INTEGRATING MICRO-CT TO IMPROVE RESEARCH AND PEDAGOGY IN EARTH SCIENCES

Emily H. G. Cooperdock

Assistant Professor

Brown University / USC

EARTH SCIENCES

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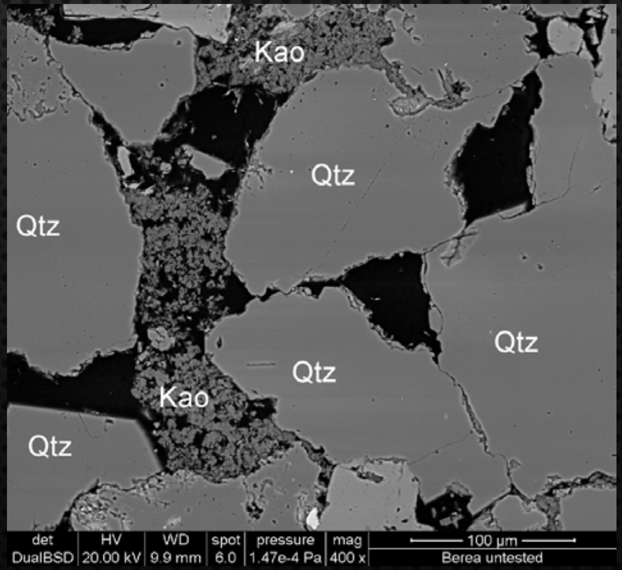


geological-digressions.com, Rosenbrand et al., 2014

EARTH SCIENCES: THE CHALLENGE

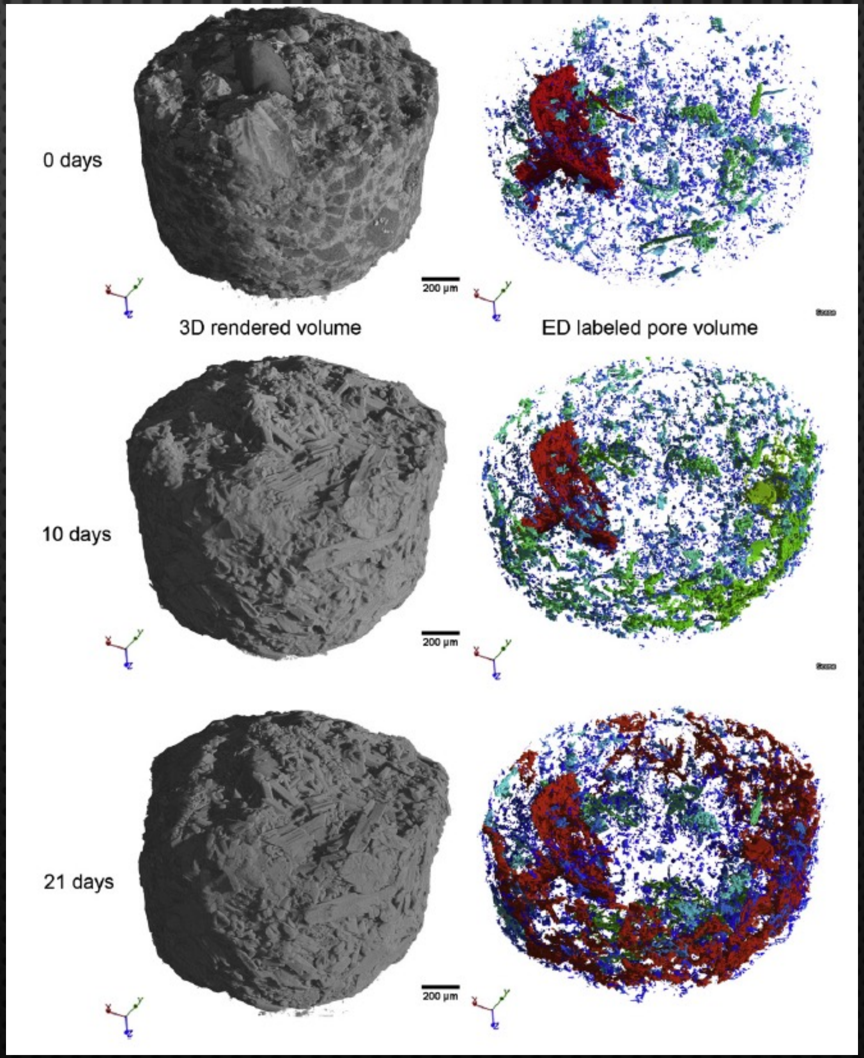
- Studying 3D systems in 2D
- The need to see inside
- The need to preserve specimens

geological-digressions.com, Rosenbrand et al., 2014

A SOLUTION: MICRO-CT

USC Earth Sciences Rigaku CT LAB HX

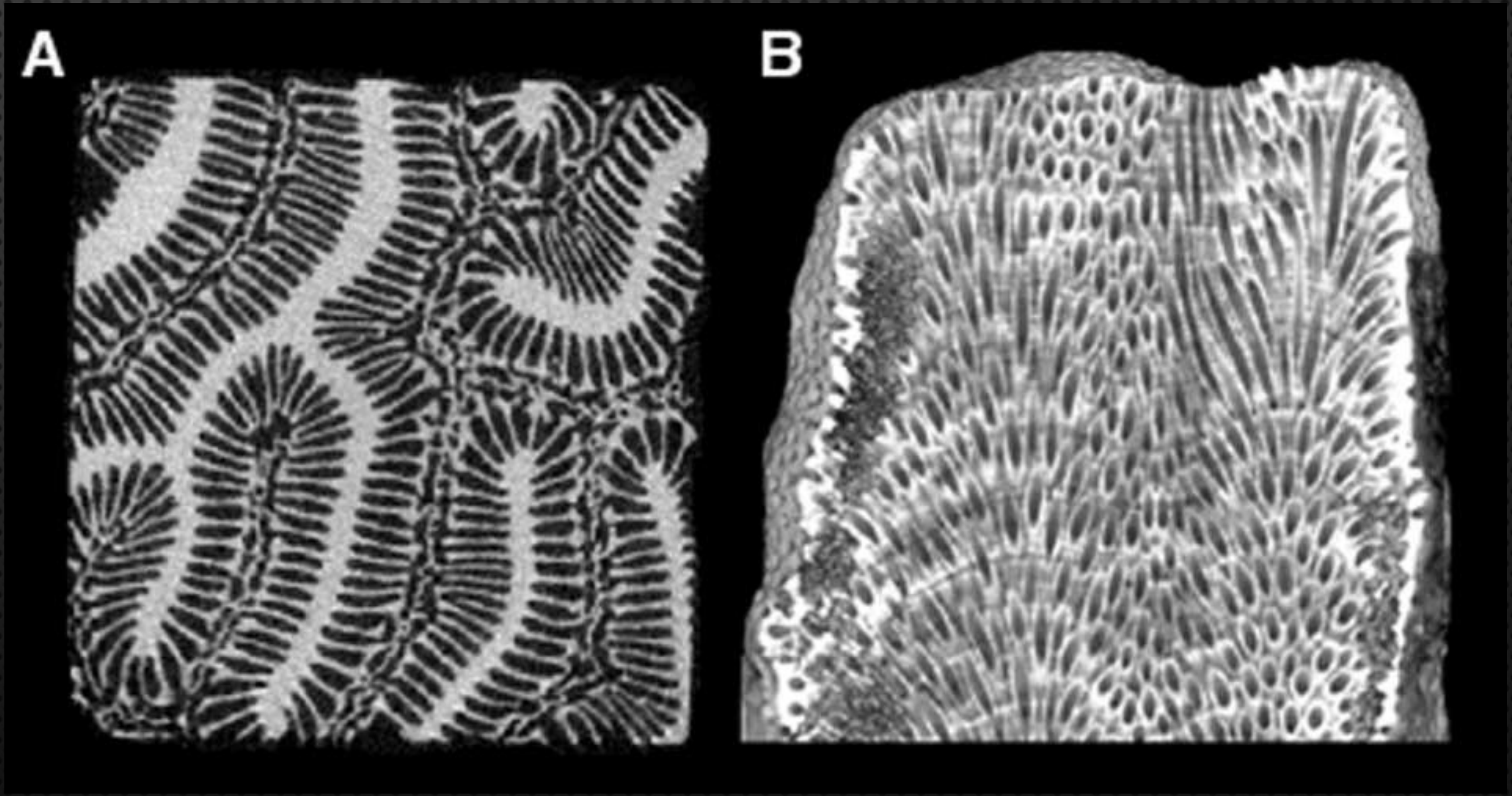
ALLOWS VISUALIZATION OF SPECIMENS IN 3D



3D rendered volumes of a calcareous sandstone

Dewanckele et al., 2012

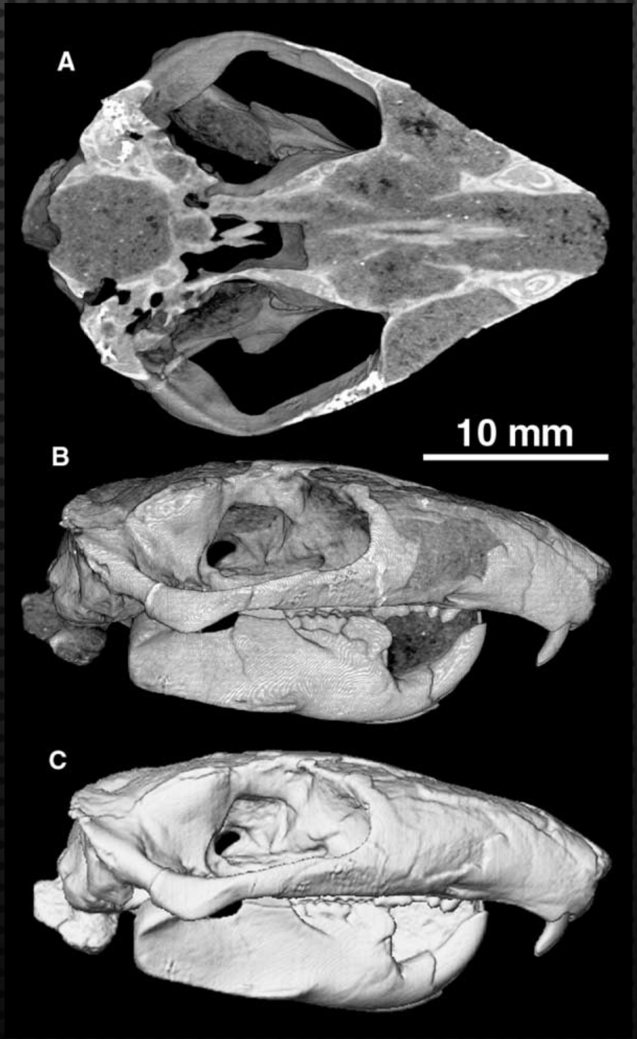
ALLOWS US TO SEE INSIDE OPAQUE MATERIALS



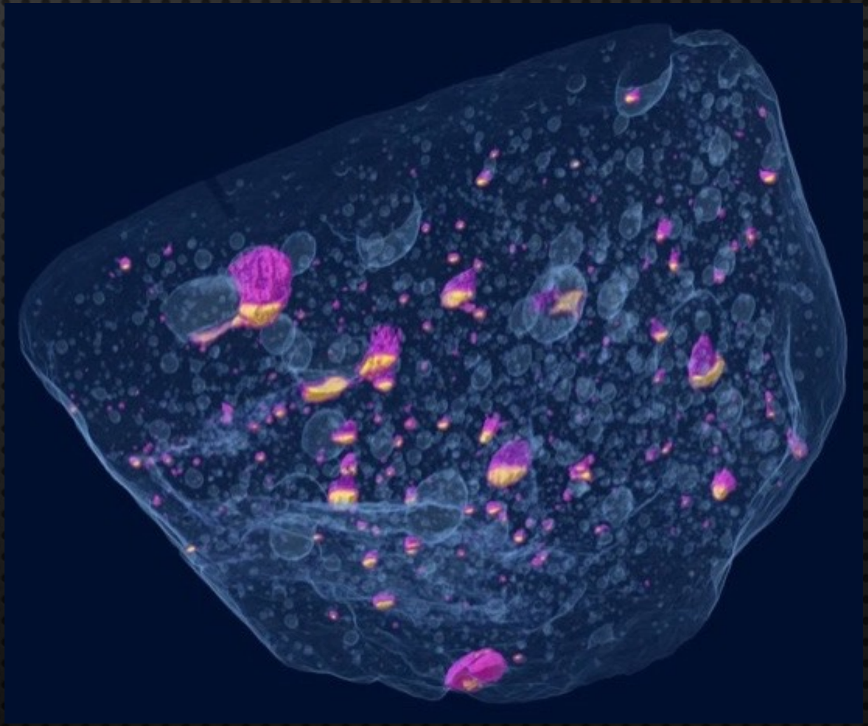
CT image of 25-cm cut cube of coral Diploria strigosa

Ketcham and Carlson, 2001

ENABLES DETAILED STUDIES OF PRECIOUS MATERIALS



CT data of skull of Kryptobataar.

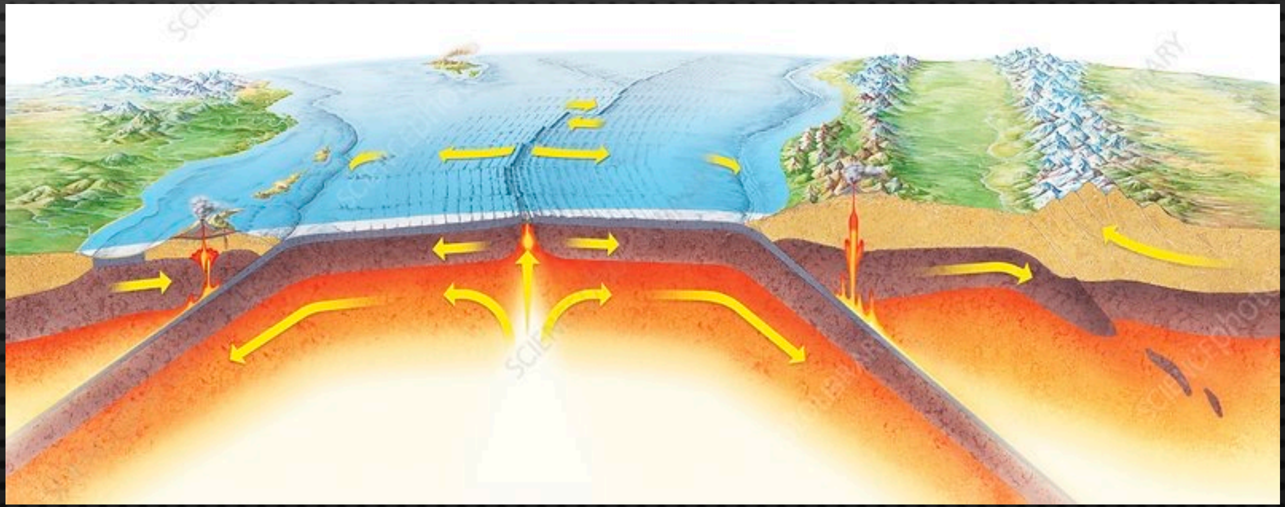


3D rendering of meteorite PAT91501-50

Ketcham and Carlson, 2001; smithsonian.org

MY MICRO-CT JOURNEY

PhD in Earth Sciences at UT Austin



Studying tectonics: understanding how the solid earth moves over geologic time

GARY HINCKS/SCIENCE PHOTO LIBRARY

(U-TH)/HE THERMOCHRONOLOGY:

