

PhD project: Petrochemical characterization of mantle overturns in terrestrial planets

After the Moon's accretion, its mantle was entirely molten. According to some models, during the cooling of the lunar magma ocean, fractional crystallization led to a spontaneous "mantle overturn" when the last (denser) layers crystallized and sank into the mantle. This event may have formed a cumulate layer rich in dense minerals, including ilmenite, at the base of the lunar mantle (Dygert et al., 2016; Hess and Parmentier, 1995; Papike et al., 1998; Parmentier et al., 2002; Ringwood and Kesson, 1976). Today, there seems to persist a dense layer at the base of the lunar mantle, known as the LVZ (Low Viscosity Zone) (Briaud et al., 2023a).

Such a process may have occurred on all terrestrial planets that had a magma ocean.

The objective of this PhD project will be to characterize the current 3D structure of the Moon, Mars, and Mercury using tidal tomography developed at Géoazur, based on available (Mars Express, MRO, Mars Odyssey, MGS) and upcoming (Bepi-Colombo) space mission data for Mars and Mercury.

The first step will involve adapting the thermodynamic tools used for the Moon to Mars and Mercury. A significant difference lies in the range of pressures within the mantles of these planets, which exceed those observed on the Moon. The databases used for the Moon, such as those by Holland and Powell (2011), are suitable for moderate pressures but not for high pressures. Databases developed for high pressures exist (e.g., Stixrude and Lithgow-Bertelloni, 2022), but they do not yet include titanium as a chemical component, an essential element in the crystallization of dense minerals, particularly ilmenite. Part of the work will therefore involve gathering high-pressure experimental petrology results and incorporating the thermodynamic properties into a self-consistent database adapted for high-pressure conditions. Once this step is completed, we will model the crystallization of magma oceans on Mars and Mercury and explore the expected petrochemical diversity and associated variations in density, rigidity, and viscosity.

The second phase will focus on mapping potential density, viscosity, and rigidity anomalies for Mars and Mercury, building on the results currently under development for the Moon. For Mars, we will examine whether the location of a mantle plume, as proposed by Broquet et al. (2023), is consistent with Martian tidal deformations. Regarding Mercury, in March 2026, the Bepi-Colombo mission will begin its scientific exploration, and updated preliminary gravity field and tidal deformation measurements will be published. These new measurements will help reveal Mercury's internal structure, both using 1-D models (as has been done for the Moon by Briaud et al. 2023) and also with potential 3-D structures.

Basic knowledge of magmatic and metamorphic petrology is required. The candidate should also have a strong interest in numerical modeling. Funding (ANR-X-MAT) has already been secured to support this PhD project as well as associated missions (conferences/partner lab visits).

Further information is available upon request (clement.ganino@univ-cotedazur.fr).