

Figure 1 | Dinosaur relationships and skin characteristics. The dichotomy between feathered birds and scaly reptiles was demolished by the discovery of true pennaceous feathers in the non-avian maniraptoran dinosaurs thought to be closest to birds. More controversial have been the filamentous skin structures, variously regarded as external ‘protofeathers’ or internal structural fibres. Zheng and colleagues’ discovery⁷ of filamentous structures in *Tianyulong* further complicates the picture, in that this is an ornithischian dinosaur far removed from the ancestry of birds. Many other dinosaurs, such as other ornithischians and basal saurischians, had reptilian, scaly skin. So, were the ancestral dinosaurs fuzzy animals cloaked in ‘protofeathers’, which were subsequently lost multiple times in later groups? Or were dinosaurs primitively scaled, and did later groups independently evolve wispy, feather-like or even bristly skin coverings?

group, Maniraptora, that is skeletally the most bird-like, and from which birds are widely thought to have evolved. Feathers became just one more character showing that link, albeit a compelling one. But *Tianyulong* is not at all closely related to birds and, as a heterodontosaurid ornithischian, is on an entirely separate branch of the dinosaur family tree (Fig. 1).

And indeed, *Tianyulong* doesn’t have true pennaceous feathers. It has long filaments, very similar to what have been called ‘protofeathers’

or, more non-committally, ‘dinofuzz’. These filaments are evident in some theropods such as *Caudipteryx* that have true pennaceous feathers, but are also found in a range of other theropods that lack definitive feathers, such as the basal coelurosaur *Sinosauroptryx*, the therizinosauroid *Beipiaosaurus* and the basal tyrannosauroid *Dilong*^{3,4,10}.

Herein lies the controversy. No one disputes that these filaments are integumentary (in the skin). The question is, from what part of the

skin do they come — the outside or the inside? Many^{3,4,10,11} have regarded them as epidermal (that is, as projecting, external appendages that are somehow evolutionarily related to feathers). Others^{5,6} have regarded them as dermal (that is, as the remains of collagen fibres below the skin’s surface). In this context, the difference between epidermal and dermal is huge. If they are epidermal, then they bear not only on feather evolution and avian origins, but also on metabolic physiology, behavioural display and flight. If they are dermal, then they’re ultimately structural in function and have little bearing on those other issues. Unfortunately, the rhetoric of this debate has overshadowed the scientific evaluation of evidence⁹. If the integumentary filaments of *Tianyulong* are dermal (collagen fibres), then they become interesting but not of monumental importance. However, if they are epidermal, then they take on great significance.

Given the position of *Tianyulong* near the evolutionary base of ornithischian dinosaurs, the presence of epidermal, filamentous, feather-like structures could mean that the ancestral dinosaur was a fuzzy (though maybe not cuddly) animal. Of course, that would also mean that a fuzzy coat of protofeathers was lost many times in dinosaur evolution, because lots of dinosaur groups on both great branches of the dinosaur family tree are known to have scaly, reptilian skin (Fig. 1). But, before complicated scenarios for feather evolution are concocted, the fundamental question to be answered is whether the filaments of *Tianyulong* are on the outside or inside of the skin’s surface.

That seemingly simple question is surprisingly hard to answer. The obvious test would be a biochemical or molecular assay to find out if the filaments are composed of the feather protein keratin or the collagen protein, but the mode of fossil preservation may not

CHEMISTRY

Thinking outside the flask

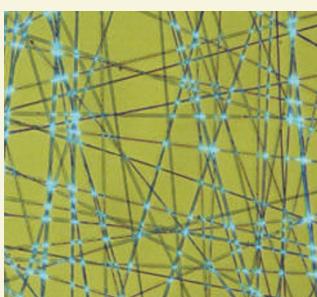
The present credit crunch is forcing everyone to save money, and chemists are no exception. A good cost-cutting measure is to perform reactions on a small scale, thereby reducing the outlay on raw materials and minimizing the energy required to drive the reactions.

Reporting in *Nature Chemistry*, Anzenbacher and Palacios describe the ultimate in miniature reaction vessels — junctions formed when two polymer nanofibres are fused together (P. Anzenbacher Jr & M. A. Palacios *Nature Chem.* doi:10.1038/nchem.125; 2009).

The authors prepared nanofibres — each hundreds of times narrower than a human hair — from readily

available polymers, and loaded them with various chemical reactants. They then laid fibres containing different reactants across each other and exposed them to either heat or solvent vapour. This caused the fibres to fuse together, forming junctions that defined discrete chemical reactors with attolitre-scale volumes (1 attolitre is 10^{-18} litres). The junctions contained as few as 1,500 molecules of each reactant.

To illustrate the principle of their ultra-small reactors, Anzenbacher and Palacios doped fibres with two non-fluorescent compounds that form a fluorescent product when they react. When the two types of fibres were overlapped to form



a random mat and then heated, fluorescence at the fused junctions clearly indicated the formation of the reaction product (pictured).

The authors showed that several types of reactions can be performed in their attoreactors, including those in which one of the reactants is polymeric (although reactions with two polymeric reactants are expected to be problematic,

because polymers can’t easily diffuse through the nanofibre matrix). Furthermore, the products can be analysed directly within the junctions using fluorescence measurements or mass spectrometry.

Several applications for these attoreactors suggest themselves. For example, libraries of nanofibres could be prepared in which each nanofibre is loaded with a different compound from the same chemical class. Selected libraries could then be reacted with each other, as in combinatorial chemistry, to prepare many different products quickly and easily. If the products could be screened directly for biological activity, this would be useful for the high-throughput preparation and testing of compounds in drug-discovery programmes.

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