Journal of Astrobiology & Outreach

Wallis and Wickramasinghe, Astrobiol Outreach 2015, 3:1
DOI: 10.4172/2332-2519.1000127

Review Article Open Access

Rosetta Images of Comet 67P/Churyumov – Gerasimenko: Inferences from Its Terrain and Structure

Wallis MK[1]* and Wickramasinghe NC[1,2,3]

[1]Buckingham Centre for Astrobiology (BCAB), Buckingham University, UK
[2]Institute for the Study of Panspermia and Astroeconomics, Gifu, Japan
[3]University of Peradeniya, Peradeniya, Sri Lanka

Abstract

The Rosetta mission has given us remarkable images of comet 67P/C-G both from the orbiter, and recently from the Philae lander during its brief days before running out of power. Though its crust is very black, there are several indicators of an underlying icy morphology. Comet 67P displays smooth, planar 'seas' (the largest 600 m x 800 m) and flat-bottomed craters, both features seen also on comet Tempel-1. Comet 67P's surface is peppered with mega-boulders (10-70 km) like comet Hartley-2, while parallel furrowed terrain appears as a new ice feature. The largest sea ('Cheops' Sea, 600 x 800 m) curves around one lobe of the 4 km diameter comet, and the crater lakes extending to ~150 m across are re-frozen bodies of water overlain with organic-rich debris (sublimation lag) of order 10 cm. The parallel furrows relate to flexing of the asymmetric and spinning two-lobe body, which generates fractures in an underlying body of ice. The mega-boulders are hypothesised to arise from bolide impacts into ice. In the very low gravity, boulders ejected at a fraction of 1 m/s would readily reach ~100 m from the impact crater and could land perched on elevated surfaces. Where they stand proud, they indicate stronger refrozen terrain or show that the surface they land on (and crush) sublimates more quickly. Outgassing due to ice-sublimation was already evident in September at 3.3AU, with surface temperature peaks of 220-230 K, which implies impure ice mixtures with less strongly-bound H_2O. Increasing rates of sublimation as Rosetta follows comet 67P around its 1.3 AU perihelion will further reveal the nature and prevalence of near-surface ices.

Keywords: Comets; Rosetta mission; Comet 67P; Churyumov-Gerasimenko; Comet Tempel-1; cometary ice; Cometary lakes

Introduction

The old comet model of frozen elementary gases, perhaps combined with H_2O in clathrates and condensed in the early solar system, has not been tenable since the 1986 missions to comet Halley. Comets evidently have high fractions of carbonaceous and mineral solids, and are well-processed bodies, with a geology that reflects their past history and particularly their orbits within the inner solar system. They cannot be viewed as an "onion", with a layer by layer peeling off on perihelion passages when solar heating sets in; rather they suffer meteorite impacts and develop surface crusts that severely restrict gas escape. We have previously discussed evidence for carbonaceous-crust covered bulk ice in cometary images, including possible remnants of an early refrozen centre and refrozen near-surface lakes [1,2]. Like comet Tempel-1 in 2005, comet 67P/Churyumov–Gerasimenko (for short '67P') shows the latter features. The evidence and potential for icy cometary habitats harbouring primitive life is left to a companion paper [3].

The mapping of comet 67P/C-G has thus far revealed a number of distinct types of region. These have been grouped by Thomas et al. [4], into five categories: dust covered terrain, regions exhibiting brittle surface material with pits and circular structures, large-scale depressions, and smooth exposed surfaces resembling the Cheops Sea. Such features are not consistent with the Whipple dirty snowball model of a comet, but indicative of composition high in carbonaceous material with models of icy material under organic crusts that we have developed over four decades [1,5-7].

Re-frozen Seas

Similar to earlier cometary nuclei, comet 67P/Churyumov–Gerasimenko has very a low albedo of 0.06 [8]. This is indicative of a largely carbonaceous surface and regolith, a fact that is also borne out by infrared reflectance spectroscopy [3,8]. Comet 67P has a large smooth area like a 'sea' surrounded by an elevated rugged terrain, resembling local seas on Mars (Figure 1, left image). Like the Elysium sea [9], such seas are thought to be the result of water flooding from below the surface, freezing over and developing a protective regolith. We refer to comet 67P's sea as the Cheops sea, because the largest of the cluster of boulders (~45 m) in its upper part has been named Cheops. Debris shed from a cliff bordering the Cheops sea (top left of Figure 1) spreads onto the 'sea' with the Cheops boulder marking its maximum extent.

