$^{40}Ar/^{39}Ar$ data from the project

Collaborative Research: Using Multisystem Deep-Time Thermochronology to Decipher Neoproterozoic Exhumation Patterns in Time and Space

This collaborative project was funded by the U.S. National Science Foundation (to Lehigh University, the award was 2044603). It involved PI Brenhin Keller (Dartmouth), c0-PIs Willy Guenthner (University of Illinois at Urbana Champaign - UIUC), and Peter Zeitler (Lehigh University) as well as research participants Kalin McDannel (Dartmouth) and Ryan Sigat (UIUC).

This document provides an overview to the $^{40}Ar/^{39}Ar$ data and other files archived at this dataverse site. This overview includes both project context as well as miscellaneous technical details.

Project Abstract. Earth's history as recorded in rocks is frequently incomplete in any one place, with gaps of missing time known as unconformities. Such gaps are very common in the rock record and occur at different times in different places at different scales. A major exception is the abundance of such gaps across multiple continents shortly before the start of the current geological Eon, shortly before the diversification of shelly fossils in the famous Cambrian Explosion. The origin of this global gap, known as the Great Unconformity, has been a subject of debate for some time.

It is important to recognize that while the shared feature of Great Unconformity outcrops is deposition of basal Phanerozoic strata on older eroded basement, different processes with different timing could have contributed at various localities. In some sense, while clearly widespread and significant relief-reducing erosion is required to set up an unconformity, it is the uniformity of the overlying strata that defines the feature, meaning that beyond erosion, development of widespread coeval accommodation space is also required.

One recently proposed hypothesis links the Great Unconformity to glacial erosion during the global "snowball Earth" ice ages that occurred about 715-660 and 740-735 million years ago. This would provide a mechanism for both widespread erosion as well as development of accommodation space. Alternatively, some have argued that formation of the Great Unconformity at least in part predates Cryogenian glaciation and is more related to tectonic activity.

Because erosion decreases the depth (and thus temperature) of rocks beneath the surface of the crust, one test of these hypotheses involves using minerals known as thermochronometers to record the past temperatures they experienced over time, due to the rate of diffusion of isotopes produced in these minerals at a known rate by radioactive decay. While timing can provide some constraints on the cause of erosion, the time resolution of thermochronometers is limited in old rocks. In order to distinguish Neoproterozoic glacial erosion from erosion associated with the tectonic activity we proposed to study not only the timing but also the spatial pattern of erosion over this time period, using thermochronometers collected from both stable continental interiors and less stable continental margins. Since the glacial erosion hypothesis predicts substantial erosion of stable crust in the interior of continents, while the tectonic hypothesis predicts erosion only near tectonically active regions, the spatial distribution of erosion should allow us to constrain whether erosion associated with the Great Unconformity was the result of glacial processes, tectonic processes, or both.

In general we found the erosional record from continent-marginal sites to be more variable, but the thermal history data alone are permissive of either tectonic or glacial origins for Neoproterozoic erosion, or more likely, both. However, we found that stable continental interiors, far from regions of active faulting and tectonic uplift, also recorded significant erosional exhumation of at least 3 to 6 km. This suggests to us that Snowball Earth glaciation played a significant role in development of the Great Unconformity

Additional Context. This project involved integrative modeling of time-temperature data obtained using multiple methods. In addition to utilizing published data such as apatite-fission-track results and framing high-temperature metamorphic geochronology, we generated significant U-Th/He zircon and $^{40}Ar/^{39}Ar$ K-feldspar data sets from samples from cratonic and craton-marginal rocks in Canada, the North American mid-continent, Finland, Morocco, India, and the Pilbara in Australia. To a significant degree these samples are from localities that would all have been grouped into the Rodinian supercontinent at the time of Neoproterozoic glaciation.

The data placed in this archive amount to the $^{40}Ar/^{39}Ar$ K-feldspar stepheating results from the project (as well as a few total-fusion biotite data from the mid-continent). These $^{40}Ar/^{39}Ar$ data were collected at the Lehigh University noble-gas laboratory from ~2020 to 2025, spanning the COVID pandemic.

File Information. Besides root-level information files, the actual data were uploaded as zip files that when downloaded, will retain their organized folder structure. Data files are named with both their internal laboratory number as well as their field number.

