Impact Bombardment on Terrestrial Planets During Late Accretion. O. Abramov[1], S.J. Mojzsis[2], [1]Planetary Science Institute, 1700 E Fort Lowell Rd # 106, Tucson, AZ 85719; abramov@psi.edu, [2]Dept. of Geological Sciences, University of Colorado, UCB 399, Boulder, CO 80309; mojzsis@colorado.edu

Introduction: Impact bombardment in the first billion years of solar system history determined in large part the initial physical and chemical states of the inner planets and their potential to host biospheres. Impact heating can lead to localized sterilization of the crust, but can also create hydrothermal oases favorable for life. The range of the consequences of the impact epoch, however, is not well quantified. In this ongoing study we assess the effects of impact bombardments on terrestrial planets, and make predictions for crustal melting, ejecta deposits, habitable volumes, and preservation of evidence of impacts in ancient mineral grains.

Methods summary: The impact bombardment model [1,2] consists of (i) a stochastic cratering model which populates the surface with craters within constraints derived from the lunar cratering record, the size/frequency distribution of the asteroid belt, and dynamical models; (ii) analytical expressions that calculate a temperature field for each crater [e.g., 3,4]; and (iii) a three-dimensional thermal model of the terrestrial lithosphere, where craters are allowed to cool by conduction and radiation (Fig. 1). In addition, ejecta volumes and temperatures are calculated, and ejecta blankets deposited on the surface are allowed to cool in both conductive and hydrothermal regimes. Equations for lead diffusion in zircon [5,6] are coupled to these thermal models to estimate the amount of age-resetting.

We present preliminary modeling results for Earth, Moon, and Mars between 4.5 Ga and 3.5 Ga based on the late accretion bombardment scenario [7]. Mean surface temperatures and geothermal gradients were assumed as 20 °C and 70 °C/km for the Earth and -63 C and 12 °C/km for Moon and Mars. Total delivered mass was: 0.0003(M_{planet}) for Earth and Mars, and 0.00013 (M_{planet}) for the Moon [7]. The size-frequency distributions of the impacts, and the comet/asteroid ratios were derived from dynamical modeling by [7]. Mean impactor density of 3000 kg/m^3, for asteroids, and 1000 kg/m^3 for comets was used. Impactor velocity distribution from [7] was used, and impact angle of each impactor was stochastically generated from a gaussian centered at 45 degrees.

Results: Figure 2 shows a comparison of impact melt produced by the bombardment on Mars and Earth. On Mars, only 0.7% of the crust is melted at any time, compared to almost 10% for the Earth. Note that this is different from the cumulative melt production, which approaches 25% for the Earth, indicating that nearly a quarter of its crust would have melted at some point. The shape of the plot for Mars is dominated by relatively few very large impacts, whereas for the Earth, a lot more impacts are contributing to the melting, resulting a smoother curve that reaches steady state and gradually declines as the flux subsides. The differences between the two plots are due to (i) Higher crustal temperatures on Earth, making it easier to melt,

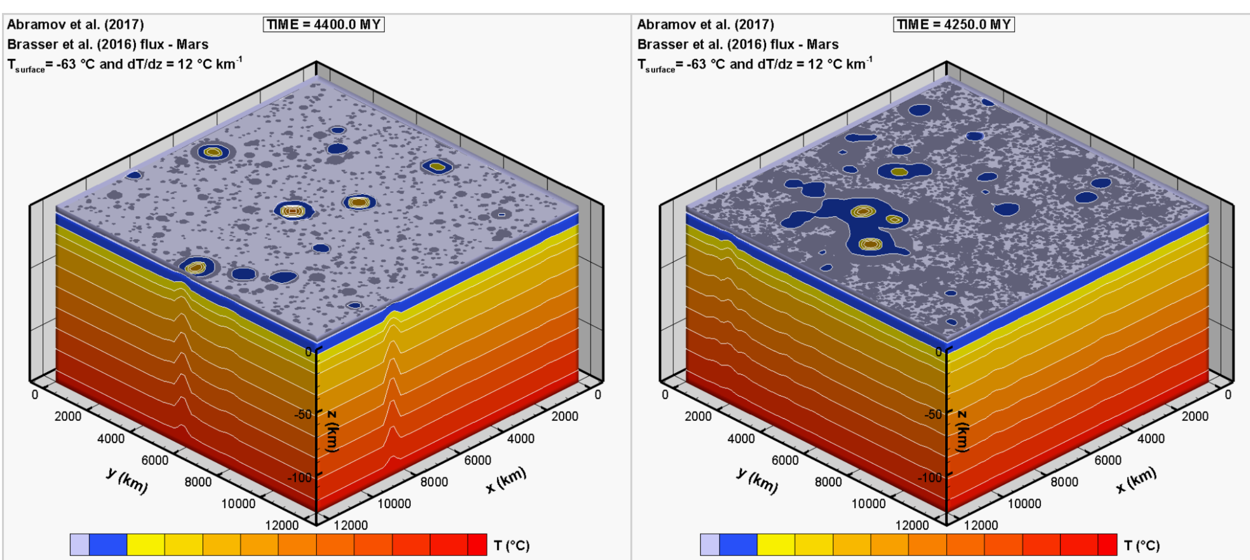

Figure 1. A three-dimensional thermal model representing the upper 140 km of Mars during two different times. Dark circles indicate crater locations, and blue areas indicate the extent of the subsurface habitable zone. The upper boundary shows temperatures at a depth of 4 km.

