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Origin of the Earth

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Understanding the origin of Earth requires reconstructing the specific pathway of Earth's formation from the accretion of its precursor objects into a fully formed and chemically differentiated planet. We show that comparing the chemical and isotopic composition of Earth to that of meteorites allows us to identify the sequence of key events in the formation of Earth. Isotopic measurements on meteorites reveal that by around 1 Ma after CAI formation, the solar system was divided into the non-carbonaceous (NC) and carbonaceous (CC) meteorite reservoirs, which may represent the inner and outer solar system, respectively. Earth formed primarily by hierarchical collisions from inner solar system (NC) planetesimals and embryos, including materials from the innermost disk unsampled among meteorites. Only a few percent outer solar system (CC) materials – originally scattered inwards as Jupiter grew or migrated – were added ‘late’ in Earth’s growth history. The dearth of outer solar system materials in Earth reflects the early efficient isolation of the inner disk from sunwards-drifting pebbles by a pressure bump at the ice line or the early growth of Jupiter. Earth accreted from a mix of volatile-poor and -rich bodies, where the latter were more common during the later stages of accretion, but which included both inner and outer solar system objects. Collisional growth of Earth led to several global magma oceans, each impact causing discrete metal-silicate separation and core formation events, but involving uncertain degrees of impactor core re-equilibration with Earth’s mantle. Overall, accretion of the Earth took several tens of Ma and only terminated with the Moon-forming impact, but the timing of this event is still uncertain. Finally, the late veneer comprises the material added to Earth after the Moon-forming impact and predominantly derives from left-over (NC) planetesimals in the terrestrial planet region, making it an unimportant source of Earth’s volatiles and water.