

# Ocean in Enceladus Enhances the Case for Panspermia

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## ABSTRACT

**Abstract:** The recently announced confirmation of a global ocean beneath the icy outer shell of the Saturnian moon Enceladus provides strong support for cometary panspermia. Arguments for the presence of liquid water domains in other icy bodies, including comets, Europa and Pluto that might harbour life gains new strength from this discovery. The recent discoveries of abundant and varied microbial communities in the deep, dark oceans of Earth, adds credence to the concept of a single connected microbial biosphere in the solar system

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## 1. INTRODUCTION

The icy bodies of the solar system including, hundreds of billions of comets and a vast number of Kuiper-Belt objects, including Pluto, arose largely from the aggregation of icy planetesimals (eg. Hoyle and Wickramasinghe, 1985). The outer layers of the icy moons of Jupiter and Saturn, including Enceladus, were also, most probably, the result of a similar accretion process of icy planetesimals. The theory of cometary panspermia (Hoyle and Wickramasinghe, 1981,1985; Wickramasinghe, 2015) posits that these icy planetesimals carried not merely water ice and the organic building blocks of life but also a residue of iterant interstellar bacteria/diatoms/viruses that had retained viability over millions of years.

The comets, Kuiper-Belt objects as well as the icy mantles of the moons of the outer planets would, according to this picture, have all possessed an initial endowment of deep-frozen extant microbial life. Following their accumulation into solid bodies the heat released from the decay of radionuclides, from short-lived Al-26 to long-lived U-238, will produce liquid water interiors that serve as culture media for the regeneration of dormant microorganisms (Hoyle

and Wickramasinghe, 1985; Wallis, 1980). Once melted the heat flow outwards through kilometres of ice (with low thermal conductivity) would be so slow that liquid conditions could persist for billions of years (Wallis, Wickramasinghe, Wickramasinghe, 2005). The application of these earlier results to the case of Enceladus is discussed in Section 3. Micrometeorite impacts on the surface as well as nutrients supplied from underlying rocks would provide the required suite of biogenic elements, mineral compounds and organics to support an active microbial ecology within the liquid water in the oceans bodies deep beneath the icy crust. It is now known that diatoms and many other organisms produce "ice active substances" and enzymes that are capable of melting ices and for this reason living organisms also inhabit glaciers and the polar ice sheets of Earth. Sea ice is a habitat of diatoms and other microorganisms that thrive under extremes of temperature, salinity and light levels (Janech *et al.*, 2006).

