Using Micro-CT and petrographic analysis to select optimal U-Th samples from challenging stalagmites.

Jessica Oster[1*], Cameron de Wet[1], Kate Neal[1], Warren Sharp[2]

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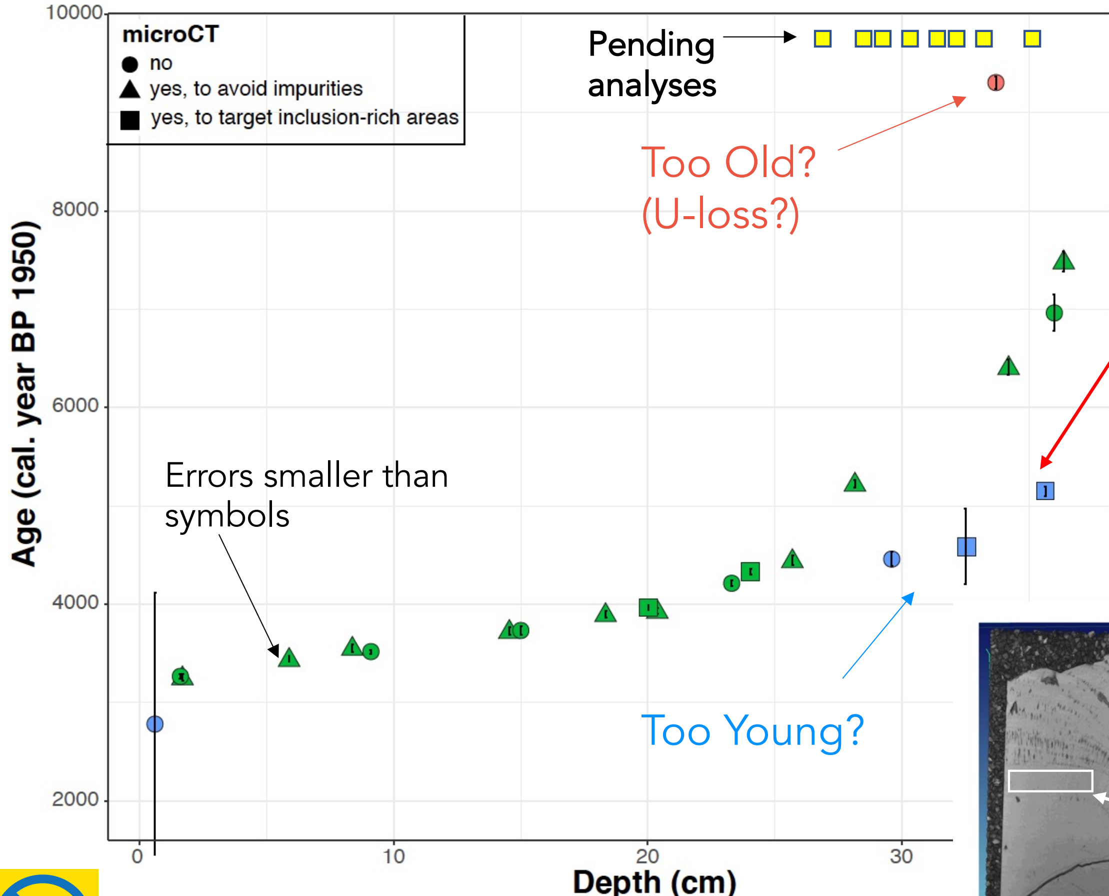
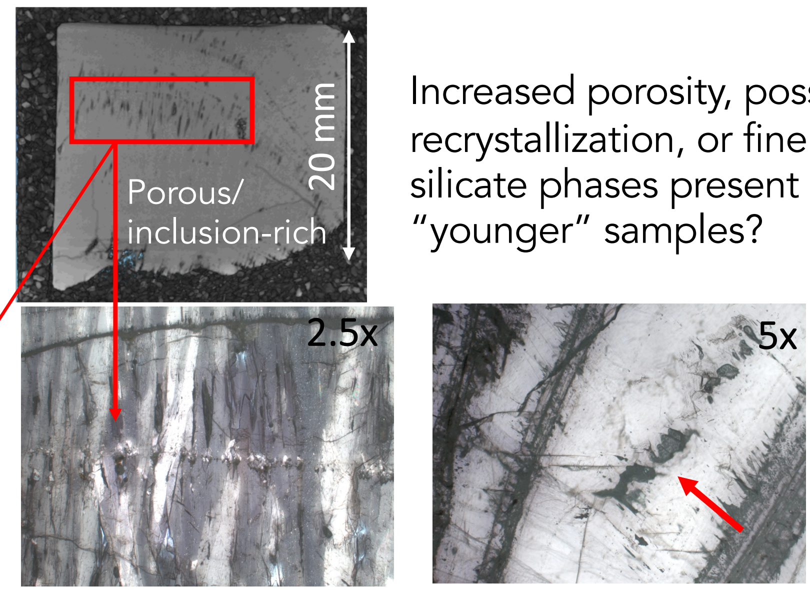
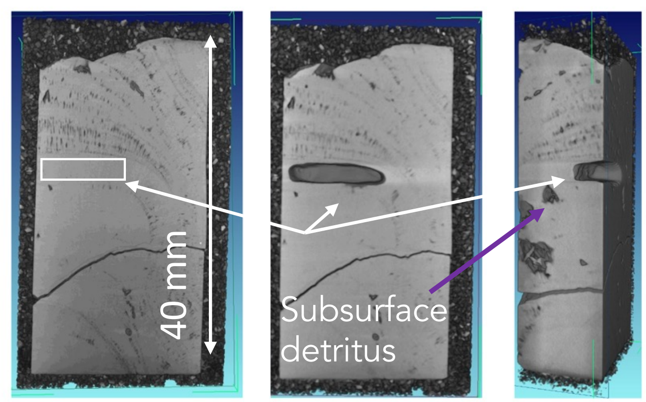




Increased porosity, possible recrystallization, or fine silicate phases present in “younger” samples?



