CINDER LAKE CRATER FIELD GUIDE: BRINGING THE MOON TO NORTHERN ARIZONA. A. L. Gullikson[1], L. A. Edgar[1], M. E. Rumpf[1], [1]U.S. Geological Survey, Astrogeology Science Center (agullikson@usgs.gov).

Introduction: Terrestrial analog sites are used for many purposes, including testing new technologies, habitats, robotic and human mobility, assessing geologic processes in environments similar to off world sites, and studying the effects of long-term isolation on humans. Analog sites allow researchers the ability to evaluate the successfulness and utility of an instrument or method before using it in space and allow these experiments to be done at a fraction of the cost, time, and effort.

In 2019, the United States Geological Survey (USGS) released a questionnaire to assess the needs of the planetary science community regarding terrestrial analog studies [1]. Results from this survey led the USGS Astrogeology Science Center (ASC) to establish the Terrestrial Analogs for Research and Geologic Exploration Training (TARGET) program. The focus of this service-oriented program is to provide training resources, sample collections, and data archiving to the planetary community [e.g., 2–4].

One objective of the 2019 survey was to gauge respondent's needs for multipurpose guides for widely used analog locations in northern Arizona [1]. The aim for these field guides were to be accessible for a range of target audiences (e.g., undergraduate and graduate students, NASA managers) and developed using a standardized format for systematic purposes. In response to community needs, two field guides thus far have been completed and released: SP Mountain [2] and Verde Valley [5], whose focus are on basaltic volcanism and lava-water interaction, respectively.

Cinder Lake Crater Field Guide: Presented here is our third field guide, the Cinder Lake Crater Field Guide. This guide provides a visual and written history of the Cinder Lake crater fields, detailing how and why the sites were constructed, and the types of training that took place there. Additionally, we explore these crater fields in their current state, digitally replicate activities that were carried out on site, and provide lessons on crater morphology, landform degradation and erosion, and the importance and usefulness of sun angle on resolving the shape of features on the ground.

Preparation for the Moon: When the decision was made that humans were first going to the Moon, extensive preparations began. Among these included training astronauts in conducting field work, using field instruments, and describing their surroundings in a geologic context. Additionally, without having sophisticated GPS equipment, once astronauts landed on the Moon, they would need to locate themselves quickly and accurately to maximize the allotted time spent exploring and mapping the lunar surface [6]. To prepare astronauts for these undertakings a lunar analog site with similar geology and morphology would be imperative.

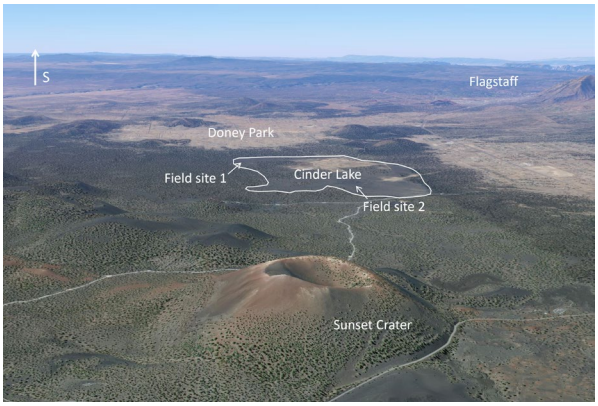

Figure 1. *Aerial view looking south. Cinder Lake (outlined in white) is south of Sunset Crater, and Flagstaff, AZ is to the southwest.*

Figure 2. *Completion of Crater Field 1 [9].*

Cinder Lake, AZ: Cinder Lake is located northeast of Flagstaff, AZ and is a relatively flat area ~5 km south of Sunset Crater, the youngest volcano in the San Francisco Volcanic Field (**Figure 1**). The eruption of Sunset Crater took place ~900 years ago, dispersing tephra at least 2,000 km^2 across northern Arizona [7]. [8] described a continuous blanket of tephra within a proximal radius of Sunset Crater, and at greater distances a finer-grained thin layer of discontinuous tephra. Cinder Lake is located within the continuous layer of tephra.

Overall horizontality, lack of vegetation, and layers of loose basaltic tephra made Cinder Lake an ideal location for a decidedly unique type of analog site. Using explosives and a backhoe, Cinder Lake was transformed into two crater fields, replicating sites in Mare Tranquillitatis at a 1:1 scale.

Building Crater Fields: Crater Field 1 was constructed in 1967; the final crater count was 143, craters ranging in size from 1.5 to 18 m in diameter, in a space of 245 m x 245 m (**Figure 2**). Crater Field 2 was constructed in 1968; explosions were done in a more systematic way compared to Crater Field 1 and thus were able to detonate in three successive groups, representing a progression of relative crater ages [6]. Crater Field 2 had 354 craters assigned to the "oldest" age group, 61 craters to the "intermediate" group, and 11 craters in the "youngest" group, totaling 426 craters that ranged in size from ~2 to 22 m in diameter [6].

Training at the Crater Fields: The Cinder Lake crater fields provided a unique and valuable opportunity for Apollo astronauts, engineers, and scientists to train, test instruments, and carry out simulations in the preparation for missions to the Moon (**Figure 3**). Such work included implementing location tests, preliminary field methods, and providing complex geologic layouts that would enable trainees to reflect on stratigraphy, superposition, and geologic processes [6,7]. Today, the crater fields are of historic importance, but they can also still be used as training grounds for the on-going preparation for missions to the Moon, Mars, and beyond.

After the Apollo program ended and the crater fields were no longer needed as training sites, a fence prohibiting motorized activity was placed around Crater Field 1 for preservation. Fencing was not installed around Crater Field 2 and later became a popular off-roading recreational site. Human activity has exacerbated erosion on the craters, however because the accessibility between crater fields differs, so does the amount of erosion. This opportunity allows us to observe firsthand how craters degrade over time at different rates (**Figures 4, 5**).

Dissemination: We have designed this field guide as both printable and virtual versions, removing the need to be physically present at this site to take full advantage of the guide and its activities. Once published it will be available as a USGS Open-File Report and the virtual guide hosted as an online ArcGIS StoryMap.

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Figure 3. *Exploration vehicle driving into a freshly made crater in Crater Field 1 (image from [9], USGS photo P741).*

Figure 4. *Oblique view of Crater Field 1 present day. Crater in foreground is ~7 m in diameter.*

Figure 5. *Oblique view of a crater within Crater Field 2. The dark material is basaltic tephra, and the tan material is clay sediments.*

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