COMPREHENSIVE MODELING OF LATE ACCRETION IMPACTS ON EARTH. O. Abramov[1], R. Brasser[2], and S. J. Mojzsis[3], [1]Planetary Science Institute, 1700 E Fort Lowell Rd # 106, Tucson, AZ 85719 (abramov@psi.edu), [2]Earth-Life Science Institute (ELSI), 2-12-1-IE-1 Ookayama, Meguro-ku, Tokyo, 152-8550, Japan, [3]Dept. of Geological Sciences, University of Colorado, UCB 399, Boulder, CO 80309.

Summary: We present the latest comperehensive models of the effects of comet and asteroid impacts onto the Earth during the timeperiod of 4.5 to 3.5 Ga. The parameters of the bombardment population are taken from the latest dynamical models, rooted in highly-siderophile (HSE) abundances in terrestrial and lunar mantles. We compare the results of our simulations to the terrestrial zircon record.

Introduction: Impact bombardment in the first billion years of solar system history significantly affected the initial physical and chemical states of the inner planets and their potential to host biospheres. Impact heating can lead to localized [e.g., 1-3], or extreme cases, global sterilization of the crust [e.g., 4], but can also create hydrothermal oases favorable for life [e.g, 5]. Evidence of impacts can be preserved in zircon grains [e.g., 6], the oldest known terrestrial materials, with the oldest ages of ~4.4 Ga [7]. In this study we assess the effects of impact bombardment on the early Earth, and make predictions for crustal melting, habitable volumes, and preservation of evidence of impacts in ancient mineral grains.

Methods: 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., 8,9]; 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 [2]. Equations for lead diffusion in zircon [10,11] are coupled to these thermal models to estimate the amount of age-resetting.

We present modeling results for the Earth between 4.5 Ga and 3.5 Ga based on the late accretion bombardment scenario [12]. Mean surface temperatures and geothermal gradients were assumed as 20 °C and 70 °C/km [2]. Total delivered mass was estimated at 0.0013(M_{planet}), or 7.8×10^{21} kg. The size-frequency distributions of the impacts were derived from dynamical modeling by [12], based on the results of [13].

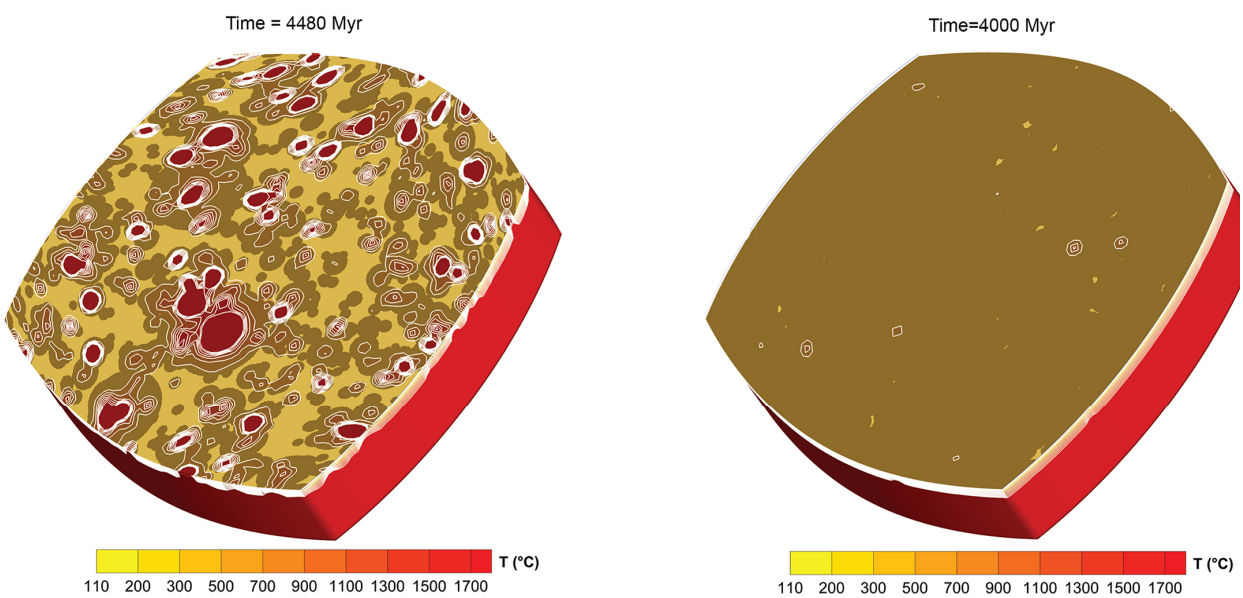

Figure 1. A three-dimensional thermal model representing the upper 140 km of Earth during two different times: (i) 4.48 Ga, near the beginning of late accretion, and (ii) 4.0 Ga, towards the tail of late accretion. Dark circles indicate crater locations, and white lines are temperature contours. The upper boundary shows temperatures at a depth of 4 km.