Tracks when rocks cool below a certain temperature

Thermo

+

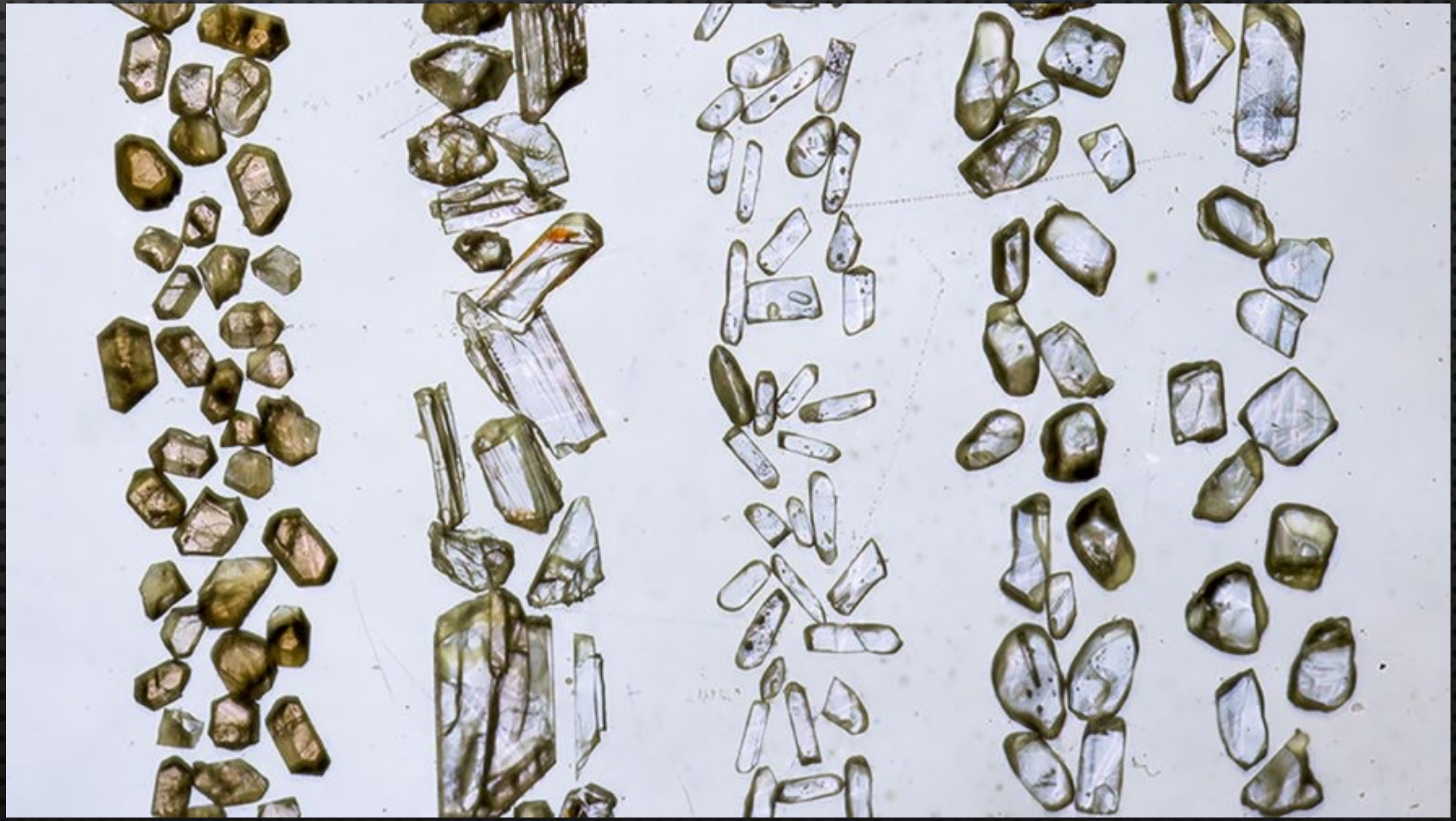
Chronology

Uses individual mineral grains

Requirements for dating

Pure mineral phase free of inclusions or fractures

Precise measurement of grain dimensions
(Mass, concentrations and Age correction factor)



zircon crystals

Requirements for dating

Pure mineral phase free of inclusions or fractures

Precise measurement of grain dimensions
(Mass, concentrations and Age correction factor)

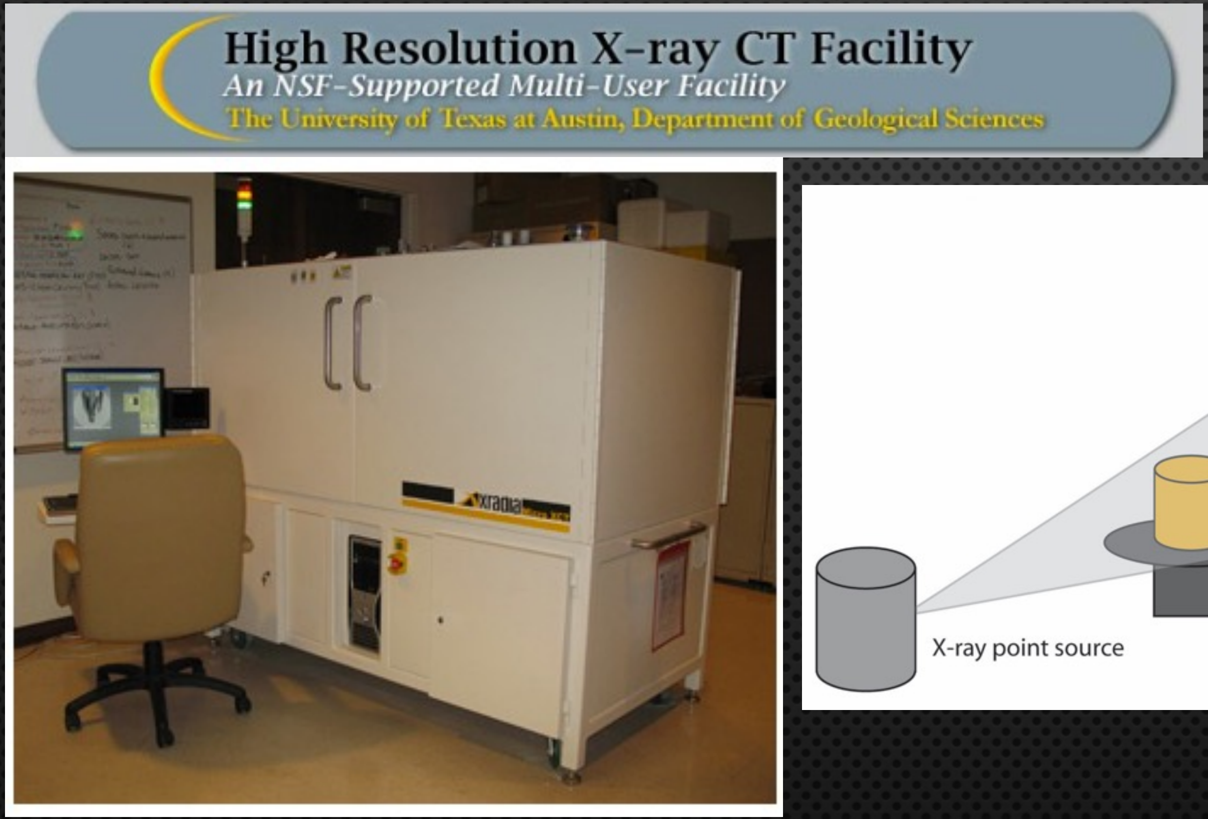
magnetite crystals

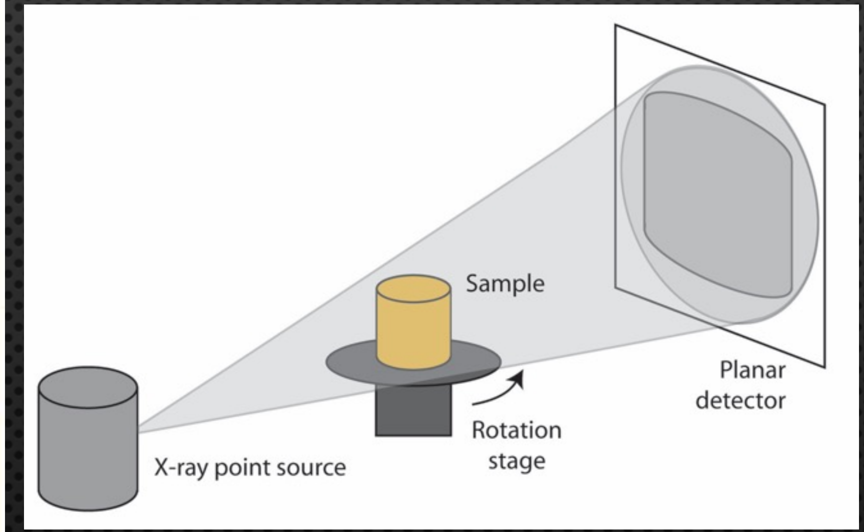
CHECK FOR INTERNAL TEXTURES, INCLUSIONS

Common way: Optical microscope with camera (OR SEM)

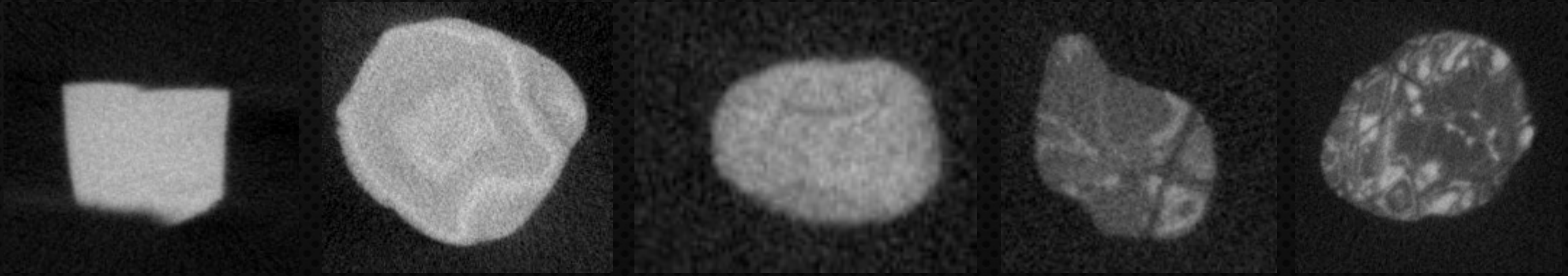
Limited to translucent minerals → limits rock types and applications

X-Ray CT is non-destructive, 3D check for internal grain structure





Brighter material more attenuating (higher atomic number composition or density)



X-Ray image slice of magnetite

Kyle and Ketcham (2015)

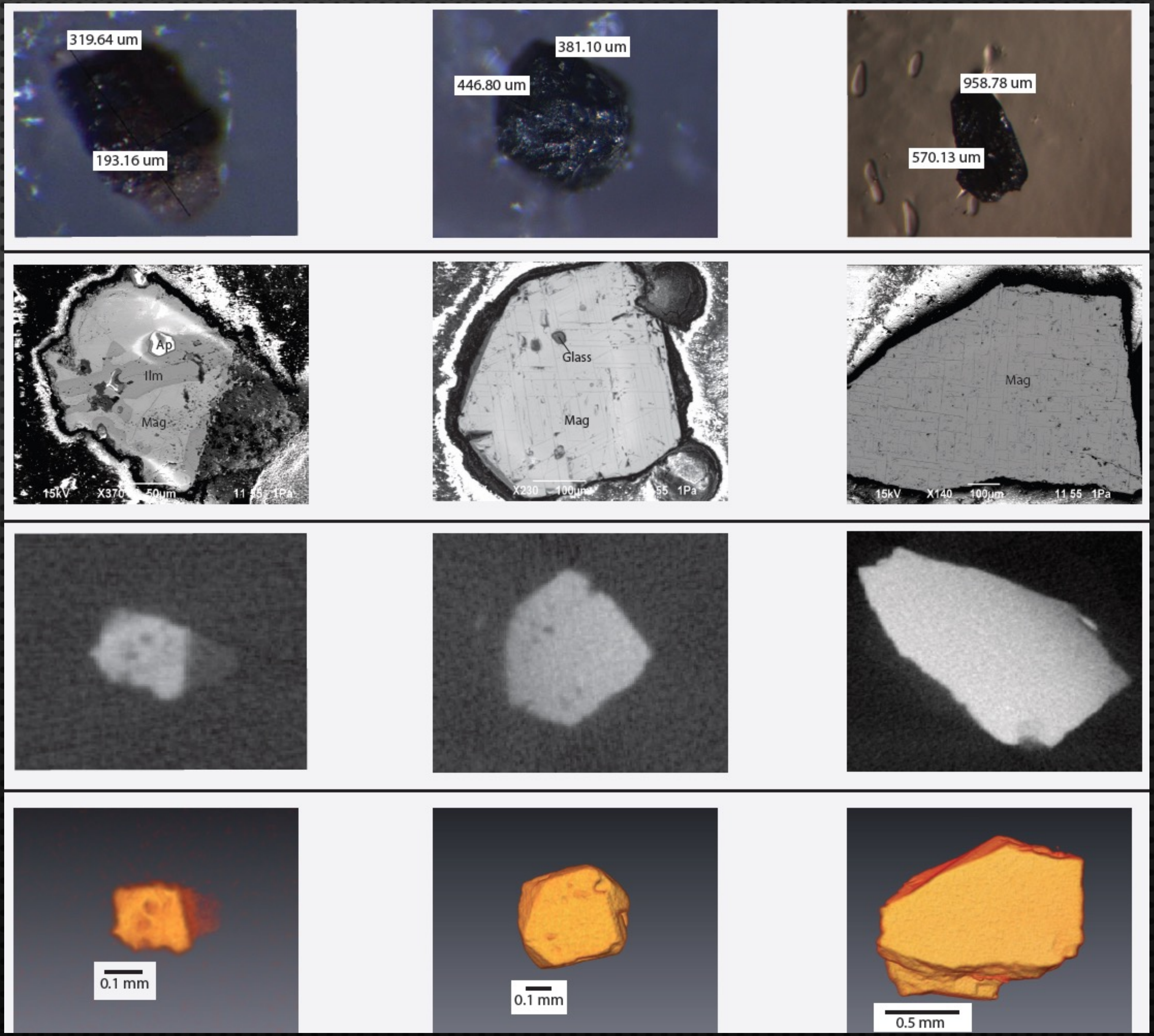
COMPARISON OF 2D AND 3D TECHNIQUES

Microscope image

BSE image

X-ray image

X-ray reconstruction

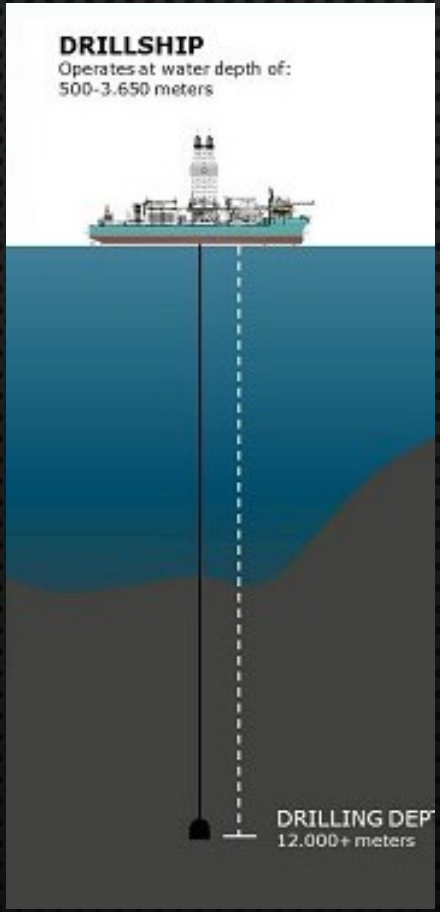


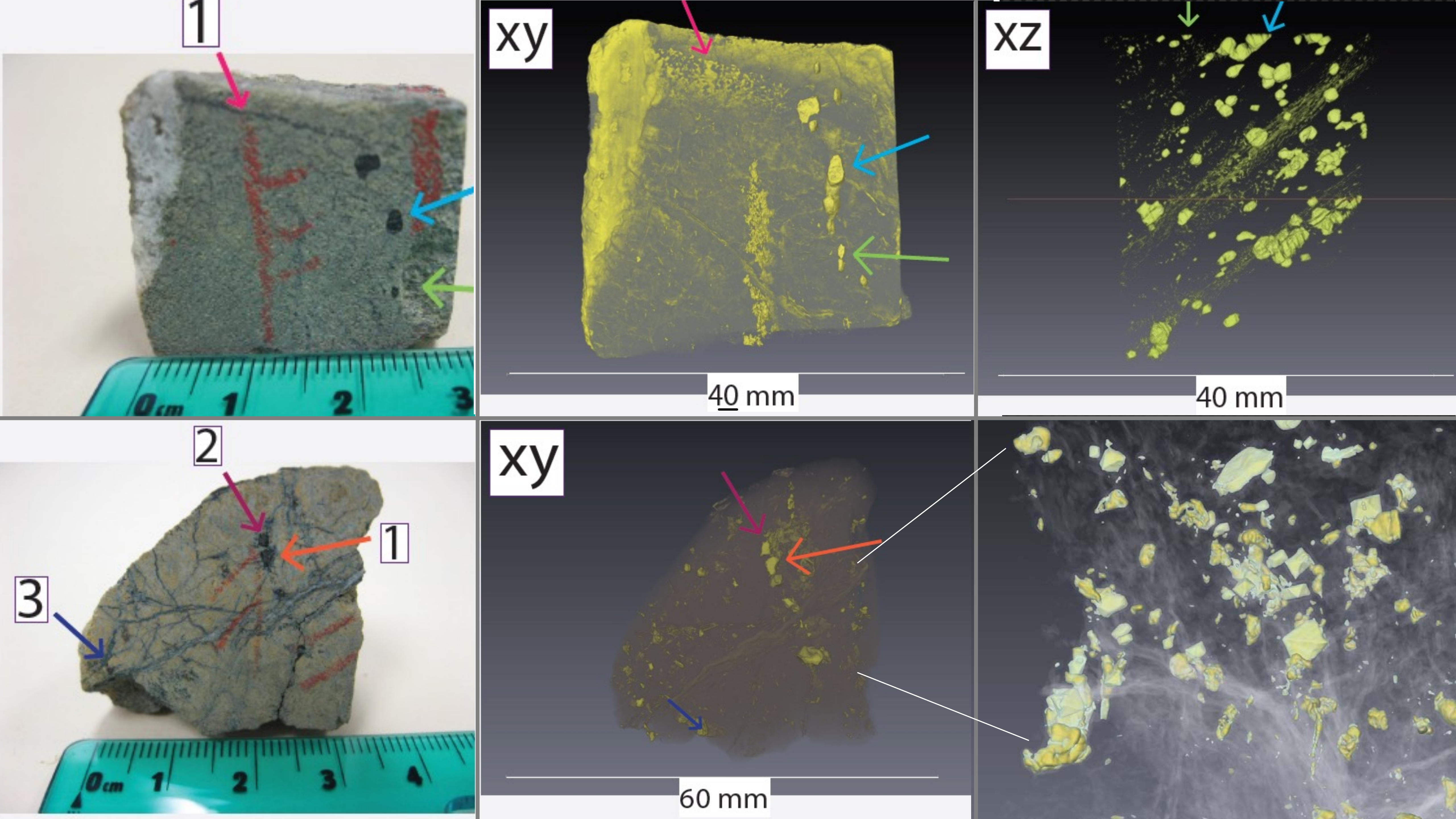
Check viability of minerals within rocks

