Microstructural dynamics of central uplifts: Reidite offset by zircon twins at the Woodleigh impact structure, Australia

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The recent work of Cox et al. (2018) shows reidite lenses crosscut and offset by shock microtwin lamellae in zircon, clearly showing the order of events from a very short timescale. They explain that reidite formed at the peak shock pressure and that shock microtwins formed after shock pressure was released. However, the details of the interpretations and implications are imprecise. The paper over-interprets poorly constrained processes, leading to unwarranted assertions about processes in the central uplift of impacts.

Firstly, the choice to represent the interpretations on a pressure-temperature (P-T) diagram (Cox et al.’s figure 3) is unfortunate, as temperature is not constrained, and the results are entirely pressure dependent (Fig. 1). The authors do not explain where the temperature data in their P-T graph originated. The known constraints on zircon-to-reidite transition and microtwin formation are not strongly affected by temperature, and the temperature of transformation cannot be constrained. The uppermost post-impact temperature is constrained by the preservation of reidite, which decomposes at ~1200°C (Kusaba et al., 1985). A more appropriate temperature path might show that the temperature increasing after the passage of the shock wave, such that reidite formed closer to the initial ambient temperature of 200°C. The temperature of shock microtwin formation has no known relevant constraints.

Secondly, the shock pressure estimation of the Woodleigh core is problematic. Cox et al. state that the pressure must be ≥30 GPa based on the presence of reidite, but local effects can greatly influence the shock pressure on a small scale. Kowitz et al. (2013; 2016) have demonstrated that quartz glass, which forms at 45 GPa in single-crystal experiments, can form at shock pressures as low as 5 GPa in rocks with pre-existing porosity. Similarly, in the samples of Cox et al., reidite appears to form along fractures in the zircons. The closure of pre-impact fractures or pores in shock conditions would have greatly amplified the local shock pressure, so that even with the lowest shock estimate for the core of the Woodleigh structure (15 GPa), reidite could have formed. Thus, the study of Cox et al. does not “unambiguously” establish a minimum shock pressure.

Thirdly, the conditions of microtwin formation are poorly explained. The key distinction between reidite and microtwin formation is that reidite forms at high mean stress, while microtwins form at high differential stress (Fig. 1); this is alluded to in the text and figure 3 of Cox et al. The onset of high differential stress is coincident with the rarefaction wave removing the σ₃ stress. However, the authors repeatedly refer to the “rarefaction shock wave,” but a rarefaction wave is defined explicitly as, “a pressure wave, not a shock” (Melosh, 1989). This misunderstanding may have resulted in the inaccurate portrayal of shock microtwins forming with the central uplift and occurring at 20 GPa. However, the maximum differential stress between σ₁ and σ₃ occurs when the rarefaction wave catches the shock wave, or in other words at the end of the transient cavity formation, rather than during central uplift (Melosh 1989). Shock microtwins form at the moment of pressure release, when differential stress is at a maximum (Fig. 1). Once the rarefaction wave is acting upon a rock, the effective pressure of that rock is negligible (allowing the central uplift to form), not 20 GPa. The central uplift is clearly not required for shock microtwins to form, as they are found in impact craters that do not have central uplifts, such as Meteor Crater (Cavosie et al., 2016).

Furthermore, the experimental constraints on formation of shock microtwins are not well determined, and the current experimental work is not appropriate for comparison with natural shock conditions. The recent work of Morozova et al. (2018) suggests that microtwins may nucleate at <11 GPa under static conditions, which are vastly different than the dynamic conditions of shock metamorphism. Taking into account that the microtwin lamellae in zircon have not yet been discovered in tectonic settings, the significance of Morozova et al. (2018) remains to be told. Therefore, the estimate that Cox et al. use for microinam formation (~20 GPa) is rather loose.

The study by Cox et al. is fascinating, and demonstrates an amazing discovery of timing relationships between reidite and shock microtwins. We suggest, however, that readers not assume that the presence of shock microtwins in zircon suggests a central uplift, and to carefully interpret Cox et al.’s figure 3.

REFERENCES CITED