PETROGRAPHY AND XRD ANALYSIS OF THE HOWELL STRUCTURE, LINCOLN COUNTY, TENNESSEE.
K.A. Milam[1], T. Henderson[1], B. Deane[2], and J. Bensko[3], [1]Department of Geological Sciences, Ohio University, 316 Clippinger Laboratories, Athens, Ohio 45776 (milamk@ohio.edu), [2]Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, [3]formerly of the NASA Marshall Spaceflight Center, Huntsville, Alabama.

Introduction: Approximately one third of all known terrestrial impacts have occurred in carbonate-rich sedimentary rocks [1]. In comparison to silicate-rich targets, less is known about the effects of shock metamorphism on calcite and dolomite. Early petrographic observations of samples from the Flynn Creek structure, a confirmed impact crater, indicated that enhanced mechanical twinning occurs in calcite during impact [2]. Subsequent observations of experimentally-shocked calcite have demonstrated that mechanical deformation does occur during shock metamorphism, leading to an increase in fracturing, twin density, and a decrease in twin spacing [3]. Similarly, but on a macroscale, carbonates are fractured, faulted, and even brecciated with increasing intensity nearer to the center of confirmed impact structures [e.g. 4-5].

Other empirical and experimental studies have demonstrated that lattices of calcite and dolomite crystals can be deformed by impact, a phenomenon identifiable by the analysis of X-ray diffraction (XRD) spectra. [6] first observed peak broadening in shocked limestone and marlstone samples from the Karla and Steinheim impact structures in Russia and Germany respectively. Similar observations were later noted in the Ries [7] and Sierra Madera [8] impact structures. Likewise, calcite and dolomite samples experimentally-shocked to peak pressures simulating those produced during impact, show peak broadening that can be correlated with increasing shock pressures [9-10].

These recent petrographic and XRD observations provide new ways of examining enigmatic carbonate structures that have been proposed as impact craters, but have yet to be associated with shock metamorphism, a requirement for demonstrating hypervelocity impact [11]. In this study, we take a new look at one such site, the Howell structure, using similar techniques to determine if this structure can be associated with a shock metamorphic event.

The Howell Structure: The Howell structure is located in Lincoln County, Tennessee, United States, centered at 35.23°, -86.61°. It is a anomalous circular feature ~2.5 km in diameter, comprised of mostly brecciated, Middle Ordovician limestones (Fig.1). Field and laboratory observations indicate that breccias are mostly monolithic and range between matrix- and clast-supported. Clasts range in size up to ~meter-sized blocks and are subrounded to subangular in shape.

Figure 1. Visible image of a typical monolithic, matrix-supported breccia in the northeastern portion of the Howell structure (photo by K. A. Milam).

Some clasts are comprised solely of colonial tabulate coral and most clasts do not appear to be internally deformed. Breccias are capped by over-thickened, flat-lying Upper Ordovician strata, constraining the deformation event to Middle-Upper Ordovician [12-13], a notion that has been disputed [14].

The Howell Structure was first mapped and interpreted as a feature of cryptovolcanic origin [12]. Some have postulated an impact origin [12, 14, 15] and have offered questionable observations in support of this [14]. Definitive evidence of shock metamorphism however, has been lacking. In this study, we have peformed petrographic observations and XRD analyses in an effort to assess the validity of the impact hypothesis proposed for the formation of the Howell structure.

Methods: The primary sample sources for this study were from eight 2.5 cm diameter drill cores from the center and along the periphery of the Howell structure. These cores were collected under the direction of Mr. John Bensko in the mid to late 1960s as part of a program to develop drilling equipment for the (later canceled) Apollo 18 mission to the Moon. Most of these cores were not preserved; however 112 thin sections remain from all 8 drill sites and were used for petrographic study. Drilling depths represented by these thin sections ranged from 1.5-152 m beneath the local surface. Fifteen fragments of only one drill core (#1 –located just northwest of the structure's center) have been preserved and were used for XRD analysis. One representative sample was collected from each of these fragments. All of these specimens were cut into small pieces with a Hillquist SF-8 trim saw and reduced to <25 μm powder by hand, grinding in isopropyl alcohol using a mortar and pestle (to avoid the introduction of lattice strain). Samples were analyzed using a Rigaku Multi-flex X-ray diffractometer at 30 kV and 15 mA over a 2θ ranging from 20-120°. Rigaku PDXL software was used to perform a Rietveld peak refinement for each spectrum to identify peak broadening. Full width half maximum (FWHM) values were calculated for all samples over 20-120° as a part of this process. Similar analyses were performed on 2 unshocked calcite standards for comparison to Howell specimens.

Initial Results/Discussion: Most of the thin sections observed using a petrographic microscope showed minimal or no signs of deformation similar to what has been observed in other confirmed impacts into carbonate targets. There is virtually no evidence of extensive fracturing or faulting. Likewise, most preserved bedding is subhorizontal (<20°) in nature. Twinning does occur in many large calcite crystals, but not of the nature observed in experimentally-shocked calcite [3]. Of the 113 thin sections, only 12-18% are brecciated. This brecciation occurse over an elevation range of 176-206 m above sea level (ASL). Interestingly, stylolites, features indicative of pressure solutioning occur in 34% of the thin sections. Stylolites are present at Howell over an elevation range of 122-192 m ASL, which coincides with the same elevation ranges for Howell breccias.

XRD spectra have been collected for all 15 powdered samples from drill core #1. Of the six samples that have thus far been processed using the Rietveld peak refinement technique, only 2 of the spectra have FWHM values that deviate significantly from those of our unshocked calcite standards. The degree of peak broadening in those 2 samples coincides with the range of peak broadening observed in tectonically-deformed limestones from [8] and low shock-metamorphosed carbonates surrounding the central peak of the Sierra Madera structure [8]. They are not consistent with the level of peak broadening observed in shatter-coned carbonates from Sierra Madera [8], suggesting that they these 2 samples would not have been shocked to the peak pressures (3-10 GPa) thought to be involved in shatter cone formation [16]. This stand in contrast to the reported identification of shatter cones at Howell by [14].

Conclusion: Only limited evidence exists in support of an impact origin for the Howell structure (peak broadening in 2 of the 6 samples fully analyzed thusfar. Additional Rietveld analyses will undoubtedly provide more information in this regard. The notable lack of peak broadening, coupled with the absence of deformation common in other impacts and the limited abundance and distribution of breccias would suggest that, if an impact were responsible for the formation of Howell, it would have been a relatively small, resulting in very low (<3 GPa) peak pressures.

Field investigations by K. A. Milam and B. Deane have found no evidence for dipping strata or a deformed concentric rim surrounding the brecciated area that would be indicative of a crater rim. Although the postulated diameter does approach the simple-to-complex transition for terrestrial impact craters [17], there is no evidence for a structurally uplifted center, an observation earlier made by [14].

Although only circumstantial evidence exists to support an impact origin, it is possible that Howell may represent the remains of an impact crater whose most highly-shocked material and rim has been eroded away.

The presence of stylolites throughout most of the drill cores and their association with breccias, the limited abundance and spatial distribution of said breccias, and the monolithic nature of the breccias are all consistent with the formation of Howell by localized dissolution of Middle Ordovician limestones. Such dissolution would resulted in the collapse of strata overlying vacant solution cavities.

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