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The authors declare no competing interests.
This article was published online on 22 November 2023.

Evolution

Landscape's overlooked role in steering biodiversity

Alexandre Pohl

Scientists have long sought to understand what drives biodiversity changes. A study unifies ideas about marine and terrestrial biodiversity in one explanatory framework, pointing to physical geography as dictating life's trajectory. **See p.115**

On page 115, Salles *et al.*[1] present numerical simulations of changing continental landscapes during the past 540 million years, representing the high-resolution changes in surface elevation (topography) on land and the associated sedimentary fluxes resulting from the effect of interactions between climate and plate tectonics on landscape. In the simulations, the flux of sediments generated by the erosion of the continents and then delivered to the oceans mimics the pattern of long-term changes in marine biodiversity reconstructed from fossil data, and simulated sediment cover on the continents correlates with plant biodiversity on land. These results suggest that landscape dynamics modulates the number of species that Earth can support (carrying capacity), and ultimately has dictated the evolution of biodiversity in the oceans and on the continents over geological ages. In this way, the results reconcile, for the first time, the histories of marine and terrestrial biodiversity in a single theory.

Reconstructions of the evolution of marine biodiversity on Earth, based on the compilation of palaeontological data, date back to a key publication[2] in 1981. Sampling and preservation biases in compiled fossil data have since been reduced and trends refined, and some biodiversity patterns seem robust (Fig. 1a). These include a strong increase in marine biodiversity during the Cambrian and Ordovician periods (539 million to 444 million years ago), stabilization during the second part of the Palaeozoic era (444 million to 252 million years ago), a large drop in biodiversity 252 million years ago at the boundary between the end of the Permian and start of the Triassic periods – corresponding to the largest mass extinction ever – and a subsequent rise to unprecedentedly high levels during the Mesozoic and Cenozoic eras (252 million years ago to today).

Plants on land showcase a completely different story. Broadly, the rate at which their biodiversity increased did not begin to change until the start of the Devonian period, around 420 million years ago – more than 100 million years after this change began in the oceans (Fig. 1b). Many hypotheses have been put forward to explain these temporal trends but there is no consensus, and most previous work considered marine and terrestrial biodiversity separately.

Salles and colleagues' model represents the interplay between tectonics and climate, which together drive the evolution of landscape – valleys, mountains and rivers – on our planet. Their model is driven by

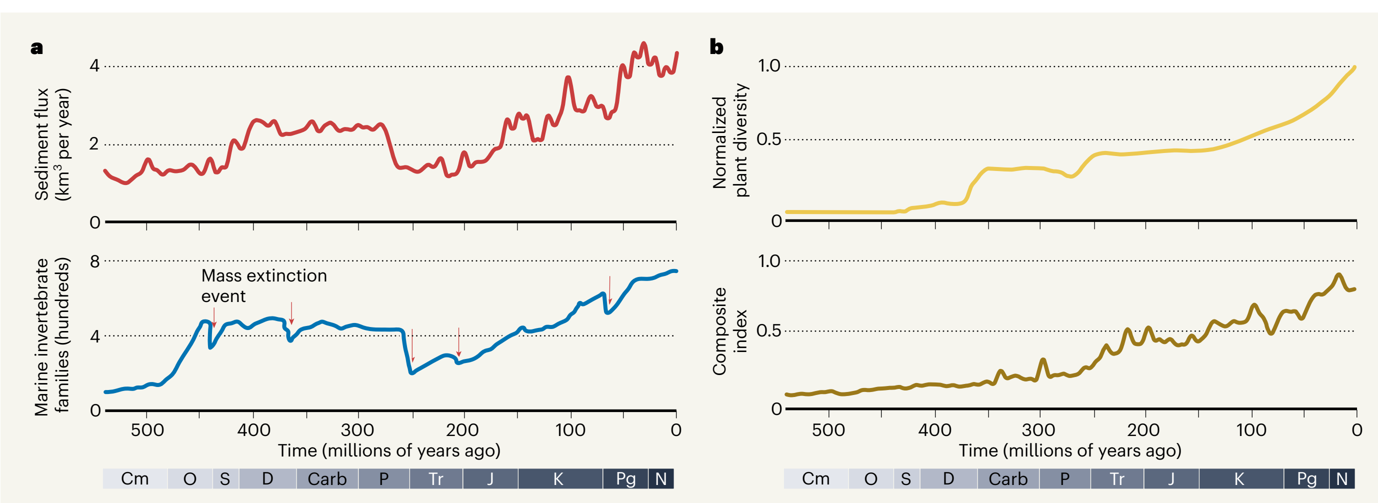

Figure 1 | Simulated landscape changes and the corresponding biodiversity changes. Salles *et al.*[1] simulated landscape dynamics over the past 540 million years and demonstrate that landscape changes might have driven the evolution of biodiversity in the oceans and on land. **a**, The simulated flux of sediments generated by the erosion of land-based rocks and delivered to the oceans correlates strongly in time with the level of biodiversity of marine invertebrates as reconstructed from fossil data[8]. Some drops in sediment flux have been followed by mass extinctions. **b**, To assess landscape effects on terrestrial plant biodiversity as tracked using fossils, the authors designed a simple metric, termed the composite index, to represent sediment cover on the continents and landscape variability (heterogeneity). Changes in the value of this index mirror long-term trends in land-plant diversity[9]. The indicated periods or eras are Cm, Cambrian; O, Ordovician; S, Silurian; D, Devonian; Carb, Carboniferous; P, Permian; Tr, Triassic; J, Jurassic; K, Cretaceous; Pg, Palaeogene; N, Neogene.

palaeogeographical reconstructions describing changes in shorelines, large-scale topography and the position of the landmasses over the past 540 million years, as well as by climatic simulations showing the concomitant changes in the water cycle. The model simulates elevation on land at high resolution (5 kilometres) using a source-to-sink approach, which means that sediments eroded on land are tracked while they travel in river networks until they reach the ocean. By doing so, the model also represents the location and magnitude of deposition of sediments on the continents.

