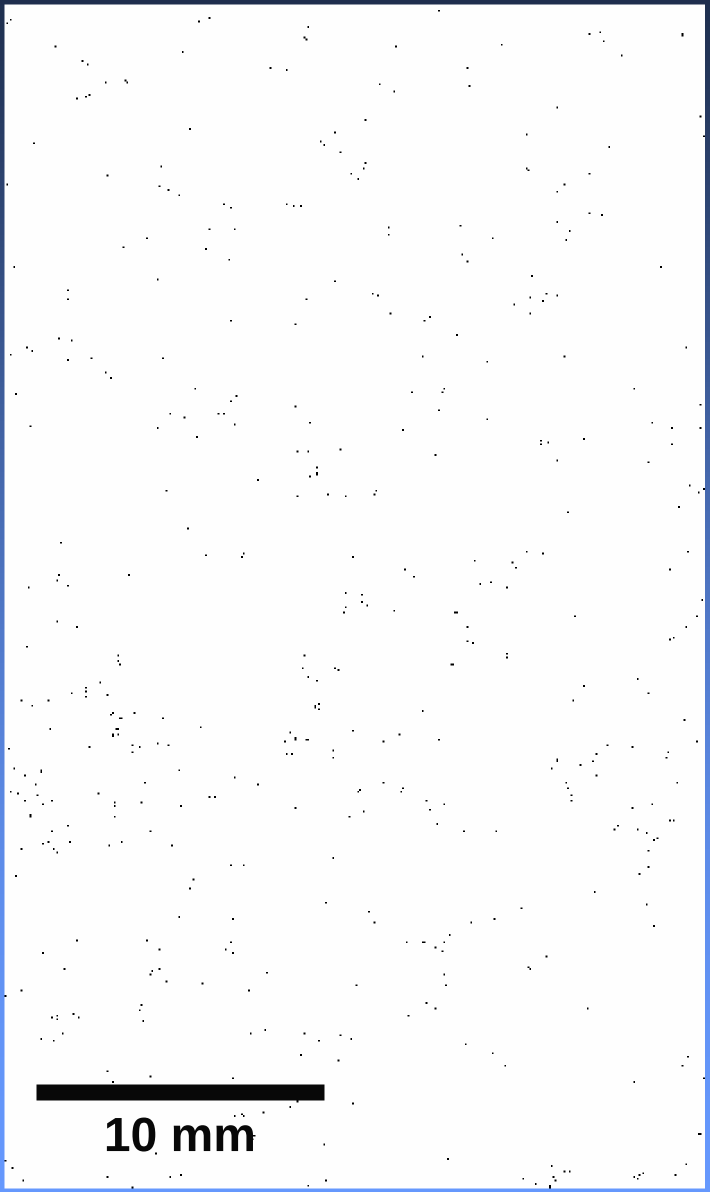
- **Bulk analysis difficulties:**
  - time-intensive, highly inefficient mineral separation
  - 100's of grains (<20 μm) required
  - contamination risk (though inheritance unknown)
  - abrasion impossible (Pb-loss)
- **In-situ advantages:**
  - grains can be located and analyzed in thin-section
  - no separation required
  - petrographic context preserved
  - limited sample size (e.g., drill samples, extraterrestrial)
  - screening for concordant grains



