Records of the Western Australian Museum Supplement No. 57: 191–200 (1999).

Is *Agrosaurus macgillivrayi* Australia's oldest dinosaur?

Patricia Vickers-Rich[1], Thomas H. Rich[2], Gregory C. McNamara[3] and Angela Milner[4]

[1] Monash Science Centre, Earth Sciences Department, Monash University, Clayton, Vic 3168; email: prich@orion.earth.monash.edu.au

[2] Museum Victoria, PO Box 666E, Melbourne, Vic 3001

[3] Albert Kersten Geocentre, PO Box 448, Broken Hill, NSW 2880

[4] Department of Palaeontology, The Natural History Museum, Cromwell Road, London SW7 5BD, UK

Abstract – The holotype and only known specimen of the prosauropod *Agrosaurus macgillivrayi* Seeley, 1891 probably comes from the Late Triassic Durdham Down locality near Bristol, England. Originally it was reported as being from the northeast coast of Australia. Firsthand examination of the most plausible northeast Australian source for such a fossil, outcrops of the Jurassic Helby Beds exposed on the east coast of Cape York Peninsula, have demonstrated that the rock in that unit was quite unlike that associated with the holotype. Gross and trace element comparisons between possible fossil bone fragments from the Helby Beds and the holotype also showed them to be quite different. On the other hand, similar comparisons between the holotype and fossil bone from Durdham Down showed them to be quite comparable, as were the rocks and microvertebrates there and the ones associated with the holotype. Furthermore, *A. macgillivrayi* is probably a junior synonym of *Thecodontosaurus antiquus* Morris, 1843 from Durdham Down.

INTRODUCTION

In 1844, four British ships headed by H.M.S. *Fly* were sent to construct a beacon on Raine Island off the eastern side of Cape York Peninsula, Australia (Figures 1 and 2). They were in the area for four and a half months, and while the beacon was under construction, the ships' crews explored in detail the eastern side of Cape York Peninsula, north of Cape Grenville (Jukes 1847).

Nearly half a century later, Seeley (1891) published a description of a few limb bones and phalanges of the dinosaur *Agrosaurus macgillivrayi* (Figure 3). The only locality information available to Seeley was a label, "in a small, delicate handwriting, '*Fly*, 1844. Jn. Macgillivray, from the N.E. coast of Australia.'" (Seeley 1891) (cf. Figure 4).

John MacGillivray was a naturalist attached to the expedition whose job it was to collect animals for Edward Smith Stanley, the 13th Earl of Derby (Ralph 1993). His notebooks for the expedition have never been found, and he never mentioned anything about having discovered such a specimen in the book he wrote about a subsequent expedition to the same area a few years later, when

FLY

HM Sloop *Fly* was launched at Pembroke Dock on 25 August 1831.

Tonnage	485 BM
Length	114 ft 6 in (34.9 m)
Beam	32 ft (9.7 m)
Armament	Eighteen 6 pndrs

Arrived Sydney October 1842. Surveyed Great Barrier Reef, visited Papua. Sailed for home December 1845. Reduced to coal hulk 1855. Broken up 1903.

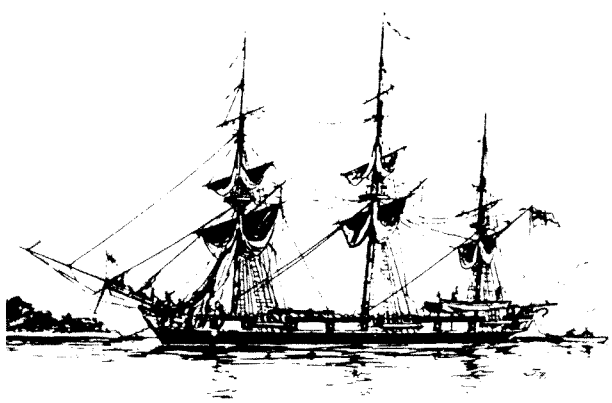
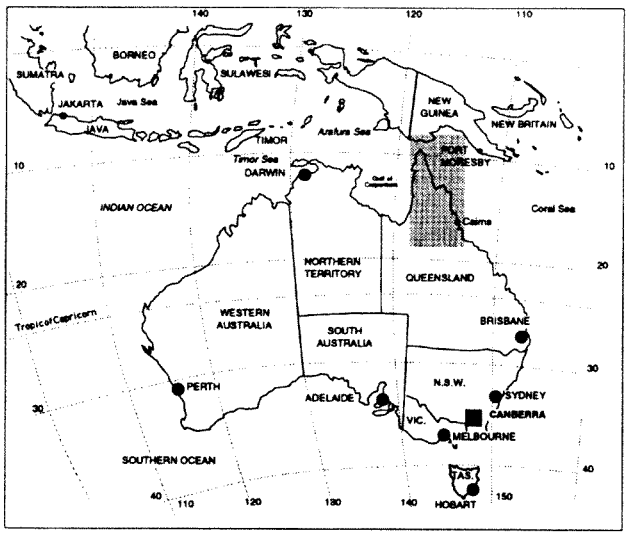
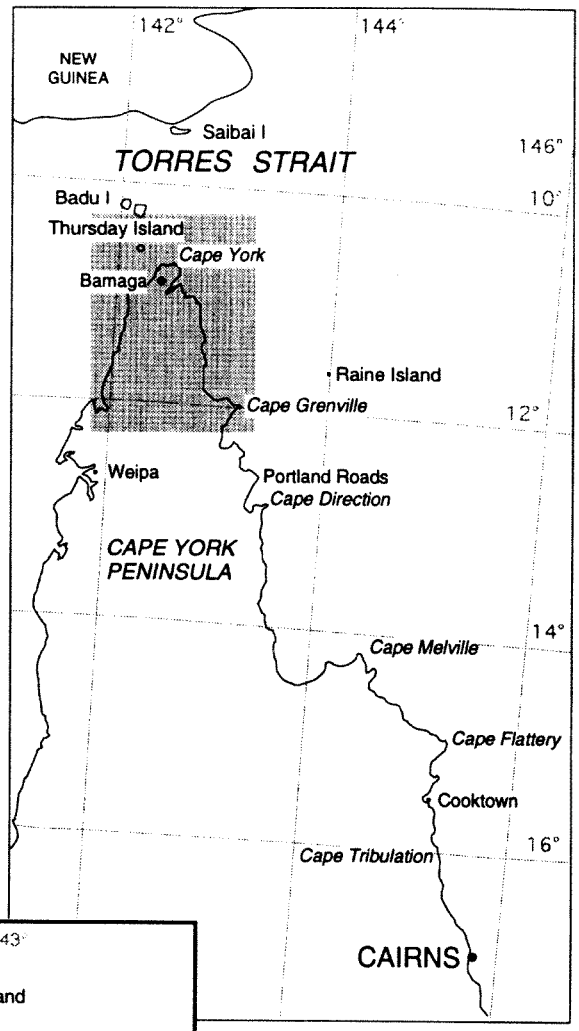