Comet Tempel-1 showed two analogous seas: Figure 2 shows the larger tadpole-shaped 'sea', a smooth flat plateau, curving away into the shadow. The plain would be covered by sublimation regolith of order 10-cm thick, with strength of a cold-welded carbonaceous crust [1,9,10]. Between its first imaging in 2005 and second in 2011, changes are identified that indicate the operation of active erosion processes. Note in particular an advance of the escarpment shown by the yellow lines and the merging of crater-features in the yellow box.

Giant Boulders

Large boulders standing proud on the surface and tens of metres in size are widely scattered over much of comet 67P [4]. This feature leads

***Corresponding author:** Wickramasinghe NC, Buckingham Centre for Astrobiology (BCAB), Buckingham University, UK, Tel: +44 (0)2920752146; E-mail: ncwick@gmail.com

Received December 15, 2014; **Accepted** February 04, 2015; **Published** February 09, 2015

Citation: Wallis MK, Wickramasinghe NC (2015) Rosetta Images of Comet 67P/Churyumov–Gerasimenko: Inferences from Its Terrain and Structure. Astrobiol Outreach 3: 127. doi:10.4172/2332-2519.1000127

Copyright: © 2015 Wallis MK, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Citation: Wallis MK, Wickramasinghe NC (2015) Rosetta Images of Comet 67P/Churyumov–Gerasimenko: Inferences from Its Terrain and Structure. Astrobiol Outreach 3: 127. doi:10.4172/2332-2519.1000127

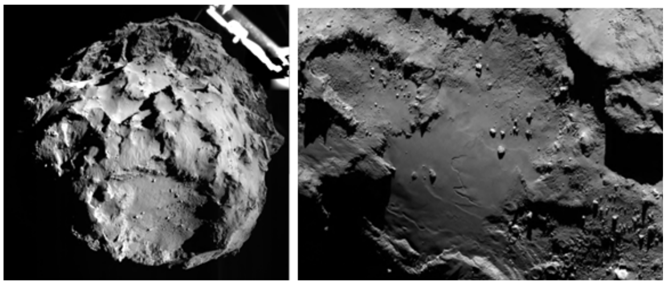

Figure 1: Large planar 600 x 800 m Cheops 'sea' on comet 67P, lower centre in the left image. Note also the near circular depression to the left of the 'sea', resembling an eroded crater (ROLIS descent image from 3 km. ESA/Rosetta/Philae/ROLIS/DLR). The image at higher resolution on the right shows the sea curving away into shadow approaching the terminator at bottom left. The plateau at the top right corner (semi-circular) is a few 100 m higher than the sea and appears to have shed debris at the cliff-foot. (ESA/Rosetta/MPS for OSIRIS Team).

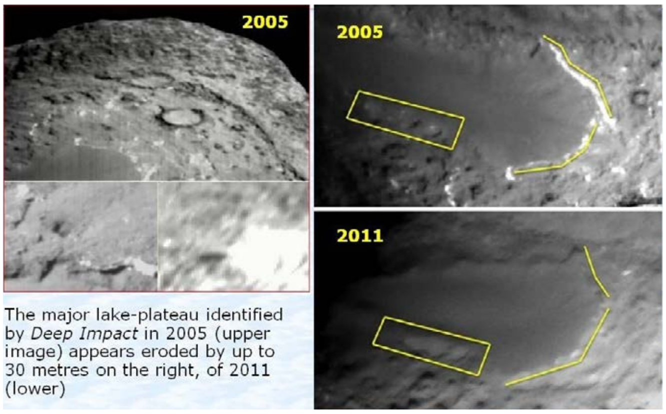

Figure 2: Images of Comet Tempel-1; upper left shows two flat-bottomed 300 m craters above the head end of the 'tadpole sea' shown on the right. The pair of images on the right shows fuller extent of the smooth sea-like area, bending around the body of the comet to the left, into the shadow. The yellow lines mark an escarpment bordering the sea on the right, the 'sea' being a raised plateau at that end. Differences between the 2005 and 2011 images are interpreted as retreat of the sea's margin (by up to 30 m) and merging of pits (in the rectangular box).

to the 'spotty' appearance of comet Hartley-2 (Figure 3), whose neck-area is devoid of boulders and craters. Figure 1 shows boulders up to 70 m in size on comet 67P near and adjacent to the Cheops sea. Most boulders on comet 67P are not associated with any eroding cliffs or craters. Nor do they show any layering, but an irregular surface judging by the resolved picture of the one 5-m boulder (Figure 4).

