

A peculiar faunivorous metatherian from the early Eocene of Australia

ROBIN M.D. BECK



Beck, R.M.D. 2015. A peculiar faunivorous metatherian from the early Eocene of Australia. *Acta Palaeontologica Polonica* 60 (1): 123–129.

I describe *Archaeonothos henkgodthelpi* gen. et. sp. nov., a small (estimated body mass ~40–80 g) tribosphenic metatherian from the early Eocene Tingamarra Fauna of southeastern Queensland, Australia. This taxon, known only from a single isolated upper molar (M2 or M3) is characterised by a very distinctive combination of dental features that, collectively, probably represent faunivorous adaptations. These include: a straight, elevated centrocrista; a metacone considerably taller than the paracone; a wide stelar shelf (~50% of the total labiolingual width of the tooth); reduced stelar cusps; a long postmetacrista; a small and anteroposteriorly narrow protocone; an unbasined trigon; and the absence of conules. Some of these features are seen in dasyuromorphians, but detailed comparisons reveal key differences between *A. henkgodthelpi* and all known members of this clade. *A. henkgodthelpi* also predates recent molecular estimates for the divergence of crown-group Dasyuromorphia. Similar dental features are seen in a number of other metatherians, including the South American sparassodonts, *Wirunodon chanku* from the ?middle–late Eocene Santa Rosa local fauna of Peru, and *Kasserinotherium tunisiense* from the early Eocene Chambi fauna of Tunisia, although whether *A. henkgodthelpi* is closely related to any of these taxa is unclear based on available evidence. I therefore refer *A. henkgodthelpi* to Metatheria *incertae sedis*. Potential relatives of *A. henkgodthelpi* are unknown from any other Australian fossil deposit.

Key words: Mammalia, Metatheria, Marsupialia, Sparassodonta, Eocene, Tingamarra Fauna, Australia.

Robin M.D. Beck [r.m.d.beck@salford.ac.uk], School of Environment & Life Sciences, Room G48, Peel Building, University of Salford, Salford M5 4WT, UK; and School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia.

Received 1 March 2013, accepted 5 June 2013, available online 6 June 2013.

Copyright © 2015 R.M.D. Beck. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

With a handful of exceptions (e.g., Archer et al. 1988; Beck et al. 2008a), all fossil Australian metatherians known from the late Oligocene onwards can be confidently referred to one of the four Australian marsupial (i.e., crown-group metatherian) orders still extant today, namely Dasyuromorphia (predominantly faunivorous forms such as quolls, marsupial “mice”, the numbat, and the extinct thylacine), Diprotodontia (“possums”, kangaroos, wombats, and the koala), Notoryctemorphia (marsupial moles), and Peramelemorphia (bandicoots and bilbies). The only known Australian metatherians older than the late Oligocene are from the early Eocene Tingamarra Local Fauna in southeastern Queensland (Godthelp et al. 1992). In direct contrast to younger Australian deposits, none of the fossil metatherians described to date from Tingamarra can be referred to a modern marsupial order (Archer et al. 1993; Godthelp et al. 1999; Beck et al. 2008b; Sigé et al. 2009; Beck 2012). The Tingamarran metatherians are

therefore of critical importance for understanding the early evolutionary history of the clade in Australia, and the timing of diversification of modern Australian marsupials. However, they are represented by highly fragmentary specimens, mainly isolated teeth, and much of this material remains to be described.

Here, I describe a new metatherian from Tingamarra, *Archaeonothos henkgodthelpi*, that also does not appear to be a member of any known Australian marsupial order. Given that this taxon is currently represented by extremely limited material (a single upper molar), and pending a formal phylogenetic analysis that includes a suitably diverse sample of potential relatives, I simply discuss its derived similarities to other metatherians, and refer it to Metatheria *incertae sedis*.

Institutional abbreviations.—EY, Service de la Carte collections, Office National des Mines, Tunis, Tunisia; LACM, collection of the Natural History Museum of Los Angeles County, Los Angeles, USA; MHNC, Museo de Historia Natural Alcide d’Orbigny, Cochabamba, Bolivia; QM F, Queensland

Museum Fossil Collection, Brisbane, Australia; YPFB Pal, Yacimientos Petroliferos Fiscales Bolivianos, Colección de Paleontología, Santa Cruz, Bolivia.

Other abbreviations.—L, maximum anteroposterior length; M, upper molar; StA–E, stylar cusps A–E; W, maximum labiolingual width.

Material and methods

As with all other mammalian fossils collected to date from the early Eocene Tingamarra Local Fauna (Godthelp et al. 1992, 1999; Archer et al. 1993; Hand et al. 1994; Beck et al. 2008b; Sigé et al. 2009; Beck 2012), the holotype and only known specimen of *Archaeonothos henkgodthelpi* gen. et sp. nov. (QM F53825) was recovered by repeated screen-washing of illite-smectite clay samples and subsequent microscope-assisted sorting of the concentrate. Following Luckett (1993), the plesiomorphic upper molar formula for Metatheria is assumed to be M1–4, although it has been proposed that the “M1” of metatherians is in fact a retained deciduous premolar (Averianov et al. 2010; O’Leary et al. 2013). Maximum anteroposterior length (L) of a molar is here measured parallel to a line running through the apices of the paracone and metacone, while maximum labiolingual width (W) is measured perpendicular to this (see Muizon 1998: 137, A4, A5).

