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Review of Exchange Processes on Ganymede in View of Its Planetary Protection Categorisation

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Introduction

The outer planet satellites are a rich and diverse set of planetary bodies, with great relevance to astrobiological studies, satisfying a number or all of the prerequisites for habitability. Some of them show evidence for organic chemistry in their atmospheres, surfaces or interiors. Many of the satellites, including the smallest, thus contain organic material. In addition, the largest satellites are believed to hide global-scale oceans within. During the earlier Galileo mission, strong evidence for the presence of an internal ocean was obtained at Europa. Since then, the evidence has accumulated for such sub-surface liquid water oceans to exist not only on Europa but also on the two other icy Galilean satellites, Ganymede, and Callisto.

Our current understanding of the deep habitats has raised the question of the necessary measures regarding planetary protection procedures for future missions. Many of the science questions relate to the prospects for life and habitability in the Solar System. As a consequence, some of the future mission opportunities and their potential encounters with habitable zones raise serious questions about biological or organic forward contamination that may be caused by these missions. In the 2012 NAP report[1], it is suggested that Ganymede is of significant interest relative to the process of chemical evolution and the origin of life, but that there is only a remote chance that contamination by a spacecraft could compromise future investigations. Still, further studies were desired to assess the possibility, the timescale, and the mechanisms of transport of any organism from the surface to the liquid layer. This is the purpose of this work.

Habitable zones in Ganymede

Two kind of habitable zones should be considered: a deep and global liquid layer, and also shallow liquid reservoirs in the icy crust. On Ganymede, the hydrosphere must be split into a high-pressure ice layer consisting of various water-rich high-pressure ices denser than liquid water, the subsurface water ocean, and an ice-I layer forming the outer crust of the satellite. The liquid layer could be up to 100 km thick. It has been suggested that the depth of the ocean should be close to 150 km[2]. Chemical and energy exchanges between the rocky layer and the ocean at present, which are crucial for habitability, cannot be ruled out but imply efficient transport processes through the thick high - pressure icy layer. Such processes are indeed possible[3] but not as clear-cut as the exchanges envisaged for Europa and that probably prevailed until recent times.

Based on Galileo data, there is no evidence of present activity, or recent features which could suggest the existence of shallow reservoirs. No evidence for recent cryovolcanic resurfacing is identified thus far. However, locally restricted scalloped depressions called paterae adjacent to Ganymede's bright terrain, which could represent caldera-like features [4] are interpreted as cryovolcanic features that appear in Ganymede's past history. In fact, the geologic record on Ganymede does not support the existence of shallow liquid reservoirs at present. Still, these occurrences cannot totally be ruled out because most of the Galileo data was acquired at medium spatial resolution, impeding the detection of small features.

Exchange processes from space to habitable zones

The different processes needed to go from the surface to the liquid layer (i.e. to cross the entire icy mantle on top of the habitable domain) have been thoroughly explored in this study. The main results are summarised in Table 1. First, it is very difficult for a microorganism to penetrate the regolith over a reasonable time scale, except in the case of an impact by a large object. Second, the upper icy layer must be at least 50 km thick and therefore it is implausible to have direct contact between the surface of the moon and the liquid water, because tectonic features cannot go deeper than a few kilometres. It will also be shown that the transition from brittle to ductile domains is shallower than the transition from the lid on top the icy mantle to the convecting sublayer above the ocean, which indicates that there is no way to reach the convecting domain over timescales smaller than millions of years. Even if this could occur, it would still require a few thousands of years for any material to be dragged down along cold plumes close to the ocean. Finally, it is not certain that exchange processes are possible in the lower zone of the icy mantle just above the ocean. The only process we could think of is diffusion, meaning that a few thousand of years must still be added. Based on these different estimates, a total of a few millions of years are needed to exchange materials from the surface of the moon to the liquid layer because of the thickness of the upper lid.

Table 1: Processes of downward migration through the sublayers of the icy shell above the ocean

Layer (from top to bottom)	**Minimal Thickness**	**Downward migration process**	**Time duration (years)**	**Comments**
Regolith	First centimeters of the crust	Diffusion	a few years	Impact is the only way to introduce microorganisms into the regolith in a short time scale.
		Impact	Instantaneous	
icy crust (stagnant lid) and upper thermal boundary layer	From a few kilometers to a few tens of kilometers	Diffusion	Several millions of years	No way envisaged to go through the lid in a short time scale. Geologic evidences demonstrate that the faults cannot propagate through the total thickness of the crust because it is too old.
		Tectonism	Rapid but impossible through the entire lid	
Convecting layer	From a few kilometers to a few tens of kilometers	convective transport up to a few m/yr along a descending cold plume.	a few thousand years	Duration estimate is based on a very conservative approach regarding the vigour of convection.
Lower thermal boundary layer	A few hundred meters	Almost impossible - Diffusion could be envisaged	a few thousand years at least if diffusion is feasible	Upwards thermal buoyancy impedes downwards migration.

Conclusions

Ganymede is of strong interest regarding the organics, and its potential for hosting a habitable ocean. It displays no evidence at the surface of recent activity that could propagate biological contamination beyond a spacecraft landing zone, in spite of the evidence of past and possibly present endogenic activity. Nonetheless, the different constraints arising from Galileo data and the structure and dynamics modelling of the upper layers, demonstrate that Ganymede should not be considered as having a significant chance of being contaminated by a space mission. Following COSPAR's categorisation, we suggest that Ganymede is definitely of significant interest relative to the process of chemical evolution and the origin of life, and there is only a remote chance that contamination by a spacecraft could compromise future investigations.

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