EUROPE: THICKNESS OF AN OUTER WATER-ICE SHELL AND CORE RADII

Kuskov O.L., Kronrod V.A.
ol_kuskov@mail.ru

Financial support by RFBR, grants NN 00-05-64371, 01-05-64318
Herald of the Earth Sciences Department RAS, № 1(20)′2002
URL: *http://www.scgis.ru/russian/cp1251/h_dgggms/1-2002/informbul-1.htm#planet-6.engl*

Introduction. Jupiter's rocky satellite Europe has a water-ice surface. There are indirect geological and geophysical evidence that Europe may possess subsurface salty liquid-water ocean. The existence of a water ocean was recently supported by magnetic measurements and surface morphology features obtained with *Galileo* [1-2]. The new gravitational field data yield a mean density and a moment of inertia for Europe with various thicknesses of an outer envelope and core sizes [3]. Because of their simplicity, the available models [3] do not give any compositional information. Further modelling of the internal structures based on thermodynamics and geophysical constraints is required to understand mineralogy and chemistry of the satellite. The aim of this paper is to reproduce characteristic features of the internal structure of Europe (thickness of an outer water-ice shell, mantle composition and density, and core sizes and masses) on the basis of its mass and moment-of-inertia factor (inverse modelling). Ordinary and carbonaceous chondrites are taken as representatives of nebula matter. The general methodology is to combine the geophysical and geochemical constraints and thermodynamic approach, and to develop, on this joint basis, the self-consistent models of Europe, accounting for its chemical composition and internal structure.

Geophysical and geochemical constraints. Europe's mass and moment-of-inertia factor are used to model the internal structure of Europe for three first-order parameters: (1) the thickness of an outer water-ice shell, H_{sh}; (2) the chemical composition (the ratio of total iron to silicon, Fe_{tot}/Si, and metallic iron content, Fe_m, where $Fe_m=Fe^{\circ}$ from metal + Fe from FeS); (3) the core sizes and masses.

The solution of the inverse problem involves the computation of the allowed bulk compositions of a satellite from the available geophysical data, and is based on the minimization of the deviations between the observed and calculated parameters (the mass and moment of inertia) [4]. For the numerical solution, we adopted the following parameters: M ($47.99 \cdot 10^{24}$ g), ρ (2.989 ± 0.046 g cm^{-3}) and R (1565 km) are the total mass, mean density and mean radius of Europe; the moment of inertia $I^{\circ}/MR^2=0.346 \pm 0.005$ [3]. The density variations in the mantle shells and core radii are found by the Monte-Carlo method [4]. We consider models of Europe's internal structure with five to six layers including an outer water-ice layer, a three-layer silicate mantle, and a Fe-FeS core. The model thickness of an outer envelope is a variable parameter. The unknown density and moment of Europe's rock-iron core (rocky mantle + central Fe-FeS-core) are a function of the only parameter - the thickness of an outer shell. We adopted ρ=0.94 g cm^{-3} for icy crust at depths of 0-10 km and ρ=1.0 g cm^{-3} at greater depths. If Europe had differentiated sufficiently to form a core, then a low-density crust is expected. This would lead to a significant reduction of the moment of inertia for the rock-iron core and the thickness of an outer water-ice shell for the completely differentiated mantle with a crust as opposed to the undifferentiated mantle (crust-free models). The crustal thickness and density are taken to be 60 km and 2.7 g cm^{-3}.

Additional geochemical limits on Europe's mantle density are introduced from the density of the equilibrium phase assemblages (phase diagrams) calculated from the composition of silicate fraction of ordinary (H, L and LL) and carbonaceous (minus volatiles) chondrites [5]. We have taken CM chondrites as an intermediate type between CI (the most volatile rich), and CV and CO (much less volatile rich) carbonaceous chondrites. Two boundary compositional models are considered for Europe's core: a conservative Fe-10 wt%S core ($Fe_{0.84}S_{0.16}$, ρ=5.7 g cm^{-3}) for ordinary chondrites and a FeS core (ρ=4.7 g cm^{-3}) for CM chondrites. Europe's phase compositions and mantle densities are modeled within the system Na_2O-TiO_2-CaO-FeO-MgO-Al_2O_3-SiO_2 including the solid solution phases. The equilibrium phase assemblages were calculated using the technique of free energy minimization and thermodynamic data for minerals summarized in the THERMOSEISM database [4].