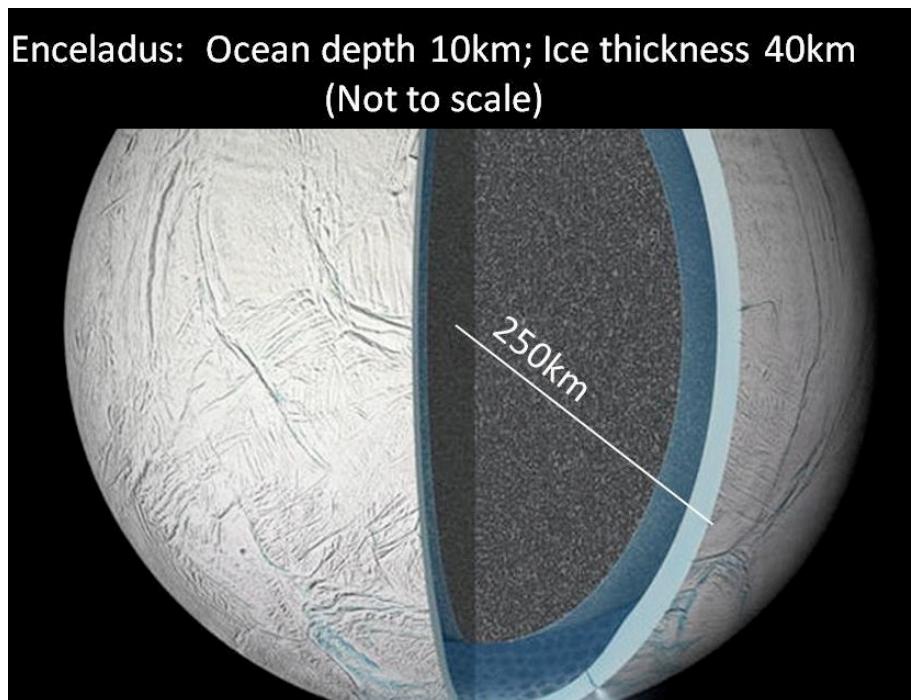
## 2. CASSINI RESULTS FOR ENCELADUS

In 2011 the Cassini spacecraft discovered jets of water, methane, dust and salt crystals (NaCl) issuing at speeds exceeding 1000km/s from vents in the south polar region of Enceladus (Spencer and Nimmo, 2013). More recently, these jets were interpreted as "curtain eruptions" issuing through a network of linear fractures in the ice surface (Spitale *et al.*, 2015). In any case the "curtains" of issuing material travel outward at escape speed and are almost certainly driven by high gas pressures generated beneath the ice shell. Since Enceladus orbits within Saturn's E ring it is tempting to suggest that the particulate material in this ring is contributed from the recently observed eruptions in this moon.

In another development Thomas *et al.* (2015) have analysed data relating to a very slight wobble in the rotation of Enceladus about its axis and modelled the interior structure of the moon on this basis. They concluded that the only viable explanation of the wobble was the existence of a global ocean lying beneath its frozen crust. This is perhaps the closest we can hope to get of a direct proof of a liquid interior of any icy object in the outer solar system. The fact that this agrees with predictions on the nature of life-carrying icy bodies of the solar system is worthy of note and is relevant to the theory of cometary panspermia (Hoyle and Wickramasinghe, 1985).

## 3. PERSISTENCE OF LIQUID OCEAN

In this section we discuss the specific conditions that are related to the global sub-surface ocean of Enceladus.



**Fig.1** Schematic image of Enceladus showing mineral core, ocean and outer icy crust.

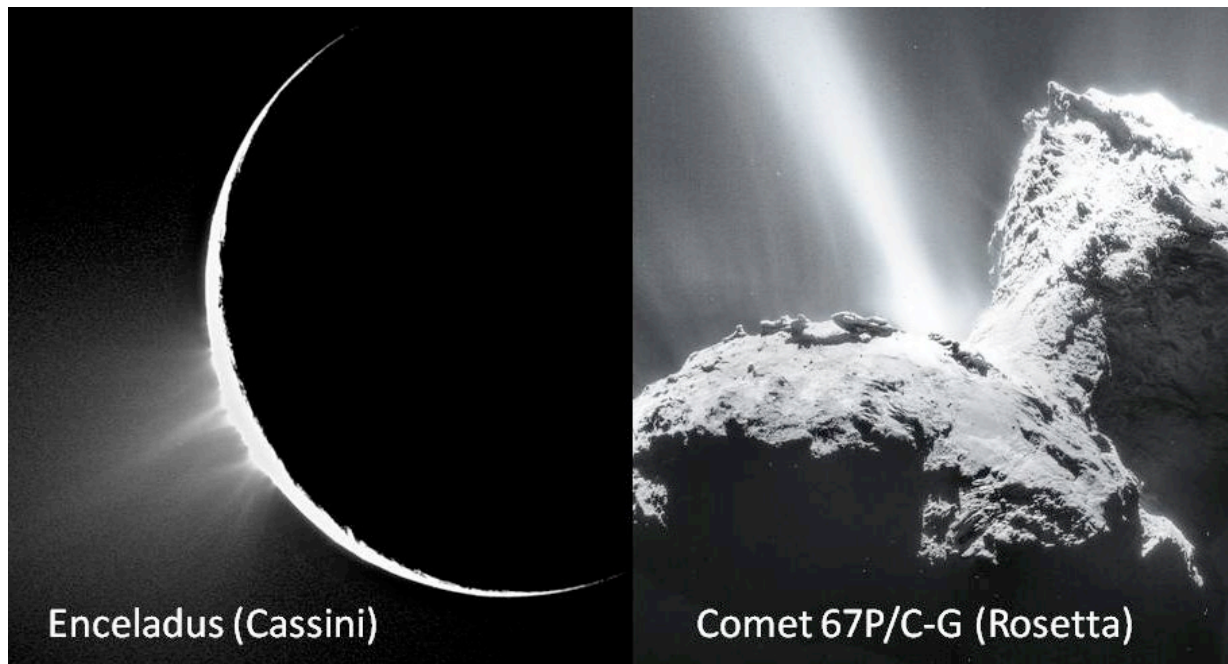
**Figure 1** shows a schematic section of Enceladus based upon the data currently available. We assume here an inner siliceous/mineral core of radius 200 km overlain by 50 km of a largely salty ocean with a 40km-thick outer crust of impure water-ice. (Note, however, that our conclusions are not sensitive to the precise dimensions assumed here.) The main energy source for maintaining a warm liquid ocean would be from the fission of Uranium and Thorium.

