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PLANETARY PROTECTION FOR A EUROPA SURFACE SAMPLE RETURN: THE ICE CLIPPER MISSION

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ABSTRACT

The surface of Europa may hold biochemical evidence of life in the ocean below. Plans for the analysis and return of samples containing organics from the surface of Europa are well developed; for example, the Ice Clipper Mission. Planetary protection issues must be considered in planning for a returned sample from Europa. Previous studies for sample return from Mars and the return of comet dust by the Stardust mission provide a basis for comparison for a Europa sample return mission. The extreme radiation environment on the surface of Europa would kill even the most radiation resistant microorganism present to depths of many tens of meters in the ice. The Ice Clipper mission would impact sample the upper 1.2 to 3.4 m of the ice depending on the surface hardness. At these depths the radiation dose is expected to be 500 and 40 rads/year, respectively. These dose rates would kill dormant cells in less than 36,000 and 450,000 years even for the most radiation resistant strains. It is therefore likely that a Europa sample return mission such as Ice Clipper can be treated using the Stardust mission as a model for planetary protection, that is, the returned material can be assumed to pose no biological risk.

INTRODUCTION

There is considerable indirect evidence that Europa may have an ocean beneath its surface layer of ice (Pappalardo et al. 1999). The ice may be about 10 km thick or more in most places (Pappalardo et al. 1999, Schenk 2002) but some models indicate that the ice cover may be much thinner in places and the ocean may occasionally reach the surface (Greenberg et al. 2000). The linear features seen on the surface of Europa may be cracks in the ice cover through which ocean water has reached the surface. Thus it is possible that the surface features on Europa contain deposits of material that originate in the ocean. If there is life in the ocean then biochemical signatures of that life may be found in the surface materials. If Europa does have an ocean, and if that ocean does have life, and if the ocean waters do leave deposits on the surface, then this would be the most accessible biochemical evidence for life beyond Earth in our solar system. From a technical point of view obtaining a sample from the surface of a small airless world may well be easier than deep drilling for organics on Mars. Hence a sample return from Europa is a serious mission option for exobiology and may occur before a Mars sample return mission.

The motivation for sample return rather than simply in situ analysis comes from the need to differentiate between organic material and biochemical material. Organic material is any material containing carbon and we know that the outer solar system is rich in organic material and that this material does not reflect biological processes. Detection of abiotic organic material on Europa's surface is only of secondary importance. By definition, biochemicals are organic materials that have been produced by biological processes.

There are several methods by which biochemicals can be distinguished from abiotically produced organics. Lovelock (1965) pointed out that life selects and utilizes only a subset of organic molecules. In a set of abiotically produced organics the relative concentrations would be expected to follow a smooth distribution with similar concentrations of different enantomers and closely related types. However biological processes can use one molecule at high concentrations and contain negligible concentrations of closely related types or enantomers. The use of L amino acids to the virtual exclusion of D amino acids by terrestrial life is one example.

Figure 1, from Lovelock (1965), shows another example based on the abundance of *n*-alkanes from an inorganic source compared to a biological source. A smooth Poisson distribution is compared to the data and fits the abiotic source well. The biological source shows a highly irregular distribution reflecting the biological preference for certain types of molecules.

Other characteristics of biochemicals include the predominate use of one handedness in an entire category of basic organic types which have more than one handedness. Thus, virtually all amino acids used by life on Earth are L (left handed) and the D (right handed) form is absent and all sugars used are D while the L sugars are absent. Finally biochemicals can be distinguished from abiotic molecules by the fact that biochemicals are made by enzymes that often show distinct isotopic selection. For example biogenic organic deposits on Earth show a characteristic enhancement of ^{12}C over ^{13}C of 2% (eg., Schidlowski, 1988). It is likely that the signature of the biological origin of surface organics on Europa would survive much longer than any dormant organisms carried to the surface. However, experiments with biogenic organic material under Europa-like radiation levels have not yet been done.

