At the roots of the mammalian family tree

Timothy Rowe

An exceptionally complete skeleton, dating back roughly 140–150 million years, offers our closest look yet at the last common ancestor of modern mammals.

Mesozoic mammals are among the most challenging and prized entries on a fossil hunter's list of discoveries. The essence of the challenge is size — the Mesozoic history of mammals was played out by tiny animals. Few specimens survived the destructive agencies of fossilization, and those that did are supremely difficult to find and collect. Most are fragmentary, and most named species are based on isolated teeth and jaws. In nearly two centuries of searching, only a few precious complete specimens have been recovered and, without better fossils, long stretches of mammalian history have remained in the dark. But, on page 326 of this issue, Ji, Luo and Ji[1] describe one of the most complete and exquisitely preserved specimens ever found. It comes from the same Late Jurassic/Early Cretaceous deposit of Liaoning, China, that recently yielded spectacular feathered dinosaurs[2] and one other complete mammal skeleton[3]. The latest discovery helps to fill a wide gap in the fossil record, and brings new information to classic problems on the origin and interrelationships of early mammals.

The first Mesozoic mammals were discovered in 1812 by a mason in a tilestone quarry near Headington, England. These specimens came from the Middle Jurassic (roughly 165-Myr-old) Stonesfield Slate, and consisted of two isolated lower jaws, each belonging to a different species. Today, the Stonesfield jaws are still the oldest known fossils of the 'crown clade' Mammalia[4] — the lineage founded by the last common ancestor of living mammals (Fig. 1).

The tiny jaws quickly found their way to the University of Oxford where, in 1818, Baron Georges Cuvier examined them while on a sojourn in England. Renowned for his ability to judge the nature and affinities of an extinct animal from a part or even a single fragment of a skeleton, Cuvier pronounced the Stonesfield specimens to be mammalian[5]. He lived up to his reputation, and his identification was the first of many violations of what had been considered a very general rule — that mammals did not live during the Age of Reptiles.

A century and a half later and hundreds more Mesozoic mammal fossils had been discovered, yet the Stonesfield jaws remained among the most complete specimens known. Screen-washing techniques pioneered by Claude Hibbard in the 1940s offered the first clues to an unsuspected diversity of Mesozoic mammalian species[6]. Many tonnes of Mesozoic sediments were sieved through a series of screens designed to trap even the smallest fossils. But most recovered specimens consisted only of teeth and broken jaws, and the emerging view of early mammalian history became overly focused. In 1968, Alfred Sherwood Romer[7] admonished: "So great has been this concentration on dentitions that I often accuse my 'mammalian' colleagues, not without some degree of justice, of conceiving of mammals as consisting solely of molar teeth and of considering that mammalian evolution consisted of parent molar teeth giving birth to filial molar teeth and so on down through the ages."

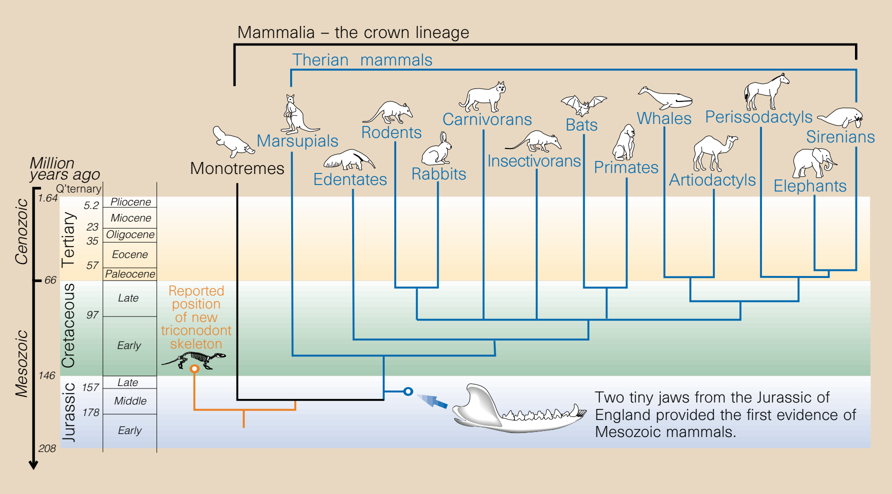


Figure 1 **Timescale of mammalian evolution. The new skeleton discovered by Ji *et al.*[1] has been placed near the base of the crown lineage, Mammalia.**

The first great advance towards a more complete knowledge of the structure and relationships of Mesozoic mammals came in the 1960s, when the Polish Academy of Sciences sent a series of expeditions into central Asia. Dozens of Late Cretaceous mammal skeletons representing several different lineages were collected[6]. Throughout the 1990s, Asian expeditions led by the American Museum have been collecting hundreds more Late Cretaceous specimens that document, in even greater detail, the initial diversification of therian mammals (Fig. 1)[8,9].

