

Rosetta images of Comet 67P/Churyumov–Gerasimenko 2. Prospects for cometary biology

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Abstract

The data obtained so far from the Rosetta Mission appear to be fully consistent with the theory of cometary panspermia. The evidence of refrozen seas and lakes plus the early outgassing activity point to the action of microbiology, which could also explain more distant outbursts. While micro-organisms probably require liquid water bodies for their early colonising of a comet, they can inhabit cracks in ice and sub-crustal snow, especially if they contain anti-freeze salts and biopolymers. Some organisms metabolise at temperatures as low as 230K, explaining the coma out at 3.9AU and our prediction is that they would become increasingly active in the near-surface layers as the comet approaches its 1.3 AU perihelion. The detection of organic molecules at the surface by Philae and through IR imaging by the Rosetta orbiter would be most significant.

Keywords: Comets, Rosetta Mission, Comet 67P, comet Churyumov–Gerasimenko, Panspermia

Introduction

"2061. The return of Halley's Comet; first landing by humans. The sensational discovery of both dormant and active life-forms vindicates Hoyle and Wickramasinghe's century old hypothesis that life is omnipresent throughout space....."

from *Greetings, Carbon-based Biped!* (Arthur C. Clarke, 1999)

The Rosetta mission and doubtless one or more follow-up comet missions in the foreseeable future make Arthur C. Clarke's 2061 date overly pessimistic. In this communication we show that indirect pointers to cometary panspermia are already available and may well be confirmed by the Rosetta.

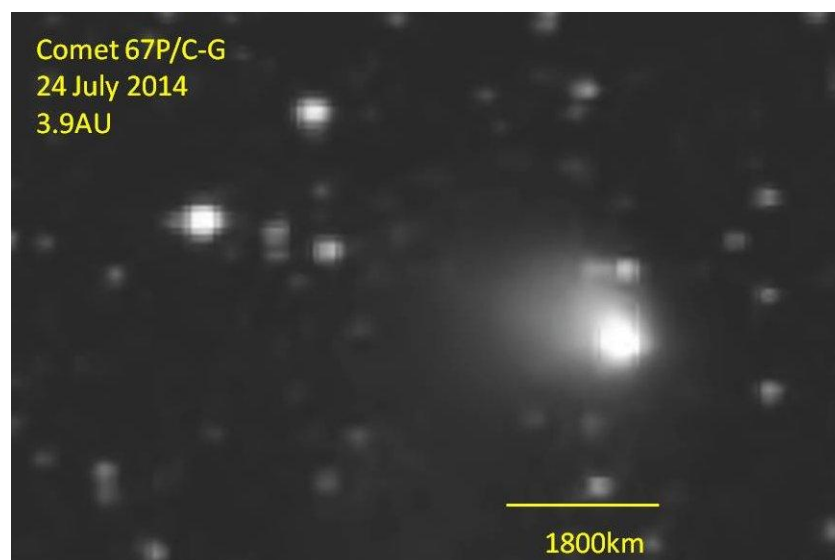


Fig. 1 July 24, 2014, Image of Comet 67P/C-G at 3.9AU showing dust/gas coma and tail (Courtesy, OSIRIS/ESA)

Activity of comets at perihelion distances much greater than 3AU have stretched the limits of credulity for dirty snowball models of comets. A pre-perihelion dust outburst from Comet Halley was observed in 1983/84 at a heliocentric distance of 6.2 AU (Djorgovski and Spinrad, 1984). Likewise, observations of CO around comet Hale-Bopp at ~ 6.5 AU, together with its extensive dust coma at this distance (Jewitt *et al.*, 1996; Biver *et al.*, 1966; Weaver, 1996) presented further difficulties of interpretation within the constraints of conventional cometary paradigms. The data for Comet Hale-Bopp at 6.5 AU implied a CO production rate of 2×10^{28} molecules s^{-1} ($\sim 1 \text{ t s}^{-1}$) and some 15 times this rate of emission in the form of micron and sub-micron-sized dust particles along a collimated jet. The emissions from Hale-Bopp were recorded as several distinct bursts on 19 August, 24 September and 12 October 1995, with each event lasting for about 2 days (Biver *et al.*, 1996).

