EVIDENCE FOR MARS DEEP MANTLE LAYERING IN THE LIGHT OF INSIGHT SEISMIC DATA.

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Introduction: The recent identification of deep reflected phases in the seismic recordings of the InSight mission [1] as core reflected phases have led to the first seismic detection of the Martian core [2]. These results indicated that the core size of Mars spans the higher end of InSight pre-mission estimates, implying a large fraction of Sulfur in the core together with smaller fractions of O, C, and H. These fractions lie beyond the experimental petrological range [3]. In addition, the recent detection of P-diffracted phase [4] requires a significant reduction of seismic velocities in the deep mantle, which is difficult to explain with compositionally homogeneous mantle models [5].

The presence of a well-separated metallic core indicates that Mars experienced an early global magma ocean stage whose crystallisation likely led to the formation of a compositionally distinct layer at the bottom of the mantle [6]. Such a layer is expected to be heavily enriched in heat-producing elements and in iron, leading to long-term stability with little mixing between the layer and the overlying mantle. The presence of this enriched basal layer yields the development of partially molten and fully molten molten silicate layers above the core. The latter could act as a deep seismic reflector [7].

Objectives: We tested the compatibility of deep Martian mantle layering with InSight seismic [8] and geodetic [9] data along with other observational constraints.

Approach: We conducted Monte Carlo Markov chain inversions in which the long-term thermo-chemical history of Mars' main envelopes is embedded into the forward problem (Fig. 1). Contrary to more classical approaches that directly invert for seismic velocities and density along a radial planetary profile, we explore a different model space that consists of parameters that govern the thermo-chemical evolution of Mars: the planetary initial thermal state, the core size, the mantle rheology, or the crustal enrichment in heat-producing element with respect to the mantle. For each model we evolve the system for 4.5 Gyr. The models predict present-day thermal structure that are converted into seismic structures [10]. This approach allows for more consistent and better-constrained profiles than in classical inversions (Fig. 1), due to the more informative prior considered, and allows reconstructing the long-term history of the planet.

Our inversion approach also considers an enriched silicate layer above the core-mantle boundary and we invert for the layer thickness and for its thermal conductivity. We used the most recent travel time dataset that contains considerably more shallow and deep phases (including ScS and Pdiff) compared to previous studies.

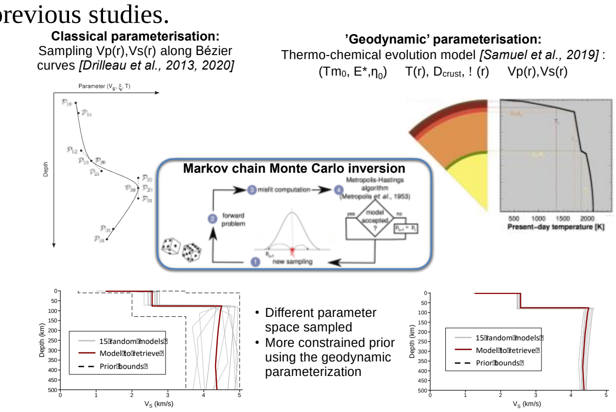

Figure 1: Schematic representation of a classical [11] (left) and a geodynamic parameterization [10] (used here) to infer Mars' seismic structure via Monte Carlo Markov chain inversion of seismic data.

Altogether, this allows us to test the hypothesis of the presence of a molten layer above Mars' core, along with the associated consequences on the interpretation of seismic, geodetic, and geochemical data.

Results: The presence of a Basal Mantle Layer (BML) yields a more complex seismic structure than the case of a compositionally homogeneous mantle (Fig. 2).

