STARTING CONDITIONS FOR HYDROTHERMAL SYSTEMS UNDERNEATH MARTIAN CRATERS: 3D HYDROCODE MODELING. E. Pierazzo[1], N.A. Artemieva[2], and B.A. Ivanov[2], [1]Planetary Science Institute (620 N. 6th Ave., Tucson, AZ 85705; betty@psi.edu), [2]Institute for Dynamics of Geospheres (Russian Academy of Sciences, Leninsky pr., 38-6, 117334, Moscow, Russia; art@idg.chph.ras.ru; ivanov@idg.chph.ras.ru).

Introduction: Mars is the most Earth-like of the other planets of the Solar System. With widespread evidence of both heat sources and water, Mars is the first place to look for any sign of present or past extraterrestrial life. The presence of sub-surface water and surface ice or liquid water reservoirs throughout the Martian history is rather evident [1] and it has received further confirmation by the current Odyssey mission [2,3,4]. On the Martian surface, impact cratering and volcanism have provided temporary heat sources throughout Mars geologic history. This alters locally the thermal evolution of a mixed ice-rock sub-surface mixture, and could cause the onset of a hydrothermal circulation.

The realization that hydrothermal systems are possible sites for the origin and early evolution of life on Earth [e.g., 5,6,7] has given rise to the hypothesis that hydrothermal systems may have had the same role on Mars [8,9,10]. The ample evidence for hydrothermal circulation underneath terrestrial impact structures suggests that hydrothermal system could have formed underneath large Martian impact structures as well [11]. Rough estimates of the heat generated in impact events, as initial conditions for the development of an impact-related hydrothermal system, have been based on scaling relations [e.g., 12,13]. Preliminary studies [14,15] suggest that the melt sheets and target uplift are equally important heat sources for the development of a hydrothermal system, while the lifetime of a hydrothermal system depends on the cooling rate of the heat source, as well as the permeability of the host rocks.

Numerical studies of the thermal evolution of the target during an impact event have been carried out for specific terrestrial cases using two-dimensional (2D) impact simulations [16,17]. We present preliminary results of three-dimensional simulations of impacts on Mars aimed at constraining the initial conditions for modeling the onset and evolution of a hydrothermal system on the red planet. The simulations of the early stages of impact cratering allow us to determine the amount of shock melting and the pressure-temperature distribution in the target caused by various impacts on the Martian surface. The late stage of crater collapse are then necessary to determine the final thermal state of the target, including crater uplift, and the final distribution of the melt pool, heated target material and hot ejecta around the crater.

Early stage: Simulations of the early stage of the impact event are carried out with the 3D hydrocode SOVA, developed at the Institute for Dynamics of Geospheres [18], coupled to tabular equations of state built from the ANEOS package [19]. 3D benchmark tests have shown that SOVA produces shock melting and vaporization patterns and volumes similar to the well-known CTH.

We model spherical comets and asteroids of various sizes impacting Mars' surface at 15.5 and 8 km/s, respectively. These roughly correspond to median impact velocities for short-period comets and for asteroids. Simulations have been carried out for 90° (vertical), and 45° impact angles (most probable angle of impact). A spatial resolution of 20 to 25 cells-per-projectile-radius (cppr) is maintained over a central region (only the y>0 half space is modeled, where the y<0 half space is its mirror image) around the impact point, followed by regions of progressively lower resolution, extending to about 13 km downrange (and 5 km uprange), and 15 km below (9 km above) the surface. Tabular versions of ANEOS equations of state for granite (no basalt ANEOS is available at this time), and water ice or granite are employed to model the target and projectile respectively. Ideally, we should model a mixed target, where the basic crystalline crust contains a component of ice and/or liquid water. While the initial simulations use a single material (granite) target, we are exploring how using a mixed material, granite and water, for the target may affect the distribution of the shock in the target and the final estimate of melting during the early stage of impact cratering. A very thin CO_2 atmosphere was included in the simulations as well to model the present-day Martian atmosphere, although this is not expected to influence the thermal characterization of the target.

