and suppresses the formation of insulating states. As a result, in a phase diagram for MATBG, regions that show an insulating state in untuned MATBG show a superconducting state in dielectrically tuned MATBG. Furthermore, when a magnetic field is applied, these previously insulating regions are associated with an increased propensity to form Landau levels (narrow, field-induced electron energy bands) at remarkably weak field strengths.

Altogether, these findings call into question earlier interpretations of certain observations in MATBG as manifestations of an unconventional form of superconductivity[3]. Instead, although it is too early to be totally certain, simpler explanations might be more relevant. These include theories centred around an effect known as quantum-Hall orbital ferromagnetism, and also conventional superconductivity mechanisms that result from a coupling between electrons and phonons (lattice vibrations), possibly assisted by electron correlations.

The enormous potential for fundamental progress implicit in these developments, as well as the challenges they imply for understanding the mechanisms involved, should be investigated far beyond the specific material at hand. Experimental observations of MATBG vary substantially from sample to sample, raising the issue of reproducibility[8]. Addressing this problem will probably become more urgent, because dielectric engineering should lead to even greater sample diversity. The tunability of electronic quantum materials, in terms of interactions and density, is increasing substantially, and is catching up with that of synthetic platforms such as ultracold atomic gases deposited in optical lattices. Therefore, we could soon witness the beginning of a new era of discoveries in tunable electronic quantum matter.

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Palaeontology

Hard evidence from soft fossil eggs

Johan Lindgren & Benjamin P. Kear

It is thought that dinosaurs laid hard-shelled eggs, whereas ancient marine reptiles gave birth to live young. However, new discoveries of fossilized soft-shelled eggs challenge these long-held tenets of reproductive evolution. **See p.406 & p.411**

The appearance of the amniotic egg marks a key event in the evolutionary history of vertebrates. Its major adaptive advantage is the amnion — an enclosing membrane that prevents the embryo from drying out, and the principal feature to which the amniotic egg owes its name. Another crucial development was the addition of a tough outer shell that provides protection and mechanical support. This allowed the first reptiles to colonize terrestrial environments more than 300 million years ago, and paved the way for the rise of birds and mammals.

Because hard-shelled, calcareous eggs, like those of birds, are reinforced by crystalline calcium carbonate, they are well represented in the fossil record. By contrast, soft-shelled eggs, such as those of most lizards and snakes, have leathery outer coverings that decay rapidly and thus are only rarely preserved. Now, Norell *et al.*[1] (page 406) and Legendre *et al.*[2] (page 411) describe multimillion-year-old soft-shelled eggs that might alter the prevailing view of dinosaur reproduction, and possibly also change current thinking about ancient marine reptiles.

Since their earliest documentation in 1859, dinosaur eggs and eggshells have been found almost worldwide, and occasionally even include the remains of associated embryos[3]. Discoveries indicating communal nesting[3] and brooding[4] have also revealed the antiquity of bird-like parenting behaviours in dinosaurs. Yet, despite research shedding light on the biochemistry[5] and coloration[6] of fossil eggs, the known diversity of egg-laying dinosaurs is still limited to only a few groups, including the gigantic sauropods, carnivorous theropods and duck-billed hadrosaurs. Moreover, most dinosaur eggs are geologically rather young, being derived from rocks of Cretaceous age[3] — the last and longest period of the Mesozoic era, lasting from about 145 million to 66 million years ago.

Given that modern crocodiles and birds lay hard-shelled eggs, the conventional assumption has been that their close ancient relatives, the dinosaurs, must have likewise produced eggs that had calcareous shells, although this is at odds with the puzzling variety of shell microstructures evident between different dinosaur groups. Norell and colleagues now propose that such anatomical inconsistencies arose because calcareous eggs evolved independently at least three times in dinosaurs, and in each instance might have developed from a different type of ancestral soft-shelled egg.

Norell *et al.* base their conclusions on microstructural and organochemical data obtained from non-calcareous fossil eggs (Fig. 1) containing embryos of the sauropod-like dinosaur *Mussaurus* from the Late Triassic (Norian stage; about 227 million to 209 million years ago), and the horned dinosaur *Protoceratops*, from the Late Cretaceous (Campanian stage; about 84 million to 72 million years ago). The authors' computer-generated evolutionary models also suggest that the scarcity of dinosaur eggs excavated from pre-Cretaceous (older than 145 million years) rocks probably reflects the poor preservation potential of parchment-like eggshells. Furthermore, because soft-shelled eggs are sensitive to both desiccation and physical deformation, it seems reasonable to speculate that they were laid and then buried in moist soil or sand, and relied on external incubation — such as heat derived from decomposing plant matter — rather than a brooding parent.