For a total mass of Enceladus of  $\sim 10^{23}$  g we can assume a solar-system mass fraction of  $\sim 10^{-8}$  in the form of fissionable U and Th. The energy output from the total fission of U and Th is known to be  $\sim 10^{18}$  erg/g, so that the total energy deposited is  $10^{18} \times 10^{-8} \times 10^{23} \sim 10^{33}$  erg.

The outer temperature of the ice shell (surface temperature of Enceladus) averages  $\sim 100$ K, whereas the inner water interface will be at a temperature of  $\sim 300$ K. The heat loss rate from thermal conduction can now be calculated from elementary physics. With a thermal conductivity of impure ice of  $\sim 10^{-4} \text{ W cm}^{-1} \text{ K}^{-1} \approx 10^3 \text{ erg s}^{-1} \text{ cm}^{-1} \text{ K}^{-1}$ , the heat loss rate through the ice layer (**Fig.1**) is

$$\sim 10^3(4\pi R^2) [200/(40 \times 10^5)] \text{ erg/s} \approx 10^{16} \text{ erg/s}$$

with  $R = 200$ km. The total energy of  $10^{33}$  erg deposited from the fission of U and Th will thus be radiated away over timescales that extend over the entire duration of the solar system. The persistence of biology over this timescale can therefore be justified on this basis.



**Fig. 2** Plumes of water and methane issuing from fissures in overlying ice. Left: Cassini image of the South pole of Enceladus; Right: ESA Rosetta NAV/CAM image of Comet 67P/C-G.

While radioactive heat provides the main source of heat in the oceans, microbial metabolism will also contribute to the energy that keeps the ice melted. We have pointed out elsewhere that prolonged microbial activity can also produce a build-up of high pressures of metabolic gaseous products such as methane (Wickramasinghe, Hoyle and Lloyd, 1996). When critical pressures are reached fissures will develop in the overlying icy crust leading to release of jets of water and organics. The situation is analogous to the popping of a cork in a bottle of fermenting wine. A similar process was recently recognised in the Rosetta observations of comet 67P/C-G (Wickramasinghe et al, 2015) and the New Horizons data on Pluto (Wallis and Wickramasinghe, 2015).

