THE ROCKY PLANETS WITH MAGNESIUM – DEPLETED MANTLE COMPOSITION. P. Futó\textsuperscript{1}
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Introduction: The observed stellar Mg/Si abundances in the Solar galactic neighborhood implies that the most of the potential rocky exoplanets may have Mg – rich bulk composition. In contrast, a small fraction of the rocky planet population may have been formed in Mg – poor chemical environments in the protoplanetary disks yielding rocky planets with Mg – depleted mineral composition. The mantle convection strongly influences the style of tectonic regime and thermal history of rocky planets. The efficiency of mantle convection depends critically on the mantle mineral composition. To estimate the magnitude of population of the geologically active terrestrial exoplanets with plate tectonics, it is necessary to study the mineral diversity by exploring the plausible bulk mineral composition of rocky planets.

The main purpose of this study is to give a comprehensive picture from the mineralogy of Mg-depleted rocky planet interiors.

Modeling low – Mg/Si mantle compositions: Silicate garnets are important mineral constituents in Earth’s upper mantle (UM) and transition zone (TZ). In the Earth’s upper mantle, pyroxenes have been dominated by three major components: enstatite (Mg$_2$Si$_2$O$_6$) (en); diopside (CaMgSi$_2$O$_6$) (di) and jadeite (NaAlSi$_2$O$_6$) (jd) [1].

In the upper and lower region of the UM, Si – rich mineral compositions have been investigated in the function of variable Mg/Si ratio focusing on a diopside – rich pyroxene – and a pyrope (pyr) – rich garnet composition. Jadeite is also thought to be a major component of clinopyroxene minerals in the UM.

In the first stage of the compositional modeling, high – (HP) and ultra-high pressure (UHP) phases of mantle – building silicates and oxides have been investigated in the deep mantles of massive terrestrial planets (MTPs). The potential sequences of phase transitions have been considered for Mg-SiO$_3$ and SiO$_2$ in the modeled planetary lower mantles (LM) at high – and ultra – high pressures ranging from 23.5 GPa to 3.5 Tpa.

The phase boundaries of the major mantle - constituent minerals based on the high pressure experi-

ments of the three-stage dissociation of MgSiO$_3$ in terms of the model of Umemoto et al. (2017) [2].

At 50 Gpa, stishovite undergoes a further transformation to the post – stishovite CaCl$_2$-type structure [3]. The phase transition between CaCl$_2$ -type and α-PbO$_2$-type SiO$_2$ is being predicted at 121 GPa [4]. α-PbO$_2$-type SiO$_2$ transforms into a higher - pressure form with a pyrite-type structure at 268 GPa [5]. The pyrite - type phase of SiO$_2$ undergoes a transformation to the Fe$_3$P -type phase at 690 GPa [6].

The modeled belts of UM are assumed to be mineralogically heterogeneous, the calculations for simplicity have been performed by considering the effect of the pyr, SiO$_2$ and di - jd systems on the bulk low – Mg/Si mineralogy.

The mineral composition determines the reological properties of the mantle. Consequently, the mantle dynamics also depends on varying elemental composition of the major mineral components.

For instance, the cation substitutions changes the microstructure of garnets, which influences the relevant physical – chemical properties [7, 8]. At ambient pressure, pyroxenes have greater values of thermal diffusivity ($\kappa$) compared to the major mineral constituents of the UM.

The plausible mineral assemblages for the Mg – depleted planetary mantles: The Figure 1. shows the characteristic high – pressure mineral phases for the mineralogically modeled lower - mantles of Mg – depleted supermassive rocky planets. SiO$_2$ – rich bulk lower – mantle mineral compositions has been explored for the case of 0.75 and 0.25 bulk Mg/Si values.

The Mg - poor LM of the approximately 1 Earth – mass planets consists of MgSiO$_3$ in higher molar percent than Earth’s lower mantle.

The mantle depletion of Mg yields a diopсидic pyroxene – and garnet – rich upper mantle mineralogy. In the uppermost zone of the UM in low – Mg/Si planets, (α) - diopside and jadeite can be the most abundant minerals among the pyroxene species. Note that jd is likely to be a major constituent in the felsic rocks of the upper crust, which
can be compositionally similar to the Earth’s upper continental crust.

**Figure 1.** Mineralogical models for the lower mantle of massive rocky planets in case of the bulk Mg/Si values 0.75 (A) and 0.25 (B). The idealized low-Mg/Si planets are characterized by pyroxene – and garnet – dominated upper mantles and Mg$_3$SiO$_3$ – dominated and SiO$_2$ – rich lower mantles.

The mineral assemblage of the uppermost zone of the UM changes with the decreasing Mg/Si ratio in the olivine – diopside – jadeite – garnet multicomponent system with the variable compositions of the olivine / garnet compounds and the di – jd solid solutions (Figure 2).

For planets with ($1 < \text{Mg/Si} < 2$), majorite – pyrope (mj – Py) [$\text{Mg}_3(\text{Mg}, \text{Si})\text{Si}_3\text{O}_{12} - \text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$] with a relatively high mj content is the typical binary for the garnet composition in mantle transition zone (TZ). In contrast, Pyrope – almandine – grossular [$\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12} - \text{Fe}_3\text{Al}_2(\text{SiO}_4)_3 - \text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$] (Pyr, Alm, Gr) with the variable ratios of compounds can be characteristic for the mineral composition of the garnet zone of the upper mantle in rocky planets with Mg/Si $< 1$. The composition of the mineral assemblage in the upper mantles depends on the relative abundance of key rock – forming elements (Mg, Si, Fe, Al, Ca).

The mantle of Mg-poor rocky planets is more viscous compared to that of Earth, resulting in sluggish – lid or stagnant – lid regime depending mostly on the planetary mass and Mg/Si ratio.

**Figure 2.** Bulk upper mantle mineralogy for the ~1 Earth-mass rocky planets for the case of bulk Mg/Si values 0.75 (A) and 0.25 (B).

Accordingly, the stagnant – lid convection can be the plausible mode of heat transfer in the mantles of low-Mg/Si rocky planets. The Fe/Si, Al/Si, Ca/Si and Na/Si ratios related to the Mg/Si ratio are amongst between the most important factors for determining the mineralogy of low–Mg/Si exoplanetary mantles.

**Summary:** The presented model approaches can provide important contraints on the plausible chemical composition of Mg-depleted planetary mantles. I has been found that the variation of Mg/Si ratio in the range of Mg/Si $< 1$ can significantly impact on the bulk mineral composition of planetary crusts and mantles. The observed wide variety of stellar abundances of key rock – forming elements in FGK – stars in the Solar neighborhood implies on a great mineralogical diversity for the nearby galactic population of rocky exoplanets.

**References:**