Söderlund and Johansson, 2002

Micro-baddeleyite analysis: in-situ advantages

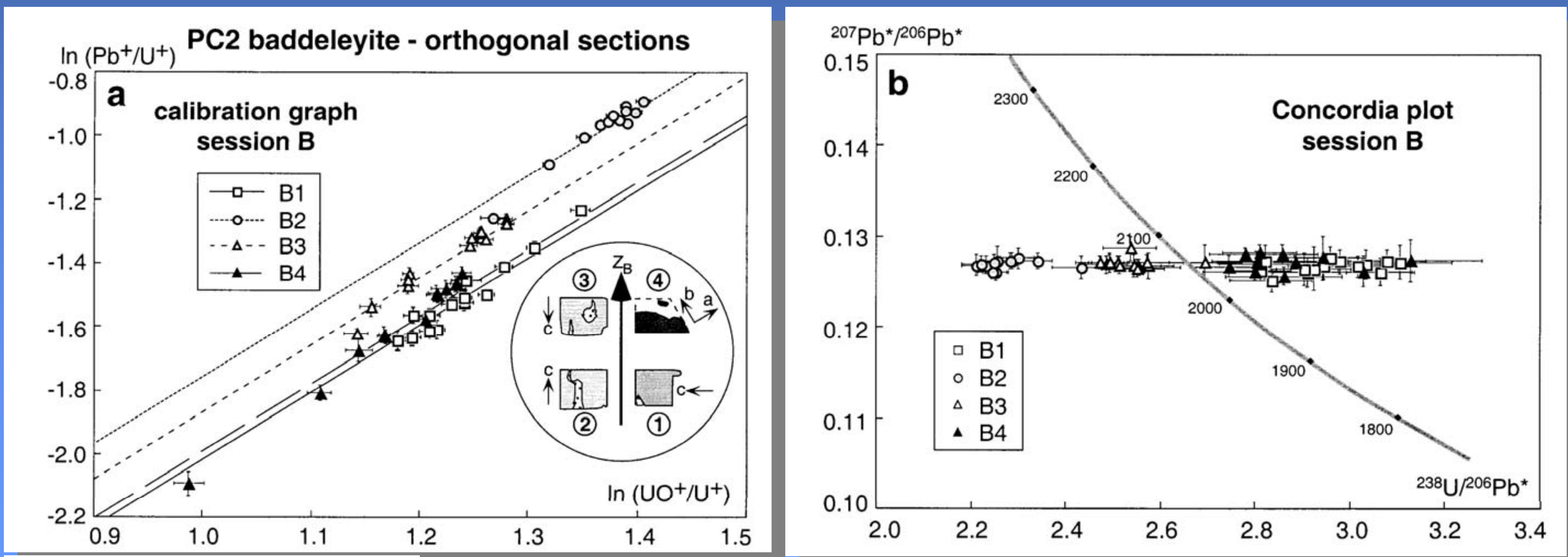
- **Bulk analysis difficulties:**
  - time-intensive, highly inefficient mineral separation
  - 100’s of grains (<20 μm) required
  - contamination risk (though inheritance unknown)
  - abrasion impossible (Pb-loss)
- **In-situ advantages:**
  - grains can be located and analyzed in thin-section
  - no separation required
  - petrographic context preserved
  - limited sample size (e.g., drill samples, extraterrestrial)
  - screening for concordant grains



Zirconium X-ray map of mafic dike rock

Previous SIMS U-Pb dating of baddeleyite

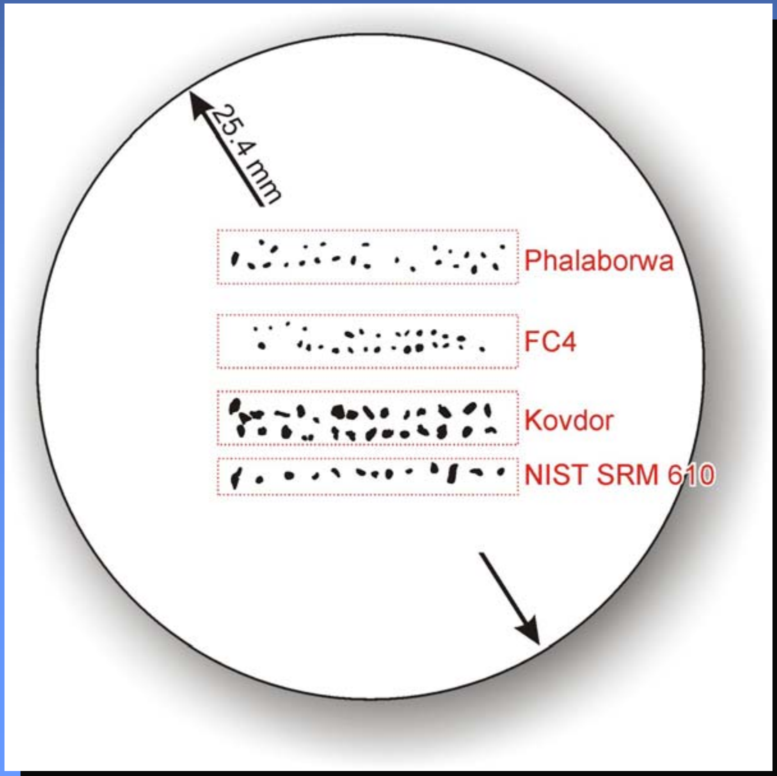
- SHRIMP II (Wingate and Compston, 2000)
  - Phalaborwa baddeleyite standard
  - $^{207}Pb/^{206}Pb$ ages accurate
  - $^{206}Pb/^{238}U$ ages deviate by up to -13% and +17%
  - crystal orientation affects U-Pb sensitivity
  - severe limitation on accuracy of U-Pb baddeleyite ages