Common way: Crush up your rock

Seafloor samples from > 3 km deep

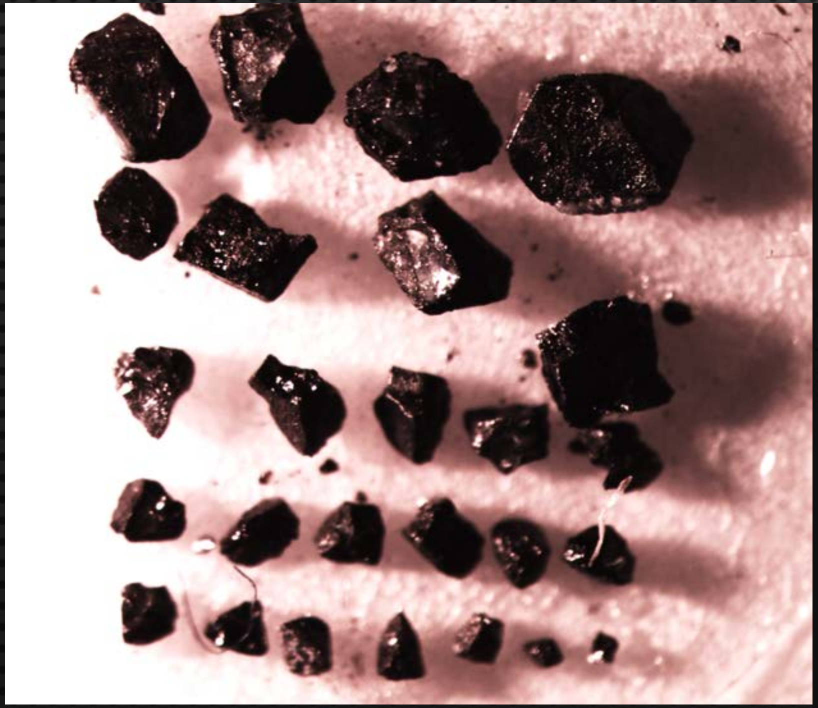
$$$$$$ to collect



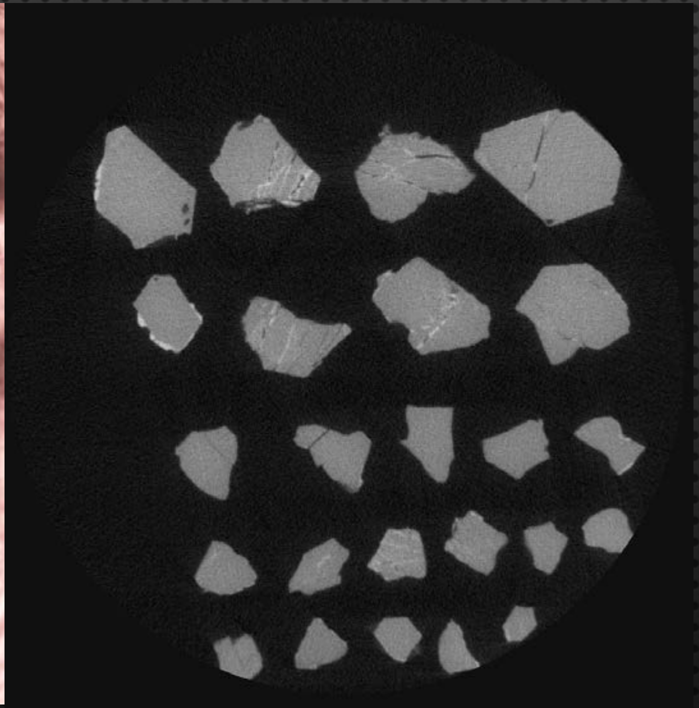


1
0cm 1 2 3
xy
40 mm
xz
40 mm
2
1
3
0cm 1 2 3 4
xy
60 mm

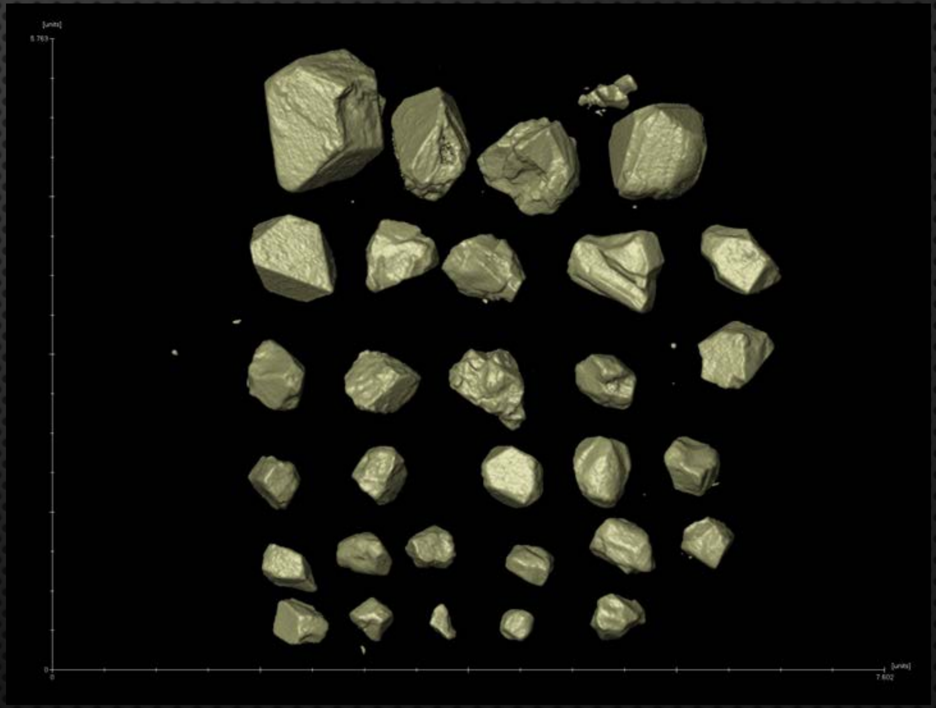
Separated minerals from CT scanned core sample



Microscope image



2D X-Ray slice

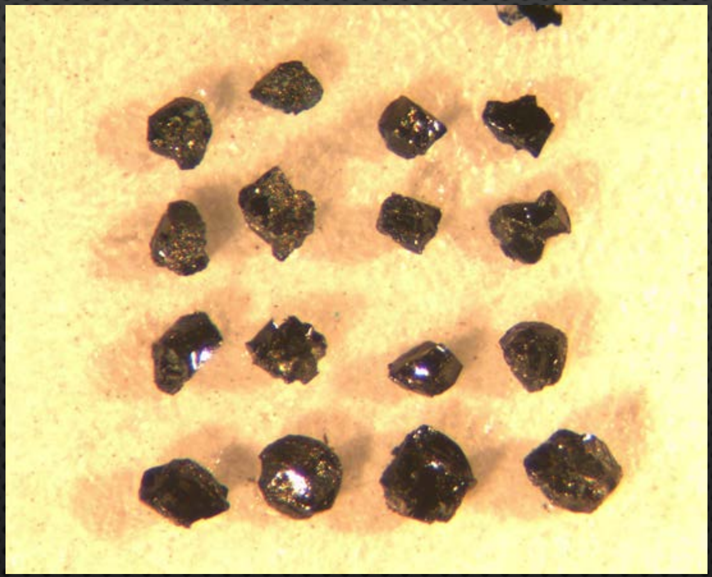


3D reconstruction

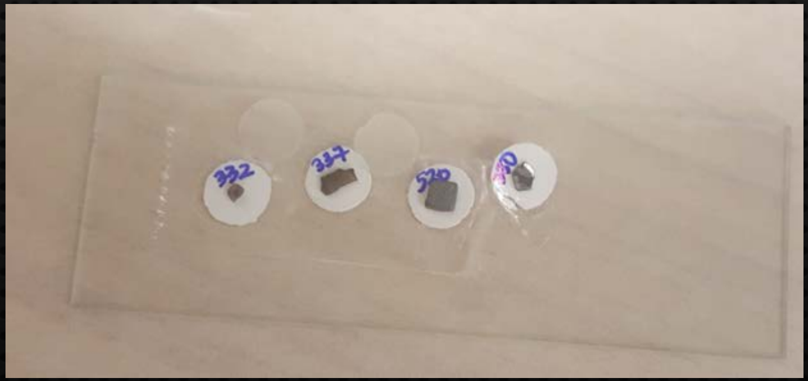
DETOUR:
CONTINUALLY CHANGING HOW WE MOUNT