Scanning samples by microCT before U-Th sampling helps avoid pockets of detritus below the cut surface. Planning 3D sample paths through clear, dense material.

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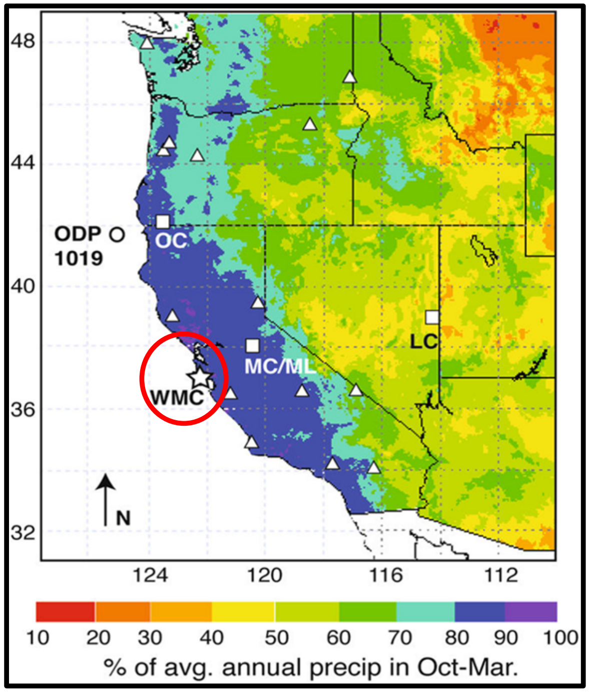
Additional Display Materials

Speleothem deposits can provide a wealth of critical, detailed paleoclimate information from low and mid-latitude terrestrial environments. A key strength of these archives is that they may be dated precisely using U-Th techniques. Yet, depending on the cave environment, overlying geology, seepage water flow characteristics, and speleothem growth habit, accurate, precise dating of speleothems can be challenging. For example, contamination by Th-bearing detritus degrades precision and accuracy when model-based corrections for initial ^{230}Th are applied, and partial dissolution or secondary infilling of porosity can also lead to inaccurate ages, thereby confounding interpretations of paleoclimatic change. Here we present a new chronology from a Holocene stalagmite, WMC2, from White Moon Cave in the Santa Cruz Mountains of California, USA, that exhibits multiple challenges. Stalagmite WMC2 was not active at the time of collection, but it was in situ, with a top age of 3267 ± 28 yrs BP 1950. WMC2 calcite has relatively high U (3-7 ppm), however, the stalagmite contains sporadically distributed sub-millimeter pockets of silicate detritus, leading to 100-fold differences in common Th (^{232}Th) concentrations in dating samples (i.e., >80 to <1ppb). Additionally, ages that appear to be anomalously young are associated with zones containing high densities of fluid inclusions, suggesting possible secondary calcite growth. We overcome these challenges using a combination of micro-CT imaging, transmitted-light microscopy and assessing replicate samples. Micro-CT provides a non-destructive method for imaging the internal structure of the stalagmite, allowing for the sampling of dense, pure calcite. Using this approach, we are able to avoid sub-millimeter pockets of silicate detritus that are not visible from the cut surface of the sample, thereby reducing ^{232}Th concentrations and associated initial ^{230}Th corrections, and obtaining more precise and accurate ages. Dating replicate samples from individual growth bands can confirm or refute whether diagenesis suspected from petrographic study has measurably affected U-Th ages since corrupt ages should scatter more than expected from analytical errors alone. We use our carefully screened ages for WMC2 to evaluate various age modeling approaches typically used for stalagmite proxy records, including those that apply Monte Carlo methods and Bayesian approaches. By employing multiple techniques to optimize stalagmite dating samples, reliable, precise U-Th ages (median 2s ~30 yr) may be obtained from stalagmites previously deemed too flawed for accurate dating, thereby broadening our ability to develop accurately dated speleothem paleoclimate records.

White Moon Cave, Santa Cruz Mountains, California, USA



The majority of rain falls in the cool season at this site.

The cave entrance is located in a marble quarry, with adjacent metamorphic and igneous rocks.

Small, tortuous passages, evidence of mica minerals and sand and intervals of high water flow.

Stalagmite WMC1 from White Moon Cave has produced a multi-proxy record of California climate change during the 8.2 kyr event.

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Climate response to the 8.2 ka event in coastal California

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Geophysical Research Letters

RESEARCH LETTER

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Key Points:

- The first semiquantitative estimates of paleorainfall rates from Ca isotope ratios measured in a California stalagmite
- The magnitude of rainfall variability in coastal California during the 8.2 kyr and precursor event approaches/exceeds that of recent decades

Semiquantitative Estimates of Rainfall Variability During the 8.2 kyr Event in California Using Speleothem Calcium Isotope Ratios

Cameron B. de Wet[1], Andrea M. Erhardt[2], Warren D. Sharp[3], Naomi E. Marks[4], Harold J. Bradbury[5], Alexandra V. Turchyn[5], Yiruo Xu[1], and Jessica L. Oster[1]

