AN EARLY MARTIAN SUPERPLUME: MIGRATION, MAGMATISM, AND MAGNETISM. R. I. Citron[1] and M. Manga[1], [1]Department of Earth and Planetary Science, University of California, Berkeley, CA 94720 (ricitron@berkeley.edu).

Introduction: An early martian superplume has been proposed to explain two key features of ancient Mars: the origin of Tharsis [1] and the strength and pattern of remanent crustal magnetic signatures [2] (Figure 1). Formation of Tharsis on the dichotomy boundary (as opposed to any random point on the surface) is hypothesized to result from migration of a superplume originally formed under the thicker southern crust [3]. Such a superplume could generate a large amount of melt residue that could promote plume migration to the dichotomy boundary [1,4]. Emplacement of new crust from a superplume could also explain the concentration of strong remanent magnetism in the southern hemisphere. Migration of melting zones and crustal production from an evolving zone is also a mechanism proposed to explain the lineations of reversing polarity observed in Mars' remanent crustal magnetism [2].

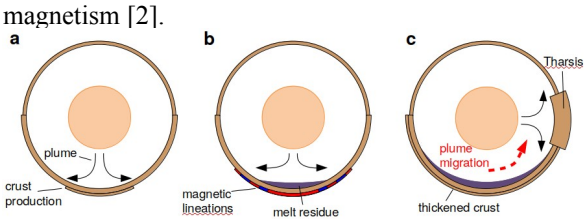

Figure 1. A hypothesis for plume migration on early Mars. (a) An initial superplume develops and thickens the crust in the present-day southern hemisphere. (b) New crust produced by the superplume can be magnetized, potentially explaining the pattern and strength of magnetization in the southern hemisphere. Melt extraction dehydrates the upper mantle, resulting in a highly viscous melt residue under the thicker southern crust. (c) The viscous melt residue induces plume migration to Tharsis' current location.

A superplume can originate on Mars due a layered mantle viscosity, a proposed mechanism for an endogenic, superplume origin of the crustal dichotomy [5]. Alternatively, a superplume could develop as a result of a giant impact on early Mars, forming under the thicker, more enriched (in radiogenic heat producing elements, HPEs) crust in the hemisphere opposite the impact [3]. In the latter scenario, post-impact crust produced in the present day northern hemisphere is more depleted in HPEs than the older crust in the southern hemisphere, and upwellings naturally concentrate under the thicker, more enriched (in HPEs) crust in the southern hemisphere, potentially resulting in the formation of a superplume that further thickens the crust in the southern hemisphere [3].

Regardless of the formation mechanism, the subsequent evolution of an early martian superplume and if it can explain the formation of Tharsis and the distribution and strength of remanent magnetism is poorly constrained. Using a suite of mantle convection simulations, we examine the formation and evolution of superplumes on early Mars, with a focus on plume migration, melt production, and remanent magnetism.

Methods: We examine the evolution of an early Mars superplume using a suite of mantle convection simulations conducted with the CitcomS mantle convection code [6,7]. Model parameters are similar to [3], except that we use constant heat production and the extended Bousinessq approximation. Melt production and extraction is modeled using a tracer method [8]. We vary parameters for initial temperature (hot or cold), temperature/pressure dependence of viscosity (weak, medium, strong), and with or without a layered viscosity structure (50x jump in viscosity in the mid-mantle), for a total of 12 model types.

For each of the 12 model types, we run three different stages of simulations: pre/no-impact, post-impact, and superplume migration. The pre/no-impact simulations determine the convective pattern of each model with no imposed crustal structure (simulating either prior to a change in crustal structure from an early giant impact, or a control case for no giant impact). The post-impact simulations start from the output of the pre-impact simulations at 100 Myr and determine how the convective pattern changes when we impose a hemispherical difference in crustal thickness and composition, such as that expected following a giant impact. In the pre/no- and post- impact simulations we determine under what conditions a superplume can form, expanding on the parameter space explored in [3]. The superplume migration simulations then use the output of the post-impact simulations (those in which a superplume formed) and determine how new crust is distributed and if the superplume migrates as a result of viscous stiffening due to melt extraction.

Results: *Pre/no-impact simulations:* For the pre/no-impact simulations we find that stronger temperature and pressure dependence of viscosity induces longer wavelength convection planforms, as does the inclusion of a viscosity jump in the mid-mantle. While these trends are consistent with other studies (e.g., [5,9]), we do not observe degree-1 convection, but instead find annular or ridge shaped upwellings, or widely spaced plumes, more similar to [10,11].