Body mass estimates were calculated for *Archaeonothos henkgodthelpi* and other metatherian taxa discussed in the text (Table 1) using regression equations for upper molar dimensions from two different datasets: the “pooled Didelphidae and Dasyuridae” dataset of Gordon (2003: fig. 7), and the “all species” dataset (based on Australian marsupials only) of Myers (2001: table 2). The most accurate (as indicated by R² values) measurement available was used for each locus: for the Gordon (2003: fig. 7) dataset, this was L for M1, M2, and M3; for the Myers (2001: table 2) dataset, this was maximum occlusal area for M1, and L for M2 and M3. Estimates based on Myers (2001: table 2) include the appropriate smearing estimate. If the precise dental locus represented was uncertain, body mass estimates were calculated for each of the different possible loci.

Systematic palaeontology

Mammalia Linnaeus, 1758

Infraclass Metatheria Huxley, 1880

Order and family incertae sedis

Genus *Archaeonothos* nov.

Type species: *Archaeonothos henkgodthelpi* sp. nov., monotypic; see below.

Etymology: From Ancient Greek *arkhaios*, ancient and *nothos*, illegitimate; in reference to the uncertain affinities of this fossil taxon.

Diagnosis.—As for type species.

Archaeonothos henkgodthelpi sp. nov.

Fig. 1.

Etymology: In honour of my colleague, friend, and mentor Henk Godthelp, who has led research at Tingamarra for over 20 years. The genus name can be rendered into colloquial English as “the old bastard”, which is an affectionate nickname for Henk.

Holotype: QM F53825, a slightly worn M2 or M3 (Fig. 1).

Type locality: Tingamarra Local Fauna, Boat Mountain area, Murgon, southeastern Queensland, Australia 26°S 152°E.

Type horizon: Potassium/argon dating of authigenic clays give a minimal age of 54.6 ± 0.05 MY BP for this site (Godthelp et al. 1992), i.e., earliest Eocene, a date congruent with geological and biocorrelative evidence (Beck et al. 2008b: text S1; Sigé et al. 2009).

Diagnosis.—Small (estimated body mass of ~40–80 g; Table 1), tribosphenic metatherian characterised by the following features: centrocrista straight and elevated above the level of the trigon; metacone much larger than paracone; protocone small and anteroposteriorly narrow; conules indistinct or absent; trigon unbasined; stylar shelf broad (~50% of the total labiolingual width of the tooth); StB tallest cusp, other stylar cusps weakly developed; preparacrista anteriorly convex and terminating at StB; small but distinct StA present; very narrow but continuous cingulum along the anterior margin of tooth, formed by preprotocrista and anterolabial cingulum; postmetacrista longer than preparacrista. Differs from many metatherians with straight centrocristae (e.g., *Kokopellia juddi* Cifelli, 1993, peradectids, alphasodontids, “pediomyids”, microbiotherians, *Caluromysiops irrupta* Sanborn, 1951) in that the apex of the centrocrista is elevated far above the trigon rather than level with it, the metacone is much taller than (rather than subequal in height to) the paracone, and the protocone is small and anteroposteriorly narrow, without a distinct trigon basin. Differs from most didelphimorphians and most dasyuromorphians in that the centrocrista is straight rather than V-shaped, the stylar shelf is wide (~50% of the total labiolingual width of the tooth), StD is very small, and the protocone is small and anteroposteriorly narrow, without a distinct trigon basin. Differs from dentally derived thylacinids, such as *Wabulacinus ridei* Muirhead, 1997 and species of *Thylacinus*, in its much smaller size (estimated body mass of 40–80 g versus >5 kg), wider stylar shelf, shorter and less oblique postmetacrista (resulting in the tooth as a whole being proportionally not as elongate anteroposteriorly), and a StD that is positioned labially (rather than posterolabially) relative to the metacone. Differs from the possible sparassodont *Mayulestes ferox* Muizon, 1998 in its smaller size, more reduced stylar cusps (particularly StD), shallower ectoflexus, less well-developed conules, smaller protocone, and more oblique postmetacrista. Differs from the sparassodont *Allqokirus australis* Marshall and Muizon, 1998 in its smaller size, shorter and less oblique postmetacrista, less closely approximated paracone and metacone, less well-developed conules, and a metacone that does not overhang the posterior margin of the tooth. Differs from most other sparassodonts in its much smaller size (estimated body mass of 40–80 g versus >800 g), less

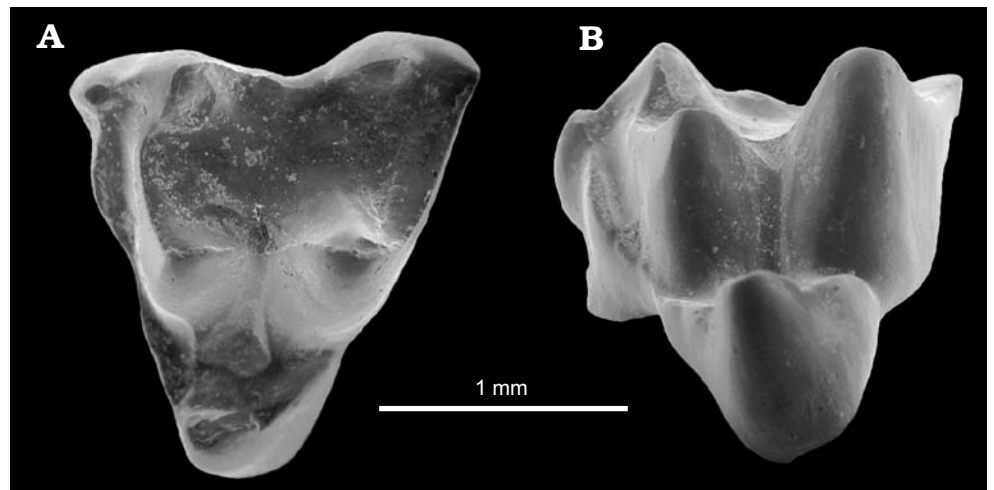


Fig. 1. Holotype and only known specimen of the metatherian mammal *Archaeonothos henkgodthelpi* gen. et sp. nov. (QM F53825; M2 or M3) from the early Eocene Tingamarra Fauna, southeastern Queensland, Australia; in occlusal (A) and lingual (B) views. Both SEM micrographs.

