EPSC Abstracts
Vol. 11, EPSC2017-895, 2017
European Planetary Science Congress 2017

A scaling law for impact-induced melt volume

M. Nakajima (1), D. C. Rubie (2), H. J. Melosh (3), S. A. Jacobson (2,4), **G. J. Golabek (2)**, F. Nimmo (5), and A. Morbidelli (4)

(1) Department of Terrestrial Magnetism, Carnegie Institution for Science, (2) Bayerisches Geoinstitut, University of Bayreuth, (3) Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, (4) Observatoire de la Côte d'Azur, (5) Department of Earth and Planetary Sciences, University of California, Santa Cruz. (mnakajima@carnegiescience.edu)

Abstract

During the late stages of planetary accretion, protoplanets experience a number of giant impacts and extensive mantle melting. Understanding the melt volume is important because it determines elemental abundances in the planetary core and mantle. Here, we develop a scaling law for melt volume based on giant impact simulations using smoothed particle hydrodynamics (SPH) as a function of the total mass, impact angle, impact velocity, and impactor-to-total mass ratio. We find that the law is most sensitive to the impact velocity and angle.

1. Introduction

Giant impacts play an essential role for determining the starting conditions of terrestrial planets. A large impact melts the outer part of the planetary mantle and delivers the impactor's iron to the planet. During descent of the iron through the molten part of the mantle (magma ocean), the iron, at least partly, experiences metal-silicate equilibration with the magma ocean [e.g., 1]. The sinking iron gains some light elements and eventually merges with the planetary core. An important parameter here is the magma ocean depth; element partitioning between silicate and iron depends on the equilibrium pressure and temperature, which are often considered as the ones at the base of the magma ocean. Thus, magma ocean depth is highly important for determining the planetary core and mantle compositions. Many insightful studies have been conducted to estimate mantle melt volume by impact [e.g., 2], but some of these studies have focused on cratering impacts and they do not consider self-gravity and geometry, which can play an important role during a giant impact. Here, we derive a scaling law for melt volume-based on impact simulations.

2. Method & Model

We perform impact simulations using a particle method called smoothed particle hydrodynamics (SPH) considering self-gravity. We develop a simple scaling law for melt volume based on SPH simulations. We use entropy of the mantle to determine the extent of mantle melting. We assume the pre-impact mantle temperature is close to solidus [3] and use M-ANEOS equation of state to describe the mantle materials.

3. Results

We derive a scaling law for mantle melting based on 80 impact simulations with various impact velocities V_{imp} (1-2 V_{esc} where V_{esc} is the mutual escape velocity), impact angle θ (0-90°), impactor-to-total mass ratio γ (0.03-0.5), and the total mass M_{T} (1-6.5 Mars mass). Our preliminary results indicate that the mass fraction of molten mantle f in this parameter range is approximately expressed as

$$f \sim \frac{M_T \gamma (1-\gamma) V_{\mathrm{imp}}^2}{2 M_m L} \left(\frac{V_{\mathrm{imp}}}{V_{\mathrm{esc}}}\right)^{-1.2} \sin^{0.86}\theta (1-\cos\theta)^{1.66(V_{\mathrm{imp}}/V_{\mathrm{esc}}-1)},$$

where M_m is the mantle mass and L is the latent heat. In this parameter range, the standard deviation between SPH and this fitting model is smaller than 0.20. We also find that self-gravity plays an important role in a large impact by converting potential energy into heat. Likewise, geometry needs to be taken into account for precise melt volume estimates.

References

[1] Stevenson D. J. (1990) *Origin of the Earth*, p. 231. [2] Tonks W. B. and Melosh H. J. (1993) *JGR*, 98, 5319. [3] Nakajima M. and Stevenson D. J. (2015) *EPSL*, 427, 286.