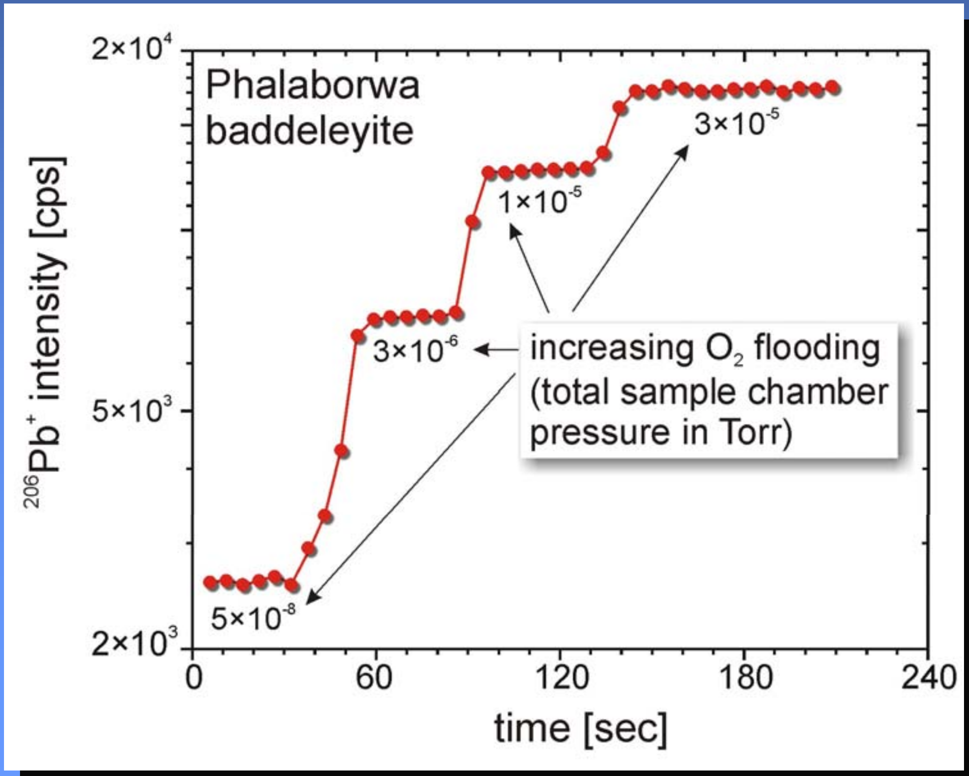


Wingate and Compston, 2000

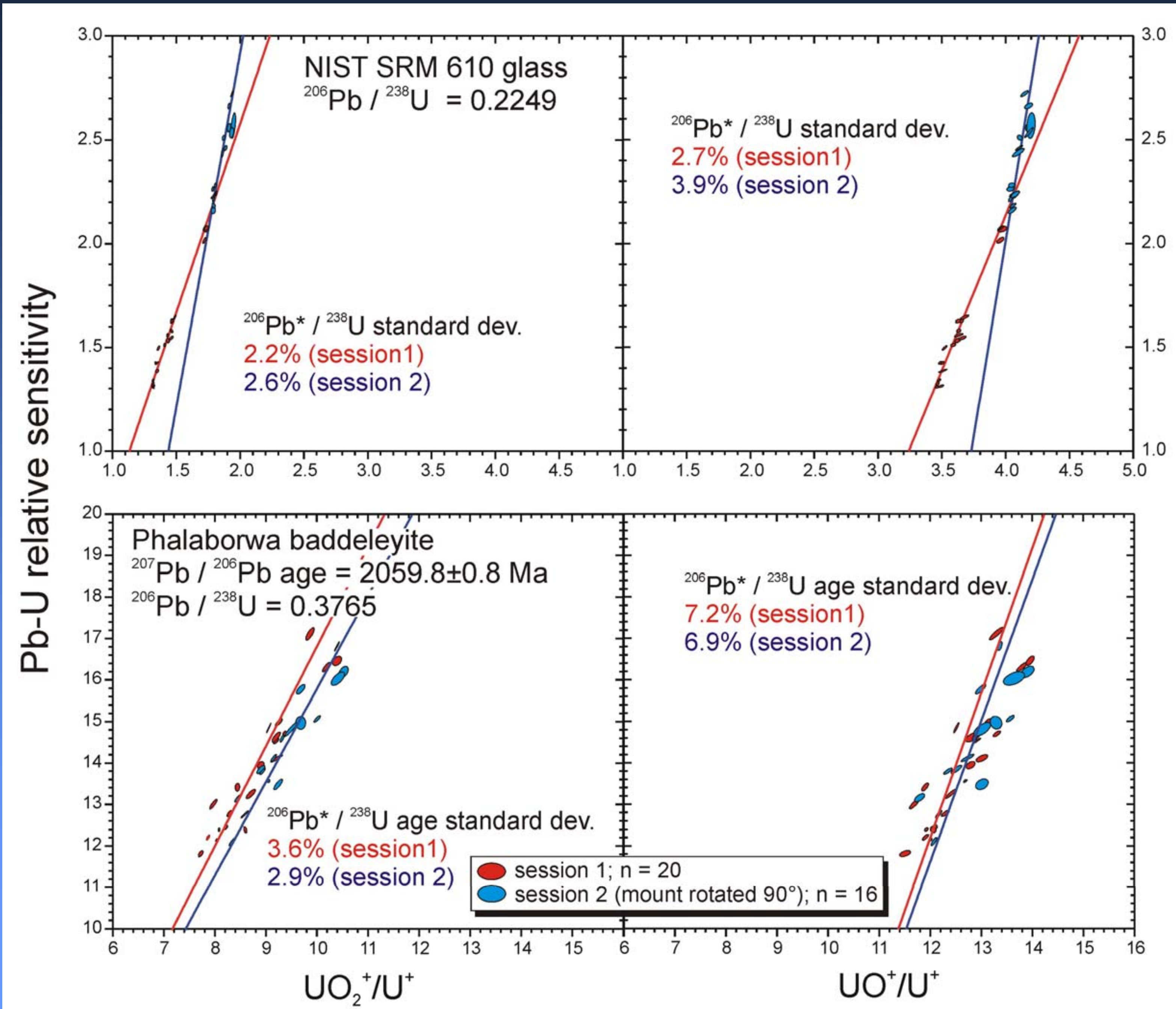
Baddeleyite U-Pb analysis with the ims 1270