Core radii and thickness of an outer water-ice shell. The relationships between the geophysically allowed ranges for the mean density and reduced moment of inertia for Europe's rock-iron core (fig. 1) show that the thickness of an outer water-ice shell (H_{sh}) and the radius of a central Fe-FeS core depend strongly on the density distribution in the mantle (fig. 2). If all Fe and FeS phases are in the core, the minimum density is obtained for H chondrite mantle (low FeO content) and the maximum density for the carbonaceous chondrite mantle (high FeO content). The derived europan Fe_{tot}/Si ratios and amounts of iron in the core are not consistent with the bulk composition of H chondrites

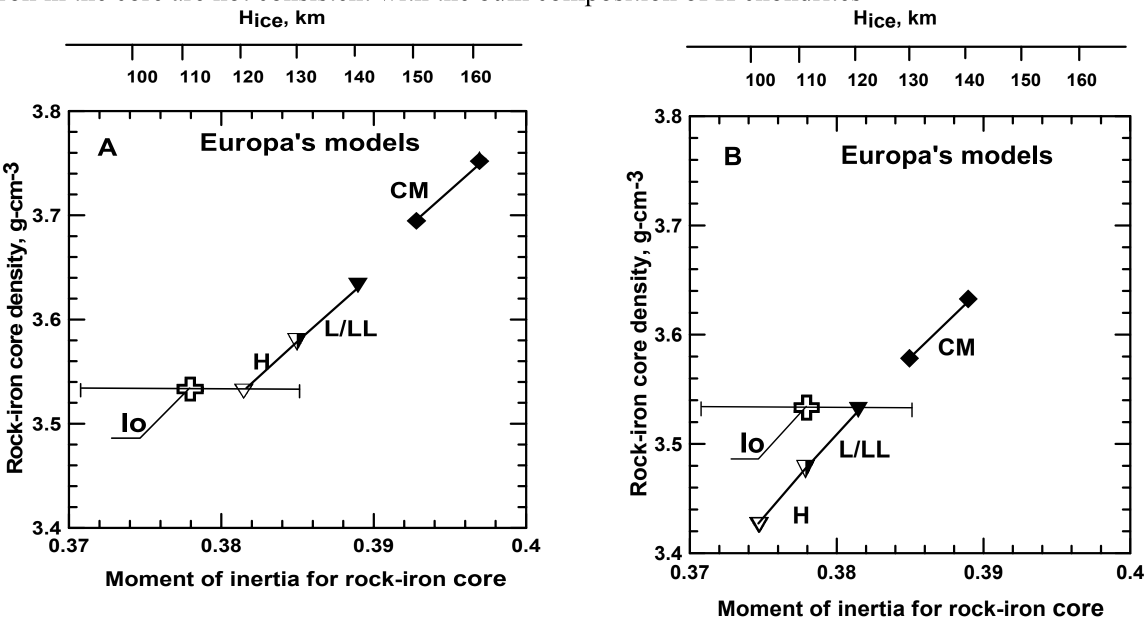

Fig. 1. The moment of inertia values for the rock-iron core (chondritic mantle + central Fe-FeS-core) of Europe vs the rock-iron core density satisfying the total mass and moment of inertia for Europe. The cross denotes the mean density (3.529 g cm^{-3}) and the moment of inertia for Io (I/MR^2=0.378±0.007). H_{sh} is the thickness of an outer water-ice shell. Note the position of Io is closer to the L/LL chondritic models of Europe than to CM chondritic models of Europe. (A) - undifferentiated and (B) differentiated mantle models.

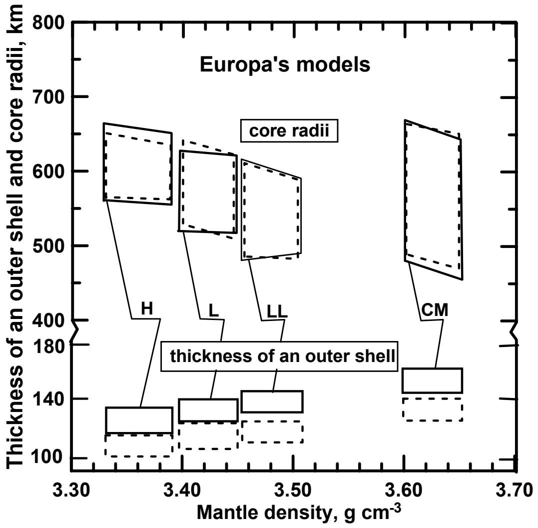

Fig. 2. The effect of the mantle density on the thickness of an outer water-ice shell and core sizes for chondritic models of Europe's differentiated (dashed lines) and undifferentiated (solid lines) mantle. For the L/LL chondritic material, the allowed thickness of Europe's H_2O layer ranges from 105 to 145 km. The highest mantle densities of CM chondrite phase assemblages lead to the largest H_{sh} values: 125-160 km.

