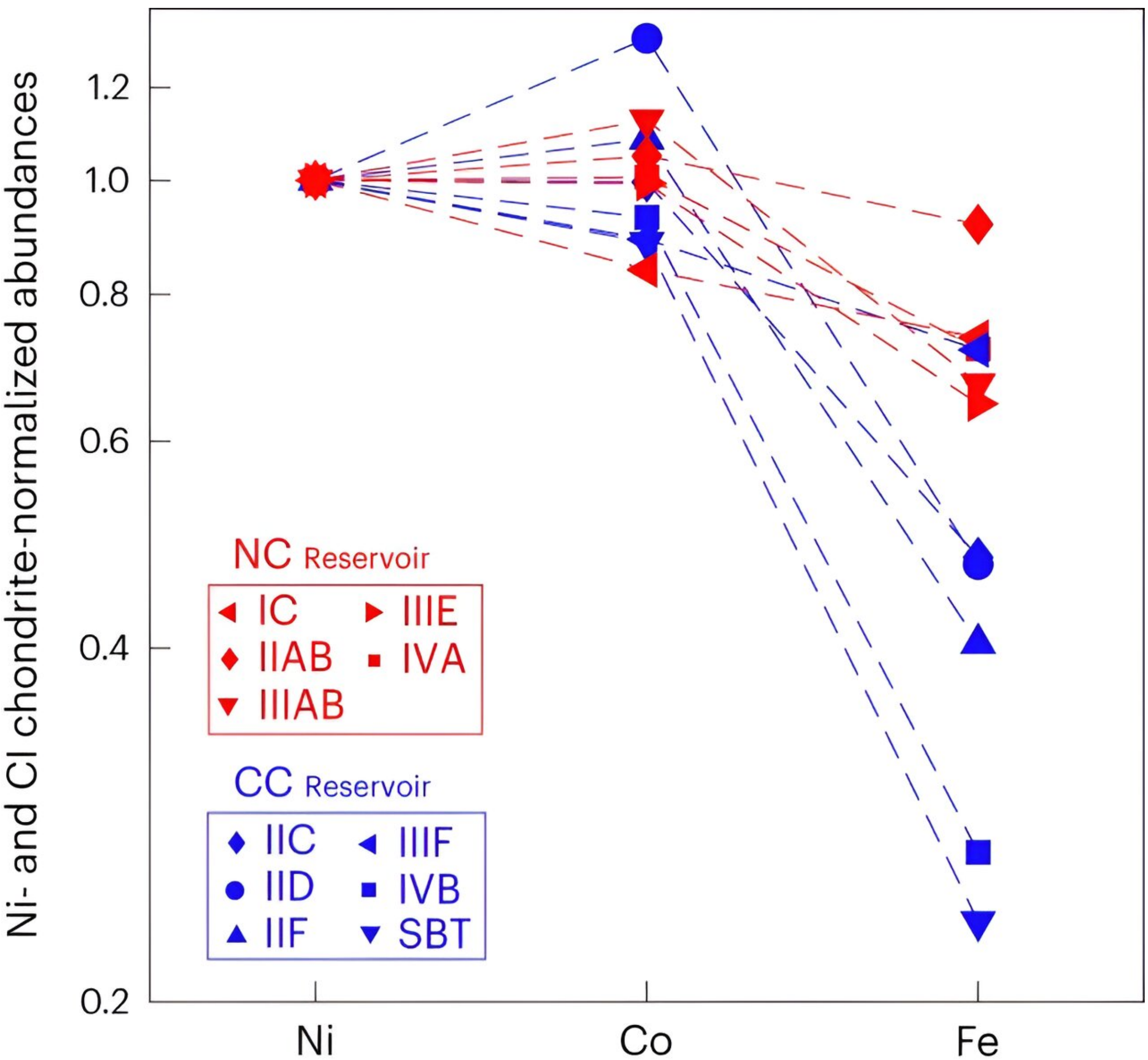
Meteorite analysis shows Earth's building blocks contained water

January 9 2024, by Lori Dajose



Ni and CI-chondrite normalized bulk Ni, Co and Fe contents in the parent cores of magmatic iron meteorites. $(Co/Ni)_{CI}$ ratios of NC and CC irons are close to 1 (except for group IID) and do not show any systematic differences between NC and CC irons. $(Fe/Ni)_{CI}$ ratios of both NC and CC irons are both lower than 1, with CC irons (except for group IIIF) having systematically lower $(Fe/Ni)_{CI}$ ratios than NC irons. NC and CC iron meteorites are shown in red and blue, respectively. Credit: *Nature Astronomy* (2024). DOI: 10.1038/s41550-023-02172-w

When our sun was a young star, 4.56 billion years ago, what is now our solar system was just a disk of rocky dust and gas. Over tens of millions of years, tiny dust pebbles coalesced, like a snowball rolling larger and larger, to become kilometer-sized "planetesimals"—the building blocks of Earth and the other inner planets.

