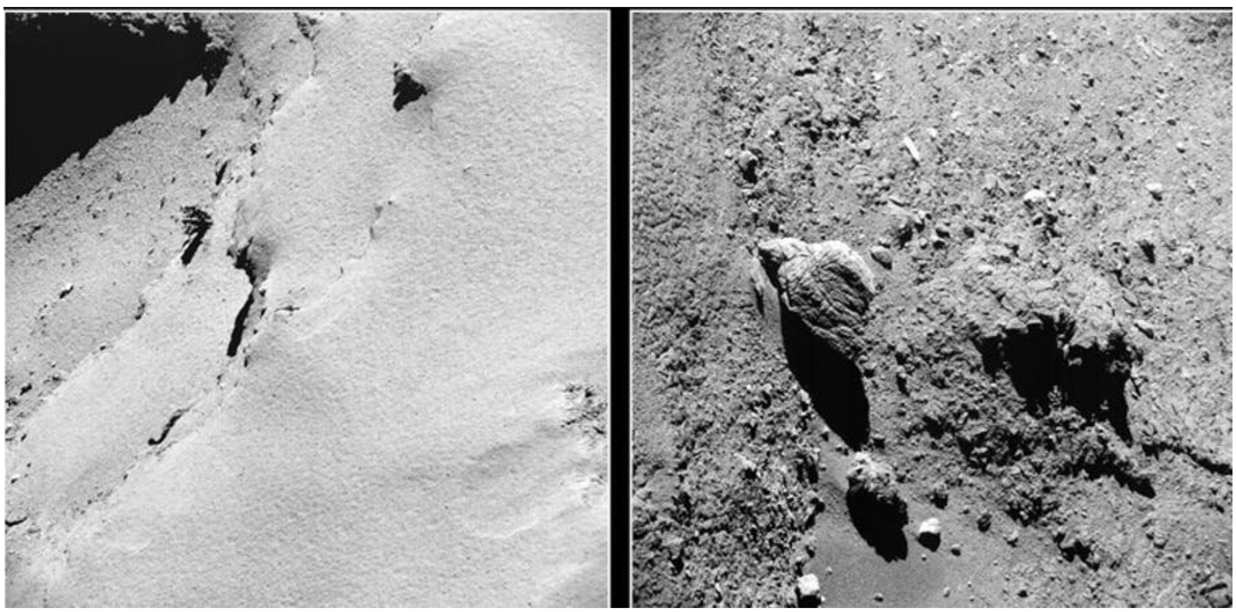
How comet dust reveals the history of the solar system

January 23 2018, by Donia Baklouti, Anaïs Bardyn And Hervé Cottin



The comet 67P/Churyumov-Gerasimenko, seen up close. Credit: ESA/Rosetta/NavCam, CC BY-SA

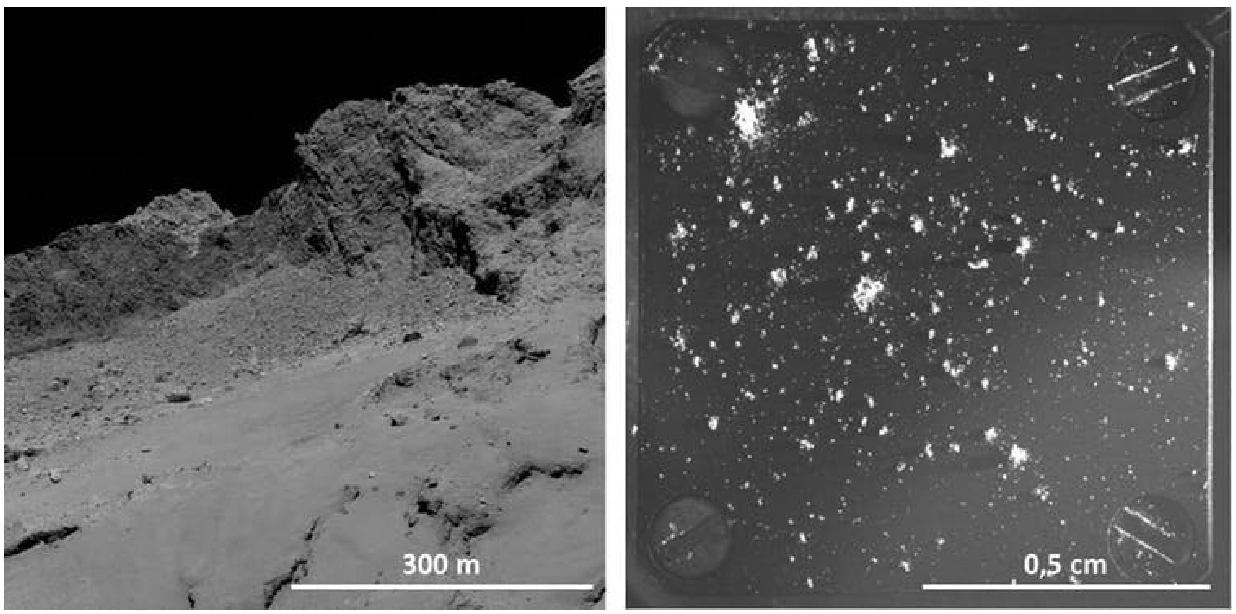
We are not used to considering dust as a valuable material – unless it comes from space. And more precisely, from the comet 67P/Churyumov-Gerasimenko. An analysis of its dust has provided valuable information about this celestial object, and, more generally, on the history of the solar system.