Unlike dinosaurs, mosasaurs (an extinct family of aquatic lizards) and other Mesozoic marine reptiles, such as the dolphin-like ichthyosaurs and long-necked plesiosaurs, are usually considered to have given birth to live young[7] — a reproductive strategy termed viviparity. However, this opinion might now be about to change, too. Legendre and colleagues report their discovery of a fossil egg about the size of a football from a latest Cretaceous (about 68 million years ago) nearshore marine setting on what is today Seymour Island, off Antarctica. The authors name their fossil egg

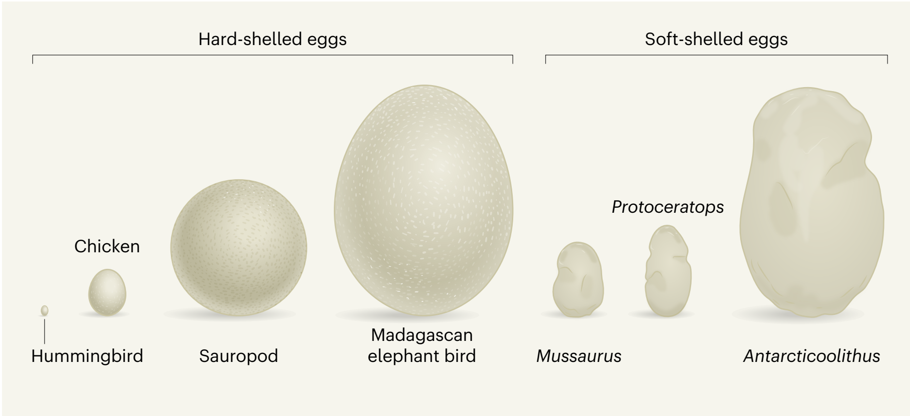

Figure 1 | Egg evolution. Hard-shelled eggs vary in size, from small eggs, such as that of a hummingbird or chicken, to the huge egg that belongs to the extinct Madagascan elephant bird, *Aepyornis maximus*. A few dinosaur groups, including sauropods, laid hard-shelled eggs. Norell *et al.*[1] report the discovery that two types of dinosaur laid soft-shelled eggs. The authors analysed *Mussaurus* eggs that are between 227 million and 209 million years old, and *Protoceratops* eggs of between 84 million and 72 million years old. This finding challenges the generally accepted view that dinosaur eggs were always hard-shelled, in turn suggesting that the earliest eggs laid by dinosaurs were soft-shelled. Legendre *et al.*[2] report the discovery of a huge originally soft-shelled egg in Antarctica, a specimen they call *Antarcticoolithus*, that is about 68 million years old. Legendre and colleagues hypothesize that this might have been laid by a marine reptile. However, Norell and colleagues' discovery raises the possibility that *Antarcticoolithus* was instead laid by a dinosaur.

specimen *Antarcticoolithus*, after the Antarctic continent and the ancient Greek words for egg and stone. *Antarcticoolithus* is among the largest eggs ever recorded (Fig. 1), being rivalled in volume only by those of some non-avian dinosaurs and the extinct Madagascan elephant bird, *Aepyornis maximus*. Notably however, these other egg types are characterized by thick calcareous shells, whereas *Antarcticoolithus* has a thin and presumably originally soft covering.

Although cautiously pointing out that no embryonic remains were found in the fossil egg, Legendre *et al.* hypothesize that it might have been laid by a giant marine reptile, and perhaps most feasibly a mosasaur, on the basis of structural similarities to the leathery eggs of lepidosaurs — the group that includes mosasaurs, living lizards, snakes, amphisbaenians (burrowing worm lizards) and the lizard-like tuatara, *Sphenodon punctatus*. Furthermore, because mosasaurs had streamlined bodies and thus were unable to move on land[8], Legendre and colleagues propose that egg laying must have taken place under some depth of water. Nevertheless, although modern viviparous lizards certainly give birth to fully developed young that are surrounded by thin coverings (mainly extraembryonic membranes)[9], the few known fossils of pregnant mosasauroids (the group containing mosasaurs and their ancestors) have not been found associated with eggshell debris[10]. Crucially, mosasaurs were also air breathers; therefore, laying a soft-shelled egg under water would have entailed a considerable risk of drowning for the emerging newborn.

Identifying the elusive producer of the *Antarcticoolithus* egg becomes even more intriguing given the findings of Norell *et al.*, which could implicate some form of dinosaur as the proud parent. Indeed, the total estimated weight of *Antarcticoolithus* clearly approaches those of the largest non-avian dinosaur and bird eggs, and both these groups have a history of fossil occurrences in Antarctica[11]. Dinosaur parentage thus at least seems plausible for *Antarcticoolithus*, which might have been laid on land and then washed out to sea as a discarded eggshell. This could have remained buoyant for some time because of trapped air, before finally sinking to the sea floor, where it was buried in sediment and eventually fossilized. Let us hope that future discoveries of similarly spectacular fossil eggs with intact embryos will solve this thought-provoking enigma.

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Coronavirus

A race to determine what drives COVID-19 severity

Marios Koutsakos & Katherine Kedzierska

Efforts are ongoing to find which human or viral factors underpin whether a person with COVID-19 will develop severe symptoms. Clinical evidence linked to two viral lineages now provides key insights into this enigma. **See p.437**

The coronavirus known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) emerged in late 2019, and certain aspects of the disease it causes — COVID-19 — continue to baffle clinicians and researchers. It is estimated that SARS-CoV-2 has already infected more than 9 million people and claimed more than 450,000 lives worldwide, and this pandemic has paralysed economies globally. On page 437, Zhang *et al.*[1] present data on the evolution of two major lineages of SARS-CoV-2, together with information regarding human-host determinants of disease severity from their analysis of 326 people in Shanghai, China, who were infected with SARS-CoV-2.

SARS-CoV-2, which caught the world by surprise, was initially thought to have 'jumped' to humans from an animal host at the Huanan Seafood Wholesale Market in Wuhan, China. When the first cases of a previously unknown disease, initially described as 'a severe