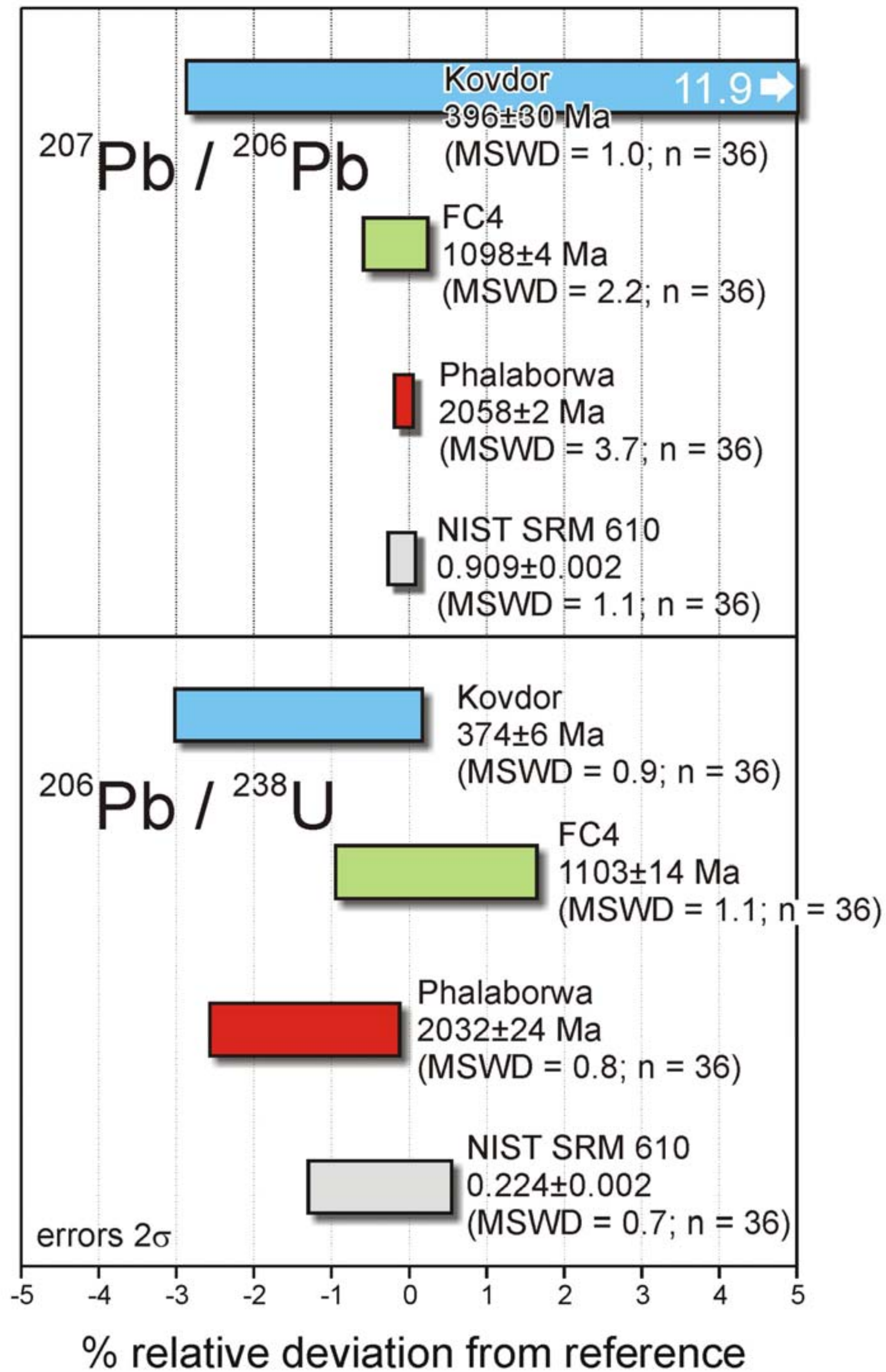
- cross-calibration of three baddeleyite standards
- randomly oriented grains, NIST SRM 610 glass on same mount
- 144 spot analyses total
- two sessions (overnight, fully automated beam centering and charge-compensation): rotate mount 90º
- ~8-11 nA $^{16}O^-$ primary beam, 25-30 μm spot size, MRP = 4500
- O_2- flooding (700% increase in Pb^+)





