AFT Dating of Clinker on Black Mesa, Navajo Nation

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Abstract

A 7-km wide circular structural feature on Black Mesa, Navajo Nation (**Figure 1**) has been proposed as representing an impact structure that formed in conjunction with nearby melt breccias. Some outcrops of mostly siliciclastic Mesaverde Group rocks on Black Mesa display various post-depositional thermometamorphic textures like melt brecciation and fusion of sand grains. Apatite fission track (AFT) analysis was applied to melt breccias and nearby unmelted sandstones to determine the age of melting at selected outcrops. For breccia sample BM-1: apatite is sparse, 1 of 9 AFT ages as young as 0 Ma (95%CI). Breccia sample BM-2B: apatite is sparse, 7 of 12 AFT ages as young as 0 Ma. Breccia sample BM-4B: 78 of 78 AFT ages as young as 0 Ma, pooled age <1 Ma. For unmelted sample BM-2A: 15 of 74 AFT ages as young as 0 Ma. Unmelted sample BM-3: 11 of 54 AFT ages as young as 0 Ma. Unmelted sample BM-4A: 76 of 87 AFT ages as young as 0 Ma. Sparse apatite likely indicates loss by thermal decomposition.

A measured AFT pooled age <1 Ma for breccia sample BM-4B supports very recent melting, probably from an underground coal fire. Our evidence therefore supports an interpretation as clinker and contradicts the impact hypothesis at these outcrops.

Fieldwork on the Navajo Nation was conducted under a permit from the Navajo Nation Minerals Department. Any person(s) wishing to conduct geologic investigations on the Navajo Nation must first apply for and receive a permit from the Navajo Nation Minerals Department, P.O. Box 1910, Window Rock, Arizona 86515, USA, and Telephone No. +1 (928) 871-6587.

Figure 1. Sample localities.

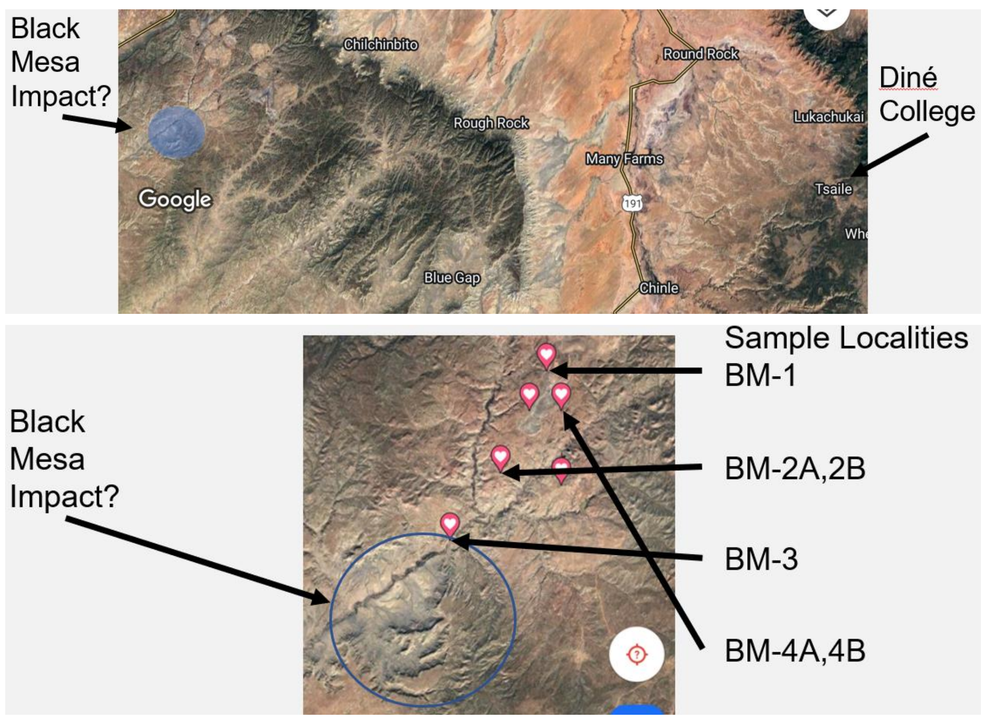


Table 1. AFT data summary (analyst Ray Donelick).

