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Chondritic component pebbles as sources of Earth's composition and water

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The classical accretion model involves collisions of chondritic-like bodies that occur over 10s of millions of years. However, no combination of known chondrites fits the Earth's major element composition. An alternative formation model is pebble accretion, in which small objects (e.g., chondrules, refractory inclusions, metal grains) are gravitationally incorporated into growing bodies within a few million years in the presence of a nebula. Our calculations demonstrate that the accretion of pebbles made of chondritic components yields a total protoplanet mass inside 1 AU exceeding the combined masses of Earth, Moon, Venus, and Mercury. Additionally, our best-fitting mixture of metal grains, chondrules, and refractory inclusions not only matches Earth's major element (Fe, Ni, Si, Mg, Ca, Al, O) composition within uncertainties but also its ^{50}Ti and ^{54}Cr values.

The rapid growth of a body in the presence of a solar nebula (<~4 My) will generate a massive, high-pressure H_2-rich hot atmosphere. A pebble passing through such an atmosphere is expected to produce water by the reaction: $FeO_{silicate} + H_{2g} = Fe_{metal} + H_2O$. We have conducted laboratory experiments in which we have melted basalt in a He atmosphere followed by an H_2 atmosphere (1000-1400°C). After collecting water in each step, we measured the H isotope fractionation between H_2 and collected H_2O. Results suggest H isotope equilibration between the falling pebble and its surrounding atmosphere. Also, as estimated from the collected water, a 50-70% reduction occurs in 0.5-1 g basalt, in the presence of H_2 within 15 minutes, whereas no reduction is seen in the He-exposed experiment. In a nutshell, FeO-rich chondritic components are good sources of Earth's water.