Computer-assisted cladistic analyses of data from these more complete specimens[4,8,9] profoundly altered the picture of Late Cretaceous mammalian diversity that was painted in Romer's time[10]. For example, Romer's generation accepted that Mammalia arose in the Triassic (which immediately preceded the Jurassic), whereas the new analyses indicate that the last common ancestor of living mammals probably lived in the Early or Middle Jurassic. In other words, Mammalia is 20–40 Myr younger than once believed. Until very recently, however, the earliest details of mammalian history were obscured owing to the lack of complete fossils.

The remarkable specimen described by Ji and colleagues[1] is, along with a primitive therian mammal announced last year from the same locality[3], by far the most complete and informative fossil discovered from a roughly 20-Myr or longer segment of Jurassic and Early Cretaceous time. Ji *et al.* present an analysis of evolutionary relationships, including dental evidence and data from throughout the skeleton, that places the new find very near the base of the mammalian crown clade (Fig. 1). Their analysis indicates that Triconodontidae — a group once believed to contain the direct ancestors of modern mammals — is not a natural group. Originally founded on the dental attributes that inspired its name, some triconodonts seem to be closer to mammals than to other so-called triconodonts.

But Ji and colleagues' specimen also highlights the presence of homoplasy — the independent evolution of similar features

© 1999 Macmillan Magazines Ltd

— in skeletal characters, corroborating an earlier finding that no region of the skeleton is immune to homoplasy[11]. Still, the data to be gleaned from the skeleton are strong enough to overthrow the apparent dental resemblance of the triconodonts to one another. And it is the skeletal characteristics that largely support the sister-group relationship of multituberculates (a long-lived and long-enigmatic lineage of extinct mammals) with therian mammals, once again contradicting hypotheses derived from dental evidence.

This beautiful specimen also offers new insight into what the ancestor of modern mammals was like. Working out when mammals first moved into the trees, and whether this happened more than once, has been problematic. Ji and colleagues' find indicates that mammals arose as terrestrial forms, and that only later did their therian descendants take to the trees.

Even with this spectacular new find, long gaps still punctuate our Mesozoic record of mammals and their extinct relatives. But this exciting Chinese locality has now produced so many exquisite tetrapod fossils that additional complete specimens of early mammals are likely to be unearthed. We can then expect rapid increases in the resolution of what was once the most fragmented segment of our early history. □

Timothy Rowe is in the Department of Geological Sciences and the Vertebrate Paleontology Laboratory, University of Texas at Austin, Austin, Texas 78712, USA.
e-mail: rowe@mail.utexas.edu

1. Ji, Q., Luo, Z. & Ji, S.-A. *Nature* **398,** 326–330 (1999).
2. Ji, Q., Currie, P. J., Norell, M. A. & Ji, S.-A. *Nature* **393,** 753–761 (1998).
3. Hu, Y., Wang, Y., Luo, Z. & Li, C. *Nature* **390,** 137–142 (1997).
4. Rowe, T. *J. Vert. Paleontol.* **8,** 241–264 (1988).
5. Owen, R. *Geol. Trans* (2nd series) **6,** 47–65 (1839).
6. Lillegraven, J. A., Kielan-Jaworowska, Z. & Clemens, W. A. *Mesozoic Mammals — The First Two-thirds of Mammalian History* (Univ. California Press, Berkeley, 1979).
7. Romer, A. S. *Notes and Comments on Vertebrate Paleontology* (Univ. Chicago Press, 1968).
8. Novacek, M. J. *et al. Nature* **389,** 483–486 (1997).
9. Rougier, G. W., Wible, J. R. & Novacek, M. J. *Nature* **396,** 459–463 (1998).
10. Dingus, L. & Rowe, T. *The Mistaken Extinction — Dinosaur Evolution and the Origin of Birds* (Freeman, New York, 1997).
11. Rowe, T. in *Mammalian Phylogeny* (eds Szalay, F. S., Novacek, M. J. & McKenna, M. C.) 129–145 (Springer, New York, 1993).

