An artist's depiction of early Cretaceous polar dinosaurs in Victoria, with *Leaellynasaura* active during the winter (top) and *Timimus* hibernating (bottom). Painting by Peter Trusler

Dinosaurs Down Underground

BY ANTHONY MARTIN

Victoria's west coast has yielded evidence of dinosaurs that dug burrows to nurture their young through the polar winter.

As the days shortened and cooler breezes became more frequent in the Cretaceous autumn, the dinosaurs and other animals on and near the floodplains of the humid, forested Victorian rift valley began preparing for winter. This winter, however, was unlike any experienced in southern Australia today. Because southern Australia was near the South Pole and still connected to Antarctica, winter would be marked by nearly 6 months of darkness and temperatures well below freezing. As a result, overwintering would be an arduous ordeal for any land-dwelling animal, even during a time when average global temperatures were nearly 7°C warmer than today.

Most of the dinosaurs living in the area, comprised of small, herbivorous ornithopods, were far too small to migrate: the energy expended by moving north to warmer climates would far outweigh the benefits of staying put. How, then, did dinosaurs and most other animals survive these dark, cold winters about 105 million years ago?

About 10 million years later and half a world away, in a more temperate, semi-arid climate in North America (Montana), a small ornithopod dinosaur was digging a den just before laying eggs and raising offspring. The burrow leading to the den was just wide enough to allow the adult dinosaur to crawl down it, a tight fit that excluded most predators while also keeping the temperature and humidity more equitable than outside of the burrow. The burrow turned to the right, then to the left, each tunnel segment corresponding to the torso length of the dinosaur. At its bottom it widened into an expansive chamber large enough for at least one adult and two half-grown juveniles. The burrow thus kept all of its occupants safe from the dangers of the outside world, such as carnivorous theropod dinosaurs, forest fires and cool winters.

Answers to palaeontological questions often come from unexpected sources and sheer luck. In this respect, the realisation that a few odd structures in Early Cretaceous rocks on the Victorian coast might be related to a burrowing dinosaur in Montana was no exception.

The questions began for me in May 2006 after a long, convoluted hike to a coastal outcrop at Knowledge Creek in Victoria's Otway Ranges. I was accompanied by some Museum of Victoria staff, Monash University graduate students and volunteers, including my wife.

I was walking along the rock exposure when a sandstone-conglomerate structure caught and held my attention. It was nearly identical in size and shape to the only previously known dinosaur burrow I had seen just 8 months earlier in Montana, which contained the remains of an adult dinosaur and two of its juveniles. Also, just above and adjacent to it was another structure with a similar form. I stared at these structures for several minutes, not sure what to do other than photograph them and take mental notes of their existence.

The following year I co-authored a paper on the Montana burrowing dinosaur (*Oryctodromeus cubicularis*) and its burrow, which led me to re-examine the intriguing structures in Victoria. I came back in July

2007 and again in May 2009, 3 years after my initial visit to Knowledge Creek.

The third trip was the proverbial charm as I found a third incomplete structure only a few metres away from the other two. The paper reporting my results was successfully published this year in the journal *Cretaceous Research*. In this paper I proposed the seemingly radical hypothesis that these structures were small dinosaur burrows, and that some dinosaurs living in polar Australia used burrows as a strategy for overwintering in such inhospitable conditions.

This scientific story, however, is not as simple as "experience meets happenstance". Palaeontologists often look to modern ecosystems and how animals have adapted to the challenges of their respective environments, however imperfect this approach might seem. Nevertheless, how do modern animals make it through a polar winter, especially ones colder than those of the Cretaceous?

The most charismatic of polar animals, polar bears, have a simple solution: they burrow into the snow, settle down in snow dens, slow down their metabolism and hibernate for much of the winter. These bears are not alone in this behaviour, either. Their close relatives, brown bears, do the same in soil, as do other mammals, such as lemmings, and a few birds, such as puffins. Even reptiles that live close to the Arctic Circle or in alpine areas use a combination of dens and group behaviour to make it through cold winters, and alligators will dig burrows once temperatures approach 0°C.

