POROSITY: THE REASON FOR SiO_2 MELT FORMATION AT EVEN 5 GPa SHOCK PRESSURE. EXPERIMENTS WITH TARGETS OF 3 DIFFERENT POROSITIES VS MESOSCALE MODELING.

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Introduction: The identification of impact craters formed in porous sandstone targets, on the basis of recognition of shock deformation features, is a complex task, especially concerning the interaction of the shock wave with open pores. There is a serious lack of diagnostic shock features, particularly for the low shock-pressure range, which is addressed in this project focusing on shock deformation experimentally generated in porous sandstone and for comparison in dense quartzite at pressures of <20 GPa. We aim to establish a shock classification scheme for porous, quartz-bearing rocks. The laboratory impact experiments were accompanied by meso-scale numerical modeling and enable a detailed description and quantification of thermo-dynamic parameters during single pore collapse.

Methods: Three series of shock recovery experiments (impedance method) [1] were conducted from 2.5 to 17.5 GPa with cylinders of two different layers of dry Seeberger sandstone (L3, porosity Φ ~25-30 vol.% (Fig. 1a); L5, Φ ~12-19 vol.%) and a quartzite (< 0.2 vol.% Φ). Numerical models were computed with the hydrocode iSALE [2] coupled with the ANEOS for quartzite [3] using a virtual experimental set-up similar to the experimental one.

Results: The determined fracture density shows that until 12.5 GPa the dense quartzite is significantly less fractured (143 f/mm) than the porous sandstone (~209 f/mm) followed by an increase in fracture density up to 17.5 GPa (277 f/mm). In contrast, the samples of L3 achieve their peak fracturing at 12.5 GPa (209 f/mm) followed by a decrease to 17.5 GPa (113 f/mm). The number of fractures in the L5 samples is intermediate between quartzite and L3. Backscattered electron (BSE) SEM images demonstrate that in the sandstones pores are entirely closed even at an initial shock pressure of only 2.5 GPa. Here, we have observed diaplectic quartz glass and/or SiO_2 melt, both of which are distributed heterogeneously (Fig. 1b); these phases rarely occur at 5 GPa (L3) but increase in frequency up to ~85 vol.% (L3) at 17.5 GPa. In the sandstone samples with lower porosity (L5) the onset of glass formation starts at higher pressures (7.5 GPa) and does not reach such high amounts. In contrast, within the quartzite there is no glass/melt formation up to 17.5 GPa. The meso-scale numerical models also show a complete closure of pores already at low initial pressures (<6 GPa). Detailed analysis of the closure of single pores indicates localized amplifications of shock pressure up to 3-4 times the average shock pressure in the porous material (Fig. 1c).

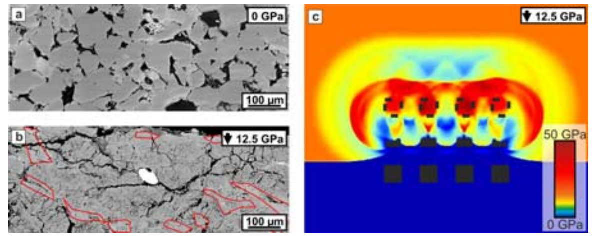

Fig. 1. SEM-BSE images of **(a)** unshocked and **(b)** shocked (12.5 GPa) Seeberger sandstone (L3). Note the total closure of pore space, the intense fracturing, and the heterogeneous distribution of diaplectic quartz glass and/or SiO_2 melt (red-framed areas). **(c)** Shock pressure distribution during pore collapse (snapshot). Note the total closure of pores (black) and the pressure amplification up to 4 times (dark red) at locations of primary pores.

Discussion: Shock compression of porous sandstone results in distinctly different effects than observed in non-porous rocks, especially at low shock pressures. Despite our low shock pressures, the formation of diaplectic quartz glass and SiO_2 melt was observed in L3 already at 5 GPa, whereas these phases usually occur only at 30-35 GPa and >45 GPa, respectively, in shocked quartz single crystals [1]. Furthermore, their amount decreases distinctly with decreasing porosity because the crushing mechanism is strongly dependent on porosity and leads to a distinctly heterogeneous distribution of localized shock pressure and temperature amplification in the target and therefore to a heterogeneous distribution of shock effects (e.g., fractures, local occurrence of diaplectic quartz glass and SiO_2 melt) (Fig. 1b, 1c). Our attempts at quantification of shock amplification (up to 3-4 times) due to pore space collapse using meso-scale modeling are in good agreement with observations on our shock experiments. According to Kieffer et al. [4] our samples of L5 can be classified by their amount of glass/melt to shock stage 1b, which then does not agree with their proposed pressure estimations. The samples of L3 can be classified to stage 1b to 3, which partly agrees with their shock pressure estimations. Nevertheless, a first step in improving a classification scheme for porous sandstone has been achieved.

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