Rosetta imaging of Comet 67P/C-G

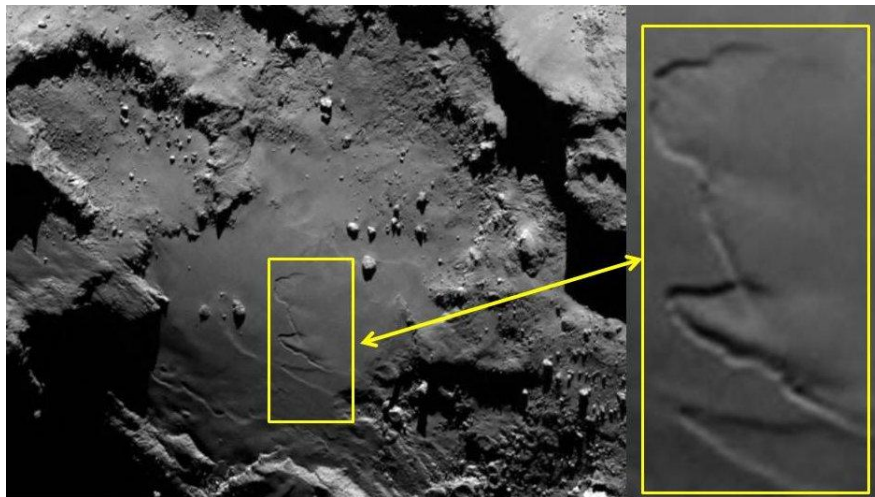


Fig. 2 Left: The 600 x 800m Cheops 'sea'. The image shows it curving away into shadow approaching the terminator at bottom left. The plateau at the top right corner (semi-circular) is a few 100m higher than the sea and appears to have shed debris at the cliff-foot. **Right:** Enlargement of a putative re-sealed fissure 10-20m wide. (ESA/Rosetta/MPS for OSIRIS Team).

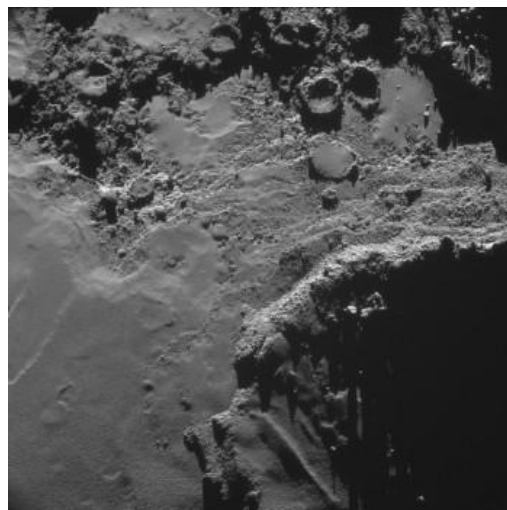


Fig.3 Flat-bottomed impact craters, showing putative re-frozen impact-melt lakes $\sim 40\text{m}$ across. The left of the image shows the corner of the Cheops sea to the upper right of the Cheops boulder cluster.

Like the earlier comets Halley and Hale-Bopp, Comet 97P/C-G also displayed unexpected activity and dust emission during its last orbit in November 2007 pre-perihelion when it was at a heliocentric distance of 4.3AU (Snodgrass et al, 2013). By comparing the pre-perihelion and post-perihelion behaviours at 2.99-2.22AU Guilbert et al (2014) inferred that this comet was covered with a 12cm thick dust layer that quenched its pre-perihelion and near-perihelion activity. During the current perihelion approach the first detection of water emission from Comet 97P/C-G was made by Rosetta instruments in July 2014 showing relatively low activity and outgassing (Fig. 1). The comet was releasing the equivalent mass of 300 ml/s (Weaver, 2013). This low gassing rate corresponds to small vents and evaporation from newly disturbed thin-crust material if the underlying surface is water ice (Guilbert et al, 2014)

