THERMAL EVOLUTION AND THE UREY RATIO OF MARS. A. C. Plesa1, M. Grott1, N. Tosi1 and D. Breuer1 (DLR, Institute of Planetary Research, Rutherfordstr. 2, 12489 Berlin, ana.plesa@dlr.de).

Introduction: The upcoming InSight (Interior exploration using Seismic Investigations, Geodesy and Heat Transport) mission, to be launched in 2016, will carry the first in-situ Martian heat flow measurement and provide an important baseline to constrain the present-day heat budget of the planet and, in turn, the thermal and chemical evolution of its interior.

The surface heat flow q_s can be used to constrain the amount of heat producing elements present in the interior (Q) if the Urey ratio (U) – the planet's heat production rate divided by heat loss – is known. Thus, the heat production rate Q (in pW/kg) in the interior can be determined from:

$$Q = \frac{\rho_{sil} V_{sil} U}{q_s A},$$

where $\rho_{sil}\ V_{sil}$ represents the mass of the silicate fraction and A is the surface area of the planet.

Model and Methods: We use numerical simulations of mantle convection in 2D cylindrical and 3D spherical geometry [1, 2], as well as 1D parameterized models [3] to model the thermal evolution of Mars and to determine the present-day Urey ratio for a variety of different models and parameters. Our models use cooling boundary conditions at the core-mantle boundary (CMB) and self-consistently treat the decay of radioactive elements. We vary the initial amount of heat producing elements (HPE) according to different HPE models suggested for the interior of Mars [4, 5, 6, 7]. Additionally, we use various viscosity formulations (e.g. temperature-, temperature- and depth-dependent viscosity, viscosity jump in the mid mantle), we vary the size of the core between 1500 - 1700 km, and we consider models with and without phase transitions in the mantle. Another set of models considers different partitioning of HPE between mantle and crust, where the crustal thickness is kept constant. Different initial conditions (e.g., initial temperatures ranging from 1650 - 1950 K, initial thermal boundary layer thickness between 50 and 300 km) and reference viscositiesbetween 10^{20} - 10^{23} Pa s have also been tested.

Results: Our results show that U is mainly sensitive to the efficiency of mantle cooling, which is associated with the temperature dependence of the viscosity (thermostat effect), and to the abundance of long-lived radiogenic isotopes.

As depicted in Fig. 1, the thermostat effect is efficient for reference viscosities smaller than 10^{23} Pas at a reference temperature of 1600 K, and present day Urey ratios converge for viscosities smaller than 10^{22} Pas. Given that models of the thermo-chemical evolution of Mars generally indicate reference viscosities below 10^{21} Pa s [e.g., 3, 8], the Martian Urey ratio is likely only a function of the Thorium (Th) concentration in the planetary interior.

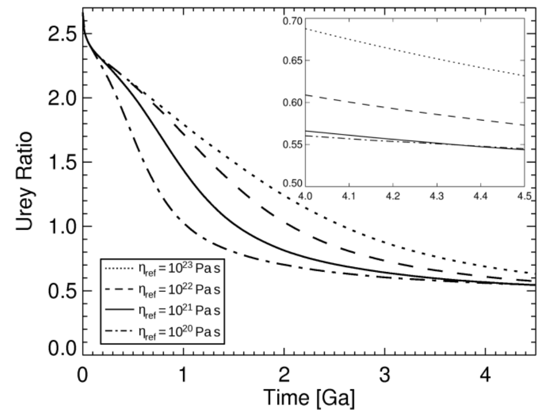


Fig. 1: Urey ratio as function of time for various reference viscosities assuming a Wänke et al. chemical composition [4].

This is illustrated in Fig. 2, where the Urey ratio is shown as a function of time for different compositional models (top), as well as the abundance of heat producing elements (bottom). Only the model by Morgan and Anders [6], which has about twice the Th concentration of the other models considered, differs significantly from the average value of U = 0.55.Therefore, for a given Th concentration, the uncertainty in the present-day Urey ratio is expected to be less than 10%.

The bottom panel of Fig. 2 shows the Urey ratio as a function of Th and Potassium (K) concentration in the planetary interior, where a fixed ratio between Th and Uranium (U) abundance of 3.5 has been assumed. Concentrations for Martian compositional models are also shown for reference. Results only weekly depend on the abundance of the relatively short-lived K, which mainly influences the early evolution of the planet. However, the dependence on Th concentration is quite pronounced.

These results have been confirmed for models using different core sizes, models with phase transitions, different viscosity formulations, and partitioning of HPE between mantle and crust. Some of these results are shown in Fig. 3. Models in 2D cylindrical geometry result in slightly smaller U values than fully 3D models

(U ~ 0.5475±0.0315 for 2D and U ~ 0.594 ±0.024 for fully 3D models).

