Chemical clues point to dusty origin for Earth-like planets

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Higher than expected levels of sodium found in a 4.6 billion-year-old meteorite suggest that the dust clouds from which the building blocks of the Earth and neighboring planets formed were much denser than previously supposed. The study, by scientists from the Carnegie Institution, American Museum of Natural History, and U.S. Geological Survey, is published in the June 20 issue of Science.

Conel Alexander and Fred Ciesla of the Carnegie Institution's Department of Terrestrial Magnetism, with colleagues Jeffrey Grossman of the U.S. Geological Survey and Denton Ebel of the American Museum of Natural History, analyzed the sodium content of grains in objects called "chondrules" from the Semarkona meteorite, which fell in India in 1940. The Semarkona meteorite, like all other chondrule-bearing meteorites (known as chondrites), dates from the early stages of the solar system's formation. Unlike most others, however, its constituents have been relatively unaltered by heat and chemical changes over the more than four billion years since its origin, making it an important window into the early history of the solar system.

Chondrules, which make up 20 to 80% of the volume of chondrites, are round, roughly millimeter-sized objects made of glass and crystals. Chondrules are thought to have formed by flash heating of dust in the primordial solar system. From the types of minerals found in chondrules, scientists have determined that they formed at temperatures of up to nearly 2,000° C (3600° F). The source of this high heat, which would have affected vast areas of dust, is unknown. The heat would also be expected to have boiled off many of the volatile chemical elements, such as sodium, leaving the chondrules depleted in these elements.

But the chemical analyses by the research team found that the Semarkona chondrules had surprisingly high sodium abundances when they formed, indicating that sodium was not driven off. Rather, it remained at nearly constant levels during chondrule formation.

"Chondrules formed as molten droplets produced by what was probably one of the most energetic processes that operated in the early solar system," says Alexander. "You would expect all the sodium to evaporate and be lost from the chondrules under such conditions. Instead, the sodium was retained. The chondrules stayed as effectively closed systems throughout the heating and melting."

The researchers determined that in order for the molten droplets that formed the chondrules to remain as closed systems and retain constant levels of sodium, the initial dust cloud must have been far denser than previously supposed. "If the droplets were crowded close enough together, then the sodium vapor in the spaces in between would reach a saturation point," says Alexander, "and that would prevent further evaporation."

To achieve this condition, the density of dust in the chondrule-forming regions of the early solar system must have been at least about 10 grams per cubic meter, and possibly much more. This is at least 100 times the densities considered by previous models of chondrule formation, which had assumed at most densities of only about 0.1 grams per cubic meter, and normally considerably less. At densities of 10 grams per cubic meter or more, regions only a few thousand kilometers across, small by astronomical standards, could collapse under their own gravity to make objects that would be 10s of kilometers across.

"What's notable about this result is that it raises the possibility that the formation of chondrules in these high-density regions was linked to the formation of kilometer-sized objects called planetesimals, which were the first stage in building Earth-like planets," says Alexander. "It will also help narrow down the possibilities for the cause of the heating that produced the chondrules, as well as the sizes of the regions where they formed. Heating chondrules to their peak temperatures and then quickly cooling them down when they are present at such high densities is a significant challenge for any mechanism proposed to explain chondrule origin. These tiny objects still have a lot to tell us about how our solar system took shape."

Source: Carnegie Institution

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