HYDROCODE MODELS OF LARGE IMPACTS INTO A NOACHIAN MARTIAN SURFACE: INITIAL RESULTS.

C. S. Plesko[1] , R. F. Coker, K. H. Wohletz, E. Asphaug[1], and D. G. Korycansky[1], [1]U. C. Santa Cruz (correspondence: cplesko@ucsc.edu), [2]Los Alamos National Laboratory.

Introduction: Carr [1] and Segura et al. [2] proposed that heat from large asteroid impacts (100 km < d < 250 km) could have broiled the surface and polar caps of Noachian era Mars. As the surface cooled, the heat from the impact would have caused about 1 meter of precipitation per day for 1–100 years. There are more than 25 known craters in the correct diameter range that might have caused this precipitation. Segura's 100 km lower impactor diameter limit is intentionally conservative. However, the lower limit on impactor diameter is of interest because it constrains the upper limit of the frequency of the effect.

Here we examine the smallest impacts capable of causing such global effects, and the potential regional effects of smaller impacts like those discussed in [3].

Model Methods: There are two mechanisms for mobilizing volatiles in a large impact. First, they may be driven from the subsurface by the shock of the initial impact, second, they may be mobilized at a distance by re-impacting ejecta. We seek to examine both through hydrocode models of primary impacts and estimates of secondary debris mass and ballistic trajectories.

The RAGE hydrocode. RAGE is an Eulerian hydrocode that runs in a variety of geometries, in up to three dimensions, with a variety of equations of state. It has undergone a variety of verification and validation tests [4-7]. Here we omit the radiation physics, and use the SESAME equation of state tables [8]. The models run on 256 processors of the Pink and Flash clusters [9], and take just under 400 wall-clock hours.

Initial model conditions. All of the models for this work are run on two-dimensional axi-symmetric grids. The simplest case model that we ran for this work was a 50 km diameter solid basalt impactor striking a solid basalt surface of 6000 km wide by 2845 km thick, seen in figure 1. This was done so that it could be run to late time without the shocks encountering a mesh boundary. Pressures and temperatures are monitored over time to indicate the volume surrounding the point of impact within which volatiles would be mobilized, after [10]. We tentatively regard this model as an upper-limit case on the extent of volatile mobilization because it lacks attenuative features like porous regions and material boundaries. This is consistent with [11].

For more realistic models than the solid basalt case, our initial conditions for the target (figure 2) are informed by [12-13]. The top 5 km of the model are informed by the RADAR images of the Martian subsurface returned by the MARSIS and SHARAD instruments [14-15].

Analysis: Computation and analysis are ongoing. The simplest case solid basalt model is complete. Shock evolution in this model corresponds well to scaling law predictions for the attenuation of shock pressure over radial distance from the point of impact, as seen in figure 3 [16]. Detailed results for more complicated cases will be presented at the meeting.

Variables of interest. The thermodynamic path of volatile inclusions are critical to determining mobilization. Thus we track pressure, temperature, specific internal energy for each cell over time, and additionally record the peak pressure seen so far in each cell at each time step.

Model convergence. Hydrocode model results, like physical measurements, have a finite level of accuracy in the measurement of time and lengths. In these models, the time step varies from dt = 1.0e-5 seconds to dt = 5.0e-3, while dr and dy vary from 1 km. to 250 m., according to the adaptive mesh refinement (AMR) and time step refinement algorithms described in [17], with the mesh tending towards higher spatial resolution near the shock front.

When the length scale of the mesh or the time step is larger than that of the processes of interest, the results are averaged out. A simulation is said to be 'converged' when further refinement does not yield an improvement in accuracy. Simple convergence analysis may be done for models on adaptive grids by comparing the results of the original model with those of models with the smallest dx or dt equal to 2 and 4x the original values [18]. We are running convergence test models along with the base simulations for all cases.

