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Detection of phosphate in ice grains from Enceladus' ocean with general implications for habitability in the outer solar system

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Enceladus's subsurface global ocean (1) can be probed by sampling the gaseous and icy material the moon expels into its cryovolcanic plume and - even further out - into Saturn's E ring (2,3,4,5). Hydrothermal outflows supported by tidal heating (4,5,6), together with rich organic chemistry (7,8) imply that the moon appears to be one of most habitable places in our solar system. Among the elements C, H, N, O, P and S that are considered to be essential for life, all except phosphorous have either been identified (5,7,8) or - in the case of sulfur - tentatively detected (9). From these elements, P has by far the lowest cosmic abundance and is usually bound in poorly soluble minerals, limiting its bio-availability.
Here we present results from a re-analysis of mass spectrometric data from Cassini's Cosmic Dust Analyzer (CDA), showing strong evidence of sodium-phosphate salts in ice grains originating from Enceladus's subsurface ocean (10). We found a population of ice grains whose spectra clearly indicate the presence of at least two soluble sodium orthophosphates: Na_3PO_4 and Na_2HPO_4. We infer phosphate concentrations in the Enceladean ocean in the order of a few mM, about 1000-times higher concentrations than in Earth's seawater (10).
We carried out geochemical experiments and calculations showing how such high phosphate abundances can be achieved in the subsurface ocean. The driver enabling the abundant availability of phosphate is the high observed concentration of dissolved carbonate species, which shift phosphate-carbonate mineral equilibria toward dissolution of phosphate minerals into Enceladus'ocean. We show that interactions between chondritic rocks and CO_2-rich fluids generally lead to conditions with high dissolved phosphate concentrations (10). Therefore, P-rich oceans would commonly occur in ocean worlds beyond the CO_2 snow line. This almost certainly applies to bodies at Saturn and beyond. It is, however, currently unclear if the Jovian moons formed under such favorable (CO_2 rich) conditions at low enough temperatures.

References:

1 Thomas et al., Icarus 264 (2016), 2 Postberg et al., Nature 459 (2009), 3 Postberg et al., Nature 474 (2011), 4 Hsu et al., Nature 519 (2015), 5 Waite et al., Science 356 (2017), 6 Choblet et al. , Nat Astron 1 (2017), 7 Postberg et al., Nature 558 (2018) , 8 Khawaja et al., MNRAS 489 (2019), 9 Postberg et al., ISBN: 9780816537075 (2018), 10 Postberg et al., Nature 618 (2023)

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