RECORDING AND ANAYLIS OF SEISMIC SIGNALS GENERATED BY HYPERVELOCITY IMPACTS FROM NUMERICAL MODELING AND LABORATORY EXPERIMENTS.

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Introduction: Upon impact of a cosmic object on Earth, Mars, Moon or any other planetary body the vast majority of the kinetic energy of the impactor is partitioned into crater excavation and the ejection of material, target deformation, light emission, and the shock wave-induced heating of matter and only a small amount of energy is converted into seismic energy. This study aims at a better quantification of how much of the impact energy is turned into seismic energy and how fast seismic waves attenuate in particular in materials of different properties. This can be quantified by the seismic attenuation factor (Q) and the seismic efficiency (k), both of which strongly depend on material properties. A better quantitative understanding of the characteristics of seismic signals (k and Q) will allow for (1) the prediction of the magnitude of impact-induced earthquakes and (2) the quantification of seismic signals after natural or artificial impacts. Here we present numerical simulations performed within the *Multidisciplinary Experimental and Modeling Impact Research Network* project (MEMIN) [1] in order to analyze the seismic signal induced by an impact event on the small scale and to quantify seismic parameters in dependency of target properties. The objectives of this work are (1) the calibration of the numerical model using real-time measurements; (2) the quantification of seismic parameters for materials of different porosity and water saturation by using the calibrated numerical models.

Methods: To simulate laboratory experiments and quantify the seismic parameters we used the iSALE-2D shock physics code [2]. iSALE uses the equation of state model ANEOS to simulate the thermodynamic response of the materials (iron, quartz) to shock wave compression [3]. Additionally, the ε-α porosity model [2] was employed to account for the effect of porosity. First we compared our models of laboratory-scale experiments directly with the recorded data from the experiments to validate and calibrate the material models and parameters, respectively. Next, we carried out a suite of numerical simulations using numerical gauges to determine the velocity, pressure amplitude, and decay behavior of the elastic wave as a function of distance to the impact point for different material properties. Here we focus on impact experiments using a target block size of 80x80x50cm edge length and iron or steel projectiles of 12mm impacting into a quartzite, sandstone, tuff, and water saturated sandstone targets with a velocity of 4.6 km s^{-1}. The impact experiments have been equipped with acoustic emission sensors to record acoustic signals and to determine the wave velocity [4]. Additionally, pressure gauges, developed at EMI Freiburg [5], have been used to measure pressure amplitudes allowing for the determination of the attenuation of the signal with distance.

Results: The experimental and numerical data are in good agreement with respect to wave velocities and pressure amplitudes. Pressure amplitudes of the elastic wave decrease with increasing porosity and water saturation. The attenuation is slightly stronger in porous material and significantly stronger in water saturated material compared to nonporous material. The seismic efficiency decreases slightly and linearly with increasing porosity and is significantly reduced if water is present. The presence of water results in strong absorption of impact energy. We determined values of $k=3.4\cdot10^{-3}$ for quartzite, $k=2.6\cdot10^{-3}$ for dry sandstone, and $k=8.2\cdot10^{-5}$ for water-saturated sandstone. These results agree well with the range of literature values of 10^{-3} to 10^{-5} [6] and the experimental data from the MEMIN experiments obtained by [5] ($k=5\cdot10^{-3}$ for sandstone). Based on the decay of amplitudes we determined by numerical modeling the seismic quality factor Q between ~35 for the solid quartzite and 80 for the porous dry targets. It is much lower for water saturated target materials, $Q<10$.

Discussion: Our systematic parameter study using numerical models enables us to quantify seismic parameters for different lithologies. The here provided range of seismic efficiencies enables us to make assumptions about seismic magnitudes resulting from an impact event of different size as a function of target properties. Seismic magnitudes are in the range of one order of magnitude smaller considering a water saturated target in comparison to a solid or porous target. For a Chicxulub size impact event, the determined seismic efficiencies lead to seismic magnitudes of 11 for a solid and porous target and to a magnitude of 10 for a water saturated target which would correspond to a value of 10^{-4} as suggested in [6]. Therefore, we conclude that previously used assumptions on the seismic efficiency tend to underestimate the seismic magnitude of such an impact event

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