Start with a hole puncher and thumb tack

Combine grains into multiple layers on hole-punch paper

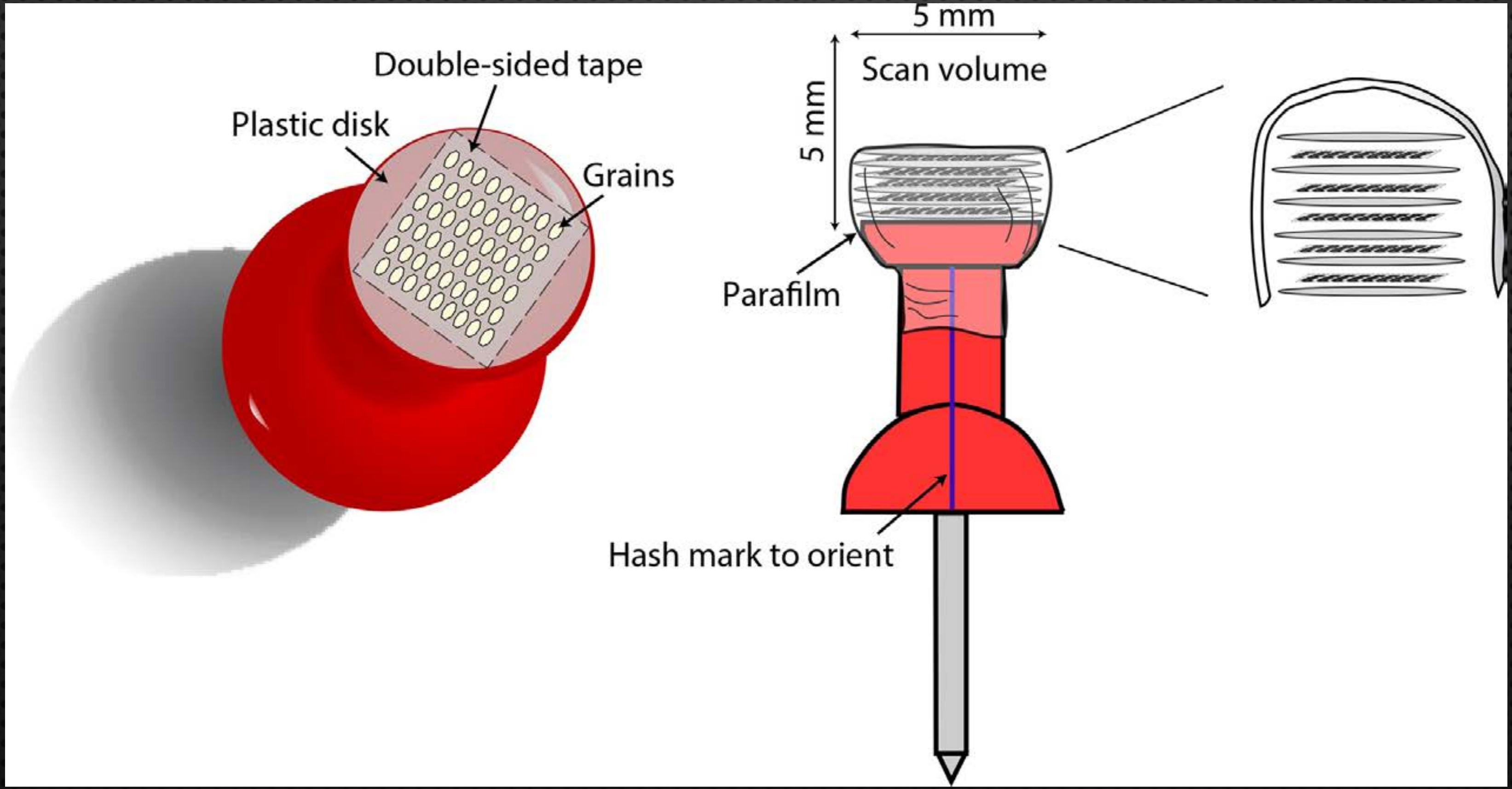


Fits 1 to 40 grains per layer

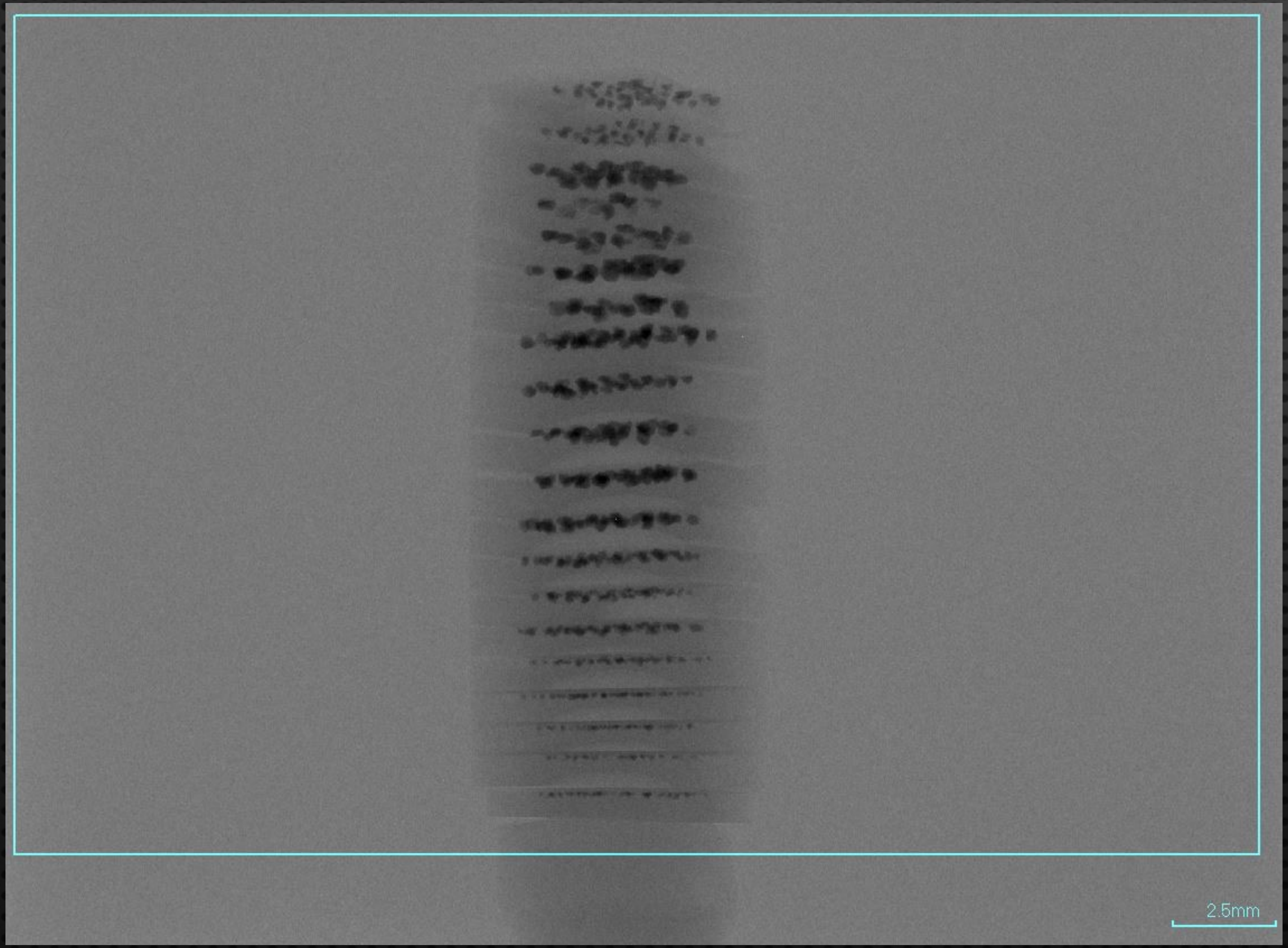


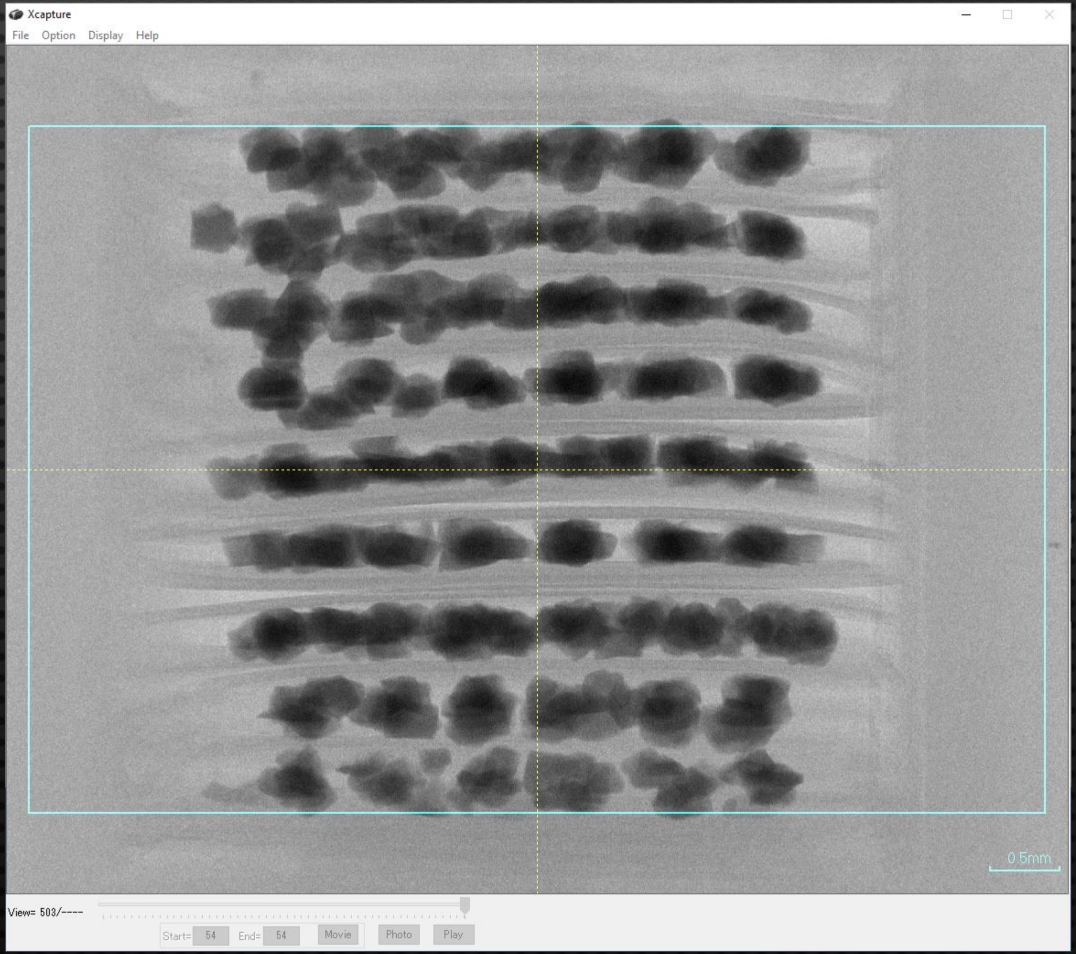
Stack the layers and seal with parafilm

Stack 1 to 5 layers

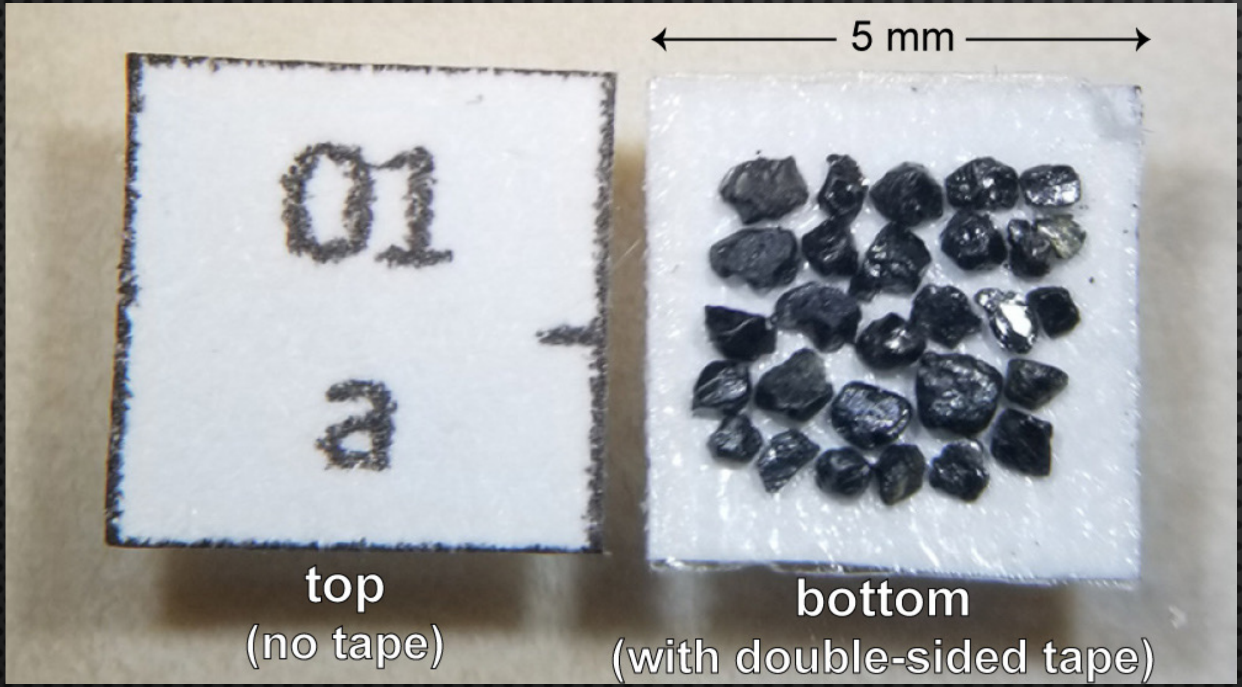


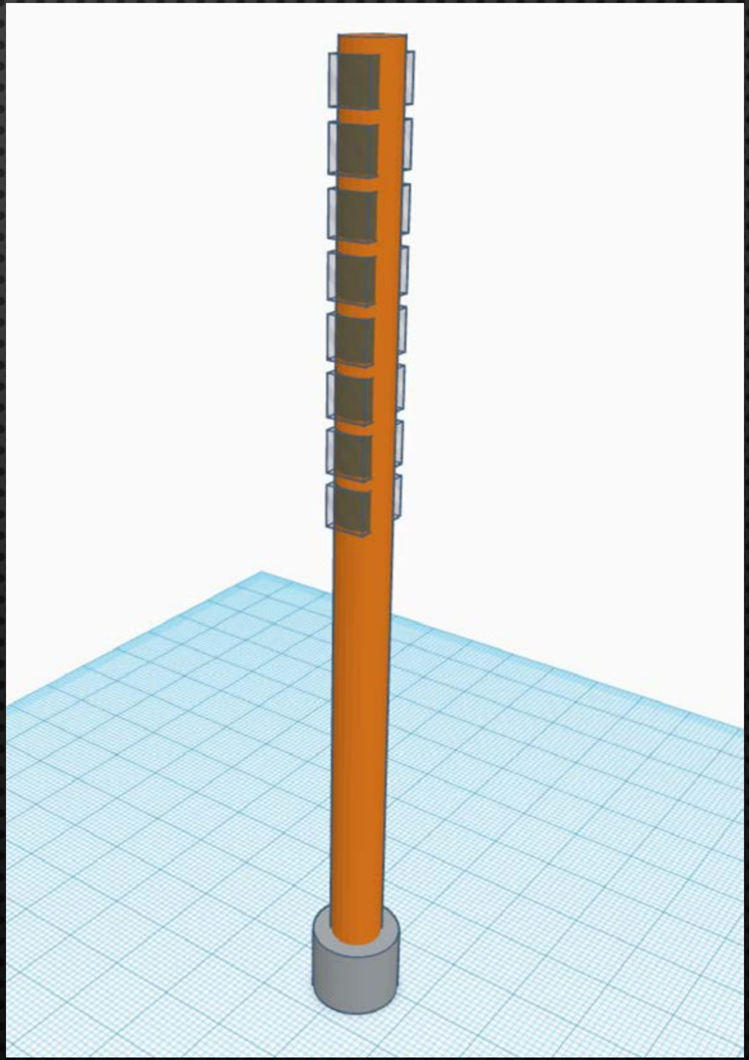
Cooperdock et al., 2019



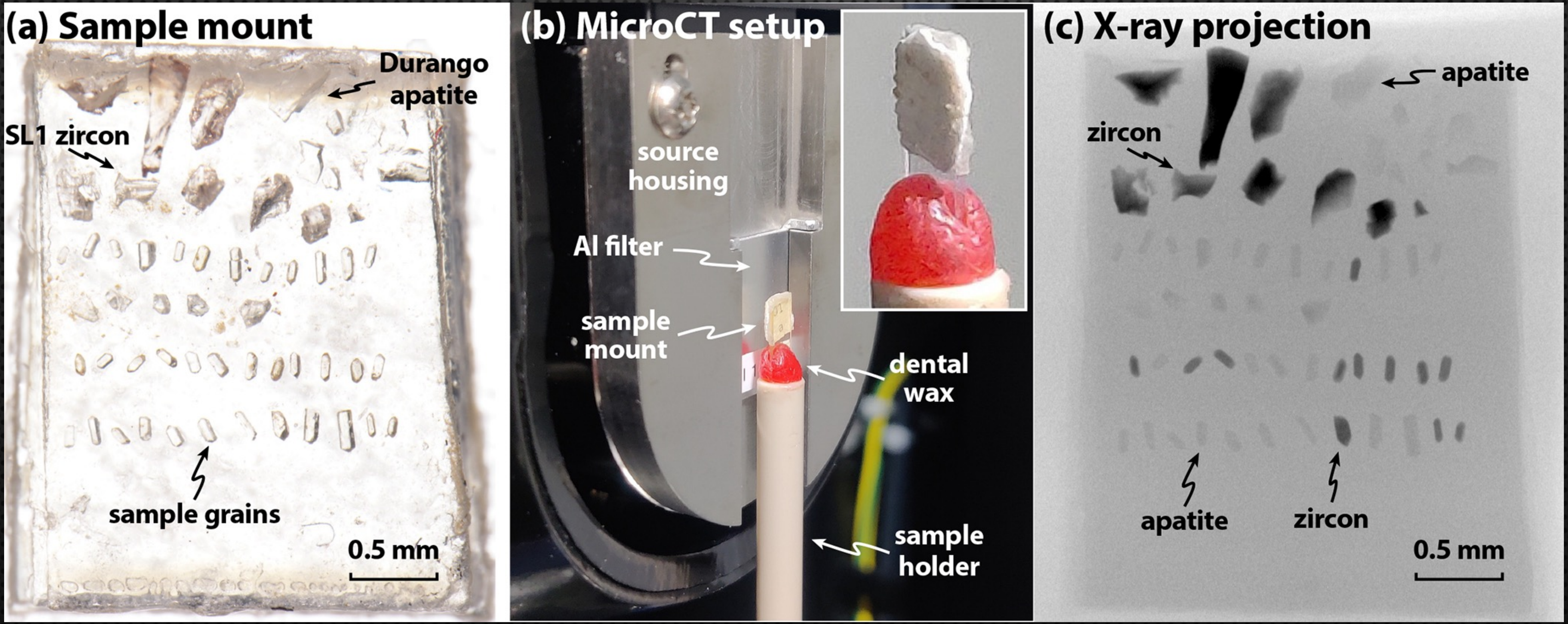


Courtesy: Florian Hofmann





Courtesy: Florian Hofmann



Cooperdock et al., 2022

VIGNETTE 1:
IMPROVED VOLUME AND SURFACE MEASUREMENTS

Geochronology, 1, 17–41, 2019
https://doi.org/10.5194/gchron-1-17-2019

GEOCHRONOLOGY
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Resolving the effects of 2-D versus 3-D grain measurements on apatite (U–Th) / He age data and reproducibility

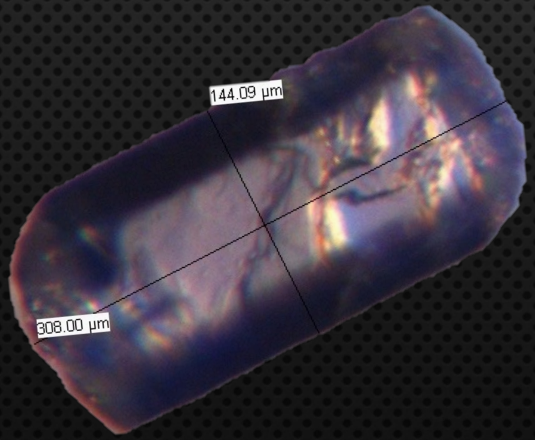
Emily H. G. Cooperdock[1,2,a], Richard A. Ketcham[1], and Daniel F. Stockli[1]

[1]Department of Geological Sciences, University of Texas at Austin, Austin, 78712, USA
[2]Woods Hole Oceanographic Institution, Woods Hole, 02543, USA
[a]now at: Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089, USA