X-ray diffraction

Table-top picosecond sources

Justin Wark

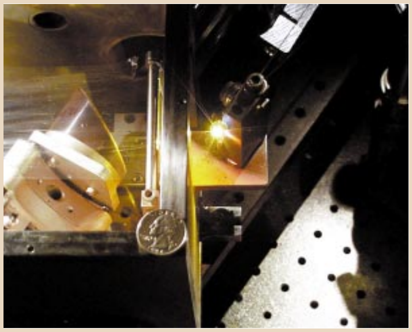
X-ray diffraction has long been one of the most widely used diagnostic tools in both the physical and life sciences. It can be used to determine structures of materials as simple as a grain of salt, and as complex as a virus or protein in the crystalline form. The majority of studies, using either conventional electron-impact sources or synchrotron radiation, yield information about the static structure of a sample. However, there has long been a desire for ultrashort X-ray pulses in order to follow the evolving electron density of structures as they are altered. Somewhat surprisingly, X-ray diffraction patterns with millisecond exposures were first produced over half a century ago[1], and for the past decade bunches of electrons circulating within synchrotrons[2], and plasmas created with large laser systems, have been used to generate X-ray pulses with tens of picoseconds to nanosecond duration. Such pulses have already been used to study shocked and annealed crystals[3,4], and photo-initiated reactions within proteins[5]. The picosecond X-ray barrier was eventually broken[6,7] following rapid developments in high-power laser technology (see Box 1).

On page 310 of this issue Rose-Petruck *et al.*[8] describe how they generate picosecond bursts of copper K_α radiation by irradiating a thin copper wire with a short-pulse high-power laser. They then use this ultrashort radiation to measure the response of a gallium arsenide (GaAs) crystal to sudden heating. This is a remarkable achievement, not only in terms of the science, but also because this picosecond X-ray diffraction did not require a large facility, but used equipment of a cost and scale commensurate with the ambitions of a well-equipped university department. This work highlights a burgeoning field of science, which may ultimately allow changes in electron density to be monitored during biological and chemical reactions, with femtosecond resolution.

This particular paper brings together X-ray diffraction and picosecond ultrasonics. When a femtosecond laser pulse of suitable intensity is incident on an absorbing material, a thin layer at the surface is heated, but the heating is so rapid that it takes place before the layer is able to expand. So, the hot region, still at its initial density, is at a high pressure — typically a few kilobars if the layer is near melting point. The material then relaxes as an acoustic wave travels into the material, forming regions of both expansion and compression (see Fig. 3 on page 312). Usually the pressure pulses are monitored by reflecting optical light from the surface, enabling the detection of underlying structures such as defects in computer chips[9], just as conventional sonar can detect underwater objects. Instead, Rose-Petruck *et al.*[8] use picosecond pulses of X-rays to directly monitor the spacing between the atoms in the heated layer as a function of

Box 1: Brighter, faster, smaller

Advances in high-power laser technology led to the development of titanium:sapphire lasers that can generate approximately 1 J of 800-nm-wavelength light in a pulse length of about 10 femtoseconds at a repetition rate of 10 Hz (refs 11–14). These peak laser powers (> 10^{13} W) are truly enormous – greater, even, than the electrical power output of the whole planet at any instant. When the output from such a laser is focused onto a target, a plasma is formed, and the laser light is absorbed in this plasma up to a point where the laser frequency equals the natural frequency of oscillation of the plasma. At this resonant position, plasma waves are driven to such large amplitudes that they break, releasing the electrons within them at high energies. These electrons penetrate the underlying solid material and generate K_α radiation, just as they would do in a standard X-ray tube. Present studies indicate that the X-ray pulse can be less than a picosecond in duration, but is usually longer than the laser pulse itself owing to both the time taken for the electrons to penetrate the solid, and their complex trajectories in the magnetic fields produced by such large electron currents. The figure shows the vacuum chamber in which the X-rays used by Rose-Petruck *et al.*[8] were produced – a bright flash of optical light can be seen from the plasma emitted by the laser-irradiated copper wire. The X-ray source itself is less than a hair's breadth in diameter, and is confined to a thin layer at the surface of the wire. **J. W.**



WILSON GROUP/UNIV. CALIFORNIA, SAN DIEGO

© 1999 Macmillan Magazines Ltd