ICE-ROCK MIXTURE BEHAVIOR IN FULL SCALE IMPACT CRATER MODELING. B. A. Ivanov[1], and E. Pierazzo[2], [1]Institute for Dynamics of Geospheres, RAS, 119334, Moscow, Russia, baivanov@idg.chph.ras.ru, ivanov@lpl.arizona.edu; [2]Planetary Science Institute, Tucson, Arizona, betty@psi.edu.

Introduction: Mars is the first place to look for any sign of present or past extraterrestrial life. Its surface shows many features indicative of the presence of surface and sub-surface water, while impact cratering and volcanism have provided temporary and local surface heat sources throughout Mars geologic history. In particular, impact-generated hydrothermal systems could have been some of the most favorable sites for the origin of life on Mars. We present initial results of numerical simulations of impacts on Mars aimed at characterizing the initial conditions required for modeling the onset and evolution of a hydrothermal system on the red planet.

Numerical modeling: In our previous works (e.g., [1]) the final crater has been modeled with the dry rock equation of state (EOS), giving only the temperature field under the just formed crater. Water was assumed to penetrate fractured under crater rocks. Two main steps forward are presented here: (1) the multiphase EOS for H_2O describing in the assumption of thermodynamic equilibrium pressure-density-temperature relation for water vapors, liquid water, and up to 10 phases of ice [2], (2) the modeling of ice/rock mixture shock compression and the final crater formation in a target with decreasing initial ice fraction with the depth (from 20 vol. % of ice near surface to zero at a depth of ~10 km).

The numerical study of the rock/ice mixture Hugoniot shows, that final temperature of an ice inclusion into hard rocks may be larger or smaller than the post-shock temperature of the host rock. To follow our previous "dry rock" model [1] here the modeling of a ~25-km Martian impact crater formation is presented to demonstrate locations of melted and partially melted ice under the crater, initial temperature and volumetric percentage of hot water under the crater walls and the central peak.

Modeling technique. The multimaterial Eulerian flavor of SALE (named SALEB) is used to solve hydrodynamic equations of motion coupled with the EOSes for involved materials, precomputed with the ANEOS FORTRAN package. The main specific of the code change here is the special treatment of the ice-rock mixture during the advection stage. Normally in SALEB (as in many other Eulerian codes) the logic of sub-cell material placement is to keep material boundaries as sharp as possible, and suppress an artificial material diffusion. In the presented modeling where H_20 and water are presented in each cell the standard advection results in H_20 "condensation" in large (a few cell) blobs. As we want to treat ice rock as a mixture of large particles (not fine dust mixture, but something like ice lenses in rock fractures), the special treatment is added to allow a smooth flow of a mixture through cell boundaries.

The second problem is the establishing of mechanical equilibrium in each cell. The iterative process equilibrate pressures in ice and rock trying to follow isoentropes as long as it is possible. This is a very time consuming process for mechanically contrast ice/rock mixture. In addition, in many cases iteration failed and the final pressure in this bad cell was computed as for gas mixture with proper partial pressures (pressure is proportional to concentration and pressure of individual materials. The process of equilibrisation is not yet fully investigated and should be improved in a close future.

The other simplification in the current model is prohibition of heat exchange between H_2O and host rocks. The heat exchange rate depends on assumed size of ice inclusions. For meter-size inclusions the heat exchange may be negligible for the time of a crater formation (a few minutes). If most of ice is fine mm-size layers, the proper heat exchange should be included into the model. The extreme case may be presented by immediate thermodynamic euqilibrization of a mixture in each time step.

Projectile, target, and crater: Following [1] we assume basalt 1 km (diameter) projectile with the velocity of 8 km s^{-1}. The same acoustic fluidization model parameters as in [1] are used here. Basalt target is changed in comparison with [1] to have exponentially decayed with depth initial H_2O content which varies from 20 vol% at the surface to zero at a depth of ~10 km. The temperature gradient in the target crosses the melting line of ice a t a depth of ~4 km, and below H_2O in rock fractures is enough warm to be liquid initially.

