News & views

Geochemistry

A hint of Earth's ancient ingredients

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Identifying Earth's building blocks from terrestrial rocks is challenging because these ingredients have become mixed as the planet evolved. Evidence of an unknown building block in ancient rocks provides fresh insight. **See p.240**

Earth formed from an unknown selection of meteoritic material. On page 240, Fischer-Gödde *et al.*[1] report that the composition of ruthenium isotopes in ancient rocks from southwest Greenland contains evidence of a previously unrecognized building block of Earth. Surprisingly, the inferred isotopic composition of ruthenium in the material does not match known meteorite compositions. The authors' findings suggest that Earth's volatile components, such as water and organic compounds, could have arrived during the final stages of the planet's growth.

Our planet is the product of a series of collisions of increasingly large celestial bodies[2–4]. These building blocks accreted from a protoplanetary disk of dust and gas that orbited the proto-Sun about 4.6 billion years ago. Identifying the compositions of Earth's building blocks is difficult because of our limited access to the disk's remnants, and because of the complex, long-term geological processing of the mantle that has mixed Earth's ancient ingredients.

Potential answers to the question of what Earth is made of can come from studies in which the isotopic compositions of terrestrial rock samples are compared with those of meteorites that formed within the first few million years of the Solar System's history. These meteorites are presumed to be representative of the smaller bodies that ultimately coalesced to form the rocky planets. Consequently, meteorites are our most promising candidates for Earth's building blocks.

Fischer-Gödde and colleagues' study builds on the finding that meteorites have characteristic isotope compositions that serve as fingerprints to distinguish different types of potential building block. For example, meteorites such as carbonaceous chondrites, which are often 'wet' (that is, they contain volatile components), have different isotopic fingerprints from meteorites that are generally 'dry'[5]. The differences in isotopic composition originate from the heterogeneous distribution of stardust in the protoplanetary disk, and are known as nucleosynthetic isotope variations. If the fingerprints could be identified in terrestrial rock samples, this might provide evidence of the material from meteorites that Earth was built from.

The documentation of fingerprints in terrestrial rocks could help to constrain estimates of when volatile elements were delivered to Earth and where they came from. This is because the abundances of certain isotopes of some elements – ruthenium-100 (^{100}Ru), for example – not only distinguish between wet and dry building blocks, but also trace different stages of Earth's accretion history.

Ruthenium is classified as a highly siderophile (iron-loving) element, because it collects in metal-rich phases of Earth's interior. Consequently, most of our planet's ruthenium is concentrated in its metallic core. There are, however, traces of ruthenium and other highly siderophile elements (HSEs) in the mantle, and their relative proportions approximate to those measured in primitive meteorites[6]. One interpretation of this is that the HSEs were added to the mantle after the core formed, during an event called the late veneer – when the final approximately 0.5% (of the total percentage weight) of Earth's mass accreted[7,8]. If so, then ruthenium and other HSEs in the mantle record the composition of the last material that accreted to Earth[9].

It has been proposed that Earth's volatile elements were also added during the late veneer, possibly by the accretion of carbonaceous chondrites[10,11]. Studies in the past few years, however, have found a mismatch between the ^{100}Ru-isotope composition (the abundances of ^{100}Ru in terrestrial rocks) in Earth's mantle and that in carbonaceous chondrites[12,13]. It could therefore be concluded that carbonaceous chondrites did not form part of the late veneer, thus casting doubt on the timing of the delivery of volatiles to Earth[13].

This conclusion rests on the assumption that HSEs in the mantle do not contain significant quantities of material from before the late

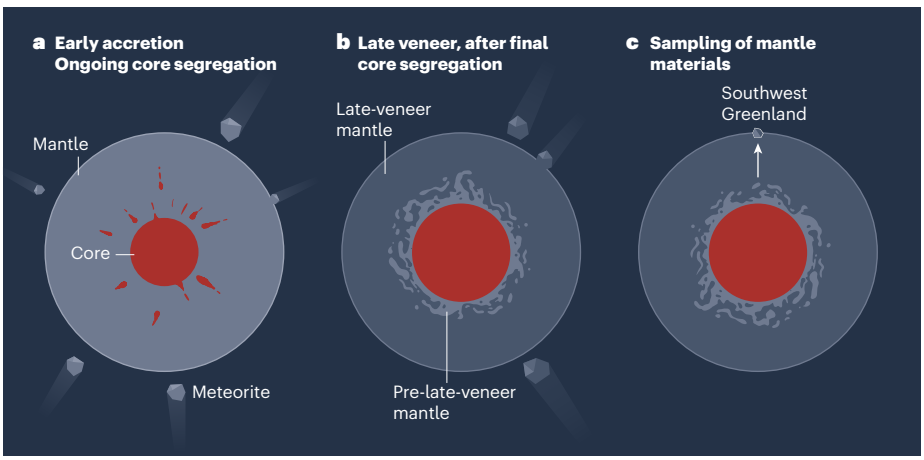

Figure 1 | A scenario for the preservation of ancient material in Earth's mantle. a, Between 4.6 billion and about 4.5 billion years ago, Earth formed from the accretion of material from meteorites. Siderophile elements, which have a strong affinity for metals, segregated into the core. **b**, The final approximately 0.5% of the total percentage weight of Earth's mass accreted from meteorites during an event called the late veneer, after the core had formed. **c**, Fischer-Gödde *et al.*[1] report that ancient rocks from southwest Greenland have an unusual ruthenium-isotope composition. They attribute this to the presence of pre-late-veneer mantle material in the rocks. The distribution of pre-late-veneer material shown here is speculative; the actual amount and distribution cannot be derived from the available data.

veneer — a reasonable assertion, given that there is limited direct evidence of this. If the pre-late-veneer mantle did contain a substantial amount of ^{100}Ru that did not collect in the core, and that was identifiable by having a different ^{100}Ru-isotope composition from that of the modern mantle, then carbonaceous chondrites could still have been accreted during the late veneer.