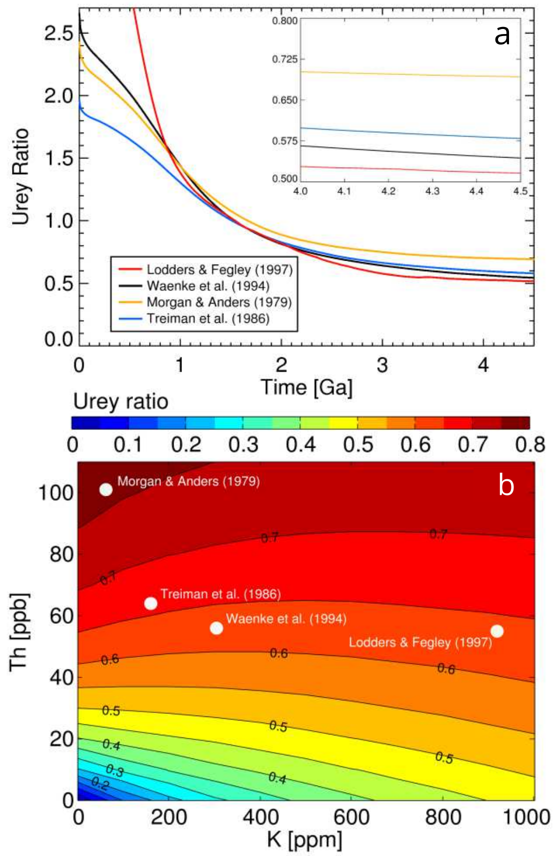
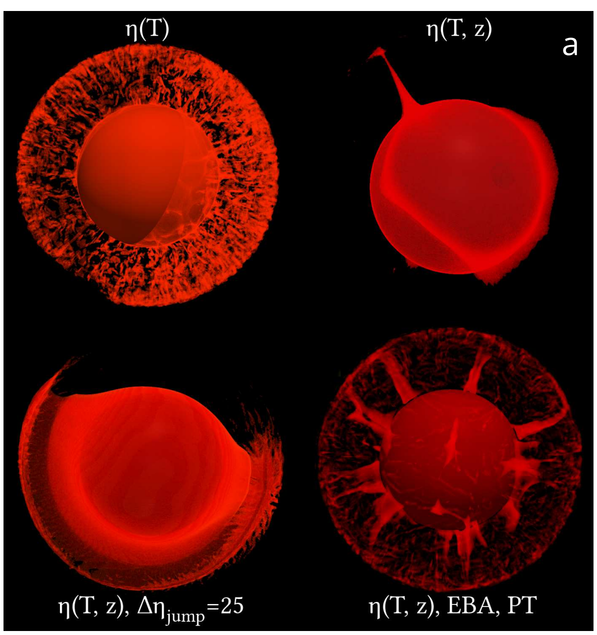


Fig. 2: a) Urey ratio as a function of time for different compositional models [4, 5, 6, 7]; b) Urey ratio as a function of Th and K content.



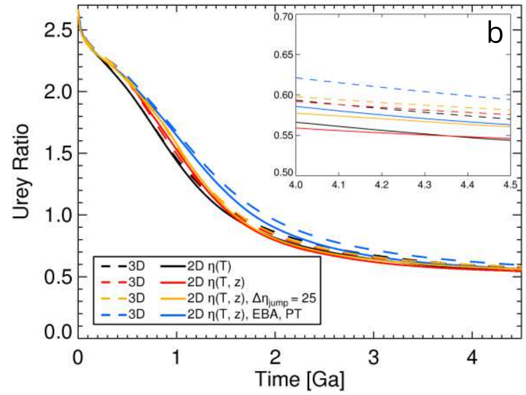


Fig. 3: a) Convection patterns obtained in our simulations and b) the corresponding Urey ratio as a function of time for 2D (solid) and 3D (dashed) models including temperature-dependent viscosity η(T) (black), temperature- and depth-dependent viscosity η(T, z) (red) including a viscosity jump ($\Delta\eta_{jump}$=25) in the mid-mantle (yellow), and with extended Boussinesq approximation (EBA) and phase-transitions (PT) in blue color.

Conclusions: The Urey ratio of Mars was found to be approximately constant, independently of model parameters if the thermostat effect is efficient, as expected for a weak mantle rheology, and the bulk concentration of long lived radiogenics is known. In fact, surface radiogenic abundances have been determined from gamma ray spectroscopy [9], and results are best consistent with the Wänke et al. compositional model [4]. Assuming the bulk Th abundance to be known, our simulations indicate that the Urey ratio of Mars can be computed with an uncertainty of likely less than 15%.

If the global heat loss derived from the upcoming heat flow measurement can be estimated with an uncertainty of 20%, and if the InSight seismological investigation can determine the silicate mass fraction of the planet to within 20%, error propagation (Eq. 1) yields an uncertainty of 35% for the heat production rate, which would allow us to distinguish between different proposed compositional models.

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