Using the COSIMA instrument aboard the European space probe Rosetta, a scientific team scrutinised the comet 67P/Churyumov-Gerasimenko (67P) in great detail from August 2014 to September 2016. They were interested in the dust particles ejected from the comet's nucleus and captured by the spacecraft, and COSIMA made it possible to study their composition. The results of their research were published in December 2017 by the Royal Astronomical Society.

The study indicates that, on average, half of the mass of each dust particle consists of carbonaceous material with a mainly macromolecular organic structure; the other half being mostly composed of non-hydrated silicate minerals. How is this result important or interesting? What does it imply? Was it expected by scientists or is it a total break pre-existing theories?

Thanks to Rosetta and its instruments, we have been able to get a better idea of what 67P is composed. This is particularly true for the gases in its atmosphere, thanks to the ROSINA instrument. During the comet's journey around the sun, it continuously releases gases and dust that form a faint halo. This phenomenon is explained by the sublimation of ices that are embedded within the nucleus of the comet – they directly change from the solid to the gaseous state. As the gas escapes into the comet's atmosphere, it bring with it small dust particles. ROSINA has characterised and quantified the gases: it's made of water vapour, carbon dioxide, carbon monoxide, molecular oxygen and a multitude of small organic molecules mainly made of carbon, hydrogen, nitrogen and oxygen atoms.

Other instruments, such as on-board cameras and the VIRTIS imaging spectrometer, studied the surface of 67P. Its structures are complex: cliffs, faults, landslides, pits and more. But above all, the comet surface is very dark and has little ice. The fact that it is so dark is possibly due to a high organic carbon content. Given that the ices and gases represent only a small fraction of the total cometary matter, the researchers rely on, among other things, the analysis of the dust grains released by the comet to learn more about the makeup of the comet's nucleus. This dust is representative of the comet's non-volatile composition, and the study of the dust's chemical characteristics will reflect those of the comet's nucleus.



On the left, the surface of the cometary nucleus seen by the Rosetta probe. Condensed ice beneath the surface sublimes from the depths of the comet when it is warmed up as the comet approaches the Sun. The escaping gas entrains small dust particles that can be collected and analysed by the instruments of the Rosetta probe. On the right, a collecting target (1 cm x 1 cm) of the COSIMA instrument showing tiny fragments of the nucleus, up to a millimetre in size, that have impacted it. All these dust particles consist of an intimate mixture of 50/50 (by mass) of silicate minerals and organic material. Credit: Left, ESA/Rosetta/MPS for OSIRIS Team; right, ESA/Rosetta/MPS for COSIMA Team., CC BY