U-Pb calibration results



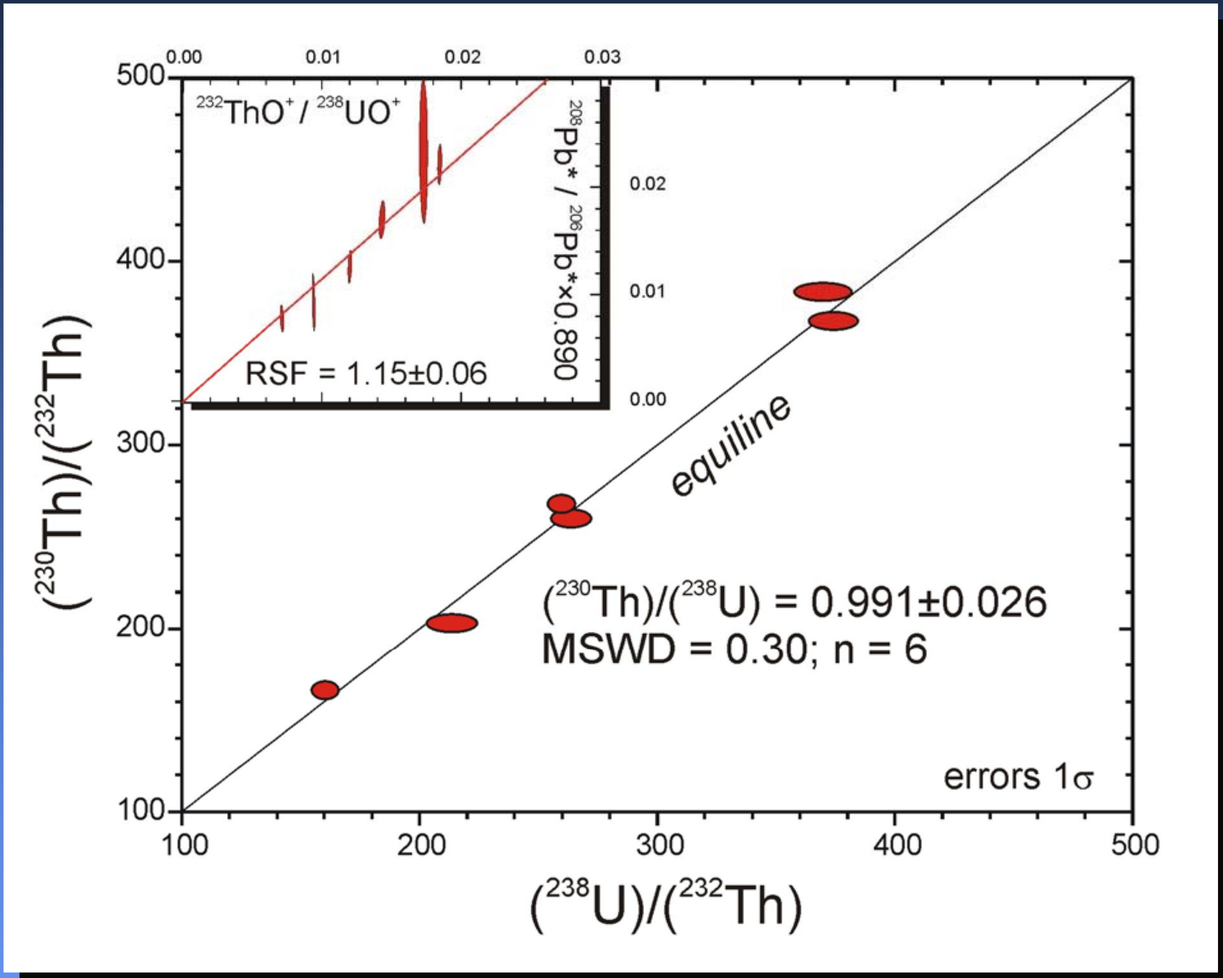


Standard intercomparison

- new TIMS results for Kovdor and FC4 (Duluth)
- differences in calibration after rotation unrelated to crystal-orientation
- reproducibility on baddeleyite slightly poorer compared to glass
- highly accurate $^{207}Pb/^{206}Pb$ ages for Precambrian baddeleyite
- $^{206}Pb/^{238}U$ ages agree within measurement uncertainties (~1-2 % 2 σ)

Phalaborwa: Heaman and LeCheminant, 1993