Post-impact simulations: A thicker crust is included in the southern hemisphere to simulate a post-giant impact crustal thickness distribution. The thicker southern crust is also enriched in HPEs relative to the mantle and northern crust, as hypothesized in [3,12]. Similar to [3], we find a superplume forms under the thicker, enriched crust (Figure 2). Including a 50x viscosity jump in the mid-mantle increases the likelihood and decreases the timescale of superplume formation.

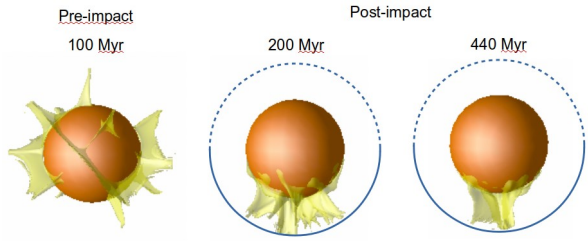

Figure 2. Example progression from a pre/no-impact simulation to a post-impact simulation. The pre-impact simulation shows multiple plume convection, and its planform at 100 Myr serves as the starting point for the post-impact simulation. The post impact simulation begins with the pre-impact temperature field, but adds a southern crust (solid line) that is enriched by a factor of 5 relative to the mantle, and is twice as thick as the northern crust (dashed line, enriched by a factor of 2 relative to the mantle). The upwellings focus under the thicker, enriched southern crust, resulting in superplume formation in several hundred Myr. Yellow contours highlight positive residual temperature upwellings.

Superplume migration simulations: Beginning with the temperature profiles from the post-impact simulations after a superplume has formed, we add the effect of viscous melt residue caused by dehydration of the upper mantle from melt extraction. We conduct several test cases with similar parameters to [9]. When there is no post-impact difference in heat production or crust thickness between the two hemispheres, production of melt residue induces large-scale superplume migration. However, when a thicker, enriched crust is included in the southern hemisphere, the insulating effect focuses upwellings under the southern hemisphere and inhibits large-scale plume migration (Figure 3).

Discussion and Future Work: We were not able to support our hypothesis that early martian superplumes generated following a giant impact could migrate to form Tharsis on the dichotomy boundary, or would produce melting in a pattern similar to the distribution of magnetic lineations. We find that it is difficult for large scale plume migration to occur when the superplume originates under a southern crust that is enriched in HPEs. The same insulating effect that promotes upwelling formation under the thicker, enriched crust resists the migration of plumes from under the crustal cap. Furthermore, our models do not predict a migrating melt zone that can explain the lineations in the remanent magnetic signatures. Different melting models might produce a different distribution of melt than found in our simulations, and can be the focus of future work. While melting and the corresponding melt residue can clearly influence plume migration and crust production, a link between early martian mantle convection and the formation of Tharsis and the pattern of magnetism remains enigmatic.

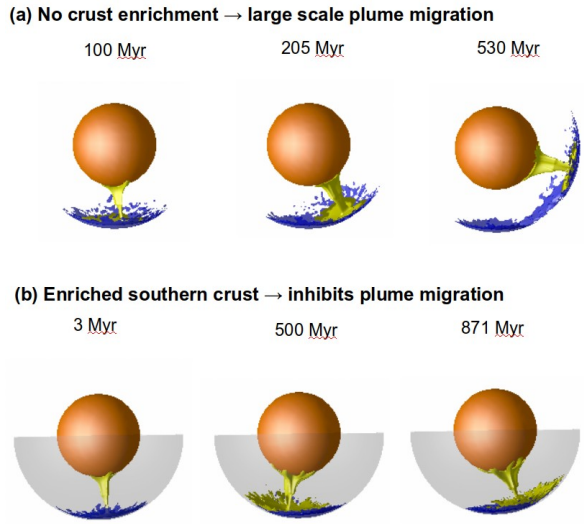

Figure 3. Plume migration caused my melt extraction. (a) When the crust is uniform in both hemispheres, viscous melt residue (blue) induces large-scale migration of the superplume (yellow). (b) When the southern crust (grey contour) is enriched in HPEs, it inhibits large-scale plume migration.

Acknowledgments: This work was supported by NASA grant 80NSSC19K0545.

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