In other words, overwintering today normally involves making and staying in burrows. So why not burrowing as a strategy for polar dinosaurs, especially those that did not have the choice of migrating?

However straightforward such reasoning might seem now in hindsight, until the Montana discovery palaeontologists had no firm evidence supporting the notion that some dinosaurs burrowed or otherwise habitually spent time underground. Dinosaur burrowing abilities were seemingly limited to constructing shallow earthen nests like those of modern emus and other large flightless birds, yet even this hypothesis was not backed by fossil evidence until the late 1990s.

Although a small revolution in thinking about the ecological niches and behaviours of dinosaurs had been going on since the 1960s, much of this debate centred on similarities between dinosaurs and birds, and emphasised above-ground adaptations of dinosaurs. Moreover, the emphasis in such studies has been on dinosaurs that lived in temperate to equatorial ecosystems. Only a limited amount of work focused specifically on polar dinosaurs and physiological traits that might have helped them to survive polar winters, such as in southern Australia during the Cretaceous.

One important exception to this generalisation was a study in 1998 by Pat Vickers-Rich of Monash University, Tom Rich of the Museum of Victoria and Anusuya Chinsamy of the South African Museum of Cape Town. These palaeontologists discovered that one species of Victoria dinosaur, the theropod *Timimus hermani*, had growth interruptions in a limb bone. These lines of arrested growth (LAGs) suggested that the dinosaur shut down its growth periodically, which in a polar environment implied that *Timimus* hibernated or otherwise periodically slowed its metabolism during its lifetime.

Dinosaur burrows in the Early Cretaceous (105 million years old) at Knowledge Creek. The most complete structure (bottom) has a twisting tunnel (right) that connects with an enlarged burrow chamber (left).

In contrast, a limb bone from the small ornithopod dinosaur *Leaellynasaura amicagraphica* showed no evidence of LAGS. This evidence, along with enlarged eye sockets in a skull of *Leaellynasaura*, suggested that this particular dinosaur might have been active throughout a polar winter and was well-adapted for seeing in the dark.

As a result of these new insights, Australian palaeontological artist Peter Trusler depicted several *Leaellynasaura* out and about in the Cretaceous forest under the aurora australis of a polar-winter sky, while a single *Timimus* hibernated nearby under the hollow provided by a fallen tree (see image on p.14). At the time of this painting (2000), no burrows were known for dinosaurs in Australia, or anywhere else in the world for that matter.

To their credit, though, the Richs and others, in a seminal 1988 paper on the polar dinosaurs of Victoria, speculated that some dinosaurs might have overwintered by burrowing. Unfortunately this idea, like an overwintering animal, became dormant for the next 20 years or so.

This is where trace fossils come in. Ichnology – the study of organismal traces such as tracks, trails, and burrows) – is an important science with wide-ranging applications, from wildlife conservation to palaeontology. One of the basic principles of ichnology is that one animal can be responsible for making a large number of traces during its lifetime, whereas its body parts have a vanishingly small chance of being buried and preserved in the fossil record. Traces are also the direct products of behaviour and sometimes can tell us more about animal behaviour than by actually watching the animal itself.

Ichnology as an informal science was well-developed in Australia over the course of more than 30,000 years by indigenous (aboriginal) peoples, who used tracking methods to great effect and recorded their awareness of animal tracks and trails in their rock art. Today, ichnologists likewise study trace fossils to gain insights on the behaviours of long-extinct animals, such as dinosaurs.

In July 2005, palaeontologists were prospecting for dinosaur bones in little-studied Cretaceous rocks in the south-western corner of Montana (USA) when Dr Yoshi Katsura of Gifu Prefecture Museum in Japan spotted limb bones of an ornithopod dinosaur exposed in sandstone. Later, the leader of the field crew, Dr David Varricchio of Montana State University realised that the sandstone surrounding the bones had a twisting, tubular form that connected with an enlarged, bulbous structure.

