LOW SHOCK PRESSURE RECOVERY EXPERIMENTS WITH DRY SANDSTONE SAMPLES WITHIN THE MEMIN RESEARCH PROGRAM.

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Introduction: The Multidisciplinary Experimental and Modelling Impact research Network (MEMIN) is focused on large-scale cratering experiments with sandstone samples, which will be investigated for (i) a better understanding of impact damaging of rocks and the nature of geophysical signatures of shocked rocks/impact structures, and (ii) the validation of hydrocodes used in the simulations of impact processes [1]. Within the MEMIN program our sub-project investigates shock effects in quartz in the low shock pressure range <5 to 15 GPa and the influence of porosity and water saturation on progressive shock metamorphism.

Shock experiments: Shock recovery experiments were carried out with Seeberger sandstone (layer 5) with a grain size of 0.17 ± 0.01 mm and a porosity of ~18 vol.% [2]. This sample material is identical to the material used in the MEMIN feasibility study [2]. For the shock experiments the well known experimental set-up of the Ernst-Mach-Institute in Freiburg, Germany, with a high-explosive driven flyer plate generating a plane shock wave was used, e.g. [3, 4]. The experiments were carried out with dry cylinders of Seeberger sandstone (diameter 1.5 cm, length 2.0 cm) using the shock impedance method to avoid multiple reflections of the shock wave within the sample material. The shock pressure in the sample is determined by graphic impedance matching using the known shock pressures in the container material at the contact to the sample and Hugoniot data of the sample material [3]. For shock pressure determination we applied the Hugoniot data of Coconino sandstone [5], which leads to an unknown error in shock pressure determination with respect to the actual sample material, for which Hugoniot data are not yet determined. The experimental parameters are summarized in Table 1.

Table 1: Compilation of experimental parameters.

Experiment	1-1	1-2	1-3	1-4
Cover plate [mm]	6.5	15.0	10.0	8.5
Flyer plate [mm]	4	4	4	3
High explosive	TNT	Comp. B	Comp. B.	Comp. B
Shock pressure at basis of ARMCO iron driver plate [GPa]	18.4	25.0	33.5	42.5
Shock pressure at top of sandstone cylinder [approx. GPa]*	5	7.5	10	12.5

* based on Hugoniot data for Coconino sandstone [5].

Results: The shocked sandstone samples show at the microscopic scale a near-complete closure of the pore space and some irregular intergranular fractures. Quartz grains of the unshocked sample show sharp and undulatory extinction under crossed polarizers. In contrast, in the shocked samples quartz grains display mainly undulatory extinction at 5 GPa and weak mosaicism at 7.5, 10 and 12.5 GPa.

All quartz grains in the shocked samples display intense intragranular fracturing. The fracture density of quartz is significantly higher than in the unshocked sample, increasing towards the sample shocked at 7.5 GPa, and thereafter, at even higher pressures remaining at a more or less constant level up to 12.5 GPa (Table 2). Irregular and roughly planar fractures could be observed together in the quartz grains of the shocked samples (e.g., Fig. 1), which makes it difficult to unambiguously separate the respective densities of these two types of fractures. Nevertheless, in the sample shocked at 5 GPa quartz grains display usually only one set of roughly planar fractures, whereas at 7.5, 10 and 12.5 GPa two or more sets could be observed. The angles between the orientations of near-planar fractures and the shock wave propagation are frequently 40-50° and/or 0-15°. The spacing of the roughly planar fractures shows a great variability within a range from <10 to 60 µm.

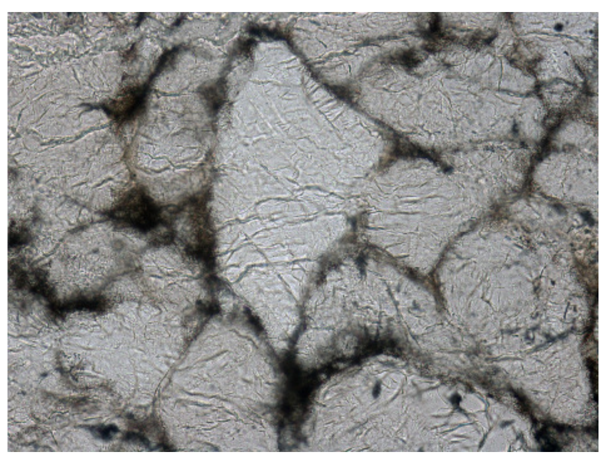

Fig. 1. Seeberger sandstone experimentally shocked at a shock pressure of ~7.5 GPa (experiment 1-2) displaying intense fracturing of quartz grains. The quartz grain in the center shows irregular and roughly planar fractures (the latter orientated NW-SE, with spacings of 20-30 µm); plane polarized light, width 570 µm.

