Evolution

Bryozoan fossils found at last in Cambrian deposits

Andrej Ernst & Mark A. Wilson

Molecular evidence has long indicated that aquatic animals called bryozoans should be found among the fossils of the Cambrian period, around 541 million years ago. Yet they have been conspicuously absent, until now. See p.251

Multicellular animals called metazoans underwent a profound diversification of their forms during what is known as the Cambrian radiation, which began about 541 million years ago. This resulted in the formation of most of the main animal groupings (phyla) known today in a geologically relatively short time of less than 15 million years. Some phyla seem to have missed this biodiversification event, as judged from their absence in the fossil record for the Cambrian period (which ran from 541 million to 485 million years ago). However, genetic evidence, based on a 'molecular clock' to estimate when they emerged, suggests that they were present in this Cambrian 'kitchen'. The most prominent animal phylum missing from the Cambrian record until now has been the Bryozoa, a group of aquatic animals that exist as individual organisms connected by tissue to form colonies. These animals are abundantly present later in the fossil record. Zhang *et al.*[1] present on page 251 a collection of fossils from early Cambrian deposits of China and Australia that are unequivocally bryozoans, and thus present evidence that solves one of the mysteries regarding the early diversification of animals.

The term Bryozoa means moss animals; these creatures have a superficial resemblance to moss. They live in both marine and freshwater habitats, and their diet consists mainly of phytoplankton. Bryozoa are a phylum of coelomate metazoans (animals with a gut in a central fluid-filled cavity), which are part of a group called Lophotrochozoa. Lophotrochozoans have a structure called the lophophore, which is a ring of tentacles with protrusions called cilia, and bryozoans extend their lophophores to capture food by filter-feeding (Fig. 1). Other anatomical features of note include a gut, and an anus that opens outside the lophophore.

Bryozoans are exclusively colonial, and, as a consequence, the individuals (called zooids) in each colony are small and relatively simple compared with individuals of non-colonial lophotrochozoans, such as phoronids and brachiopods. Owing to the modularity of their colony structure, bryozoans can delegate tasks in their colonies to specialized individuals that are responsible for activities such as cleaning, defence and reproduction. The identification of around 15,000 species of Bryozoa from fossils and about 6,500 extant species indicates the success of these animals[2].

Most bryozoans have 'skeletons' made of calcium carbonate. These skeletons can consist of one of two crystal forms of calcium carbonate, called calcite and aragonite, or a mixture of both of these minerals. The acquisition of this mineralized skeleton was a key innovation that immensely accelerated bryozoan evolution. This development happened at least twice during the evolution of the phylum, resulting in the emergence of a group of bryozoans called Stenolaemata during the Ordovician period (485 million to 444 million years ago), and another named Cheilostomata, during the Jurassic period (201 million to 145 million years ago). Mineralized body parts have a higher chance of fossilization than do unmineralized body parts, leading bryozoans to leave an impressive fossil record, especially for the Stenolaemata from the Palaeozoic era (541 million to 252 million years ago). However, the origin of Bryozoa has been obscure.

The oldest fossils previously confirmed to be bryozoans are from the earliest part of the Ordovician, during the time interval called the Tremadocian stage (485.4 million to 477.7 million years ago), and were found in China[3,4].

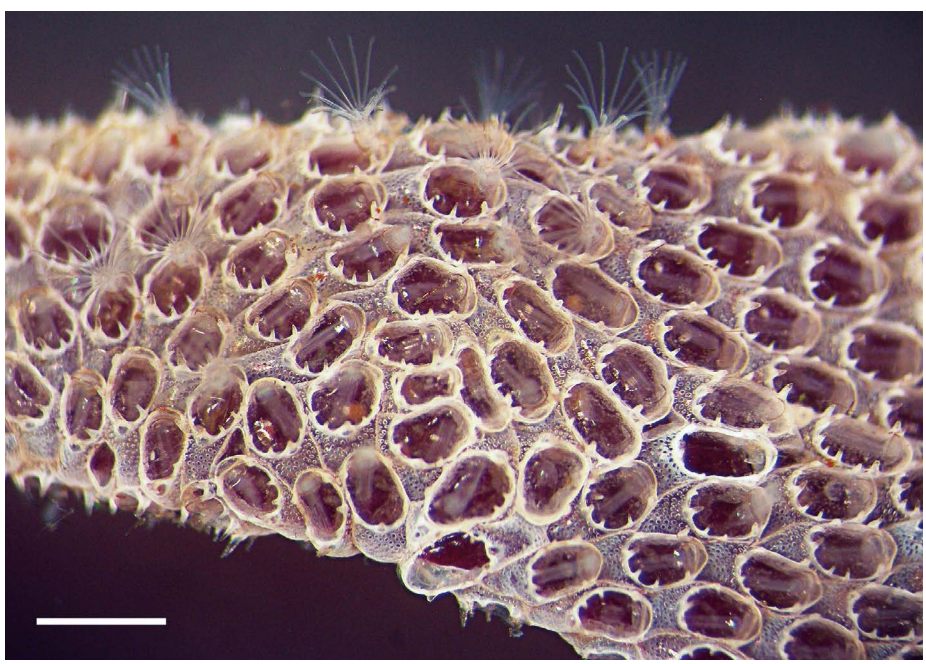

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Figure 1 | A modern bryozoan (*Electra pilosa*) from the Baltic Sea. This bryozoan exists in a colony arrangement typical of these aquatic animals. Feeding individuals termed zooids exist in a modular grouping in structures called zooecia (the large, oval units). The extruded tentacles are known as lophophores. Zhang *et al.*[1] report the identification of bryozoan fossils from a time frame associated with animal diversification called the Cambrian radiation (around 541 million years ago). This evidence fills a crucial gap in the fossil record of bryozoans. Scale bar, 1 millimetre.