We suggest these boulders originated as ejecta from large meteorites impacting a compact frozen terrain. In the very low gravity, boulders ejected at a fraction of the escape speed of 1 m/s readily reach ~100 m from the impact crater and could land perched high on elevated surfaces, provided the surface material is sufficiently crushable (like aged snow) to absorb energy. The fact that they stand proud on slopes indicates strong underlying terrain such as compact ice, or that the surface they land on (and crush) sublimates away. Dirty ice-boulders (laden with organics) develop dark protective sublimation crusts so have a long lifetime on comet 69P's distant orbit. Some brighter boulders (Figure 1, right) and brighter pixels on them at higher resolution (Comet on 11 Nov, Rosetta NavCam 3 image, CC BY-SA IGO 3.0) suggest an optically-active crystalline component in the surface material; the boulders may be sublimating slowly while sublimation of the open 'sea' is currently suppressed. This is interpreted as aged crust overlain with centimetre-sized dust (Figure 4).

Flat-bottomed Craters

The prototype pictures for comparison are the two flat-bottomed craters near Deep Impact's impact position on Comet Tempel-1, pictured on the upper left part of Figure 2. A similar pair of examples is seen at the upper left of Figure 5, some130-150 m across. These craters lack ramparts, from impact material displaced laterally, which may not be universal but dependent on the nature of the impacted material. Other possible larger crater-examples on the upper lobe of Figure 5 are unclear, due to probable debris from degraded crater ramparts. Several smaller (30-40 km) such craters are visible in comet 67P in the 18th October image of the top right corner of the Cheops sea [3]. Of the cluster of 6 craters, 5 have rampart walls, resembling a well, while the sixth is a pedestal crater with practically no ramparts, like those in Figure 4.

The craters are thought to be generated by large meteorite or small comet impacts, but clearly different from similar impacts on the Moon and rocky asteroids. On icy terrain, bolide impacts eject some material

Figure 3: Comet Hartley-2 *NASA News Release 4 Nov.2010: size* ~2 km long with 0.4 km wide 'neck'. *The* 'spotty' appearance is due to 20-50 m-sized hillocks or boulders and their shadows. Note the 400 m long ravine (left end).

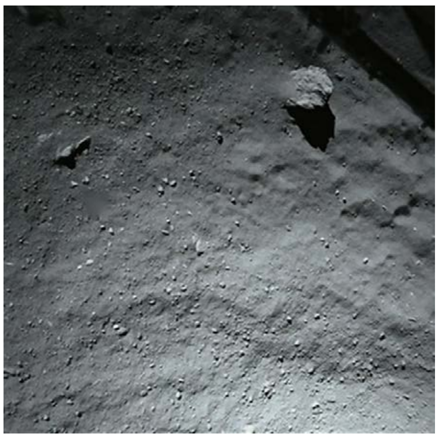

Figure 4: Comet from 40 metres, taken by Philae's down-looking descent ROLIS imager when it was about 40 m above the surface of comet 67P/Churyumov-Gerasimenko (credit ESA/Rosetta/Philae/ROLIS/DLR). The large block in the top right corner is 5 m in size.

as solid particles and gases, leaving behind transient lakes that quickly freeze over. As the H_2O-ice covering the lake thickens, with evaporative loss of H_2O from its surface, a sublimation lag accumulates to form a surface-insulating crust [11]. Sierls et al. [12], find outflow of gas from the base of an active pit (Figure 6), which would be a relatively fresh crater, still developing its crust. The formation of crust explains the low albedo and the dominance of complex organics observed in the comet 67P/C-G [8].

