Internal structure and mineralogy of differentiated asteroids assuming chondritic bulk composition: The case of Vesta

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Bulk composition (including oxygen content) is a primary control on the internal structure and mineralogy of differentiated asteroids. For example, oxidation state will affect core size, as well as Mg# and pyroxene content of the silicate mantle.

The Howardite-Eucrite-Diogenite class of meteorites (HED) provide an interesting test-case of this idea, in particular in light of results of the Dawn mission which provide information on the size, density and differentiation state of Vesta, the parent body of the HED's. In this work we explore plausible bulk compositions of Vesta and use mass-balance and geochemical modelling to predict possible internal structures and crust/mantle compositions and mineralogies. Models are constrained to be consistent with known HED samples, but the approach has the potential to extend predictions to thermodynamically plausible rock types that are not necessarily present in the HED collection.

Nine chondritic bulk compositions are considered (CI, CV, CO, CM, H, L, LL, EH, EL). For each, relative proportions and densities of the core, mantle, and crust are quantified. Considering that the basaltic crust has the composition of the primitive eucrite Juvinas and assuming that this crust is in thermodynamic equilibrium with the residual mantle, it is possible to calculate how much iron is in metallic form (in the core) and how much in oxidized form (in the mantle and crust) for a given bulk composition.

Of the nine bulk compositions tested, solutions corresponding to CI and LL groups predicted a negative metal fraction and were not considered further. Solutions for enstatite chondrites imply significant oxidation relative to the starting materials and these solutions too are considered unlikely. For the remaining bulk compositions, the relative proportion of crust to bulk silicate is typically in the range 15 to 20% corresponding to crustal thicknesses of 15 to 20 km for a porosity-free Vesta-sized body. The mantle is predicted to be largely dominated by olivine (>85%) for carbonaceous chondrites, but to be a roughly equal mixture of olivine and pyroxene for ordinary chondrite precursors. All bulk compositions have a significant core, but the relative proportions of metal and sulphide can be widely different. Using these data, total core size (metal+ sulphide) and average core densities can be calculated, providing a useful reference frame within which to consider geophysical/gravity data of the Dawn mission.

Further to these mass-balance calculations, the MELTS thermodynamic calculator has been used to assess to what extent chondritic bulk compositions can produce Juvinas-like liquids at relevant degrees of partial melting/crystallization. This work implies that alkali contents play a key role on the major element chemistry of basaltic liquids, and that basaltic eucrites were produced from melting and/or crystallization of an alkali-poor source. Overall, these results provide a useful and self-consistent reference frame for interpretation of the data from the VIR and GRaND instruments onboard the Dawn spacecraft.