Nucleosynthetic ruthenium-isotope variations have not been reported for terrestrial rocks before now. This is, in part, because Earth has active plate tectonics and mantle convection, which mix and dilute the fingerprints of its building blocks. However, in the past few years, analytical methods[14] have been further developed that enable isotope variations to be measured on the scale of parts per million, making it possible to search for these primitive isotopic signatures.

By comparing the ^{100}Ru-isotope compositions of terrestrial rocks with those of meteorites, Fischer-Gödde and co-workers report that an ancient part of Earth, preserved in rocks from southwest Greenland, retains the fingerprints of an unusual building block (Fig. 1). The fact that the inferred isotope compositions do not match known meteorite compositions indicates that current meteorite collections are considerably limited in their sampling of the protoplanetary disk.

The authors interpret their unusual ^{100}Ru data as the isotopic signature of pre-late-veneer ruthenium in the source of these rocks. Considering their findings in the context of the compositions of other HSEs in the mantle, the authors suggest that the modern composition of the mantle can be reconciled with their new data only if the late veneer contained carbonaceous chondrites to counterbalance the composition of the pre-late-veneer component of the mantle. This would mean that volatiles could have been delivered to Earth during the final stages of the planet's formation.

Fischer-Gödde and colleagues' data answer the long-standing question of whether Earth's diverse building blocks are preserved and accessible for study. But the data also raise key questions, the answers to which will undoubtedly determine the importance of the new findings. For example, how representative of the pre-late-veneer mantle is the suite of rock samples from southwest Greenland? Are nucleosynthetic fingerprints observed in the isotopic compositions of other elements in the mantle? What is the composition of the 'missing' meteorites that dominated the ruthenium composition of the pre-late-veneer mantle, and why has it not yet been identified? And how was the isotopic signature of these meteorites preserved in the convecting mantle? These questions can be addressed only by expanding the search for nucleosynthetic fingerprints in the mantle.

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Tumour biology

Tweaking DNA of myeloid cells curbs cancer spread

Ali Ghasemi & Michele De Palma

Blood cells called myeloid cells can facilitate metastasis — the spread of a tumour to distant organs. Taming these cells with drugs that alter the chemical structure of their DNA limits metastasis in mice. **See p.284**

Many tumours are successfully treated with surgery. But cancer might recur at the surgical site or in distant organs, so surgery is often followed by treatment termed adjuvant therapy. This limits the risk of relapse by killing cancer cells remaining at the surgical site or those that have already moved elsewhere. However, adjuvant therapy is not always effective. Moreover, it might not prevent certain processes that aid cancer resurgence, such as the recruitment of blood cells called myeloid cells to distant organs, where they can lay the foundation for cancer cells to settle and thrive[1]. Lu *et al.*[2] reveal on page 284 how the chemical structure of the DNA in the nucleus of myeloid cells is a vulnerability that can be harnessed to target these tumour-promoting cells and limit cancer spread.

Tumour spread from its primary site to distant organs, which is called metastasis, involves complex interactions between cancer cells and the surrounding healthy tissues. Evidence is growing that primary tumours can produce signals that modify normal cells to generate a 'soil' in distant organs — termed a pre-metastatic niche — that permits subsequent 'seeding' and establishment of cancer cells at this secondary site[3]. Such secondary tumours, or metastases, are often lethal.

Several types of cancer metastasize from their primary site to the lung. Efficient metastasis of breast cancer cells to the lung in mice requires the participation of a type of myeloid cell called a monocyte[1,4]. These cells normally function to fight infections, but they can also supply metastasizing cancer cells with factors that help them to get established and grow at a secondary site[1,4]. Certain molecules produced by the primary tumour alter the properties of monocytes and increase their numbers in the bloodstream, fostering the monocytes' tumour-supporting functions in the pre-metastatic niche[1,4]. Therefore, blocking such 'tumour-educated' monocytes might inhibit metastasis. Previous work[1,4] indicates that neutralizing a protein called CCL2, which is produced by the tumour and promotes monocyte accumulation in the lungs of mice, impairs metastasis in mouse tumour models. However, this approach was unsuccessful in clinical trials owing to difficulties in effectively neutralizing CCL2 (ref. 4).

Lu *et al.* studied mice that were given transplants under the skin of a type of tumour that metastasizes to the lung. Consistent with previous studies[4,5], the authors found that two types of myeloid cell — monocytes and neutrophils — accumulated in the lung before metastases were detectable there. These tumour-elicited myeloid cells are collectively called myeloid-derived suppressor cells (MDSCs) owing to their ability to suppress the immune response against a tumour[5]. Confirming the metastasis-promoting capacity of MDSCs, the authors report that elimination of MDSCs delayed the metastasis of cancer cells to the lung and extended the animals' survival.

Gene expression can be regulated by changes in the nucleus termed epigenetic