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The sources of Earth's volatiles: Many ideas, little consensus

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The number of ideas for how, when and in what the Earth accreted its volatiles are almost as numerous as the number of volatile elements, their potential sources in the early Solar System and terrestrial planet formation models. To make progress towards a consensus, it is essential to consider the collateral consequences of a model for all available constraints. So, for instance, enstatite chondrites have been suggested as the main building blocks of the Earth and the sources of Earths H, C and N. However, they cannot explain the Bulk Silicate Earth's (BSE's) major and moderately volatile element abundances, or its noble gases. Chemisorption of nebular H on silicate grain surfaces has been suggested as a source of Earth's H, but there is little evidence for this in chondrites, it does not explain the origin of any other volatiles, and it may not be consistent with the BSE's D/H ratio. Implanted solar wind has also been suggested as a source of Earth's H, but the relative elemental abundances and isotopic compositions of H, C, N, and the noble gases in implanted solar wind are quite different from those of the BSE. Pebble accretion is a new potential mechanism for building the terrestrial planets. However, if a significant fraction of pebbles came from the outer Solar System, volatile abundances in the terrestrial planets would be too high. If rapid pebble accretion produced embryos of $\geq$0.3-0.5 Earth masses, they would have accreted massive atmospheres from the nebula. These atmospheres must subsequently be largely lost in such a way as to reproduce the present very different elemental and isotopic compositions of volatiles in the BSE. Finally, accretion of CI- and CM-like chondritic materials mostly prior to Moon-formation, along with small amounts of cometary material and solar wind, can explain many, but not all, aspects of the BSE's volatiles. For example, it cannot explain the depletions of C and N, relative to the noble gases, without resorting to hidden reservoirs in the core or deep mantle.