As with other cometary nuclei, Comet 67P/C-G also has a very low albedo, characteristic of largely carbonaceous surfaces and regolith. It has large smooth areas like 'seas' (presumably overlain with a carbonaceous crust and dust) surrounded by elevated rugged terrain (Fig. 2). It also has several impact craters with flat central regions, as from refrozen impact melts (Fig. 3). Two smooth areas resemble local seas on Mars, which are thought to be the result of water flooding from below the surface, freezing over and developing a protective regolith. We refer to the major smooth feature on Comet 67P/C-G as the Cheops sea, because the largest of the cluster of boulders (~45m) in the upper part has been named Cheops (Fig.3).

Eruptions in Comets

The idea of a sporadically exploding organic/biogenic comet has been discussed extensively by Hoyle and Wickramasinghe, in proposing the theory of cometary panspermia (Hoyle and Wickramasinghe, 1983). It has been argued that for sufficiently large comets a substantial fraction of the comet's interior volume would have spent several Myr in a liquid state due to radioactive heating during its early history (Wallis, 1980; Wallis et al, 2009). If microorganisms (chemotrophs and methanogens) pre-existed the formation of solar system comets, they would undergo extensive replication and effectively colonise the interior of the comet before it freezes through. This inner part becomes exposed aeons later, as the outer comet layers strip off on sojourns within Jupiter's orbit and more so around perihelia closer than 1AU from the sun. Recent microbiological studies have further highlighted an almost uncanny range of survival properties for so-called extremophiles (Lloyd and Hayes, 1995; Rampelotto, 2010). Very recently Russian scientists have reported the survival of microorganisms mounted on the surface of a Spacecraft (Foton-M) launched with a Soyuz rocket in July 2014 and collected after re-entry through the Earth's atmosphere 6 weeks later (<http://en.itar-tass.com/non-political/760517>).

Extremophiles and comets

During the past decade, new data has been obtained showing that microbial extremophiles can live in permafrost, glaciers, and ice sheets. Diatoms and many bacteria have ice-active substances and antifreeze proteins that enable them to thrive in polar environments, Cyanobacteria and many other gram-positive bacteria have lipoteichoic acid in their cell walls that induces localized melting of the water-ice if the temperature exceeds 230K (Hoover and Pikuta, 2010). These discoveries further enhance the possibility that cyanobacteria and a variety of other microbial extremophiles

would be able to thrive in the cometary habitats we have discussed (Hoyle and Wickramasinghe, 1985, Wallis, Wickramasinghe and Wickramasinghe, 2009)..

Whilst the known list of culturable microbial species on the Earth is limited, an indefinitely large number (millions) of ‘dormant’ or uncultured species have been identified from studies of bacterial DNA in a variety of terrestrial environments including Antarctic snows and dry valleys. Junge et al (2004, 2006) have shown that bacterial activity in arctic sea-ice and under laboratory condition the take-up of radioactive leucine by microorganisms continuing below 20°C. Excess methane measured in ice cores shows further that methogenic organisms are active well below 270K (Tung et al, 2005).

Fig.4 shows microbial activity following the Arrhenius formula for the rate of metabolism, $R(T) \sim \exp(-A/T)$, suggesting that archaea are active in low temperature ice at T as low as -40°C (Tung et al, 2005). Water is available for cell processes, because of dissolved salts and biopolymers and also because a few monolayers of H₂O remain mobile in cracks in impure ice at such low T. Such a process was discussed by Wallis, Wickramasinghe and Wickramasinghe (2009) in the context of microbial life retaining viability in the polar regions of Mars.