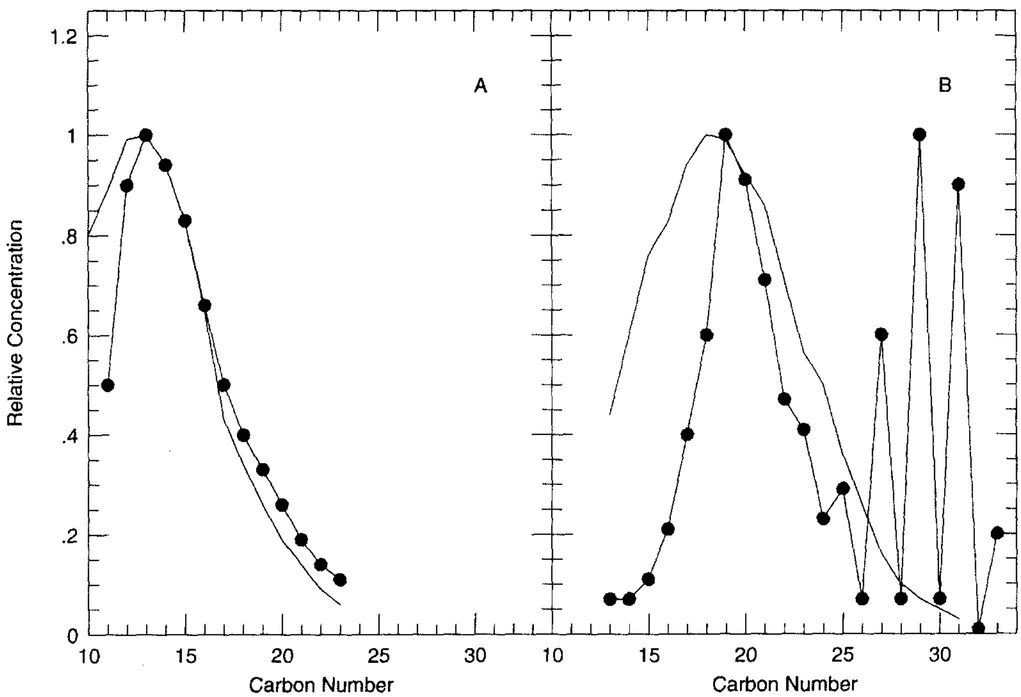

Figure 1. Biological organic material can be distinguished from abiotic organic material by the selectivity of biological enzymes. Life produces some organic molecules and does not produce other very similar types. Non-biological processes are not selective and produce all types based on some smooth distribution. This is shown in this example of *n*-alkanes from an inorganic source, A, compared to a biological source, B. A smooth Poisson distribution is compared to the data and fits the abiotic source well. The biological source, B, shows the pattern of biological preference for certain species containing a odd number of carbons and does not fit a smooth distribution. (From Lovelock, 1965)

Thus detailed analysis of the relative concentrations, optical activity, and isotopic composition of organics from the surface of Europa may reveal that these organics are of biological origin. If the discrete set of biomolecules used by a Europan biology differs from that used by terrestrial life then direct evidence of a second genesis of life would have been discovered. The detailed organic analyses required may warrant and justify a sample return mission.

MISSIONS

One concept for a sample return from Europa's surface is an impact sampler mission know as the Europa Ice Clipper Mission (McKay et al. 1996). In this mission scenario a spacecraft flies through the Jovian system on an Earth-return trajectory without the large rocket that would be needed to enter into an orbit around either Jupiter or Europa.

To obtain a sample of the surface the Ice Clipper Mission uses impact sampling, an idea developed for Europa by Henry Harris at JPL. As the spacecraft approaches Europa it releases a 10 kg copper sphere on a collision trajectory with the chosen surface feature. After releasing the impactor, the spacecraft fires a small rocket to deflect itself away from a collision trajectory and orient itself such that it will fly through the plume generated by the impactor onto Europa's surface. The copper sphere hits the surface with a velocity of 10 km/s creating a total impact energy of 500 MJ, about the same as released by about 100 kg of high explosives. The crater produced by the impact is estimated to be from 12 to 34 meters wide and 1.2 to 3.4 meters deep depending on the hardness of the surface ice. The hardness of the surface ice might vary depending on the level of compaction and crystallization. The impact creates a plume of particle debris that expands ballistically upward in the virtual vacuum above Europa's surface. Calculations predict that the ice would be shattered and ejected into the plume but would not be completely vaporized (McKay et al. 1996).

