FORMATION OF IMPACT COESITE

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Introduction: Coesite is one of the most common and reliable indicator of shock metamorphism associated with impact cratering in quartz-bearing target rocks. For this reason, coesite is the subject of numerous studies aiming to better understand how silica polymorphs react under sudden and extreme P-T increases. In impact rocks, coesite is preserved as a metastable phase in crystalline rocks that experienced peak shock pressures above ~30-40 GPa [1] and in porous sedimentary rocks shocked at pressures as low as ~10 GPa [2]. Furthermore, impact-coesite generally forms aggregates of microcrystalline grains scattered within silica amorphous material known as "symplectic regiorns", and shows a characteristic polysynthetic twinning on (100) with the composition plane (010) [3]. There is a general consensus that the characteristic twinned impact-coesite is the result of crystallisation from a dense amorphous phase, either silica shock melt [1] or highly densified diaplectic silica glass [4], during shock unloading, when the pressure release path passes through the coesite stability field. In contrast to these models, the coesite transformation mechanism through a direct solid-state transition from quartz was suggested the first time by [5] studying shocked Coconino sandstones from the Barringer crater (Arizona, USA). Our recent FESEM-TEM study, performed on impact ejecta from Kamil crater in Egypt and the Australasian tektite strewn field, confirms that the impact coesite forms through direct quartz-coesite transformation [6,7,8].

Samples and methods: Samples are from two different impact sites including a shocked porous sandstone from Kamil crater (Egypt) and two coesite-bearing quartz ejecta from the Australasian tektite/ microtektite strewn field (ODP site 1144A and Sonne Core SO95-17957-2). All samples were investigated using field emission gun – scanning electron microscopy (FEG-SEM), and then 5 electron-transparent lamellae from the Kamil crater shocked sandstone and 3 lamellae from the Australasian coesite-bearing ejecta were exctracted using focused-ion beam (FIB). These lamellae were investigated by transmission electron microscopy (TEM) and 3D electron diffraction (3D ED) [9] for nano-petrographic and crystallographic analyses. Remarkably, both samples experienced relatively fast cooling, which preserved shock metamorphic mineralogies and textures only slightly altered by post-impact melting, (i.e., virtually unaffected by post-shock annealing and/or hydrothermal overprint).

Results and discussion: In Kamil ejecta we found rounded single-crystal coesite domains of 200 nm or less. These domains are surrounded by shocked quartz, without any amorphous phase in-between. We also observed larger coesite domains. The larger the domains, the more they appear fragmented and progressively dispersed and resorbed in amorphous silica. Our observations suggest that coesite seeds nucleate and grow inside quartz during pressure uploading, probably favored by shock-wave reverberation. Later, when pressure is released and temperature is still high, coesite domains fragment and melt giving rise to the "symplectic regions" observed – for instance - at Barringer [5], Yilan [10], Lonar [11], Cheasapeak Bay [12]. In impact ejecta from the Australasian tektite strewn field, we again observe coesite crystals embedded in shocked quartz. Coesite crystals have well-developed euhedral habits, which grow at the expense of neighboring quartz and appear to postdate PDFs and other planar microstructures. In both ejecta, 3D electron diffraction reveals coesite grains displaying a recurrent crystallographic relation with quartz, with (010) coesite plane parallel to {10-11} or {-1011} of quartz. Such evidence suggests a topotactic relation between shocked quartz and impact coesite. The direct quartz to cosite subsolidus reaction is facilitated by the presence of pre-existing and shock-induced discontinuities in the target. Shock wave reverberations can provide pressure and time conditions for coesite nucleation and growth. Because discontinuities occur in both porous and non-porous rocks and the coesite formation mechanism appears similar for small and large impacts, we infer that the proposed subsolidus transformation model is valid for all types of quartz-bearing target rocks.

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