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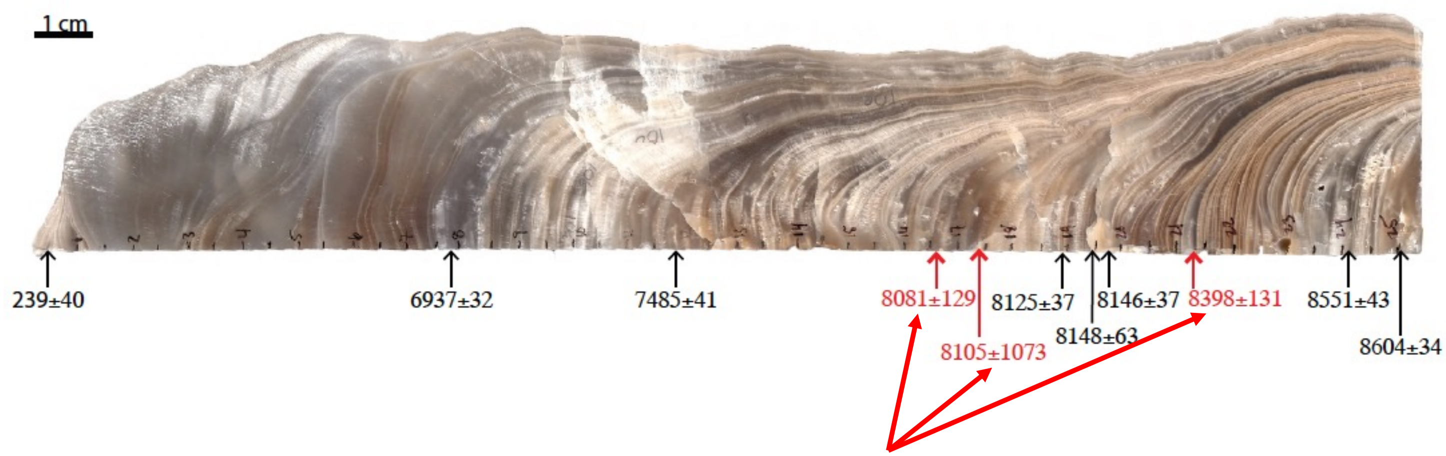
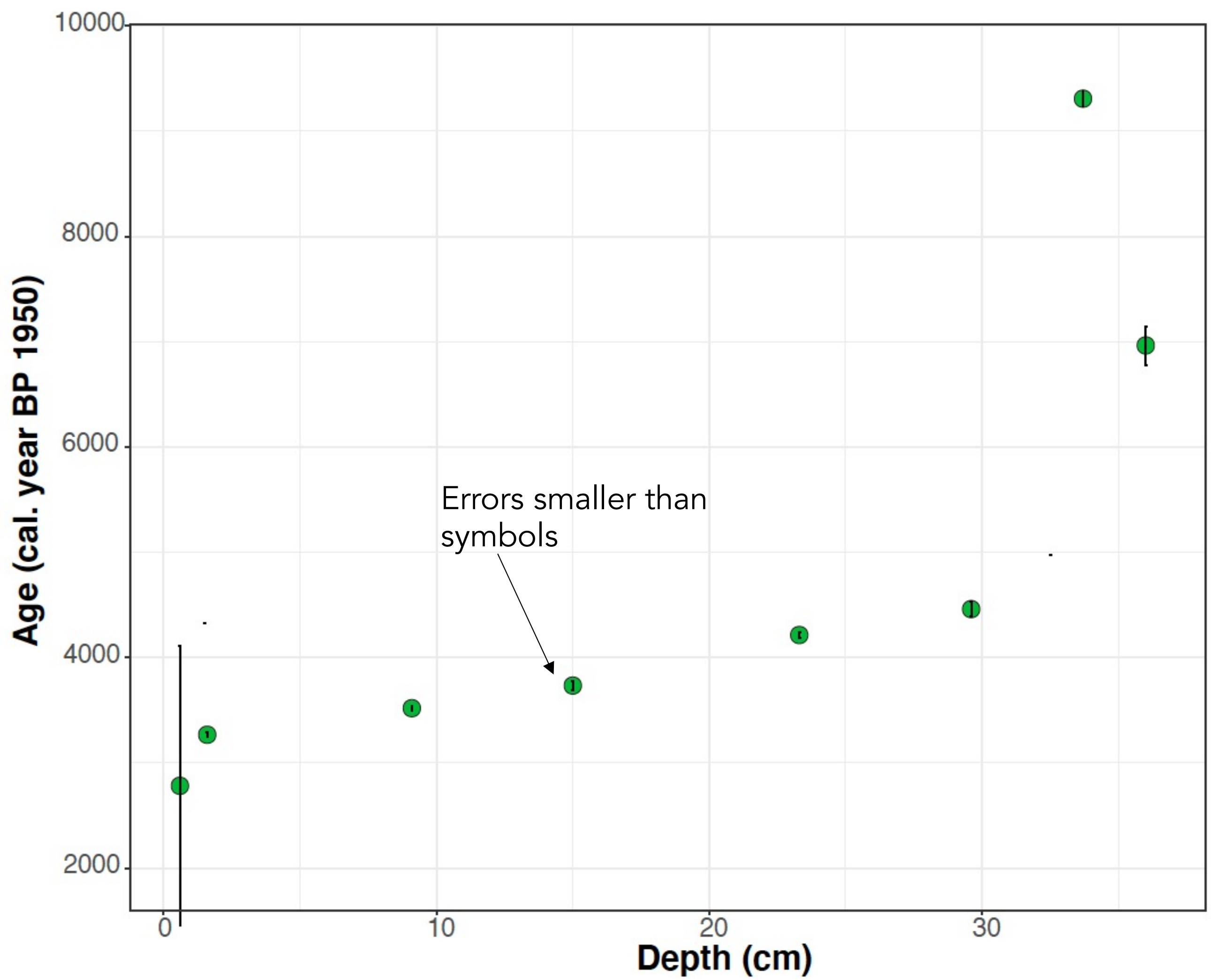


Some ages have large detrital Th corrections. We found that these were associated with small pockets of silicate detritus situated below the cut stalagmite surface that were inadvertently sampled.

