Constraints on cometary surface evolution derived from a statistical analysis of 67P’s topography


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Interested in surface changes?

We have developed the capability to map 67P at the highest resolution and automatically detect 1-10 m surface changes.

> 1000 features already found on < 2% of the surface!

See P142 after this session.
Small bodies surface evolution

Surface evolution

Asteroids

4.5GY

NOW
Small bodies surface evolution

- Asteroids
- Comets

- Time scale: 4.5 GY to 10k yrs to NOW
Small bodies surface evolution

Comet orbits are difficult to reconstruct accurately beyond their last encounter with Jupiter.

How to define the age of the surface?

Improving orbital simulations requires an additional set of constraints, like topography or composition.

No obvious craters, but surface covered with large scale topographic features, such as pits and cliffs. These structures are intimately linked to the activity: they focus gas and dust jets and their collapse may explain outbursts. (Vincent 2015a, 2016a, 2016b; Gruen 2016, Pajola 2017).

How do they evolve?
Gravity calculated for a constant density of 535 kg.m\(^{-3}\), using Werner & Scheeres 1996 model. “Cliffs” are defined as sets of connected facets with an effective gravitational slope above the angle of repose.

The algorithm detects 2633 cliffs, with a height between 13m and 621m.
Global cumulative size distribution

99.3% of the cliffs have a height < 300m, and their distribution can be represented by a power law

The remaining features (0.7% = 18 cliffs) are located mostly in Hathor (not discussed here, see Vincent et al MNRAS 2017)
Size distribution per latitude

- Northern cliffs most likely to be found at high latitudes (Seth/Hathor)
- Southern cliffs mostly at mid-latitudes (also preferred location for outbursts)

- Northern cliffs extend laterally for >100m
- Southern cliffs extend laterally for a few 10 m

Northern cliffs tend to more extensive than southern ones, and cover a larger area

} measure of macro-roughness
The well known North/South dichotomy presented in many papers is also visible in this data set.

- Power law 15% steeper in the South => more small cliffs, fewer large ones
We separated the surface in 6 regions of increasing orbital erosion rate, Keller et al (2015). Erosion rate is model dependent and a lower limit for the actual erosion. Well calibrated against multi instrument observations.

We find a perfect correlation between p-index and erosion.

The most eroded regions are also the ones with the smallest cliffs. If the two processes are related, it means that erosion is crumbling the existing topography, rather than carving out large features.

=> By extrapolation: low p-index is characteristic of a primitive topography.
- **Primitive comets (81P, 67P)** are characterized by the presence of large pits and cliffs, which likely result from early impacts and outbursts shortly after formation.

- **Evolved comets show very little topography (9P, 103P)**, with most features being erased by activity + gravitational collapse.
Summary and outlook

- On comet 67P, **cliffs size distribution follow a power law** with an average cumulative power index = $-1.69 \pm 0.02$.

- This power varies from region to region, and correlates well with the orbital erosion rate of the surface => **The more eroded the area, the steeper the power law**.

- This observation can be generalized to other comets. **The size distribution of large vertical features provides a direct measure of a comet’s erosional history**, like crater counts are used to date rocky surfaces.

The cumulative power index of the topography size distribution measures how primitive a comet nucleus is.

- Primitive comet: $p = -1.5^*$
- Evolved comet: $p = -2.3^*$

Model published in *Vincent et al, MNRAS 2017*

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