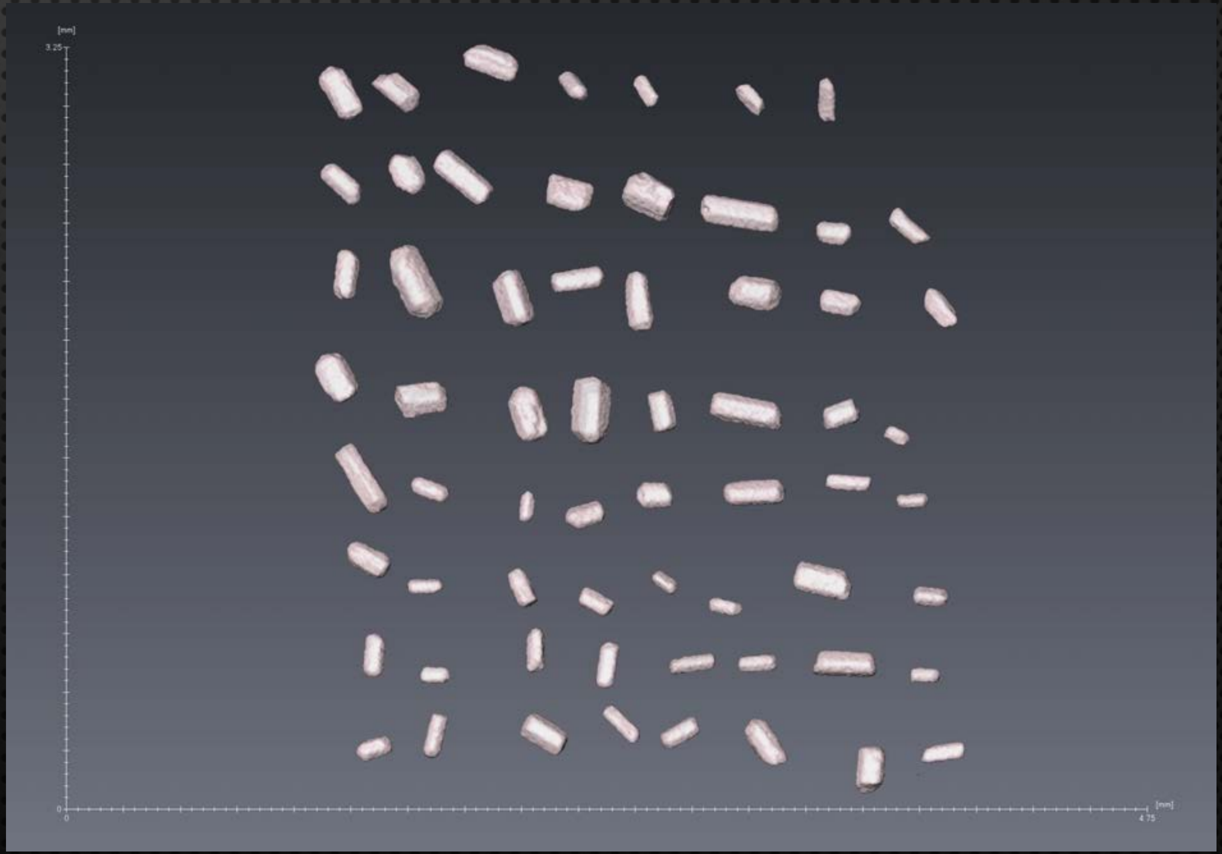
Used for mass, concentrations and age correction factor

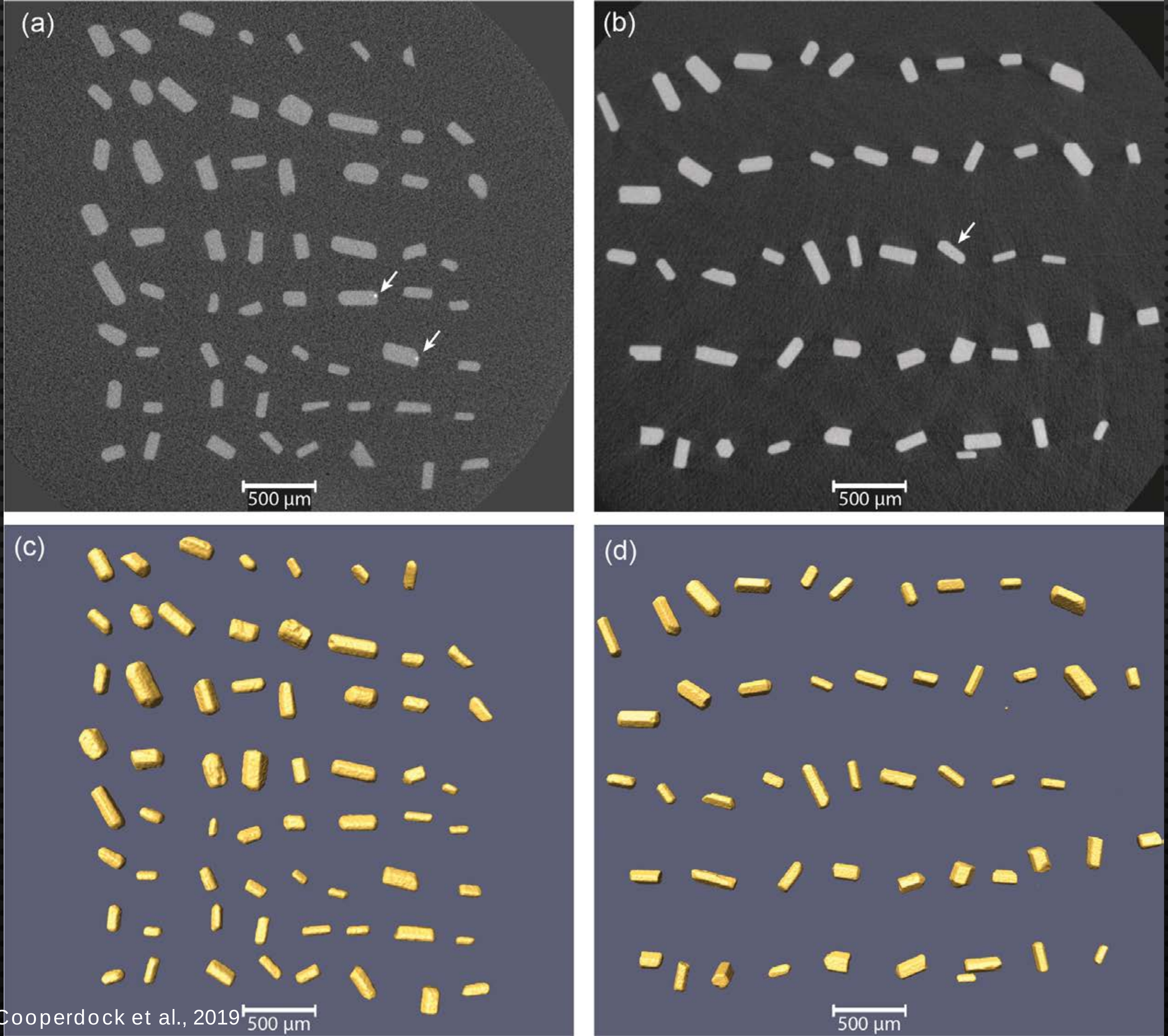
ACCURATE GRAIN MEASUREMENT

Common way: 2D measurement, assume geometry



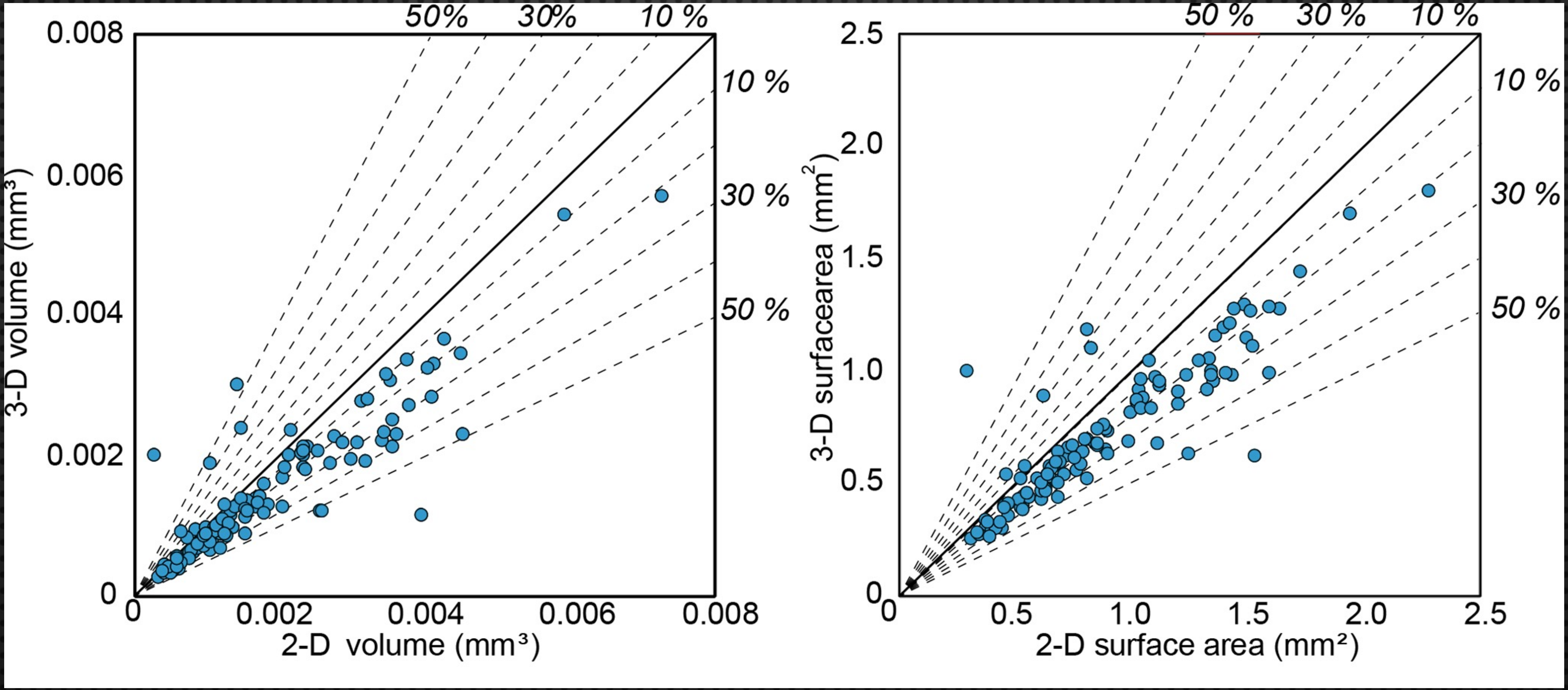
New way: CT scan, grain specific surface area and volume





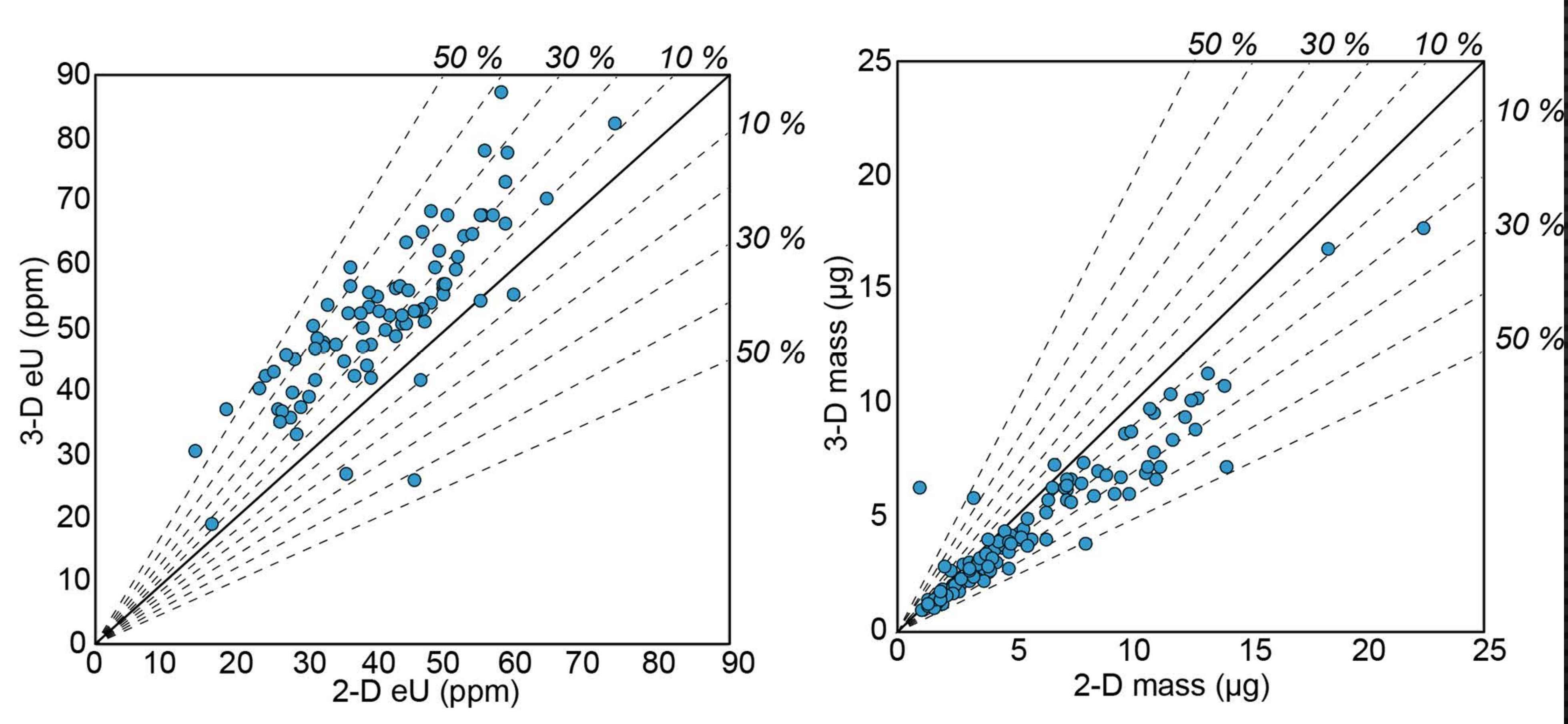
Cooperdock et al., 2019

- We used 100 apatite grains from 2 samples
- *Measured in 2D and 3D via microCT*
- *Compared accuracy and precision of the two methods*



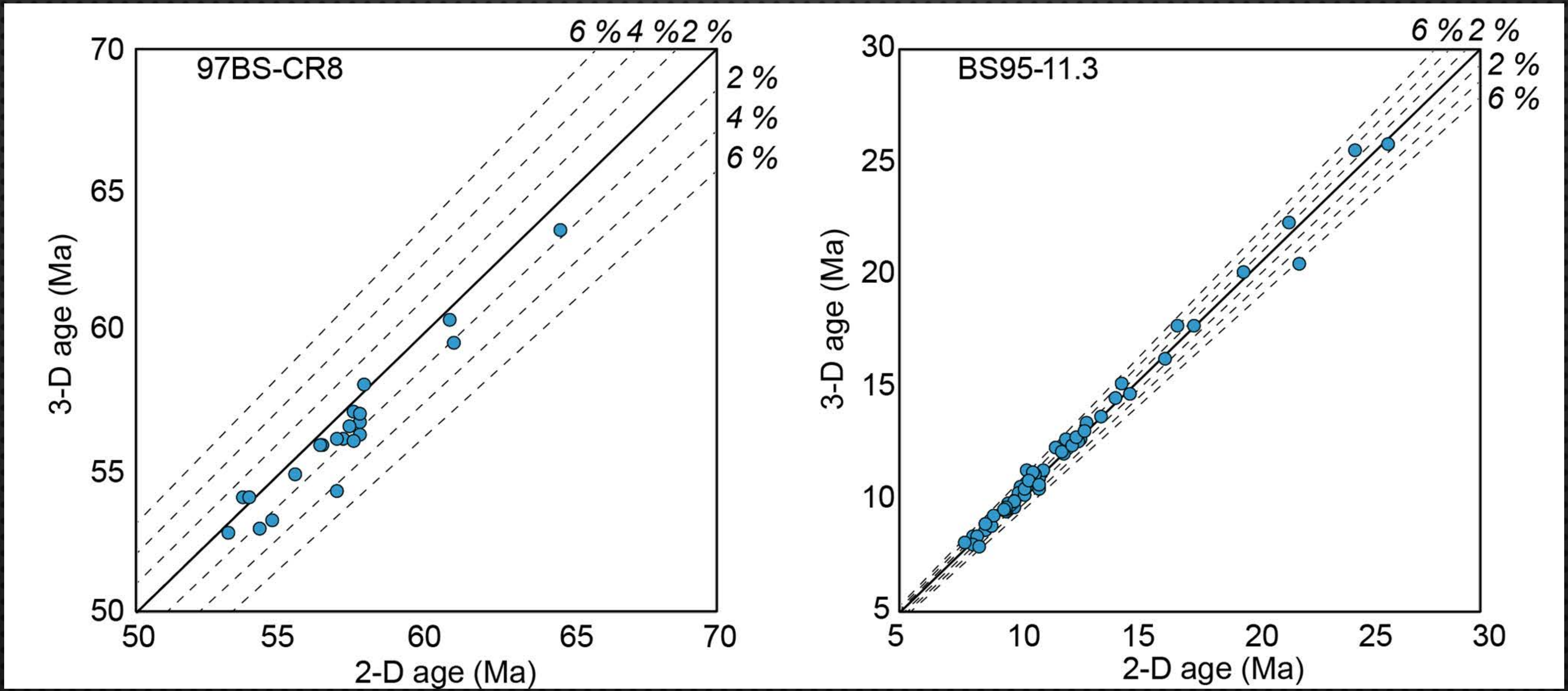
2D volumes and surface areas are consistently under-estimated