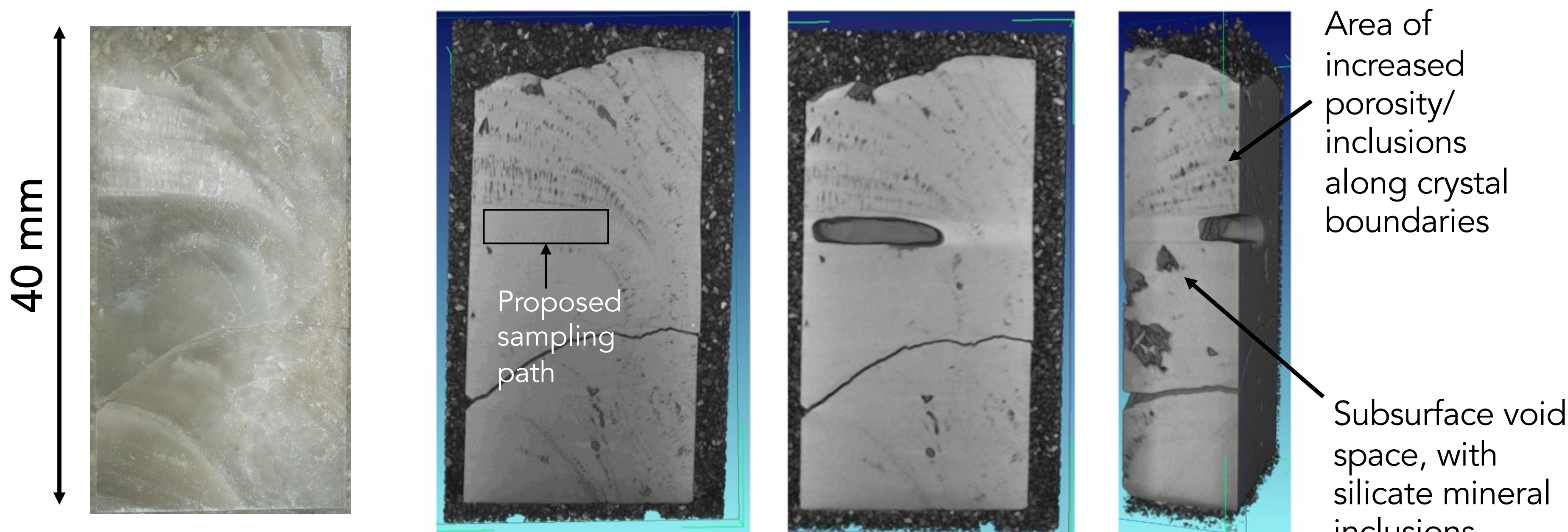
235 mm

Bottom part of Stalagmite WMC2

Some of our first U-Th ages for stalagmite WMC2 were also associated with large detrital Th corrections leading to large uncertainties.



To address this, we used microCT on sample billets to visualize sub-surface pockets of silicate detritus and map out 3D sampling paths for U-Th dates.



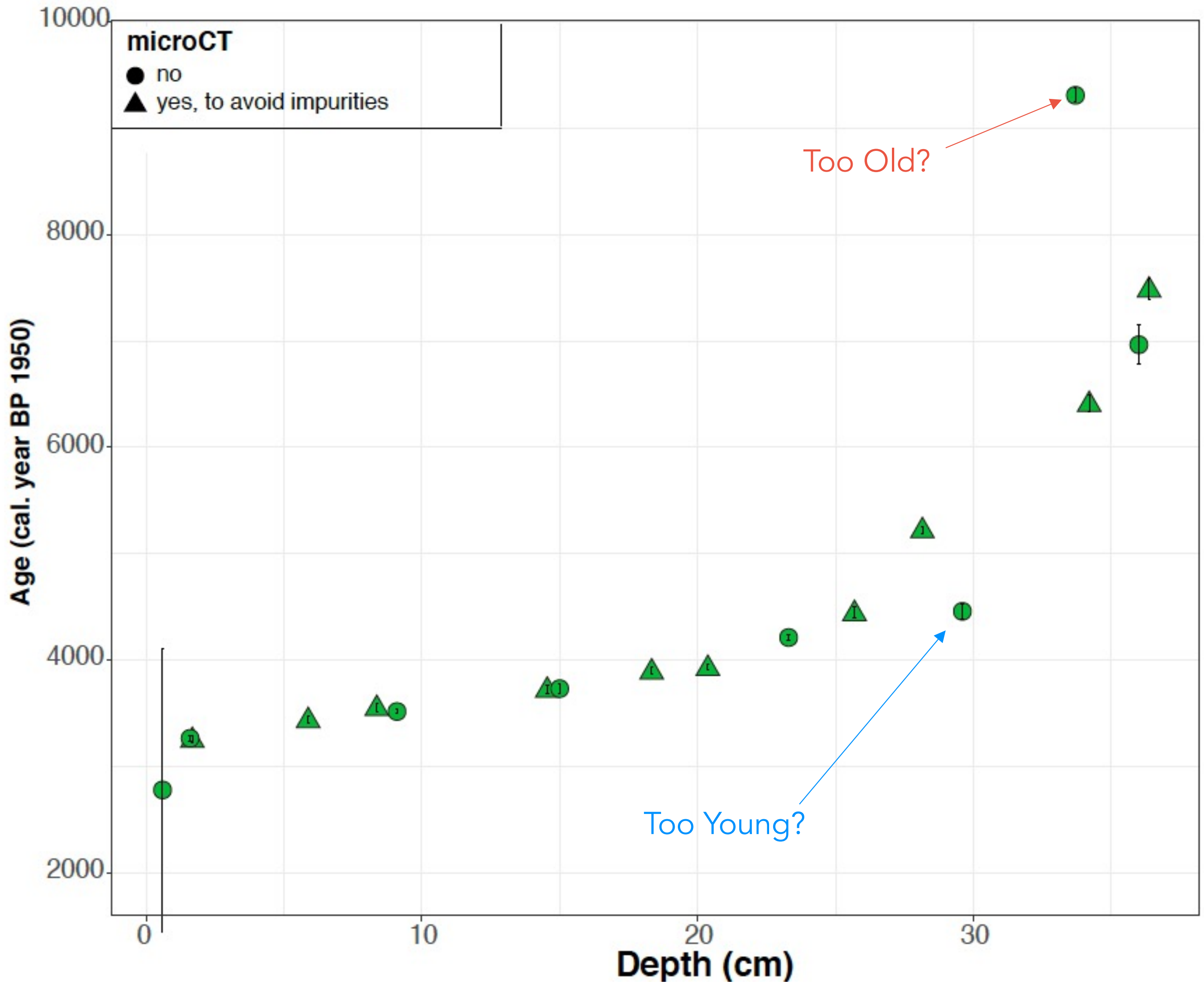
Cut surface of stalagmite billet

MicroCT images.