Over 1200 Lagrangian tracers are regularly distributed inside the (model half-) target to record the material's thermodynamic evolution (with time steps of 0.005 seconds). These tracers record temperatures and pressures as well as positions and velocities during the impact. To estimate melt volumes as accurately as possible, we use a second set of tracers to mark each computational cell of the target around the impact point (of given volume), for a total of more than 500,000 tracers. Volume estimates are determined by adding up the volume of tracers experiencing shock pressures above a given threshold. We use 46 and 56 GPa as threshold pressures for incipient and complete melting of pure granite.

Table 1 shows melt volumes, V_m, associated with impacts producing a final crater (rim to rim) of about 33 km, according to Pi-scaling laws (code use for estimates developed by H.J. Melosh: see www.lpl.arizona.edu/tekton/crater.html), for comet and asteroid impacts (D_{pr} is the diameter of impactor, v_{imp} and θ_{imp} are impact velocity and angle, respectively). These results indicate that impact velocity plays a very important role in determining the total volume of melt produced in the impact. In particular, cometary impacts, because of their larger impact velocities, are much more efficient in creating larger melt pools whose longer cooling time may contribute to a longer duration of the hydrothermal system under an impact crater. The maximum depth at which shock pressure reaches the threshold for 50% vaporization of water (20 GPa), D_{vap}, is also shown. Initial shock vaporization of water may affect the onset of the hydrothermal circulation.

Type	D_{pr} (km)	v_{imp} (km/s)	θ_{imp}	V_m (km^3)	D_{vap} (km)
Comet	2	15.5	90°	31.6	4.9
Comet	2.32	15.5	45°	32.5	4.5
Asteroid	2	8	90°	4.1	4.8
Asteroid	2.32	8	45°	3.7	1.9

Late Stages: The final temperature field around an impact crater depends both on the shock compression/decompression cycle and friction heating due to plastic deformation. As the geothermal heat flow gradient is responsible for an increase in temperature downward, material uplifted from below during the formation of the central peak/ peak ring in complex craters is at higher temperatures that surrounding material, thus providing a further source of heat. For a complete picture of the thermal field underneath an impact crater it is thus necessary to follow the entire crater-forming event, from impact to the final crater. To model crater collapse and the formation of the final crater, we use the 2D hydrocode SALE [20]. Originally developed for calculating 2D fluid flow, SALE has been modified for modeling impact cratering [21,22], and has so far been used to model the formation and thermal evolution of several terrestrial impact structures of various sizes and their thermal fields, from Kärdla (Estonia, D~4 km), to Ries (Germany, D~23 km), to Sudbury (Canada, D~250 km). We found that for the smallest craters the 373K isotherm, corresponding to the boiling point of water, is buried only ~1 km below the crater floor. For craters in the 20-40 km range (Figure 1), the 373K isotherm reaches a depth of about 5 km. For even larger craters the extent of a post-impact hydrothermal system seems to be controlled by the permeability of the rocks under lithostatic pressure. On Mars, the lower gravity should allow less self-compaction of rocks under a crater than on Earth, thus increasing the region where a potential hydrothermal system could develop. For detailed estimates, however, we will use the early stage modeling as a starting point for modeling crater collapse on Mars,

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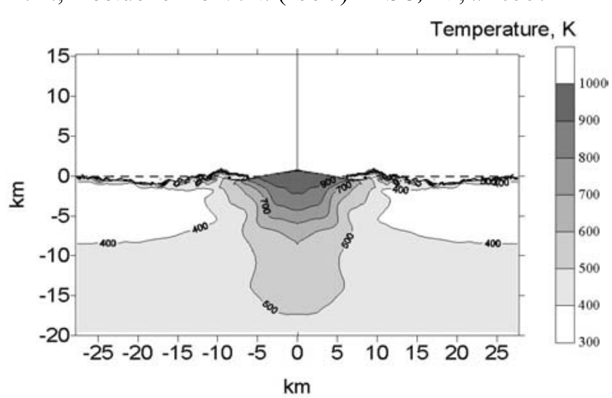

Figure 1: Post-impact temperature field for Puchezh-Katunki crater (Russia, D~40 km). Sedimentary layer (wet tuff) over granite basement, projectile 3.8 km in diameter, 15 km/s impact velocity, computational cell 200x200 m.