PROCEEDINGS OF THE ROYAL SOCIETY B
FirstCite® e-publishing

Proc. R. Soc. B
doi:10.1098/rspb.2007.0239
Published online

Comment

Dinosaurs digging deeper

Will the abilities of dinosaurs ever cease to amaze us? Living dinosaurs (the birds) hunt, feed, fight and even mate on the wing, and their courtship rituals can seem substantially more complex than those found on a typical weekend at a twenty-first century urban watering hole. Extinct dinosaurs (the Mesozoic varieties) have been inferred to exhibit an even greater range of behaviours. *Baryonyx*, Britain's first dinosaur to be discovered since the mid-Victorian era, is thought to have been a fisher (Charig & Milner 1986). Ceratopsids were supposed to have jousted, although it now appears that there are no expected puncture wounds in the obvious places on the skulls of these reptilian Sir Lancelots (Farke 2004). Pachycephalosaurs were long assumed to have headbutted like living rams, but recent studies have shown that their skulls were ill-suited for that particular activity (Goodwin & Horner 2004). It was once proposed that *Deinocheirus*, the gigantic relative of the ostrich dinosaurs, was an anteater (Rozhdestvensky 1970), mostly because its huge forelimbs and claws were reminiscent of the extinct giant ground sloth *Megalonyx*.

Palaeobiologists propose and test these hypotheses based on a great many lines of evidence. Occasionally, a preserved skeleton will leave little doubt about its behaviour in life, as the famous 'fighting dinosaurs' from Mongolia attest (Kielan-Jaworowska & Barsbold 1972). Eggs and nests of dinosaurs have strongly suggested that some species hatched in an immature condition, meaning that they had to be fed and protected for some time by the parents (Horner & Makela 1979; Horner 1982). Trackways have shown apparent herding behaviours (Lockley & Hunt 1995), predatory behaviours (Bird 1985; Farlow & Holtz 2002), leg-assisted swimming (Coombs 1980) and even some quiet idylls, such as the impressions of the small Early Jurassic ornithischian who sat resting on its metatarsus while its hands groped the substrate, as if looking for its glasses (Olsen & Rainforth 2003).

We have known for a long time that some dinosaurs were capable of digging, because they excavated nests for their eggs (Carpenter *et al.* 1994). But burrowing is a new wrinkle, thus far associated mostly with lungfishes and some ancient mammals and their relatives (Dubiel *et al.* 1987; Groenewald *et al.* 2001; Damiani *et al.* 2003). In this issue, Varricchio *et al.* (2007) ingeniously document the first record of a dinosaur that not only could dig, but could also burrow. And it seems to have kept its young protected from predators in this way.

The new dinosaur is a generalized ornithopod, a member of one of the relatively anonymous clades—meaning that it does not sport bizarre headgear, spikes, and so on—usually depicted in illustrated dinosaur books merely as the prey of some ostensibly more exciting theropod predator. It probably stood about half a metre high at the hip, which is not big for a dinosaur, but not tiny either. In fact, it is rather larger than most living burrowers, but in line with the striped hyena and the aardwolf.

This find could have simply been reported as of a new dinosaur, which indeed is part of the report by Varricchio *et al.* (2007). But the entire significance of the find would have been missed. One of the principal things that sets this report apart from dozens of others that appear each year is the care with which the entombing sediments were analysed. The researchers found that the sediments form a curved tube with small diverticula, around and above the skeletal material, and are completely different from those of the surrounding rocks. They represent the influx of new material that is normally found above the level in which the bones were preserved; and the grain sizes of the sedimentary particles that fill this tube-like structure become finer towards the top, suggesting that as they washed in, the coarser, larger particles settled to the bottom, as if filling a pre-existing hole.

It is a good thing that Varricchio *et al.* (2007) paid attention to the sedimentary context of their discovery, because the new dinosaur has several morphological features that might be otherwise difficult to explain. Compared to other 'hypsilophodontid' ornithopods, the new find has arms that seem to have larger insertion areas for muscles that would be useful in digging. The pelvis and hindlimbs are also more robust than in typical forms, and similar to those of some recent burrowers, suggesting that they were useful in anchoring the torso during digging. Yet, the authors have noticed similar specializations in forms closely related to the new dinosaur, so perhaps the behaviour was more widespread in its clade.

One question that the authors had to wrestle with is the fact that two very different kinds of fossil are described here: the skeletal remains and the burrow itself. By taxonomic convention, trace fossils such as burrows are generally not assigned the same name as their makers, even if the maker is not in doubt. The reason is that an animal can make several kinds of trace fossil, and a given trace fossil may be produced by several species of animal. Therefore, why not also give the burrow a new name in the parataxonomy of vertebrate ichnofossils? Although it cannot legally be attributed to the skeletal taxon, it has diagnostic features that if discovered again in the absence of bony remains could be recognized. In this case, however, the authors have demurred, refraining both from including the burrow as part of the referred material of the new taxon and from naming a new ichnotaxon, thus leaving a puzzle for future workers.