Using microCT, we are able to avoid pockets of silicate detritus, resulting in lower age uncertainties.

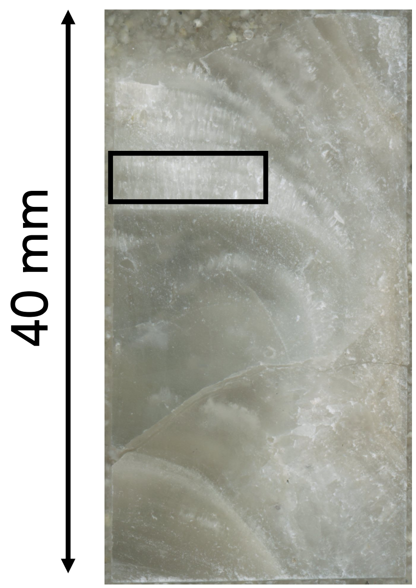
New analyses of samples selected with microCT begin to define a constant trend at depths >25cm, suggesting samples selected without microCT may be either too young or too old.

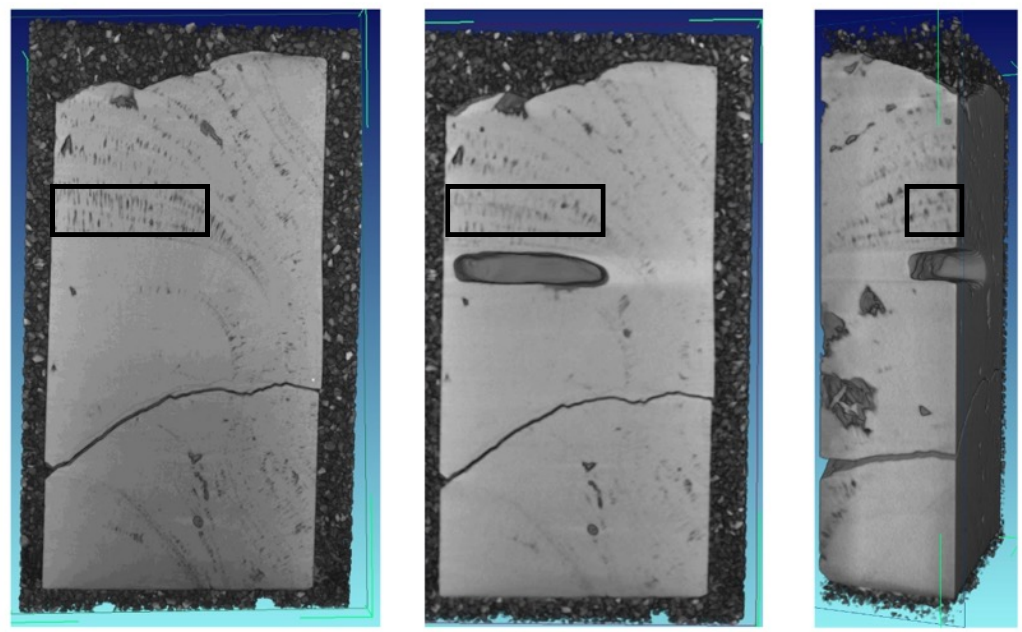
We conducted further analyses with screening by microCT to evaluate other stalagmite textures and their potential influence on U-Th dates.



We used microCT to investigate the potential of U loss and/or cryptic diagenesis near porous inclusion-rich areas.

