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Extraordinary rocks from the peak ring of the Chicxulub impact crater: P-wave velocity, density, and porosity measurements from IODP/ICDP Expedition 364

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ABSTRACT

Joint International Ocean Discovery Program and International Continental Scientific Drilling Program Expedition 364 drilled into the peak ring of the Chicxulub impact crater. We present P-wave velocity, density, and porosity measurements from Hole M0077A that reveal unusual physical properties of the peak-ring rocks. Across the boundary between post-impact sedimentary rock and suevite (impact melt-bearing breccia) we measure a sharp decrease in velocity and density, and an increase in porosity. Velocity, density, and porosity values for the suevite are 2900–3700 m/s, 2.06–2.37 g/cm^3, and 20–35%, respectively. The thin (25 m) impact melt rock unit below the suevite has velocity measurements of 3650–4350 m/s, density measurements of 2.26–2.37 g/cm^3, and porosity measurements of 19–22%. We associate the low velocity, low density, and high porosity of suevite and impact melt rock with rapid emplacement, hydrothermal alteration products, and observations of pore space, vugs, and vesicles. The uplifted granitic peak ring materials have values of 4000–4200 m/s, 2.39–2.44 g/cm^3, and 8–13% for velocity, density, and porosity, respectively; these values differ significantly from typical unaltered granite which has higher velocity and density, and lower porosity. The majority of Hole M0077A peak-ring velocity, density, and porosity measurements indicate considerable rock damage, and are consistent with numerical model predictions for peak-ring formation where the lithologies present within the peak ring represent some of the most shocked and damaged rocks in an impact basin. We integrate our results with previous seismic datasets to map the suevite near the borehole. We map suevite below the Paleogene sedimentary rock in the annular trough, on the peak ring, and in the central basin, implying that, post impact, suevite covered the entire floor of the impact basin. Suevite thickness is 100–165 m on the top of the peak ring but 200 m in the central basin, suggesting that suevite flowed downslope from the collapsing central uplift during and after peak-ring formation, accumulating preferentially within the central basin.

1. Introduction

Present in the two largest classes of impact craters, peak-ring craters and multi-ring basins, peak rings are interpreted to develop from gravitational collapse of a central peak, and exhibit a circular ring of elevated topography interior of the crater rim (e.g., Grieve et al., 1981; Morgan et al., 2016). Surface topography can be observed for craters on the Moon and other rocky planets, but on Earth craters can also be characterized at depth by boreholes and geophysical studies. The Chicxulub impact crater is the only known terrestrial crater that preserves an unequivocal peak ring (e.g., Morgan et al., 1997, 2000), and can provide important information related to peak-ring formation with implication for how impacts act as a geologic process on planetary surfaces.

The Chicxulub peak ring has been imaged by a grid of seismic reflection profiles (Fig. 1), which constrain a morphological feature that rises ∼0.2–0.6 km above the floor of the central basin and annular trough and is overlain by ∼0.6–1.0 km of post-impact sedimentary rock (Morgan et al., 1997; Gulick et al., 2008, 2013) (Fig. 2b). Tomographic velocity images associate the uppermost 0.1–0.2 km of the peak ring with low seismic velocities (Fig. 2), which were interpreted as a thin layer of highly porous allogenic impact breccias (Morgan et al., 2011). Velocities 0.5–2.5 km beneath the peak-ring surface are reduced compared to adjacent material in the annular trough and central basin (Morgan et al., 2000, 2002), and were interpreted as highly-fractured basement rocks (Morgan et al., 2000), as predicted by numerical simulations of peak-ring formation (e.g., Collins et al., 2008).

The International Ocean Discovery Program and International Continental Scientific Drilling Program (IODP/ICDP) Expedition 364 drilled and cored the Chicxulub peak ring and overlying post-impact sedimentary rock from depths 505.7–1334.7 m below the seafloor (mbsf) (Morgan et al., 2017). Hole M0077A (Fig. 1) provides the ground-truth information calibrating our geophysical data and interpretations. Here we report the first P-wave velocity, density, and porosity measurements of the Chicxulub peak ring at scales ranging from centimeters to meters. We combine these results with existing geophysical data to gain insight into deposition of suevite (impact melt-bearing breccia (Stöffler and Grieve, 2007)) and impact melt rock (crystalline rock solidified from impact melt (Stöffler and Grieve, 2007)), and into the physical state of the peak-ring rocks.

2. Datasets

2.1. Surface seismic surveys

Deep-penetration seismic reflection surveys that image the Chicxulub impact crater were acquired in 1996 (Morgan et al., 1997) and 2005 (Gulick et al., 2008). These data include regional profiles and a grid over the northwest peak-ring region. Air gun shots fired for these two surveys were also recorded by ocean bottom and land seismometers (Fig. 1). The seismic reflection images are most recently summarized in Gulick et al. (2013). Morgan et al. (2011) used wide-angle seismic data recorded on the 6-km seismic reflection hydrophone cable (streamer) to produce high-resolution full-waveform inversion (FWI) velocity models of the shallow crust. The surface seismic data predicted the top of the peak ring at Hole M0077A at 650 mbsf (Fig. 2b).

In this study we focus on comparisons of Expedition 364 results with seismic reflection images and FWI velocity models. Vertical resolution in seismic reflection images (Fig. 2b) at the top of the peak ring is ∼35–40 m (one quarter of the ∼150-m seismic wavelength (e.g., Yilmaz, 1987) for a frequency of 20 Hz and velocity of 3000 m/s, which is the average P-wave velocity in the suevite). Spatial resolution for FWI velocity models at the top of the peak ring (Fig. 2a) is ∼150-m (half the ∼300-m seismic wavelength (Virieux and Operto, 2009) for the highest FWI frequency of 10 Hz and velocity of 3000 m/s (Morgan et al., 2011)).

2.2. Core measurements

P-wave and Moisture and Density (MAD) measurements were made on sample plugs with average volumes of ∼6 cm^3 at ∼1 m spacing throughout all the cores. P-wave velocities were measured using a source frequency of 250 kHz (wavelength of ∼1 cm at