#### 4. MICROBIAL HABITATS IN THE OCEAN OF ENCELADUS

Even though the thick ice crust of Enceladus would reduce the visible light reaching the oceans within Enceladus effectively to zero, this does not preclude organisms from living within the total darkness of the frigid water under great pressure deep within the oceans of this icy moon. And the microbial ecologies that survive here would not be limited to organotrophic or chemoautotrophic microorganisms. This is known, because recent astonishing discoveries have revealed the enormous diversity of bathypelagic organisms that inhabit the deep, dark Oceans of Earth. **Figure 3** is a Table provided by (Agusti et al., 2015) that shows the relative abundance of phototrophic and heterotrophic microorganisms living in the deep dark Oceans (2000 m - 4000 m) beneath the Earth as compared to the cellular abundance of these same groups of microorganisms living in the photic zone of the near surface (0 to 200 m) waters. Clearly the heterotrophic bacteria are the dominant component of the deep ocean and they are closely followed by the picophytoplankton. What is truly amazing is the great abundance of eukaryotic organisms typically considered to be photoautotrophs. The abundance of cells of diatoms and dinoflagellates in the deep ocean is only two orders of magnitude lower than the abundance of photoautotrophs in near surface waters. Living diatoms [not just oozes of frustules of dead diatoms] are not only ubiquitous in the deep sea, but they also represent the dominant (81.5%) component of the microphytoplankton community of the deep ocean (Agusti *et al.* 2015). Diatoms were found to be even more abundant than the heterotrophic ciliates, which had previously been believed to dominate the microplankton of the bathysphere (Pernice *et al.* 2014). **Figure 3** also reveals that photosynthetic prokaryotes, such as filamentous cyanobacteria, were also present in the deep ocean, but they were in much lower abundance than the diatoms.

**Table 1 | Mean ( $\pm$  s.e.) absolute and relative abundance of phototrophic and heterotrophic plankton in the surface and deep ocean.**

	Cell abundance (cells m <sup>-2</sup> )	s.e.	N
<b>Surface ocean (0-200 m)</b>			
Microphytoplankton	$9.78 \times 10^7$	$3.63 \times 10^7$	11
Diatoms	$6.73 \times 10^7$	$3.08 \times 10^7$	11
Dinoflagellates	$3.01 \times 10^7$	$8.88 \times 10^6$	11
Others	$7.61 \times 10^5$	$4.49 \times 10^6$	11
Cyanobacteria	$1.29 \times 10^6$	$1.26 \times 10^6$	11
Ratio Diatoms/Dinoflag	2.5	0.9	11
Ciliates	$9.15 \times 10^6$	$2.83 \times 10^6$	11
Ratio Phytop/Ciliates	9.9	2.4	11
Picophytoplankton	$2.72 \times 10^{13}$	$1.10 \times 10^{12}$	226
Heterotrophic bacteria	$1.33 \times 10^{14}$	$1.24 \times 10^{13}$	123
Ratio Bact/Picophytop	4.9	11.3	123
<b>Deep ocean (2,000-4,000 m)</b>			
Microphytoplankton	$2.52 \times 10^5$	$5.29 \times 10^4$	58
Diatoms	$2.02 \times 10^5$	$5.08 \times 10^4$	58
Dinoflagellates	$3.46 \times 10^4$	$5.61 \times 10^3$	58
Others	$1.12 \times 10^3$	$3.04 \times 10^3$	58
Cyanobacteria	$5.71 \times 10^2$	$4.21 \times 10^1$	58
Ratio Diatoms/Dinoflag	13.9	3.5	58
Ciliates	$9.95 \times 10^1$	$2.24 \times 10^1$	11
Ratio Phytop/Ciliates	8.9	2.9	11
Picophytoplankton	$3.16 \times 10^{12}$	$1.05 \times 10^{11}$	123
Heterotrophic bacteria	$1.20 \times 10^{14}$	$2.62 \times 10^{14}$	123
Ratio Bact/Picophytop	38.0	24.9	123

Bact/Picophytop: heterotrophic bacteria to picophytoplankton cell abundance ratio; Cyanobacteria, filamentous forms; Diatoms/Dinoflag: diatoms to dinoflagellates cell abundance ratio; N, number of samples; Others: flagellates and silicoflagellates; Phytop/Ciliates: phytoplankton to ciliates cell abundance ratio.

