Abstractions

SECOND AUTHOR
Modern-day birds are widely thought to have descended from dinosaurs, but a nagging problem has been muddying the waters. The three-fingered 'hands' of the theropod dinosaurs — considered to be birds' closest relatives — were thought to have developed by retaining the first, second and third digits of a five-fingered ancestral hand belonging to an earlier species of dinosaur. Meanwhile, the 'hands' of modern birds — now much smaller than when they first evolved, and embedded in the wing — are thought to have retained the second, third and fourth digits of the ancestral hand. Palaeontologist James Clark of George Washington University in Washington DC tells *Nature* how he, lead author Xing Xu and their team linked the two hands (see page 940).

How did you connect birds' hands to those of theropods?
We found a transitional species of theropod at the point in this group's evolution that it underwent a major reduction in its number of fingers. If you look at the hand of this species, *Limusaurus inextricabilis*, you can see it's in the process of losing its innermost, or first, finger. The nubbin of this digit is visible next to the second and third fingers. This contradicts the long-standing theory that the first finger was retained during evolution, and that the outer fingers disappeared. It was the puzzle piece we needed.

Where did you find this species?
In the Shishugou Formation in Xinjiang, a region in the northwestern part of China. In 2001, we started discovering dinosaur 'death pits' — former mud pits that had solidified — in the Wucaiwan region. It's beautiful countryside — parts of the movie *Crouching Tiger, Hidden Dragon* were filmed there. You wouldn't know it had once been mud pits.

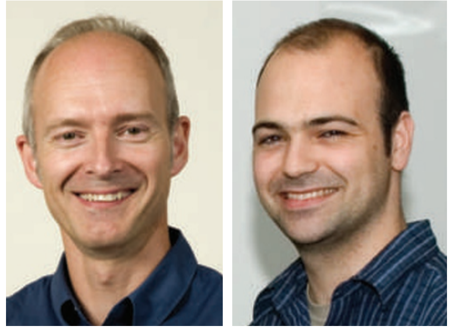
What did you uncover in the death pits?
We found stacks of dinosaur skeletons interspersed with layers of rocks. The third pit we came upon contained 16 animals, including several intact theropod skeletons. One was the most complete we'd ever found: it was the first to contain the skull, the shoulder and the arms. And it had an articulated hand. The hand bones, which were mostly preserved, provided the first clue to its transitional status.

Is this sort of work physically demanding?
It can be. We were camping out in rugged desert terrain with sandstorms and torrential rains that formed a river through our camp. It's usually around 37 °C in Wucaiwan, but one area we worked in was pushing the high 40s. We had to get our shovels out to dig a road so that we could bring the fossil blocks back in the truck to be shipped. ■

MAKING THE PAPER

Ian Harding & James Eldrett

Pollen fossils provide a timeline for cooling in Greenland.



Ian Harding (left) and James Eldrett.

Some 33.5 million years ago, a warm, humid greenhouse Earth gave way to a cooler planet that would eventually have ice blanketing its poles. The change, one of Earth's most profound climate shifts, marks the boundary between the Eocene and Oligocene epochs. However, during the past few years there has been some debate about when the first polar ice actually formed.

Two years ago, Ian Harding, James Eldrett and their colleagues reported physical evidence that ice was present during the Eocene–Oligocene transition in the region of modern-day Greenland, and that the ice may have formed as early as 38 million years ago — earlier than expected (J. Eldrett *et al. Nature* **446,** 176–179; 2007). The finding caused a stir because atmospheric carbon dioxide concentrations for the period had been estimated at double pre-industrial levels, meaning that it was unlikely that they could have supported the development of large ice sheets.

Harding, Eldrett and two new co-authors have now gathered sufficient evidence to reconstruct the climatic conditions in Greenland during the Eocene–Oligocene transition. They find that temperatures would have allowed the build-up of ice to begin during that time, putting the argument to rest.

The project first started in 2003, when Eldrett was finishing up his doctoral work in Harding's lab at the National Oceanography Centre in Southampton, UK. He was analysing a sediment core from a drilling site deep below the Norwegian–Greenland Sea, which turned out to be one of the most complete geological records of the Eocene–Oligocene boundary. An analysis of pebble striations in one sample led to the 2007 study that revealed the earliest evidence of ice on Greenland. For Eldrett, it was also the beginning of a stint of moonlighting, following up on the finding at nights and over weekends while pursuing a day job as a stratigrapher for Shell Exploration and Production UK in Aberdeen.

Eldrett and Harding had not previously been able to obtain climatic data from samples from the Norwegian-Greenland Sea site, which would support their 2007 finding of ice formation during the Eocene–Oligocene transition. This was because the samples were completely devoid of biogenic calcium carbonate, a chemical signature typically used to reconstruct past climates.

The samples were, however, incredibly rich in well-preserved microfossils of marine plankton, and of pollen and spores that had been washed into the sea from terrestrial plants. "Looking down the microscope for the first time, there were pristine examples of the diverse, organic-walled fossils characteristic of that time period," recalls Eldrett.

The duo figured that they could capitalize on the pollen fossil record to track changes in vegetation and, by proxy, climate changes. "We knew which plant species were present, but we didn't know how to translate that into climate changes," says Eldrett. "So our first port of call was David Greenwood, to try to get him on board." Greenwood, a palaeobotanist at Brandon University in Manitoba, Canada, had previously reconstructed past climates in the Arctic Circle on the basis of plant fossils.

To link the fossils to climate, the team opted for a method that uses the nearest living relative of an ancient plant species to define the temperature and precipitation parameters likely to support that plant's growth. Their analysis reveals that during the early Eocene, Greenland's flora was similar to that of modern-day Florida, and included ferns, palms and cycads, as well as trees such as hickory and willow. Later Eocene sediments also contained fir, spruce and pine pollens from coniferous forests. In the Eocene–Oligocene boundary sediments, coniferous trees dominate, with frost-sensitive plants such as palms disappearing.

"The climate shift coincides exactly with the first appearance of ice on Greenland."

The team's climate reconstruction indicates that mean winter temperatures in Eocene Greenland were above 5 °C, whereas during the Eocene–Oligocene transition they dropped to 0–2 °C. As the Oligocene approached, Greenland began experiencing colder winters and greater annual temperature ranges (see page 969).

The climate shift coincides exactly with the first appearance of ice on Greenland, indicating that, even with higher CO_2 levels, the initiation of continental ice formation in polar regions may at least have been possible. "This work is another page in the story of unravelling the driving mechanisms of profound climate change in the geological past," says Harding.

With this study completed, Eldrett says he'll probably slow his moonlighting down. This summer, he plans to spend his weekends walking in the Scottish Highlands and cycling. ■

See also *Nature* 446, xiii; 2007.

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