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News & views

Palaeontology

Faeces and vomit record the rise of dinosaurs

Lawrence H. Tanner

The earliest known dinosaur fossils are at least 230 million years old, and by 200 million years ago, dinosaurs dominated global ecosystems. Reconstructing food webs using fossil evidence of feeding activity helps to explain this ascendency.

The earliest dinosaurs were relatively small bipedal animals, distinguished from their closest ancestors by subtle differences in hip structure. They appeared at least 230 million years ago (and perhaps earlier[1]), during the Carnian stage (237 million to 227 million years ago), the first of the three stages comprising the Late Triassic Period (237 million to 201 million years ago). This evolutionary milestone is documented by the fossil record in the southern part of what was, at the time, the Pangaean supercontinent. However, for tens of millions of years, these early dinosaurs remained a relatively minor component of a global landscape crowded with other reptilian forms, and clear ecosystem dominance by dinosaurs did not occur until the start of the Jurassic Period (201 million to 145 million years ago). Writing in *Nature*, Qvarnström *et al.*[2] report evidence that helps to explain this rise to prominence.

Dinosaurs belong to a broad group of reptiles called archosaurs. Members of this group — for example, large herbivores called aetosaurs, as well as carnivorous creatures called rauisuchids and crocodile-like phytosaurs — populated the Late Triassic environment. Prominent non-archosaur reptiles at the time included large herbivores called dicynodonts. Across the 30 million years from the first known appearance of dinosaurs to their dominance at the beginning of the Jurassic Period (Fig. 1), dinosaurs increased in size and diversity as other reptile forms and most large amphibians disappeared. Decades of collecting and analysing skeletal remains have not clarified how and why this particular group rose to dominance, apparently at the expense of most others, and the incomplete nature of the fossil record has generated more controversies than conclusions.

Over the years, various scenarios have been proposed to explain the transition from a global landscape dominated by non-dinosaurian reptiles to one in which the dinosaurs were ascendant. One model proposes that competition was a key driver: other ecosystem inhabitants were outcompeted by the early dinosaurs, which had some key physiological or anatomical advantages[3,4]. In particular, it has long been thought that the upright stance of dinosaurs, resulting from the positioning of their hind limbs directly beneath their body, combined with their flexible ankles, made them highly agile and efficient competitors in the Late Triassic.

An alternative model proposes that random processes of environmental change, such as catastrophic volcanic eruptions, climate change or an asteroid impact, caused the decline or elimination of some non-dinosaur groups. This created opportunities for dinosaurs, which, by chance, were comparatively better adapted to the changes[5,6].

Qvarnström and colleagues set out to clarify the processes responsible for the early diversification of dinosaurs by reconstructing food webs of organisms represented in fossil samples from the Late Triassic through to the Hettangian stage (201 million to 199 million years ago), the first stage of the Jurassic Period. Limiting their study to samples from south-central Poland, the authors examined more than 500 bromalites. These are fossils of material from an organism's digestive system; for example, faeces, vomit and intestinal