Parallel Furrowed Terrain

Figure 7 shows striking terrain to the right of a largely smooth area, with rocky terrain on both sides. The dark furrows are aligned rather close (20°) to the solar direction and appear metres-deep, so may penetrate the protective crust well into underlying ice. Their position on the 'neck' suggests that the system of cracks and furrows above them are generated by flexing of the two lobes as the comet rotates. Sierls et al. draw attention to an isolated crack in a nearby debris-strewn region which may overlie a further furrow. The aligned furrows are reminiscent of cracks on Europa, generated by tidal flexing of that icy satellite, driving ice cracking, creep and convection. Though comet 67P lacks Europa's internal ocean [13,14], its furrows would still be sites for active outgassing and jet emissions as seen is the OSIRIS image of 10 Sept. 2014 [3]. Their higher sublimation rates make them advantageous habitats for ice-living microbes, including algae, cyanobacteria and many other gram-positive bacteria that have lipoteichoic acid in their cell walls to induce localized melting of the water-ice whenever the temperature exceeds 230 K [15].

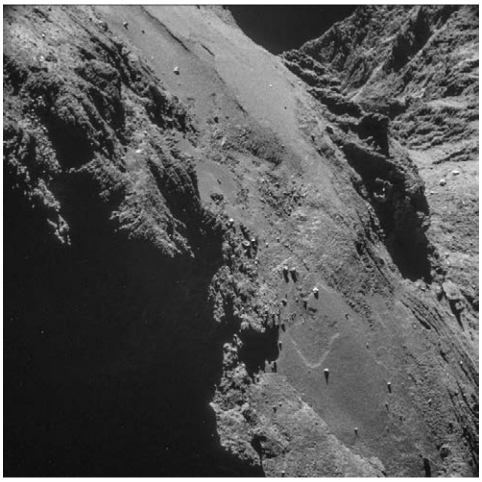

Figure 7: Terrain close to the 'neck' between the two comet lobes (see Figure 5); the smaller lobe rises in the background. The parallel furrows with 5-10 m spacing give the appearance of flexing or compression. (NAVCAM top 10 at 10 km, no. 9 ESA/Rosetta/NAVCAM – CC BY-SA IGO 3.0; full image size 857 m square).

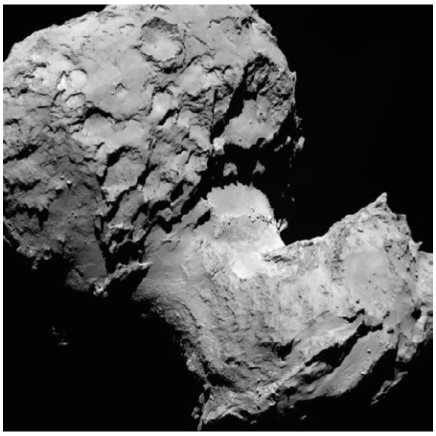

Figure 5: Cratered appearance of the larger lobe (OSIRIS image on 16 August, illumination from top; ~3 km square). Note the pair of smaller circular craters to the upper left, flat hollows in low adjacent terrain. This image was used for identifying candidate landing sites, the reserve site C being the featureless area to the right of this crater-pair. (Credits: ESA/Rosetta/MPS for OSIRIS Team).

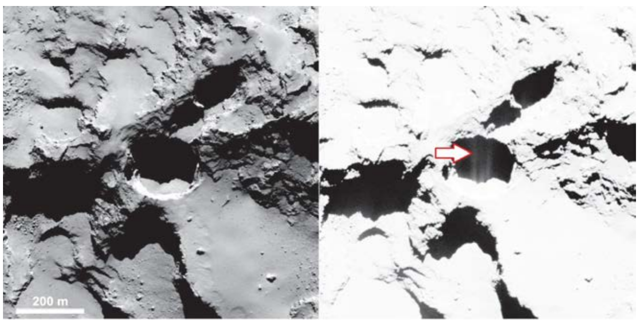

Figure 6: An active pit, described by Sierks et al. [4]. NAC image acquired on 28 August 2014. Enhanced contrast (right panel) reveals filaments interpreted as jets in the shadow of the pit.

Conclusion

We have previously discussed indications of near-surface icy morphology of comets, such as 67P's Cheops sea in Figure 1, a plain curving around the body of the comet, and flat-bottomed craters as in Figure 2, [1,2]. Comet 67P's furrowed terrain (Figure 5) is close to another smooth plain, 200 m-scale with scattered, proud-standing boulders. An icy plain would develop a protective sublimation regolith of order 10-cm thick, with strength of a cold-welded carbonaceous crust [11]. The boulders up to 70 m in size, seen also on Comet Hartley-2 (Figure 3), are not associated with eroding cliffs or craters, but may be ejecta generated by large meteorites impacting compact frozen terrain. In the very low gravity on a comet, boulders ejected at a fraction of 1 m/s would readily reach ~100 m from an impact crater, and could easily land perched on elevated surfaces as seen in these images [4]. Most of the terrain would be too weak to allow boulders to roll further, giving little accumulation in valleys. Those that stand proud indicate stronger refrozen terrain or show that the surface they land on (and crush) sublimates more quickly. Dirty ice-boulders develop dark protective sublimation crusts and so have a long lifetime on 67P's distant orbit. Brighter pixels atop some boulders (mid Figure 2) suggest an optically-active crystalline component in the surface material, so the boulders may be sublimating slowly while older regolith suppresses sublimation of the open plain.

