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Perspectives — Palaeontology in 2019

by The Palaeontology [online] editorial board[*1]

Introduction:

At the turn of most years, the editorial board at Palaeontology [online] takes the opportunity to reflect on the past year in palaeontology. Given that we published a wonderful overview of Diploporitans in January, this year we've moved our look over our favourite studies from last year to February. Palaeontology and associated disciplines are fast-moving and exciting areas of science — looking back at 2018 lets us highlight just a few of the key developments that really show this. Picking just one article each is difficult, and we have been forced to miss out many of the hundreds of exciting papers published in the past 12 months. Nevertheless, we hope that our choices reflect the breadth and depth of palaeobiological research in the twenty-first century. The papers include insights into the evolution of animals, the origin of colour in dinosaur eggs, the discovery of new, unusual fossil echinoderms, and insights into the origins of plant roots. So, in alphabetical order, here are the members of our editorial board with their highlights.

Russell Garwood — Deline *et al.*, 'Evolution of metazoan morphological disparity'

One of my favourite papers of the past year has been the work of Deline *et al.*, which was published in August. This work looks at the animal kingdom as a whole, and analyses the variation that we see across it. The authors have compiled a cladistic character matrix that includes members of every major animal group. In brief, they have put together a list of the characters (for example, presence of a head, eyes, legs) possessed by 212 animal species within 34 phyla. In total, they managed to code 1,767 characters. This is, to me, a really significant achievement in its own right — and a valuable resource that scientists can use in the future. The authors then ran a wide range of tests on this new data set to try to improve understanding of how animals have evolved.

A key question they addressed is whether groups reach their maximum disparity — that is, variety of forms or morphologies (see Fig. 1) — shortly after they evolve, or whether they continue to become more diverse as they evolve. The answer? Well, it seems both could be the case. Many groups reach the disparity we see today quite early in their evolutionary history, but some really important ones — for example, vertebrates and their kin, and arthropods — become increasingly diverse as they evolve. In short, major episodes of innovation don't necessarily occur at the beginning of a group's history.

The data also suggest that phyla look so different from each other today because of the extinction of intermediate forms — that is, lineages that share characteristics of major modern groups have gone extinct over time. The authors also have a go at investigating the driving force behind the patterns they report. They find that disparity is correlated with the size of the genome, and the range in a group of molecules called microRNAs, which regulate the expression of genes. Deline *et al.* suggest that the evolution of this system could have influenced the disparity we see in animals, but also that factors outside the groups' genetics — such as the environment that they live in — also have an impact.

I like this paper for a number of reasons. It is asking a wide range of interesting and important questions about evolution, using a major and really diverse group. The team has created a really useful data set, and then used it to explore a number of areas in one go: I've only highlighted one here! It's a really neat way to do science, and also quite a brave one (what would have happened if the data set hadn't shown anything?). And, like lots of exciting science, it leaves us with a whole bunch of new, but potentially more specific, questions we can ask in the future.