closely approximated paracone and metacone, less oblique postmetacrista, broader stylar shelf, and larger protocone. Differs from *Wirunodon chanku* Goin and Candela, 2004 in its more closely approximated paracone and metacone, more compressed protocone, metacone being proportionately larger than paracone, preparacrista terminating at StB (instead of StA), larger StB, wider stylar shelf, larger size (estimated body mass approximately twice as large), and the presence of a (very small) StC. Differs from *Kasserinotherium tunisiense* Crochet, 1986 in its more anteroposteriorly compressed protocone, wider stylar shelf, much greater size difference in paracone and metacone, and larger StB.

Description.—QM F53825 is a small (Table 1), lightly worn tribosphenic upper molar (either an M2 or M3) with promi-

nent crests and sharp cusps (Fig. 1). Three distinct roots are present: an intact lingual root below the protocone, and broken roots at the anterolabial and posterolabial corners. In occlusal view (Fig. 1A), the tooth is close to triangular in outline, with a moderately well-developed ectoflexus. When oriented such that the apices of the paracone and metacone are anteroposteriorly aligned, the metastylar lobe projects slightly further labially than does the parastylar lobe.

A low, but distinct, StA is present at the anterolabial corner of the tooth, sitting at the anterior end of the anterolabial cingulum. Immediately lingual to StA, there is a shallow notch (“metastylar indent” sensu Cramb and Hocknull 2010) in the anterolabial cingulum, which would have housed the posterolabial (metastylar) corner of the preced-

Table 1. Body mass estimates for *Archaeonothos henkgodthelpi* gen. et sp. nov. and other metatherian taxa discussed in the text, calculated using regression equations from the “pooled Didelphidae and Dasyuridae” dataset of Gordon (2003: fig. 7) and the “all species” dataset (which is based on Australian marsupials only) of Myers (2001: table 2). Measurements were taken from the indicated references. The holotype and only known specimen of *Chulpasia jimthorselli* (QM F50411, an M1 or 2) is damaged (see Sigé et al. 2009), and hence measurements for this specimen represent minimum values; as a result, body mass estimates for *C. jimthorselli* are probably underestimates. Abbreviations: L, maximum anteroposterior length; M1A, body mass estimate based on regression equation of M1 maximum occlusal area (calculated as $L \times W$); M1L, body mass estimate based on regression equation of M1 maximum anteroposterior length; M2L, body mass estimate based on regression equation of M2 maximum anteroposterior length; M3L, body mass estimate based on regression equation of M3 maximum anteroposterior length; W, maximum labiolingual width.

Taxon	Specimen	Locus	L [mm]	W [mm]	Estimated body mass [g]		References
					Gordon (2003)	Myers (2001)	
<i>Archaeonothos henkgodthelpi</i> gen. et sp. nov.	QM F53825	M2 or 3	1.88	1.73	43.6 (M2L)	54.3 (M2L)	this study
					48.7 (M3L)	76.0 (M3L)	
<i>Mayulestes ferox</i>	MHNC 1249	M2	3.09	3.91	212.1 (M2L)	355.5 (M2L)	Muizon (1998)
		M3	2.89	4.29	181.3 (M3L)	317.7 (M3L)	
<i>Allqokirus australis</i>	YPFB Pal 6104	?M3	3.2	3.4	247.7 (M3L)	445.9 (M3L)	Marshall and Muizon (1988)
<i>Kasserinotherium tunisiense</i>	EY 10	M3	1.6	1.75	29.7 (M3L)	44.4 (M3L)	Crochet (1986)
	EY 12	M1 or 2	1.42	1.55	19.2 (M1L)	29.7 (M1A)	
					17.9 (M2L)	18.8 (M2L)	
<i>Wirunodon chanku</i>	LACM 140621	?M3	1.27	1.12	14.7 (M3L)	20.6 (M3L)	Goin and Candela (2004)
<i>Djathia murgonensis</i>	QM F31458	M2	1.8	—	38.0 (M2L)	46.1 (M2L)	Godthelp et al. (1999)
		M3	1.67	—	33.9 (M3L)	51.2 (M3L)	
<i>Thylacotinga bartholomaii</i>	QM F16835	M2	5.53	—	1351.3 (M2L)	3212.3 (M2L)	Sigé et al. (2009)
<i>Chulpasia jimthorselli</i>	QM F50411	M1 or 2	2.48	2.58	120.7 (M1L)	237.9 (M1A)	Sigé et al. (2009)
					105.3 (M2L)	154.8 (M2L)	

ing molar in the intact tooth row. StB is the tallest stylar cusp, only slightly shorter than the paracone, and also the largest in terms of occlusal area. StB represents the labial terminus of the preparacrista. A weak, vertically-directed “keel” is present at the base of the anterior flank of StB, and is separated from StA by a very small, but distinct, notch. StC is extremely small and labiolingually compressed; it is identifiable only as a very slight rise on the labial margin of the tooth, immediately anterior to the deepest point of the ectoflexus and in line with midpoint of the centrocrista, merging anteriorly with the base of StB. StD is the second tallest stylar cusp, approximately 40% the height of StB. StD is located slightly more posteriorly than the apex of the metacone, and is labiolingually compressed. A slight rise at the posterolabial corner of the tooth, at the terminus of the postmetacrista, may represent StE.

