THE EFFECT OF POROSITY ON IMPACT MELT PRODUCTION K. Wünnemann[1], and G. S. Collins[2], [1]Museum für Naturkunde, Humboldt-Universität, Berlin 10099, Germany, kai.wuennemann@museum.hu-berlin.de, [2]Impacts and Astromaterials Reseach Centre, Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, UK, g.collins@imperial.ac.uk .

Introduction: Melting of rocks during impact cratering is a common process that results from shock wave compression and subsequent release from high pressure. Shock molten material is found in most terrestrial craters and the total volume and distribution of shock melt is well documented at craters in crystalline targets [1]. Hydrocode modeling has been used to develop scaling laws for melt production in an impact event [2] and there is good agreement between the modeling results and estimated melt volumes from craters in crystalline targets.

Whether rocks undergo melting during an impact event depends on the peak pressure of the induced shock wave. In experimental studies the pressure for incipient and complete melting has been determined for different materials, e.g. for granite P_{inc}=46 GPa and P_{com}=56 GPa [2]. Therefore the total melt volume corresponds to the volume of material shocked above a certain threshold pressure which is roughly a hemisphere enclosed by the expanding shock wave.

This concept has been successfully used to determine melt production in crystalline rocks with low or negligible porosity, but it does not work for sedimentary targets which often contain significant open pore space. Porosity affects shock and post-shock temperatures and thus melting. In this study we quantify the effect of porosity on impact melt production by hydrocode modeling of impact cratering and shock wave propagation in porous targets of various composition.

Numerical Model: We utilized a newly developed porosity compaction model [3] which was implemented in the well known hydrocode iSALE [3,4,5]. The thermodynamic behavior of the material is described by an equation of state (EoS). We used ANEOS [6] for quartzite and calcite, which are the dominant components in sedimentary (porous) targets on Earth. The compaction of pore space and the thermodynamic state are computed separately in our model; therefore the accuracy of our results depends in large part on the quality of the appropriated EoS (ANEOS). To test the model we calculated hugoniot curves for quartzite and calcite for different initial porosities by simulating simple planar impact experiments and compared the results with experimental data (Fig.1). The overall agreement is quite good. However, for quartzite some discrepancy between the model and experimental data occurs in a range between 20-30 GPa, where quartz undergoes a solid-state phase transition. In the porous case (red dots) the phase transition happens at lower pressure, which might be thermally induced, because porous material experiences higher temperatures than competent rock for similar shock pressures.

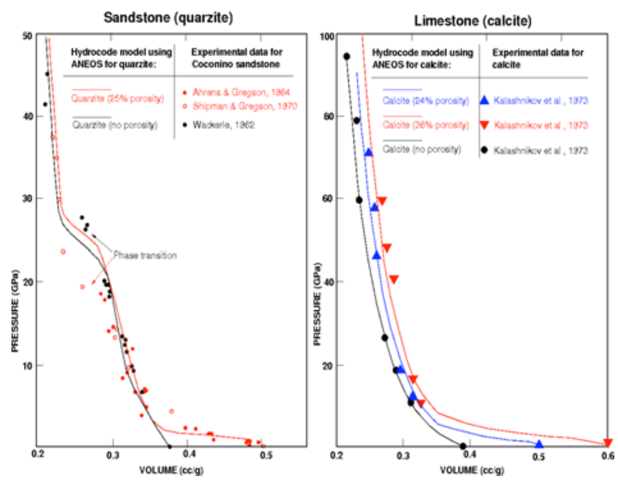

Fig 1: *Hugoniot curves for different porosities of sandstone (left) and limestone (right).*

Determination of melt pressure for porous material: Our modeling results show that the crushing of pore space is an effective mechanism for absorbing shock waves and results in higher post-shock temperatures than observed in nonporous rocks. Consequently lower peak shock pressures are required to induce melting in porous rocks. To determine the "critical pressure" where melting occurs we conducted a suite of numerical (planar) impact experiments. The recorded thermodynamic path experienced by the material during the passage of the shock wave is shown in Fig. 2 for 44% porous quartzite. The melt temperature (solidus) was computed according to the Simon approximation [7]. The measured critical pressures P_{crit} for quartzite and calcite for different porosities are listed in Tab. 1. For quartzite, melting occurs after release from high shock pressure. In case of calcite the temperature during shock wave compression as well as the post-shock temperature can be above the solidus (pressure range for calcite in Tab. 1). The analysis of experimental shock compression data and theoretical considerations have shown that calcite may decompose into CaO and CO_2 [8] and that degassing instead of melting may be the dominant effect [9]. However, this is an ongoing discussion [10] and beyond the scope of this study. The provided pressure ranges listed in Tab. 1 should be understood as an estimate of the effect of porosity on shock melting/degassing and not as a precise determination of P_{crit}.

