Plant fingerprints in the deep Earth

The colonization of Earth landmasses by vascular plants around 430 million years ago substantially impacted erosion and sediment transport mechanisms. This left behind fingerprints in magmatic rocks, linking the evolution of Earth's biosphere with its internal processes.

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How Earth's internal processes impacted the evolution of its biosphere in deep time, and in what way the interaction between these different reservoirs is responsible for Earth habitability, remains debated. For instance, it isn't clear[1–4] if the oxygenation of Earth's atmosphere was triggered by modifications in its geosphere and/or biosphere. Improving our knowledge on how a changing geosphere impacts the biosphere, and vice versa, is therefore of paramount importance for a better understanding of our planets past and the reasons for its long term habitability. Writing in Nature Geoscience, Spencer and colleagues[5] describe a change in the correlation between the oxygen (O) and hafnium (Hf) isotopic signatures of zircon grains that are younger than 430 million years, an age contemporaneous with the spreading of vascular plants on Earth. They attribute this observation to a change in the composition of sedimentary material recycled into the deep Earth within subduction zones, mediated by the newly developed biosphere on the continents.

Figure 1: Desert plant in the Sultanate of Oman. Spencer and colleagues[5] suggest that the changing surface processes due to the spreading of land plants impacted the chemistry of sediments and the composition of subduction associated magmas.

The evolution of land plants started between the middle Cambrian and early Ordovician, some 515 to 470 million years ago[6]. The coverage of the continental crust with plants strongly influenced Earth surface processes by intensifying dissolution and chemical weathering of minerals, enhancing clay formation and impacting the morphology of river systems[7,8] (Fig.1). The effect of land plants on the erosion of the continents and the sedimentary routing system is exemplified by the strong increase in the abundance of mudstone around 450 to 430 million years ago[9], and by the circumstance that flood plains and meandering rivers started to appear in the geological record around the same time that vascular plants evolved[8].

Part of the sedimentary material that is produced by the physical and chemical erosion of the continental crust is deposited on the ocean floor and subsequently transported to subduction zones where it eventually reintegrates with the magmatic cycle. Thus, Spencer and colleagues set out to investigate if the major changes in Earth surface processes that were triggered by land plants, left behind chemical fingerprints in magmatic rocks of the continental crust. For this, they compiled O and Hf isotopic data from zircon grains. Changes in the O and Hf isotopic signatures can respectively be used to track surface weathering and the residence time of material on the continents[10]. Conceptually, one would not expect a correlation between the two isotopic compositions, neither in sediments nor in magmas produced along subduction zones, as the mechanism of rock alteration and the connected O isotope fractionation should be independent of the age of the rock and its Hf isotopic signature. However, based on the data compilation by Spencer and colleagues, this assumption holds true only for zircon grains that are older than around430 million years. Younger grains exhibit a negative correlation between O and Hf isotopic signatures. This sudden change from non-correlated to correlated happens contemporaneously with the spread of vascular plants, enhanced mudstone production, and the development of flood plains and meandering rivers, implying a causal relationship between these events.

Spencer and colleagues suggest that these changes in surface processes increased the source-to-sink transport time and the duration of surface weathering, leading to the coupling of the O and Hf isotopes in the sedimentary material deposited on the ocean floor. Their interpretation that land plants are responsible is corroborated by the lack of correlation between the two isotopic systems at any point between 1,200 and 440 million years ago. This time period included icehouse and greenhouse conditions, different orogenies and supercontinent cycles, and as such these influences can be discounted.

The study of Spencer and colleagues shows that the impact on erosion and sediment routing systems of the continental crust by the spreading of vascular plants was likely of global nature. Therefore, by examining the signals left in sedimentary and magmatic rocks, future studies may be able to gain insights into how fast land plants started to occupy different regions of the continents. Further work and verification against the sediment record will also be needed to more precisely evaluate which aspect of the changing weathering regime led to the correlation of Hf and O isotope signatures in the subducted material. The appearance of flood plains and meandering rivers may not have been the only process responsible. The spread of land plants could also have exposed larger parts of landmass interiors to intense chemical weathering and thus limited fast, physical erosion of old continental crust, aiding to couple the two isotope systems.

The findings of Spencer and colleagues illustrate how processes on Earth's surface and its interior are intertwined with its evolving biosphere. These results are sure to stimulate future research that uses the sedimentary record to track changing erosion and weathering patterns of the continental crust over Earth history.

References

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