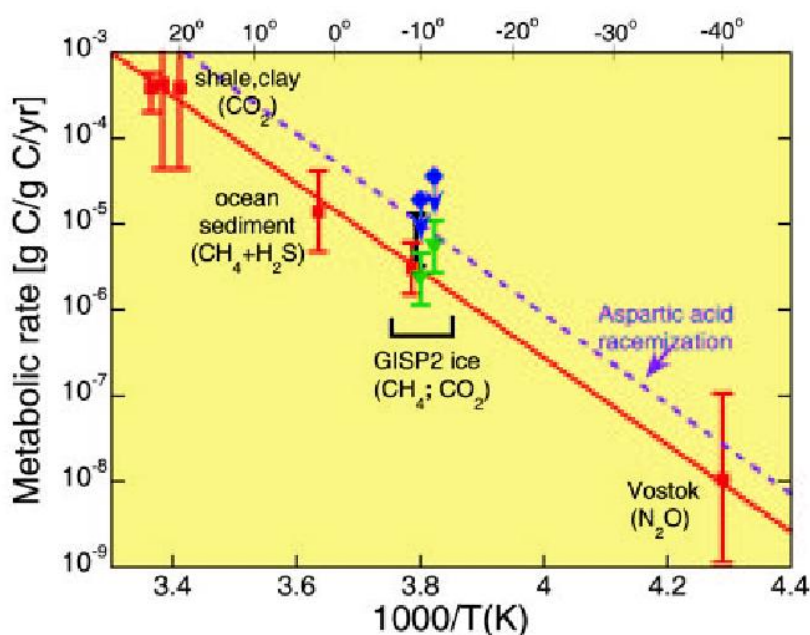


Fig 4 Metabolic rates from bacteria from Tung et al. 2005 using data on trapped CH₄ and CO₂ in ice core samples. Spontaneous racemisation of aspartic acid appears to follow the same exponential law.

At the present time the full range of conditions within which microbiology operates remains an open question, but identified limits of life are continually receding. Modern developments, combined with the lack of any known mechanism for explaining the early beginnings of terrestrial life some 3.83 b yr ago, give a new impetus to panspermia from within the science of microbiology itself (Wickramasinghe, 2014; Tokoro and Wickramasinghe, 2014).

Biological activity in Comet 67P/C-G

The surface temperature of Comet 67P/C-G averaged 205K at 3.7AU (VIRTIS IR imaging <http://blogs.esa.int/rosetta/2014/09/08/virtis-maps-comet-hot-spots/>) with peaks of 230K at

3.5AU. The surface temperature of Comet Hale-Bopp at 6.5 AU scales to ~ 155 K. In neither case can the presence of liquid water at the surface be justified. However, we can argue that transient subsurface lakes would develop from bolide impacts dissipating energy at depth (typically 10-20m in the 40m craters near the Cheops sea below the frozen surface (Wallis and Wickramasinghe, 2014). Chemoautotrophic microorganisms released from the ice into such 'lakes' laden with high-grade organics could undergo enough doublings to exhaust available nutrients within the observed eruption times of a couple of days. (Heat loss from the surface would lead to full re-freezing, but only over a longer timescale of ~ 1 yr.) An initial melt of 10^4 t (10m deep, 20m radius) would be extended by the heat released through biochemical transformations. An average heat release of $\sim 0.1 - 0.3$ eV per atom implies an increase of the melt volume by a factor $\sim 10-30$. Methane and carbon dioxide can be produced by bacteria from a variety of nutrients and such gases could build up and eventually vent through fissures in the overlying ices and crust.

As Comet 67P/C-G reached closer (3.3AU) in Sept. 2014 emissions of gas and dust as were imaged as Fig 5, emerging from a wide area of the "neck" between the two cometary lobes, where smooth but furrowed icy areas are seen (Wallis and Wickramasinghe, 2014). The furrows in the crust would probably penetrate into the underlying ice, being generated by strains due to flexing of the two lobes. The furrows and cracks provide, we suggest, an amenable habitat for micro-organisms when warmed by the sun.



Fig. 5 September, 10, 2014 imaging shows jets of cometary activity along the whole neck of the comet. Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA.