Cooperdock et al., 2019



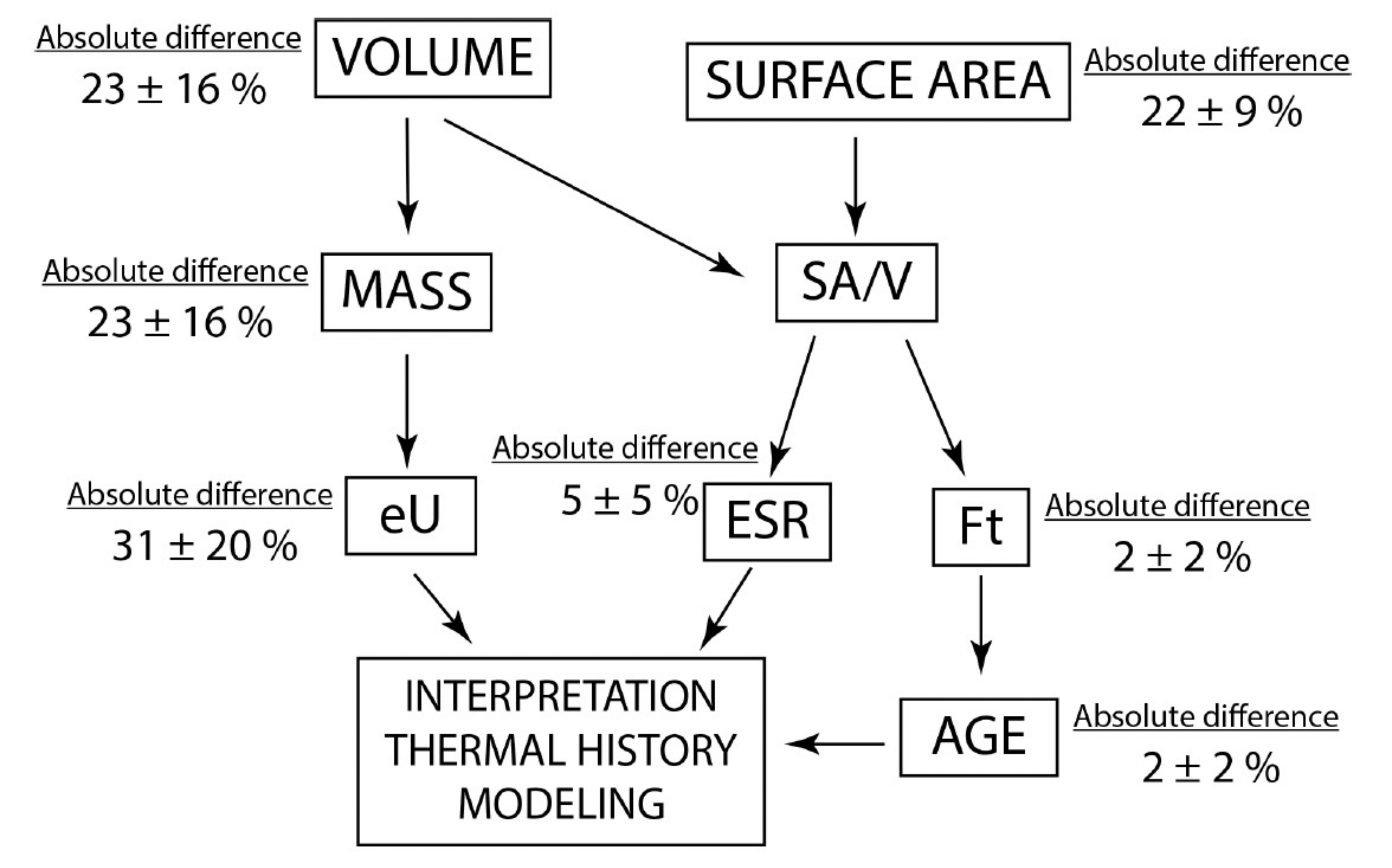
2D mass is consistently under-estimated.
Causes concentrations to be over-estimated.

Cooperdock et al., 2019



Leads to ~2-4% variation in age determinations

Cooperdock et al., 2019



We found the most significant impacts in the calculated grain mass and concentrations that use volume.

The impact on the final calculated age is muted because it uses SA/V.

Cooperdock et al., 2019

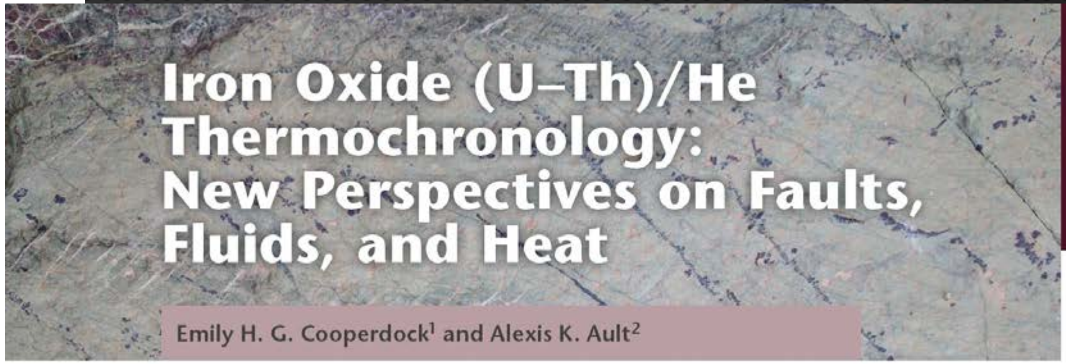
VIGNETTE 2:
IMPROVED MINERAL PHASE IDENTIFICATION

Geochronology, 4, 501–515, 2022
https://doi.org/10.5194/gchron-4-501-2022

GEOCHRONOLOGY Open Access EGU

Technical note: Rapid phase identification of apatite and zircon grains for geochronology using X-ray micro-computed tomography

Emily H. G. Cooperdock[1,★], Florian Hofmann[1,2,★], Ryley M. C. Tibbetts[1], Anahi Carrera[1], Aya Takase[3], and Aaron J. Celestian[4]

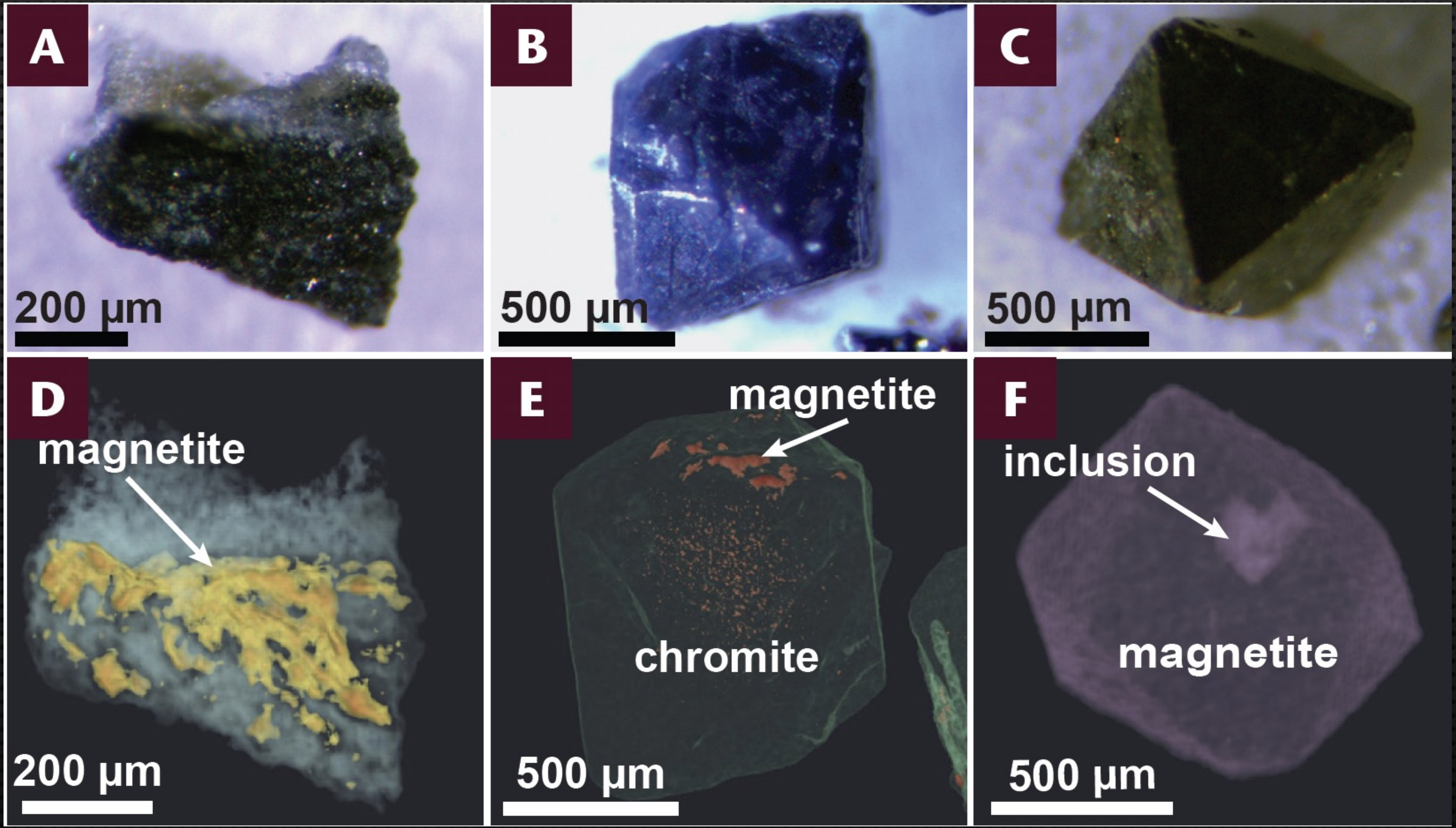


Iron Oxide (U–Th)/He Thermochronology: New Perspectives on Faults, Fluids, and Heat

Emily H. G. Cooperdock[1] and Alexis K. Ault[2]

Magnetite (black) in a deformed serpentinite from Oman. Credit: Emily H. G. Cooperdock

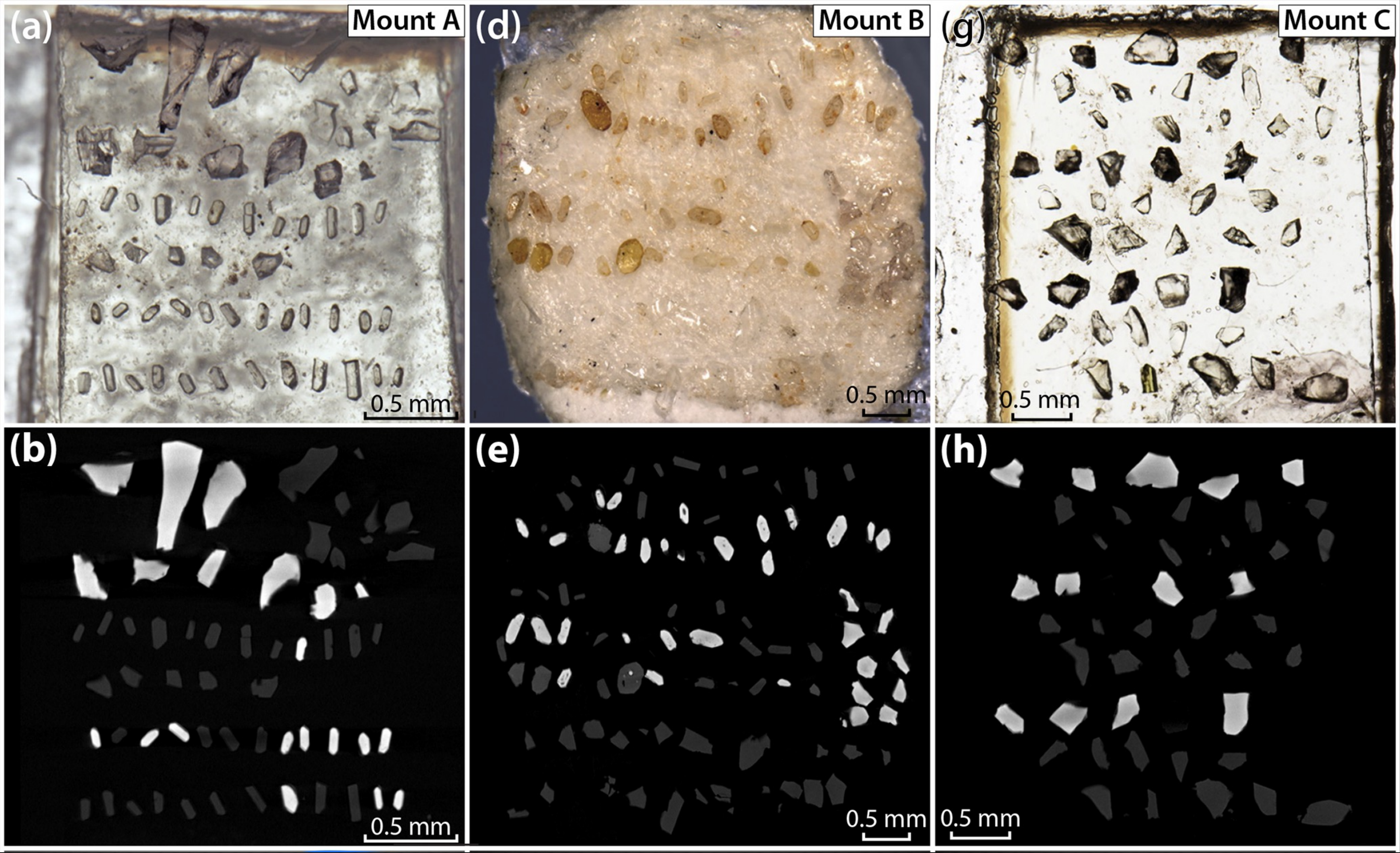
1811-5209/20/0016-0319$2.50 DOI: 10.2138/gselements.16.5.319



