A PETROLOGICAL ASSESSMENT OF SHOCK DEFORMATION IN UPLIFTED CRATER WALL STRATA OF BARRINGER METEORITE CRATER, ARIZONA. Justine G. Grabiec[1,2], Martin Schmieder[1], and David A. Kring[1], [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058; [2]Department of Geological Sciences, University of North Carolina at Chapel Hill, Chapel Hill NC 27599 (jgrabiec@live.unc.edu).

Introduction: Impact cratering is a common deformational process affecting planetary surfaces. The most frequent products are simple, bowl-shaped craters. Perhaps the best preserved terrestrial example of a simple crater is Barringer Meteorite Crater (also known as Meteor Crater), Arizona [1]. The crater was excavated when shock and rarefaction waves radiated from the point of impact. Target materials that experienced sufficiently high shock pressures were melted and/or vaporized [2]. At lower shock pressures, a series of mineral transformations to high-pressure polymorphs as well as mineral-scale structural deformation occurred. Kieffer [3] reported shock pressures >20 GPa (200 kbar) in samples from the crater, but those samples were ejected and, thus, lack direct stratigraphic context. Although they can be found on crater walls [1], those stratigraphically unoriented samples do not reflect the shock pressures experienced by the crater walls. Instead, those ejected materials presumably originated relatively close to the point of impact, where shock pressures may have been close to 30 GPa [4]. As of now, the shock attenuation between the point of impact and the crater walls is not quantitatively constrained.

To address the uncertainty associated with the level of shock in the crater walls and to test new numerical models of crater formation [4], wall rock deformation has been evaluated petrographically. Determining shock pressures experienced by the crater walls also helps constrain the rheological properties of the rock as it was uplifted and overturned during crater excavation.

Target Strata: Meteor Crater is ~1.2 km in diameter, is ~400 m deep from the rim crest to the base of the breccia lens, and was excavated from sedimentary lithologies. The stratigraphically lowest units are the Coconino and Toroweap sandstones (hereafter referred to as Coconino), which are dominantly fine-grained, white, granular sandstones [1] ~210 to 240 m thick [5]. Unshocked Coconino is >95% unfractured quartz with visible overgrowths [2] and ~9 to 25% porosity [1]. Above the Coconino are a ~80 m-thick Kaibab (sandy carbonate) Formation and the Moenkopi (siltstone) Formation that formed the paleosurface struck by the impacting asteroid.

Samples: One-hundred-twenty-two thin-sections were prepared for petrologic studies. The Kaibab and Moenkopi Formations have carbonate minerals and/or small grain sizes that do not reliably record shock-produced features, so our study focused on 47 Coconino crater wall rock samples; 44 of those samples were collected in intervals of ~1 to 3 m upsection [6] from the east-southeast corner of the crater wall. Three supplemental samples were collected from outcrops of fractured rock on the eastern crater wall. The maximum depth of the sampled Coconino was ~120 m below the pre-impact surface, which is ~20 to 35 m above the water table at the time of impact (e.g., [1, 5, 7]), so our subset of the porous Coconino target rocks would not have been saturated with groundwater.

Methods: Thin sections were surveyed using a Leica DMLP optical microscope. Petrographic descriptions were created for each sample that include mineralogy; tectonic, sedimentary, and shock-related deformation features; and other characteristics. In particular, the samples were compared with those that Kieffer [3] previously categorized into shock Classes 1 through 5 (Table 1).

Results: Common deformation features include reduced porosity (1 to 20%), undulatory extinction in quartz (7 to 42°), percussion marks (Fig. 1a), offsets within quartz and feldspar grains, and bent or kinked sheet silicates. Interestingly, silica overgrowths were absent in some cases. Deformation was not, however, sufficient enough to destroy two-phase fluid inclusions (Fig. 1b), which disappear beyond Class 2 conditions (~5 to 8 GPa) [8]. All samples have quartz with undulatory extinction; 90% of the samples may have reduced porosity; only 62% contain remnant visible silica overgrowths; 35% contain bent or kinked sheet silicates; 21% have grains with internal offsets; and 6% contain percussion marks in quartz grains. The shock wave traveled through the target rocks in a heterogeneous fashion, as deformation features vary within and between thin sections of adjacent strata. Furthermore, there seems to be no correlation between shock levels

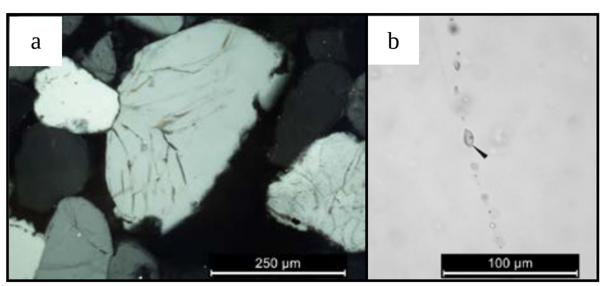

Figure 1: (a) Percussion marks (radiating fractures) in quartz. (b) Two-phase fluid inclusion in quartz. Cross-polarized light.

and stratigraphic height. All 47 samples can be classified as Class 1a (83%), Class 1b (11%), or, in some cases, both (6%).