Tab 1: *Modelled shock pressure P_{crit} required to induce melting/degassing during and/or after shock compression (Experimental measurements in brackets for comparison)*

Porosity	P_{crit} Quartzite [GPa]	P_{crit} Calcite[c] [GPa]
0 %	69 (~50-65[a])	92-113
9 %	54	64-85
25 %	37 (~35[b])	35-45
44 %	15	13-18

[a] Quartz, Stöffler (1972)
[b] Coconino Sandstone, Kieffer (1971)
[c] P_{crit}=55 GPa ANEOS output, Pierazzo et al. (1998)

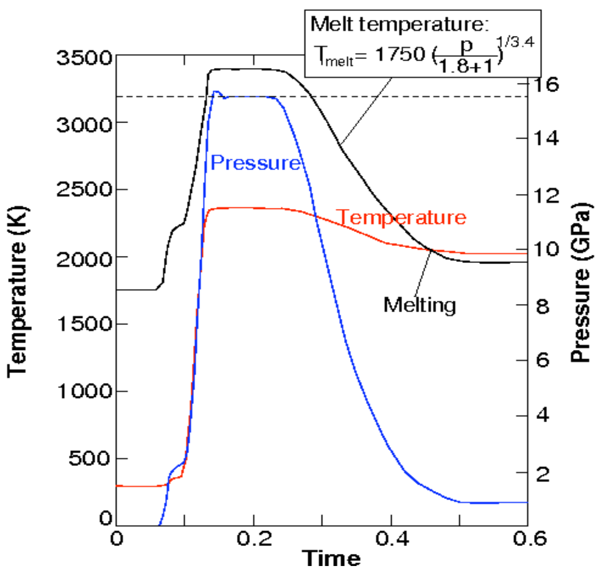

Fig. 2: *Thermodynamic path (pressure, temperature, and melt-temperature) experienced by a material tracer during the passage of a shock wave. The material is 44% porous quartzite. The parameters for the Simon approximation to calculate melt temperature as function of pressure were taken from [8]*

Production of impact melt in porous targets: The critical pressures listed in Tab. 1 were used to determine the volume of shock melting in an impact event. Fig. 3 shows how melt volume changes as a function of initial porosity in the target (the projectile was assumed to have zero porosity in all model runs). For quartzite the melt volume increases by ~0.5 between 0% and 25% porosity. At 33% porosity the melt volume has a local maximum of more than 2 times of the initial melt volume (0% porosity). The melt volume in calcite increases almost monotonically by more than an order of magnitude between 0% and 50% porosity.

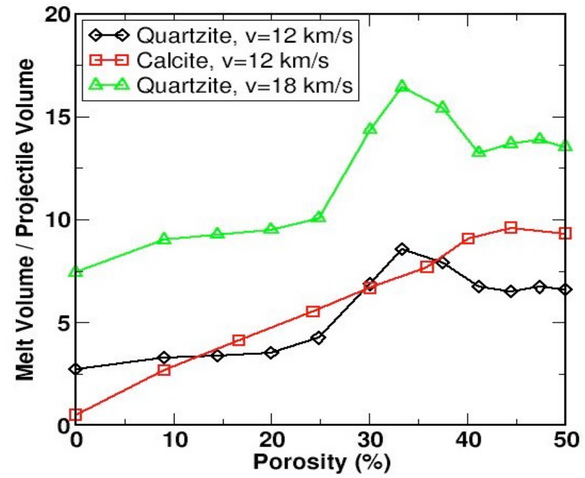

Fig. 3: *Melt volume relative to projectile volume as a function of porosity for quartzite and calcite.*

Conclusion: Our results show that the presence of porosity significantly reduces the critical pressure required for melting and thus enhances melt production during an impact event. However, as porosity increases the net increase in melt produced is limited due to two competing factors. First, porous materials are effective shock absorbers; with increasing porosity the amplitude of the shock wave is reduced. Second, as porosity increases the volume of *solid* material that can be melted decreases.

Our model results contradict observations of shock melt at most terrestrial craters in sedimentary targets, (e.g. Bosumtwi, Ries), which show a deficiency in impact melt relative to craters in crystalline targets. However, the presence of pore water may completely alter the effect of porosity on melt production. So far, we have only considered dry-porosity in our models. A much better understanding of shock-wave thermodynamics in porous, wet rocks is required to explain melt production in sedimentary targets.

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