The stylar shelf is broad, comprising about 50% of the total labiolingual width of the tooth, and hence the paracone and metacone are located quite centrally on the tooth crown. The metacone is much taller than the paracone, and is also larger in occlusal area, with its base extending further lingually towards the protocone. The labial face of the metacone shows slight labial buttressing such that the cusp is distinctly conical, whereas the labial face of the paracone is flatter. A very short, weak crest extends lingually from the base of the lingual margin of the paracone, and another extends lingually from the base of the anterolingual margin of the metacone; these indistinct crests may represent vestiges of the postparaconule crista and the premetaconule crista, respectively, although a distinct paraconule is absent and the metaconule is barely identifiable. The preparacrista is slightly convex anteriorly, but extends in an overall labial direction from the paracone to the large StB. The centrocrista is essentially straight, and the bases of the paracone and metacone are somewhat approximated. In labial view (Fig. 1B), the centrocrista appears elevated far above the level of the trigon. The postmetacrista is at an angle of ~65 degrees relative to an axis passing through the apices of the paracone and metacone. The trigon is not distinctly basined.

The protocone is small in terms of both height and occlusal area, and its posterior flank slopes more shallowly than its anterior flank. The apex of the protocone is located slightly more posteriorly than that of the paracone. In lingual view, the protocone apex appears distinctly anteriorly directed. A paraconule does not appear to be present anywhere along the preprotocrista. The preprotocrista does not terminate at the base of the paracone, but forms an extremely narrow cingulum along the anterior flank of the latter, which is continuous with the anterolabial cingulum labially. A remnant of the metaconule may be present as a slight bulge in the postprotocrista, as it descends from the apex of the protocone. The postprotocrista terminates at the base of the lingual flank of the metacone. The base of the metacone extends slightly further posteriorly than the terminus of the postprotocrista, and hence the posterior margin of the trigon appears slightly “pinched in” relative to the stylar region.

Discussion and conclusions

Two eutherians have been described from Tingamarra (Godthelp et al. 1992; Hand et al. 1994), namely the bat *Australonycteris clarkae* and the probable condylarth *Tingamarra porterorum*. However, *Archaeonothos henkgodthelpi* gen. et sp. nov. can be confidently identified as metatherian based on the following combination of (not always apomorphic) features characteristic of Metatheria, or subclades within Metatheria: metacone much larger than paracone; stylar shelf broad; presence of distinct stylar cusps including StD; absence of a postcingulum; postprotocrista does not extend past the base of the metacone (Luo et al. 2011). The presence of a straight centrocrista is probably plesiomorphic for Metatheria, as in, for example, the North American *Kokopellia*, “pediomyids”, alphadontids, and peradectids (Johanson 1996; Cifelli and Muizon 1997; Case et al. 2005; Davis 2007; Williamson et al. 2012). However, in these forms the apex of the centrocrista descends to the level of the trigon, and the paracone and metacone are similar in height (features also seen in some crown-marsupials, such as microbiotherians and the extant didelphid *Caluromysiops*; see Wroe et al. 2000: character 10; Voss and Jansa 2003, 2009). By contrast, in *Archaeonothos henkgodthelpi* the apex of the centrocrista is elevated far above the trigon, and the metacone is much taller than the paracone; I interpret this as a derived condition, probably functionally connected with faunivory. Similarly, it seems more likely that the small protocone and weakly developed stylar cusps of *A. henkgodthelpi* are secondarily derived, faunivorous adaptations, rather than plesiomorphic retentions.

Within Metatheria, *Archaeonothos henkgodthelpi* has the following apomorphic features seen to various degrees in faunivorously-adapted forms: small, anteroposteriorly compressed protocone; metacone much larger than paracone; metacone and paracone slightly approximated basally; postmetacrista longer than preparacrista; conules very reduced; centrocrista straight and elevated above the level of the trigon; and stylar shelf wide, but with reduced stylar cusps. Amongst known Australian marsupials, only some dasyurids and thylacinids (both members of Dasyuromorphia) show similar dental specialisations. However, dasyurids and most thylacinids appear less derived than *A. henkgodthelpi* in, for example, their more V-shaped centrocristae and better-developed protocones and conules. A straight centrocrista occurs only in the modern thylacinid *Thylacinus cynocephalus* and the Oligo-Miocene fossil forms *T. macknessi*, *T. potens*, and *Wabulacinus ridei* (Wroe and Musser 2001: character 10), all of which are much larger than *A. henkgodthelpi* (estimated body mass >5kg; Wroe et al. 2004, Travouillon et al. 2009). Dasyurids are also characterised by a relatively anteriorly-placed StD (further anterior than the metacone, close to the ectoflexus) that is distinctly larger than StB, particularly in smaller (<100g) forms, such as species of *Sminthopsis*, *Antechinus* and *Planigale* (Archer 1976; Wroe 1997); this is unlike the very small, labiolingually compressed StD directly labial to the metacone seen in *A. henkgodthelpi*. Further, in

most dasyuromorphians StA is not identifiable as an obviously distinct cusp (particularly on M2–4), whereas this cusp is low, but cusp-like and clearly distinct from StB in *A. henkgodthelphi*.