Cooperdock & Ault, 2020

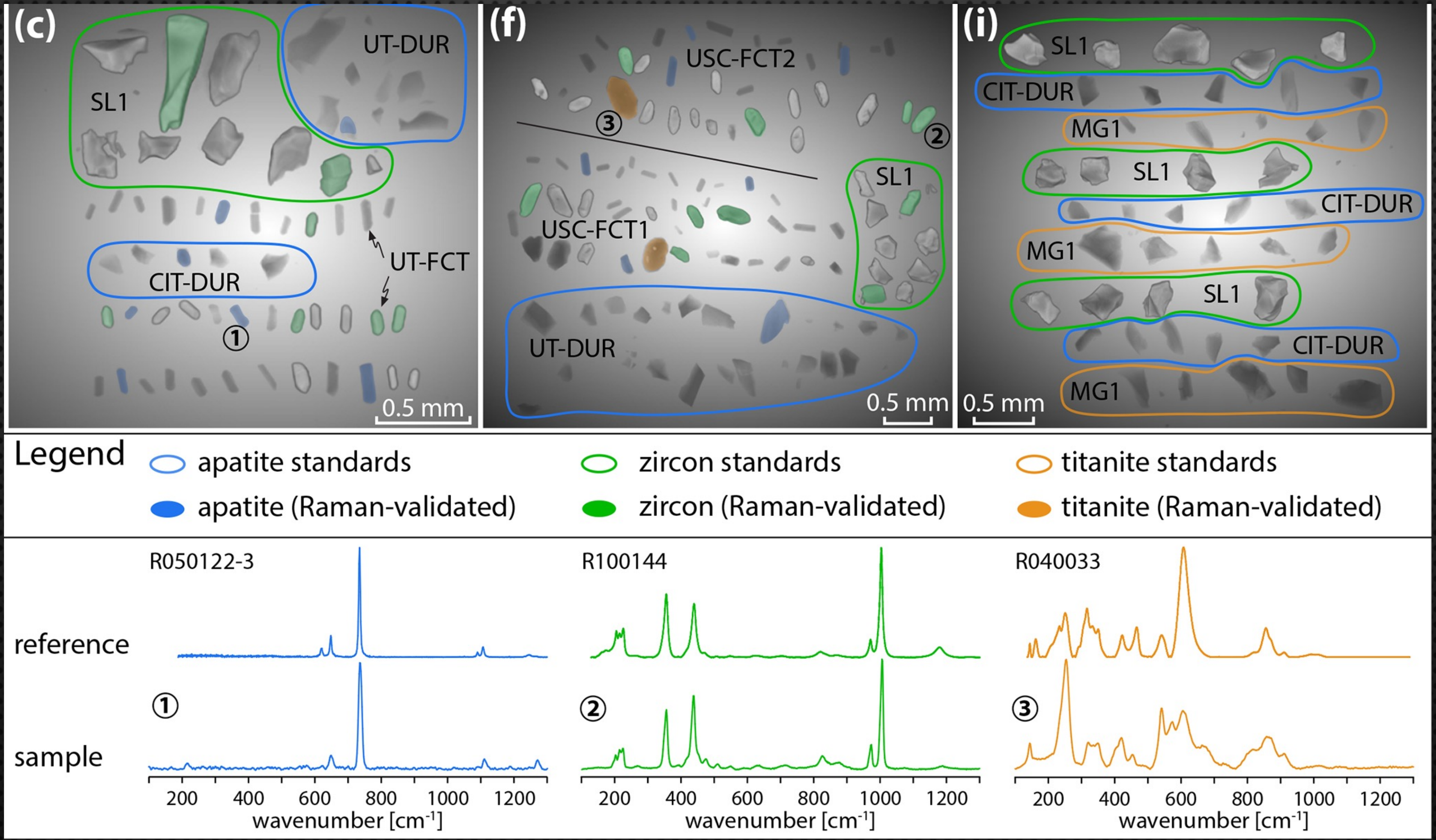
Microscope image

2D X-Ray slice



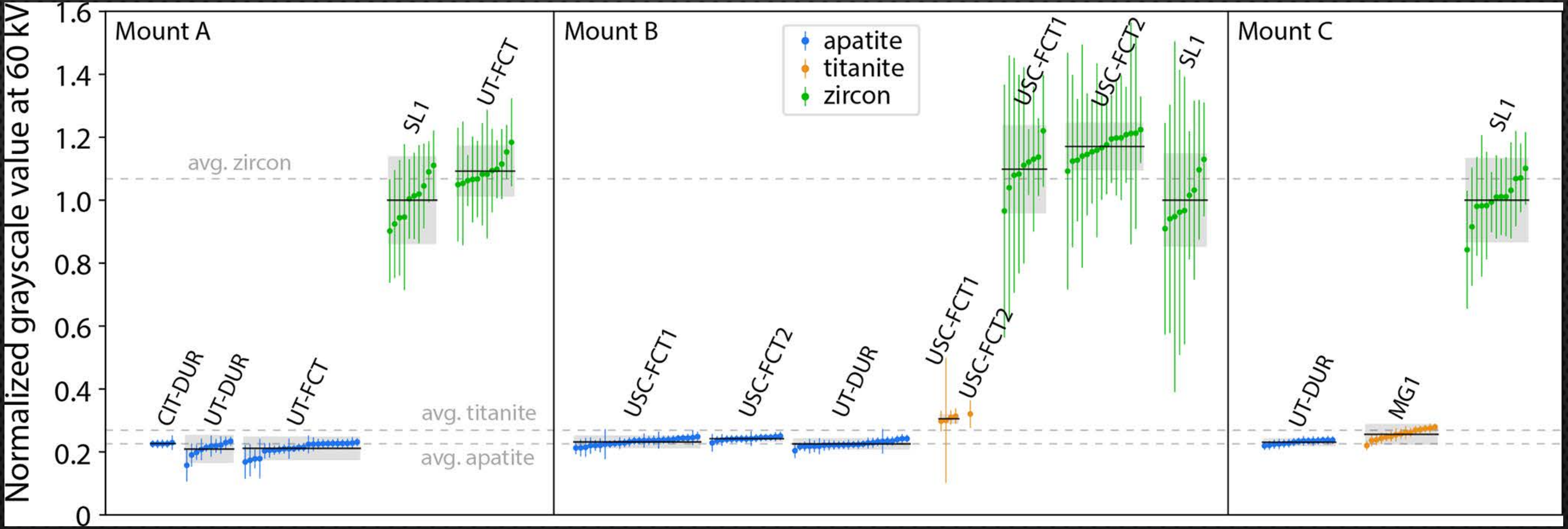
We asked researchers to pick apatite or zircon grains exclusively.
We ended up with mixed mounts with 3 phases.

Cooperdock et al., 2022



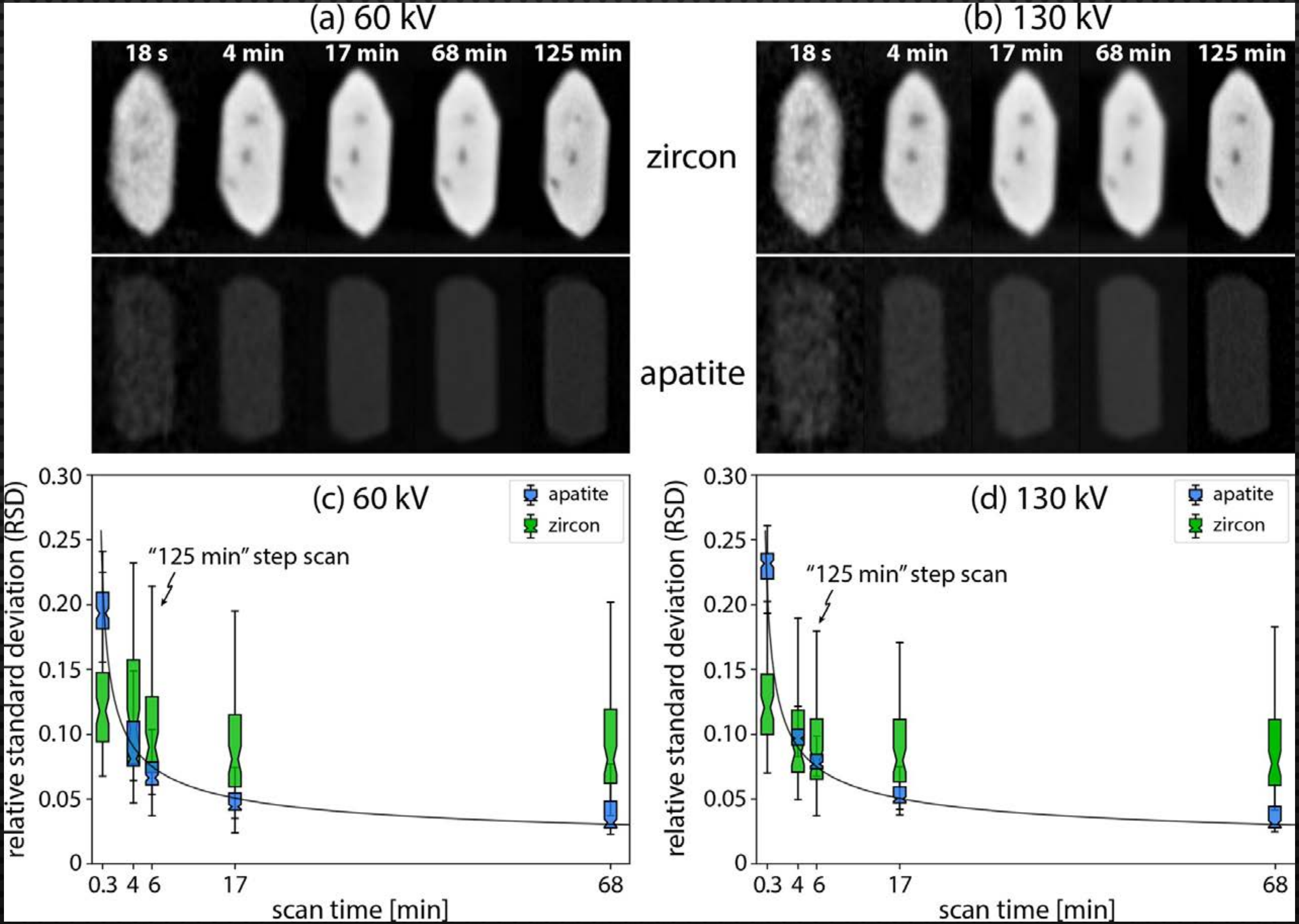
We used raman spectroscopy to validate grain ID.
It revealed that we have zircon, apatite, and titanite.

Cooperdock et al., 2022



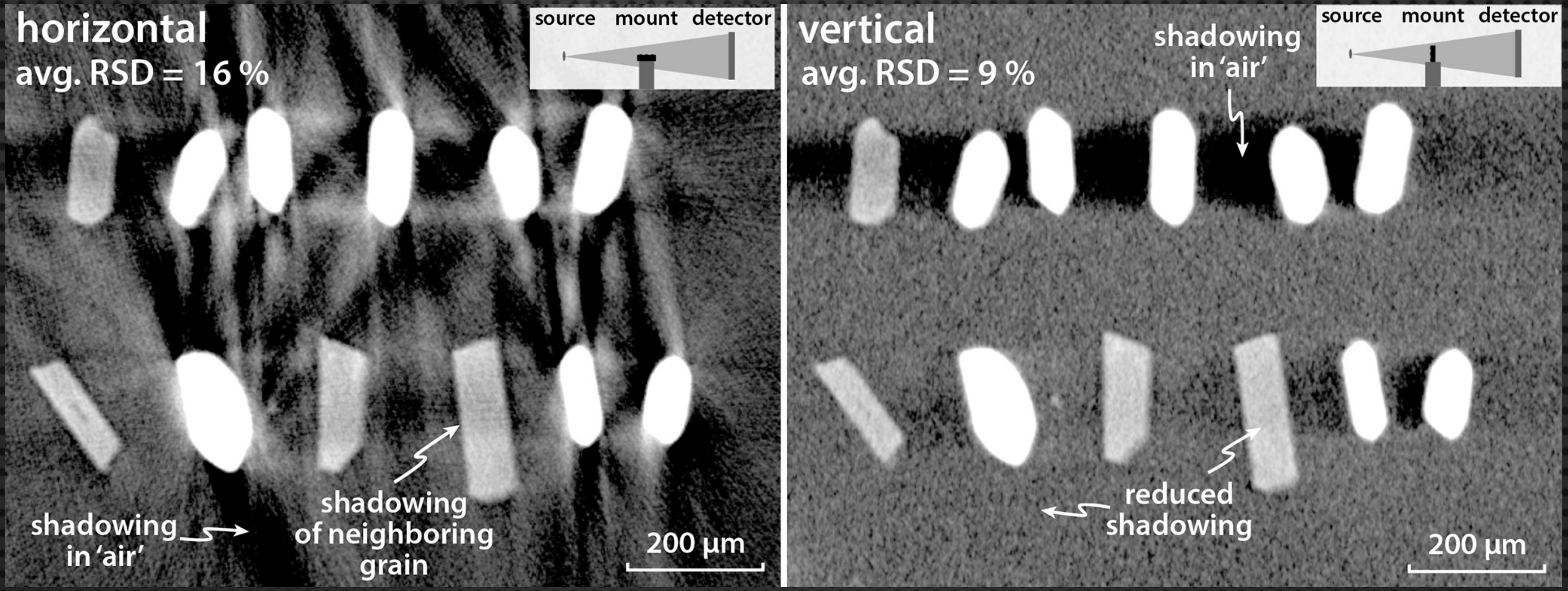
We found that zircon is very distinguishable based on high X-ray attenuation.
Apatite and titanite are both much less attenuating and are within error.

Cooperdock et al., 2022

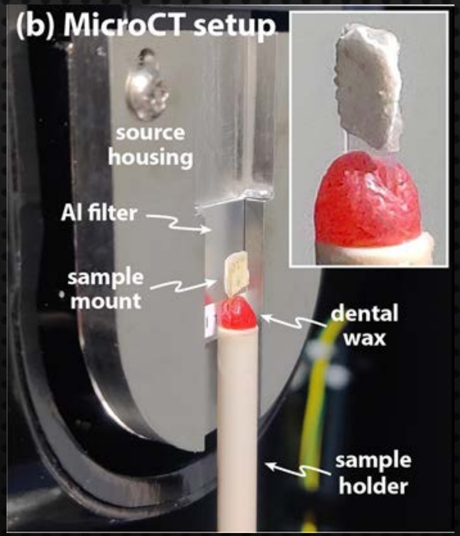


We tested different scan times and settings.

Cooperdock et al., 2022



We tested horizontal vs vertical scanning.



Cooperdock et al., 2022

VIGNETTE 3:
IMPROVED AGE DATA QUALITY FOR OPAQUE PHASES

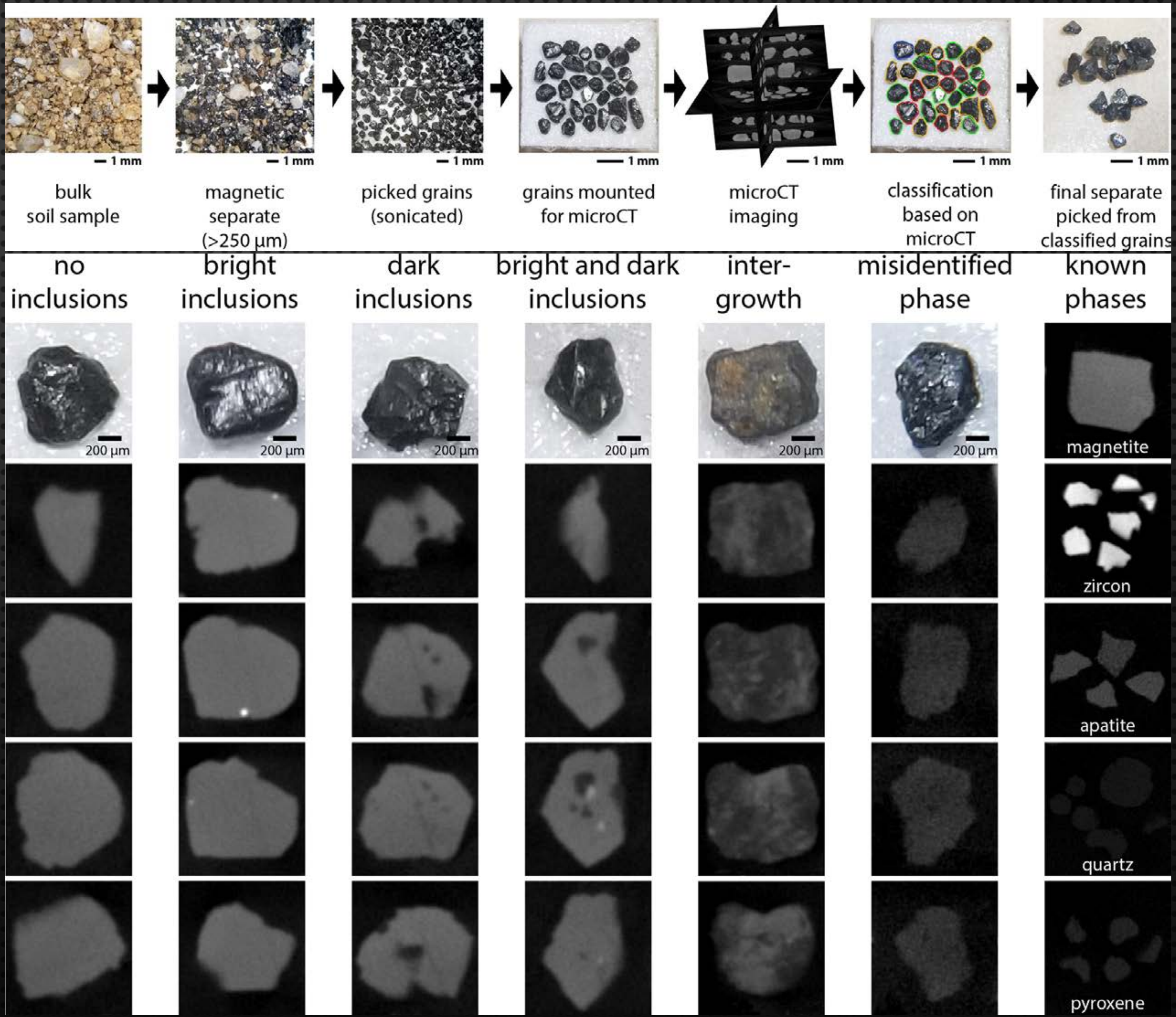
Geochronology, 3, 395–414, 2021
https://doi.org/10.5194/gchron-3-395-2021