Figure 1 H.M.S. *Fly*. From Bastock (1988) (with permission).





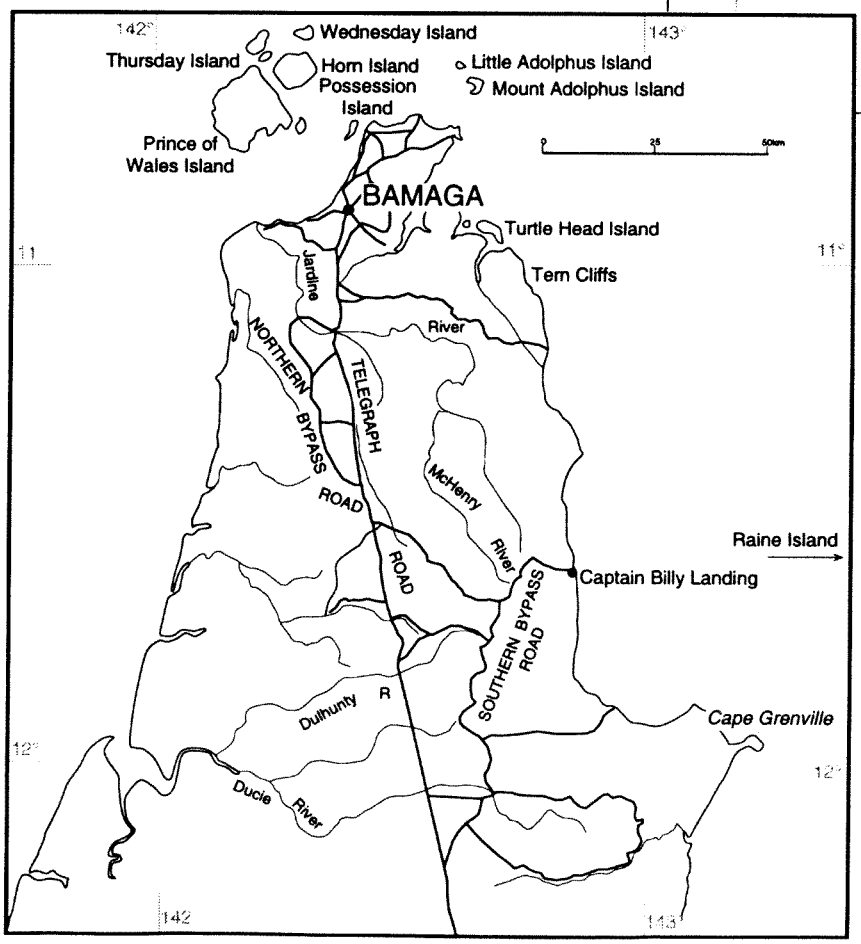


Figure 2 Map of Cape York Peninsula, northern Queensland, and environs, with localities mentioned in text.

he sailed on H.M.S. *Rattlesnake* (MacGillivray 1852). A geologist, J. Bette Jukes, did publish a book on the results of the 1844 voyage of H.M.S. *Fly* (Jukes 1847), but he, too, did not mention anything about

Figure 3 Postcranial elements of holotype of *Agrosaurus macgillivray* Seeley, 1891, BMNH 49984. From left: left tibia, ungual phalanx, distal caudal vertebra, proximal part of right tibia, distal end of right radius.

