A ‘recipe’ for Earth’s accretion, without water (January 2017)

The Earth continues to collect meteorites, the vast majority of which are about as old as our planet; indeed many are slightly older. So it has long been thought that Earth originally formed by gravitational accretion when the parental bodies of meteorites were much more abundant and evenly distributed. Meteorites fall in several classes, metallic (irons) and several kinds that contain silicate minerals, some with a metallic component (stony irons) others without, some with blebs or chondrules of once molten material (chondrites) and others that do not (achondrites), and more subtle divisions among these general groups. In the latter half of the 20th century geochemists and cosmochemists became able to compare the chemical characteristics of different meteorite classes with that of the Sun –from its radiation spectrum – and those of different terrestrial rocks – from direct analysis. The relative proportions of elements in chondrites turned out to match those in the Sun – inherited from the gas nebula from which it formed – better than did other classes. The best match with this primitive composition turned out to be the chemistry of carbonaceous chondrites that contain volatile organic molecules and water as well as silicates and sulfides. The average chemistry of one sub-class of carbonaceous chondrites (C1) has been chosen as a ‘standard of standards’ against which the composition of terrestrial rocks are compared in order that they can be assessed in terms of their formative processes relative to one another. For a while carbonaceous chondrites were reckoned to have formed the bulk of the Earth through homogeneous accretion: that is until analyses became more precise at increasingly lower concentrations. This view has shifted...

Geochemistry is a complex business, bearing in mind that the rocks which can be analysed today come predominantly from the tiny proportion of Earth that constitutes the crust. The igneous rocks at the centre of wrangling how the whole Earth has evolved formed through a
host of processes in the mantle and deep crust, which have operated since the Earth formed as a chemical system. To work out the composition of the primary source of crustal igneous rocks, the mantle, involves complex back calculations and modelling. It turns out that there may be several different kinds of mantle. To make matters worse, those mantle processes have probably changed considerably from time to time. To work back to the original formative processes for the planet itself faces the more recent discovery that different meteorite classes formed in different ways, different distances from the Sun and at different times in the early evolution of the pre-Solar nebula. Thankfully, some generalities about chemical evolution and the origin of the Earth can be traced using different isotopes of a growing suite of elements. For instance, lead isotopes have revealed when the Moon formed from Earth by a giant impact (see Oceans of magma, Moon formation and Earth’s ‘Year Zero’ August 2016), and tungsten isotopes narrow-down the period when the Earth first accreted (see Tungsten isotopes show a vestige of a beginning May 2016). Incidentally, the latest ideas on accretion involve a series of ‘embryo’ planets between the Moon and Mars in size.

Calculating from a compendium of isotopic data from various types of meteorite and terrestrial materials, Nicolas Dauphas of the University of Chicago has convincingly returned attention to a model of heterogeneous accretion of protoplanetary materials from different regions of the pre-Solar nebula (Dauphas, N. 2017. The isotopic nature of the Earth’s accreting material through time. Nature, v. 541, p. 521-524; DOI: 10.1038/nature20830). His work suggests that the first 60% of Earth’s accretion involved materials that were a mixture of meteorite types, half being a type known as enstatite chondrites. These meteorites are dry and contain grains of metallic iron-nickel alloy and iron sulfides set in predominant MgSiO₃ the pyroxene enstatite. The Earth’s remaining bulk accumulated almost purely from enstatite-chondrite material. A second paper in the same issue of Nature (Fischer-Gödde, M. & Kleine, T. 2017. Ruthenium isotopic evidence for an inner Solar System origin of the late veneer. Nature, v. 541, p. 525-527; DOI: 10.1038/nature21045) reinforces the notion that the final addition was purely enstatite chondrite.

This is likely to cause quite a stir: surface rocks are nothing like enstatite chondrite and nor are rocks brought up from the upper mantle by volcanic activity or whose composition has been back-calculated from that of surface lavas; and where did the Earth’s water at the surface and in the mantle come from? It is difficult to escape the implication of a mantle dominated by enstatite chondrite From Dauphas’s analysis, for lots of other evidence from Earth materials seem to rule it out. One ‘escape route’ is that the enstatite chondrites that survived planetary accretion, which only make up 2% of museum collections, have somehow been changed during later times. The dryness of enstatite chondrites and the lack of evidence for a late veneer of ‘moist’ carbonaceous chondrite in these analyses cuts down the options for delivery of water, the most vital component of the bulk Earth and its surface. Could moister meteorites have contributed to the first 60% of accretion, or was post-accretion cometary delivery to the surface able to be mixed in to the deep mantle? Nature’s News & Views reviewer, Richard Carlson of the Carnegie Institution for Science in Washington DC, offers what may be a grim outlook for professional meteoriticists: that perhaps “the meteorites in our collection are not particularly good examples of Earth’s building blocks” (Carlson, R.W. 2017. Earth’s building blocks. Nature, v. 541, p. 468-470; doi:10.1038/541468a).

Animation of how the Solar System may have formed.