Geophysical Research Abstracts
Vol. 13, EGU2011-461, 2011
EGU General Assembly 2011

Carbonate melt lithologies from the Steinheim impact structure (Baden-Württemberg, Germany)

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The ~3.8 km Steinheim impact structure, hosted by a thick suite of Triassic to Upper Jurassic sedimentary rocks of the Swabian Alb plateau (SW Germany), counts among the best-preserved small, complex impact structures with central uplift on Earth [1;2]. Although studied for decades and intensely drilled since the 1960s [3], no impact melt lithologies were known from this impact crater until the recent report of melt-bearing suevitic impact breccias in the B-26 drill core [2]. We newly investigated this core drilled in the western central annular basin of the Steinheim Basin in the search for potential new carbonatic melt lithologies (compare [4]).
An optical and SEM-based reinvestigation of microscopic impact melt particles in the B-26 core (carbonatic suevitic impact breccia at depth 76-77 m) revealed numerous minute, droplet-shaped to partially fluidal, and rarely honeycomb-textured Ca-carbonate domains (accompanied by monomineralic, fluidal silica patches and spinifex-textured Fe-Ni-Co sulfides) embedded in melt particles largely transformed into phyllosilicates [2]. SEM-EDX analyses yielded an essentially pure calcite composition of the monomineralic Ca-carbonate melt patches. The microtextural characteristics of these melt domains suggest that calcitic limestone (or larger calcite crystals) as constituents of the target rock were molten upon impact (see also [2] and review by [5]). Similar impact breccias were encountered in shallower, coherent parts of the B-26 core (46-48 m and 52-53 m, respectively).
At a depth of 78-79 m, closely beneath the structural crater floor of the Steinheim Basin, the B-26 drill core consists of fractured and brecciated parautochthonous Upper Jurassic limestone of the subcrater target rock. Macroscopic fractures in the limestone are filled with brownish, partially fluidally-textured veins of Ca-Mg-carbonates. Numerous calcitic and dolomitic clasts, set into a crypto- to microcrystalline 'dolomitic' Ca-Mg-carbonate groundmass poor in vesicles, are commonly well-rounded (in some cases nearly spherical to lenticular), often show 'crackeled' textures, and are marginally decomposed into micro- to cryptocrystalline aggregates of Ca-Mg-carbonates. The vein groundmass is, furthermore, host to idiomorphic and spherule-shaped Fe-sulfides and rare, micrometer-sized, Fe-Ni spherules (compare [2;6]). Electron microprobe and SEM-EDX measurements yielded detectable enrichment in Al and Si (locally >3 wt% Al2O3 and SiO2 in total, dominant in interstices) within the dolomitic groundmass.
The petrographic characteristics of the fluidal Ca-Mg-carbonatic veins and clasts therein suggests that they formed as local carbonate melts, injected into open target rock fractures. This interpretation is in accord with the admixture of Ni-rich spherules presumably inherited from the (iron meteoritic?) Steinheim impactor [2;6], the crystallization of idiomorphic and spherule-shaped Fe-sulfides from a liquid, the marginal melting and decomposition (thermal corrosion and/or degassing) of limestone clasts, the injection of the vein groundmass material into SEM-scale microfractures within the adjacent wall rock limestone, and the incorporation of resolvable amounts of Si and Al into the Ca-Mg-carbonate groundmass [7].
Based on our observations on the B-26 drill core, we conclude that the Steinheim impact produced smaller amounts of carbonate melts, either as monomineralic calcitic patches within mixed-melt particles in the Steinheim suevite, or as veins of impact melt rocks predominantly generated from dolomitic parts of the Steinheim target rock and subsequently injected into host limestone fractures. The occurrence of such melts might be in some analogy to the carbonatic impact melt rocks reported from the ~24 km Haughton impact structure, Canada [7]. A search for periclase (MgO) as a dolomite decomposition product (e.g., [5]) is projected. In context with the generally low pressure estimates for the Steinheim impact event (numerous shatter cones but very rare shocked quartz grains [2]), which might be ascribed to a distinct 'shock buffering effect' due to a water-saturated, deeply karstified (i.e. highly porous) target in the Miocene [8], we suggest that shock metamorphism and target rock melting at Steinheim was dominated by comparatively high post-shock temperatures [2].

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