EPSC Abstracts
Vol. 13, EPSC-DPS2019-73-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Morphological and color changes on comet 67P/CG from high-resolution OSIRIS images

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1. Introduction

The Anhur region is located in the southern hemisphere of the 67P/Churyumov-Gerasimenko comet. Anhur is dominated by outcropping consolidated terrains that are sculpted by staircase terraces, which are interpreted as the surface expression of extended discontinuities that separate superimposed layers of consolidated material (1,2). The region also shows various types of deposits and a peculiar canyon-like structure (2,3).
Anhur shows local compositional heterogeneity on a scale of tenths of meters, and several exposure of water ice, as well as the first and unique detection of CO_2 ice (4,5). The observations of different ices clearly point to a more pristine area where different volatiles are exposed. Anhur is also a highly active region that is the source of several jets and, in particular, of the perihelion outburst, one of the brightest activity events reported for the 67P nucleus by Rosetta.
This work focuses on the morphological and color changes observed in the Anhur region during the extended Rosetta mission in 2016 at sub-meter spatial resolution with the OSIRIS cameras.

1.1. Morphological changes

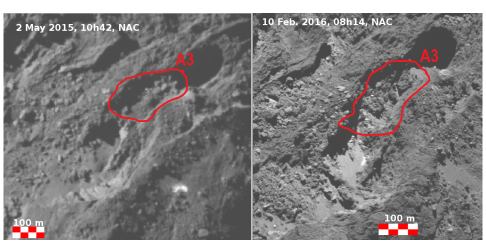

Figure 1: Images from May 2015 and February 2016, showing the removal of a dust bank inside the canyon-like structure of Anhur.

The Anhur region only became observable by OSIRIS in March 2015, at a heliocentric distance of 2 au inbound. We examined more than 100 images from March 2015 until 8 September 2016, with spatial scales ranging from 1.7 m/pixel to $\sim$ 0.1m/px.
The most important changes took place in and nearby the Anhur canyon-like structure, where a significant dust cover of 45 m long and $\sim 14 \pm 2$ meters high was removed (Fig 1), an entire structure vanished, and many boulders were re-arranged. All such changes are potentially associated with one of the most intense outbursts observed by Rosetta, which occurred one day before the perihelion passage. In addition, we also observe in the Anhur region the formation of scarps and cliff retreats, the shift and the disappearance of boulders.
A new scarp (Fig. 2), of about 10$\pm$2 m in height and with an estimated surface > 320 m^2 formed in January 2016. Images at high resolution acquired between June and September 2016 indicate the ongoing crumbling of one edge of this scarp, which retreated by at least 5 m in two months.

The estimated localized mass loss related to all the changes observed in Ahnur is higher than 50 million kg, that is $>$0.5% of the mass loss by the comet (6). It should be noted, however, that we cannot estimate the mass lost for several observed changes because we are limited by the fact that Anhur, as most of the southern hemisphere regions, was not observed at high spatial resolution before perihelion passage.

1.2 Exposures of water ice

At the base of the new scarp indicated in Fig. 2 we observe exposure of fresh water ice, located underneath the dust surface coating. Using a linear mixing model of the comet dark terrain and water ice, we estimate a water ice abundance of 26-30% in June 2016, and of 11% in January 2016, just after the scarp formation. This points to a progressive enrichment in the exposed

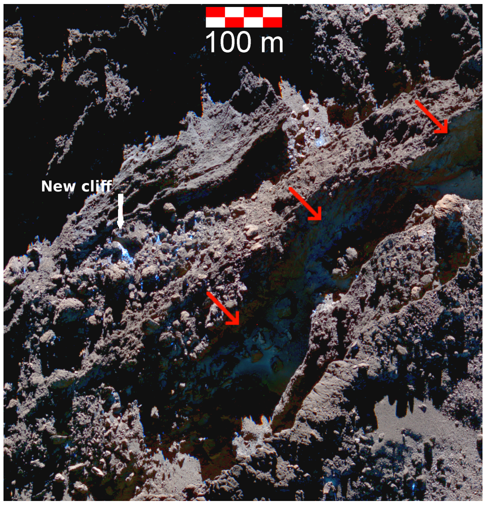

Figure 2: RGB composite of the Anhur region from observations acquired on 25 June 2016 at 11h50. The new scarp and cliff is indicated. The red arrows indicate the frost inside the canyon-like structure.

water ice in this area from January to June 2016 and to the persistence of volatiles for at least six months. Moreover, several tiny bright spots of ~ 1 m^2 size enriched in water ice were observed across the region, as well as frost inside shadowed areas, especially within the canyon-like structure. This confirms that Anhur is relatively rich in volatiles compared to other nucleus regions. Globally, we see on the comet an asymmetry in the presence of frost, which is observed mainly post-perihelion. This may be related to thermal time lag for the turnoff of subsurface volatile sublimation created by the propagation of the thermal wave that is driven by the comet's perihelion passage. This also indicates that the infalling dust from the coma after perihelion passage, when the cometary activity progressive decreases, still preserve some water ice.

2 Conclusions

The observed destruction and fragmentation of boulders and development of new cliffs or scarps in the region Anhur suggests that here the cometary surface is weak and very friable. We observed clear evidence of removal of dust mantle in some localized areas of Anhur, especially within the canyon structure, which experienced several changes that were probably driven by the intense perihelion outburst.
The observations of new small-scale exposures of water ice in Anhur near shadowed regions or at the base of new scarps indicate that water ice is very close to the cometary surface, as noticed also on other regions of the nucleus. Shadowed areas such as the canyon-like structure act as cold traps and host frost when the comet reaches colder regions of the solar system (beyond 3 au).

Acknowledgements

OSIRIS was built by a consortium led by the Max-Planck-Institut für Sonnensystemforschung, Goettingen, Germany, in collaboration with CISAS, University of Padova, Italy, the Laboratoire d'Astrophysique de Marseille, France, the Instituto de Astrofísica de Andalucia, CSIC, Granada, Spain, the Scientific Support Office of the European Space Agency, Noordwijk, The Netherlands, the Instituto Nacional de Técnica Aeroespacial, Madrid, Spain, the Universidad Politéchnica de Madrid, Spain, the Department of Physics and Astronomy of Uppsala University, Sweden, and the Institut für Datentechnik und Kommunikationsnetze der Technischen Universitat Braunschweig, Germany. The support of the national funding agencies of Germany (DLR), France (CNES), Italy (ASI), Spain (MEC), Sweden (SNSB), and the ESA Technical Directorate is gratefully acknowledged. The authors acknowledge the financial support from the France Agence Nationale de la Recherche (programme Classy, ANR-17-CE31-0004)

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