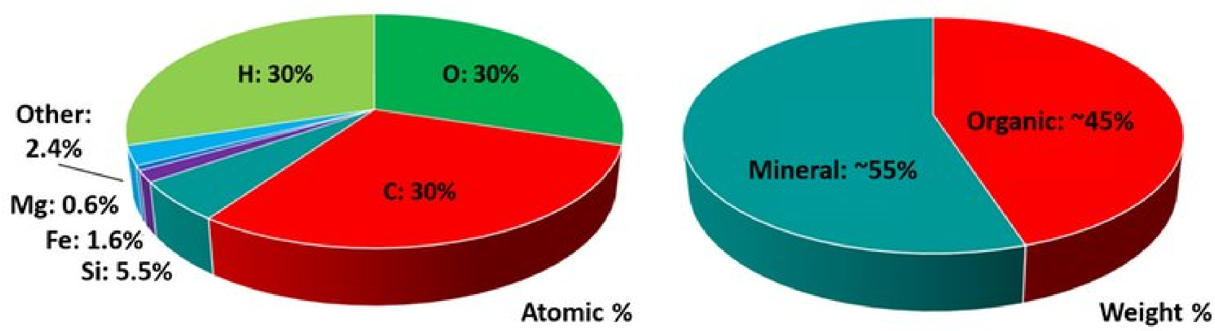
35,000 particles collected

The COSIMA instrument is a kind of physico-chemical mini-laboratory, whose function was to collect dust particles released by the comet 67P, image them and then measure their chemical characteristics using a surface analysis method called "time-of-flight secondary ion mass spectrometry" (TOF-SIMS). During the two years spent orbiting the comet, data collection was more successful than dared hoped for by the researchers and engineers who designed the instrument about 20 years ago. Indeed, COSIMA has collected more than 35,000 particles that are up to 1 millimetre in diameter. We had expected many fewer and infinitely smaller dust grains.

The analysis and scientific interpretation of the mass spectrometric measurements made on a fraction of the particles collected (about 250) was long and challenging. The ultra-porosity of the dust, collected almost intact after ejection from the comet's surface, has few analogues in our laboratories and the mastery of the TOF-SIMS technique, already complicated in the laboratory, had proved to be almost heroic when conducted remotely in space.

From these measurements, it was possible to deduce the dust particles' main constituent elements (oxygen, carbon, silicon, iron, magnesium, sodium, nitrogen, aluminium, calcium…), as well as some information on the chemical nature of some components. From these data, the team showed that each dust particle (size ranging from ~0.05 to 1 mm in diameter) contained, on average, about 50% by mass of organic carbonaceous material. This material was mainly macromolecular, meaning that it was made of large structures put together in a totally disordered and complex fashion; the other half of the mass is mainly composed of non-hydrated silicates minerals.

According to the measurements, this dust composition is independent of the particle collection date. In other words, on average, there is no difference in composition between the dust ejected by the comet before, during or after its perihelion, which is when, in August 2015, 67P made its closest approach to the sun and where its activity was the most intense. The composition of cometary dust is also not dependent on their size or morphology – "fluffy aggregates" or more "compact grains." The analysed particles are small fragments of the nucleus, coming from its surface as well as pits that sink into the depths of the comet. Therefore, the average composition determined by COSIMA most likely reflects the overall volatile-free composition of 67P's nucleus. Most of the cometary matter is thus formed by this intimate mixture of 50-50 by weight of minerals and solid carbonaceous material.



Left: the average elemental composition of the dust particles of comet 67P. Right: the average mass distribution of minerals and organic material in the dust. Credit: ESA/Rosetta/MPS for COSIMA Team

A primitive material

These results, as well as those obtained 30 years ago during the flyby of comet Halley by the Giotto and Vega probes, prove that comets are among the most carbon-rich solar system objects. Experts suspected this, but this is finally a direct experimental proof. The high value of the abundance ratio between carbon and silicon measured by COSIMA is very close to the abundance ratio of these elements measured in the sun's photosphere. Moreover, the silicates contained in 67P dust do not show any notable signs of alteration by liquid water. These two observations are an important proof of the primitive character of this cometary substance. It means that this material has hardly been modified since the comet's formation, unlike most other objects in the solar system. Studying it takes us back to the very beginning of the solar system, nearly 4.5 billion years ago.

The COSIMA measurements, combined with the observations of the other Rosetta instruments, indicate that most of the cometary carbonaceous material is not found in ices and gases, but in dust, in this non-volatile macromolecular form. This result is in line with laboratory analyses of other extra-terrestrial materials that have been collected on Earth – meteorites, micrometeorites and interplanetary dust particles. With these, however, the original object from which these materials originated is rarely known. And above all, heating during the atmospheric entry alters and modifies, at least in part, their carbonaceous components.

COSIMA's in situ measurements and its collection of dust at low speeds (a few metres per second, the pace of someone jogging) have made it possible to totally preserve the chemical information. Thus, it is possible to say today that if comets like 67P played a role in the appearance of life on Earth, especially by bringing carbon-rich material, it would have been this complex macromolecular component that dominated what was delivered.

This article was originally published on The Conversation. Read the original article.

Provided by The Conversation

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