Quiescent outgassing such as seen from Comet 67P in July 2014 at 3.9AU from the Sun is evidence of near-surface ice under a crust that has been weathered by micrometeorite impacts during the comet's transits around aphelion. More distant episodes of H_2O outgassing from comets, like comet 67P/C-G in Nov 2007 when it was at a heliocentric distance of 4.3AU, may be due to larger bolide impacts; but the low probability of such an event and the observed tendency for repetitive outbursts (e.g. of Hale-Bopp at 6.5AU) point strongly to another cause [3]. Chemoautotrophic microorganisms released into the transient lakes laden with organics would rapidly metabolise and replicate, releasing heat that might increase the initial melt volume by a factor of 10 to 30. Methane or carbon dioxide produced by bacteria as metabolic products can then build up to be eventually released through fissures in the overlying ices or at the lake edges, in the furrows, cracks in ice (sea or craters), bottoms of crater pits, or at the feet of exposed rocks/boulders. In our companion paper [3], we argue that most of the features described in this communication and others described by Thomas et al. [4] have a ready explanation on the basis of recurrent biological activity close to the exposed surface of the comet.

References

1. Wallis MK, Wickramasinghe NC (2007) Mars Polar Cap - a Habitat for Elementary Life . Geophys Res Abstr 9: 10256.
2. Wallis MK, Wickramasinghe NC (2011) Icy Morphologies of Comet Tempel-1 imply past lake-habitats for Life. ISSOL 7-21.
3. Wickramasinghe NC (2015) Rosetta images of Comet 67P/Churyumov–Gerasimenko 2. Prospects for establishing cometary biology (JAO in press).
4. Thomas N, Sierks H, Babieri C, Hasig M, Altwegg K, et al. (2015) Time Variability and Heterogeneity in the Coma of 67P/Churyumov-Gerasimenko. Science 345: aaa 0440-1.
5. Vanýsek V, Wickramasinghe NC (1975) Formaldehyde polymers in comets. Astrophys. Space Sci. 33: L19-L28.
6. Hoyle F, Wickramasinghe NC (1981) In: C. Ponnamperuma (ed.) Comets and the Origin of Life. Dordrecht: D. Reidel.
7. Hoyle F, Wickramasinghe NC (1985) Living Comets. Cardiff: Univ. College, Cardiff Press.
8. Capaccioni F, Coradini A, Filacchione G (2015) Science, 347: aaa0628-1.
9. Murray JB and the HRSC Co-Investigator Team (2005) Nature 434: 352-356.
10. Wallis M, Wickramasinghe NC, Wickramasinghe JT (2009) Liquid Water in Comets and Implications for Exobiology, Water Workshop, Durham.
11. Wickramasinghe JT, Wickramasinghe NC, Wallis MK (2009) Int J Astrobiol 8: 281-290.
12. Sierks H, Barbieri C, Lamy PL, Rodrigo R, Koschny D, et al. (2015) On the nucleus structure and activity of comet 67P/churyumov-Gerasimenko . Science 347: aaa1044-1.
13. Kargel JS, Kaye JZ, Head J (2000) Europa's Crust and Ocean: Origin, Composition, and the Prospects for Life. Icarus 148: 226-265.
14. Greenberg R (2008) Unmasking Europa: The Search for Life on Jupiter's Ocean Moon, Praxis Publishing Ltd, Springer.
15. Hoover RB, Pikuta EV (2010) Psychrophilic and Psychrotolerant Microbial Extremophiles in Polar Environments. In Polar Microbiology: The Ecology, Diversity and Bioremediation Potential of Microorganisms in Extremely Cold Environments (Asim K. Bej, Ronald Atlas and Jackie Aislabie, Eds.) CRC Press, Taylor and Francis Group, New York.