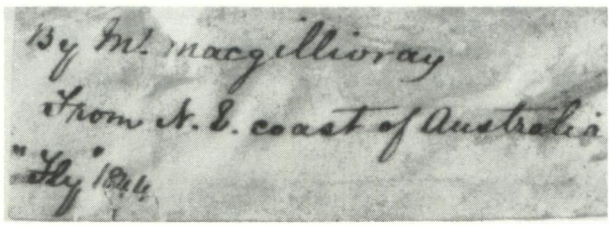


Figure 4 Original hand written label associated with holotype of *Agrosaurus macgillivrayi* Seeley, 1891, BMNH 49984. Label reads, By Jn.[Mr?] Macgillivray. From N.E. coast of Australia. "Fly" 1844

the discovery of fossil vertebrate bones during the course of that trip either there or in other publications (Jukes 1850; Brown 1871).

Seeley (1891) regarded these fossils as most similar to dinosaurs known to him from the Late Triassic and Early Jurassic. Modern opinion concurs, placing *Agrosaurus macgillivrayi* in the prosauropods, a group of early dinosaurs confined to that time (Galton 1990; Molnar 1991).

Institutional Abbreviations

BMNH = The Natural History Museum, London, U.K. (formerly British Museum (Natural History)); QM = Queensland Museum, Brisbane, Queensland, Australia.

EARLY MESOZOIC GEOLOGY OF CAPE YORK PENSINULA

Late Triassic and Early Jurassic continental deposits are not rare in eastern Australia. However, for the most part, they are deeply weathered rock units, unfossiliferous except for trackways in some cases; e.g. the aeolian Precipice Sandstone. Therefore, it is not surprising that additional dinosaurian remains of this age have not been forthcoming there. The one possible exception is the partial skeleton of the primitive sauropod *Rhoetosaurus brownei* from southeastern Queensland which might be Early rather than Middle Jurassic.

Knowing where H.M.S. *Fly* was in 1844 and examining the currently available geological information about the northeast coast of Australia, one rock unit stands out as being the most likely source for the holotype of *Agrosaurus macgillivrayi*. This is the Helby Beds which occur on the east coast of Cape York Peninsula, due west of Raine Island. The ships supporting the original construction of the beacon on Raine Island repeatedly journeyed to the mainland to obtain wood and freshwater. Both MacGillivray and Jukes would have taken whatever opportunities there were to go ashore to collect specimens and make

observations. The easiest place for a block of rock with fossil bones in it to have been collected by people operating out of longboats was along that coast west of Raine Island.

Not only are the Helby Beds exposed on the coast where voyagers might have easily reached them, but their age as indicated by palynological evidence is appropriate: Jurassic (Powell *et al.* 1976).

RECONNAISSANCE OF THE HELBY BEDS

A reconnaissance flight carried out in September 1993 over the northeastern coast of Australia from Cairns to the tip of Cape York Peninsula, revealed that the only Mesozoic outcrops that from the air do not appear to be deeply weathered, are some of the coastal exposures of the Helby Beds north of Cape Grenville (Powell and Smart 1977). This is the same area that H.M.S. *Fly* visited in 1844.

The outcrops were observed to occur as coastal exposures reminiscent of those in Victoria, which have yielded a significant collection of Australian Early Cretaceous tetrapods (Rich *et al.* 1988; Rich and Rich 1989). The apparently unweathered outcrops were seen over a distance of 80 km and have a combined extent of 3–5 km along the coast.

A ship, *El Torito,* was engaged in July 1995 for six days of reconnaissance of the outcrops of the Helby Beds between Captain Billy Landing at 11°40'S., 142°53'E. and the Tern Cliffs at 11°01'S., 142°45'E.

During the winter on the far North Queensland coast, temperatures are commonly a pleasant 25°C with a cool onshore breeze, whereas during summer temperatures can climb to 35°C or more with less breeze and oppressive humidity. Winter was therefore chosen as the time of year to carry out this reconnaissance because it is easiest to keep a clear head searching for elusive fossils when it is not too hot. This decision was made despite the fact that winter is also the time when steady southeasterly winds commonly cause high seas in the area. Fortunately, unusually calm conditions prevailed during most days of the work, which made it possible to examine all the outcrops of the Helby Beds for as long desired. Had normal sea conditions been the case during the work, a thorough examination of all the outcrops during the time available most likely would not have occurred.

The people searching for the fossils had varied backgrounds. This was important because the context in which fossils might be found was unknown. The hardest fossil to find is the first one. Once a single specimen has been located in an area, the fossil hunter has an idea not only of what the fossils themselves will look like in the context of where she/he is working but also the type of rock they are likely to occur in. Unfortunately, the holotype of *Agrosaurus macgillivrayi* has been completely removed from the rock it was found in, and all that associated rock has been chemically disaggregated. Thus, in a practical sense, the first fossil bone from the Helby Beds had yet to be found. In bringing their different experiences to the search, this group made up of fossil hunters who had collected in many parts of the world maximized the likelihood of finding a fossil. In addition to three of the authors (P.V.-R., T.H.R., G.C.McN.), the searchers included Timothy Hamley (Department of Zoology, University of Queensland, St Lucia), Leaellyn Rich (Ormond College, University of Melbourne), Lucinda Hann (Wesley College, Glen Waverley, Victoria), Lesley Kool (Earth Sciences Department, Monash University), Alan Fraser (Johns Hopkins University, Maryland, U.S.A.), Pablo Puerta (Museo Paleontologico Egidio Feruglio, Trelew, Argentina), and Fan Jun hang (Institute of Vertebrate Palaeontology and Palaeoanthropology, Beijing, China).

