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Habitability potential of icy moons

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Abstract

The satellites of Jupiter and Saturn have been revealed as extremely astrobiologically interesting bodies presenting promising conditions for habitability and the development and/or maintenance of life. Titan and Enceladus, Saturn's satellites, were found by the Cassini-Huygens mission to possess active organic chemistries with seasonal variations, unique geological features and possibly internal liquid water oceans, among other. Additionally, Jupiter's Europa and Ganymede show indications of harboring liquid water oceans under their icy crusts, which may be in direct contact with a silicate mantle floor and kept warm through time by tidally generated heat. All of these environments satisfy many of the "classical" criteria for habitability (liquid water, energy sources to sustain metabolism and "nutrients" over a period of time long enough to allow the development of life). In order to study the habitability of icy moons around giant planets, we look at the atmosphere-surface-interior connections with their similarities with the Earth as a starting point [1]. The discovery of the water jets on Enceladus, the possibility for cryovolcanic processes on Titan and the hypothetically active mantle of Europa suggest that icy moons around giant planets may well contain subsurface oceans.

1. Atmosphere

Titan is the perfect candidate for prebiotic research due to its thick, nitrogen-dominated atmosphere, rich in organics. A complex photochemistry occurs, forming heavy hydrocarbons and nitriles, which accumulate in an optically thick haze. Some of these species are of prebiotic importance, such as C6H6, HC3N and HCN. These species are considered as key molecules in terrestrial prebiotic chemistry as well. Due to the wealth of the Cassini/Huygens data a detailed study of the trace gases, the minor species and the isotopologues derive the isotopic ratios of C, N, H and O [e.g. 2] throughout its atmosphere and give temporal variations of temperature and composition [3]. In particular, the presence of C6H6 and HCN is extremely interesting, as they may contribute to the synthesis of biological building blocks. Additionally, the atmosphere has an equivalent structure from the troposphere to the ionosphere, and a surface pressure of 1.5 bars – the only such case of an extraterrestrial planetary atmospheric pressure close to that of the Earth.

2. Morphotectonic - exogenous features and terrestrial analogues

Nevertheless, the atmosphere is not the only place for astrobiology research in the icy moons. Titan and Enceladus' surface expressions are very complex in terms of composition, materials and size while they highly resemble the Earth's geomorphology. Titan's rigid crust and the probable existence of a subsurface ocean create an analogy with terrestrial, at least surficial, plate tectonics while Enceladus' plumes find an analogue on the terrestrial volcanic water jets known as geysers. Titan's surface consists of structures like mountains, ridges, faults and canyons, formed most probably by tectonic processes, as indicated by the Cassini-Huygens mission. Titan, is also unique among outer planet satellites, subjected to aeolian and fluvial processes operating to erode, transport, and deposit material [4]. As revealed by Cassini the liquid hydrocarbon lakes [5] distributed currently mainly at polar latitudes on Titan are ideal isolated environments to look for biomarkers. Such deposits supplied by the atmospheric organics or by possible internal sources may sustain the synthesis and the preservation of complex aromatic molecules [6]. Recently, the largest lake on Titan, Ontario Lacus, was found to be in a very good analogy with the terrestrial lake Etosha Pan in Namibia [7]. Furthermore, Europa and Ganymede present a major diversity in terms of appearance and surface geological structures and therefore in terms of the surface-shaping forces. Europa seems to be subject to active tectonism and cryovolcanism [19] since it displays a young, smooth and active surface. The features of intersect lineae that seem to dominate Europa's surface is a common tectonic feature on Earth. On the contrary, Ganymede is heavily cratered on most of its surface and internal processes like cryovolcanism seem to have played only a minor role in the surface modification since there is little indication of resurfacing. In general, erosion as well as mass movement and landform degradation seem to play an important role in resurfacing as it reduces the topographic relief by moving surface materials to a lower gravitational potential [4].

3. Interior and liquid water oceans

The four satellites are dynamic planetary bodies and the possible existence of an internal ocean plays an important role in the formation and modification of their surfaces. Our current knowledge of the icy moons' internal stratification and their composition is being built on a combination of spacecraft data, laboratory experiments, and theoretical geophysical modeling. Evidence for hydrated sulfate salts on the surfaces of Europa and Ganymede from spectroscopic data support the possible existence of subsurface oceans [8 and references therein] suggesting the deposition of minerals following internal hydrothermal events. Furthermore, the detection of a low viscosity layer underneath the icy crust again endorses the presence of a subsurface liquid ocean inducing recent geological activity. Currently, in Titan's and Enceladus' case, all the geophysical models try to explain the possible existence of an oceanic layer that decouples the mantle from the icy crust. Recent studies suggest that Titan has a partially hydrated interior with a clathrate crust, where underneath it there must be a liquid water ocean in contact with the silicates beneath, for most of Titan's history [9]. Titan is tidally locked with respect to Saturn and thereby subject to periodic tidal forcing of its interior and surface. The tidal stresses are expected to induce significant seismic activity comparable to tidally-induced quakes on the satellite, and possibly along with seismicity induced by localized cryovolcanic activity [10]. Thus, geodynamic processes seem to be in interplay on Titan, triggering cryovolcanic and/or seismic phenomena resulting in the observed surface morphotectonic features [1] similarly to Earth's geodynamics. Cryovolcanic phenomena would be an expression of the outgassing of methane that is possibly stored as clathrate hydrates within the ice shell of Titan [20]. Furthermore, in a recent study Choukroun and Sotin (2012) concluded that percolation of ethane-dominated liquids in Titan's methane clathrate-rich subsurface yields substitution of methane by ethane and methane release. For the examination of the cryovolcanic candidate regions we use spectroscopic data and follow a specific Cassini data analysis process [12; 13]. The observations of large plumes ejected from Enceladus' South Pole by Cassini, make it quite an important object for astrobiology and habitability. This jet activity is intimately linked to the satellite's interior structure and dynamics, while it provides hints on the heat sources, internal reservoirs of volatiles and eruptive processes [14]. If the silicate mantles of Europa and Ganymede is geologically active as on Earth, giving rise to the equivalent of hydrothermal systems, the simultaneous presence of water, geodynamic interactions, chemical energy sources and a diversity of key chemical elements may fulfill the basic conditions for habitability [15; 16].

4. Future missions

In the Solar System's neighborhood, such potential habitats can only be investigated with appropriate designed space missions, like JUICE-Laplace for Ganymede and Europa [17] and TiME for Titan [18]. JUICE stands for JUpiter ICy moon Explorer and it is an ESA mission to Jupiter and its icy moons, recently selected to launch in 2022.

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