Sample Locality	Type	Strat Age (Ma)	N Ages All (grain)	N Ages as young as 0 (grain)	Pooled Age(95% CI) (Ma)	N Lengths (track)	Mean Length(1σ) (µm)
BM-1	breccia	100.5 - 66.0	9	1	41.2(- 8.1 + 1.0)	7	10.15(1.04)
BM-2A	unmelted	100.5 - 66.0	74	15	65.6(- 5.4 + 5.9)	245	12.87(0.11)
BM-2B	breccia	100.5 - 66.0	12	7	128.7(-37.6 +53.0)	0	
BM-3	unmelted	100.5 - 66.0	54	11	95.8(- 9.2 +10.2)	62	12.60(0.22)
BM-4A	unmelted	100.5 - 66.0	87	76	19.9(- 3.3 + 3.9)	10	12.36(0.66)
BM-4B	breccia	100.5 - 66.0	78	78	0.37(-0.24 +0.64)	0	

Methods

The AFT samples were prepared for analysis following the detailed description of Donelick et al. (2005). AFTs were etched using 5.5N HNO_3 for 20 s at 21°C (Donelick et al., 1990). Apatite grains were selected and AFT data (ρ_s, CFT lengths, mean Dpar and Dper for host apatite grain) measured live (prior to digital recording) by Ray Donelick at Apatite.com Partners LLC laboratory in Viola, Idaho (Nikon E600 microscope, Ludl Kinetec XY-stage, ASI Z-drive, Lumenera Infinity1 digital camera, Apatite.com Partners' Sample_Scanner.py software). Apatite grains were reviewed and AFT data re-measured by analysts Benjamin Craig and Jayson Begay at Diné College Apatite Fission-Track (DCAF-T) laboratory in Tsaile, Arizona (Olympus BX60 optical microscope, ASI MS-2000 XY-stage, ASI Z-drive, Lumenera Infinity2 digital camera, Sample_Scanner.py software). CFT length measurements were enhanced using ^{252}Cf-derived fission fragment irradiation (Donelick and Miller, 1991). LA-ICP-MS data were collected by Ray Donelick and Benjamin Craig at Washington State University Geoanalytical Laboratory using a NWR UP-213 laser (213 nm, 8 s warmup, 20 s ablation, 20 s washout, 25 µm diameter spot) and Agilent 7700 quadruple mass spectrometer (37 masses for 33 elements including P, Cl, Ca, REEs, Pb, Th, U). AFT ages (Donelick et al., 2005; Cogné et al., 2019), UPb ages (Chew and Donelick, 2012), and chemical compositions (Donelick and Donelick, 2014; Chew et al., 2014) were calculated using Apatite.com Partners' MSData software.

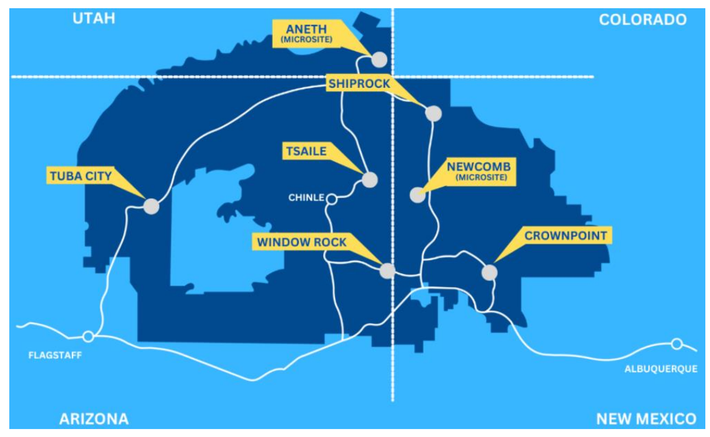
Results

Sample localities are shown in **Figure 1**. AFT data are summarized in **Table 1**.