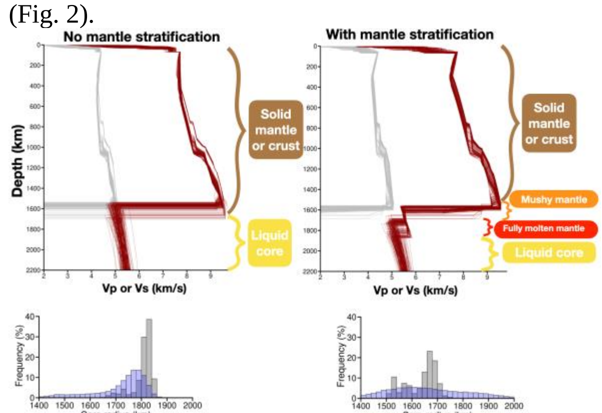

Figure 2: Inversion output for a compositionally homogeneous mantle (left) or a layered mantle (right). Top:

Seismic output models. Bottom: prior (blue) and posterior (grey) distributions for the core radius.

The BML enriched in heat-producing element leads to the presence of a fully molten silicate layer above the core, overlain by a partially molten (mushy) layer. The fully molten silicate layer acts as a seismic extension of the iron core and triggers S-reflections above the core-mantle boundary. This results in a core 100-200 km smaller than previous estimates that assume a compositionally homogeneous mantle [2].

The smaller core inferred in models that account for a BML is considerably denser than previous estimates. This revised core density can be explained by fewer amounts of S and other light elements within the experimental petrological range (Fig. 3).

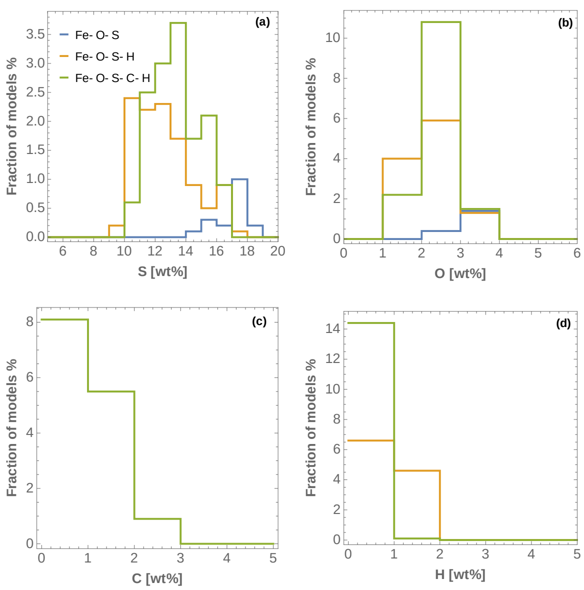

Figure 3: Core density-velocity histogram for Mars models with a BML. The blue, yellow, and green dots represent interior models that have elastic properties compatible with and Fe-O-S, Fe-O-S-H, and Fe-O-S-C-H alloy, respectively.

The structures produced by the basal mantle layer are also compatible with geodetic constraints on k_2 values [12], in good agreement with theoretical predictions [7] (Fig. 4) and is consistent with data from InSight radio tracking experiment (RISE [9]) that provide constraints on free core nutation and core amplification factor [13].

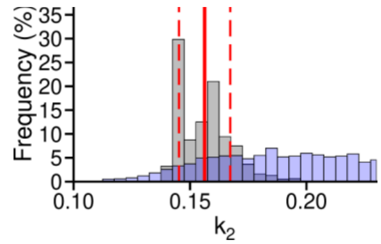

Figure 4: Prior (blue) and posterior (grey) distributions for the degree-two Love number from the inversion with a basal mantle layer. The plain and dashed red lines indicate the posterior mean value and 1-sigma range.

Conclusions: Our inversion results show that the presence of a basal mantle layer is compatible with seismic, geodetic and petrological experimental data. The basal mantle layer stores a significant fraction of heat-producing elements and depletes the rest of the mantle. This leads to the presence of a fully molten silicate layer that triggers deep S-wave reflections above the core and reduces the travel time of P-diffracted waves along the CMB, yielding a good data fit for the differential travel time between PP and Pdiff phases. The fully molten layer is overlain by a partially molten silicate layer that accommodates tidal dissipation. The resulting structure is compatible with RISE data (free-core nutation and core amplification factor) and k_2 estimates [12, 13].

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