Some carbonate deposits on Ceres and other ocean worlds might be clathrites

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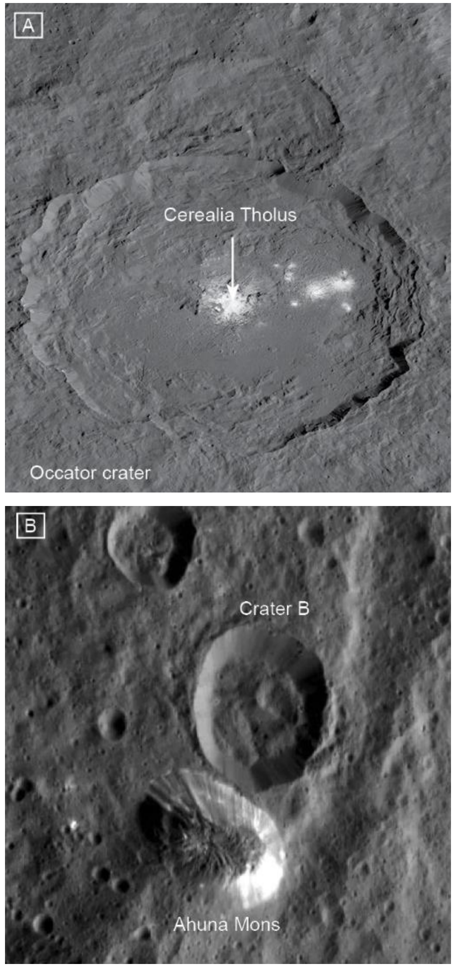

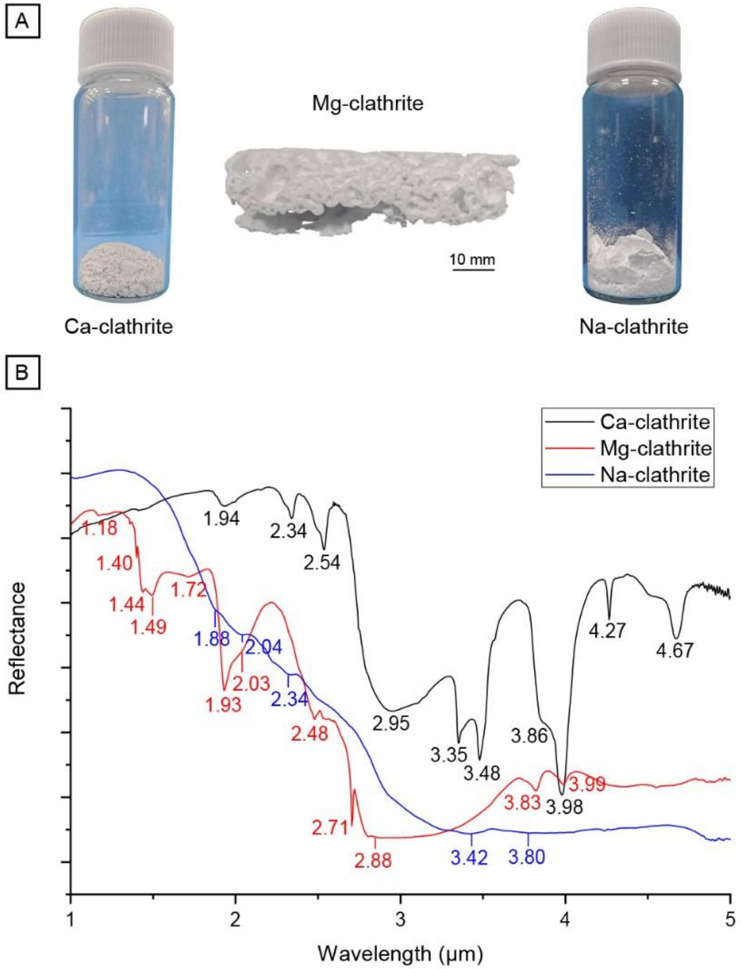

LEFT: Cryovolcanic features observed on the surface of Ceres, such as Cerealia Tholus (A) and Ahuna Mons (B), are composed of bright materials that have been identified by the Dawn near-infrared instrument as Mg-Ca and Na carbonates, along with chlorides. RIGHT: A) Images of the three synthesised clathrites. B) Near-infrared spectra of the Ca-clathrite (calcite, black line), the Mg-clathrite (nesquehonite, brucite and shekolvite, red line), and the Na-clathrite (nahcolite and thermonatrite, blue line).

Carbonate deposits on ocean worlds have been widely identified using several techniques, ranging from near-infrared spectroscopy by the Galileo NIMS instrument on Europa and the Dawn VNIR instrument on Ceres to mass spectrometry by the Cassini CDA instrument on Enceladus. Based on the geological context of each body and the features associated with these deposits, the genesis of the detected carbonates has generally been attributed to processes such as hydrothermal mineralisation or fractional cryomagmatic crystallisation.

However, there may be another possible formation mechanism that has not yet been considered in planetary geology, but which commonly occur on Earth, specifically at cold seeps along continental margins, where the formation and dissociation of a type of high-pressure mineral take place. These minerals are clathrate hydrates, solid crystalline compounds that act as carbon sinks. Geophysical and geological observations of outer solar system ocean worlds, as well as geochemical models, suggest that clathrate hydrates could be present within their ice shells and oceans. As on Earth, the dissociation of clathrate hydrates would release large amounts of CO_2 and CH_4 into the surrounding environments, where these gases could interact with cation-bearing salts and promote the precipitation of carbonate minerals, known as clathrites. These carbonates are termed clathrites because the carbon in their structure comes from carbon-bearing gases that were once trapped within the crystal lattice of clathrate hydrates.

To explore this hypothesis, we conducted high-pressure laboratory experiments to simulate whether clathrites could form under the high-pressure and low-temperature conditions that prevail within the ice shells of these ocean worlds. The experimental results show that clathrites can indeed precipitate under such conditions. Furthermore, the mineralogy of the synthesised clathrites correlates with that of the carbonates identified on these moons, which would support the hypothesis that some of these carbonate deposits could in fact be clathrites.

DE DIOS-CUBILLAS, A., PRIETO-BALLESTEROS, O., LÓPEZ, I., FERNÁNDEZ-SAMPEDRO, M., RULL, F., BONALES. L.J. ASTRONOMY & ASTROPHYSICS, 2025, https://doi.org/10.1051/0004-6361/202556029