**Fig. 3.** Absolute and relative abundance of prokaryotic and eukaryotic marine plankton in waters of the ocean surface layers (0 to 200 meters) and the deep (2000-4000 m) dark bathysphere. *Image Credit:* Agousti et al. (2015)

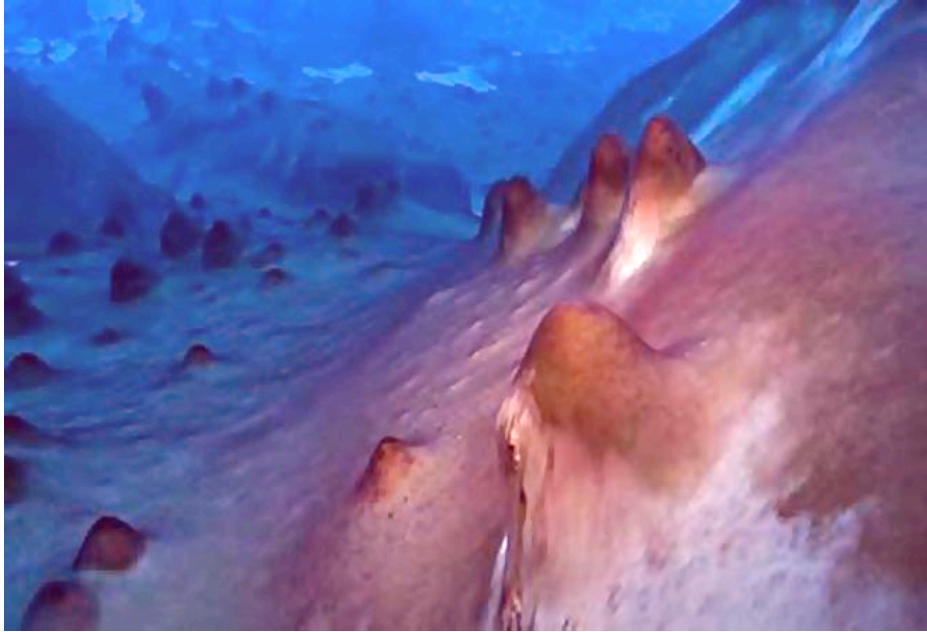
However, some of the cyanobacteria found are extremely important. Aggregates of colonial *Synechococcus* cells were found in the deep ocean. These coccoidal cyanobacteria are capable of producing the organic methyl chloride which was first detected on Mars during the Viking Missions (Hoover, 2015).

All known life forms on Earth require water and an energy source along with a suite of approximately 20 life-critical biogenic elements. Due to the strong triple bond, the di-nitrogen N<sub>2</sub> molecule is not be used by living organisms until it has been fixed into organic nitrogen molecules in nitrates or ammonia. Nitrogen-fixing microorganisms are absolutely essential for life on Earth and it is reasonable to conclude

that they would also be essential for life on Enceladus. However, this implies that there would need to be nitrogen-fixing organisms that could live in oceans deep beneath a thick ice crust.

*Trichodesmium* species were found by Agusti *et al.* (2015) to be abundant on occasions in the deep waters of the Subtropical Atlantic and Equatorial Pacific. This colonial planktonic organism is light brown to red in colour due to the presence of phycobillin and phycoerythrin light harvesting pigments. The Red Sea experiences periodic blooms of *Trichodesmium erythraceum* and was named for the color imparted to it by these pigments. The brown and red colors discovered along cracks in the ice of the Jovian moon Europa or on comets and the surface of Pluto and on comets (such as 67P/Cheryumov-Gerasimenko) might arise from pigments within the cells of diatoms or cyanobacteria growing in low light level conditions (Hoover, 2008a,b, 2011, 2015; Hoover and Pikuta, 2010; Hoover *et al.*, 1986a,b). The discovery of *Trichodesmium* in deep ocean waters is very mysterious, since it has long been known that this filamentous colonial cyanobacteria is the major diazotroph that fixes nitrogen without heterocysts by aerobic photosynthesis in nutrient poor waters of marine pelagic systems (Siddiqui *et al.*, 1991). This organism typically performs aerobic photosynthesis (but light levels in the deep ocean are very near zero) and uses the Mehler Reaction to remove oxygen that poisons the nitrogenase enzyme. An exciting symbiotic relationship (Foster *et al.*, 2011) was discovered in the cyanobacteria *Richelia* sp. and *Calothrix* sp. with the marine diatom *Hemialus* sp. In the Arabian Sea and in the deep ocean the N<sub>2</sub>-fixing cyanobacteria *Richelia intracellularis* has been found living in cells of *Rhizosolenia hebetata* a large marine diatom (Padmakumar *et al.*, 2010; Agusti *et al.*, 2015). The discovery of deep sea diatoms in symbiotic relationships with nitrogen-fixing cyanobacteria is profoundly important with regard to considerations the possibility of life on Enceladus, Europa, Pluto or comets. This may also be relevant to the discovery of sea water diatoms in the 2013 meteorite fall in Polonnaruwa, North Central Sri Lanka (Wallis *et al.*, 2014).

