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Interactive Comment

Interactive comment on "Comets, carbonaceous meteorites, and the origin of the biosphere" *by* R. B. Hoover

R. B. Hoover

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Reply to Comment on "Comets, carbonaceous meteorites, and the origin of the biosphere" submitted by M. Wallis.

I thank the reviewer for the helpful comments he has submitted on this manuscript. I am presently preparing a significantly re-structured version and the paper and your helpful criticisms will be carefully considered, as the revised version is prepared.

Pg. S3, Paragraphs 1-4. I fully agree with the reviewer that the Whipple "dirty snowball" was hit hard by the results from the probes to comet Halley. However, the "dirty snowball" model has continued to persist, despite all data to the contrary and it is for that reason that I chose the word "paradigm." That seems to be the nature of paradigms; they are so deeply entrenched into the consensus view of scientific community that they remain firmly accepted until the weight of evidence finally becomes so great that they collapse abruptly and catastrophically. However, I also think that the term "paradigm"

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has become somewhat overused and I agree that this model may not actually merit the status of a “paradigm”. In the revised text, I will refer to it as the Whipple “model”.

I am well aware of your work with Sir Fred Hoyle and Prof. Wickramasinghe and your important contributions to cometary science especially relating to liquid water on comets and the models of dark organic crusts that have been confirmed by a number of space missions. My view is totally in keeping with the model you have developed of a comet with a hot, semi permeable organic rich crust capable of sustaining liquid water in crevices, pools, subsurface cavities and voids within different regimes and at different levels beneath the comet surface.

The Deep Impact probe has shown that the surface of a comet can be very hot ($>$320 K) even as far away from the Sun as Mars (1.5 AU). It is very difficult to envision how thermodynamics would allow the surface of a comet to remain at such high temperatures if they were continually bathed in a flow of water vapor that has passed directly from solid to gas phase at a sublimation temperature of 200 K. This suggests that the crusts of comets must be semi-permeable. As long as the subsurface pressure exceeds 6.1 mbar the phase transition from water ice to water vapor must go through the liquid state. The repeated freeze-thaw cycles could then play a significant role of rendering the rocky components near the crust into minute particulates in a manner analogous to that of the active region of permafrost on Earth.

The spectacular burst of fine particulates that was observed just after the Deep Impact collision suggested the release of subsurface pressure, and if there was sufficient subsurface pressure then liquid water could certainly have been present beneath the surface of Tempel 1. Many regimes beneath the outer surface layer of the comet could very well contain pockets and crevices filled with hot water that would be suitable for the growth of hyperthermophilic and thermophilic photoautotrophs and chemolithotrophs. It is important to note that the near surface regions of comets in the inner solar system could contain hot water and provide suitable habitats for thermophilic and even hyperthermophilic microbial extremophiles. This possibility is dramatically at variance with the long standing view of comets as frigid, pristine, sterile bodies that are devoid of liquid water and totally incapable of supporting any form of life. Other regions near the surface of the comet, but at different depths beneath the crust, could contain lower temperature pools of water suitable for mesophilic, psychrophilic, or psychrotolerant microorganisms. It is known that several genera (e.g., Calothrix, Oscillatoria, Phormidium, and Spirulina) of motile filamentous cyanobacteria can grow in geothermal springs and geysers at temperatures ranging from 320K to 345K (Ward and Castenholz, 2000). I have found morphotypes of all of these groups of cyanobacteria embedded in freshly fractured interior surfaces of the Orgueil CI1 carbonaceous meteorite and have presented images of some of them in this paper.

The rapid replication growth of cyanobacteria and other microbes at high temperature is such that if few viable microbes ever found their way into similar hot aqueous regimes within the upper regions of a comet regolith of a comet, very large numbers could be produced in extremely short periods. Most cyanobacteria are photosynthetic autotrophic microorganisms. However, there is a facultatively heterotrophic strain of the cyanobacterium Nostoc sp. (Juhász et al., 1987). Newton and Calvin have shown that a facultatively heterotrophic cyanobacterium can liberate ammonia during the process of nitrogen fixation.

Deep-Impact data have also provided the first direct detection of exposed water ice deposits by distinct 1.5 and 2.0 μm absorptions in the IR spectral scans of the surface of comet 9P/Tempel 1 (Sunshine at al., 2006). The maximum observed was 330 K for the region of the nucleus in direct sunlight and the minimum measured temperature of the surface of Tempel 1 was 280 ś8 K. Even though this is the precise regime in which the water ice to liquid water phase change transition takes place, the prevailing view that liquid water can not exist on comets remains strong and the paper makes no suggestion that this result in any way suggests the presence of liquid water on comet 9P/Tempel 1. This paper also show that relatively large regions (total area 0.5 km2) of higher albedo associated with a large flat area of water ice in a depression that is

80 M ś 20M below the surrounding area. This result suggests that the crust thickness on Tempel 1 may be of the order of 80 M and that the geyser-like jets are the result of failures of large chunks of comet crust that occur when the internal gas pressures exceed the structural strength of the crust.

Ice geysers have also been recently observed on Enceladus and near infrared observations of the large Kuiper Belt object (50000) Quaoar has revealed the presence of crystalline water ice and ammonia hydrate indicating that Quaoar has been recently resurfaced, either by impact exposure of previously buried and shielded ices or by cryovolcanic outgassing or some combination of these two (Jewitt and Luu, 2004).

Pg. S4. I agree with all of these comments also. I will be more straightforward in the interpretation of the data in the revised version of the paper. I am confident that the forms I am finding in the Orgueil CI1 and Murchison CM2 meteorites are both biogenic and indigenous and cannot be dismissed as either recent contaminants or unusual abiotic microstructures that just happen to precisely mimic the large number of morphological, physiological, reproductive, biological, and ecological characteristics of known genera and species of cyanobacteria and prokaryotic mats and microbial assemblages. I also agree that if life can exist on comets, then there has bee many opportunities during the past 4.5 Ga for it to have entered the Earth's atmosphere and dramatically altered the Biosphere or for it to have been ejected from the planet and accreted by any number of comets whose trajectories bring them to cross the orbit of the Earth. It is not ny intent to speculate in this paper regarding which of these two scenarios is most likely because they both imply that the Biosphere is not restricted to the planet Earth, which is the essence of the thesis of this manuscript.

Some of this information and these new References will be included in the Revised Version of the Manuscript. I want to thank you for your comments on this paper as they are very helpful to my effort to present a sound and well focussed manuscript which challenges several widely held views on the origin and evolution of the Earth's biosphere.

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