SHOCK CLASSIFICATION OF POROUS QUARTZ-RICH ROCKS – IMPROVED CLASSIFICATION AND NEW CALIBRATION

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Introduction: The shock classification and calibration of porous, quartzose rocks [1] such as sandstone has been based on observations on Coconino sandstone samples from Meteor Crater by Kieffer et al. from the 1970s [2,3], and these findings have never been checked since. Our research within the framework of the MEMIN Research Group is focused on diagnostic shock features experimentally generated in quartzose, porous rocks at low -shock pressures. The *laboratory impact experiments* were accompanied by *meso-scale numerical modeling.* The ultimate aim was to improve the shock classification and calibration for such rocks.

Methods: Four series of *shock recovery experiments* with the impedance method [4,5,6] were conducted, with two dry Seeberger sandstone sample suites of different porosities (L3 – Φ 25-30vol.%, L5 – Φ 12-19vol.%), a near-completely water-saturated sandstone of L3 composition, and a quartzite of porosity < 0.5 vol.%. *Numerical modeling* used the multi-material, multi-rheology hydrocode iSALE [7] coupled with the ANEOS for quartzite [8], and a virtual experimental set-up similar to that used in the experiments.

Results: The experiments clearly show that shock compression of porous sandstone results in a strongly heterogeneous distribution of shock deformation and transformation features that, in non-porous rocks, are generated in a distinct progressive sequence. In porous quartzose rocks an onset of formation of diaplectic quartz glass, SiO_2 melting, and generation of high-pressure phases are observed at much lower shock pressures than in quartz single crystals. Porosity has a very strong effect on the formation of shock deformation features: Increasing porosity, in comparison to non-porous quartzite or water-saturated sandstone, leads, e.g., to the replacement of fracturing by melting at comparatively lower shock pressures; and onsets of formation of higher amounts of diaplectic quartz glass and/or SiO_2 melt at distinctly lower shock pressures. Following evaluation of our numerical modeling, these observations can be explained as a result of pore-crushing processes leading to local pressure amplifications of up to 4 times the nominal experimental shock pressures - attained in non-porous rock [6].

Discussion: These findings require a thorough revision and recalibration of the previous shock classification scheme for porous sandstone. In a first step we have revised the shock stages of the former classification scheme [2,3], whereby shock stages 0, 1a, and 1b can be retained more or less without changes (Table 1). The classification into shock stages 2 to 4 is based on the aggregate abundances of diaplectic quartz glass + SiO_2 high-pressure phases, and/or SiO_2 melt, all of which can be easily determined by thin section analysis. The boundaries between shock stages 1b+2, 2+3, 3+4, and 4+5 are set at 2, 20, 50, and 85 vol.% for this aggregate parameter, respectively, also referring to the original values of [2]. Shock stage 5 is indicated furthermore by presence of a vesicular, pumice-like texture. We have calibrated this revised classification scheme based on our experiments and numerical modeling (Fig. 1). The limits between shock stages depend on the individual porosity of a given sample. There are strong differences between this new calibration scheme and the pressure estimations originally given by [2,3]. Thus, for shock classification and shock calibration of porous natural samples, the original porosity (and water content) of the unshocked material has to be determined before shock calibration can be attempted.

Shock stage	Shock effects	Amount of diapl.qz glass, SiO_2 melt + high pres. phases of SiO_2 [vol.%]		Equilibrium Shock pressure [GPa]		
		Coconino	Seeberger Sst	Coconino Sst Φ ~25 vol.%	Seeberger Sst L3 Φ ~25-30 vol.%	Seeberger Sst L5 Φ ~12-19 vol.%
0	Undeformed sandstone					
				0.2-0.9	—	—
1a	Compacted sandstone with remnant porosity					
			0	~3.0 (2.2-4.5)	< 1.5	< 2.5
1b	Compacted sandstone compressed to zero porosity	<10				
			2	~5.5 (3.6-13)	9	11.5
2	Dense (non-porous) sandstone with diaplectic quartz glass, SiO_2 melt, SiO_2 high-pressure phases, SiO_2 glass (lechatelierite), and quartz	11-16				
			20	~13	14	16.5
3		22-47				
			50	~30	16	19
4		62-82				
			85		18	21.5
5	Vesicular (pumiceous) rock with dominant SiO_2 glass (lechatelierite)					

Tab. 1. Comparison of shock classification and calibration of the Coconino sandstone data [2,3] with our results for experimentally shocked Seeberger sandstone.

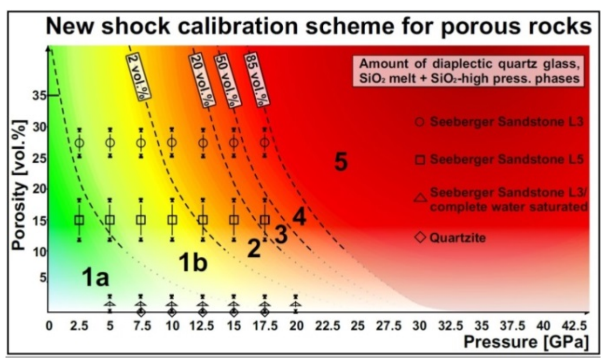

Fig. 1. Calibration of shock stages 1a to 5 for porous sandstone as a function of variable porosity. Isolines represent various amounts of diaplectic quartz glass, SiO_2 high-pressure phases, and SiO_2 glass/melt, and indicate the limits between shock stages 1b to 5.

References: [1] Stöffler D. and Grieve R.A.F. (2007). *Metamorphic Rocks - a Classification and Glossary of Terms,* pp. 82-92. Chapter 2.11, Cambridge University Press. [2] Kieffer, S. W., 1971. *Journal of Geophysical Research* 76:5449-5473. [3] Kieffer S. W. et al. (1976) *Contributions to Mineralogy and Petrology* 59: 41-93. [4]Stöffler D. and Langenhorst F. (1994) *Meteoritics & Planetary Science,* 29: 155-181. [5] Kowitz A. et al. (2013) *Meteoritics & Planetary Science* 48: 99-114. [6] Kowitz A. et al. (2013) *Earth and Planetary Science Letters* 384: 17–26. [7] Wünnemann K. et al. (2006) *Icarus* 180: 514–527. [8] Melosh H.J. (2007) *Meteoritics & Planetary Science* 42: 2035–2182.