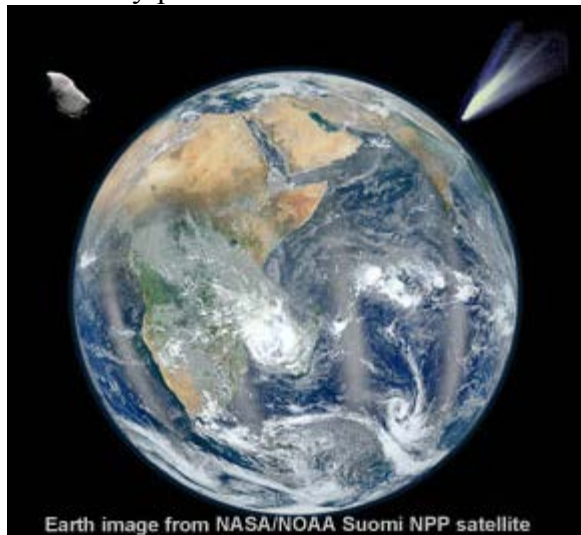


## Water, Carbonaceous Chondrites, and Earth

Besides the water we assume was in the original materials that accreted to form Earth, theory holds that water has since been added to Earth by impacting **comets** and pieces of **asteroids**—especially the chemically primitive carbonaceous **chondrites**.



Earth image from NASA/NOAA Suomi NPP satellite

Along with the water, we know from laboratory studies of extraterrestrial materials that comets and asteroids contain prebiotic organic chemicals and amino acids, which only heightens our interest in them as carriers of the ingredients for life. Sorting out the details of water delivery to Earth as well as the larger issue of the different inventories of water ice in the early Solar System are hot research topics. The answers are relevant to planetary accretion models and also to dynamical models that seek to explain how materials moved and mixed in the early Solar System.

A vital piece of information in this work, the detail that connects Earth's water to extraterrestrial bodies, is the water deuterium/hydrogen ratio (D/H). Deuterium is an **isotope** of hydrogen that's also called heavy hydrogen. Its nucleus contains a proton and a neutron; hydrogen's nucleus contains only a proton. As a reference, the measured D/H in Earth's standard mean ocean water (**SMOW**) is  $1.558 \times 10^{-4}$ . In our Solar System, the water D/H ratio is a kind of fingerprint of where icy **planetesimals** formed; the ratio increases with increasing formation distance from the Sun. Bodies formed in the same source regions and at similar times should have accreted ice with similar D/H ratios. That's part of the reason why researchers have been collecting hydrogen isotopic data on a variety of planetary materials to compare with Earth's D/H ratio to help determine the contributions of water delivered to Earth by (outer Solar System) comets versus (inner Solar System) water-bearing carbonaceous asteroids.

Conel Alexander (Carnegie Institution of Washington) and colleagues from the US and Canada have added more data to the table. They analyzed bulk hydrogen, carbon, and nitrogen elemental and isotopic compositions of 86 samples of carbonaceous chondrite meteorites and inferred the initial water D/H ratios. The remnants of ice preserved in these chondrites are in the form of hydrated silicates, such as clays. Their results show the range in water D/H ratio of the carbonaceous chondrites is  $\sim 0.2 \times 10^{-4}$  to  $\sim 7.3 \times 10^{-4}$ . This range spans the value for oceanic water and is lower (by a factor of two) than the mean D/H ratio of the six measured **Oort cloud** comets suggesting (a) carbonaceous chondrites and these comets did not form in the same region and (b) water was delivered to Earth mainly by bodies that formed in the **asteroid belt** (and/or sunward from Jupiter) rather than by bodies made in the Solar System's outer comet-forming regions. Alexander and coauthors' results support the idea that Earth's **volatiles** are in roughly chondritic abundances. Though no single chondrite group has identical composition to the bulk Earth, the team suggests the Earth's hydrogen and nitrogen isotopic compositions can be most easily explained by the mixing of CI-like material with a small contribution of materials with isotopically solar compositions. CIs, the most volatile-rich chondrites we know of, are considered to have formed in the outer asteroid belt.

While meteorite studies are adding to a growing body of data suggesting asteroids, rather than Oort cloud

comets, were the principal sources of Earth's acquired volatiles, including water, the investigations are far from over. Consider the 2011 announcement from the European Space Agency's Herschel infrared space observatory that comet Hartley 2, a Jupiter-family comet, has water with an Earth-like hydrogen isotopic composition. Details of whether comets like Hartley 2 could have delivered a large proportion of water to early Earth still need to be settled. The more data we collect, the more dynamic our early Solar System appears. The drive continues to understand all the possible sources of Earth's water.

See: Alexander, C. M. O'D., Bowden, R., Fogel, M. L., Howard, K. T., Herd, C. D. K., and Nittler, L. R. (2012) The Provenances of Asteroids, and Their Contributions to the Volatile Inventories of the Terrestrial Planets, *Science*, v. 337(6095), p. 721-723, doi: 10.1126/science.1223474. [ [article](#) ]. See also the [Press Release](#) from the Carnegie Institution for Science.

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