ICE CRUST THICKNESS AND INTERNAL COMPOSITION OF EUROPA. R. C. Ghail, T.H.Huxley School, Imperial College, London, SW7 2BP, United Kingdom. *R.Ghail@ic.ac.uk*.

1. Background.

The radius (1569 km), mass ($4{\cdot}868 \times 10^{22}$ kg) and I/MR^2 (0·264, E4; 0·347, E6), have been determined from data returned Galileo encounters, and provide useful constraints on bulk composition models of Europa. I present new physical and chemical models derived from known meteoritic compositions expected to be representative of Europa's bulk composition. A core is differentiated, along with a mantle, crust and cryosphere. Using a modified CIPW norm method, the mineralogy of the crust and of the depleted and fertile mantle is derived, and hence the density of each layer is found. The thickness of the crust and cryosphere are adjusted to match the observed mass, radius and moment of inertia of Europa. Radiogenic and tidal energy production rates are calculated and used to define two possible thermal structures of the crust and mantle.

2. Bulk Composition.

A full treatment of cosmochemical planetary modelling is given in [1], but for the present purposes a much simpler approach has been taken by using the measured composition of chondritic meteorites as a guide to the bulk composition of Europa. At the position appropriate to Europa in the proto-jovian accretionary nebula, a composition intermediate between an ordinary and a carbonaceous chondrite is likely [2]. Chemical analyses of meteorites are readily available [3] and three meteorite compositions have been adopted from which to construct a model of Europa. These three compositions were chosen to represent the most likely composition (Nawapali, •Fe/S = 4·304) together with an iron-rich, sulphur-poor (Lance, •Fe/S = 6·209) and iron-poor, sulphur-rich (Ivuna, •Fe/S = 1·628) end member compositions. In order to fractionate the derived mean composition properly, the wt% composition has been converted to molar number fractions by dividing by the molar mass and multiplying by 100.

3. Core, Mantle and Crust Fractionation.

An amount of FeO is assigned to the mantle from the bulk composition such that the mantle Mg/[Mg+Fe] ratio is 0·88, arbitrarily the same as the terrestrial ratio [1]. A ratio similar to that predicted for Mars, 0·77, was tested but found to result in a narrow range in I/MR^2 that does not fit the Galileo data (see Fig 2). The remaining FeO is assigned to the core, together with any FeS and Ni-Fe (all NiO is assumed to be reduced to Ni), so that the core is composed of troilite (FeS), wuestite (FeO), kamacite and taenite (for convenience calculated as $NiFe_{15}$ and $NiFe_2$ respectively). Two case were tested: a cold thermal evolution model in which the core FeO remains unreduced, and a hot evolution model in which all the FeO is assumed to reduce to Fe, resulting in an FeS and NiFe core composition.

The fertile mantle is then differentiated into a crust and depleted mantle. The melting process was approximated using the CO_2/H_2O saturated pyrolite melting data given by [4], from which the compositions of the crust and depleted residue were derived, assuming the experimentally determined values of 28% partial melting, at a temperature of 1373 K and a pressure of 1·0 GPa.

The minerals stable in the lower mantle (eclogite facies) are constructed following a modified CIPW norm technique. This results in a composition dominated by omphacite, pyroxene and olive, with minor augite and garnet. The modified norm technique is also used to construct the minerals stable in an H_2O and CO_2 saturated amphibolite facies of the upper mantle. To avoid excessive complexity only the appropriate minor minerals and the major minerals hornblende, chlorite, calcite, serpentine and olivine were calculated. Other mineral phases may be stable or metastable, but for the purposes of calculating the layer density only these 5 major phases need be considered. An even wider variety of minerals are stable in the greenschist layer but again, to avoid complexity, the major mineral phases aegirine, albite, chlorite, calcite, anthophyllite and opal are used in the crustal mineralogy model. Opal is used rather than quartz in order to represent the water saturated mineralogy of the crust. In the case of silica oversaturation serpentine is produced rather than anthophyllite.

4. Thermal Structure.

The radiogenic production rate can be determined from the abundances of ^{238}U, ^{232}Th and ^{39}K in the model compositions. The total radiogenic energy production rate is therefore $4{\cdot}81 \times 10^{11}$ W, implying a surface heat flow of 15·5 mW m^{-2}, about a quarter of the average terrestrial heat flow.