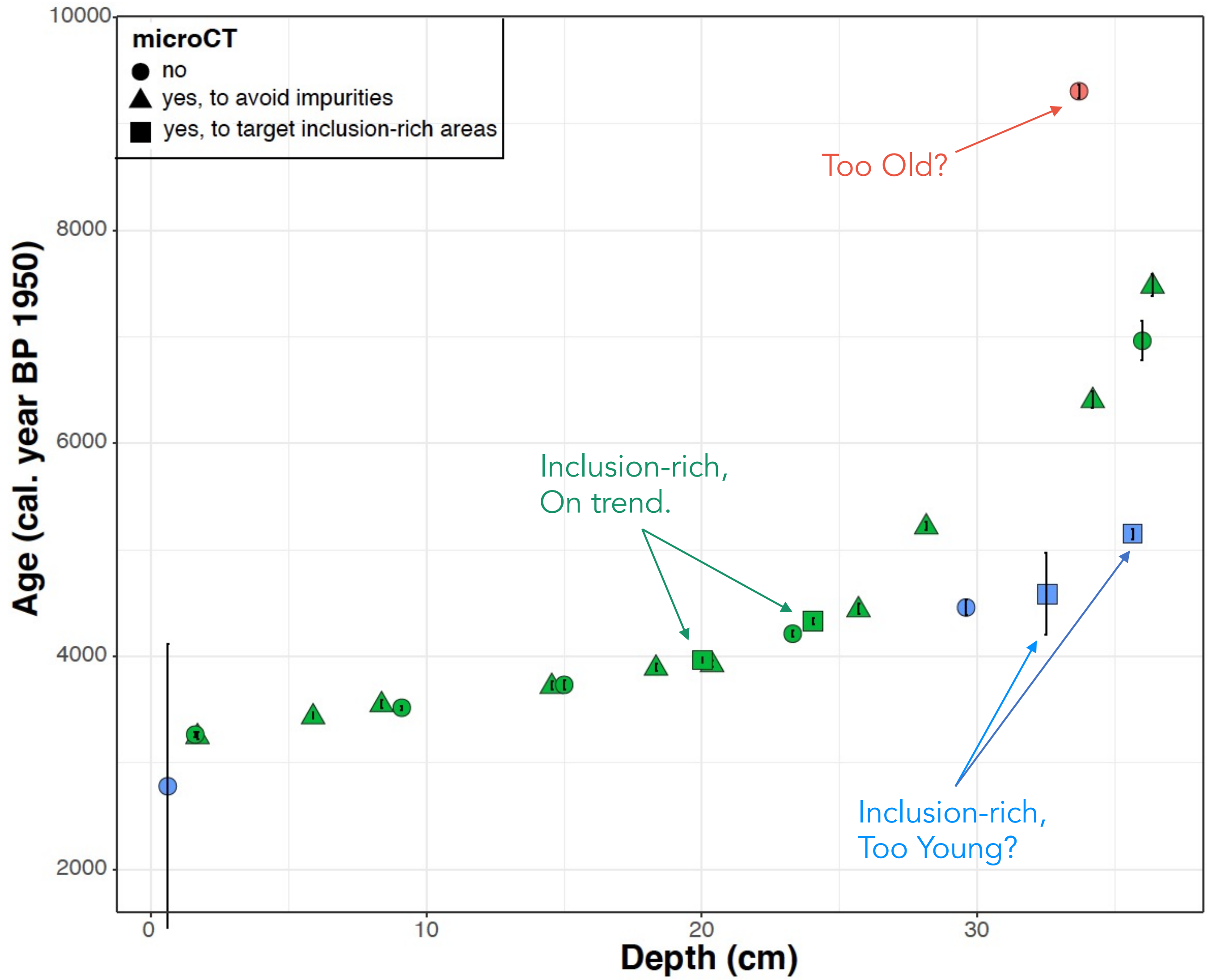
We targeted areas with a high concentration of porosity to evaluate U-loss, recrystallization or other phases that may lead to apparently younger ages.

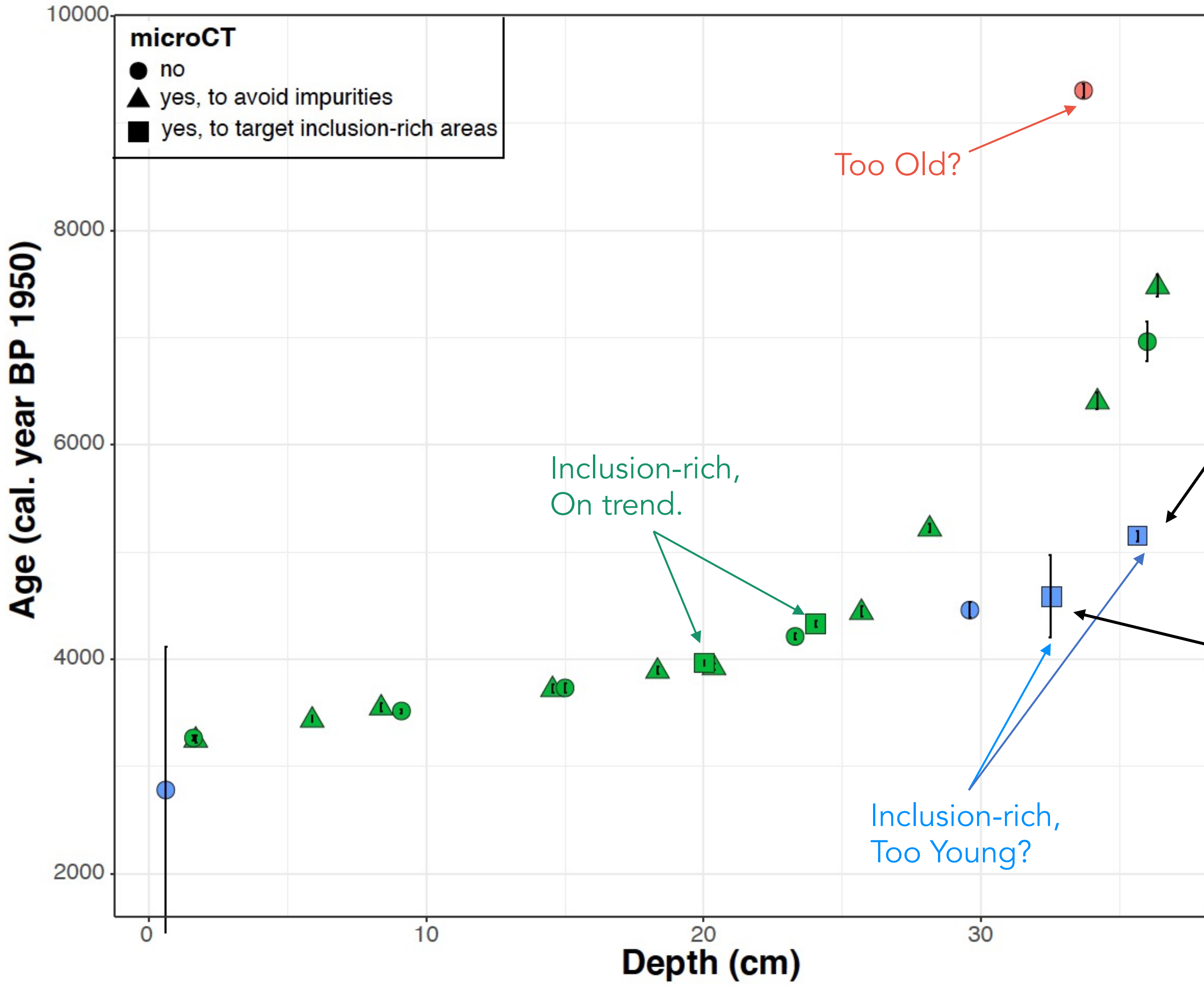




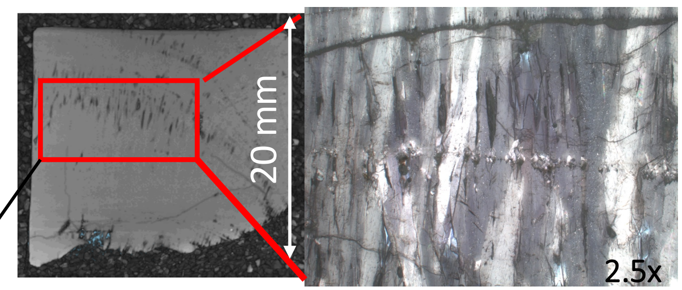
Example of new target samples – areas of high porosity along crystal boundaries.