Discussion: The characteristics and frequency of deformation features found in quartz, assuming they were produced by shock, can constrain the pressures experienced by crater wall rocks during impact. Class 1a samples resemble unshocked Coconino in that they contain visible silica overgrowths and some, albeit reduced, porosity. The presence of undulatory extinction in all 47 samples, however, is evidence for crystallographic strain, some of which may be attributed to shock pressures that are nominally below ~3 GPa, but possibly as high as 4.5 GPa. Class 1b samples also preserve visible silica overgrowths and contain undulatory extinction. However, in contrast to Class 1a rocks, Class 1b rocks lack porosity and contain percussion marks in quartz (Fig. 1a), which are interpreted as having been produced by grain collisions, preferentially at point contacts, as pore space was compressed [3]. That deformation occurs nominally below 5.5 GPa, but possibly at pressures as high as 13 GPa.

Neither coesite nor glass, characteristic of Class 2 rocks (Table 1), were observed in the Coconino crater wall samples. Shock pressures associated with coesite formation are ~5.5 to 13 GPa [3]; other Class 2 features are produced at pressures of ~5 to 8 GPa [8]. The absence of Class 2 features suggests pressures experienced by the crater wall rocks were at the lower end of that range; i.e., ≤5.5 GPa.

Table 1. (Top) Classes of Coconino Sandstone deformation with shock increasing down the table [3]. (Bottom) Shock pressures and associated deformation features and/or SiO_2 polymorphs [3]. Nominal values are those of Kieffer, while those in parentheses are “possible extreme values for upper limits” that Kieffer noted [3].

Class	SiO_2 Polymorphs and Deformation Features
1a,b	Quartz only; a) reduced porosity; no fracturing of quartz grains; b) no porosity; fractured quartz grains; small amounts of plastic deformation
2	No stishovite, little coesite and glass, mostly quartz; jigsaw puzzle-like fabric; symplektic pockets containing coesite
3	Little to no stishovite, some glass and coesite, mostly quartz
4	No stishovite, some quartz and coesite, mostly glass; vesicular
5	No stishovite, little to no coesite and (relic) quartz, mostly glass; vesicular

Pressure (GPa)	Dominant Deformation Features
0 to 0.2–0.9	Little grain damage
0.2–0.9 to ~3.0 (2.2–4.5)	Compressed pores
~3.0 to ~5.5 (3.6–13)	No porosity
~5.5 to 13	Small amount of coesite
13–30	High-pressure SiO_2 phases present
>30	Stishovite present; melted/fused silica

Fluid inclusions are a supplemental proxy for minimal degrees of shock experienced by the Coconino. Two-phase fluid inclusions are found in unshocked through Class 2 samples; once Class 3 conditions are reached, two-phase fluid inclusions begin to reequilibrate to form single-phase inclusions [8]. Based on the ubiquitous nature of two-phase fluid inclusion in the wall rock samples, Class 2 pressures were not exceeded, and likely not reached, in the crater wall.

We note that an alternative calibration based on experiments using a different sandstone with different degrees of porosity suggests the transition between Class 1b and 2 features occurs at 9 GPa (~25 to 30 vol. % porosity target) to 11.5 GPa (~12 to 19 vol. % porosity target) [9]. Those same experiments indicate impact pressures of 7.5 to 13 GPa produce planar deformation features (PDFs) in quartz. Likewise, they suggest diaplectic glass begins to appear at ~5 GPa. Because neither PDFs nor diaplectic glass were observed, pressures >5 GPa probably did not affect the crater wall. Although pore water increases the Class 1b to 2 transition shock pressure to ~22 GPa [9], the target rocks sampled here from the crater wall were dry.

Conclusions: Unlike the variably shocked material deposited in fall-back breccias, the crater wall rock experienced relatively low pressures during the impact. Using a variety of deformation features, we infer shock pressures <5 GPa. Most of the samples analyzed are likely on the lower end of this pressure range, because some porosity is still preserved.

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