Exposure dating of detrital magnetite using ^{3}He enabled by microCT and calibration of the cosmogenic ^{3}He production rate in magnetite

Florian Hofmann[1,2], Emily H. G. Cooperdock[3], A. Joshua West[3], Dominic Hildebrandt[2], Kathrin Strößner[2], and Kenneth A. Farley[1]

STEP 1:

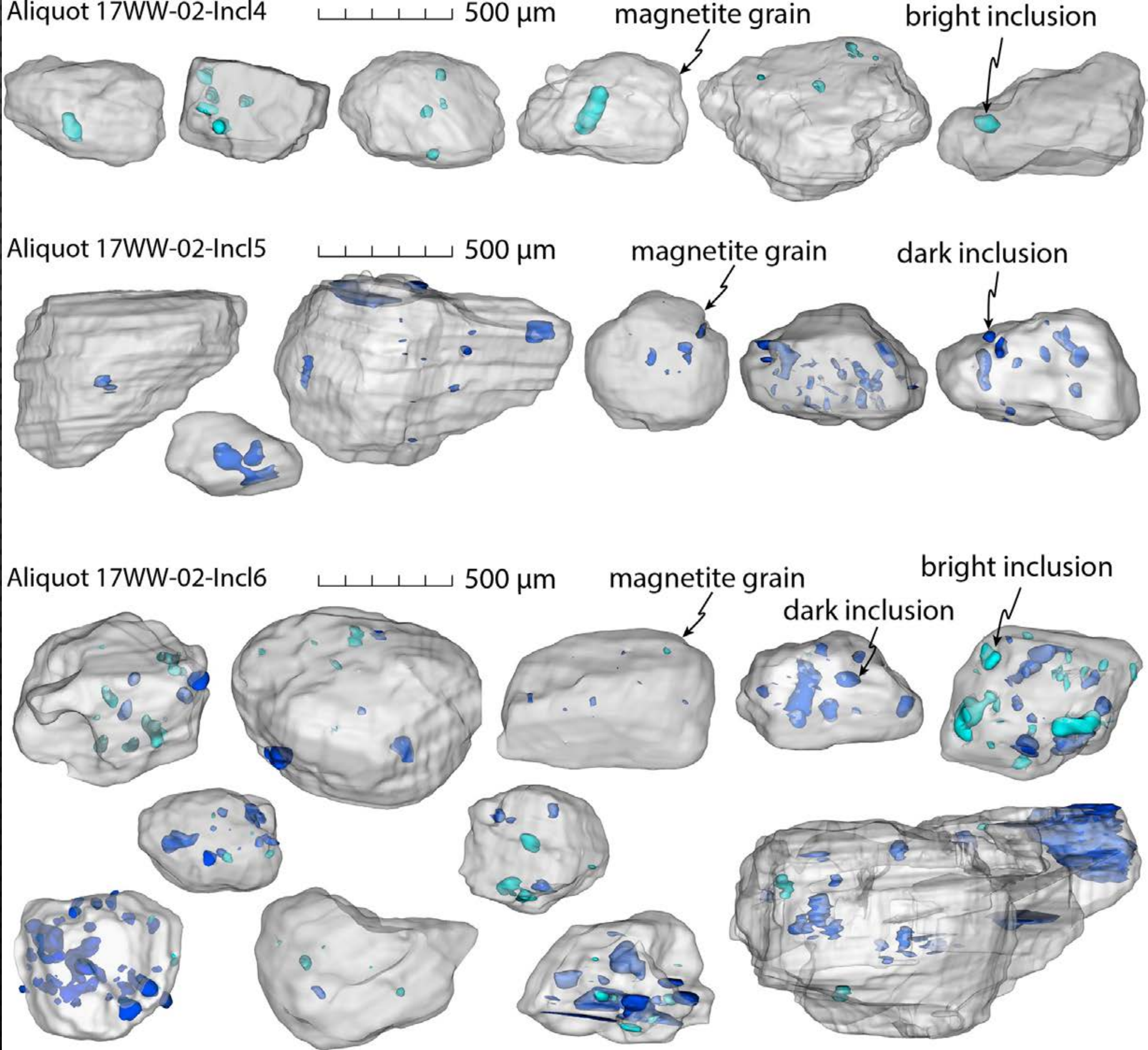
Use microCT to screen opaque mineral grains for presence and type of inclusions.



Hofmann et al., 2021

STEP 2:

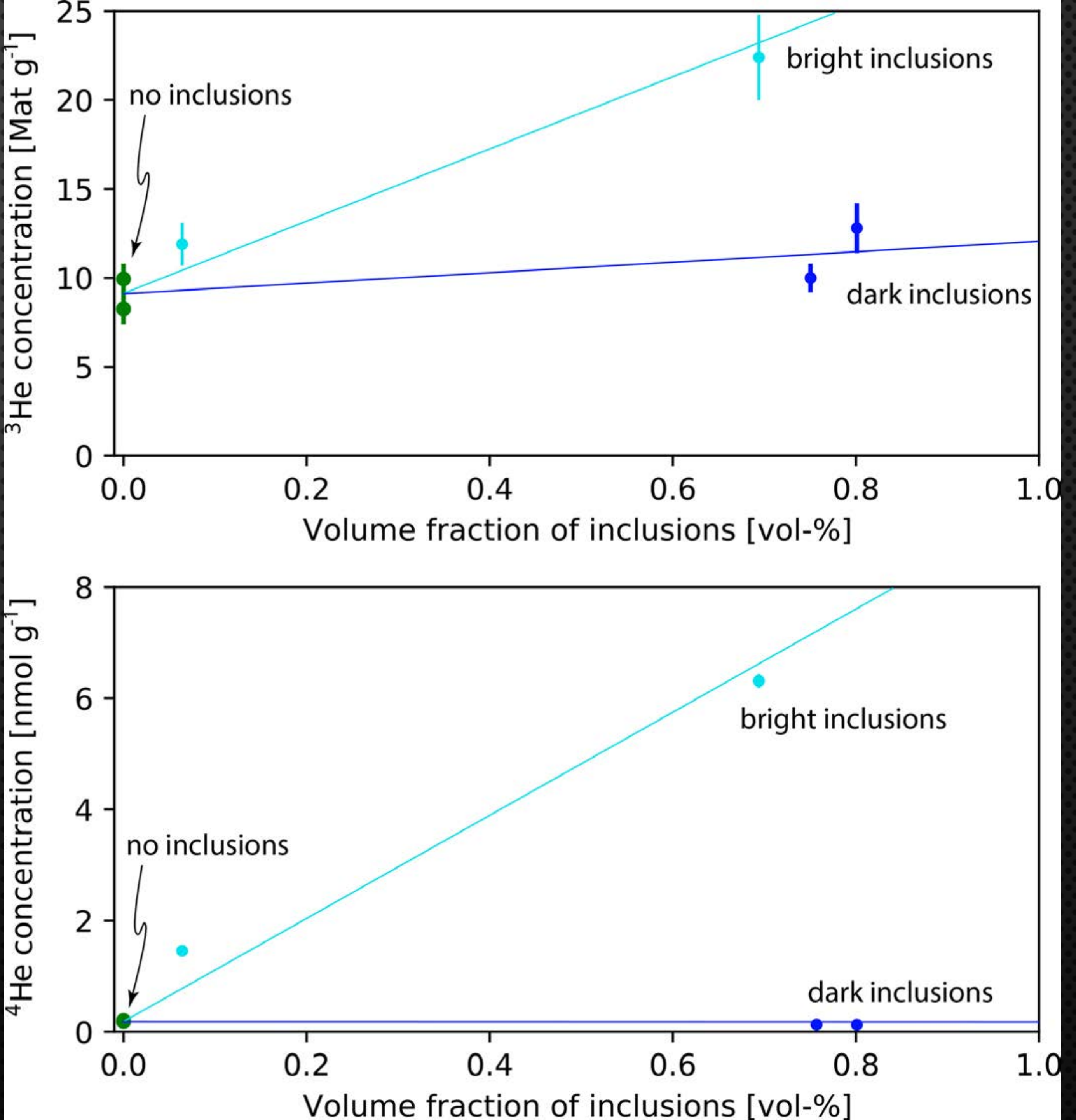
Combine grains with similar inclusion suites (bright, dark, both)



Hofmann et al., 2021

We found that bright inclusions contribute “excess” helium.

Filtering out inclusions resulted in more accurate and precise data.



Hofmann et al., 2021

Weaving research into core classes

GEOL 315L: Minerals and Earth Systems (4.0 units)

Minerals and their formation in Earth geosystems; includes discussions of mineral properties, crystal structures, uses and biogeochemical importance. Lecture, 3 hours; laboratory, 6 hours; required field trips. **Recommended preparation:** any introductory GEOL course.

- Required course for all Earth Science minors and majors.
- Typically 6-15 students per session (typically offered every year).
- Fall 2022: 10 undergraduates (sophomores to seniors)

Weaving research into core classes

10 unique final research projects.

Collected novel datasets.

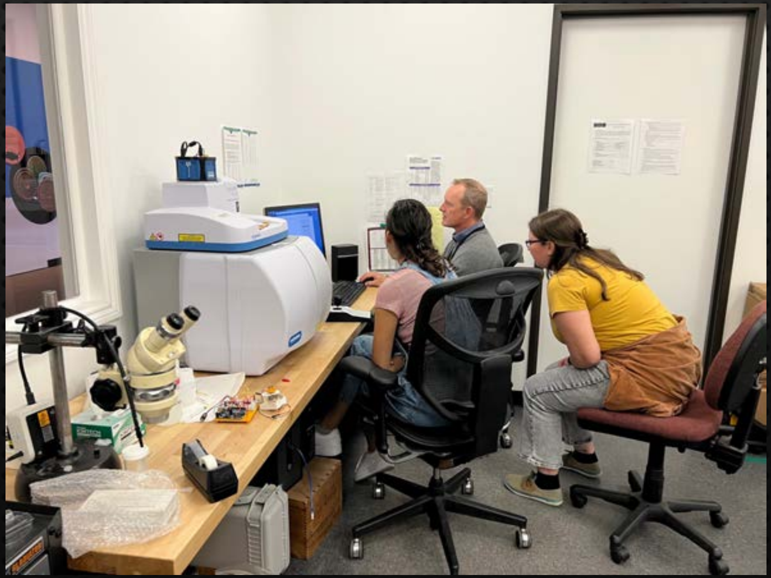
All part of active research.

Guided, hands-on data collection.

Group 1: Natural History Museum

6 projects using XRF, XRD, Raman, SEM

Guided by me, Dr. Aaron Celestian (NHM) and PhD students Alexia Rojas and Justine Grabiec



Weaving DEI into core classes

10 unique final research projects.

Collected novel datasets.

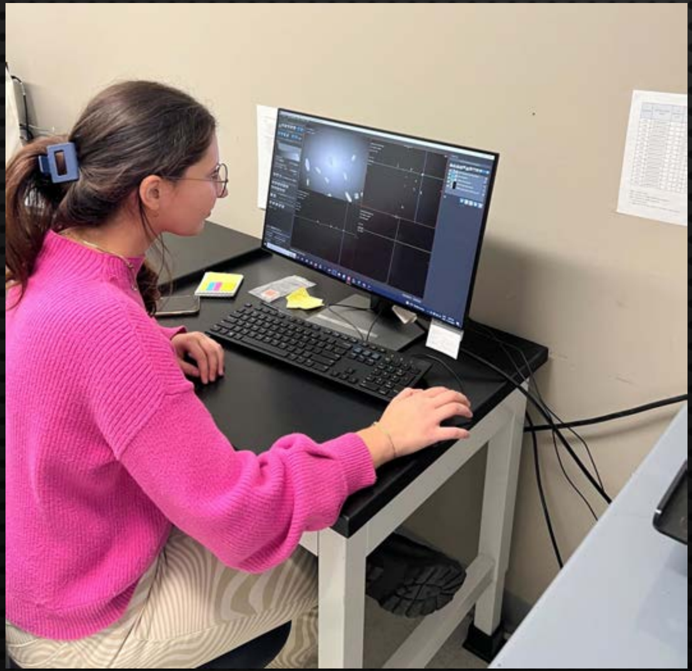
All part of active research.

Guided, hands-on data collection.

Group 3: USCHelium Lab

2 projects, microCT data

Guided by PhD students Alexia Rojas



Weaving DEI into core classes

GEOL 315L: Minerals and Earth Systems (4.0 units)

Minerals and their formation in Earth geosystems; includes discussions of mineral properties, crystal structures, uses and biogeochemical importance. Lecture, 3 hours; laboratory, 6 hours; required field trips. **Recommended preparation:** any introductory GEOL course.

Key lessons and outcomes:

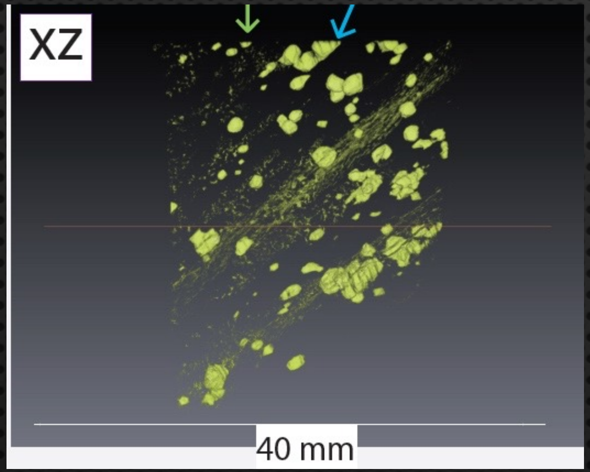
1. Students loved the research experience (source: student evaluations)
2. 6/10 requested to continue working in my lab (We've accommodated 4)
3. 6/10 continued on to Petrology in the spring (not required)

Summary:

Improves current measurements and uncertainties.

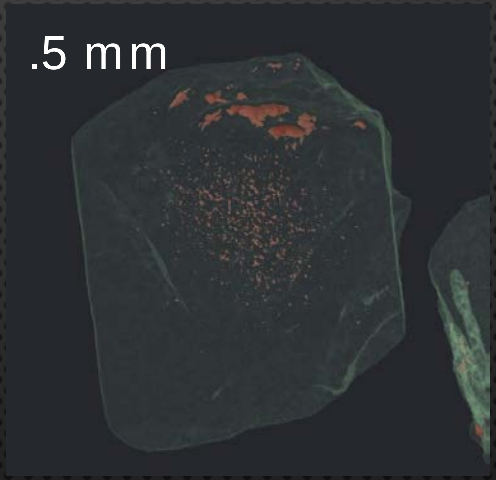
Opens up new minerals for dating – applications to different rock types – novel geologic questions.

Screen precious rock samples

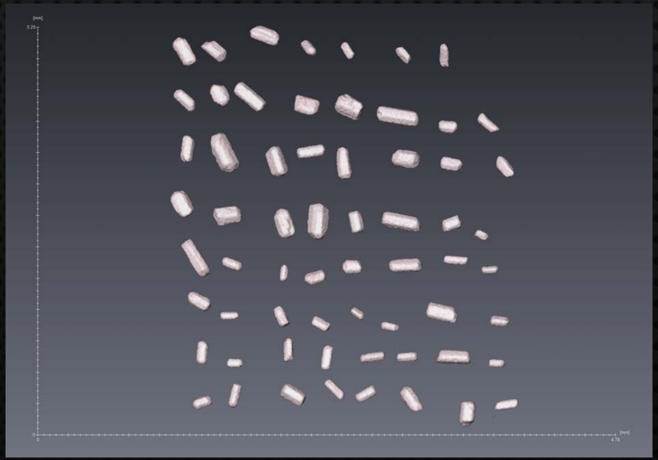


Efficient mass grain screening

See inside opaque mineral phases



More accurate grain measurements



Great for in-class research projects