The field party departed on 10 July 1995 from Cairns on the *Gulf Express,* a coastal freighter that makes a weekly return voyage to Thursday and Horn Islands off Cape York. On the evening of 11 July, the field party transferred to *El Torito* at Portland Roads.

A landing was made the following morning at Captain Billy Landing, where the prospecting began. Most encouraging was the fact that the first rocks seen were reminiscent of the coastal outcrops of the dinosaur-bearing units well known to several of the party in Victoria. Working northward, all outcrops of the Helby Beds near Captain Billy Landing were examined by the end of the second day without the discovery of a single fossil bone, despite many rock exposures being remarkably similar to those that produce dinosaurs in Victoria.

On the third and first half of the fourth day, the rocks of the Helby Beds further north, which from the air had not seemed remarkably different from those at Captain Billy Landing, proved on close inspection to have been extensively chemically altered. They were, for the most part, laterite boulders and kaolinized clays. Searching in detail for small areas that were not chemically altered did turn up some places where the rocks were similar to those near Captain Billy Landing, but again no fossil bones of any kind were found.

With no fossils found anywhere by noon on the fourth day, it was decided to return to Captain Billy Landing and search there a second time to maximize the chances of finding evidence of fossil bones. *El Torito* spent the afternoon retracing its northward path and arrived off the southern most exposures of the Helby Beds less than an hour before sunset. Going ashore, the field party spread out and in quick succession two objects that appeared to be bone, (QM F35957, Figure 5, and

Figure 5 QM F35957, one of two possible fossil bone fragments from 11°40'28"S., 142°51'34"E. coastal outcrops of the Jurassic Helby Beds just south of Captain Billy Landing, eastern side of the Cape York Peninsula, Queensland. Scale bar = 10 mm.

QM F35958), were found by Pat Vickers-Rich at least 50 m apart. Passed amongst us, in the failing light of day and again on board the ship that night, we could not convince ourselves one way or the other whether, in fact, the objects were bone — although gradually the doubts became weaker.

The following day cracking rock at that site by a number of the field party did not reveal another object like either of the two possible fossil bone fragments. After these two objects had been found so quickly in a few minutes of twilight one day, and then nothing similar to them could be located searching all the following day until the light conditions were similar to the previous one, we were greatly puzzled as to what they were. Disappointed, some of us reprospected other outcrops of the Helby Beds near Captain Billy Landing for about half the day, again to no avail.

The final day on *El Torito* was spent reaching Thursday Island. While under way, the opportunity was taken to examine the possible fossil bone fragments in full sunlight for the first time. There, with the knowledge that nothing more like them had been found, it was harder to convince ourselves that they were, in fact, small pieces of fossil bone. To decide for sure, they were carefully rewrapped to be transported to Monash University where they could be examined under a microscope and chemical tests carried out if necessary for a more definitive analysis.

LABORATORY RESULTS AND DISCUSSION

The two possible fossil fragments found in the Helby Beds were examined at length at Monash University. If they were water worn rock pebbles, there were two things odd about them. First, on both specimens, one smooth surface was a partial cylinder in shape. This smooth surface was truncated by a smooth flat surface. Such a combination is what might be expected in a fragment of bone but unlikely in a water-worn rock pebble. Second, again on both specimens, opposite the smooth cylindrical surface was a very rough surface, as if broken. Although pebbles with rough, broken surfaces are found, usually they are rare in fine-grained sandstones, and in this case the only two objects discovered had this pattern more common in a bone fragment than an ordinary rock pebble.

Visual comparison of a bone of the holotype of *Agrosaurus macgillivrayi* with the two possible fossil fragments found near Captain Billy Landing shows they are quite different in preservation. The Captain Billy Landing specimens are solid, whereas the spongiosa of the holotype bone is open. The rock in which the holotype of *Agrosaurus macgillivrayi* was found has been disaggregated with acetic acid, suggesting it was originally cemented with calcium carbonate. The leaching quite evident in all outcrops of the Helby Beds visited had removed any carbonate that might once have been present in those rocks.

The difference in preservation between the holotype of *Agrosaurus macgillivrayi* and the two possible bone fragments from Captain Billy Landing, coupled with the absence of carbonates from the Helby Beds, strongly suggests that the holotype specimen came from elsewhere than the Helby Beds of Cape York Peninsula. The lack of other coastal outcrops in "N.E. Australia" of the right geological age to have yielded a prosauropod to a ship's landing party operating inland on foot in 1844, makes it unlikely that *A. macgillivrayi* came from that area at all.