Goals: We are modeling the impacts of asteroids smaller than those predicted by Segura, and Sleep and Zahnle [19] to cause global climate effects in order to better constrain the lower size limit, and thus the upper limit of the frequency of such events. We seek to quantify volatile mobilization given a variety of target conditions from solid basalt to heterogeneous porous permafrost. Initial simplest-case results are consistent with analytical scaling models.

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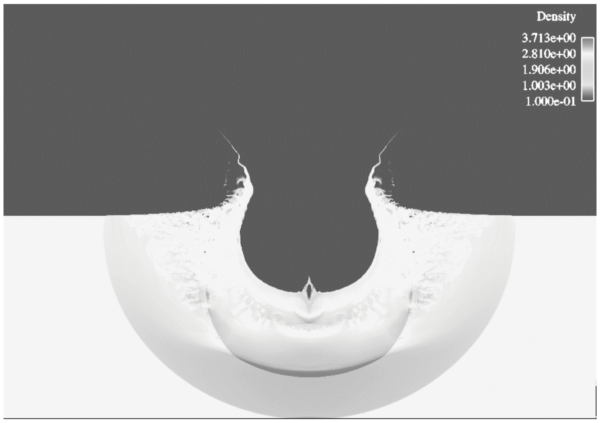

Figure 1: Transient crater opening in a solid basalt target after the impact of a 50 km impactor at 9 km/s, density profile, axi-symmetric, reflected across the center line. Grid dimensions as displayed are 6000 km by 3000 km, dt ~ 10 seconds after impact.

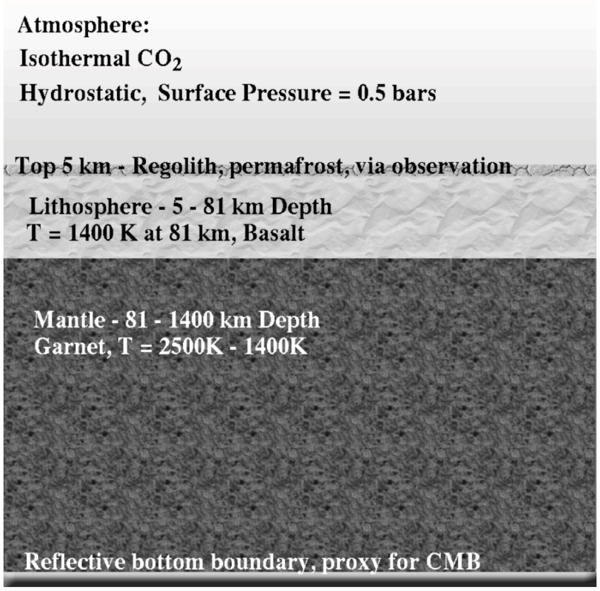

Figure 2: Initial conditions with detailed geology. Large-scale stratigraphy from [12], Noachian atmosphere via [13], near-surface layers generalized from [14] and [15].

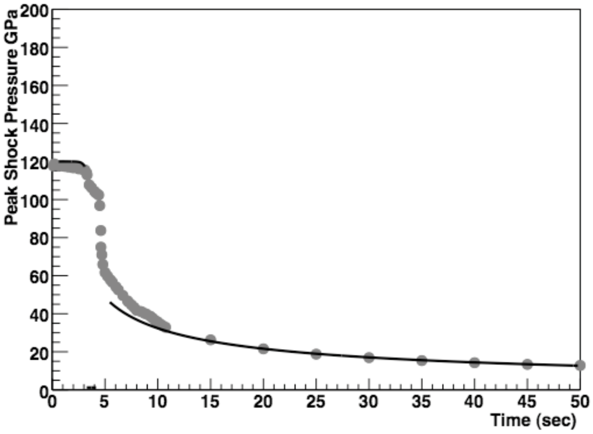

Figure 3: Peak shock pressure attenuation over time (and thus radial distance) from the hydrocode model (red dots) of a d=50 km solid basalt impactor into a solid basalt surface at 9 km/s compared to attenuation rates predicted by scaling laws [20].