GLOBAL CRUSTAL THICKNESS MODELING OF MARS USING INSIGHT SEISMIC CONSTRAINTS.

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Introduction: The crust of Mars formed as a result of differentiation processes that occurred early in solar system history and subsequent magmatism that continues to the present day. If the average thickness of the crust were known, it could be used as a key constraint on deciphering the thermal evolution of the planet [1]. Several studies have attempted to estimate the thickness of the crust of Mars by modeling the relationship between gravity and topography, but these studies depend upon making assumptions concerning isostasy and the densities of the crust and upper mantle [2, 3].

Current estimates for the average thickness of the crust of Mars span a large range, from values as low as 30 km to values that exceed 100 km [4]. This range implies that the crust could comprise anywhere from 2 to 10% by mass of the total inventory of silicates in the planet. If gamma-ray measurements of the surface are representative of the bulk crust [5], this range further implies that anywhere from 20 to 100% of the planet's heat-producing elements could reside within the crust. For comparison, it is noted that the crust of Earth comprises less than 1% of the planet's silicates by mass, whereas for the Moon this value is higher at 4-6% [6].

NASA's InSight mission is currently making seismic measurements on the surface of Mars [7] and one of the primary objectives of the mission is to determine the thickness of the crust beneath the landing site. Here, we describe how a single crustal thickness measurement can be combined with gravity and topography data to estimate the average thickness of the crust of Mars and to generate global models of how the crustal thickness varies across the planet.

Methodology: The observed gravity field of a planet has contributions from hydrostatic density interfaces in the mantle and core, relief along the surface, and relief along the crust-mantle interface. We follow the modeling approach of [8], and for the materials beneath the lithosphere, we make use of 13 possible interior reference density profiles from [9]. An *a priori* density structure is assumed for the crust, which allows us to calculate the gravitational signal of the surface relief. The gravitational signal that remains after accounting for the surface relief and hydrostatic interfaces beneath the lithosphere is assumed to be the result of relief along the crust-mantle interface, which can be inverted globally if the crustal thickness is known at a single location.

Three key parameters affect these global crustal thickness models: (1) the upper mantle density, which is specified by the interior reference model, (2) the measured crustal thickness at the InSight landing site, and (3) the density structure of the crust. For the density structure of the crust, three models will be tested. The first uses a crust with a constant density, the second employs a constant thickness porous layer above a constant density crust, and the third considers the possibility that the crust of the northern lowlands is denser than the southern highlands. All assume that the crustal thickness is everywhere greater than zero.

For the sake of demonstrating how a single crustal thickness determination constrains our global crustal thickness models, we will assume a value of 30 km at the InSight landing site, which is consistent with preliminary seismic receiver function analyses of [10].

Constant density crust: In Figure 1, the computed average crustal thickness is plotted as a function of crustal density for each of the 13 interior density models. The minimum density of the crust was taken to be 2550 kg m^{-3}, as suggested by gravity inversions of [11], and the average crustal thickness is seen to increase with increasing crustal density. The minimum crustal thickness (which is located within the Isidis impact basin) is found to decrease with increasing crustal density, and the maximum average crustal thickness for each model corresponds to the case where the minimum crustal thickness is zero.

If the crustal thickness at the InSight landing site is 30 km, the average crustal thickness of the planet would be constrained to lie between about 38 and 45 km, and the crustal density would be constrained to be less than 2950 kg m^{-3}. If the InSight crustal thickness were instead 45 km, the maximum permissible crustal density would be 3100 kg m^{-3} and the average crustal thickness would lie between 54 and 68 km.

Constant porosity upper crust: For this scenario, the crust of Mars was assumed to have a constant grain density, but that porosity was present in a constant-thickness surficial layer. These models are found to be nearly the same as those with no porosity. Even for the case of 10% porosity in a 20-km thick layer, the differences with respect to a model with no porosity is only