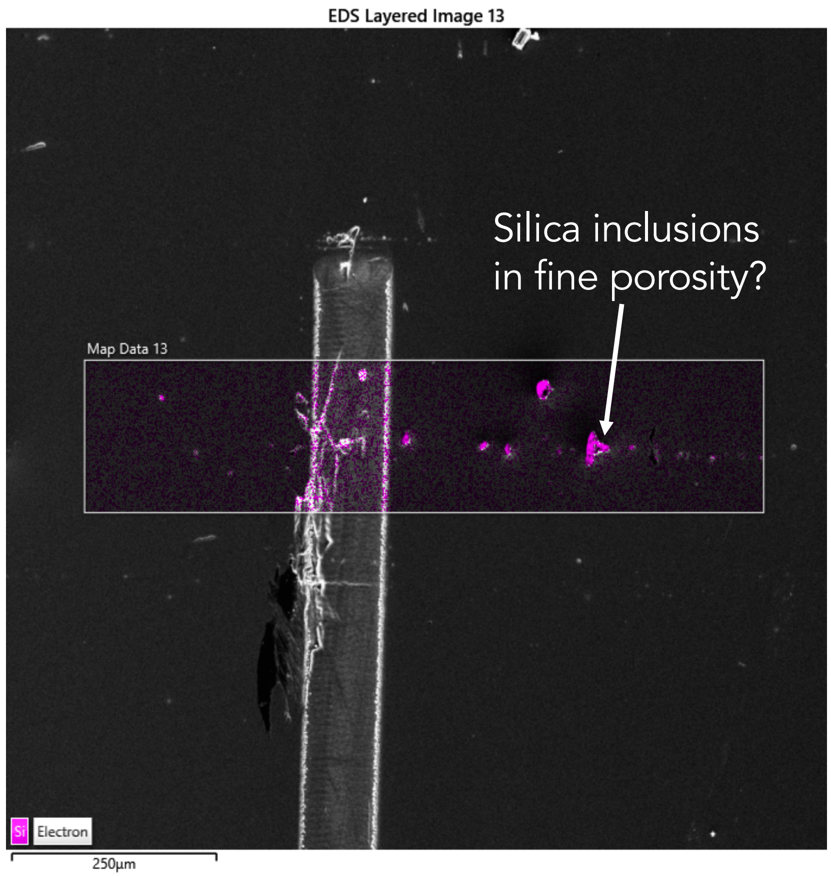
Some of our samples from inclusion-rich areas yield ages that are apparently "too young". Other samples from inclusion-rich areas fall on the overall age-depth trend.





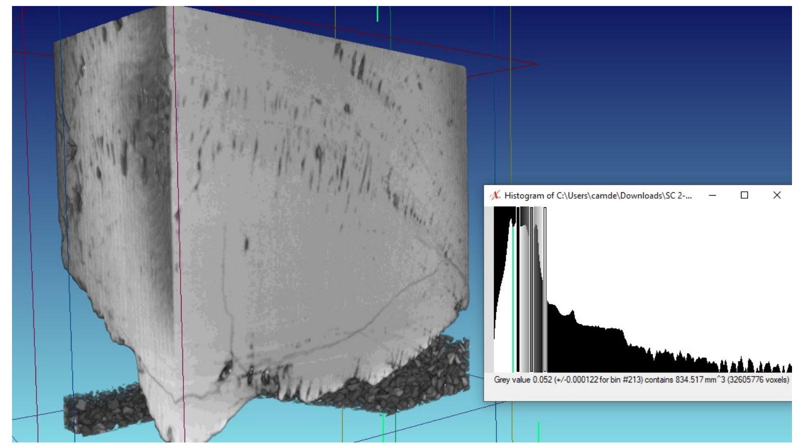
Are samples that appear "too young" associated with fine secondary recrystallization or small-scale silicate inclusions?



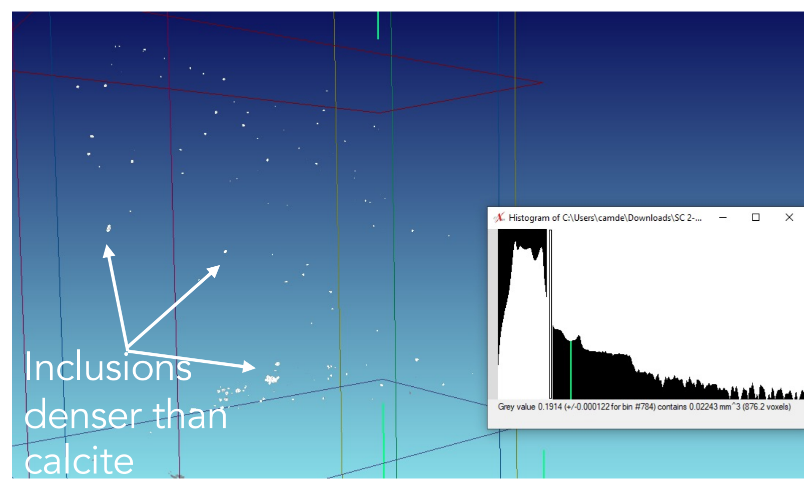


We see evidence of fine-grained silicate material in some of these small pore spaces using EDS and denser minerals through MicroCT. Could this be a silica phase that contributes to the apparently young ages?