NIST SRM 610: Walder et al., 1993; Hirata and Nesbitt, 1995

Baddeleyite U-Th dating



- Multicollection analysis of Phalaborwa baddeleyite (30 nA $^{16}O^{-}$ beam)
- U-Th relative sensitivity calibration comparable to zircon
- Yields equilibrium $(^{230}Th)/(^{238}U)$
- Potential for young mafic volcanics (e.g., Hawaii, Eifel)

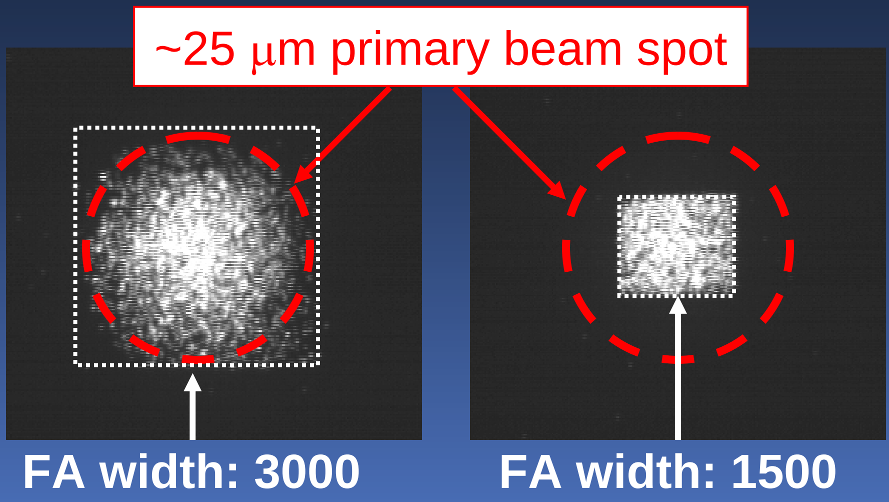
Micro-baddeleyite: analytical parameters

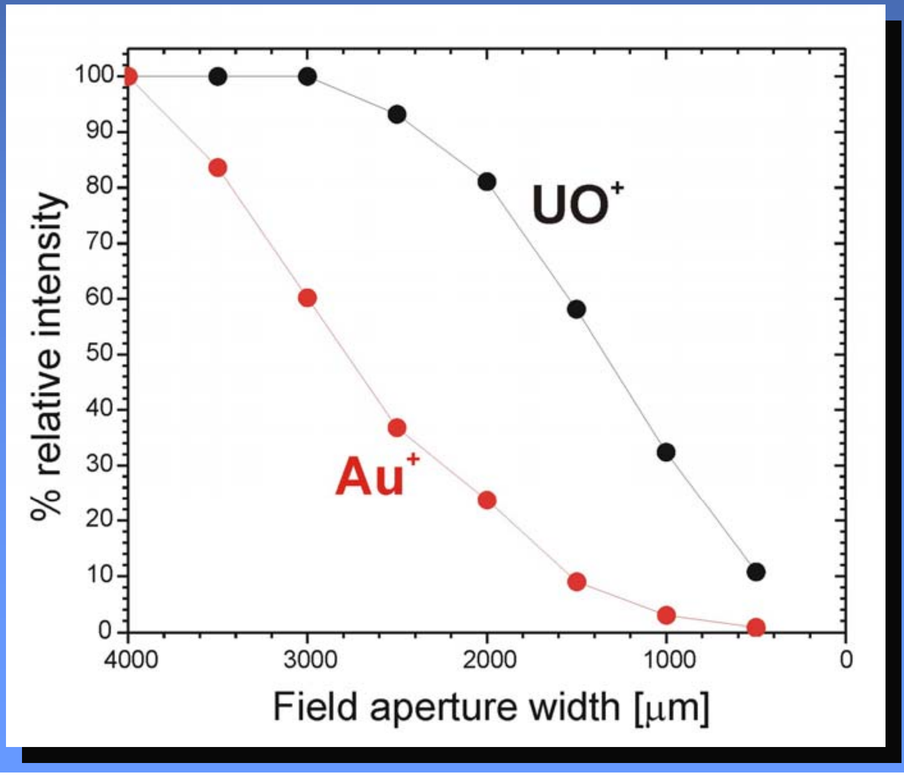
- Pb useful yield ~0.4 % (similar to zircon)