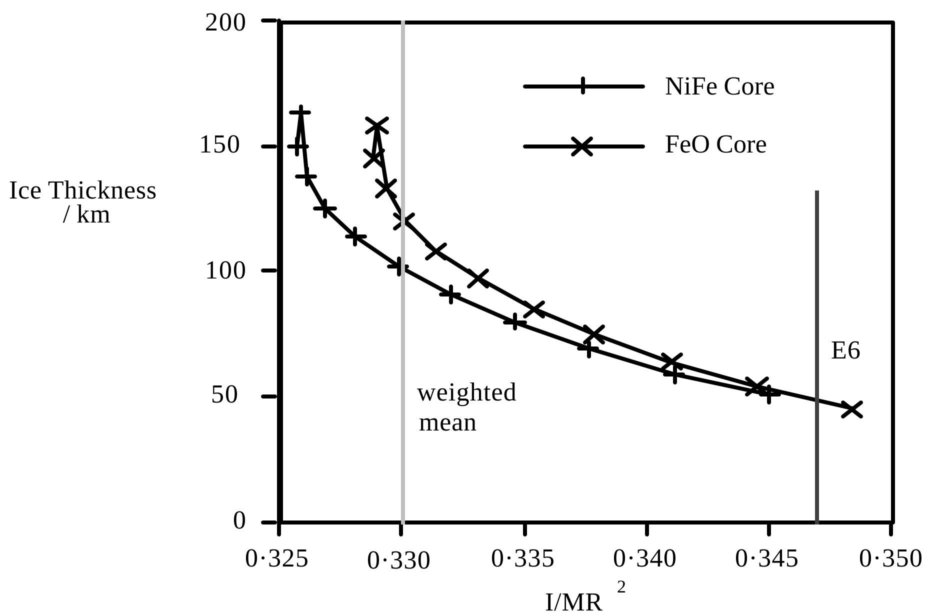
The principal tidal stress in the Europan body arises from the distortion of the primary tidal bulge due to orbital eccentricity. This eccentricity is forced by orbital resonances with Io and Ganymede [2], with the result that tidal stress has been an important and relatively uniform source of energy throughout Europan history. Using the model of [5], the homogeneous tidal energy production rate is found to be $8{\cdot}34 \times 10^{10}$ W, giving a surface heat flow of 2·7 mW m^{-2}. However, this is effectively the minimum energy generated by tidal stress, since Europa is not a homogeneous solid. Two regions in Europa may generate additional tidal stress: a liquid water layer at the base of the cryosphere, and a weak layer at the base of the greenschist crust. The maximum tidal energy is generated in highly rigid crust overlying a fluid body.

The theoretical maximum tidal energy so produced is $1{\cdot}42 \times 10^{12}$ W, or 45·8 mW m^{-2} (after [5]). It is unlikely that such a situation exists in the silicate interior of Europa but a weak semi-fluid layer may exist at the convective-conductive boundary, similar to the terrestrial asthenosphere. Such a layer may increase the tidal energy production by a factor of five to ten. If the cryosphere was ever liquid and there is significant topography on the silicate surface (> ~1 km), the basal part of the cryosphere will remain liquid through tidal friction on that surface, providing a further source of energy. Therefore I estimate that the surface of the silicate layer is likely to be near 273 K and that heat flow through the silicate crust is about 35 mW m^{-2}, giving a thermal gradient through the crust of about 10 mK m^{-1}. Advection may reduce this gradient to about 7 mK m^{-1}. Convection may occur in the hydrated silicates at about 800 K, which would reduce the thermal gradient in that layer to 0·05 mK m^{-1}.

5. Interior Structure.

A program was written for each of the three composition models which calculated the radius and moment of inertia from the density structure of the model. The pressure/radius structure was determined by the program and used to adjust the density structure. The total mass of the model was fixed, as was the core mass for each composition. The crust was maintained at 28% of the combined mass of the crust and the depleted mantle. The ratio of fertile to depleted mantle was varied between end cases and the thickness of the cryosphere was adjusted to match the observed radius. The resulting moment of inertia was then calculated. Fig 1 illustrates the variation in I/MR^2 against cryosphere thickness by the Nawapali composition model. The results of the other two composition models are similar.

Fig 1. Variation of Moment of Inertia with Ice Thickness for Two Models of Europa.



6. Discussion.

The derived models indicate that Europa may have a cryosphere only two to five times thicker than any underlying topography on the silicate surface. Topographic features on the silicate surface may allow oceanic basins to form in which any liquid water may collect, and continental regions may be in direct contact with the ice. A range of features may be visible on the surface of Europa that are related to volcanic and tectonic processes in the silicate crust of Europa. There is still some uncertainty in the I/MR^2 of Europa; a higher value would indicate a more evolved mantle and thinner cryosphere. Alternatively, the very different values determined may indicate that Europa is significantly non-hydrostatic.

References

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