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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 thermotectonic 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. 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 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.

References Cited
Beelen and Donelick, 2021: Virtual Thermo 2021, February 23
Chew and Donelick, 2012: Mineralogical Association of Canada, Short Course, v. 42, pp. 219-247
Cogné et al., 2019: Chemical Geology, v. 531, no. 119302
Donelick and Doenelick, 2014: U.S. Patent Number 8,961,485
Donelick et al., 1990: Nuclear Tracks and Radiation Measurements, v. 17, no. 3, pp. 261-265
Donelick et al., 2005: RIMS, Mineralogical Society of America, v. 58, p. 49-94

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 1. Sample localities.

Figure 2. Diné College campuses on the Navajo Nation.

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

Methods
The AFT methods were prepared for analysis following the detailed description of Donelick et al. (2005). AFTs were etched using 5.5N HNO3 for 20 s at 21°C (Donelick et al., 1990). Apatite grains were selected and AFT data (p, 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 Kinnetex XY-stage, AFI-Z drive, Lumenera Infinity1 digital camera, Apatite.com Partners Sample_Scraper.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 Tsali, Arizona (Olympus BX60 optical microscope, AFI MS-2000 XY-stage, AFI-Z drive, Lumenera Infinity2 digital camera, Sample_Scraper.py software). CFT length measurements were enhanced using CFT-derived 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 warmup, 20 s ablation, 20 s washout, 25 µm diameter spot) and Agilent 7700 quadrupole 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.

Table 1. AFT data summary (analyzed by Ray Donelick).

<table>
<thead>
<tr>
<th>Sample Locality</th>
<th>Type</th>
<th>Strat Age (Ma)</th>
<th>U/Pb Age (Ma)</th>
<th>Initial AFT Age (Ma)</th>
<th>Natural AFT Age (Ma)</th>
<th>Pooled Age (95% Cl) (Ma)</th>
<th>Length Mean (μm)</th>
<th>Length Std (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM-1</td>
<td>breccia</td>
<td>0.00-0.60</td>
<td>9</td>
<td>41.2±6.1-1.6±0.6</td>
<td>7</td>
<td>10.15±1.04</td>
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<td></td>
</tr>
<tr>
<td>BM-2A</td>
<td>unmel.</td>
<td>100.00-0.60</td>
<td>74</td>
<td>35.6±5.4-5.5±5.1</td>
<td>245</td>
<td>12.8±7.0±11</td>
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<td></td>
</tr>
<tr>
<td>BM-2B</td>
<td>breccia</td>
<td>100.00-0.60</td>
<td>42</td>
<td>128.7±9.5-39.5±5.0</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BM-3</td>
<td>unmel.</td>
<td>100.00-0.60</td>
<td>54</td>
<td>36.8±5.2-3.2±0.0</td>
<td>62</td>
<td>12.6±0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BM-4A</td>
<td>unmel.</td>
<td>100.00-0.60</td>
<td>87</td>
<td>79.5±3.3-3.3±3.3</td>
<td>10</td>
<td>12.3±0.66</td>
<td></td>
<td></td>
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<tr>
<td>BM-4B</td>
<td>breccia</td>
<td>100.00-0.60</td>
<td>78</td>
<td>30.7±0.2-40.4±6.0</td>
<td>0</td>
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