MODELS OF CHEMICAL COMPOSITION AND INTERNAL STRUCTURE OF THE GALILEAN SATELLITES OF JUPITER

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Being a smaller analogue of the solar system, the Jupiter system consists of 16 moons: the four Galilean moons - Io, Europa, Ganymede, and Callisto (in order of increasing distance from Jupiter) - and a number of smaller satellites. A direct study of the Galilean satellites, started by space probes of the Pioneer and Voyager series, was continued by the Galileo spacecraft. The data obtained on the gravitational fields of the satellites made it possible to determine the dimensionless moments of inertia for Io, Europa, and Ganymede and to estimate their core sizes. We consider here a five-layer model of the internal structure of a satellite, including a silicate crust or an ice layer, a three-layer mantle, and an Fe-FeS core. Solving the optimisation problem, we have used the separation of the mantle in order that to estimate the ranges of the composition and density distribution in the mantle reservoirs and to find out the dependence of the core sizes on the densities. The chemical and phase compositions of the satellite's mantle were modeled within the system Na_2O-TiO_2-CaO-FeO-MgO-Al_2O_3-SiO_2 (NaTiCFMAS) including the solid solution phases: olivine, spinel, plagioclase, ilmenite, and garnet (almandine, grossular, pyrope); orthopyroxene and clinopyroxene are 5-6-component solutions. The core was modeled by the Fe-FeS system with the density of 8.1 g cm^{-3} for iron core and 5.15 g cm^{-3} for a eutectic Fe-FeS composition at P-T conditions in the center of the satellites. The equations of state of the high-pressure phases of ice are taken into account.

The densities in the mantle shells and core radii are found by the Monte-Carlo method [1, 2]: the entire range of the geophysically and petrologically allowed mantle densities is examined and those values that obey the balance relations for the mass and moment within the uncertainty limit are chosen. The core sizes are evaluated from the conservation equation for the mass. For computation of the geophysically admissible density distribution models in the mantle layers and core radii, several million models were generated and tested. The successful models are analysed and are interpreted in terms of the bulk composition and internal structure of the satellites. The results are shown in Figs.1-3.

The correspondence between the density and moment of inertia values for bulk Io and rock-iron cores of Europa and Ganymede shows that their bulk compositions are, in general, similar and may be described by the composition close to L and LL chondrites. Geophysical and geochemical constraints show that H and carbonaceous chondritic materials may be excluded for the bulk compositions of these satellites. For L and LL chondritic composition and density models, radii of the Fe core and eutectic Fe-FeS core are estimated to be: R(Fe-core)=590-630 km and R(Fe-FeS-core)=830-875 km for Io; R(Fe-core)=420-490 km and R(Fe-FeS-core)=580-650 km for Europa; R(Fe-core)=610-710 km and R(Fe-FeS-core) = 820-900 km for Ganymede with an outer shell composed of the ice solid phases. If the Galilean satellites do have the L-, LL-chondritic composition, then their cores are probably Fe or Fe-rich, whereas large FeS cores are excluded by the composition of chondrites. The results of modeling support the hypothesis that Io, Europa and Ganymede have a massive metallic core in which a magnetic field may be produced.

For the L-, LL-chondritic composition of rock-iron cores, thickness of an ice-liquid outer shell in Europa is estimated to be 120-140 km (7-8% of total mass); thickness of a solid ice outer shell in Ganymede is expected to be 890-920 km. The content of H_2O in Ganymede's icy envelope is 46-48% of the total mass which is different from the cosmic mixture (~60% ice, 40% rock by mass).

Models, showing the outer shell of Ganymede to consist of a mixture of water and ice are considered, and thickness of the outer shell (750-840 km) and Fe-FeS-core radii are estimated. The possibility of an inner liquid-water layer beneath the icy surface of Ganymede can not be ruled out, if the bulk composition of its rock-iron core would be close to the composition of LL (rather than L) chondrites. In such a case, Ganymede's magnetic field may be associated with the existence of a metallic core as well as with a liquid-water ocean containing some electrolite.

1. Kuskov O.L.,Kronrod V.A.,1997. Models of internal structure of Io. Geokhimiya, 1171-1180.
2. Kuskov O.L., Kronrod V.A.,1998. Models of internal structure of Jupiter's satellites (Ganymede, Europa and Callisto). Astronom. Vestnik, 32 (1) 49-57.