Molecular divergence dates suggest that the modern dasyurid families Dasyuridae, Thylacinidae and Myrmecobiidae probably diverged from each other less than 40 million years ago (Krajewski et al. 2000; Beck 2008; Meredith et al. 2009, 2011). If these molecular dates were accurate or overestimated the true divergence times, members of these families could not have been present at Tingamarra during the early Eocene, thus excluding *A. henkgodthelphi* from crown-Dasyuromorphia. However, it is clear that rates of molecular evolution within mammals are more variable than previously appreciated (Kitazoe et al. 2007; Steiper and Seiffert 2012; Dornburg et al. 2012), and hence molecular estimates of divergence times should not be viewed uncritically. Even if *A. henkgodthelphi* is not a member of crown-group Dasyuromorphia, it is possible that it belongs to the dasyuromorphian stem. If so, however, its faunivorous dental specialisations must have evolved independently prior to the similar apomorphies seen in some dasyurids and thylacinids.

Most other faunivorously-specialised metatherians, such as sparassocynid and didelphin didelphimorphians (Reig and Simpson 1972; Voss and Jansa 2003, 2009; Forasiepi et al. 2009), differ from *Archaeonothos henkgodthelphi* in exhibiting a V-shaped, rather than straight, centrocrista. The centrocrista is straight in the Cretaceous Laurasian deltatheroidans, but the latter differ markedly from *A. henkgodthelphi* in having a paracone that is taller than the metacone (probably a boreosphenidan plesiomorphy; Rougier et al. 2004; Davis et al. 2008). Members of the Cenozoic South American clade Sparassodonta typically possess a straight, elevated centrocrista (or the centrocrista is no longer identifiable as a distinct structure, owing to fusion of the bases of the paracone and metacone), a metacone that is considerably taller than the paracone, and a small protocone (Marshall 1978; Forasiepi 2009). Dentally plesiomorphic sparassodonts that retain identifiable styler cusps also resemble *A. henkgodthelphi* (but differ from dasyuromorphians) in that StD is usually reduced, but not shifted anteriorly or posteriorly relative to the metacone (Marshall and Muizon 1988; Muizon 1998). *A. henkgodthelphi* appears more derived than the dentally most plesiomorphic known sparassodont, the early or middle Palaeocene *Mayulestes ferox* (if the latter is indeed a member of Sparassodonta; see Rougier et al. 2004; Forasiepi 2009) in its smaller protocone, more reduced styler cusps, and absence of distinct conules (Muizon 1998). *Allqokirus australis*—which, like *Mayulestes*, is from the early or middle Palaeocene Tiupampa fauna (Marshall and Muizon 1988)—resembles *Archaeonothos henkgodthelphi* in terms of its broad styler region and overall morphology of the styler cusps (particularly the very small, labiolingually-compressed, crest-like StD), but differs from the latter in terms of its better-developed conules, more closely approximated paracone and metacone, and longer postmetacrista

(Marshall and Muizon 1988; Muizon 1998). Other sparassodonts exhibit more specialised dental morphologies, usually with narrower styler shelves, more closely approximated paracones and metacones, smaller protocones, and more elongate postmetacristae (Marshall 1978; Forasiepi 2009). If *Archaeonothos henkgodthelphi* were a sparassodont, it would represent the first member of this clade known outside of South America, and, with an estimated body mass of ~40–80 g, by far the smallest known. By comparison, *Mayulestes ferox* probably weighed ~180–360 g (Table 1; see also Argot 2004), while *Allqokirus australis* probably weighed ~250–450 g (Table 1; see also Prevosti et al. 2013: electronic supplementary material), and all other known sparassodonts are estimated as weighing >800 g (Wroe et al. 2004; Prevosti et al. 2013: electronic supplementary material).

Finally, *Archaeonothos henkgodthelphi* also shows derived similarities to two other probable metatherians: *Kasserinotherium tunisiense* from the early Eocene Chambi fauna of Tunisia (Crochet 1986), and *Wirunodon chanku* from the ?middle–late Eocene, or possibly early Oligocene, Santa Rosa Fauna of Peru (Goin and Candela 2004). Goin and Candela (2004: 43) noted that these two taxa share the following features that are also present in *A. henkgodthelphi*: “very small size, straight centrocrista, conules absent, reduced protocone and trigon fossa, reduced and labiolingually compressed styler cusps, wide styler shelf, and well-developed postmetacrista”. *A. henkgodthelphi* has an estimated body mass about twice as large as that of *W. chanku*, but is only slightly larger than *K. tunisiense* (Table 1). However, *A. henkgodthelphi* differs from both of these taxa in its smaller, more anteroposteriorly compressed protocone, a much greater height differential between the paracone and metacone, larger StB, smaller StD, and a preparacrista that ends at StB rather than StA. In addition, *K. tunisiense* resembles peradectids, but is unlike *A. henkgodthelphi*, in that the paracone is subequal in height to, as opposed to much smaller than, the metacone. An unpublished phylogenetic analysis by Maga (2008) placed *Kasserinotherium* as sister-taxon to the peradectid *Junggaroperadectes* from the early Oligocene of China (Ni et al. 2007).

