Silicate stardust from comets

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Interplanetary dust particles (IDPs) collected in the Earth's stratosphere are 5 – 50 µm fragments of asteroids and comets [1-3]. Anhydrous IDPs have escaped significant parent body hydrothermal alteration [2] and are further distinct from meteorites in their greater abundances of volatile elements and C, fine grained (100 – 500 nm) textures, and unequilibrated mineralogies. Many anhydrous IDPs contain high abundances interstellar organic compounds [4] and grains of silicate stardust [5]. These observations are consistent with properties of comets inferred from remote astronomical observations.

Comets have been thought to be pristine aggregates of interstellar materials. However, spectroscopic observations of crystalline silicates in comets has challenged this notion, given their apparent absence in the interstellar medium.

We measured the isotopic compositions of crystalline and amorphous grains in anhydrous IDPs to establish the relative proportions of solids of presolar and solar system origin in these materials. Stardust grains are distinguished from solar system materials by their exotic isotopic compositions as measured by NanoSIMS ion microprobe. Mineralogical characterization of some of these grains was performed by transmission electron microscopy (TEM) on 70 nm thick IDP microtome sections prior to isotopic analysis.

Roughly 1031 grains were measured for their O isotopic composition with sufficient precision to distinguish solar system material from stardust. Among these, 113 were characterized by TEM prior to analysis by NanoSIMS. We identified 6 grains of silicate stardust, two of which were previously analyzed by TEM where they were identified as an amorphous GEMS [6] grain and a forsterite grain. The remainder of the 1025 grains had O isotopic compositions indistinguishable from solar system materials.

The mineralogy of the isotopically solar grains include enstatite, GEMS, olivine, anorthite, Ca-Al-Mg-rich glass, diopside, and chromite. It has been suggested that interstellar grains may be rendered amorphous and isotopically homogenized by shock sputtering and re-accretion. However, crystalline silicates are very unlikely to form in the ISM. The most probable source of isotopically solar crystalline grains is the solar system itself.

References

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The Tono Natural Analogue Project: A system model for the origin and evolution of the Tono uranium deposit, Japan

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Natural analogue studies of the Japan Nuclear Cycle Development Institute (JNC) in the Tono uranium deposit, central Japan, are developing generic approaches for simulating geological perturbations within models describing radionuclide migration. Numerical model development is being made based upon extensive field and laboratory investigations.

The investigations are focusing on the Tsukiyoshi orebody, which is relatively large and accessible, being generally <150 m below the surface, about 3.5 km long, 500 m wide, and several metres thick. Approximately 2600 tonnes of uranium occur at an average concentration of 0.05%. Mineralisation is concentrated in lacustrine, lignite-bearing rocks of the Miocene (c. 18-20 Ma) Toki Lignite-bearing Formation, up to a few tens of metres above an unconformable contact with the late Cretaceous Toki Granite.

The sedimentary sequence contains several unconformities and mostly is cut by the Tsukiyoshi Fault (c. 30 m apparent reversed displacement). Marine Miocene rocks also occur at higher levels than the mineralisation. Thus, the deposit is preserved in spite of it being affected by exhumation, subsidence and sedimentation, marine transgression and faulting.

Conceptual and numerical models for these environmental perturbations were constructed using a novel adaptation of a Safety Assessment methodology. A 'reference scenario' was developed using a Systems Analysis approach. This scenario is a best estimate of how the geological system and the uranium deposit reached their present states and includes descriptions of all major environmental perturbations. Uranium is mobilized from the upper granite under relatively oxidizing conditions, and then transported by groundwater into the sedimentary rocks. There, reducing conditions cause uranium deposition. A specially-designed numerical model simulated the main features of this scenario.

Many simulations were performed to identify key uncertainties to which the simulated timing of ore deposition and uranium distribution are sensitive. The approach could be used elsewhere, in safety assessments of the high-level radioactive waste (HLW) geological disposal concept in Japan. A particular application would be at potential future waste disposal sites elsewhere, to prioritise site characterisation so that the most safety-relevant uncertainties are reduced.