Dr Varricchio had some training in ichnology, and immediately thought that this structure might be a burrow. Moreover, the presence of a small ornithopod in the structure lent well to the hypothesis that the ornithopod was the burrow-maker.

He tested his initial identification by sending me a photograph of the structure. In a cheeky (but smart) move, though, he purposefully did not tell me that the structure contained a dinosaur, thus preventing bias in my assessment. I verified his identification of the structure as a burrow, and later jumped for joy when he told me that the structure had a dinosaur in it: we had the first preliminary evidence of a burrowing dinosaur in the geologic record.

Two months later he flew me out to Montana, where we excavated the entire burrow structure from the soft Cretaceous rock and described it in detail. The dinosaur turned out to be a new species, too, and Drs Varricchio, Katsura and I named it *Oryctodromeus cubicularis* ("running digger of the den") in recognition of its bipedalism and adaptations for digging. In fact, its anatomy further confirmed that it was the likely maker of the burrow, possessing:

- fused bones in its snout, which would have assisted in shoveling soil;
- a shoulder girdle with enlarged muscle attachments that would have helped with digging; and
- an extra vertebra in its hip, which would have helped brace the animal while burrowing with its forelimbs.

An artist's depiction of an Early Cretaceous polar dinosaur of Victoria using a burrow as a hibernation chamber during the winter, based on the dinosaur burrows interpreted from rocks at Knowledge Creek. Illustration by James Hay, Fernbank Museum

Perhaps luckiest of all, preparation of the specimen gradually revealed that its bones were mixed in with two juveniles of the same species. This added discovery helped to flesh out the lives of these dinosaurs: a nurturing adult in a den with two partially grown juveniles, the first evidence of a burrowing and denning dinosaur from the fossil record.

So I went to Australia in 2006 with a search image of a dinosaur burrow. The possibility of dinosaur burrows in the Cretaceous rocks of Victoria had flitted through my mind before arriving, but it certainly was not my intention to find these. In fact, when our field team visited Knowledge Creek in May 2006, it was mostly to look for dinosaur tracks, as this was one of the few sites in the Cretaceous of Victoria that had yielded these important dinosaur trace fossils. Of course, not one to ignore such a fortuitous gift as the dinosaur burrows, I relished my two subsequent follow-up visits to study the structures.

The most complete of these, the one that beckoned to me in 2006, is a sandstone-conglomerate filled structure (originally hollow)with a gently sloping, semi-helical form that turns to the right, then to the left before connecting with an enlarged chamber. It is identical in form to the one in Montana.

The tunnel cross-sectional area correlated with a burrower with a body mass of about 10 kg, whereas the other two incomplete structures corresponded with 14–19 kg animals. These sizes eliminated all of the known fish, mammals and turtles from the Cretaceous of Victoria (these were too small), and all of the crocodilians and amphibians (these were too big), leaving small ornithopod dinosaurs as the most likely makers.

This interpretation also made sense, seeing that these were the most common dinosaurs in the Cretaceous rocks of Victoria. In fact, one of the most famous dinosaur dig sites in Australia, Dinosaur Cove, was only about 7 km away, having yielded *Leaellynasaura* and other small ornithopods.

Based on the sediments surrounding the burrow, the dinosaurs had dug into a gravelly river bank. Considering the torrential floodwaters that must have accompanied spring thaws, the burrows must have been dug during a lower water stage, such as the late summer or early autumn: just in time for winter.

Why were there no bones in these purported dinosaur burrows? Remember one of the tenets of ichnology: that one tracemaker can make many traces. Gopher tortoises can make more than 50 burrows during their lifetimes, and wombats are well known for digging out more than one den, too.

Nonetheless, I anticipate that because we now know what to look for and have burrowing dinosaurs in the Cretaceous of Victoria as a hypothesis, more burrows will be identified and some day, like the dinosaur burrow in Montana, one may contain the bones of its maker.

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