Von Huene (1906) described the rock in which the bones of the holotype of *Agrosaurus macgillivrayi* occurred as, "... einer grauen Breccie voll von Knochensplittern ... [a grey breccia full of bone fragments]." He then noted, "Das Gestein erinnert in höchstem Grade an die Knochen breccie von Durdham Down in Bristol [The rock is extremely reminiscent of the bone breccia at Durdham Down near Bristol]." This reference was to the Late Triassic Magnesian Conglomerate fissure site in the Carboniferous Limestone from Durdham Down near Bristol, England (Figure 6) (Locality 18, Avon, England in Weishampel 1990), dated as Carnian to Rhaetian (Benton and Spencer 1995). Because of the subsequent chemical disaggregation of the rock surrounding the

Figure 6 Location of Durdham Down near Bristol, the likely actual source of the holotype of *Agrosaurus macgillivrayi* Seeley, 1891.

holotype, von Huene's observation cannot now be confirmed, although there is no reason to doubt it. Microvertebrate remains recovered from the residue remaining after the acid preparation include jaw fragments of a sphenodontid reptile and the tip of a prosauropod tooth crown bearing denticulated margins.

The most complete small reptilian element (and the only one that can be identified with certainty) is a 3 mm long posterior fragment of a right maxilla of a sphenodontid, BMNH R14111. The fragment includes ten teeth. The eight most posterior ones, situated on the posterior process of the maxilla, are acrodont (firmly fused to the jaw bone) with large and small teeth alternating, the small ones positioned on the lingual side of the jaw. The two most anterior teeth, in line with the back of the nasal process of the maxilla, are pleurodont (one side of the tooth base fused to the jaw bone) and similar in size. This dual type of tooth implantation is found only in the sphenodontian *Diphyodontosaurus avonis* Whiteside, 1986. *Diphyodontosaurus* is recorded from several Triassic fissure sites in the Carboniferous Limestones of the Bristol area: Tytherington Quarry (Whiteside 1986), Cromhall Quarry (Fraser and Walkden 1983, 1984) and Durdham Down (Benton and Spencer 1995; Fraser 1994). Remains of the prosauropod *Thecodontosaurus* also occur at these fissure sites (Benton and Spencer 1995). Of these sites where both *Thecodontosaurus* and *D. avonis* have been found, only Durdham Down was a known fossil locality in 1879, the year the holotype of *Agrosaurus macgillivrayi* was acquired by the Natural History Museum, London. Thus, the occurrence of *Diphyodontosaurus* in the same block as elements of the holotype of *A. macgillivrayi*, BMNH 49984, together with the similarities in bone preservation and matrix, provide very strong evidence that the holotype is from Durdham Down.

This still leaves unanswered how the specimen came to be labelled as Seeley found it to be when he wrote his paper in 1891. However, the material had already passed through several hands; it was purchased by the Natural History Museum in 1879 from Edward Charlesworth after the dispersal of a collection belonging to Mr Samuel Long Waring Esq. of 'The Oaks', Norwood, following his death that year (Seeley 1891). It is clear that the label was associated with the specimen when the Natural History Museum purchased it from Charlesworth in 1879 since the register entry detail for July 1879 is an exact transcription in quotation marks of that information, except that it reads "Mr.[.??] Macgillivray" instead of "Jn.[.??] Macgillivray" as Seeley (1891) quoted it. So, any specimen mislabelling happened prior to that date. No earlier record of the history of the material can be traced.

Von Huene (1906) regarded *Agrosaurus macgillivrayi* Seeley, 1891 as quite close to *Thecodontosaurus antiquus* Morris, 1843 from the Durdham Down locality, noting that they differed only in that the radius and ulna of *A. macgillivrayi* were more slender. The similarity was so close that he transferred *A. macgillivrayi* to *Thecodontosaurus macgillivrayi*. Despite this degree of similarity and the likeness of the rock enclosing the holotype of *A. macgillivrayi*, nowhere did he express doubt as to the Australian provenance of the specimen. Given what was known of the geology of the Cape York Peninsula at the time, there was no reason for him to have done so.

One of the bones of the holotype of *Agrosaurus macgillivrayi*, together with a sample of fossil bones known to be from the Magnesian Conglomerate, Durdham Down, BMNH R1548, and the two possible bone fragments from Cape York Peninsula, QM F35957 and QM F35958, were analysed using a mass spectrometer in the VIEPS Trace Analysis Laboratory at Monash University by Ms Louise Frick, assisted by Ms Donna Korke and Mrs Lesley Kool. The detailed results of this work are presented in the Appendix. The data show that the fossil bone sample of the holotype of *A. macgillivrayi* and that from Durdam Down, England have much higher U/Th ratios, and much lower Th/Pb ratios than the

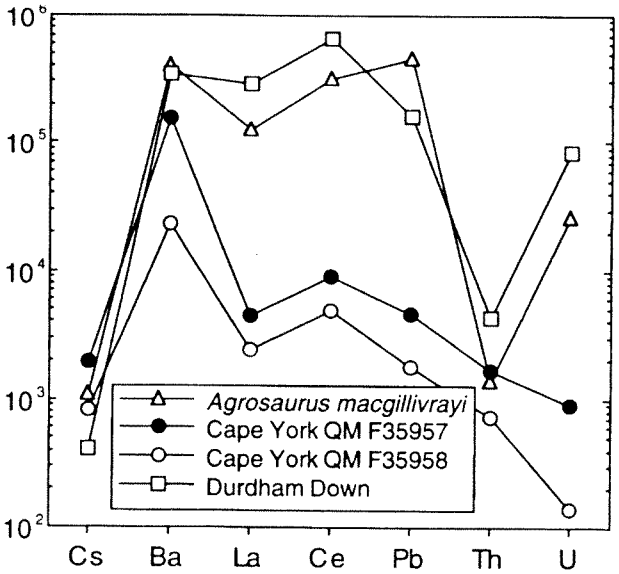


Figure 7 Logarithmic plot of the abundances in parts per billion of seven trace elements in four samples. Note how the abundances in the fossil bone from the holotype of *Agrosaurus macgillivrayi* and the sample from Durdham Down closely track one another, while the two objects found on Cape York Peninsula have a quite different trace element abundance signature.

possible fossil bone samples from Cape York Peninsula (Figures 7 and 8). This further supports the contention that the holotype of *A. macgillivrayi* is from the Durdham Down locality rather than from Cape York Peninsula.

