Origin and evolution of the Galilean satellites and Titan

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A review on origin and evolution of the Galilean satellites and Titan is presented. Although these giant satellites have similar masses, each body has unique character with respect to bulk composition and surface features. Formation of such diversity is a general issue for study of these satellites. Observed phenomena such as intense volcanic activities, thermal and chemical interactions between water ocean and rocky crust, photochemical processes in an atmosphere containing organic matter, and so on are analogous to processes which may drive the evolution of early Earth. So, exploring these satellites can provide clues to understand the early Earth, independently of exploring other bodies which preserve ancient geologic records.

A review on the origin and evolution of the Galilean satellites and Titan is presented. Each body has unique character with respect to bulk composition and surface features. Cause of such diversity is a general issue to study these satellites. Observed phenomena such as intense volcanic activities (Io), possible thermo-chemical interactions between water ocean and rocky crust (Europa), photochemical processes in an atmosphere containing organic matter (Titan), and so on are analogous to the processes which may occur on early Earth. So, exploring these satellites can provide clues to understand the early Earth, independently of exploring other bodies that preserve ancient geologic records.

The Galileo mission has greatly expanded our knowledge on the Galilean satellites. One of its most significant results concerns the internal structure of these satellites, which can provide useful insight for understanding the observed surface features. Along with gravity data, electro-magnetic field data have been employed to search for the internal structure of Galilean satellites. In particular, finding the strong evidence for Europa's subsurface ocean by magnetic study is a quite important result.

The Galileo mission has revealed that the Galilean satellites have somewhat curious internal structures. Several lines of evidence indicate the existence of metallic iron cores at the centers of Io, Europa, and Ganymede. According to the theory of Earth's core formation, a high degree of melting is required for metal-silicate separation. However, the Galilean satellites are not massive enough to cause such extensive melting during accretion. Other heating mechanisms such as tidal heating are also questionable to induce such extensive melting. A possibility to resolve this problem is that the cores of Galilean satellites consist of $FeS-Fe_3O_4$ system rather than metallic iron. $FeS-Fe_3O_4$ system has relatively low melting temperature and low surface tension which enables its melt to separate gravitationally through silicate grain boundaries by percolation. It is reasonable to consider that $FeS-Fe_3O_4$ is a major constituent of the Galilean satellites because the raw materials of these satellites are rich in H20 and thus expected to be highly oxidized like CI chondrite. Large electrical conductivity of $FeS-Fe_3O_4$ is consistent with the Galileo's magnetic field data.

In contrast to three inner satellites, Galileo's gravity data suggest that ice and rock are incompletely differentiated in Callisto. However, electro-magnetic field data imply a subsurface ocean of Callisto, which seems inconsistent with the gravity data. From theoretical ground, Callisto likely experiences melting of ice during accretion and thus has a differentiated structure. Since Callisto rotates slowly and may have cold interior, non-hydrostatic component might affect the gravity data.

Titan has a thick N_2-CH_4 atmosphere, which may be similar to the early Earth's one where organic matters may abiotically evolve. Titan's surface is veiled by atmospheric haze, probably photo-synthesized organic compounds, with orange color. In 2004, the Cassini spacecraft will arrive at Titan and make experiments including the entry of atmospheric probe and the radar mapping of the Titan's surface. Prediction of Titan's surface features, atmospheric dynamics, and internal structure is important issue for years from now.

The formation of the giant satellites of Jupiter and Saturn remains an unresolved issue. Recently, gas capture processes of a jovian planet are numerically investigated, suggesting that the jovian planets form with very large spin angular momentum. Spin down mechanism is not known but is likely related with the formation of circum-planetary nebula where the major satellites are formed. This is an important issue remaining for planet formation theory.