Archaeonothos henkgodthelphi is a rare component of the Tingamarran mammal fauna: no other upper molars resembling the distinctive morphology of the holotype have been found to date, and I have been unable to identify lower molars that might be plausibly referred to this taxon. Instead, the fauna is dominated by small-bodied, dilambdodont, presumably faunivorous-omnivorous forms such as *Djarthia murgonensis*, and larger, bunodont, presumably omnivorous-frugivorous forms such as *Thylacotinga bartholomaii* and *Chulpasia mattaueri* (Table 1). Nevertheless, this peculiar taxon adds significantly to the known morphological and ecological diversity of the Tingamarran metatherians. The small size of *A. henkgodthelphi* would appear to preclude a predominantly vertebrate-based diet; instead, its small protocone and styler cusps, as well as its relatively elongate postmetacrista may reflect a specialisation towards softer-bodied invertebrates

compared to the likely diet of *D. murgonensis* (Strait 1993; Beck 2009), although possibly also with a vertebrate component. However, confirmation of this hypothesis will require quantitative functional analysis of dental morphology and, ideally, the discovery of additional specimens, particularly lower molars. Regardless of its true affinities, *A. henkgodthelpi* further emphasises the fact that the Australian mammal fauna during the early Eocene was radically different from that characteristic of the late Oligocene onwards, and included taxa that lack obvious relatives in younger deposits.

Acknowledgements

Collection and study of the Tingamarra Local Fauna has been led by Henk Godthelp, Mike Archer, and Sue Hand (all University of New South Wales, Sydney, Australia), who kindly allowed study of the fossil specimen described here. I thank Christian de Muizon (Muséum National d'Histoire Naturelle, Paris, France) for his comments on this specimen, particularly his suggestion to compare it to *Allqokirus australis*, and also Phil Creaser (University of New South Wales, Sydney, Australia) for informing me of Henk Godthelp's nickname. I thank the Associate Editor Felix Marx (National Museum of Nature and Science, Department of Geology and Paleontology, Tsukuba, Japan), Richard Cifelli (University of Oklahoma, Norman, USA) and an anonymous reviewer for their insightful comments and suggestions that improved the final version of this paper. Financial support for RB's research on the Tingamarra Local Fauna has been provided by the Leverhulme Trust (via Study Abroad Studentship SAS/30110), Phil Creaser and the CREATE fund at the University of New South Wales (via a CREATE scholarship), the National Science Foundation (via grant DEB-0743039, in collaboration with Rob Voss at the AMNH) and the Australian Research Council (via Discovery Early Career Researcher Award DE120100957). Other critical support for research on the Tingamarra Local Fauna has been given by the Australian Research Council (ARC DP0453262 to Mike Archer, and ARC LP045366 and LP0989969 to Sue Hand) and the University of New South Wales.

