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Meteorite 4.5Gyr halite crystals likely to originate from Comets

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Abstract

Halite crystals in the ZAG and Monahans meteorites have been of special interest because they imply a watery crystallisation environment.. The crystals contain some organic-rich brine inclusions, so the recent dating at 4.5Gyr implies a watery organic pool in the very early solar system. Media publicity in January 2018 talked of finding the "building blocks of life", much as comets have been depicted as bringing the building blocks of life to planet Earth. Indeed, the organic complement shows similarities with comet Wild 2 and Stardust particles.

We hypothesise that the organics in the meteorite halite inclusions are biotic or pre-biotic chemicals from the first 10Myr of comets. This corresponds to the few Myr radiogenic heating by short-lived ^{26}Al and ^{60}Fe.

1. Evidence from the Zag and Monahans meteorites

Both these 1998 meteorites are regolith breccias containing mm-sized halite crystals (NaCl; KCl), blue in colour due to extensive cosmic-ray processing. Rubin et al [3] identified shock metamorphism, thermal metamorphism and aqueous alteration on the asteroid (H-chondrite) parent body. Subsequent studies [6] found µm-sized zones of complex mixtures of primitive organics (aliphatic, aromatic/olefinic, vinyl-keto, carboxyl/ester and carbonate) .

Recently Chan et al. [1] made a comprehensive analysis of soluble and insoluble organic compounds trapped in brine inclusions in the mm-sized halite crystals. They summarised them as organic precursors, intermediates and reaction products that make up precursor bio-molecules such as amino acids. The organic compounds also contain a mixture of C-, O-, and N-bearing macromolecular carbon materials, including aromatics, ketones and imine or imidazole compounds.

Their data showed nitrogen ^{15}N is enriched but carbon ^{13}C is depleted. Enrichment compared with solar system values can arise from preferential retention on partial evaporation to space, whereas depletion of ^{13}C is normally taken as indicative of biological fixing processes. A C-rich area of Monahans was found as $\delta^{13}C=37.6\pm 4.2\ ^{o}/_{oo}$, mid-range for terrestrial biological carbon ($\delta^{13}C$ = 25-60 $^{o}/_{oo}$) whereas C-rich meteorites Murchison and Orgeil are less depleted $\delta^{13}C \sim 17\text{-}19^{o}/_{oo}$

2. Comets as a source

The origin suggested [1] for the halite crystals was icy moons such as Enceladus and Europa, but their gravitational pull and that of the parent planet means such ejected crystal (via cryo-volcanism) can hardly escape to space. Comets are a possible and more plausible source

Early comets have been hypothesised since the 1980 to have liquid interiors, on the basis that radiogenic heating potentially caused the interior of snowballs >10km radius to reach 273K and melt. Distillation of the volatile components diffusing through the porous comet tends to concentrate gases in the outer regions, with slow reactions forming more complex molecules there. If micro-organisms are active, one would expect the suite of complex molecules to show this in highly complex compounds. Alternatively, the early surface of a snowball comet – prior to development of a quasi-stable coherent dark crust as observed on current epoch comets [5,6] – would be an environment where micro-organisms and/or biomolecules concentrate out of the sublimating aqueous phase [2]. Crystallisation processes would form patches of gas hydrates (clathrates), rather than simple distillation supposed to create pockets of volatiles CO, NH_3, CH_4, CH_3OH etc.

As shown by the comet Halley spaceprobes and Rosetta recently to comet 67P, 'dust' and micro-crystals are blown out by cometary gas jets. Large quantities are simply released on disintegration of comets. Such crystals would have impacted asteroid regoliths during their accretion stage, eg. the asteroids Ceres or Hebe suggested as parent body of Zag and Monahans.

3. Comets as a source of organic-rich brines within halite crystals

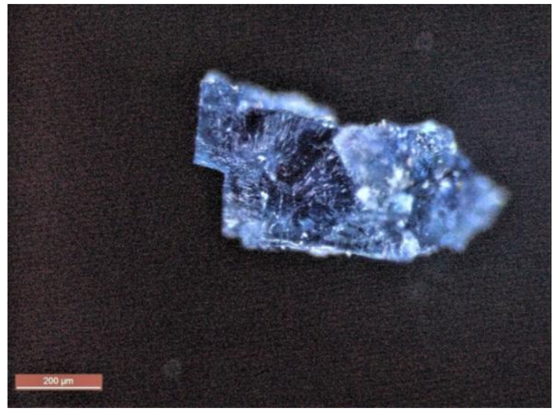
Astronomical arguments in favour of complex organics in comets, summarised recently in Steele et al [4], go back to 1975. Interstellar organics from the pre-solar nebula together with any debris from living matter, spores etc. would be accreted on the early comets. Space probes to Halley's comet in 1986 established its dust as high in carbonaceous compounds and its surface as very dark, challenging Whipple's 'dirty snowball' comet model that was the reigning paradigm at the time. Imaging of comet nuclei on fly-by missions and the recent landing on 67P by Philae in the Rosetta mission have established comets to have coherent crusts, processed by insolation, micro-impacts and outgassing [6]. Beneath the crust, we infer temporary gassy regions, even pools [5] which, as they freeze and gradually lose H_2O, concentrate the biotic and pre-biotic organics in brines. We suggest this as a source of micron-scale halite crystals in current-day comets, but they would not survive long in free space.

4. Summary

We argue that the organics in the Zag and Monahans halite inclusions reveal biotic or pre-biotic chemicals in the first 100Myr of comets. The analyses are compatible with previous studies of cometary organics, but in the meteorite case shows a more complex suite of compounds, indicative of biotic organics. The ^{13}C depletion is particularly indicative of biotic rather than pre-biotic chemistry; if confirmed, it would be highly significant, implying comets were endowed from birth with micro-organisms able to colonise the icy cometary environment, as they colonise terrestrial antarctic snows. The comet timescales were of course far longer, ~10-100 Myr after the initial radiogenic heating decayed away.

Where are the halite crystals from more recent evolving comets? Comet formation and disintegration was of course more vigorous in the first 100 Myr. But the late bombardment and accretion of planetary oceans is put at ~500Myr. Do relatively few halite crystals survive from asteroids in this period? More intensive searches of other meteorites are eagerly awaited.

5. Figure



Blue halite crystal from Monahan [1]

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