Plants rooted in rocks

The rise and evolution of land plants fundamentally changed how rocks weathered, altering the biogeochemical and geomorphological processes of Earth with ongoing consequences for plants today.

Plants came very late to the party of Earth's evolution but have since substantially contributed to shaping today's world. The first land plants, such as mosses and liverworts, arrived about 480 million years ago[1], bringing fundamental changes to biogeochemical cycles. These rootless plants quickly evolved over the next 50 million years or so, leading to the expansion of vascular plants with complex root systems. The development of root systems enhanced the stability and complexity of sedimentary systems, changing water flow and reshaping the landscape completely. Thus, Earth dramatically and fundamentally changed as plants evolved. In this issue, two articles exemplify the coevolution of plants and Earth, with a specific focus on the interplay between plants and rocks.

Rocks, soil and plants constitute a critical zone where the geosphere and biosphere interact. Before soils became abundant, rocks were the main terrestrial source of nutrients. Rocks directly and indirectly provide nutrients to plants. To get the nutrients they need, plants can break up rocks and produce acids that dissolve them. Rock composition greatly influences the accessibility and abundance of nutrients that plants take up and thus can play a dominant role in shaping the plant biome and the ecosystems they inhabit. For example, in global mountainous regions, places predominantly covered by rocks with high water retention and abundant nutrients, such as claystones, often have lush vegetation and a rich animal species diversity[2].

On early Earth, rock weathering, a process driving biogeochemical cycles, happened less aggressively. The advent of land plants increased the rate of silicate weathering of rocks by a factor of 2 to 10 (ref. [3]). This step change caused atmospheric CO_2 to drop dramatically, which led the world to transit from a warm climate to a cold ice age. Boosted chemical weathering also enhanced organic carbon burial in

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sediments, and thus the accumulation of atmospheric oxygen. Evidence suggests that atmospheric oxygen reached modern levels soon after the emergence of land plants[4].

The evolution of root systems about 430 million years ago greatly changed how plants interacted with rocks. Roots can effectively break up rocks and promote weathering and the generation of sediment. They also reduce the mobility and erodibility of sediment. The spread of plants with root systems led to the stabilization of river banks and the accumulation of sediments in fluvial systems. A geomorphological comparison of modern vegetated and barren rivers has suggested that plants slow down meanders' migration of rivers by about ten times[5].

In addition to physical interactions with rocks, the emergence of plants altered chemical weathering with compositional consequences for the geosphere. Land plants likely facilitated substantial increases in mud production[6], which, together with increased mud retention in a stabilized sediment system, led to muddier rivers. Indeed, the amount of mud deposition jumped by more than one order of magnitude after the first land plants widely colonized Earth[6]. Mud-rich sediments were then recycled in subduction zones, leaving a compositional imprint on the crust. In this issue, an Article by Spencer et al. provides geological evidence to piece together these processes: the rise and evolution of early land plants induced a series of biogeochemical and geomorphological changes, leading to compositional changes recorded in continental rocks.

As plants have changed the composition of crustal rocks, rocks can impact the fate of plants. In another Article in this issue, Callahan et al. find that the variation in tree mortality observed during a recent period of drought in California can mostly be explained by differences in bedrock composition, with a larger scale of dieback in forests with weathered and nutrient-rich bedrock. Benefiting from abundant nutrients and water, forests in wet environments with more weathered bedrock often grow denser. However, lush vegetation is more vulnerable to drought as there is a heavier system to support. It turns out that in the case of California, forests that flourished in wet conditions experienced a higher proportion of tree deaths.

Today, with the development of mature soil, the contribution and interaction of rocks with plants can easily be ignored in the Earth system. However, given rocks impacts on hydrology, soil fertility and soil chemicals, they can still directly and indirectly alter plant growth and functionality. For example, more than 50% of aboveground carbon stocks in California are from wood plants that take up water from bedrock[7]. Therefore, the co-evolution of rocks and plants is ongoing. There is much still to learn about the interactions between them. ❐

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