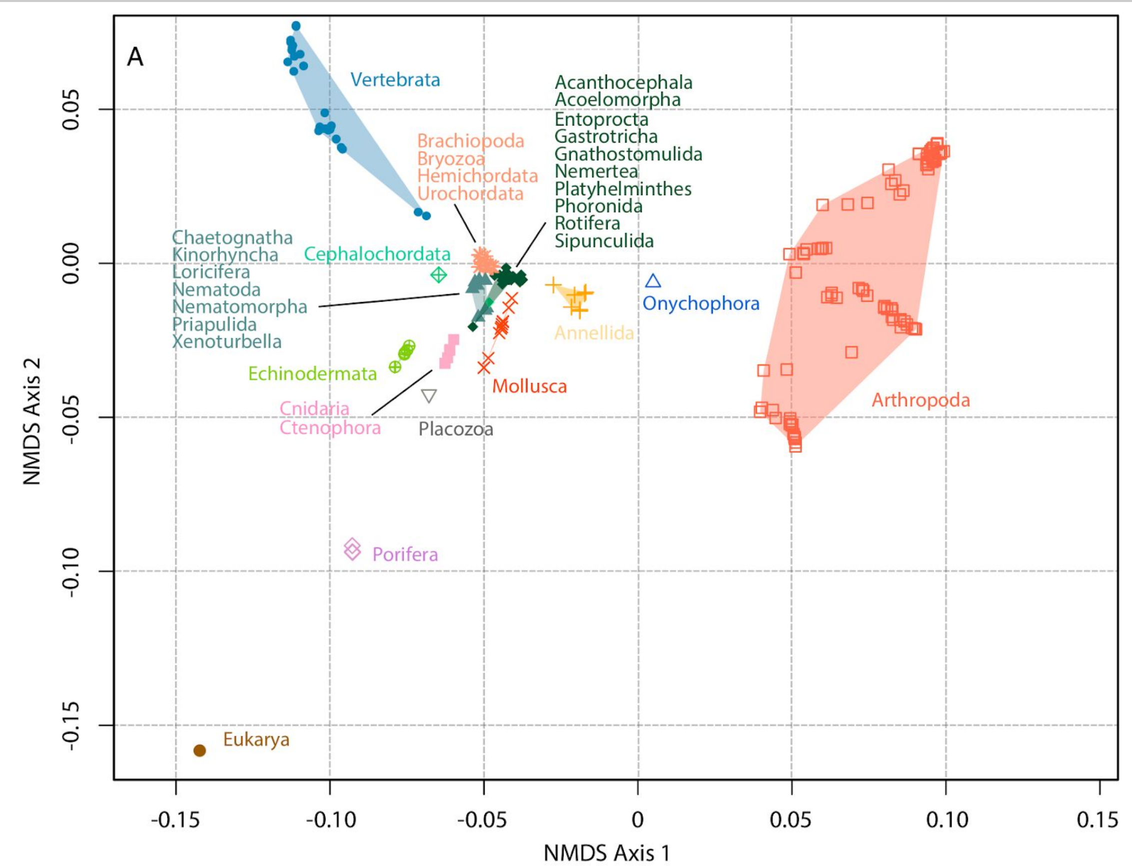

Figure 1 — Plot based on a statistical technique called nonmetric multidimensional scaling. This takes a large number of dimensions in a data set (in this case, characters that record the morphology of a large number of animals), and then allows them to be plotted on a few axes. The more different the morphology of the groups, the further away they appear from each other on this plot. Modified from Deline *et al.* (2018).

Stephan Lautenschlager — Wiemann *et al.*, '[Dinosaur egg colour had a single evolutionary origin]'

My favourite paper of 2018 was published in October, although Easter would have been much more fitting. Wiemann and colleagues' study focuses on eggs — more specifically, dinosaur eggs. This by itself is not that spectacular. We have known for more than a century that dinosaurs laid eggs like modern birds; for several decades, we have also had clear fossil evidence that birds are the descendants of dinosaurs. So what makes this study so interesting? The eggs of modern birds are unique among vertebrate eggs in showing a huge variety of colours, hues and patterns. It was generally assumed that this was a fairly modern innovation of birds, but Wiemann and colleagues' study demonstrates that coloured eggs date back more than 150 million years and probably had a single origin, within dinosaurs. Using Raman microspectroscopy (a technique that exploits the scattering pattern of light to identify molecular structures and material composition), the authors searched for traces of pigments in fossilized dinosaur egg shells (Fig. 2). With this method, they were able to identify two pigments — one responsible for giving the egg a blue-green hue, and another resulting in a red-brown hue. However, not all dinosaur eggs had the same colour and pattern. Some theropod dinosaurs, such as *Deinonychus*, laid blueish-green eggs with dark speckles, whereas others laid white to beige eggs. Interestingly, many herbivorous dinosaurs, including sauropods and hadrosaurs, laid eggs without any pigments. Those were probably more similar to the eggs of modern crocodiles.

But why did different dinosaur groups lay differently coloured eggs? Probably for the same reason that modern bird eggs show such a colourful variety. Coloured and speckled eggshells probably helped to camouflage eggs in open nests, and might also have helped the breeding parents to identify their own eggs (perhaps to avoid nest parasitism from cuckoo-like dinosaurs planting their eggs in other nests). The plain eggs of sauropods and ornithischians, by contrast, were probably left in nests covered by soil and dirt, making camouflage unnecessary. Eggs of different species have in fact been found in different styles of nest, which does support these results.

This study is one of several showing how many features associated with modern birds (such as feathers) have been around for millions of years in their ancestors. At the same time, this goes to show that although we have known many of these fossils for years, if not decades, new results can be obtained with the help of new methods and technologies.

