# INVESTIGATING THE RELATIONSHIP BETWEEN THE SEISMIC EFFICIENCY AND SEISMIC MOMENT AND IMPACTOR PROPERTIES ON MARS.

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**Introduction:** Two principal goals of the InSight mission are to establish the present rate of impact activity on Mars and to infer the subsurface structure of Mars. Meteorite impacts could be a key seismic source for achieving these goals [1, 2], but understanding of impact-generated seismic signals has been limited by a lack of observational data and the practical difficulty of replicating relevant martian impact conditions in experiments. Here we use numerical impact simulations to better understand the seismic waves likely to be detected by InSight while on Mars.

We simulate idealised m-scale impacts on Mars to compute the seismic efficiency, $k_s$, and the seismic moment, $M$, for a set of impact scenarios. A suite of simulations was designed where both the velocity and the impactor size were varied within the expected range of impacts on Mars likely to be detected by InSight [3] (i.e. $r_i$ was varied between 0.1 and 4.8 m, and $v_i$ between 6 and 27 km/s [4]).

Seismic efficiency is defined as the fraction of initial kinetic impact energy that is converted into seismic energy during the impact. Here, we use an expression adapted from the derivation of the total energy of a simple, sawtooth pressure pulse by J. S. Rinehart [5], later developed by P. Shultz and D. Gault [6], as follows:

$$k_s = \frac{\pi r^2 P^2 \Delta t}{3 \rho v_s E_i} \quad (1)$$

where $r$ is the radius of the numerical pressure gauge; $\rho$ is the density of the target material; $E_i$ is the impact energy; and $\Delta t$ and $P$ are the duration and amplitude of the pressure pulse, respectively.

While previous experimental and numerical studies have constrained seismic efficiency in a range of impact scenarios, values reported in the literature vary between $10^{-6}$ and $10^{-2}$. Teanby proposed in [2] that $10^{-4}$ is an expected order of magnitude for impacts on the Martian surface. Placing tighter constraints on the value of seismic efficiency of m-scale impacts on Mars would enhance efforts to derive the impact energy from impact-generated seismic signals detected by InSight.

The second parameter investigated here is the seismic moment. While there are multiple models for calculating $M$, this study uses the numerical method developed by J. Walker in [7] where the scalar moment is given by:

$$M = \frac{1}{3t}\left(\int \rho v_r r dV + \int \rho v_z z dV\right) \quad (2)$$

where $\rho$ is density, $t$ is time, $v_r$ and $v_z$ are the radial and vertical particle velocities of the target material, respectively, and $r$, $z$ are the radial and vertical coordinates. The integral is taken over a large volume, to include all the impact-induced motion, as well as to ensure that all the seismic waves generated by the impact have decayed to elastic waves.

**Modelling:** The impacts were modelled using iSALE shock physics code [8–10]. Both the target and the impactor were modelled using the Tillotson equation of state for basalt. An initial porosity of $44\%$ was included in the target to represent a porous regolith surface on Mars. A strength model appropriate for pre-fractured rock / granular regolith [8] was used for the impactor and target. Gravity and atmosphere were not included in any of the simulations.

All impacts assumed 90° incidence. The impactor velocity and radius were varied within the likely range of impacts on Mars that might be detected by InSight [1, 2, 4]; i.e. $v_i$ was chosen between 6 and 27 km/s, and the radii between 0.1 and 5 m. The study was divided into three sets of simulations with a constant impact energy. In each set, $v_i$ was varied over the full range 6-27 km/s, while impactor radii was varied over a smaller subset of the full range. The computational domain typically comprised 1000 cells in the radial and vertical directions and the impactor was resolved by 10-20 cells across its radius.