Recent modelling of data from Cassini (Glein *et al.*, 2015) leads to the conclusion that Enceladus' ocean is a Na-Cl-CO<sub>3</sub> solution with an alkaline pH in the range 11-12. This adds a further limitation of microbial population, but photosynthetic microorganisms do inhabit cold, dark hyperalkaline environments on Earth. The dominance of aqueous NaCl in Enceladus oceans make them similar to terrestrial seawater, whereas dissolved Na<sub>2</sub>CO<sub>3</sub> suggests that soda lakes are more analogous to Enceladus. The perennially ice-covered lakes of Antarctica clearly represent the best terrestrial analogs for the liquid water oceans beneath the frozen crusts of Pluto or the icy moons of Jupiter (Europa, Ganymede, Callisto) or Saturn (Enceladus or Titan) (Hoover, 2008a). Oxygenic photosynthesis by cyanobacteria was detected (Galchenko, 1994) in most of the perennially ice-covered lakes of Antarctica that they explored in the Vestfold Hills and the Bunger Hills. However, none of these lakes afford the opportunity to study the constraints on life in conditions as extreme as those in upper 90 meters of the water column of Lake Untersee (T 0.5–0.8 °C; pH 11-12.1) above the anoxic trough (Wand *et al.* 1997, 2006) first characterized.



**Fig. 4.** Large red, pink and brown conical stromatolites comprised almost exclusively of filamentous cyanobacteria (*Leptolyngbya* spp. and *Phormidium* spp.) growing on the floor of the perennially ice-covered hyperalkaline (pH 10-12) Lake Untersee in East Antarctica. *Image Credit:* Tawani Expedition/Dale Anderson

The *Tawani Foundation 2008 International Schirmacher Oasis/Lake Untersee Antarctica Astrobiology Expeditions* were organized to search for microbial extremophiles in the permanently ice covered Lake Untersee in Dronning Maud Land of East Antarctica. During dives carried out by Dale Anderson and team members, large conical stromatolites (up to 3 m in height) were discovered living on the floor of the perennially ice-covered Lake Untersee (Anderson *et al.*, 2011). **Figure 4** shows the large red, pink and brown conical stromatolites that were comprised almost exclusively of filamentous cyanobacteria (*Leptolyngbya* spp. and *Phormidium* spp.) growing on the floor of the perennially ice-covered, hyperalkaline (pH 10-12) Lake Untersee in East Antarctica in almost total darkness 90 meters beneath the thick ice sheet.

## 5. CONCLUSION

In view of the vast number of aqueous terrestrial habitats that are thus colonised by a wide range of microbial species it is scarcely conceivable that the seas of Enceladus would not provide similar opportunities for microbial colonisation. Of course we know nothing about how life originates in the first place but transfers of life between planetary habitats via processes of cometary panspermia are now almost to be taken for granted (Hoyle and Wickramasinghe, 1981). The proximity of Saturnian moon Enceladus to the Earth affords many opportunities for viable microbial transfers to have occurred over the lifetime of the solar system. It is even possible that some of the exotic species described in Section 4 may actually have been transferred from the oceans of Enceladus. We could speculate that the E-ring of Saturn in which Enceladus is embedded provides a microbial reservoir for such potential transfers to Earth. Additionally asteroid/comet impacts on Earth may have ejected life-bearing rocks that reached the Saturnian system over the past 3.5 billion years (Wallis and Wickramasinghe, 2004). Thus we could regard Enceladus and the oceanic microflora of the Earth as one connected biosphere – linked through the processes of panspermia.

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