With the possible exception of the poorly exposed

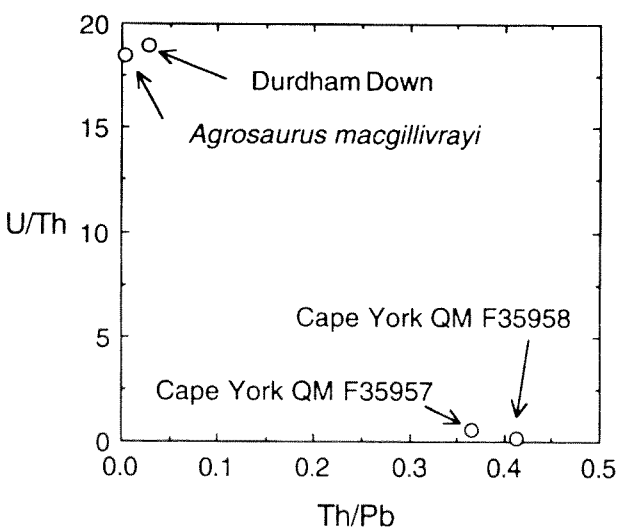


Figure 8 Plot of the uranium-thorium and thorium-lead ratios in four samples. Note how the ratios in the fossil bone from the holotype of *Agrosaurus macgillivrayi* and the sample from Durdham Down are close to one another and quite distinct from the two objects found on Cape York Peninsula which also are close to one another.

Injune Creek Group where *Rhoetosaurus brownei* was found, nowhere else in Australia are fossil terrestrial vertebrates of the age of the Helby Beds known*. Therefore, although the trail followed was a century and a half old, and in the end may have led nowhere, the effort to try and decide whether the holotype of *Agrosaurus macgillivrayi* came from the Helby Beds was worthwhile.

A negative scientific result can never be established with complete certainty. It is not possible, for example, to find the non-thylacine to demonstrate that there are no Tasmanian tigers alive today. The best one can hope to do is to conduct a thorough search. The one satisfaction of this result, although a negative one, is that it is robust. Because the weather and sea conditions were so favourable, the field party was able to examine all the outcrops of the Helby Beds for as long as necessary to establish with the highest probability possible that fossil bones similar in preservation to those of *Agrosaurus macgillivrayi* either do not occur at all in that unit or if so, are extremely rare.

A caveat about this negative result is that the amount of outcrop examined was necessarily limited. In Victoria, Early Cretaceous dinosaurs have been found in circumstances rather similar to the outcrops of the Helby Beds. In both cases, the exposures are on shore platforms frequently washed by waves from the sea. If one were to be restricted at random to the same amount of outcrop in Victoria as was available to us in the Helby Beds, there is every chance that not a single fossil bone fragment would be found there. It, therefore, cannot be completely ruled out that a single block of rock containing the holotype of *Agrosaurus macgillivrayi* Seeley, 1891 was found by John MacGillivray in 1844 and no additional fossils were found by us. But that is probably not what occurred.

Certainly, this thorough examination of the Helby Beds shows that it has a low potential of eventually proving to be a rich source of fossil vertebrates. Given its age, however, as being from a time interval in Australia from which fossil tetrapods are unrepresented unless the two objects found at the end of the fourth day are, in fact, fossil tetrapod bones, if opportunities to revisit the outcrops of the Helby Beds near Captain Billy Landing occur from time to time, an effort to find more of whatever those objects are is justified. From its form alone, a third such specimen might make it clear whether such objects are in fact bones or a rare rock type.

* *Editors footnote added in proof*: Long and Molnar (1998), recently described a Middle Jurassic theropod, *Ozraptor subotaii*, from Western Australia.

On the days the outcrops of the Helby Beds in the vicinity of Captain Billy Landing were visited, there was much mud on the shore platform. It is, therefore, well to keep in mind the circumstances in which one of the most productive Cretaceous dinosaur localities in Victoria was discovered. Despite repeated, prior visits to the site, nothing had been found there. On the day of discovery, a recent storm had stripped away all the sand that ordinarily covered the lens where the fossil bones occur, making them readily visible.

CONCLUSION

The brief answer to the question posed in the title of this paper is "No". The presently available evidence strongly suggests that the holotype of *Agrosaurus macgillivrayi* Seeley, 1891 did not, in fact, come from northeastern Australia despite the label associated with the specimen. Rather, it is quite likely that it came from the Magnesian Conglomerate at Durdham Down near Bristol, a site already well known when the holotype was purchased by The Natural History Museum in 1879 (Seeley 1891). Given the likelihood that the holotype of *Agrosaurus macgillivrayi* Seeley 1891 did come from the Durdham Down locality, the species is quite probably a junior synonym of *Thecodontosaurus antiquus* Morris, 1843, a conclusion foreshadowed by von Huene (1906).

