Probing Life History of Meteorite From Early Solar System

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Scientists at Johnson Space Center (JSC) and colleagues at Lawrence Livermore National Laboratory, the University of California, Berkeley, and the University of Chicago have performed a microprobe analysis of the core and outer layers of a pea-size fragment meteorite some 4.6 billion years old to reconstruct the history of its formation, providing the first evidence that dust grains experienced wildly varying environments during the planet-forming years of our solar system. These dust grains—called calcium-, aluminum-rich inclusions (CAIs)—are understood to have formed very early in the evolution of the solar system and in contact with nebular gas, either as solid condensates or as molten droplets. On the basis of the oxygen isotope record found, the team interpreted these findings in the context of models about how matter formed in the early protoplanetary nebula and reported their implications for the formation of terrestrial planets in the March 2011 issue of the journal *Science*.

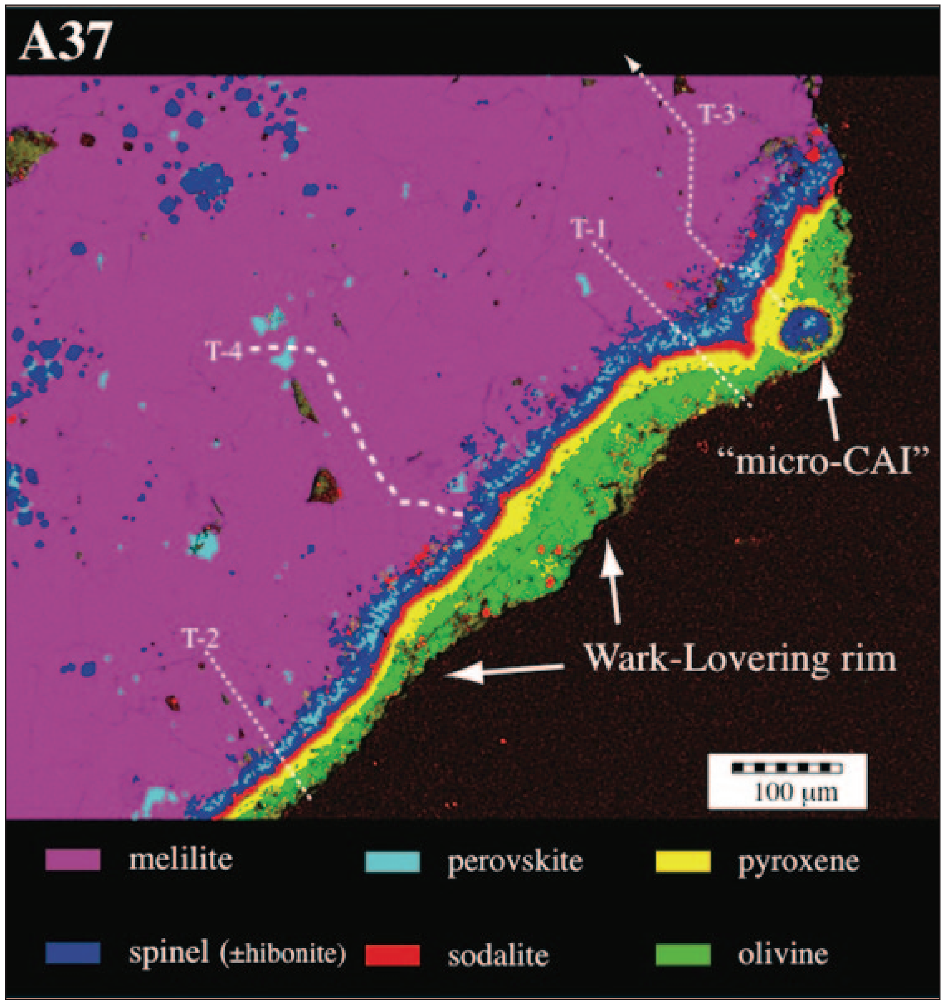

Fig 1. *Compositional x-ray image of the rim and margin of an approximately 4.6-billion-year-old calcium-, aluminum-rich refractory inclusion from the Allende carbonaceous chondrite.*

The micrometer-scale analyses of a CAI, and the characteristic mineral bands mantling the CAI, reveal that the outer parts of this primitive object have a large range of oxygen isotope compositions. The variations are systematic; the relative abundance of ^{16}O (oxygen isotope 16) first decreases toward the CAI margin, approaching a planetary-like isotopic composition, then shifts to extremely ^{16}O-rich compositions through the surrounding rim. The variability implies that CAIs formed from several oxygen reservoirs, likely located in distinct regions of the solar nebula. The observations support early and short-lived fluctuations of the environment in which CAIs formed, either because of transport of the CAIs themselves to distinct regions of the solar nebula or because of varying gas composition near the proto-sun.

Scientists measured a component of the primitive meteorite Allende (the CAI called A37) and its surrounding concentric rim by nanometer-scale, secondary ion mass spectrometry (NanoSIMS)—an ion microprobe with nanometer-scale spatial resolution—to investigate intra-CAI oxygen isotopic variations. An image of A37 can be seen in figure 1. The core of A37, extending well beyond the field of view to the upper left, consists of the minerals melilite, spinel, and perovskite. The rim consists of a sequence of monomineral layers (hibonite, perovskite, spinel, melilite/sodalite, pyroxene, and olivine) a few micrometers thick. A spinel-rich micro-inclusion appears to have been entrapped while the rim was forming. The ion microprobe measurements were obtained as approximately 2 micrometers (µm) spot analyses spaced every 7 to 10 µm across the rim and the outer approximately 150 µm of the interior. At the resolution that is accessible with the NanoSIMS, both A37 and its rim exhibit more than 20‰ (part per thousands) variation in Δ17O (the deviation of the O isotopic composition from the terrestrial fractionation line)—a range that is close to the full range thought to exist among solids formed in the entire solar system. These data imply that A37 was transported among several different nebular oxygen isotopic reservoirs, potentially as A37 passed through and/or into various regions of the protoplanetary disk.

The evidence for transport of solid matter reported by the team supports the inference from theoretical studies that outward radial transport of solid matter is a basic consequence of protoplanetary disk evolution. Large-scale radial circulation of nebular solids is also consistent with the reports of crystalline material located in the outer reaches of our solar system, and in the outer, cool regions of distant stars. The variable but largely ^{16}O-rich composition of the rim suggests that after transport out of the inner solar system, CAIs either continued to form within a region in the outer solar system that varied in composition, or they were returned back to the inner solar system.