However, those bryozoans have a complex form (morphology), and must therefore have already had a long evolutionary history. In addition, molecular studies estimating when bryozoans originated point to a time 44 million years earlier than these fossils, in the early part of the Cambrian[5,6].

Many fossils were suggested previously to be candidate Cambrian bryozoans, but ultimately proved to be something else. Now Zhang and colleagues describe a fossil species as being the oldest known bryozoan. The species is named *Protomelission gatehousei*, and it is assigned to the early Cambrian of Australia and south China. The remains represent millimetre-sized skeletons of a modular animal that has characteristics best known in bryozoans. The skeletons of this fossil have features that are associated in particular with a bryozoan suborder called the Ptilodictyina, which was present in the Ordovician.

Protomelission gatehousei does not show any kind of variation in the forms of the zooids that would indicate a division of labour in the colony. The zooids are uniform in shape and size and are arranged in simple linear series of rows. This animal is assumed to have been unmineralized, and was preserved because of other changes (a chemical modification called secondary phosphatization) to its body walls. Such mineralization is common in the Cambrian because the waters of this period were highly enriched in the phosphorus ions required for this modification. In the Ordovician, the level of dissolved calcium carbonate in seawater increased, and these conditions enabled the rapid diversification of animals and plants that contained calcite in their skeletons. Bryozoans acquired carbonate skeletons and diversified, together with many other phyla, as part of what is called the Great Ordovician Biodiversification Event.

Zhang and colleagues' study shows that bryozoan evolution had a notable, previously hidden history in the early Cambrian. Although this was assumed by many researchers, only now is there reliable evidence for it. The absence of hard skeletal parts in *P. gatehousei* explains why bryozoans were previously missing from the fossil record of the Cambrian.

Among modern bryozoans, groups called the Ctenostomata and the Phylactolaemata are unmineralized, and both, predictably, have poor fossil records. Stenolaemata – the group of calcite-skeleton-containing bryozoans that is most abundant and diverse in the Palaeozoic – are assumed to have been derived from an unknown, soft-bodied ancestor described as being ctenostome-like, with an unmineralized body wall and a box-shaped zooecia (the compartment surrounding the animal's zooids). *Protomelission gatehousei* shares features with both ctenostomes (an unmineralized body wall and a box-shaped zooecia) and stenolaemates (a budding pattern of zooecia and a two-sided colonial structure, similar to a leaf, with zooids on each side), and fits well as a candidate for one of the early ancestors of bryozoans. Now that this ancestral mystery has been solved, attention can move to filling in the story of bryozoan evolution from the early Cambrian to the early Ordovician.

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Genomics

The unexpected ancestry of Inner Asian mummies

Paula N. Doumani Dupuy

The genomes of Bronze Age mummies from the Tarim Basin in northwest China suggest that these individuals were descended from an ancient Asian population that was genetically isolated, despite extensive cultural interactions in the region. **See p.256**

Discoveries of 4,000-year-old naturally mummified individuals in the remote deserts of the Tarim Basin in the south of present-day Xinjiang, northwest China, have prompted decades of speculation about the individuals' ancestry. On page 256, Zhang *et al.*[1] resolve the question of the genetic origins of the mummies, and suggest that they were descended from an ancient, genetically isolated population. The authors' conclusions have implications for future studies of Inner Asian prehistory that must address the complex relationship between cultural exchange and genetic ancestry.

Natural preservation of organic material in ancient archaeological sites of Inner Asia is usually poor, thus limiting the scope of prehistoric research. The arid environment of the Tarim Basin is exceptional because it enabled the preservation of its inhabitants after burial, through natural mummification. The basin holds several intact Bronze Age cemeteries of a founding population known as the agropastoral Xiaohe culture, which formed around 2100 BC in what were then freshwater environments (the Bronze Age spanned from about 3000 to 1000 BC). The individuals' paddleboat-shaped wooden coffins, covered by cattle hides, are unlike any other type of burial custom from Inner Asia. Notably, the mummies have a 'Western' physical appearance, and wear colourful clothing made from the wool of west Eurasian sheep breeds. Their graves also contain a mix of preserved foods – including cheese, wheat and millet – that suggest wider trans-Eurasian interactions.

The cosmopolitan character of this ancient civilization has resulted in various hypotheses that mostly favour migration from other regions as underlying the emergence of the Xiaohe culture. Zhang *et al.* set out to test three such hypotheses, named on the basis of the proposed source population of these migrations (Fig. 1). The first is the steppe hypothesis, which proposes that herders with Afanasievo (west Eurasian) ancestry made their way south from the Altai and Sayan mountains in south Siberia, through the Dzungarian Basin, to the Tarim Basin[2]. The second proposal, the oasis hypothesis, suggests that oasis farmers from the Bactria and Margiana regions in southern Central Asia moved eastward to the Tarim Basin[3]. The third proposed account, the Inner Asian Mountain Corridor (IAMC) island-biogeography hypothesis, posits that the Xiaohe culture emerged from mobile agropastoral communities along the Tianshan and Altai mountains that border Xinjiang to the west[4].

To investigate these hypotheses, the authors analysed the DNA of 18 individuals in Xinjiang: 13 from the Xiaohe culture in the Tarim Basin, dated to the Middle Bronze Age (2100–1700 BC), and 5 from the Dzungarian Basin in northern Xinjiang, dated to the Early Bronze Age (3000–2800 BC). The proteins in