THE USGS FLYNN CREEK CRATER DRILL CORE COLLECTION. J. J. Hagerty, T. A. Gaither, J. F. McHone, and O. Abramov, U.S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, AZ 86001, email: jhagerty@usgs.gov.

Introduction: Flynn Creek crater is a 3.8 km diameter, 360 million-year-old impact structure located in north central Tennessee (Figure 1) [1,2]. The impactor that produced the crater likely struck a shallow sea, punching a flat hole into underlying Ordovician marine limestones, with the crater being filled with black Devonian muds that underwent lithification to become the Chattanooga Shale [1,2]. Between 1967 and 1979, Dr. David Roddy of the USGS conducted a drilling program at Flynn Creek crater. The drilling program produced more than 3.8 km of nearly continuous core from 18 separate bore holes. These samples are now contained in 1,271 standard core storage boxes archived at the USGS in Flagstaff, Arizona.

Previous studies have laid the groundwork for understanding this unique impact structure [1,2]. Since those initial studies, new techniques and technological advancements have made it possible to revisit this crater and the drill core collection such that we can fill gaps in the knowledge base and further define the spectrum of marine impact craters. The overarching goal of this project is to first document and characterize the drill cores using a combination of bulk rock and microbeam analyses, which in turn will be used to inform and constrain numerical models of the impact event. This intentionally broad approach will use iterations between complementary techniques to address multiple, critical issues regarding the effects of carbonate melting, shock deformation, and impact-induced hydrothermal activity within a well-documented marine impact crater.

Background: Surface and subsurface studies of the Flynn Creek impact structure have demonstrated that it can be classified as a complex crater, with a central uplift, and terraced crater rim [1 – 3]. Confirmation of an impact origin for the Flynn Creek structure came with the discovery of shatter cones in exposures of the central uplift [4]. Remnants of the ejecta blanket, which contains crudely inverted stratigraphy, are present within a large graben along the southern rim. Roddy [2] suggested that both subaqueous and subaerial erosional processes removed all but 0.05 km^3 of ejecta that remained trapped in the down-dropped part of the southern rim graben.

The entire crater and central uplift were quickly protected by the rapid deposition and complete filling by marine sediments of early Late Devonian age that lithified to become the Chattanooga Shale [2]. The shale was subsequently overlain by the Lower Mississippian Fort Payne and Upper Mississippian Warsaw Limestone [5], which now cap the ridges in the Flynn Creek area [3]. Uplift and erosion during the Quaternary have produced the highly dissected region of steep-sided hills and valleys of the Eastern Highland Rim [3]. Local relief, averaging 150 m along the many valley walls and floors, now contributes to the excellent exposures of Flynn Creek material [3].

Roddy [1,2] argued that the impacting body that produced the crater was likely a cometary mass or a stony meteorite and that the projectile was largely destroyed/volatilized at or near the surface during its rarefaction phase, since no traces were found in geochemical studies. More recently, Milam et al. [6] examined three samples of impact-generated breccias for evidence of the impactor using major, trace, and platinum group element concentrations. Their results suggest a lack of chondritic or Fe-meteorite component remaining in the breccias or post-impact fill [6].

The USGS drilling program. The USGS drilling program at Flynn Creek crater was conducted in two phases. The first phase was completed in 1967, and produced 6 holes of continuous NX core (5.5 cm diameter) totaling 762 m. These holes were drilled along an approximate east-west diameter on the crater floor, with the goal of determining the thickness of the breccia lens and nature of the underlying deformation. The most important results of this drilling indicated that the breccia lens averaged only ~40 m in thickness along the east-west diameter and that stratigraphic units were relatively undisturbed and continuous at depths of ~100 m, beneath the breccia lens [7].

The second phase of drilling was completed in 1978-1979, and produced 12 holes of continuous BX core (3.5 cm diameter) totaling 3,064 m. This phase provided more comprehensive coverage of the crater. Four holes, up to ~625 m deep, were devoted to determining the structure of the innermost western rim, crater walls and floor. Another 4 holes, up to ~166 m deep, were devoted to crater floor structure in the northeast quadrant of the crater. Three deep holes, up to 853 m deep, were drilled in the central uplift, and a single 216 m deep hole was drilled in the terrace graben on the south rim.

The USGS Astrogeology Science Center in Flagstaff, Arizona currently has twelve of the drill cores from the Phase 2 study conducted by Roddy. Nine drill cores (from the central uplift, northwest crater rim and wall, and the graben on the south rim) are contained within boxes labeled with the core number/location and depth interval data (Figures 2 and 3); three cores from the northeast quadrant (15, 16, and 17) have ambiguous core numbers on the box labels, but this uncertainty does not preclude the extraction of valuable data.