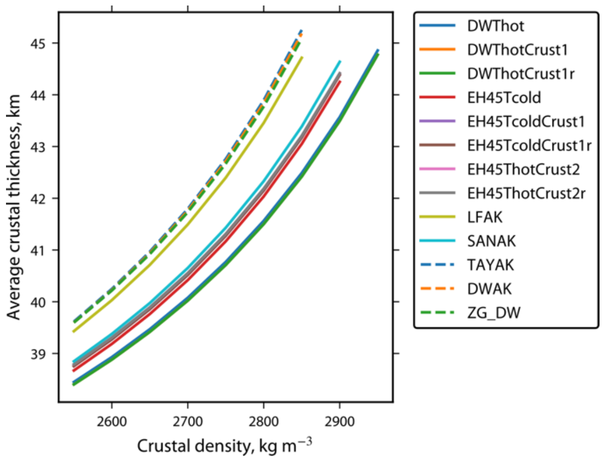

Figure 1. Average crustal thickness as a function of the density of the crust. The crustal thickness at the InSight landing site is assumed to be 30 km, and each curve corresponds to a different interior density model from [9].

about 2 km. This behavior results because the negative gravitational contribution from porosity at the surface is counterbalanced by a positive signal of similar magnitude at the base of the porous layer.

Dichotomy in crustal density: We next consider the possibility that the density of the northern lowlands crust is greater than the southern highlands. Evidence for this hypothesis comes from high crustal densities estimated beneath the Elysium rise [12] and the existence of some low-density felsic rocks in the southern highlands [13].

Two possible models are plotted in Figure 2. For the upper image, the density of the crust is assumed to be constant with a value of 2800 kg m^{-3}, whereas for the lower image the density of the southern highlands is set to a lower value of 2550 kg m^{-3}. The thickness of the northern lowlands is seen not to depend on the assumed density of the southern highlands.

The thickness of the southern highlands crust decreases as the density of the southern highlands crust decreases, and for the model that is shown, there is no discernable difference in crustal thickness across the dichotomy boundary. The maximum allowable density of the crust is the same as for the constant density model (2950 kg m^{-3}), and permissible average crustal thicknesses are found to range from 31 km to 45 km.

Conclusions: A single crustal thickness determination beneath the InSight landing site will place firm constraints on global models of the thickness of the martian crust. If a value close to 30 km is found [10], this would require an average crustal thickness of 31 to 45 km, the crust would comprise between 2.5 and 4.5% of the silicate portion of the planet by mass, and 25 to 45% of the planetary heat production could be located in the crust. The maximum allowable crustal density of 2950 kg m^{-3} would either exclude models that have crustal densities similar to the martian basaltic meteorites [4] or would require that there was at least 12% porosity in the entire crust [15].

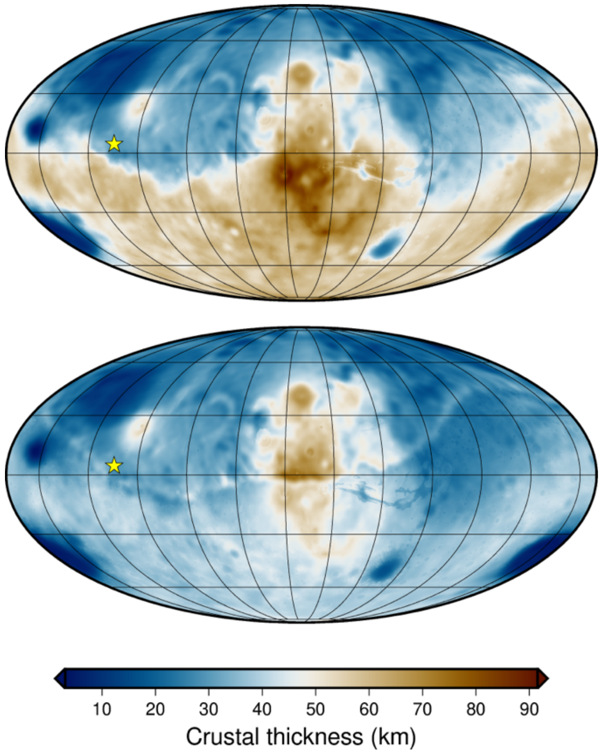

Figure 2. Global crustal thickness of Mars assuming a 30 km thickness at the InSight landing site (yellow star). The crustal density is everywhere 2800 kg m^{-3} in the upper image, whereas in the lower image the densities of the northern lowland and southern highland crust are 2800 and 2550 kg m^{-3}, respectively. The dichotomy boundary is from [14].

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