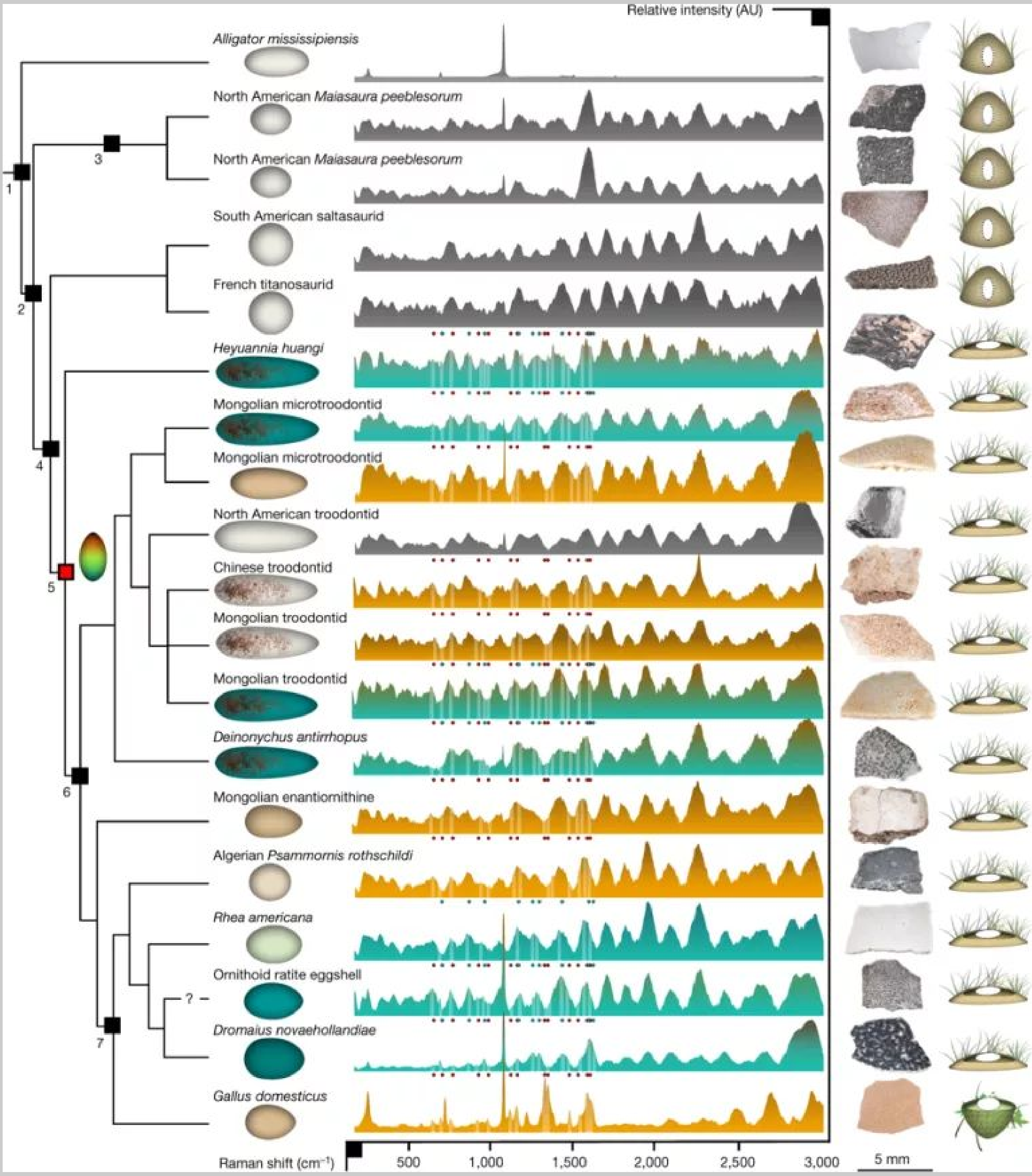

Figure 2 — Egg colour and speckling patterns of different dinosaurs and modern birds reconstructed by Raman spectroscopy. Different nest styles associated with each species shown on the right. Modified from Wieman et al. (2018).

Imran Rahman — Lefebvre *et al.*, '[Exceptionally preserved soft parts in fossils from the Lower Ordovician of Morocco clarify stylophoran affinities within basal deuterostomes](#)'

My favourite paper was actually only officially published this month, but given that it first came online in November 2018, I think it still counts! The study in question is by Lefebvre and colleagues, who described new fossil echinoderms from 480-million-year-old rocks in Morocco. The fossils belong to an extinct class called the stylophorans, which are arguably the most controversial group of fossil echinoderms ever known. The evolutionary relationships of stylophorans are hotly contested by palaeontologists, in part owing to disagreements about what soft parts were located inside the single appendage extending from the main body. Some have suggested that this appendage was a muscular tail for moving the animal over the sea floor, whereas others thought it represented a feeding arm that housed tube feet, similar to those of modern echinoderms. This disagreement stems from the fact that soft parts had never previously been described in a fossil stylophoran, leaving the interpretation of the appendage uncertain.