Clinker, not Impact Breccia, on Black Mesa

This study seeks AFT evidence for or against the existence of a meteorite impact structure on Black Mesa (**Figure 1**; Beelen and Donelick, 2021). The Black Mesa Region in Navajo County, Arizona between the villages of Pinon and Kayenta contains multiple outcrops of what appears to be melt breccia. This project seeks to determine the age of melting at selected breccia outcrops on Black Mesa, and to determine if the melt breccias resulted from a meteorite impact or from the natural burning of abundant coal in the area, the latter forming a rock known as 'clinker'. In October 2022, students from Diné College undertook a field trip to the area of Black Mesa containing these melt breccia outcrops. These outcrops also lie near the inactive Peabody Coal Mine that operated from 1972 to 2019. Breccia sample BM-4B yields a pooled AFT age < 1 Ma (**Table 1**), consistent with a clinker interpretation. If the potential impact structure shown in **Figure 1** had formed <1 Ma ago and heated breccia BM-4B, the structure would appear much fresher than it does in this satellite image. Similarly, the very wide range of AFT grain ages observed for melt breccia sample BM-2B supports a clinker interpretation, as clinker often involves cold rock falling into molten rock. We predict a similar interpretation for the many melt breccia outcrops that occur northeast of the potential impact structure on Black Mesa.

Figure 2. Diné College campuses on the Navajo Nation.



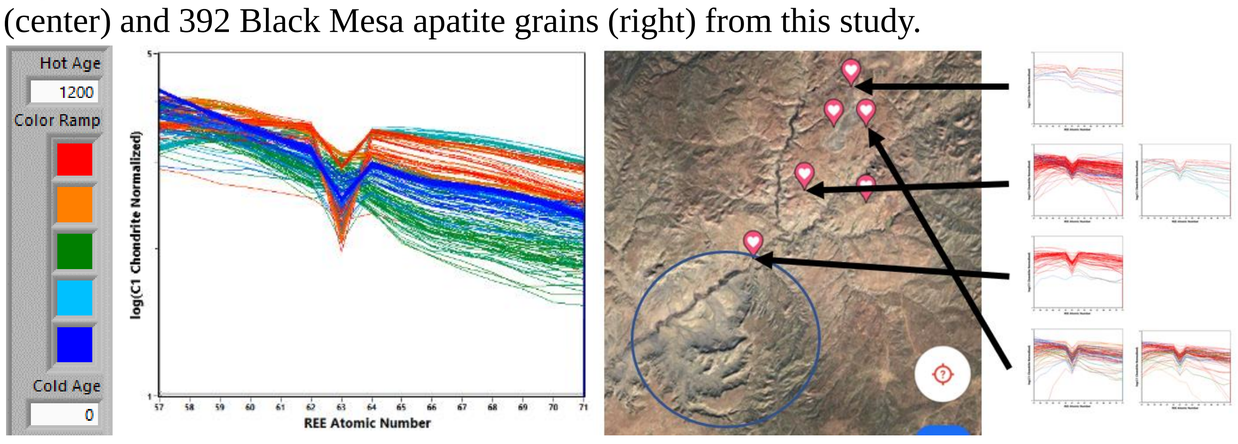
State-of-the-art Laboratory for Undergraduate Students

During Academic Year 2023-2024, the Diné College Apatite Fission-Track (DCAF-T) lab will use the digital imagery collected in this study to build a training dataset and curriculum for the non-expert AFT analyst. These data will be combined with digital imagery for required standards including: initial and natural AFT length distributions for AFT age standards, and initial AFT length distributions for a range of etching protocols and resultant Dpar and Dper values. The lab will demonstrate this training curriculum and its effectiveness, publish the results of the study, and make available to the AFT community this training dataset. We are developing real-world AFT case studies to incorporate into appropriate STEM and non-STEM courses offered at Diné College. The DCAF-T lab microscope system is mobile and can be set up in most communities across the Navajo Nation (**Figure 2**). The lab is exploring delivering science education to students who otherwise cannot routinely attend class at regional campuses.

Connecting Science to Indigenous Land and Culture

AFT data (**Figure 3**) are fascinating and offer a low-cost science and mathematics connection to the land and culture of the Diné (Navajo) People. AFT data generated by the DCAF-T lab for rocks from Navajo Nation are the property of the Diné People and the lab is beginning the process of reaching out to Chapter Houses (local governmental entities) on the Navajo Nation to integrate these data with current cultural resources. The lab is operated to maximize its benefits to the Diné People.

Figure 3. Colored by apatite UPb age (left), REE profiles for 275 standard apatite grains (center) and 392 Black Mesa apatite grains (right) from this study.



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