Mean impactor density of 3000 kg/m^3 and impactor velocity distribution from [12] was used, and impact angle of each impactor was stochastically generated from a gaussian centered at 45 degrees. The typical impact velocity of the Earth is ~21 km s^{-1}.

Results: Figure 2 shows a comparison of impact melt produced by the bombardment under two different scenarios. In the first case, we begin with a global magma ocean, which would have been formed by the Moon-forming impact at ~4.51 Ga [14]. In this scenario, the percent of crust molten at a particular time is dominated by the cooling of the lithosphere from this initial giant impact, rather than individual impacts. In the second case, we begin with a fully-formed lithosphere at 4.5 Ga. In this scenario, effects of the individual impacts on crust melting are observed, reaching a maximum of ~25% lithosphere molten at ~4.42 Ga. We also calculate that ~80% of the lithosphere would have undergone cumulative melting between 4.5 and 4.0 Ga.

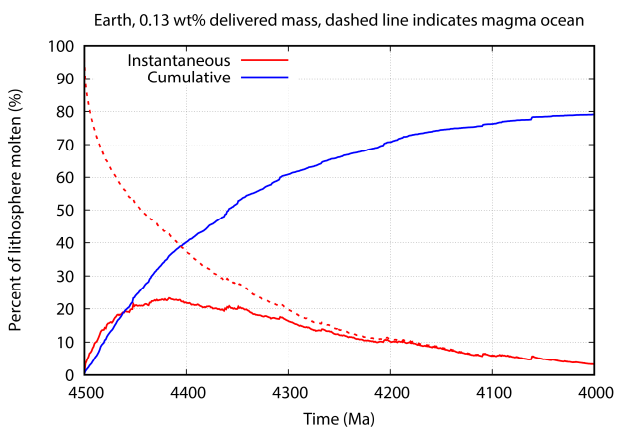

Figure 2. Percent of the Earth's thermal lithosphere in a molten state as the bombardment progresses. Derived from a three-dimensional transient thermal model (Fig. 1). Dashed line represent a magma ocean initial condition. Melt deposited in ejecta blankets is not included.

We also calculate that, for the distribution of impact velocities used and a mean impactor density of 3000 kg/m^3, ~9.3 × 10^{21} kg of impacting mass is needed to completely melt the lithosphere. This corresponds to a single object with a diameter of ~1700 km.

Figure 3 shows the geophysical habitable volumes within the upper 4 km of the Earth as the bombardment progresses. For this evaluation, we invoke a hypothetical biome composed of meso-, thermo- and hyperthermophilic microorganisms [e.g., 1]. In the case of the initial magma ocean, the habitable volumes start at zero and increase as the lithospheric thickness increases. In the case without an initial magma ocean, habitable volumes initially decrease, dropping ~25% as the impacts make substantial crustal volumes uninhabitable due to hight temperatures, reaching a minimum at ~4.42 Ga. After that point, the habitable volumes gradually increase due to the waning intensity of the bombardment. Thus we argue that the Earth was conducive to origins of life from about 4.4 Ga onwards.

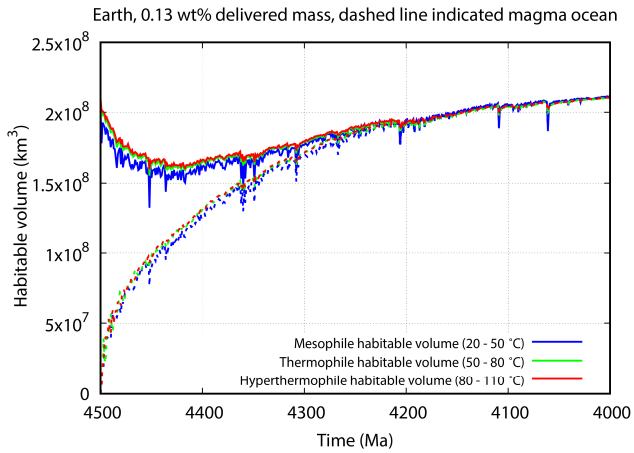

Figure 3. Habitable volumes for three temperature intervals in the Earth's near-surface during the bombardment. Dashed lines represent a magma ocean initial condition.

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