Whereas abiotic chemical reactions leading to gas production are in general self-limiting, being impeded by pressure increase in the surrounding medium, microbial biochemistry, that takes place within the confines of exceedingly strong cell walls, is evidently unaffected by pressure to a large extent. Several examples could be cited of bacteria functioning in media subject to very high hydrostatic pressure: barotolerant or barophilic bacteria function normally at depths of 5.5 km in the sea corresponding to a pressure of 600 atmospheres (Parkes *et al.*, 1995). Bacteria recovered from drills of the Siljan crater at depths of 6.7 km evidently thrive in a sludge subject to even higher pressures (Gold, 1992, 1999). Such pressures of $\sim 10^3$ atmospheres are interestingly close to the limits set by the tensile strength of water-ice. Thus fractures and fissures in the cometary crust could easily develop, their formation being assisted by the more frequent impact of smaller meteorites which both dig over the surface and serve as a source of nutrients.

The outbursts of comet Hale-Bopp and likewise of comet 67P/C-G could not result from the volatilisation of the comet's surface, but from gas pressure built up in subsurface (presumed liquid) domains. The contents of a pressurised 10^6 – 10^7 t lake flooding out with say 10% going as gases and entrained particles into the coma, could explain the outbursts of CO and dust observed in comet Hale-Bopp (Wickramasinghe et al 1996). Although CO₂ or CH₄ may well be constituents of the driver gas at the base of ruptured vents, most of this material would recondense on grains close to the surface while liquid water would form and ice crust due to sublimation cooling. The CO production would most naturally be explained as a photodissociation product of volatile and fragile biochemicals that contain weakly bonded CO groups which re-evaporate from superheated (smaller) grains).

The process suggested here is analogous to the explosion of a bottle of wine in which fermentation has taken place. The wine bottle, once ruptured, stays ruptured of course. The surface layers of a comet, however, re-freeze back to their initial tensile strength, providing for a repetition of the phenomenon, such as was seen comet Hale-Bopp and now in Comet 67P/CG. The repetitions are driven by continued input of metabolic heat dissolving new material and mixing in new nutrients.

Rosetta and Panspermia

In the absence of a life detection experiment on Philae, similar the 1976 Mars Viking Labelled Release Experiment (Levin and Straat, 1978), we can only hope for indirect pointers to the presence of microbial life on Comet 97P/C-G. The characterisation of the organic molecules at the surface by Philae would be important in this context. Perhaps the most interesting result will be the 3-D imaging of dust escaping from the surface by μm -nm size range aboard the Rosetta orbiter. Comparison of the distribution of sizes of grains with the size spectrum of interstellar dust would be of interest, in particular to look for nanometric sized grains. Hoyle and Wickramasinghe (1996) interpreted the X-ray fluxes obtained from comet C/1996B2 (Hyakutake) on the basis of small angle scattering of solar X-rays by nanometric-sized particles. A mass of a few tenths of a megatonne of such viral-sized grains was inferred to be present in the coma of the comet on March 26-28 1996. The interpretation of virus-like organic particles is tempting in view of recent findings that the total biomass of the Earth is overwhelmingly dominated by viruses; the total number of virions in the biosphere is estimated as 10^{31} (Villareal, 2014; Wickramasinghe and Tokoro, 2014). In this context the analysis to be conducted by MIDAS as Comet 97P/G-G approaches perihelion could be of paramount importance to the theory of cometary panspermia.

Concluding Remarks

The evidence of refrozen lakes, the low albedo of Comet 67P/C-G and activity at large perihelion distances give credence to the theory of cometary panspermia first proposed by Fred Hoyle and one of the present authors over 3 decades ago (Hoyle and Wickramasinghe, 1981). According to this theory comets carry not only organic molecules that could serve as chemical building blocks of life, but life itself in the form of freeze-dried microorganisms - bacteria and viruses. As Comet 67P/C-G approaches its 1.3AU perihelion in August 2015, *Rosetta* should be searching for further signs of life - ice-living micro-organisms becoming active as their habitats warm up - in the furrows, cracks in ice (sea or craters) or at the feet of exposed rocks/boulders.

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