After the projectile penetration, transient crater growth, and a cavity collapse the crater has the rim diameter of 26 km – close to the crater size in a dry basalt [1].

Discussion: Fig. 1 presents rock volume concentration (a) and the under-crater temperature field (b). We see the uplift of less porous and warmer rocks from a depth. Together with shock and friction heating the uplift creates a "neck" of rocks with liquid water with a diameter of 8 km (1/3 of the crater rim diameter). Beyond this neck the zone of partially melted ice id located near radial distance of ~7 km from the cen-

ter. At larger radial distances ice is not melted, except poorly resolved upper near surface layer where ejecta with liquid water are deposited.

The computation of ice and rock in mechanical equilibrium only results in an interesting effect of different temperatures of ice and rock (Fig.2). In the central zone of high shock pressure and a large central uplift H_20 (water) is 50 to 100 K colder than host rocks (before the final heat exchange, not implemented in the model). At the crater periphery where the main agent is plastic heating ice may be 10 to 50K warmer than host rocks.

However, in the central uplift (below ~ 1km) water occupies <5% of space and the final heat exchange does not influence the rock temperature field shown in Fig. 3.

The rock volume content picture in the central uplift (Fig. 1a) demonstrates that the central uplift is constructed of less porous initially rocks (they will get increased porosity due to the shear strain during crater collapse). Hence for larger craters the central uplift should be constructed with mostly dry rock from larger depth. Following the general rule of the stratigraphic uplift amplitude of ~1/10 of a crater diameter, one can estimate that in the crater with D>100 km rocks in central uplift should present initially dry rocks from a depth >10 km. Impact craters like Lyot should have initially dry fractured hot central uplifts. The hydrothermal circulation here would start with the primary phase of water penetration into the hot central body.

The crater margins in larger craters may have more complex thermal history than in the presented ~30 km crater. The modeling should continue now toward larger Martian impact craters with diameters from 100 to 200 km.

Conclusions: The complex ice-rock mixture behavior during the impact crater formation on Mars needs much more modeling skill than for "dry rock" modeling. First results demonstrate some progress. However, even the necessary in future change of pure water to brines promises a lot of new problems for modeling as a way to understand Martian impact-related hydrothermal systems.

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References: [1] Pierazzo E. et al. (2005) GSA Special Paper 384, 443-457. [2] Ivanov B.A. (2005) 36th Lunar Planet. Sci. Conf., Abst. #1232.