References

- Archer, M. 1976. The dasyurid dentition and its relationships to that of didelphids, thylacynids, borhyaenids (Marsupicarnivora) and peramelids (Peramelina: Marsupialia). *Australian Journal of Zoology, Supplementary Series* S39: 1–34.
- Archer, M., Godthelp, H., and Hand, S.J. 1993. Early Eocene marsupial from Australia. *Kaupia* 3: 193–200.
- Archer, M., Hand, S., and Godthelp, H. 1988. A new order of Tertiary zalambdodont marsupials. *Science* 239: 1528–1531.
- Argot, C. 2004. Evolution of South American mammalian predators (Borhyaenoidea): anatomical and palaeobiological implications. *Zoological Journal of the Linnean Society* 140: 487–521.
- Averianov, A.O., Archibald, J.D., and Ekdale, E.G. 2010. New material of the Late Cretaceous deltatheroidan mammal *Sulestes* from Uzbekistan and phylogenetic reassessment of the metatherian-eutherian dichotomy. *Journal of Systematic Palaeontology* 8: 301–330.
- Beck, R.M.D. 2008. A dated phylogeny of marsupials using a molecular supermatrix and multiple fossil constraints. *Journal of Mammalogy* 89: 175–189.
- Beck, R.M.D. 2009. Was the Oligo-Miocene Australian metatherian *Yalkaparidon* a “mammalian woodpecker”? *Biological Journal of the Linnean Society* 97: 1–17.
- Beck, R.M.D. 2012. An “ameridelphian” marsupial from the early Eocene of Australia supports a complex model of Southern Hemisphere marsupial biogeography. *Naturwissenschaften* 99: 715–729.
- Beck, R.M.D., Archer, M., Godthelp, H., Mackness, B.S., Hand, S.J., and Muirhead, J. 2008a. A bizarre new family of Marsupialia (*incertae sedis*) from the early Pliocene of northeastern Australia: implications for the phylogeny of bunodont marsupials. *Journal of Paleontology* 82: 749–762.
- Beck, R.M.D., Godthelp, H., Weisbecker, V., Archer, M., and Hand, S.J. 2008b. Australia's oldest marsupial fossils and their biogeographical implications. *PLoS ONE* 3 (3): e1858.
- Case, J.A., Goin, F.J., and Woodburne, M.O. 2005. “South American” marsupials from the Late Cretaceous of North America and the origin of marsupial cohorts. *Journal of Mammalian Evolution* 12: 461–494.
- Cifelli, R.L. 1993. Early Cretaceous mammal from North America and the evolution of marsupial dental characters. *Proceedings of the National Academy of Sciences of the United States of America* 90: 9413–9416.
- Cifelli, R.L. and Muizon, C. de 1997. Dentition and jaw of *Kokopellia juddi*, a primitive marsupial or near-marsupial from the Medial Cretaceous of Utah. *Journal of Mammalian Evolution* 4: 241–258.
- Cramb, J. and Hocknull, S. 2010. Two new species of *Antechinus* Macleay (Dasyuridae: Marsupialia) from mid-Pleistocene cave deposits in eastern central Queensland. *Australian Mammalogy* 32: 127–144.
- Crochet, J.Y. 1986. *Kassserinotherium tunisiense* nov. gen., nov. sp., troisième marsupial découvert en Afrique (Eocène inférieur de Tunisie). *Comptes Rendus de l'Académie des Sciences, Paris* 302: 923–926.
- Davis, B.M. 2007. A revision of “pediomyid” marsupials from the Late Cretaceous of North America. *Acta Palaeontologica Polonica* 52: 217–256.
- Davis, B.M., Cifelli, R.L., and Kielan-Jaworowska, Z. 2008. Earliest evidence of Deltatheroidea (Mammalia: Metatheria) from the Early Cretaceous of North America. In: E.J. Sargis and M. Dagosto (eds.), *Mammalian Evolutionary Morphology: a Tribute to Frederick S. Szalay*, 3–24. Springer, Dordrecht.
- Dornburg, A., Brandley, M.C., McGowen, M.R., and Near, T.J. 2012. Relaxed clocks and inferences of heterogeneous patterns of nucleotide substitution and divergence time estimates across whales and dolphins (Mammalia: Cetacea). *Molecular Biology and Evolution* 29: 721–36.
- Forasiepi, A.M. 2009. Osteology of *Arctodictis sinclairi* (Mammalia, Metatheria, Sparassodonta) and phylogeny of Cenozoic metatherian carnivores from South America. *Monografias del Museo Argentino de Ciencias Naturales* 6: 1–174.
- Forasiepi, A.M., Goin, F., and Martinelli, A.G. 2009. Contribution to the knowledge of the Sparassocynidae (Mammalia, Metatheria, Didelphoidea), with comments on the age of the Aisol Formation (Neogene), Mendoza Province, Argentina. *Journal of Vertebrate Paleontology* 29: 1252–1263.
- Godthelp, H., Archer, M., Cifelli, R.L., Hand, S.J., and Gilkeson, C.F. 1992. Earliest known Australian Tertiary mammal fauna. *Nature* 356: 514–516.
- Godthelp, H., Wroe, S., and Archer, M. 1999. A new marsupial from the Early Eocene Tingamarra Local Fauna of Murgon, southeastern Queensland: a prototypical Australian marsupial? *Journal of Mammalian Evolution* 6: 289–313.
- Goin, F.J. and Candela, A.M. 2004. New Paleogene marsupials from the Amazon Basin of Eastern Peru. In: K.E. Campbell Jr (ed.), *The Paleogene Mammalian Fauna of Santa Rosa, Amazonian Peru. Natural History Museum of Los Angeles County, Science Series* 40: 15–60.
- Gordon, C.L. 2003. A first look at estimating body size in dentally conservative marsupials. *Journal of Mammalian Evolution* 10: 1–21.
- Hand, S., Novacek, M., Godthelp, H., and Archer, M. 1994. First Eocene bat from Australia. *Journal of Vertebrate Paleontology* 14: 375–381.
- Johanson, Z. 1996. Revision of the Late Cretaceous North American marsupial genus *Alphadon*. *Palaeontographica Abteilung A* 242: 127–184.
- Kitazoe, Y., Kishino, H., Waddell, P.J., Nakajima, N., Okabayashi, T., Watabe, T., and Okuhara, Y. 2007. Robust time estimation reconciles views of the antiquity of placental mammals. *PLoS ONE* 4: e384.