• *Craton-Project_Overview.pdf*
This file, containing project context and technical information.

• *SAMPLE_INFORMATION_FINAL.xlsx*
This file summarizes location, rock, type, origin, numbering, quality assessment and other data for each sample.

• *39beam-weight-I63-I64-I67_kspars.xlsx*
Contains a summary of 39-Ar beam intensity versus weight for each K-feldspar sample, organized by irradiation. This is useful for identifying samples with relatively lower K contents than expected for a typical K-feldspar, which in turn can assist decisions about whether an analysis is suitable for MDD modeling.

• *ArArCalc_files.zip* (organized into folders by irradiation, or mineral type in the case of biotites)
These are final reduced data for each sample, containing all measured data and supporting calibrations and constants. They are output from the ArArCalc Excel plugin written by Anthony Koppers. These were saved as .xlsx files containing numerous worksheets.

• *mdd_modeling_files.zip*
These files in tab-delimited tex format contain the core information needed for thermal-history modeling of MDD K-feldspar stepheating data (step temperature (˚C), fractional ^{39}Ar loss, step duration (min), step age (Ma), uncertainty (Ma), and flag for whether the step should be modeled).

Generally, steps suitable for modeling show a continuously rising pattern without sudden jumps, and were collected below sample breakdown by incongruent melting at 1150˚C. Often the first few percent of gas release showed old ages impacted by inclusion-hosted Ar, and such steps cannot be modeled for age. Note that for most samples, isothermal duplicates or triplicates were run at lower temperatures to identify the presence of inclusion-hosted Ar, in which case generally only the last of the isothermal steps should be used for modeling (because the samples were irradiated with Cd shielding, there was insufficient $^{38}Ar_{Cl}$

production to permit using the isothermal replicates to determine correction factors).

Technical Information. Analytical and data reduction methods largely followed those described by McDannell (2017); one difference is that all five Ar beams were measured using Faraday detectors (1e13 ohm resistor for ^{39}Ar and 1e12 ohm resistors for the others). Samples were irradiated for ~100 hours in Cd shielding at the USGS Triga and Oregon State University reactors.

McDannell, K.T., 2017. Methods and application of deep-time thermochronology: Insights from slowly-cooled terranes of Mongolia and the North American craton. Ph.D. Dissertation, Lehigh University, 262 pp. Obtainable at: https://preserve.lehigh.edu/lehigh-scholarship/graduate-publications-theses-dissertations/theses-dissertations/method
(or see https://asa.lib.lehigh.edu/asa/Record/10773739).

Some Related Publications.

Guenthner, W., McDannell, K., Keller C. B., Zeitler, P.K., Sigat, R.O., Babarinde, O.O., and Orme, D.A., 2022. (In)stability of the Laurentian surface from multisystem thermochronometry. Abstract T22C-01 presented at 2022 Fall Meeting, American Geophysical Union, Chicago, IL, 12-16 December.

McDannell, Kalin T. and Keller, C. Brenhin and Guenthner, William R. and Zeitler, Peter K. and Shuster, David L., 2022. Thermochronologic constraints on the origin of the Great Unconformity. *Proceedings of the National Academy of Sciences*, v. 119. https://doi.org/10.1073/pnas.2118682119

McDannell, Kalin T. and Keller, C. Brenhin and Guenthner, William R. and Zeitler, Peter K. and Shuster, David L., 2022. Reply to Flowers et al.: Existing thermochronologic data constrain Snowball glacial erosion below the Great Unconformity". *Proceedings of the National Academy of Sciences* , v.119. https://doi.org/10.1073/pnas.2209946119

McDannell, K., Keller, C.B., Guenthner, W., Zeitler, P., 2022. Thermochronological test of the glacial and tectonic origin hypotheses for the North American Great Unconformity. Geological Society of America Abstracts with Programs, 54(5), doi: 10.1130/abs/2022AM-378958.

McDannell, K.T., Zeitler, P.K., and Schneider, D.A., 2018. Instability of the southern Canadian Shield during the late Proterozoic. Earth and Planetary Science Letters. v. 490, 100-109, DOI: 10.1016/j.epsl.2018.03.012.