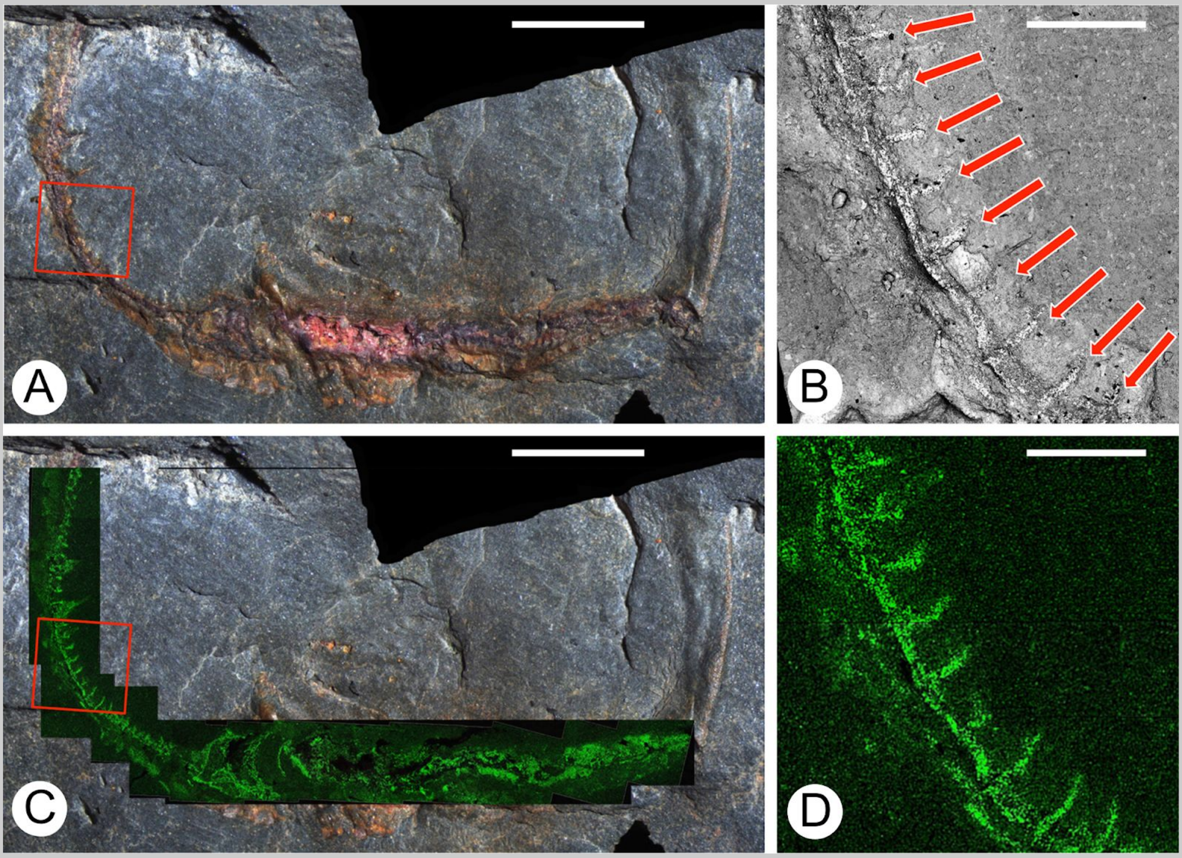

Figure 2 — Fossil stylophoran from the Fezouata biota of Morocco. A, C. Photographs and elemental maps of specimen in side view. B, D. Magnified views of box shown in A, C. Internal soft parts preserved in iron are shown in green in C and D. Modified from Lefebvre *et al.* (2019). Scale bars: 5 millimetres (A, C), 1 millimetre (B, D).

