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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 Sheldon Comment on "Comets, carbonaceous meteorites, and the origin of the biosphere"

I would like to thank the reviewer for taking the time to review the manuscript and providing these thoughtful comments.

Pg. S5. Par. 1. I completely agree with the reviewer that one of the main conclusions of the paper is that the generally accepted view that the endogenous origin of life on Earth "requires careful reconsideration." The important contributions of comets, asteroids, meteorites, and interstellar dust particles to the Earths biosphere are now becoming more widely understood. However, I do not agree with the reviewer that I asserted in this paper that the "endogenous origin of life must be replaced Ě" because I consider it possible that the endogenous origin of life on Earth may still be correct. However, the fact that Earth is an open (rather than a closed) system and the data that I have

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collected during the past decade on microfossils in carbonaceous meteorites have led me to conclude that the possibility of an exogenous origin of life certainly can no longer be dismissed out of hand.

Although I do not intend to specifically address these speculative and theoretical philosophical points in the revised version in the paper, I will still provide my thoughts on the reviewer's comments. I fail to appreciate the comment: "Although endo/exo appears to exhaust the places for life to begin, there traditionally exist four options given two variables: 1)endo only, 2) exo only, 3) endo + exo, 4) neither endo nor exo." While this may be true as an abstract proposition, it seems to me that Option 4 is clearly invalid since this option implies a sterile Earth and we have strong evidence that life does exist on our planet. Option 3 is also of questionable validity if the concept "origin of life" is interpreted to mean the first appearance of life on the planet. However, this option might be valid if it is considered in terms of "life forms" and some organisms originated endogenously and others were transferred via the influx of viable microbiota contained with comets, asteroids, meteorites, or on interstellar dust particles. At NASA/NSSTC we are currently conducting experiments (based on discussions with Paul C. W. Davies) to search for living microorganisms that exhibit metabolic and physiological properties that allow them to use biomolecules of chirality different from the known bacteria and archaea on Earth and some of the results of these experiments may bear on the question of "multiple origins" of life.

I certainly did not intent to imply that the endogenous origin of life on Earth is incorrect but rather to assert that there is no valid scientific reason to exclude the possibility of an exogenous origin. I do favor the hypothesis of the exogenous origin, since it is now apparent that life appeared on Earth very early in the history of our planet, which excludes the possibility that a very long period of time was available on Earth of a slow and protracted molecular and chemical evolution to take place in prebiotic oceans, clay, "warm little ponds", or RNA worlds. It is also now abundantly clear that bacteria, cyanobacteria, and archaea are tremendously complex and can in no way be considered ‘simple cells’. Also all available evidence in the fossil record is that the most ancient prokaryotic life forms found on Earth are not dramatically different from present day prokaryotes. We simply do not yet know how, where or toa high degree of accuracy when life originated and it is for that reason that I want to emphasize in this paper that that this subject would best be approached with an open mind.

The major point that I intended to make in this paper is that there is clear and convincing evidence for the existence of indigenous microfossils in several of the CI and CM carbonaceous meteorites. The implication of this observation is that the biosphere extends beyond planet Earth — in other words — Extraterrestrial life does in fact exist.. This conclusion follows from the fact that there is a considerable body of solid scientific evidence (e.g. elemental composition, stable isotopes, etc.) that the planet Earth is most certainly not the parent body for the carbonaceous meteorites. Therefore if valid biogenic microstructures are indigenous to these meteorites the life is not restricted to the planet Earth but rather is more widely distributed within the Cosmos.

I feel I must strongly disagree with the comment “Hoover makes the argument that endo-only cannot explain the comet data. He even suggests locations for exo origins.” Nowhere in this paper do I assert that the endogenous only origin of life on Earth "cannot explain the comet data.” I did co-author a paper with Sir Fred Hoyle many years ago arguing that the nature and characteristics of the ice microbiota known on Earth suggested that they might well be capable of surviving on comets (as well as on Europa and Mars). However, we do not as yet have any hard scientific data regarding the existence of microbial life on comets. This could be altered if valid microbial remains should be found embedded in the aerogel samples that were just returned from comet Wild-2 by the Stardust Mission. However, to my knowledge such dramatic evidence has not yet been obtained.

The arguments that I intended to make in this paper concerning comets are of an entirely different nature. It is well established that water comprises the dominant volatile of comets. I do not think it would be possible for the high temperatures observed on the low albedo surface of the nucleus of comet 1P/Halley (~400 K) and on the surface of Tempel 1 (330 K) to be present if the comets truly had a porous surface that was continuously suffused with 200K gas emanating from sublimation of water ice. Furthermore, these temperatures are sufficiently high to melt (and even boil) water ice beneath the crust and produce sub-crustal pools or cavities infilled with liquid water and water vapor under pressure. The complex morphology (e.g., mountains, craters, cliffs, pinnacles, and spires) observed on the nuclei of comets Halley, Borrelly, Wild-2 and Tempel 1 clearly indicate that the outer layer can not be composed of fine porous dust (which is needed to permit direct sublimation at 200 K of the interior water ice) unless the dust is held together by being embedded within ice matrix, If the crust is impermeable or sufficiently semi permeable that the internal pressures can be brought to exceed the three phase equilibrium point of water (611.73 pascals; 6.1 mbar at 273.16 K; 0.01 C) then water could exist within the comet in liquid state. I also argue that when subsurface pressures exceed the structural strength of the upper layers of the comet 'crust" (possibly composed of black kerogen-like organics and grains and dust particles cemented together with ice and evaporite minerals or salts) then sections of this surface crust could be blown off resulting in the sporadic and spontaneous appearance of bright jets rich in organics, water vapor, ice and dust particles. As I discussed in the paper, several space missions have obtained images and movies of jets associated with the nuclei on several different comets.