- Krajewski, C., Wroe, S., and Westerman, M. 2000. Molecular evidence for the pattern and timing of cladogenesis in dasyurid marsupials. *Zoological Journal of the Linnean Society* 130: 375–404.
- Luckett, W.P. 1993. An ontogenetic assessment of dental homologies in therian mammals. In: F.S. Szalay, M.J. Novacek, and M.C. McKenna (eds.), *Mammal Phylogeny, Volume 1: Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials*, 182–204. Springer Verlag, New York.
- Luo, Z.X., Yuan, C.X., Meng, Q.J., and Ji, Q. 2011. A Jurassic eutherian mammal and divergence of marsupials and placentals. *Nature* 476: 442–445.
- Maga, A.M. 2008. *Systematic Paleontological Investigation of the Metatherian Fauna from the Paleogene Uzunçarşidere Formation, Central Turkey*. 309 pp. Unpublished Ph.D. Dissertation, The University of Texas, Austin.
- Marshall, L.G. 1978. Evolution of the Borhyaenidae, extinct South American predaceous marsupials. *University of California Publications in Geological Sciences* 117: 1–89.
- Marshall, L.G. and Muizon, C. de 1988. The dawn of the age of mammals in South America. *National Geographic Research* 4: 23–55.
- Meredith, R.W., Janecka, J.E., Gatesy, J., Ryder, O.A., Fisher, C.A., Teeling, E.C., Goodbla, A., Eizirik, E., Simao, T.L., Stadler, T., Rabosky, D.L., Honeycutt, R.L., Flynn, J.J., Ingram, C.M., Steiner, C., Williams, T.L., Robinson, T.J., Burk-Herrick, A., Westerman, M., Ayoub, N.A., Springer, M.S., and Murphy, W.J. 2011. Impacts of the Cretaceous Terrestrial Revolution and KPg extinction on mammal diversification. *Science* 334: 521–524.
- Meredith, R.W., Krajewski, C., Westerman, M., and Springer, M.S. 2009. Relationships and divergence times among the orders and families of Marsupialia. *Museum of Northern Arizona Bulletin* 65: 383–406.
- Muirhead, J. 1997. Two new thylacines (Marsupialia: Thylacinidae) from early Miocene sediments of Riversleigh, northwestern Queensland and a revision of the family Thylacinidae. *Memoirs of the Queensland Museum* 41: 367–377.
- Muizon, C. de 1998. *Mayulestes ferox*, a borhyaenoid (Metatheria, Mammalia) from the early Palaeocene of Bolivia: phylogenetic and palaeobiologic implications. *Geodiversitas* 20: 19–142.
- Myers, T.J. 2001. Marsupial body mass prediction. *Australian Journal of Zoology* 49: 99–118.
- Ni, X.J., Meng, J., Wu, W.Y., and Ye, J. 2007. A new Early Oligocene peradectine marsupial (Mammalia) from the Burqin region of Xinjiang, China. *Naturwissenschaften* 94: 237–241.
- O’Leary, M.A., Bloch, J.I., Flynn, J.J., Gaudin, T.J., Giallombardo, A., Giannini, N.P., Goldberg, S.L., Kraatz, B.P., Luo, Z.X., Meng, J., Ni, X., Novacek, M.J., Perini, F.A., Randall, Z.S., Rougier, G.W., Sargis, E.J., Silcox, M.T., Simmons, N.B., Spaulding, M., Velazco, P.M., Weksler, M., Wible, J.R., and Cirranello, A.L. 2013. The placental mammal ancestor and the post-K-Pg radiation of placentals. *Science* 339: 662–667.
- Prevosti, F.J., Forasiepi, A., and Zimicz, N. 2013. The evolution of the Cenozoic terrestrial mammalian predator guild in South America: competition or replacement? *Journal of Mammalian Evolution* 20: 3–21.
- Reig, O.A. and Simpson, G.G. 1972. *Sparassocynus* (Marsupialia, Didelphidae), a peculiar mammal from the late Cenozoic of Argentina. *Journal of Zoology* 167: 511–539.
- Rougier, G.W., Wible, J.R., and Novacek, M.J. 2004. New specimens of *Deltatheroides cretacicus* (Metatheria, Deltatheroidea) from the Late Cretaceous of Mongolia. *Bulletin of Carnegie Museum of Natural History* 36: 245–266.
- Sanborn, C.C. 1951. Two new mammals from southern Peru. *Fieldiana Zoology* 31: 473–477.
- Sigé, B., Archer, M., Crochet, J.-Y., Godthelp, H., Hand, S., and Beck, R.M.D. 2009. *Chulpasia* and *Thylacotinga*, late Paleocene–earliest Eocene trans-Antarctic Gondwanan bunodont marsupials: New data from Australia. *Geobios* 42: 813–823.
- Steiper, M.E. and Seiffert, E.R. 2012. Evidence for a convergent slowdown in primate molecular rates and its implications for the timing of early primate evolution. *Proceedings of the National Academy of Sciences of the United States of America* 109 (16): 6006–6011.
- Strait, S.G. 1993. Molar morphology and food texture among small-bodied insectivorous mammals. *Journal of Mammalogy* 74: 391–402.
- Travouillon, K.J., Legendre, S., Archer, M., and Hand, S.J. 2009. Palaeoecological analyses of Riversleigh’s Oligo-Miocene sites: implications for Oligo-Miocene climate change in Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 276: 24–37.
- Voss, R.S. and Jansa, S.A. 2003. Phylogenetic studies on didelphid marsupials II. Nonmolecular data and new IRBP sequences: separate and combined analyses of didelphine relationships with denser taxon sampling. *Bulletin of the American Museum of Natural History* 276: 1–82.
- Voss, R.S. and Jansa, S.A. 2009. Phylogenetic relationships and classification of didelphid marsupials, an extant radiation of New World metatherian mammals. *Bulletin of the American Museum of Natural History* 322: 1–177.
- Williamson, T.E., Brusatte, S.L., Carr, T.D., Weil, A., and Standhardt, B.R. 2012. The phylogeny and evolution of Cretaceous–Palaeogene metatherians: cladistic analysis and description of new early Palaeocene specimens from the Nacimiento Formation, New Mexico. *Journal of Systematic Palaeontology* 10: 625–651.
- Wroe, S. 1997. A reexamination of proposed morphology-based synapomorphies for the families of Dasyuromorphia (Marsupialia). I. Dasyuridae. *Journal of Mammalian Evolution* 4: 19–52.
- Wroe, S. and Musser, A. 2001. The skull of *Nimbacinus dicksoni* (Thylacinidae: Marsupialia). *Australian Journal of Zoology* 49: 487–514.
- Wroe, S., Argot, C., and Dickman, C. 2004. On the rarity of big fierce carnivores and primacy of isolation and area: tracking large mammalian carnivore diversity on two isolated continents. *Proceedings of the Royal Society of London B* 271: 1203–1211.
- Wroe, S., Ebach, M., Ah Yong, S., Muizon, C. de, and Muirhead, J. 2000. Cladistic analysis of dasyuromorphian (Marsupialia) phylogeny using cranial and dental characters. *Journal of Mammalogy* 81: 1008–1024.