The seismic efficiency was calculated from pressure-time data recorded by Lagrangian tracer particles located at a radial distance from the impact point that was large enough for the wave to have decayed to the elastic regime (gauges F, G and H in Figs. 1 and 2). $P$ in Eq. 1 was defined as the maximum pressure in the time series; $\Delta t$ was defined as the full width at half height of the pulse. The value of $M$ was calculated as a function of time using Eq. 2 until it achieved a plateau; $M_0$ is defined as the value of $M$ at this plateau.

**Results:** Preliminary calculations show that the seismic efficiencies for the range of impacts onto martian regolith described here falls between $10^{-5}$-$10^{-4}$,

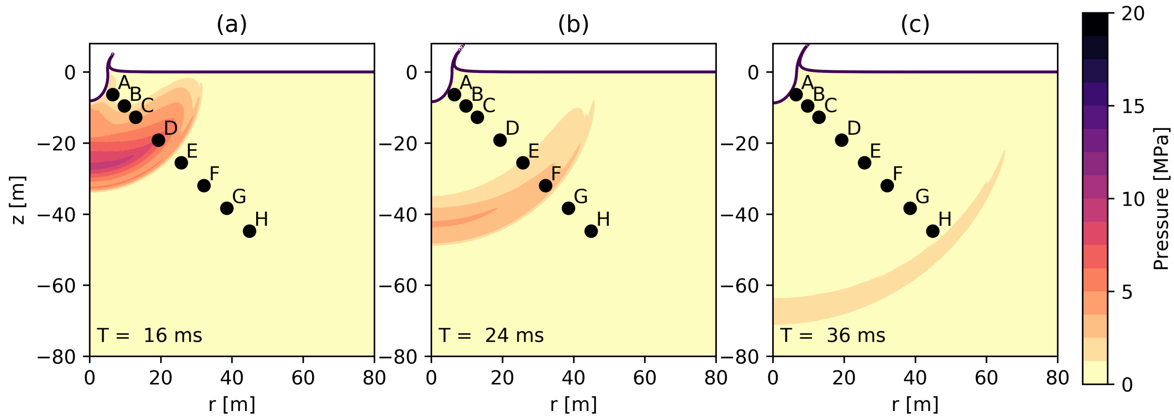


Figure 1: The progression of the pressure wave caused by a 2 m-diameter projectile impacting porous martian regolith surface at 7 km/s. Lagrangian tracer particles (A)-(H) are used as numerical wave gauges to record pressure-time series and estimate seismic efficiency.

which is consistent with recent cm-scale experimental impacts in sand [4], but is substantially smaller than recent numerically- and experimentally-derived estimates of seismic efficiency of cm-scale impacts in porous and nonporous rocks [11]. A goal of our analysis is to determine how $M_0$ scales with individual impactor properties, as well as whether it is approximately proportional to impactor momentum [4, 12, 13] or energy [1].

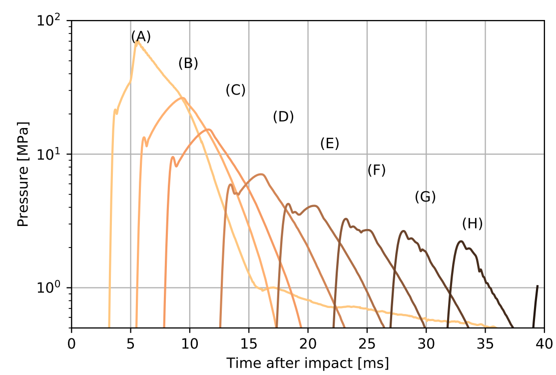


Figure 2: Pressure-time records for numerical wave gauges (A)-(H) shown in Figure 1, showing the transition of the wave from a plastic wave (A)-(E) to an elastic wave (F)-(G).

**Conclusion:** Better understanding of the seismic efficiency and the seismic moment of m-scale impacts onto Martian surface will inform efforts to differentiate an impact generated seismic signal from that of a marsquake and to determine the impact energy from a detected seismic signal without the need of corroborating visual detection and measurement of the crater. This is particularly important for determining the current impact flux on Mars using InSight seismic data.

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