Following von Huene (1906), Galton and Cluver (1976) referred *Agrosaurus macgillivrayi* to *Thecodontosaurus macgillivrayi* (Seeley) and listed it under the family Anchisauridae as a *nomen dubium*, as they regarded the material as generically and specifically indeterminate. More recently, Galton (1990) showed *Thecodontosaurus* to be a basal sauropodomorph taxon and assigned it to its own family.

ACKNOWLEDGEMENTS

The Committee for Research and Exploration of the National Geographic Society provided the funding to carry out this study: grants 4938–92, 5257–94, and 5835–96. Andrew Kos and David Cantrill hand-couriered the type specimen to Australia, and back to England, respectively. Phil Hurst of the Natural History Museum, London, took the photographs in Figures 3 and 4. Val Hogan of the Museum of Victoria Library, Wendy Cawthorne of the Geological Society Library, London, and John Thackray, Archivist for the Natural History Museum, London, and the Geological Society, London, helped gather historical information.

REFERENCES

Bastock, J. (1988). *Ships on the Australia Station*: 1–175, Child and Associates Publishing, Frenchs Forest, N.S.W.

Benton, M.J. and Spencer, P.S. (1995). *Fossil reptiles of Great Britain*: 1–386, Chapman and Hall, London, U.K.

Browne, C.A. (1871). *Letters and Extracts from the Addresses and Occasional Writings of J.B. Jukes*: 1–596, Chapman and Hall, London, U.K.

Fraser, N.C. (1994). Assemblages of small tetrapods from British Late Triassic fissure deposits. *In* Fraser, N.C. and Sues, H.-D. (eds), *In the shadow of the dinosaurs:* 214–226, Cambridge University Press, Cambridge, U.K.

Fraser, N.C. and Walkden, G.M. (1983). The ecology of a late Triassic reptile assemblage from Gloucestershire, England. *Palaeogeography, Palaeoclimatology, Palaeoecology* **42**: 341–363.

Fraser, N.C. and Walkden, G.M. (1984). Two Late Triassic terrestrial ecosystems from south west England. *In* Reif, W.E. and Westphal, F. (eds), *Third Symposium on Mesozoic Terrestrial Ecosystems:* 87–92, Tubingen, Short Papers.

Galton, P.M. (1990). Basal Sauropodomorpha–Prosauropoda. *In* Weishampel, D.B., Dodson, P and Osmólska, H. (eds), *The Dinosauria*: 320–344, University of California Press, Berkeley, Calif., U.S.A.

Galton, P.M. and Cluver, M.A. (1976). *Anchisaurus capensis* (Broom) and a revision of the Anchisauridae (Reptilia, Saurischia). *Annals of the South African Museum* **69**: 121–159.

Huene, F. von (1906). Ueber die Dinosaurier der aussereuropäischen Trias. *Geologische und Palaeontologische Abhandlungen* **8**: 97–156.

Jukes, J.B. (1847). *Narrative of the surveying voyage of the H.M.S. Fly*: vol. 1, 1–423, vol. 2, 1–362, Boone, London, U.K.

Jukes, J.B. (1850). *A sketch of the physical structure of Australia as far as it is at present known*: 1–95, Boone, London, U.K.

Long, J.A. and Molnar, R.E. (1998). A new Jurassic theropod dinosaur from Western Australia. *Records of the Western Australian Museum* **19**: 221–229.

MacGillivray, J. (1852). *Narrative of the voyage of the H.M.S. Rattlesnake*: vol. 1, 1–402, vol. 2, 1–395, Boone, London, U.K. [Libraries Board of South Australia facsimile edition, 1967.]

Molnar, R.E. (1991). Fossil reptiles in Australia. *In* Vickers-Rich, P., Monaghan, J.M., Baird, R.F. and Rich, T.H. (eds), *Vertebrate palaeontology of Australasia:* 605–702, Pioneer Design Studio, Lilydale, and Monash University Publications Committee, Melbourne, Victoria.

Morris, J. (1843). *A Catalogue of British fossils*: 1–222, The British Museum, London, U.K. [2nd ed. 1854].

Powell, B.S., Gibson, D.L., Smart, J., Grimes, K.G. and Doutch, H.F. (1976). New and revised stratigraphic nomenclature, Cape York Peninsula. *Queensland Government Mining Journal* **April 1976**: 179–188.

Powell, B.S. and Smart, J. (1977). Jardine River-Orford Bay, Queensland, 1:250,000 Geological Series – map and

explanatory notes. *Bureau of Mineral Resources, Geology and Geophysics. Geological Survey of Queensland.* Australian Government Publishing Service, Canberra, A.C.T.

Ralph, R. (1993). John MacGillivray — his life and work. *Archives of Natural History* **20**: 185–195.

Rich, P.V., Rich, T.H., Wagstaff, B., McEwen Mason, J., Douthitt, R.T., Gregory, R.T. and Felton, A. (1988). Evidence for low temperatures and biologic diversity in Cretaceous high latitudes of Australia. *Science* **242**: 1403–1406.

