Plate Tectonics on Mars Hindered by Buoyant Martian Eclogite

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Introduction: Mars lacks ongoing tectonic activities such as volcanism, marsquakes with large magnitude (e.g. M>4.0) and mountain building process [1-3]. On Earth, plate tectonics is primarily driven by dense lithospheric slabs subducting into the mantle [4]. The crustal slabs, made of the dense eclogite metamorphosed from the Mid-Ocean Ridge Basalt (MORB), provide one of the most important driving forces for slab subduction [5]. Thus, mantle convection inside Mars can be hindered if the density contrast between Martian crustal slabs and the ambient Martian mantle is sufficiently different from Earth. To evaluate this hypothesis, we carried out high pressure-temperature phase equilibrium experiments and calculations using Yamato 980459, a near-primitive Martian basalt [6], and examined its buoyancy in the Martian mantle. We find that this crustal slab is less dense than the ambient Martian mantle down to the depth of ~300 km and neutrally buoyant compared to the mantle down to the depth of ~500 km. Our estimated slab sinking torques and velocities suggest that sustained subduction on Mars is difficult if the Martian crust is represented by the Al-Ca poor shergottic basalt.

Methods and Results: We have carried out PerpleX computation, as well as high P-T multi-anvil experiments on a primitive Martian basalt (Yamato 980459) to study its mineral composition, proportion and the geophysical properties along a typical Martian areotherm [7], and then compared out results with the ambient Martian Mantle with DW composition [8]. We performed all the phase equilibrium experiments using Multi-anvil Apparatus at UNM. The experiments at 1-9 GPa were performed with the UNM 14/8 assemblies and experiments at 12-16 GPa were performed using the COMPRES 10/5 assemblies. The chemical composition of individual minerals and the chemical composition maps were obtained by JEOL 8200 Electron Microprobe at the Institute of Meteoritics. Based on the average chemical composition of each phase and the chemical composition of starting material, we calculated the weight percent (wt.%) of each mineral phase using Least Square Mass Balance method. With the known elastic properties of different minerals, we utilized third-order and forth-order finite strain equation of state to obtain the density, bulk modulus, and shear modulus of each mineral phase in each run product. The volume percent of each mineral (vol%) in each run product can then be derived. We further calculated the bulk density, Vp, Vs for the mineral aggregates using the Voigt-Ruess-Hill average methods. We applied the same method to calculate the density, Vp, and Vs for the ambient Martian mantle with DW composition based on the experimental results from [8]. The Perple_X computational results are in reasonable agreement with the experimental results, with small differences primarily in the orthopyroxene (Opx) and Fe-enriched Wadsleyite stability field. This is likely caused by the uncertainties in the thermodynamics properties of Fe-end members. these slight differences did not significantly affect the density profile calculated from the phase diagram due to the density similarity of Opx and clinopyroxene (Cpx). Unless otherwise noted, our results refer to experimental values.

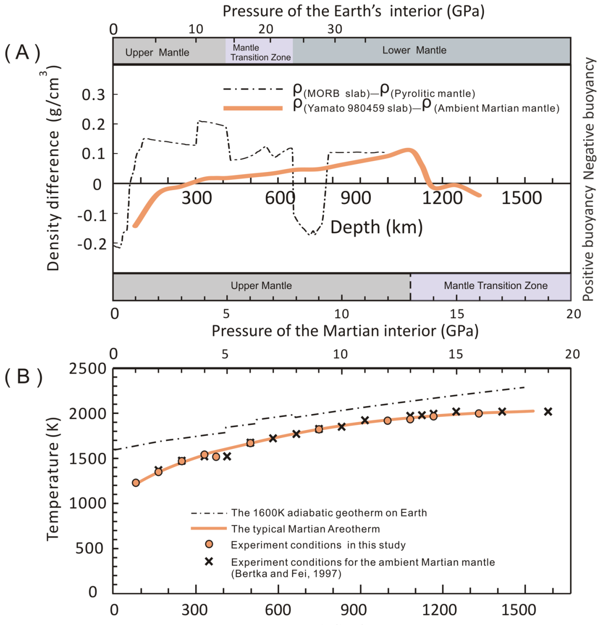

Figure 1. (**A**) Dotted line: density difference between the Earth's crustal slab (MORB) and the Earth's ambient mantle (pyrolite) along the 1600 K adiabatic geotherm; Solid line: density difference between Martian crustal slab (Yamato 980459) and the ambient Martian mantle (DW model) along the typical Martian areotherm. (**B**) Dotted line: the 1600 K adiabatic geotherm of the Earth [9]; Solid line: the typical Martian areotherm [7].

We found out that the density of the Martian eclogite made of Yamato 980459 is on average ~0.7 % less dense than the eclogite transformed from MORB on

Earth, however, the ambient Martian mantle is on average ~3 % denser than the ambient Earth's mantle at the similar P-T conditions. The relative buoyancy of eclogite and ambient mantle is different between Mars and the Earth, primarily due to the differences in their chemical compositions. On Earth, the crustal slab made of MORB remains denser than the pyrolitic ambient mantle from ~60-100 km down to ~660 km depth. This is one of the most important driving forces for the subduction-induced plate tectonics on Earth. In comparison, the Martian shergottic basalt is found to be less dense than the ambient Martian mantle even after it transforms into eclogite at ~250 km depth (Fig. 1). This positive buoyancy persists down to ~300 km depth, after which the eclogite remains neutrally buoyant compared to the ambient Martian mantle down to ~500 km depth, which is completely different from the Earth. Therefore, Earth-like plate tectonics driven primarily by slab subduction is unlikely to have occurred on Mars.

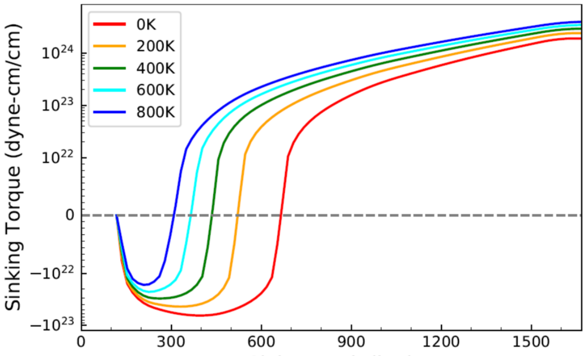

Figure 2. Martian slab sinking torque

In addition, we also calculated the sinking torques for a simplified slab with a 45º dipping angle in the ambient Martian mantle (Fig. 2). Assuming no temperature difference between the slab and the ambient Martian mantle, the torque remains negative for slabs shorter than 650 km in length, thereby prohibiting slabs of this length or less from sinking. We considered an extreme case in which the slab is colder than the mantle by 800 K, and found that subducted slabs need to be longer than ~300 km to sink. Based on these calculations, buoyancy-driven continuous subduction cannot be sustained unless Martian slabs were somehow forced into the Martian mantle to depth of few hundred kms depending on the temperatures.

References:

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