The Ice Clipper trajectory carries the main spacecraft through the plume at a predetermined altitude. This allows for both direct analysis of the plume material and for the collection of material for return to Earth. The free return trajectory brings the spacecraft back to Earth about 5 years after the Europa encounter and 10 years after launch. The original Ice Clipper design included three modes of sample collection. The most direct mode was based on the Stardust collection technique and involved collection of plume particles in aerogel. A second mode involved exposing sealed containers to the plume. Due to the high relative velocity between the spacecraft and the plume (10 km/s), the plume particles puncture the cover of the container and are vaporized on impact with the far wall. However since the mean free path of the vaporized gas is so much larger than the entry holes created by the particles the vaporized gas does not escape. After encounter, seals are placed on the container lids for secure transport to Earth. For both the aerogel and container collection modes the main goal is to collect refractory material such as organics that might be present in the plume. To collect an isotopically pristine, albeit tiny, sample of the surface ice, a third sample collection mode was proposed. In this mode a soft metal plate (tungsten) was exposed to the plume. Gas particles colliding with the plate are embedded in the soft metal. As this occurs a tungsten filament above the plate is heated and the successive coats of fresh metal are deposited on the collecting plate. This effectively traps and preserves the embedded gas.

SURFACE STERILIZATION

The radiation level on Europa is intense reaching over 10 Mrad/year at the surface and diminishing as a power law with depth to about 10 krad/year at a depth of 0.1 m (NRC, 2000; Cooper et al., 2001). Figure 2 shows the dose expected over a range of depths on Europa based on the radiation models used in the recent study of forward contamination control for Europa (NRC 2000). For reference, 3 Mrads is the radiation level at which the population of *Deinococcus radiodurans*, the most radiation resistant organism known is reduced by five orders of magnitude (Minton, 1994; Battista, 1997; Richmond et al, 1999). At lower temperatures the radiation level needed to achieve the same degree of sterilization may increase (Richmond et al., 1999). Clark (2001) suggests that 18 Mrad provides an *assured* sterilization dose reducing the initial population by 15 decades. The depth of sampling by the Ice Clipper impact is shown for hard ice (1.2 m) and soft ice (3.4 m). The radiation dose at these depths are 500 and 40 Rad/year, respectively. These radiation dose rates are not high and radiation resistant organisms can tolerate these levels. However since the surface temperature of Europa is less than 200 K, any organisms present are likely to be profoundly dormant. Thus the key factor in their survival is not the radiation rate but the total accumulated dose from the time of their deposition to the time of sampling. There is no lower limit on this time since we might happen to sample a site with ejecta emplaced only moments before impact. The upper limit for this time, and the average for most of the surface, is the timescale for the surface processing by ice movement and water vapor deposition on Europa. The geological processing of the surface implies that timescale for surface burial of surface material is from 10^7 to 10^9 years (Zahnle et al. 1998). Thus any material ejected from the surface of Europa is likely to have received 10^7 years or more of radiation dose. For the dose at a depth of 1.2 m this is 5,000 MRads and for the dose rate at a depth of 3.4 m this is 400 Mrads. These radiation doses are extremely high compared to what *D. radiodurans* can tolerate. It is likely that any Europa microorganism would have less resistance to radiation *D. radiodurans* since the Europa ocean would have low radiation levels due to the shielding by the ice cover and dehydration stress would not be an evolutionary factor. The radiation resistance of microorganisms in the ocean of Europa would probably be similar to that of marine microbes on Earth.