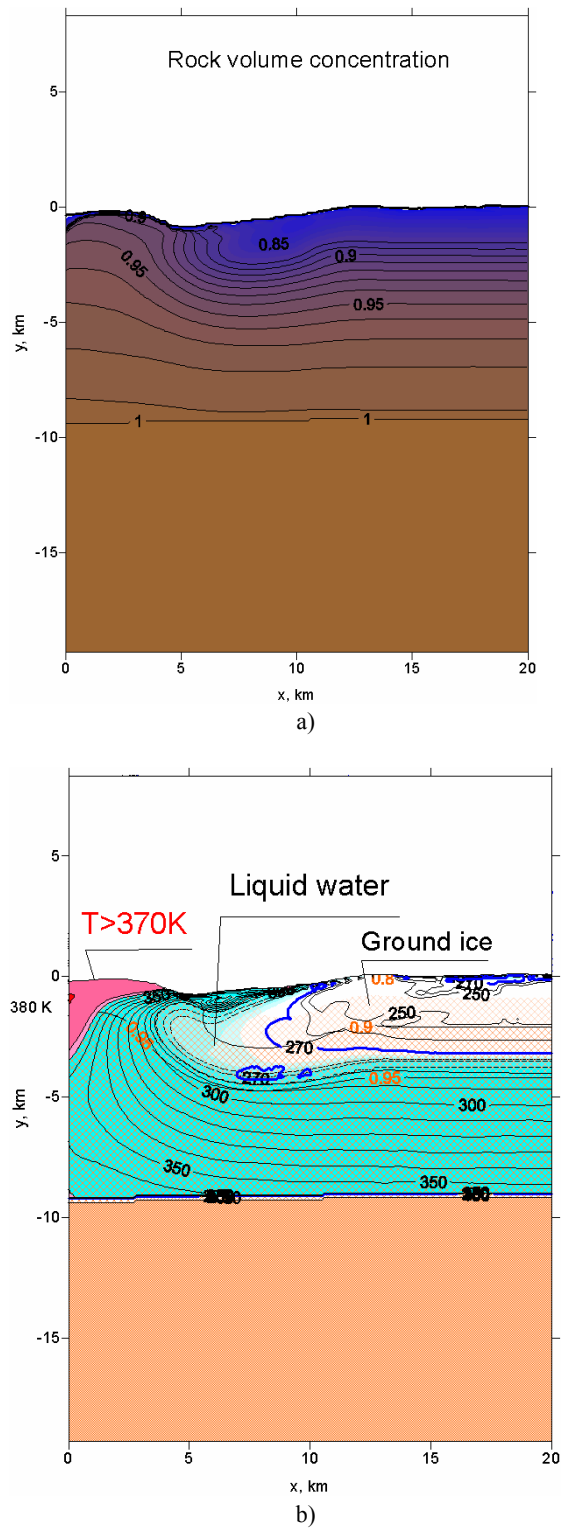

Fig. 1. (a) Rock/ice distribution and (b) isotherms and phase state of pore water relative to local pressure and temperature below a martian crater with rim diameter ~30 km formed by an asteroid impact (v= 8 km/s). Color scheme on the right: pink= region where water exists as vapor; cyan= region

where water is liquid; white= region where water is present as ice. Below about 10 km the target is pure rock.

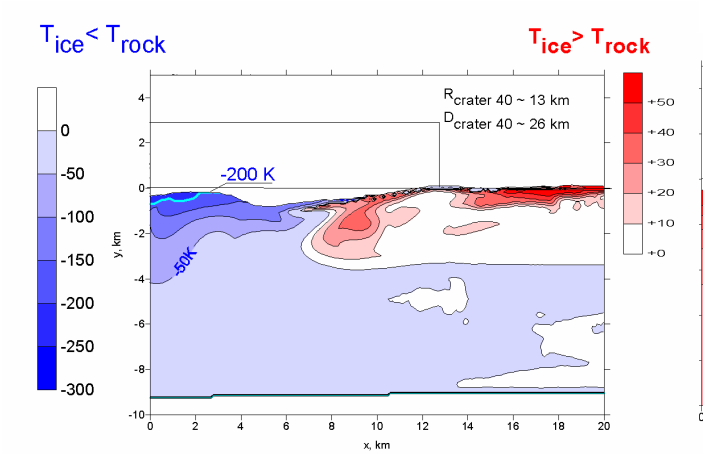

Fig. 2. Distribution of regions where water is hotter/colder than the surrounding rock. Blue shading shows where water is cooler than rock, causing heat transfer from the rock to the water. Red shading shows regions where water is warmer than rock, causing heat transfer from the water to the rock. In the central uplift the temperature in the rock is substantially higher than in the water, providing an extra source of heating.

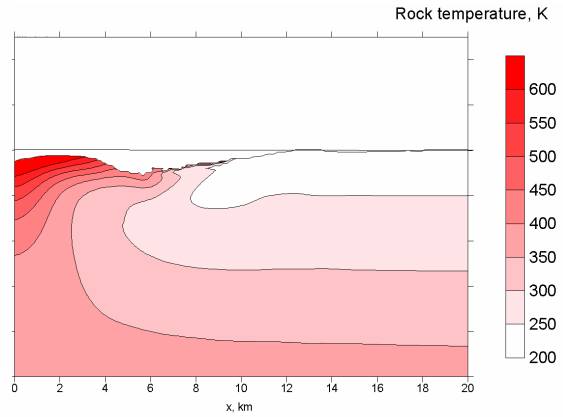

Fig 3. Rock temperature field after the crater formation just before hydrothermal circulation starts.