Lefebvre and colleagues were able to address this debate through the discovery of new, exceptionally preserved fossils. The fossils come from the Fezouata biota, a deposit, or Konservat-Lagerstätten, in southeastern Morocco. Similar to other famous Lagerstätte, Fezouata preserves the soft parts of animals, as well as their hard parts, and thus offers unique insights into past life. Incredibly, some of the stylophorans described by Lefebvre *et al.* have soft parts preserved inside the single appendage. In at least one specimen, these soft parts consist of a canal along the length of the appendage, with tube-like extensions coming off it to the sides (Fig. 3). Chemical analyses demonstrate that the soft parts are rich in iron, clearly distinguishing them from the rest of the fossil. The organization of the soft parts is almost identical to what we see in many modern echinoderms, which possess a series of fluid-filled canals (the water vascular system). This has a number of functions in living echinoderms, but one of the most important is feeding; for example, tube feet are used to capture food particles suspended in the water. The new Moroccan fossils make it highly likely that stylophorans used their single appendage primarily as a feeding arm, although they might also have been capable of moving slowly over the sea floor.

The finding that stylophorans possessed a feeding arm does not in itself unambiguously resolve the group's relationships with other echinoderms. Nevertheless, this is a key discovery that greatly enhances our understanding of the palaeobiology of an important fossil group. It is discoveries such as this that drive palaeontology forward, by shedding new light on old questions. Who knows what we will find next!

Alan Spencer — Hetherington and Dolan, 'Stepwise and independent origins of roots among land plants'

One of my favorite papers of 2018 was published by Hetherington and Dolan in *Nature* and shed new light on one of the fundamental questions associated with early plant terrestrialization: when did plants evolve roots?

All vascular plants we know today produce roots — which have important roles in nutrient and water uptake, ground anchorage and the symbiosis, or close mutual relationship, of plants and fungi. Roots are characterized by a self-renewing structure called a root meristem. This appears at the root tip and is covered by a 'root cap' allowing the roots to be guided by gravity through the substance in which the plant is growing. To date, the fossil record has hinted at root-cap development with known examples from the Carboniferous period (356 million years ago to 299 million years ago) and the Permian period (299 million years ago to 252 million years ago), but poor preservation of earlier land plants has hampered our understanding of where, when and how they first developed. In their paper, Hetherington & Dolan re-investigated historical plant specimens from the 407-million-year-old Rhynie chert Lagerstätte (Scotland, UK) and discovered in the species *Asteroxylon mackiei* the earliest meristems without root caps associated with a terrestrial ecosystem (see Fig. 4).

Through a series of observations using the exceptional preservation of other plant tissues as a basis, they ruled out the loss of root-caps through taphonomic processes. They also looked for evidence at the cellular level in the preserved promeristem, where cell-division patterns can indicate root-cap formation. They found that the pattern was inconsistent with the development of root caps. However, the cell patterns indicated that *A. mackiei* had a continuous surface called the epidermis. To test this hypothesis, Hetherington & Dolan constructed 3D models of the meristem surface using confocal microscopy.

