Understanding the Early Evolution of Mars and the Formation of Crustal Dichotomy. Shijie Zhong, Department of Physics, University of Colorado at Boulder, Boulder, Colorado 80309, szhong@colorado.edu.

Introduction: The crustal dichotomy and the Tharsis rise are the most prominent topographic features on Mars. The dichotomy is largely an expression of different crustal thicknesses in the northern and southern hemispheres, while Tharsis is a volcanic construction that affects nearly 25% of the planetary surface. Both features are very old, and even the younger one of the two, Tharsis, may have largely completed its formation by Late Noachian [1]. Recent observations from MGS and MARSIS indicate that the basement of the northern plains are formed in the pre-Noachian, and are as old as the southern highlands [2,3], suggesting that crustal dichotomy may have formed very early in Mars geological history. Given the large length scales of the dichotomy and Tharsis, the thermal and chemical evolution of Mars is most likely predominated by the events that produce these two features. Although exogenic/impact-related processes have been proposed to explain both crustal dichotomy and Tharsis [4,5], here we will limit our discussions to endogenic processes that are related to mantle convection.

Tharsis is generally believed to result from a major mantle plume activity [6]. If Tharsis is largely formed by Late Noachian, as suggested by surface tectonics [1], this plume activity must occur in the Noachian or earlier, leaving relatively short time duration between formations of Tharsis and crustal dichotomy. However, the link between Tharsis and the crustal dichotomy has not yet been established, partly because the formation mechanism for crustal dichotomy remains in debate (see [7,8] for more discussions), which is the main focus on this work.

Competing Mechanisms for the Crustal Dichotomy: Three endogenic mechanisms have been proposed in the past to explain the formation of the crustal dichotomy: degree-1 mantle convection [9,10], overturn of magma ocean residue [11], and plate tectonic process [12]. It should be pointed out that these three mechanisms focus on different aspects of the formation problem and may not necessarily be mutually exclusive to each other.

Degree-1 mantle convection was first proposed to account for the hemispheric asymmetry of the crustal dichotomy – possibly the most fundamental observation of the dichotomy, but with little physical basis [9]. Later studies of mantle convection [10,8] focus on uncovering the physical mechanisms that lead to degree-1 convection. Plate tectonic process was proposed by Sleep [12] to account for the smoothness and young age of the northern plains and the thin crust there by the process of 'seafloor spreading' and its associated crustal thinning. However, Sleep [12] did not really address the question why such 'seafloor spreading' process only happened in the northern hemisphere, not globally as on the Earth. The pre-Noachian age suggested by the new MGS and MARSIS observations [2,3], suggesting that the plate tectonic process as envisioned by Sleep [12] is untenable. However, early plate teconic style of mantle convection remains possible.

The overturn of magma ocean residue idea [1] focuses more on compositional and petrological aspects of crustal formation. It should be pointed out that degree-1 mantle and crustal flow is still required to produce the crustal dichotomy. However, the conditions under which the overturn of magma ocean residue leads to degree-1 mantle and crustal flow for Mars has not yet been demonstrated. The major difference between this mechanism and degree-1 mantle convection is the magma ocean origin for the crust, whereas degree-1 mantle convection models formulated so far [10] suggest that the crustal dichotomy results from mantle convection after the completion of magma ocean process.

Solomon et al [7] suggested that crustal dichotomy may have formed in the first 50 million years of Mars geological history as result of the planetary differentiation on the basis of geochemical mass balance calculations. They also suggested that mantle convection was untenable because it would take too long (several hundred millions years) for degree-1 mantle convection to establish. However, we recently show that degree-1 mantle convection can be established in less than 100 Ma and that it can happen even faster depending on mantle viscosity. We also show that degree-1 mantle convection is needed to maintain the degree-1 structure of crustal materials. Furthermore, other geochemical mass calculations show that significant amount of crust materials formed significantly after the primary differentiation [13].

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