PINNACLES ON THE NUCLEUS OF COMET 67P/CHURYUMOV–GERASIMENKO.

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Introduction: Pinnacles are local promontories of different shapes. This term is defined as a positive spire-like structure (e.g. [1]). For comets it was first used in the description of the nucleus of comet Wild 2 by [2]. Our presentation is mostly based on findings of [3, 4] and some additional new considerations. For identification, mapping and analysis of pinnacles on the 67P nucleus we used the NavCam [5] and OSIRIS NAC [6] images (http://imagearchives.esac.esa.int/), and the nucleus shape model SHAP7 [7]. The highest resolution of the NavCam images is ~2m/px, of the OSIRIS NAC ~0.04 m/px, and the SHAP7 model has a horizontal resolution of 1–1.5m and a total vertical accuracy of 0.3m. Using these images and the shape model, we identified 166 pinnacles starting from ~20 m in diameter and ~10 m in height (Figure 1).

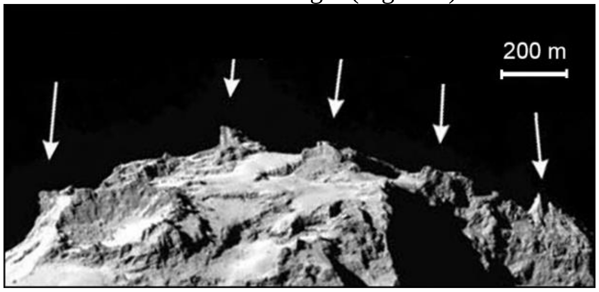

Figure.1. Examples of pinnacles (arrows) in the Seth region. OSIRIS N20150320T021247587ID30F22.

For each pinnacle two planimetric directions (the smaller d and the larger D diameters), the height (h), measured as perpendicular to the base line, the tilt angle Φ, measured as differences between line h and the local gravity vertical and the slope angles (α and β) were recorded as shown in Figure 2.

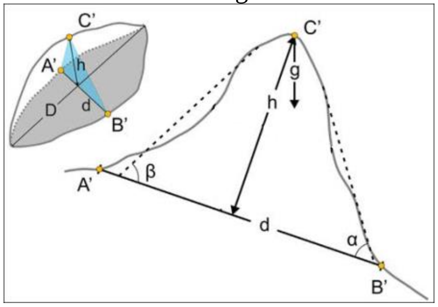

Figure.2. Sketches showing the measured parameters, from [4] with changes.

Pinnacles identification and mapping results: For each of 166 pinnacles an ascending number is assigned in the regions listed in alphabetical order (see Figure 3). Pinnacles were divided into two subclasses: (1) those having planimetrically equidimensional shapes – \- ‘rounded pinnacles’ ($d/D > 0.7$) and (2) those having planimetrically elongated shape - ‘local ridges’ ($d/D < 0.7$). 54 rounded pinnacles and 112 local ridges were identified.

Parameters of these subclasses are as following:

Planimetric dimensions: For rounded pinnacles the range R of small diameters d is 29-269 m, mean value is 80 m, and standard deviation σ is 51 m while R of large diameters D is 33-349 m, mean value is 95 m, and σ is 61 m. For local ridges, R of small diameters d is 22-378 m, mean value is 70 m, and σ is 50 m while R of large diameters D is 43-736 m, mean value is 237 m, σ is 151 m. In summary, the pinnacle planimetric dimensions vary within tens and a few hundreds of meters and elongated pinnacles are twice more frequent than planimetrically equidimensional ones.

Heights: Rounded pinnacles have heights from 10 to 93 m, their mean value is 33 m and σ is 21 m. The local ridges have heights from 9 to 137 m with a mean value of 35 m and σ of 23 m. In summary, the largest pinnacle heights h are ~100 m.

Inclinations to local gravity: The mean value of this parameter for rounded pinnacles is 59° and for local ridges it is 54°.

The slope angles α and β: Their mean values vary from 41 to 73° and from 49 to 74° for local ridges.

The height to small diameter ratio: The mean value of this parameter for rounded pinnacles is 0.43 and σ is 0.16 and for local ridges the mean value is 0.56 and σ is 0.31.

North-south distribution: In the southern hemisphere, the numbers of both round pinnacles (38) and local ridges (62) are larger than in the northern hemisphere (16 and 50, correspondingly).