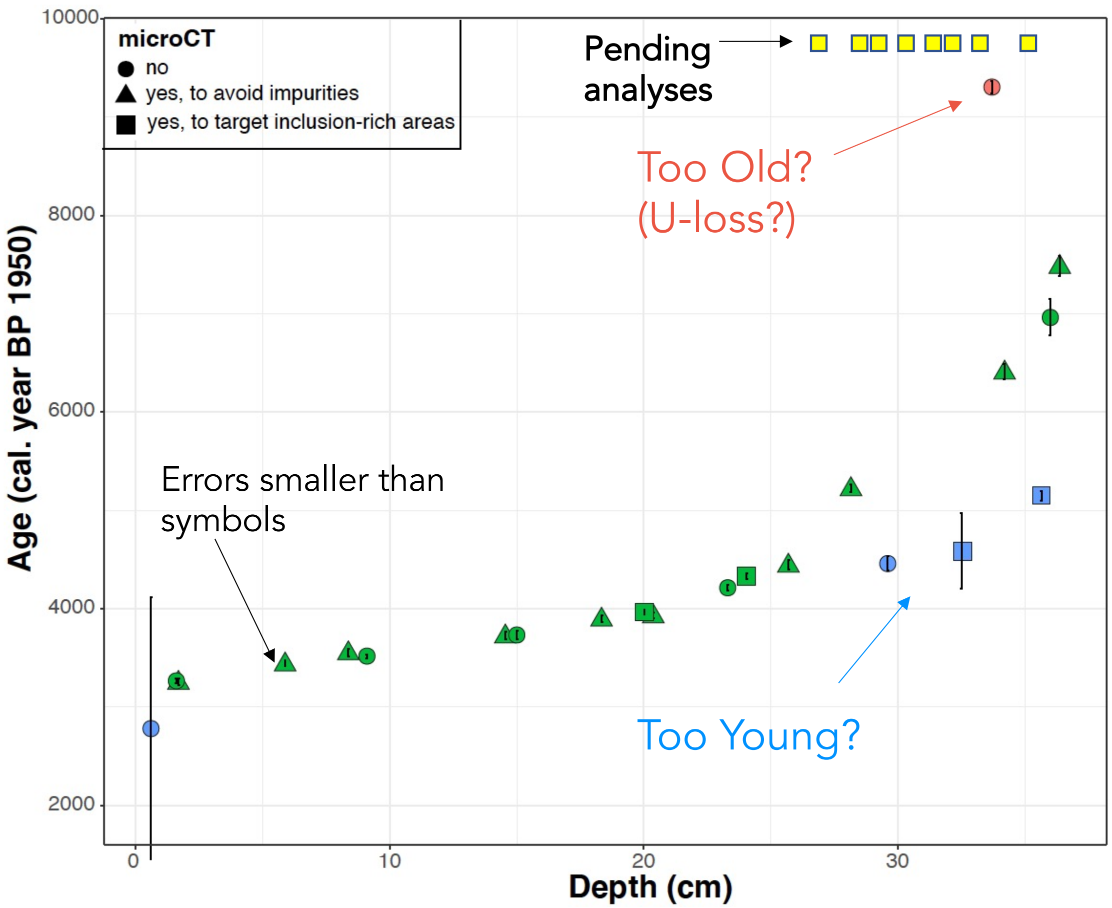
MicroCT of lowermost billet with the density peak for calcite selected and denser material removed.



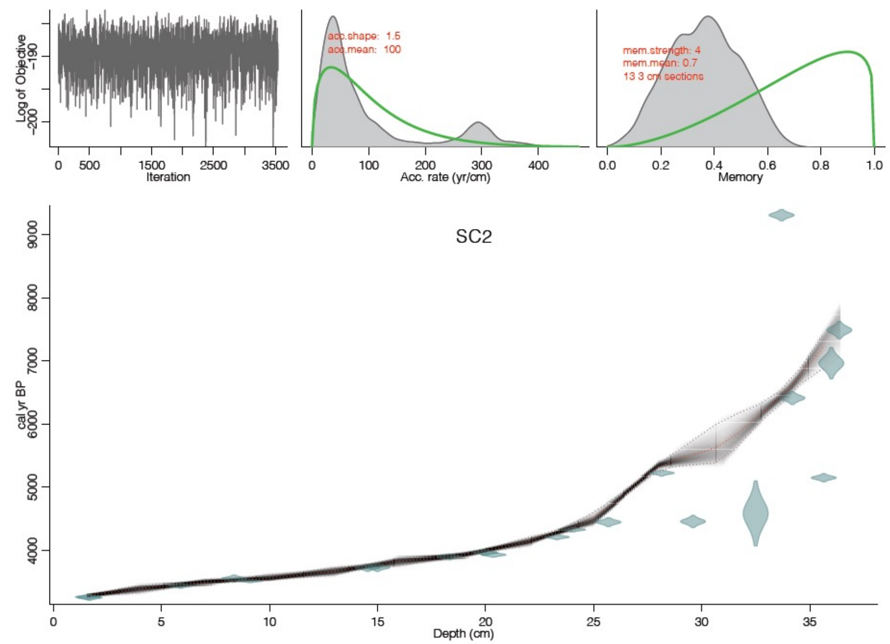
Same image showing only material that is denser than calcite – distributed in small void spaces.



Ongoing work



We are continuing to evaluate these relationships with a new suite of samples, including replicates from the same growth bands to evaluate the potential influences of diagenesis and silicate inclusions on U-Th ages.



We are evaluating age-depth modeling algorithms. The Bayesian algorithm, Bacon, discards the apparently young samples in this model.

Our goal is to provide recommendations for sample screening to develop robust U-Th age models for problematic stalagmites.