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Collisional fragmentation as a source of early martian impactors

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Abstract

An early dynamical instability in the outer solar system, prior to the accretion of the terrestrial planets, can be linked to the martian cratering chronology through collisional fragmentation. Two distinct impactor sources, basin-forming planetesimals and crater-forming collisional debris, can reproduce an apparent spike in basin formation ~3.9 Ga, removing the need for a Late Heavy Bombardment and simplifying the martian cratering chronology.

1. Introduction

Many previous models of solar system evolution have suggested that the craters seen on the most ancient surfaces in the inner solar system were created by a late dynamical instability in the outer solar system. Recently, Clement et al. showed that an early dynamical instability, prior to the end of terrestrial planet accretion, could satisfy many constraints placed on the architecture of the solar system as well, or better than, a late dynamical instability [1]. Their model successfully replicates the structure of the inner and outer solar system but does not currently provide a source for impactors in the inner solar system.

Collisional fragmentation during the accretion of the terrestrial planets can provide a source for inner solar system impactors. Impacts between growing terrestrial planets and smaller bodies, like planetesimals and planetary embryos, generate collisional debris. This debris creates a source of impactors that is localized and preferentially impacts one terrestrial planet over another. While previous work has been done to incorporate fragmentation into an early instability model [2], in this work we address the effects of fragmentation on the cratering history of the inner solar system, with a focus on Mars.

2. Martian Cratering Chronology

An analysis of the ages of observed martian basins reveals a spike in basin formation ~3.9 Ga [3], [6]. This increase in basin formation is often interpreted as an influx in basin-scale impactors entering the inner solar system, often referred to as the Late Heavy Bombardment. Instead, we argue that the apparent spike in basin formation is rooted in the assumption that basins and small craters share a common impactor source. Separate impactor sources, with distinct size-frequency distributions, can replicate the apparent spike in basin ages when interpreted through the lens of the lunar cratering chronology and the Neukum Production Function (fig. 1a and 1b). Therefore, instead of an influx of basin-scale impactors into the inner solar system, a sudden influx of smaller impactors, such as collisional debris from giant martian impacts, can explain the apparent spike in basin-scale impactors ~3.9 Ga.

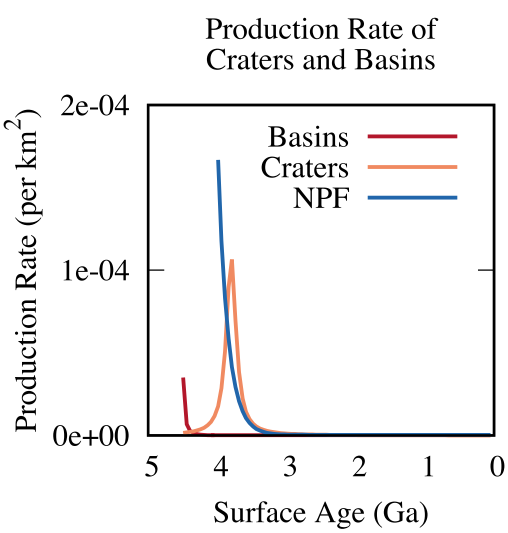

Figure 1a: A plot of production rate vs. surface age. In red, the production rate of basins (+250 km) steadily decays after the end of planetesimal accretion [4]. In orange, the production rate of ~50 km craters begins at 0, spikes ~3.9 Ga, and then returns to 0. In this model, the production rate of small craters was the derivative of an arctangent chronology function. In blue is the standard NPF [5].

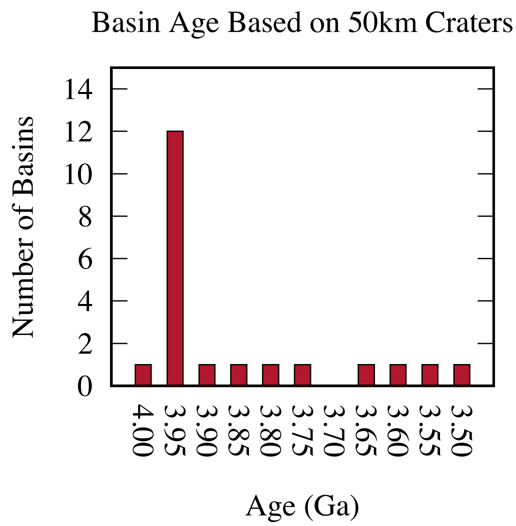

Figure 1b: A histogram of basin ages calculated using the NPF, which assumes that basins and small craters share a common impactor source. In this model, the majority of basins form prior to 4.4 Ga but the NPF skews the calculated ages of these basins younger, creating an artificial spike in basin production rate ~3.95 Ga.

3. Summary and Conclusions

An early instability, during the formation of the terrestrial planets, can explain the cratering history of Mars. A reinterpretation of the martian cratering chronology, distinct from the lunar cratering chronology, implies separate impactor sources for basin-scale impactors and smaller, crater-forming impactors. Late-stage accretion provides a source for basin-forming impactors, while collisional debris from giant impactors provides a source for smaller, crater-forming impactors. The incorporation of fragmentation into early instability models better represents the terrestrial planet accretion environment and fosters a new interpretation of the martian cratering chronology.

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