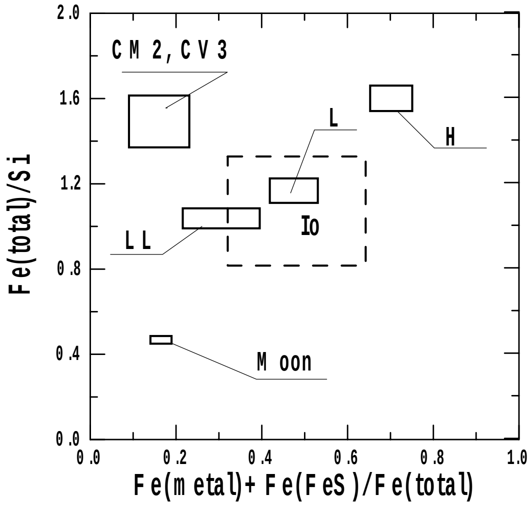

Fig. 1. Element weight ratios in Io derived from the geophysical constraints in comparison with those in chondrites. The ratios of $(Fe_{tot}/Si)^{Io}$=1.04-1.14 and $(Fe_m/Fe_{tot})^{Io}$ =0.37-0.5 calculated for bulk Io from silicate fraction of L and LL chondrites are in agreement with bulk elemental ratios for L and LL chondrites.

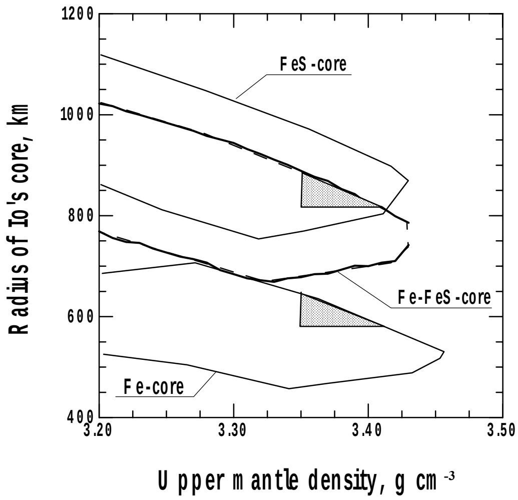

Fig. 2. Geophysically admissible variations of core radii for Io (H_{crust} =60 km and ρ =3.0 g cm^{-3}). The allowed core radii of Io vary from 440 to 720 km for an Fe core, from 640 to 1020 km for a eutectic Fe-FeS core, and from 750 to 1120 km for an FeS core. The silicate fraction of the L and LL chondrite composition assumed for the mantle yields core radii between 590 and 630 km for an Fe core, and between 830 and 875 km for a eutectic Fe-FeS core (shaded zone).

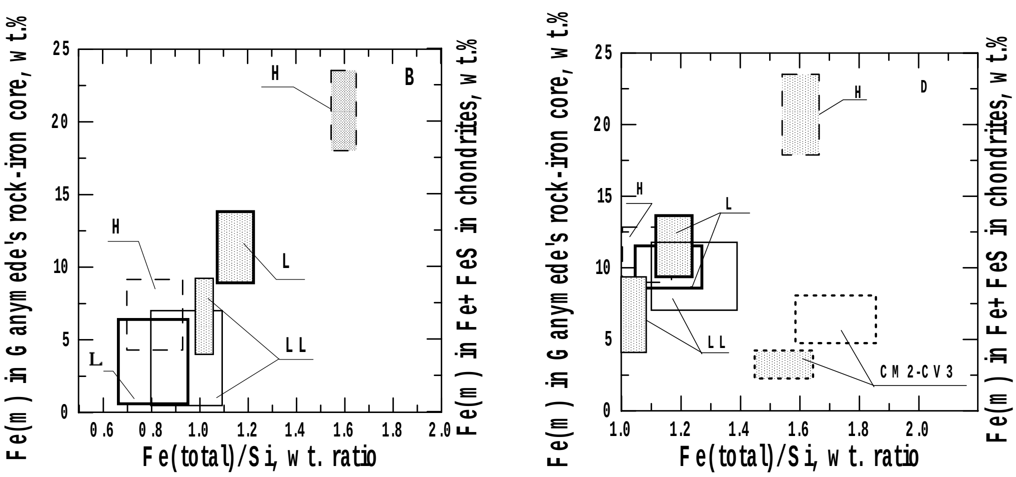

Fig. 3. Element weight ratios for chondritic models of Ganymede's rock-iron core (empty boxes) derived from the geophysical constraints in comparison with those in chondrites (shaded boxes). The empty boxes outline an allowed content of pure iron in a central Fe-core relative to the total rock-iron core mass. The density of the mantle is calculated from the silicate fraction of ordinary and carbonaceous chondrites. Model (D) - an outer shell is composed of solid ice phases. Model (B) - an outer shell with an inner liquid-water ocean (with the uppermost shell of ice-I 30-120 km thick)