I disagree with the reviewer's assertion that I even suggest "locations for exo origins." I would not do this for the simple reason that I have absolutely no idea concerning the location or locations of the origin of life. My point is simply that if bacteria, cyanobacteria, archaea or "protocells" did not originate endogenously on Earth, then they must have originated somewhere else in the Cosmos. I certainly do not suggest that comets comprise the best location for the origin of life. However, if life originated elsewhere in the Solar System or the Cosmos, then comets (and the frozen interiors of carbonaceous meteorites which may be nothing more than comets with the volatiles removed) seem to provide suitable transport mechanisms for its distribution throughout the Cosmos.

Furthermore, the interior of comets can provide a measure of protection for viable microorganisms from the solar wind, UV and x-rays and provide conditions for long term storage by the phenomenon of lyophilization. Our studies of permafrost and ice from Alaska, Siberia and Antarctica have shown that microorganisms can remain alive after being frozen in ice for geological periods of time. Furthermore, it is now well established liquid water with dissolved salts (and thin films of pure water at the interface between ice and dust grains) can exist at temperatures far below 273K. These phenomena would afford opportunities for DNA repair and slow growth of psychrophiles in comets well beyond the orbit of Mars. During periodic approaches to the Sun, the melting of water ice in internal pockets, cavities and subcrustal pools may afford conditions suitable for rapid growth and possibly even the formation of mats, such as have been detected in the Orgueil meteorite. The high temperatures observed the sunlit portions of Halley (400 K) and Tempel 1 (330 K) would even afford conditions conducive to the rapid growth of hyperthermophiles such as Pyrococcus so with their astonishingly fast (˜40 minutes) doubling time. Under these conditions, extremely large amounts of biomass can be produced in only a few days. The explosive ejection of dust, ice and large portions of the black crust afford as the comet crosses the Mars or Earth during approach to perihelion, provides an ideal mechanism for the comet to transfer organic matter and possibly even lyophilized or active microbial extremophiles to the inner planets, where these that were favored to fall y might in niches affording suitable conditions might survive and continue to grow.

The discovery of chemolithotrophs has clearly shown that organic matter is not required. Carbon, hydrogen, oxygen, nitrogen, sulfur, and other critical biogenic elements (as well as water and energy) are readily available from a wide variety of sources on comets and they would have also been available on the primordial Earth. The studies of microbial extremophiles have shown that the range of physical, environmental, and chemical parameters in which life can exist are far greater than previously understood. This paper does not specifically address Sir Fred Hoyle's arguments concerning "panspermia" or the implications of the complexity of life in regard to how difficult it would to get started. It is not my intent in this paper to make “philosophical arguments” about some sort of “universal imperative” that forces systems to self organize. Life exists on Earth and there is no valid scientific reason to argue that the Earth is unique in this regard. It is quite clear that the laws of physics, nuclear physics, chemistry, and organic chemistry work the same way throughout the Cosmos, regardless of whether we are dealing with the Earth or Mars, the sun or a star in some distant galaxy.

There is clearly no reason to suspect that the laws of biochemistry and molecular biology that govern the fundamental processes of all life on Earth (from archaea, bacteria and cyanobacteria to diatoms and neurons) would be unique to Earth and operate nowhere else in the Cosmos. In this paper, I have reviewed a large body of recent scientific data and presented observational results from the ESEM and FESEM study of the deep cold biosphere, the deep hot biosphere, living cyanobacteria and possible microfossils in carbonaceous meteorites. I interpret these results as providing clear and convincing evidence that the biosphere is far more extensive than thought possible only a few decades ago.

I also argue that the long held model that liquid water cannot exist on comets due to direct conversion to water vapor by sublimation is not consistent with several spacecraft observations of cometary nuclei. I have also provided new Field Emission Scanning Electron Microscope images and EDAX elemental data that I interpret as providing evidence that indigenous micofossils of the mineralized remains of biological entities (recognizable as morphotypes of a variety of filamentous cyanobacteria) do exist in-situ in the Murchison and Orgueil carbonaceous meteorites. I am also convinced that these forms are neither abiotic mimics or recent (i..e., post-arrival biological contaminants)

I would like to thank the reviewer for these thought provoking comments. I will make a significant revision to the manuscript in an effort to make the text more sharply focussed and to remove extraneous and redundant text. I appreciate this opportunity to more thoroughly discuss and hopefully clarify the main points of the paper.

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