CALLISTO'S WATER-ICE SHELL

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We have constructed models of the constitution of Callisto based on Galileo gravity measurements and geochemical constraints on the composition of silicate fractions of ordinary chondrites. The total thickness of an outer water-ice shell of Callisto is estimated in the range of 270-315 km. The permissible thicknesses of an icy crust and internal ocean are estimated to be 135-150 km and 120-180 km respectively. The surface temperature is found to be 100-112 K.

Results from the *Galileo* mission have increased the scientific interest in knowledge of the internal structure of large icy satellites. An important question is the possible existence of a subsurface water ocean. There are indirect geological and geophysical evidence that Callisto may possess subsurface salty liquid-water ocean. The existence of water ocean was recently supported by magnetic measurements and surface morphology features obtained with *Galileo.* The discovery of the induced magnetic field of Callisto has been interpreted as evidence for a subsurface ocean [1].

The purpose of this paper is to reproduce characteristic features of the internal structure of Callisto's water-ice shell on the basis of its mass and moment-of-inertia factor [2]. Models of the internal structure of the ice-liquid outer shell are based on geophysical (the mass and moment of inertia from recent *Galileo* gravity measurements), geochemical (chemical composition of meteorites), and thermodynamic (modeling of phase relations and physical properties in the Na_2O-TiO_2-CaO-FeO-MgO-Al_2O_3-SiO_2-Fe-FeS-H_2O system) constraints [3]. The equations of state of water and high-pressure ices are taken into account. The equilibrium phase assemblages were calculated using the technique of free energy minimization and thermodynamic data for minerals. The density variations in the mantle shells and core radii are found by the Monte-Carlo method.

There are two possible models for the radial structure of large icy satellites. If the heat transfer in the outer layer is efficient enough to transport all of the heat to the surface, the initial ocean has completely crystallized. In the other models the outer shell is not able to release all of the heat outward. A residual ocean is still present below the outer shell, Fig. 1. The evolution of the structure of large icy satellites is usually based on models of heat transfer through the outer ice I layer. Reynolds and Cassen (1979) [4] have shown that thermal convection is very likely to occur in this layer. Moreover, they pointed out that heat transfer is efficient enough to complete the crystallisation of the initial ocean in a short time ($\approx 5\text{x}10^8$ years); the viscosity of water ice was taken as newtonian. The real behaviour of water ice, as observed in laboratory experiments, is in fact non-newtonian. In the present study we proposed that rheological behaviour was non-newtonian. In this case the outer ice shell becomes stable against convection [5].

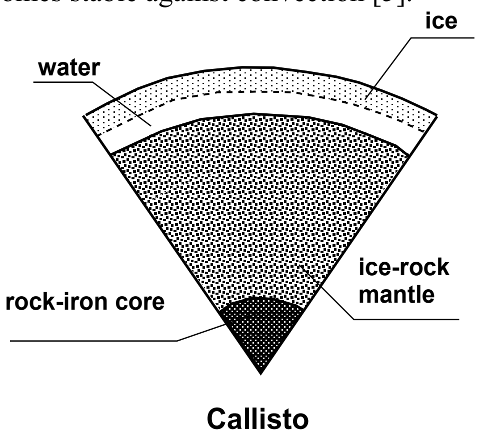

Fig. 1. Internal structure of Callisto

The mass and moment-of-inertia factors are used to model the internal structure of Callisto and the thickness of an outer water-ice shell. Ordinary L and LL chondrites are taken as representatives of the nebular matter. Our calculations were confined to a five-layer model of icy differentiated satellite, which consists of an outer water-ice shell, a three-layer rock-ice mantle and an iron-rock core. The phase diagram of H_2O and equations of state of the high-pressure polymorphs of ice are taken into account. The density variations in the mantle are found by the Monte-Carlo method [*3*]; the entire range of the geophysically allowed mantle densities is examined for balancing the mass and moment within the experimental error.

Table 1.

Total thickness of Callisto's water-ice shell*

ρ_{Fe-Si} , g/cm^3	H_{ice-I}, km	H_{water}, km	$H_{tot} = H_{ice-I} + H_{water}$, km
3.15	135-150	120 -180	270-315
3.62	135-150	120-165	270-300

H_{ice} – thickness of a conductive ice shell of Callisto, H_{water} – thickness of a water ocean, H_{tot} - total thickness of a water-ice shell of Callisto, ρ_{Fe-Si} – density of a rock-iron core.

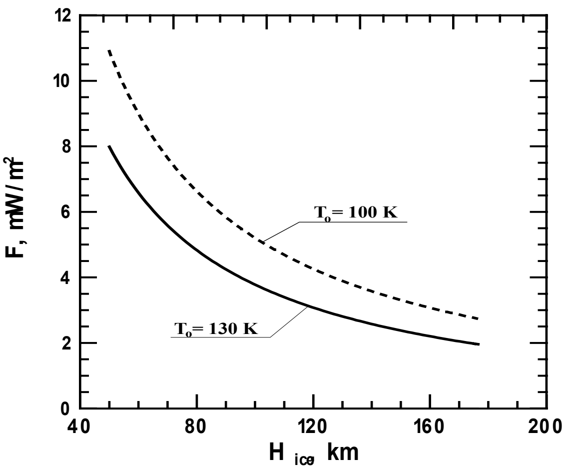

Fig. 2. Heat flux F as a function of the thickness of a conductive ice shell of Callisto (H_{ice}) and two possible values of the surface temperature T_o

Before the onset of convection, heat is transmitted into Callisto's outer shell only by conduction. Under these conditions, the variation of temperature in the outer ice I with depth can be described through Fourier’s law. Water ice I thermal conductivity is a function of the temperature, $k=k_oT^{-1}$, where k_o is a constant. The temperature at the base of the shell obviously corresponds to the melting point of ice, which is a function of pressure. Distribution of pressure can be described by the equations of hydrostatic equilibrium.

The results of calculations are illustrated in Fig. 2 and Table I. The thickness of a conductive ice shell of Callisto in terms of heat flow (F) through the shell is shown in Fig.2. The modelling results indicate that we can estimate the thickness of Callisto’s outer ice shell with confidence. The total thickness of an outer water-ice shell of Callisto is estimated in the range of 270-315 km. The permissible thicknesses of an icy crust and internal ocean are estimated to be 135-150 km and 120-180 km respectively. The surface temperature is found to be 100-112 K. The results of modeling support the hypothesis that Callisto may have an internal liquid-water ocean.

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