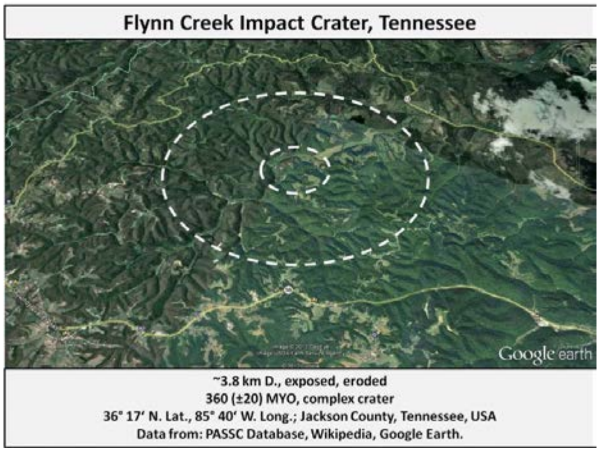

Figure 1. Google Earth view of Flynn Creek crater with an outline overlay of the crater diameter. Source: "Flynn Creek crater," 36°16'58.4036"N 85°39'57.0622"W, Google Earth 2012, January 4, 2013.

Figure 2. Example of drill cores in standard boxes from the USGS Flynn Creek Crater Drill Core Collection in Flagstaff, AZ.

Numerical Modeling. Results from the initial textural and compositional characterization of the drill cores will be used to inform and constraint a series of numerical models meant to better understand the formation of Flynn Creek crater as well as the crater's potential for impact-induced hydrothermal activity. Hydrocode models will be used to perform a suite of impact simulations designed to recreate the formation of a 3.8 km diameter crater using different impact velocities. Simulation results will be compared to the Flynn Creek crater to establish the most likely velocity and density, providing a test/comparison to Roddy's conclusion [i.e., 1,2,7] from theoretical modeling that a low-density projectile was responsible for the complex crater morphology at Flynn Creek crater. Multiple water depths at the time of impact will also be tested to determine the effect of ocean depth on the final crater morphology. The results of this modeling will have implications for understanding all impact events into water-rich environments. Hydrothermal modeling will also be conducted in an effort to predict the extent and duration of hydrothermal activity at the crater, which will inform the likely location of alteration mineral assemblages within the drill cores, allowing for an iterative, thorough, localized search for the effects of hydrothermal activity.

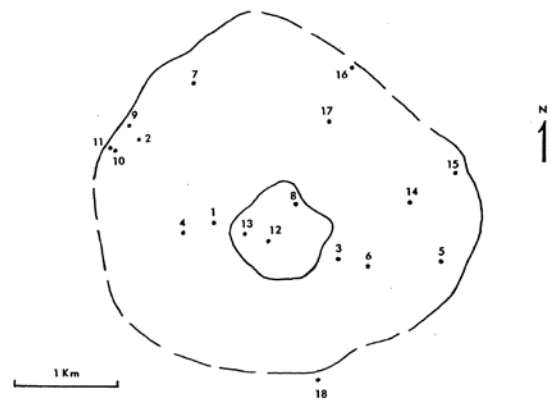

Figure 3. Locations of 1967 and 1978-1979 drill holes completed by the USGS at the Flynn Creek crater. Outer line shows the location of the top of the crater wall and inner line shows the location of the base of the central uplift. Figure modified from Roddy [7].

References: [1] Roddy, D.J., (1977a) *Impact and Explosion Cratering*, Pergamon Press, New York, pp. 125-161; [2] Roddy, D. J., (1977b) *Impact and Explosion Cratering*, Pergamon Press, New York, pp. 277-308; [3] Evenick, J. C. (2006) *Field Guide to the Flynn Creek Impact Structure*. Knoxville: University of Tennessee. 22 pg; [4] Roddy, D.J., (1966) *The Paleozoic crater at Flynn Creek, Tennessee*. PhD Dissertation, California Institute of Technology; [5] Wilson, C.W., and Roddy, D.J., (1990), *Geologic map and mineral resources summary of the Gainesboro quadrangle, Tennessee*: Tennessee Division of Geology, GM 325-SW, Scale 1:24,000; [6] Milam, K.A., and Deane, B. (2007) *LPSC 38*, abstract #2320; [7] Roddy, D.J., (1980) Abstr. *LPSC 11th*, 941-942; [8] Zahnle, K.J., and N.H. Sleep (1997) *Impacts and the early evolution of life, in Comets and the Origin and Evolution of Life*, pp. 175-208, Springer-Verlag, New York; [9] Kring, D.A. (2000) *GSA Today, 10(8)*, 1-7.