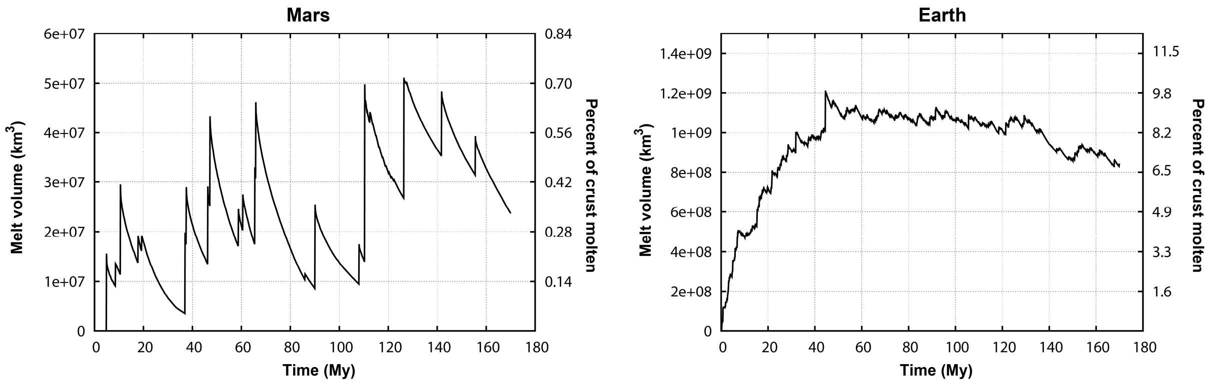

Figure 2. Percent of the planet's crust in a molten state as the bombardment progresses. Derived from a three-dimensional transient thermal model (Fig. 1). Melt deposited in ejecta blankets is not included.

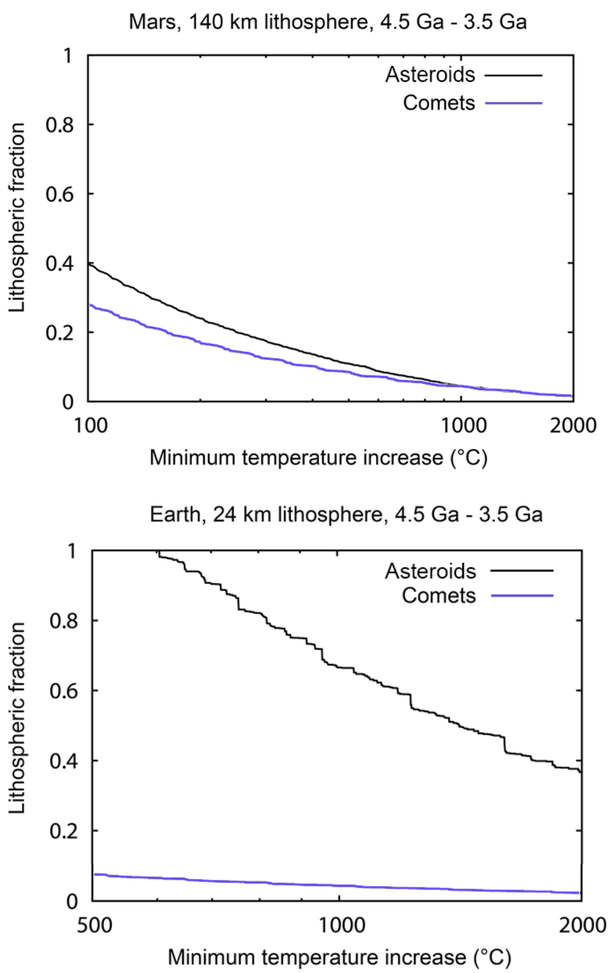

Figure 3. The degree of heating in the planet's crust as a result of energy deposited by comet and asteroid impactors. (top) Mars (bottom) Earth. The y-axis shows the fraction of the Earth's lithosphere to experience a temperature increase given on the x-axis as a result of the impact bombardment.

(ii) Higher impact velocities on Earth, which nearly quadruple the energy of each individual impact and (iii) Larger number of impacts on the Earth, due to its surface area. These results are consistent with previous studies [e.g., 2].

Figure 3 shows the crustal heating as a result of impact bombardment between 4.5 and 3.5 Ga. For reference, a temperature increase of ~700 °C would melt the crust, when geothermal heating and latent heat of fusion are accounted for.

We have also estimated the geophysical habitable volumes within the upper 4 km of the Earth and Mars crust as the bombardment progresses. For this evaluation, we invoke a hypothetical biome composed of meso-, thermo- and hyperthermophilic microorganisms. The general trend is for all geophysical habitable volumes to increase in the early stages of the bombardment as the impacts melt the icy cryosphere, and to then decline with decreasing impact fluxes. This is consistent with the results of [8].

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