It struck me in reviewing this paper—and I suspect most knowledgeable colleagues will agree—that the behavioural inferences made possible by the careful work of Varricchio *et al.* (2007) would probably have been overlooked if this specimen had been discovered and excavated by most commercial collectors. It probably

Received 20 February 2007
Accepted 27 February 2007

would have been excavated from the ground with all possible expedience, prepared from its matrix with relatively little consideration of geological or environmental context, and its missing pieces restored from whatever models were handy, in order to be sold on the open market with the greatest and most rapid monetary return possible. I have seen many specimens like this in auction houses and catalogues. The science, and therefore the value to the public, would have been lost in the shuffle (Padian 2000). This discovery is first and foremost a testament to the value of keeping one's eyes open in the field and noticing everything, and it took a special group of scientists to realize the meaning of the discovery that they made. But it is also an implicit indictment of the situation in the United States, where discoveries of incalculable importance to science, education and posterity are routinely lost by the strongly lobbied efforts of commercial fossil collectors. Only legislation will stop their depredations, because they currently have no financial incentive to cooperate with scientists and educators (Sax 1999).

Kevin Padian*
Museum of Paleontology, University of California, Berkeley, CA 94720-4780, USA
*kpadian@berkeley.edu

REFERENCES

Bird, R. T. 1985 *Bones for Barnum Brown*. Fort Worth, TX: Texas Christian University Press.

Carpenter, K., Hirsch, K. F. & Horner, J. R. (eds) 1994 *Dinosaur eggs and babies*. Cambridge, UK; New York, NY: Cambridge University Press.

Charig, A. J. & Milner, A. C. 1986 *Baryonyx*, a remarkable new theropod dinosaur. *Nature* **324**, 359–361. (doi:10.1038/324359a0)

Coombs Jr, W. P. 1980 Swimming ability of carnivorous dinosaurs. *Science* **207**, 1198–1200. (doi:10.1126/science.207.4436.1198)

Damiani, R., Modesto, S., Yates, A. & Neveling, J. 2003 Earliest evidence of cynodont burrowing. *Proc. R. Soc. B* **270**, 1747–1751. (doi:10.1098/rspb.2003.2427)

Dubiel, R. F., Blodgett, R. H. & Bown, T. M. 1987 Lungfish burrows in the Upper Triassic Chinle and Dolores formations, Colorado Plateau. *J. Sediment. Res.* **57**, 512–521.

Farke, A. A. 2004 Horn use in *Triceratops* (Dinosauria: Ceratopsidae): testing behavioral hypotheses using scale models. *Palaeontol. Electron.* **7**, 10.

Farlow, J. & Holtz Jr, T. 2002 The fossil record of predation in dinosaurs. *Paleontol. Soc. Pap.* **8**, 251–266.

Goodwin, M. B. & Horner, J. R. 2004 Cranial histology of pachycephalosaurs (Ornithischia: Marginocephalia) reveals transitory structures inconsistent with head-butting behavior. *Paleobiology* **30**, 253–267. (doi:10.1666/0094-8373(2004)030<0253:CHOPOM>2.0.CO;2)

Groenewald, G. H., Welman, J. & MacEachern, J. A. 2001 Vertebrate burrow complexes from the Early Triassic *Cynognathus* Zone (Driekoppen Formation, Beaufort Group) of the Karoo Basin, South Africa. *Palaios* **16**, 148–160. (doi:10.2307/3515526)

Horner, J. R. 1982 Evidence of colonial nesting and site fidelity among ornithischian dinosaurs. *Nature* **297**, 675–676. (doi:10.1038/297675a0)

Horner, J. R. & Makela, R. 1979 Nest of juveniles provides evidence of family structure among dinosaurs. *Nature* **282**, 296–298. (doi:10.1038/282296a0)

Kielan-Jaworowska, Z. & Barsbold, R. 1972 Narrative of the Polish–Mongolian paleontological expeditions 1967–1971. *Palaeontol. Pol.* **27**, 5–13.

Lockley, M. G. & Hunt, A. P. 1995 *Dinosaur tracks and other fossil footprints of the western United States*. New York, NY: Columbia University Press.

Olsen, P. E. & Rainforth, E. C. 2003 The Early Jurassic ornithischian dinosaurian ichnogenus *Anomoepus*. In *The great rift valleys of Pangea in eastern North America: sedimentology, stratigraphy, and paleontology*, vol. 2 (eds P. M. Letourneau & P. E. Olsen), pp. 314–368. New York, NY: Columbia University Press.

Padian, K. 2000 Feathers, fakes, and fossil dealers: how the commercial sale of fossils erodes science and education. *Paleontol. Electron.* **3**, 8. (http://palaeo-electronica.org/2000_2/editor/padian.htm)

Rozhdestvensky, A. K. 1970 Giant claws of enigmatic Mesozoic reptiles. *Paleontol. J.* **1970**, 117–125.

Sax, J. 1999 *Playing darts with a rembrandt: public and private rights in cultural treasures*. Ann Arbor, MI: University of Michigan Press.

Varricchio, D. J., Martin, A. J. & Katsura, Y. 2007 First trace and body fossil evidence of a burrowing, denning dinosaur. *Proc. R. Soc. B* (doi:10.1098/rspb.2006.0443)