The model was calibrated and validated in the present day before being used to analyse the deep geological past. This approach forms part of current efforts to build a virtual planet, in which a variety of processes are integrated to generate a digital twin of Earth, permitting researchers to gain mechanistic understanding of the coupling between Earth's surface and its interior.

The simulations demonstrate a striking, positive correlation between marine biodiversity and the flux of sediments delivered to the ocean (Fig. 1a). Nutrients constitute the fundamental building blocks required by organisms to generate their tissues. In the ocean, nutrients come mainly from the river-provided input of dissolved chemical species generated by the alteration of rocks on land. Postulating that the quantity of nutrients delivered to the ocean scales with the sedimentary flux, the authors interpret the correlation between the simulated sedimentary flux and marine biodiversity as reflecting the nutrient-driven variation in the carrying capacity of the oceans.

For land, the authors designed an index representing the landscape's capacity to host diverse species. This index combines the extent of sediment cover on land and the landscape variations (heterogeneity). The former represents the area available for land plants to develop their rooting networks, whereas the latter is a way to represent the number of distinct ecological niches, and thus the potential number of species. The biodiversity of land plants strongly correlates over time with this index, suggesting that landscape dynamics have also set the agenda for the evolution of land plants during the past 540 million years (Fig. 1b).

These results are innovative in many ways. They explain the evolution of terrestrial and marine biodiversity and notably suggest that limited sediment cover and low landscape heterogeneity delayed the development of land plants before the Devonian period — which would explain the previously mysterious temporal lag of more than 100 million years between the increase in marine biodiversity and the subsequent increase in terrestrial biodiversity. This study offers a fresh reading of biodiversity on geological time scales — one that considers a carrying capacity of the environment, but does not need to account explicitly for ecological innovations and evolution. It thereby raises questions about existing models that do account for such factors[3,4].

In the authors' framework, several of the largest mass extinctions followed large drops in the sediment flux to the ocean (Fig. 1a). This is notably the case for the largest such mass extinction, at the Permian–Triassic boundary, which post-dates the largest decrease in sediment flux simulated over the past 540 million years. The possibility that nutrient shortage could constitute an important precondition for extinctions contrasts with the widely held idea that nutrient increase would drive these extinctions[5]. In this view, a consequence of nutrient increase is that photosynthetic algae in the shallow ocean would produce extra organic matter, which would then be degraded by bacteria in deeper water consuming dissolved oxygen, ultimately leading to ocean deoxygenation.

Simulations such as this work by Salles and colleagues could be refined by including information on the types of rock eroded on land and refining details concerning the location and elevation of ancient mountains. Moreover, the conclusions are based on temporal correlations, and alternative interpretations are possible. The correlation between marine biodiversity and the simulated sediment flux might imply that biodiversity curves mostly reflect preservation biases — with strong fossil records, and thus high levels of documented biodiversity, corresponding to periods when marine sedimentation rates are high.

To go beyond temporal correlations and to assess causality, it would now be beneficial to quantify the effect of landscape dynamics on biodiversity using macroecological models[6] based on the high-resolution, open-access layers of environmental data produced in this study (see go.nature.com/41pqrz8). This would help to confirm or revise the interpretations. It might also assist in explaining some model–data mismatches, such as a lack of pointers to the Great Ordovician Biodiversification Event[7] in the simulations.

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The author declares no competing interests.
This article was published online on 29 November 2023.

Nanotechnology

Self-assembling structures close the gap to trap light

Takashi Asano

An innovative method uses the intrinsic attractive force between silicon surfaces that are separated by a tiny gap to engineer structures that can confine light — offering an ideal set-up for manipulating single photons. **See p.57**

Light is generally thought of as an electromagnetic wave that propagates through space, but it is actually possible to trap it in a tiny region for a short time[1–5]. Confining light increases its energy density, and thus strengthens the intensity of its electric field. This enhances the interaction between light and matter — an effect that can be used to generate single photons on demand[6], enabling the processing of quantum information[7–9]. One of the most promising light-confinement techniques uses silicon, and can therefore benefit from the advanced silicon-processing technologies of the electronic-circuit industry. But this method requires the silicon to be fabricated with nanoscale features that are difficult to engineer. On page 57, Babar *et al.*[10] report a clever approach that uses attractive interactions to create gaps that solve the problem.

Two main techniques are used to confine light: plasmonics[11,12], which involves metallic nanostructures; and photonics[1–4], which uses materials, known as dielectrics, that are transparent to light and have a high refractive index. Plasmonics works on the principle that the wavelength of light becomes shorter