L/LL-chondritic model. Fig. 1 shows that Europe's major element composition (mantle+core) matches the bulk composition of L and LL chondrites. The H_{sh} values satisfying the L/LL type mantle are estimated to be 115±10 km (6.8±0.6% H_2O of total mass) for the differentiated mantle models with a crust and 135±10 km (7.9±0.5% H_2O) for the undifferentiated mantle models without crust (fig. 2). Core radii constrained by the above conditions are 505-640 km and Fe_m=M(Fe_m)/M*=9.3±3% for the L chondritic mantle, and 470-620 km and Fe_m=8.1±3% for the LL chondritic mantle (where M* is the mass of a rock-iron core). The europan $(Fe_{tot}/Si)_{wt}$ ratios are estimated to be 0.91-1.32 for the L/LL chondritic material. The amounts of iron in a central core as well as Fe_{tot}/Si weight ratios are in agreement with those observed in L and LL chondrites, implying that a material close to the L/LL meteorites might be a representative sample of Europe's rock-iron core.

CM-chondritic model. The highest mantle densities of CM chondrite phase assemblages (3.60-3.67 g cm^{-3}) consisting mainly of Ol and Cpx lead to the largest allowed thickness of Europe's H_{sh} = 125-140 km (7.4-8.2% H_2O of total mass) for the differentiated mantle with a crust and 145-160 km (8.4-9.2% H_2O) for the crust-free models (fig. 2). CM chondrites contain about 10% H_2O, which is close to the estimated amount of water in Europe's models based on the composition of a CM chondrite silicate fraction. FeS core radii are estimated to be 450-670 km with the Fe_{tot}/Si weight ratios of 1.43-1.83, which is in general agreement with those of carbonaceous CI, CM, CO, CV, CR, and CK chondrites. Such a FeS-core will occupy 4.2-13.6% of the rock-iron core mass that is consistent with 8.2-wt% FeS in bulk CM chondrites, but does not match more than 20 wt% FeS in bulk CI chondrites normalized on volatile-free basis.

The L and LL chondritic models give I*=0.378-0.389 and ρ*=3.476-3.636 g cm^{-3} for Europe's rock-iron core. These estimates are closest to the currently accepted values for Io (fig. 1). A comparison of fig. 1a and fig. 1b illustrates the strong influence of the existence or absence of a crust on the moment of inertia of a rock-iron core and the thickness of an outer water-ice shell of Europe. The existence of a low-density silicate crust leads to a decrease in the moment of inertia of a rock-iron core and the thickness of a water-ice shell.

The correspondence between the density and moment of inertia values for bulk ice-free Io and rock-iron core of ice-poor Europe shows that their bulk compositions may be, in general, similar and may be described by the composition close to a material of the L/LL type chondrites. An icy component might have been added during the accretion of the satellite in the cooling circumjovian disk. Recently reported major element composition ratios for the asteroid 433 Eros show that ordinary chondrites are the most likely analogs for this asteroid [6]. It is therefore likely that Europe could have inherited a significantly higher proportion of material close to the moderately oxidized L/LL type chondrites rather than to the carbonaceous chondrites, and an addition of an icy component (a late H_2O-rich veneer?) during its formation in the cooling circumjovian disk. The allowed thickness of Europe's H_2O layer (whether liquid or ice) ranges from 115±10 km (6.8±0.6% of total mass) for a differentiated L/LL-type chondritic mantle with a crust to 135±10 km (7.9±0.5%) for an undifferentiated L/LL-type chondritic mantle. The melting temperature of ice-I decreases with pressure to about 251 K at 0.21 GPa (ice-I – ice-III – liquid triple point) leading to the likelihood of the existence of liquid water.

References

1. *Pappalardo R.T. et al.* (1999) J. Geophys. Res. 104E: 24015.
2. *Kivelson M.G. et al.* (2000) Sci. 289: 1340.
3. *Anderson J.D. et al.* (1998) Sci. 281: 2019.
4. *Kuskov O.L., Kronrod V.A.* (2001) Icarus. 151: 204.
5. *Jarosewich E.* (1990) Meteoritics. 25: 323.
6. *Trombka J.I. et al.* (2000) Sci. 289: 2101.