- for 100 Ma baddeleyite, 500 ppm U, $^{206}Pb/^{238}U$ counting error of 1% requires ~25 μm^3 baddeleyite

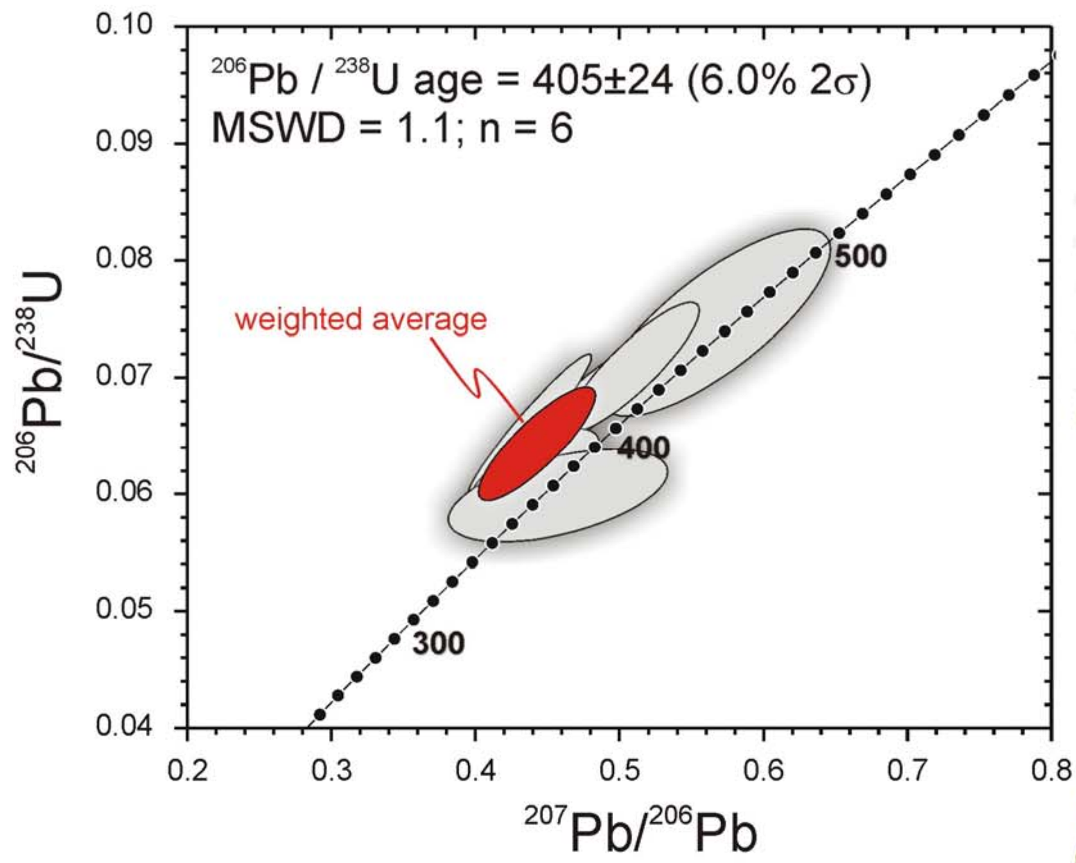
- In-situ thin-section analysis

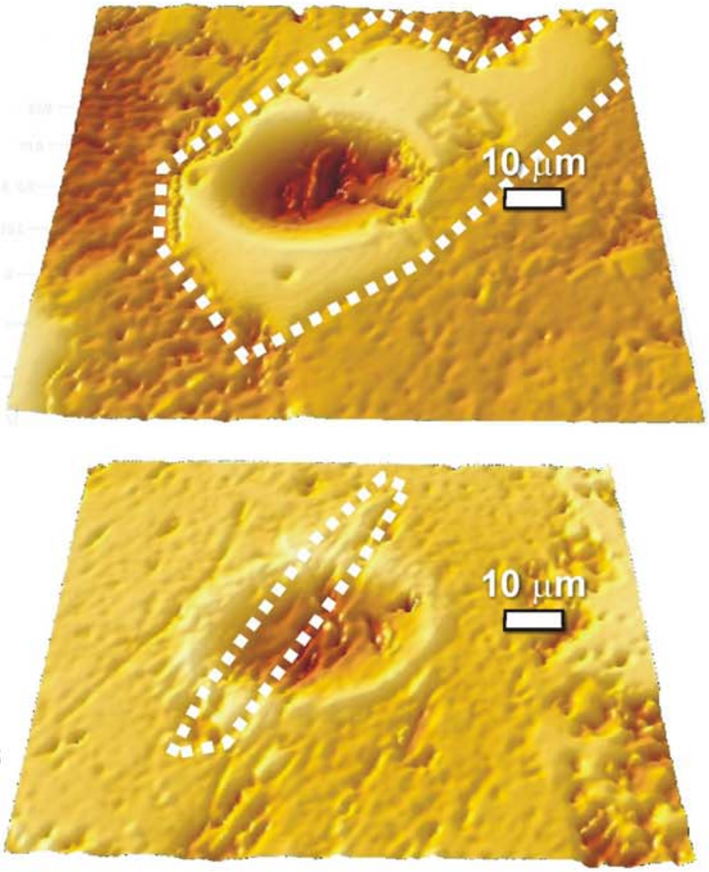
- use field aperture to exclude common Pb from crater margins and matrix minerals





Micro-baddeleyite: preliminary results





- baddeleyite from Sette Daban (N Siberia)
- mafic sills within carbonate platform sequence
- analyzed grains between 30 and 10 μm (short dimension), depth resolution ~1-2 μm

SIMS micro-baddeleyite geochronology: future developments

- more testing of crystal-orientation effects on Pb-U sensitivity (EBSD analysis underway)

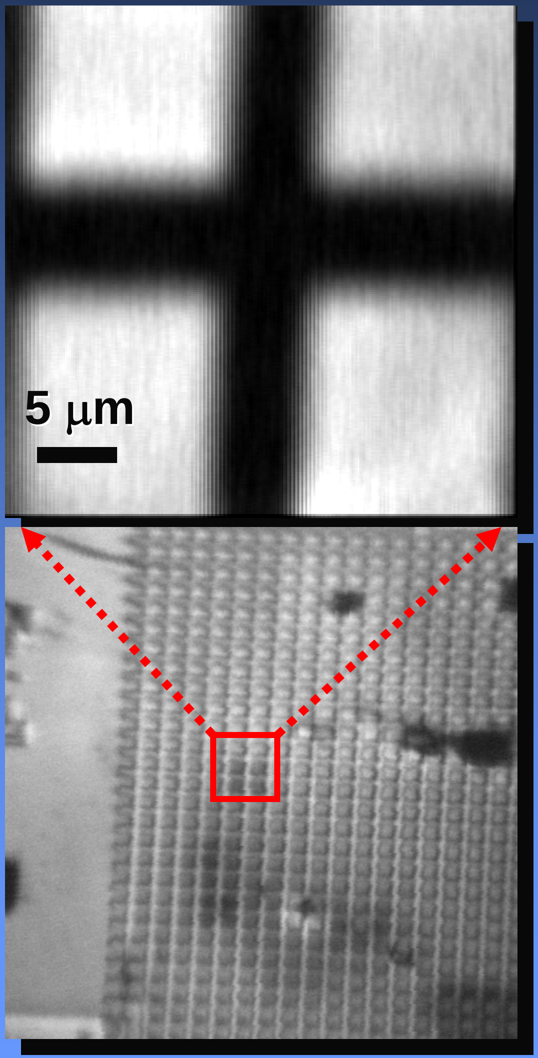
- multi-collection of Pb isotopes to increase duty cycle

- implement sample maps (e.g., by SEM) into sample stage control

- explore potential of ion-beam generated secondary electron imaging (UCLA ims1270 features Ga liquid metal source, and new channeltron particle detector)

Secondary electrons

Reflected light



scanning electron images of Ta-Si grid, 2 pA Cs^+ (1.5 μm lateral resolution)

Conclusions

• SIMS U-Pb dating of baddeleyite possible at ~3-4% (rel. uncertainty) level

• crystal-orientation effects under investigation, but appear to be minor/absent (O_2-flooding? secondary ion extraction geometry?)

• U-Pb ages accurate within internal reproducibility for randomly oriented crystals (e.g., in-situ baddeleyite in thin-section)

• U-Th calibration comparable to zircon

• potential for U-series dating of young mafic volcanics