Table 2: Fracture density of quartz grains in experimentally shocked Seeberger sandstone.

Shock experiment		1-1	1-2	1-3	1-4
Shock pressure [GPa]	unshocked	5	7.5	10	12.5
Fracture density [fratures/μm^2]					
Mean	<0.0002	0.0026	0.0044	0.0042	0.0039
Stand. dev.		0.0006	0.0009	0.0008	0.0006

Besides these two types of fractures, a typical combination of fractures was also observed in the shocked samples (Fig. 2). This combination consists of a characteristically longer (in same cases as long as the diameter of the quartz grain) fracture which is oriented mainly at an angle of 40-50° to the shock wave propagation. This fracture occurs together with a set of roughly parallel, shorter fractures, which have a spacing of 5-20 µm and are oriented at angles of 40-90° to the main fracture. The set of shorter fractures is generally not oriented at an angle of approximately 90° to the shock wave propagation, an observation that has been made for feather features [6]. Nevertheless, typical feather featureas as described by [6] could not be observed within these shock experiments.

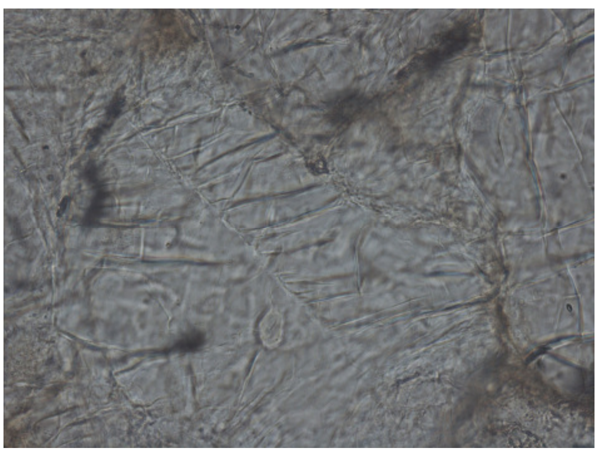

Fig. 2. Seeberger sandstone experimentally shocked at a shock pressure of ~5 GPa (experiment 1-1) with a quartz grain with a typical combination of fractures. One long fracture is oriented NW-SE, a set of roughly parallel fractures with a spacing of 5 to 15 µm is oriented at an angle of 55-70° to the long fracture yielding a configuration similar but seemingly not identical to that of feather features [6]; plane polarized light, width 230 µm.

Subplanar microfeatures which show strong similarities to planar deformation features (PDF) could only be observed locally at the edge of the sandstone cylinders shocked at pressures of ~10 and 12.5 GPa. As shock pressure outliers caused by the geometry of the experimental set-up can not yet be excluded, these features are not taken into consideration at this point.

Discussion: These shock experiments with Seeberger sandstone have produced shock features in quartz as known from shock experiments with quartz single crystals and quarzites, e.g., [3, 7, 8]. Nevertheless, in the porous sandstone the onset of planar fracturing in quartz is at a slightly lower shock pressure and the frequency of planar fractures is higher than in quartz single crystals and quartzite. Based on the shock classification system of porous sandstone [7, 9-11] the experimentally shocked samples belong to shock stages 1b (5 GPa) and 2 (7.5, 10 and 12.5 GPa). For the shock stages 1b and 2 shock pressures of ~3 - ~5.5 GPa and ~5.5 – 10 GPa, respectively, were estimated by [9] based on shocked Coconino sandstone. For shock stage 2 (pressure range ~5.5 - ~10 GPa) [9] and [11] observed in shocked Coconino sandstone and carbonate-bearing sandstone with a porosity of up to 23 vol.%, respectively, the common occurrence of PDF and up to 20 vol.% quartz glass, and high pressure phases, which were not recognized in our shock experiments. For shock stage 3 (pressure range ~10 - ~15-20 GPa after [9]) frequently mulitiple sets of PDFs and up to 50 vol.% quartz glass and high pressure phases were reported. These differences might be caused by the lower porosity of the Seeberger sandstone (18 vol.%) used in the shock experiments in comparison to Coconino sandstone (25 vol.%) and carbonate-bearing sandstone (up to 23 vol.%), respectively, or is a general effect due to the differences in pressure pulse duration and post-shock temperature between experimental shock and natural shock events.

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