Rich, T.H. and Rich, P.V. (1989). Polar dinosaurs and biotas of the Early Cretaceous of southeastern Australia. *National Geographic Research* **5**: 15–53.

Seeley, H.G. (1891). On *Agrosaurus macgillivrayi* (Seeley), a saurischian reptile from the N.E. coast of Australia. *Quarterly Journal of the Geological Society* **47**: 164–165.

Weishampel, D.B. (1990). Dinosaurian distribution. *In* Weishampel, D.B., Dodson, P. and Osmólska, H. (eds), *The Dinosauria*: 63–139, University of California Press, Berkeley, Calif., U.S.A.

Whiteside, D.I. (1986). The head skeleton of the Rhaetian sphenodontid *Diphyodontosaurus avonis* gen. et sp. nov. and the modernizing of a living fossil. *Philosophical Transactions of the Royal Society of London* **B 312**: 379–430.

Manuscript received 9 March 1998; accepted 9 August 1998.

APPENDIX

Determination of trace elements in bone samples

Louise Frick
VIEPS Trace Analysis Laboratory, Monash University, Clayton, Vic 3168

Chemistry

All wet-chemistry was performed in "class 350" clean air cabinets. 50–100 mg samples of rock powder were dissolved in HF-HNO_3 mixture then evaporated to dryness. They were refluxed twice in concentrated HNO_3, and once in concentrated HCl to remove fluorides, then dissolved in 2% HNO_3. This solution was then diluted to 50 ml of 2% HNO_3 (made with sub-boiled distilled concentrated HNO_3 and 18.2 M-ohm Millipore water). Aliquots of this solution were then taken and diluted to an appropriate dilution factor for presentation to the mass spectrometer (approximately 1:10,000). One analytical blank was prepared with the run. A multi-element solution standard was used as a check standard to monitor accuracy during the analysis procedure.

Mass Spectrometry

Diluted rock and acid samples were analysed by

Table 1 Resolved concentrations of trace element isotopes in ppb.

	^{133}Cs	^{135}Ba	^{139}La	^{140}Ce	^{208}Pb	^{232}Th	^{238}U
Acetone blank	304	633	390	235	299	335	N/D
Agrosaurus macgillivrayi	1,077	393,931	126,264	315,082	449,818	1,405	25,987
Cape York Peninsula QM F35957	1,988	156,111	4,438	8,763	4,289	1,709	877
Cape York Peninsula QM F35957 repeat	1,949	156,970	4,548	9,426	4,888	1,647	926
Cape York Peninsula QM F35958	837	23,344	2,404	4,843	1,770	729	140
Durdham Down	410	342,570	282,371	649,463	157,208	4,371	82,864
Reproducability of the standard data							
dum 1	9.837	9.719	9.825	9.588	9.938	9.863	10.101
dum 2	9.791	9.687	9.829	9.493	9.944	9.895	10.109
dum 3	9.885	9.752	9.822	9.695	9.933	9.832	10.093
std 5 ppb	9.924	9.780	9.819	9.783	9.929	9.803	10.086
mean	9.859	9.734	9.824	9.639	9.936	9.848	10.097
standard deviation (SD)	0.058	0.040	0.004	0.126	0.006	0.039	0.010
relative SD (= SD/mean)	0.59%	0.42%	0.05%	1.31%	0.06%	0.40%	0.10%
Accuracy of the 1 ppb dummy standard							
dum 1	-2.68%	-3.85%	-2.79%	-2.93%	-1.67%	-0.14%	-0.07%
dum 2	-3.13%	-4.17%	-2.76%	-3.89%	-1.62%	-0.18%	-0.01%
dum 3	-2.20%	-3.52%	-2.83%	-1.84%	-1.72%	-0.45%	-0.14%
std 5 ppb	-1.82%	-3.25%	-2.86%	-0.95%	-1.77%	-0.75%	-0.21%
Reproducability of the repeated sample							
Cape York Peninsula QM F35957	-1.93%	0.55%	2.49%	7.56%	13.98%	-3.63%	5.51%

inductively-coupled plasma mass spectrometry (ICP-MS) using a high resolution Finnigan MAT ELEMENT™ magnetic sector ICP-MS. The following isotopes were chosen for each element of interest, on the basis of no or minimal isobaric interference: ^{133}Cs, ^{135}Ba, ^{139}La, ^{140}Ce, ^{208}Pb, ^{232}Th and ^{238}U. Twenty-five runs of one mass spectrometer sweep through the mass spectrum were performed. The run specifications resulted in approximately 10 sample points per peak.

Data Reduction

Integrated count data from the instrument were reduced using a custom, off-line, spreadsheet-based program. During each analysis a series of dummy samples was run to provide a check on instrument drift. The count data were then corrected by a polynomial in time for each element analysed to provide constant counting efficiency in the dummy samples. Next, calibration curves were constructed for each element using a simple, least squares linear regression of the multi-element solution standard data points. Using these calibration curves, the data were resolved into ppb in solution (Table 1; Figures 7–8).

Estimate of Precision and Accuracy

Precision (in-run statistics quoted as relative standard deviation = standard deviation / mean) is better than 5% for each analysis. As described above, determination of analytical accuracy is based on analysis of the solution standards, and is typically better than 5% for most elements at the 95% confidence level.