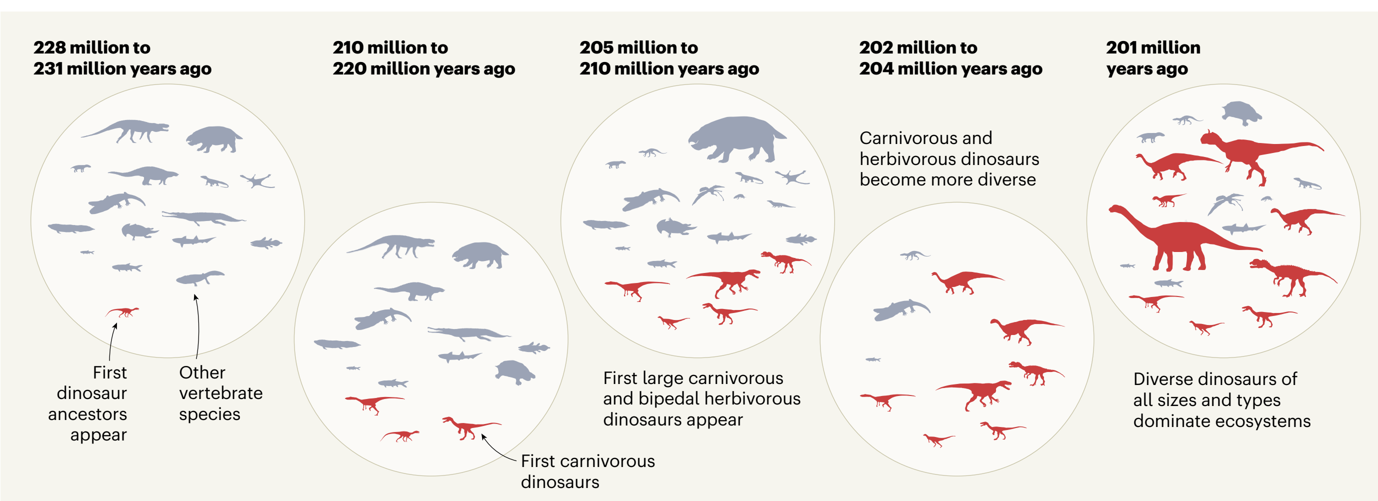

Figure 1 | The rise of the dinosaurs. Over time, from the start of the Late Triassic Period to the early Jurassic Period (between 231 million and 201 million years ago), dinosaurs (red) became more prominent and larger than non-dinosaurian vertebrates (grey), according to fossils from Poland. Qvarnström *et al.*[2] examined fossilized faeces and vomit to investigate the food webs underlying these changes. (Adapted from Fig. 1 of ref. 2.)

contents. By comparing the size, composition and abundance of the bromalites with data from fossil skeletal and footprint records, the authors were able to infer the identity, feeding behaviour and relative size and prevalence of the organisms that produced them. On the basis of these interpretations, Qvarnström and colleagues generated food webs from specific time intervals, which track the temporal shifts in the populations and body sizes of both primary consumers (herbivores) and secondary consumers (carnivores).

The methodology of this study is particularly creative, including techniques such as optical microscopy to examine thin sections; chromatographic and mass spectrometric methods to extract and separate plant remains and scanning electron microscopy to analyse them; and synchrotron microtomography to produce 3D images of the internal structures of the samples. The food remains identified in the bromalites included a wide variety of plants and cuticles from invertebrates called arthropods — often with preservation on a level that enabled some basic assignment of specimens to taxonomic groupings — as well as various vertebrate bones, scales and teeth.

The skeletal fossils, footprints and bromalites from sites in Poland provide a series of discrete temporal snapshots that demonstrate a transition from a world with few dinosaurs to one in which they dominated (Fig. 1). This transition occurred against a backdrop of climatic factors that caused shifts in floral communities and might have driven changes in feeding behaviour. The first step in the process was the appearance of small omnivores that were the direct ancestors of early dinosaurs. These eventually evolved to become the early herbivorous and carnivorous dinosaurs that gradually replaced their competitors. The climate-mediated disruption of vegetation communities would favour dinosaurs that were able to feed on a wide variety of food sources, resulting in the emergence of larger and more diverse herbivorous dinosaurs later in the Triassic, and large carnivorous dinosaurs by the start of the Jurassic.

This study advances our understanding of dinosaur diversification and dominance by providing empirical evidence of a mechanism based on random (stochastic) processes. However, the research is limited in its context and scope, and thus should be seen as a starting point for further work. If the replacement of non-dinosaurs with dinosaurs was a consequence of disruptions to the climate, future studies should be able to confirm that these climatic changes happened locally in Poland. Major global climate events of the Late Triassic included an extended humid interval during the Carnian stage (the Carnian Pluvial Episode), and potentially extreme disruptions during the volcanic eruptions that occurred in the Central Atlantic magmatic province in the last part of the Triassic Period. Furthermore, regional changes in the climate could have resulted from plate tectonics — for example, the northward drift of the Polish Basin during the Late Triassic might have altered the area's location in relation to climate zones.

This study is a detailed examination of the fossil record of just one basin. Southern Poland was in the northern part of the Pangaean supercontinent, but the fossil record clearly suggests that dinosaurs first appeared in southern Pangaea, and that they might have diversified before reaching the Northern Hemisphere[7,8]. Using the techniques from this study in other locations would provide a more global context and build a nuanced picture of the connection between Late Triassic environmental disruptions and the ascendancy of the dinosaurs.

Lawrence H. Tanner is in the Department of Biological and Environmental Sciences, Le Moyne College, Syracuse, New York 13214, USA.
e-mail: tannerlh@lemoyne.edu

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