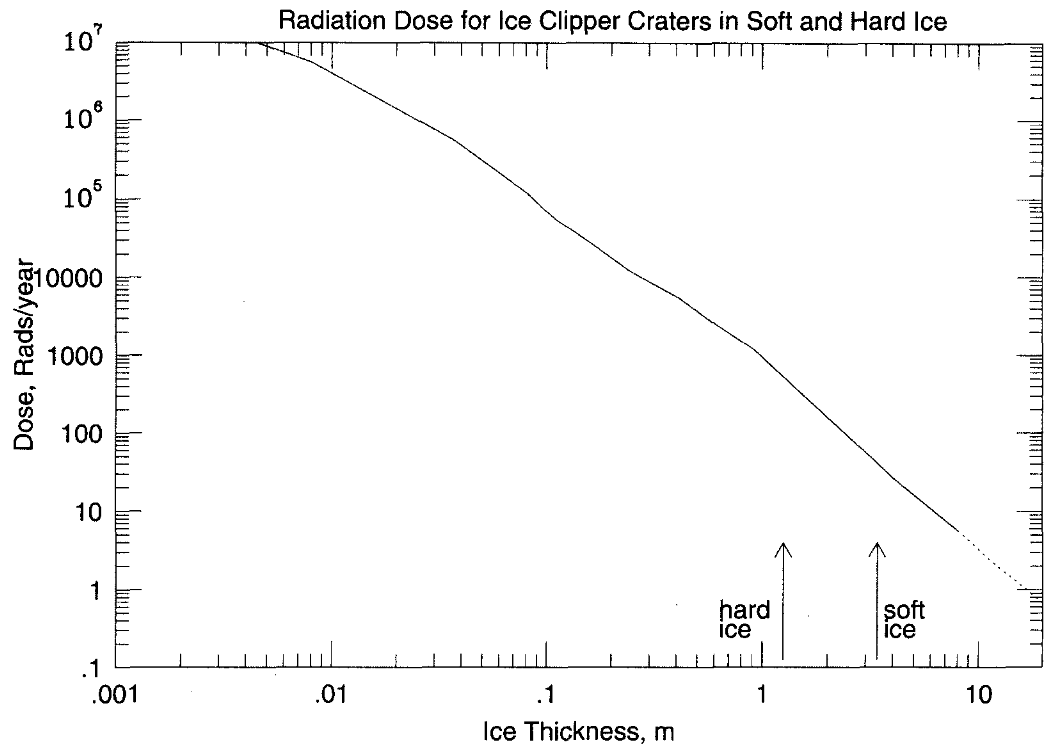

Figure 2. Radiation dose as a function of depth beneath the surface from NRC (2000). Also shown is the depth of the crater excavated by the Ice Clipper impact sampling for hard and soft ice.

CONCLUSIONS

Planetary protection concerns with a sample returned from Europa would logically vary considerably depending on where the sample is obtained. Samples from an area with fresh deposits of ocean material could contain viable examples of life from the ocean. Along the same lines if the ice were thin enough that a few meter crater reached the ocean then fresh material would also be obtained. However most of the surface of Europa, and the likely target site of any sample return mission has thick ice and has been exposed to considerable radiation levels. Clearly surface material that had been heavily irradiated would pose a much less significant risk of biohazard than material obtained from the ocean itself.

We have considered the proposed Ice Clipper mission for a surface sample return from Europa. We conclude that the depth to which the impact will sample material is small enough that only heavily irradiated ice would be sampled. The radiation levels would be in excess of the sterilizing dose of even the most radiation resistant organisms. The radiation dose received by the samples is in excess of the radiation does (10 – 100 MRads) proposed as a method to sterilize samples returned from Mars (Allen et al. 1999). In that respect any biological hazard is expected to be nil. The effect of this high radiation dose on the organic material is not known but presumably the biological signature of biochemicals could be preserved at radiation levels orders of magnitude larger than the sterilization levels.

Based on these considerations it may be that the planetary protection protocols for a near-surface sample return mission from Europa (eg. the Europa Ice Clipper Mission) could be patterned after the Stardust mission rather than after Mars sample return missions. The sterilized, but still interesting, biochemistry of Europan life may await collection on the surface of that world.

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