Researchers have long tried to understand the ancient environments in which these planetesimals formed. For example, water is now abundant on Earth, but has it always been? In other words, did the planetesimals that accreted into our planet contain water?

Now, a new study combines meteorite data with thermodynamic modeling and determines that the earliest inner solar system planetesimals must have formed in the presence of water, challenging current astrophysical models of the early solar system.

The research was conducted in the laboratory of Paul Asimow, Eleanor, and John R. McMillan, Professor of Geology and Geochemistry, and appears in the journal *Nature Astronomy*.

Researchers have samples of the solar system's earliest years in the form of iron meteorites. These meteorites are the remnants of the metallic cores of the earliest planetesimals in our solar system that avoided accretion into a forming planet and instead orbited around the solar system before ultimately falling onto our planet.

The chemical compositions of meteorites such as these can reveal information about the environments in which they formed and answer questions such as whether the building blocks of Earth formed far from our sun, where cooler temperatures allowed the existence of water ice, or if they instead formed closer to the sun, where the heat would have evaporated any water and resulted in dry planetesimals.

If the latter is correct, Earth would have formed dry and gained its water through another method later in its evolution.

Though the meteorites contain no water, scientists can infer its long-lost presence by examining its impact on other chemical elements.

Water is composed of two hydrogen atoms and one oxygen atom. In the presence of other elements, water will often transfer its oxygen atom away in a process called oxidation. For example, iron metal (Fe) reacts with water (H_2O) to form iron oxide (FeO). A sufficient excess of water can drive the process further, producing Fe_2O_3 and FeO(OH), the ingredients of rust.

Mars, for example, is covered in rusty iron oxide, providing strong evidence that the Red Planet once had water.

Damanveer Grewal, a former Caltech postdoctoral scholar and first author of the new study, specializes in using chemical signatures from iron meteorites to gather information about the early solar system.

Though any iron oxide from the earliest planetesimals is now long gone, the team could determine how much iron would have been oxidized by examining the metallic nickel, cobalt, and iron contents of these meteorites. These three elements should be present in roughly equal ratios relative to other primitive materials, so if any iron was "missing," this would imply that the iron had been oxidized.

"Iron meteorites have been somewhat neglected by the planet-formation community, but they constitute rich stores of information about the earliest period of solar system history once you work out how to read the signals," says Asimow. "The difference between what we measured in the inner solar system meteorites and what we expected implies an oxygen activity about 10,000 times higher."

The researchers found that those iron meteorites thought to be derived from the inner solar system had about the same amount of missing iron metal as meteorites derived from the outer solar system. For this to be the case, the planetesimals from both groups of meteorites must have formed in a part of the solar system where water was present, implying that the building blocks of planets accreted water right from the beginning.

The signatures of water in these planetesimals challenge many of the current astrophysical models of the solar system. If planetesimals formed at Earth's current orbital position, water would have existed only if the inner solar system was much cooler than models currently predict. Alternatively, they may have formed further out, where it was cooler and migrated in.

"If water was present in the early building blocks of our planet, other important elements like carbon and nitrogen were likely present as well," says Grewal. "The ingredients for life may have been present in the seeds of rocky planets right from the start."

"However, the method only detects water that was used up in oxidizing iron," adds Asimow. "It is not sensitive to excess water that might go on to form the ocean. So, the conclusions of this study are consistent with

Earth accretion models that call for late addition of even more water-rich material."

The paper is titled "Accretion of the earliest inner solar system planetesimals beyond the water-snowline." In addition to Asimow and Grewal, co-authors are former Caltech postdoctoral scholar Nicole X. Nie, Bidong Zhang of UCLA, and Andre Izidoro of Rice University. Grewal is currently an assistant professor at Arizona State University.

More information: Damanveer S. Grewal et al, Accretion of the earliest inner Solar System planetesimals beyond the water snowline, *Nature Astronomy* (2024). DOI: 10.1038/s41550-023-02172-w

Provided by California Institute of Technology