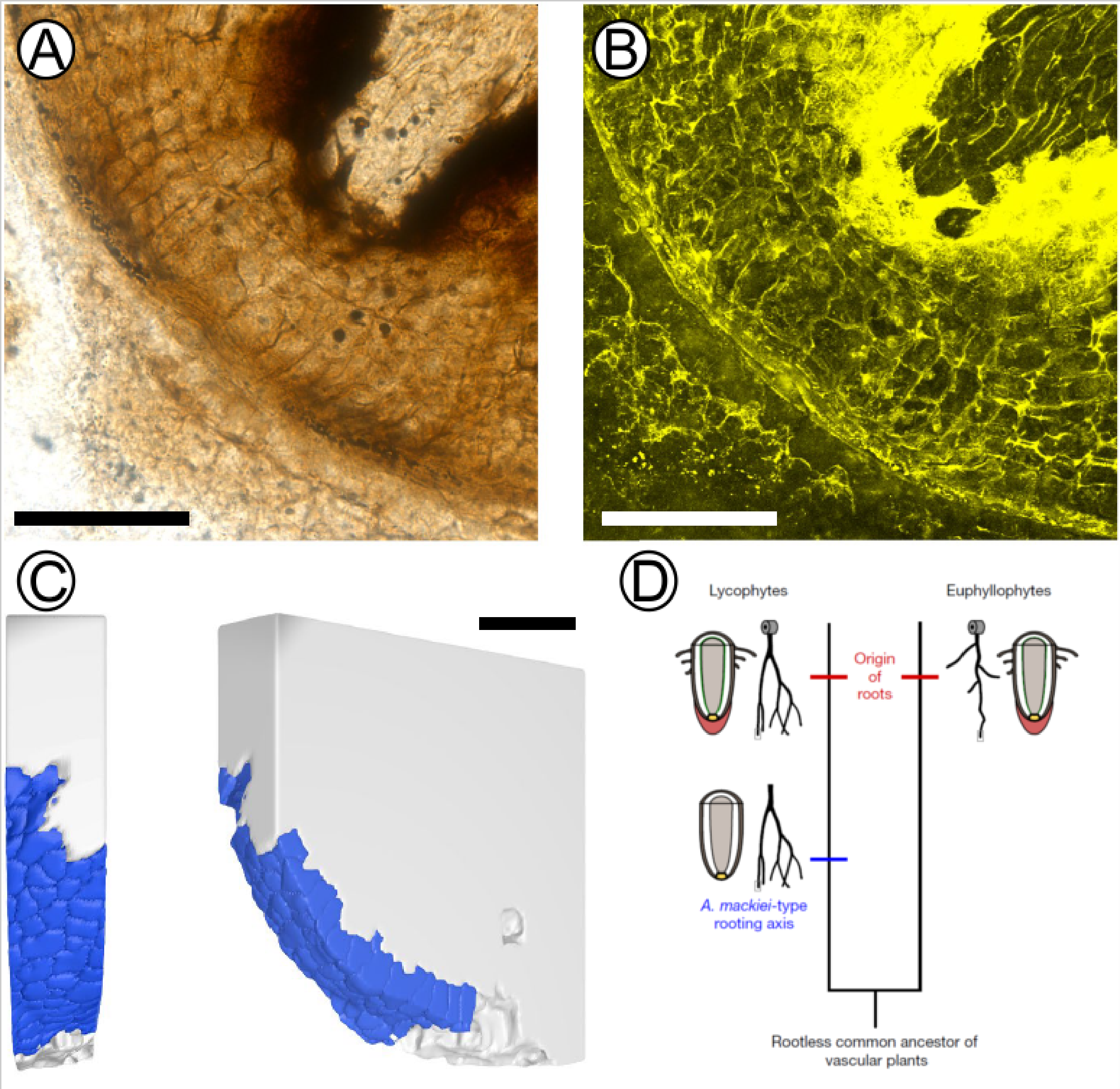

Figure 3 — A, B. Images showing that the cell-division patterns in meristems of the rooting axes of *A. mackiei* are inconsistent with the formation of root caps — taken with a transmitted-light microscope (A) and a confocal laser microscope (B). Scale bars 100 micrometres. C. Three-dimensional model showing that the meristems of the rooting axes of *A. mackiei* were covered by a continuous layer of epidermis and lacked a root cap. Scale bar 50 micrometres. D. A diagram showing the stepwise manner by which roots of extant lycophytes might have evolved. Modified from Hetherington & Dolan (2018).

This is a modern technique that uses several laser beams (at varying wavelengths) to capture 2D images at different focal depths in a sample. Their results showed that there was a continuous and smooth layer of epidermis covering the meristem, and that there was no evidence of tapering or cells breaking off. This led to them to conclude that *A. mackiei* developed rooting axes from a previously unknown type of meristem, which lacked both root caps and root hairs. Furthermore, this indicates that the evolution of rooting axes in the plant group lycopsids, to which *A. mackiei* belongs, occurred in a stepwise fashion. Their findings point towards independent root evolution in different plant lineages at differing points throughout geological time, with them all deriving from a common rootless ancestor. This study once again proves that using historical material with new techniques can throw up unexpected but welcome discoveries!

Suggestions for further reading:

Deline, B., Greenwood, J. M., Clark, J. W., Puttick, M. N., Peterson, K. J. & Donoghue, P. C. Evolution of metazoan morphological disparity. *Proceedings of the National Academy of Sciences of the United States of America* **115**, E8909–E8918 (2018). (DOI: 10.1073/pnas.1810575115)

Hetherington, A. J. & Dolan, L. Stepwise and independent origins of roots among land plants. *Nature* **561**, 7722 235–238 (2018). (https://doi.org/10.1038/s41586-018-0445-z)

Lefebvre, B., Guensburg, T .E., Martin, E. L. O., Mooi, R., Nardin, E., Nohejlová, M., Saleh, F., Kouraïss, K., El Hariri, K. & David, B. Exceptionally preserved soft parts in fossils from the Lower Ordovician of Morocco clarify stylophoran affinities within basal deuterostomes. *Geobios* **52**, 27–36 (2019). (DOI: 10.1016/j.geobios.2018.11.001)

Wiemann, J., Yang, T.-R. & Norell, M. A. Dinosaur egg colour had a single evolutionary origin. *Nature* **563**, 555–558 (2018). (DOI: 10.1038/s41586-018-0646-5)

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[1]The Palaeontology [online] editorial board can be found here.