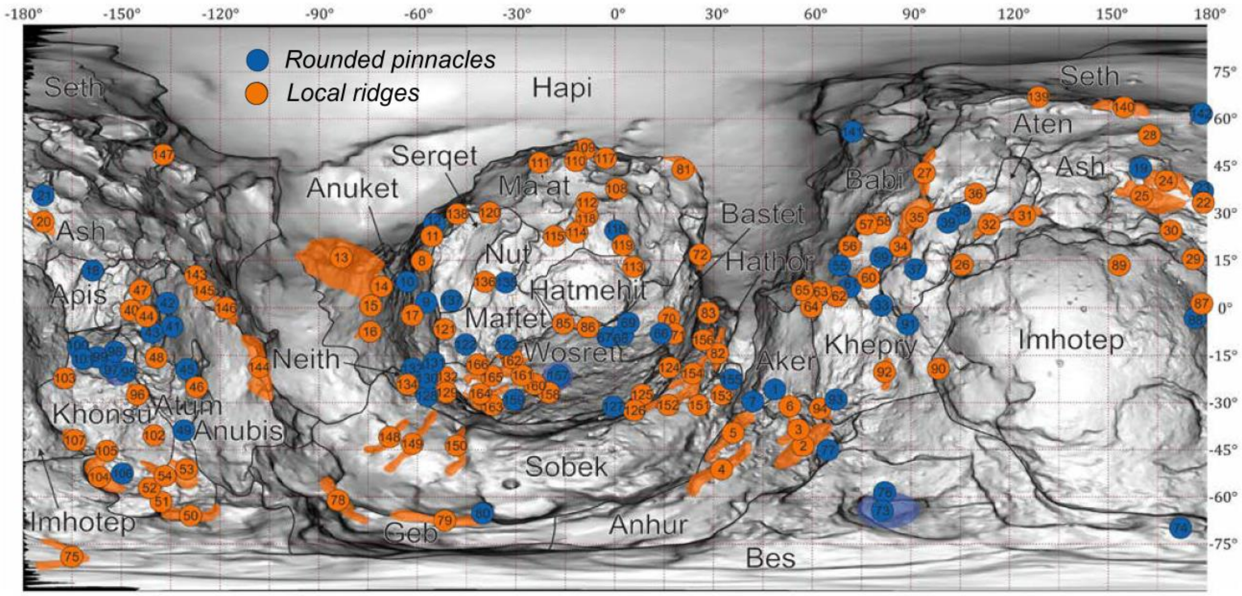

Figure 2. Map of rounded pinnacles (blue) and local ridges (orange) in equidistant cylindrical projection. For each pinnacle the assigned number is given, from [4] with changes.

Discussion and conclusions: Pinnacles on the comet nuclei are considered to result from the sublimational erosion of the nuclei material [2,3,4,10]. Parts of the nucleus composed of the material more resistant to erosion than the material surrounding them, form pinnacles. Pinnacles are not the only manifestations of the different erosion-resistivity of the nucleus consolidated material. Areas not covered by the loose "air-fall" deposits (including surfaces of the pinnacle slopes) often show the knobby surface texture which is also considered as a result of similar phenomenon [e.g.,11-13].

If so, the above considered pinnacle parameters allow one to draw conclusions concerning several issues about the formation of comet nucleus material and its subsequent evolution. The planimetric sizes of pinnacles that we determined, which vary within tens to hundreds of meters, is probably a measure of the sizes of the more erosion resistant parts of the comet.

The observations that the height to diameter ratios of the 67P pinnacles cluster around ~0.5 and that the slope angles vary from ~40 to 75^o suggest that the degree of resistance to sublimational erosion of the pinnacle material (and thus its composition) differs only slightly from that of the surrounding material. If the difference would be large, the relative pinnacle heights and the slope angles should be larger.

The maximum heights of pinnacles are considered to be a measure of minimum thickness of the eroded layer. In the case of comet 67P this is ~100 m. Following [8] that the mean thickness of the 67P comet surface material lost to space per orbit is ~2 m, then to loose ~100 m of the surface material takes ~50 orbits.

The observation that in the south numbers of both round pinnacles and local ridges are larger than in the north could indicate the higher effectiveness of the pinnacle formation process in the south: Orbital parameters of comet 67P are such that summer in the south is shorter but hotter than that in the north, so annual sublimation in the south is currently significantly higher [8, 9]. But the mean values of most the of parameters considered show no statistically reliable difference between the north and south. Therefore, we suggest that the larger number of pinnacles in the south compared to north may be due to a different reason. Possibly in the south the abundance of pinnacle-causing inhomogeneities in the near-surface part of the nucleus material is larger than in the north. The fall back material covering large parts of the northern hemisphere [8,9] may have some influence.

References: 1] Lipar M. and Webb J.A. (2015) *Earth-Science Reviews, 140*, 182-202. [2] Brownlee D. E. et al. (2004) *Science, 304, 5678,* 1764-1769. [3] Basilevsky A. T. et al. (2017) *PSS, 140*, 80-85. [4] Krasilnikov S. S. et al. (2020) *MNRAS, 491*, 2664-2673. [5] Geiger G. and Barthelemy M. (2015) *ESA PSA, NASA PDS*. [6] Keller H. U. et al. (2007) *Space Science Reviews, 128, 1–4,* 433–506. [7] Preusker F. (2017) *Astronomy & Astrophysics, 607,* Article L1. Pages 5. [8] Keller et al. (2015) *Astronomy & Astrophyisics, 583,* A34. [9] Keller H. U. (2017) *MNRAS, 469*, 357–371. [10] El-Maarry M. R. (2019) *Space Sci. Rev. 215, 36,* 1-33. [11] Sierks H. et al (2015) *Science, 347,* aaa1044-1-5. [12] Davidson B. (2016) *A&A*, A63. [13] Basilevsky A.T. et al (2017). PSS, 137, 1-19.