

## A revised faunal list and geological setting for Bullock Creek, a Camfieldian site from the Northern Territory of Australia

LEAH R.S. SCHWARTZ

School of Geosciences, Monash University, Victoria, Australia (present address: leah.schwartz@sydney.edu.au)

### Abstract

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The Camfield beds, in which the Bullock Creek Local Fauna occurs, is a freshwater carbonate unit deposited in a braided-meandering river environment in which abandoned channels formed oxbow lakes. Fossil quarries in the Small Hills outcrop occur in stratigraphically superposed beds. Despite this, there are no detectable changes to the fauna obtained at different levels that demonstrate a significant biochronologic time difference. Within the small mammal fauna, macropodoids are the most abundant group at Bullock Creek. Two species have been described, *Balbaroo camfieldensis* and *Nambaroo bullockensis*. A number of other macropodid taxa are also present. A diverse ‘possum’ fauna is found here, in addition to the miralinids *Barguru maru* and *Barguru kayir*, including the phalangerid *Wyulda sp. cf. asherjoeli*. Dasyuromorphians are also present, as are yaraloid peramelemorphians, including a species referred to *Yarala*.

### Keywords

Bullock Creek, Northern Territory, Camfieldian, Camfield beds, Middle Miocene.

### Introduction

Fossil remains at Bullock Creek, a site on Camfield Station in the Northern Territory of Australia (fig. 1), were first reported in the late 1960s (Plane and Gatehouse 1968). Subsequent work has seen the recovery of some of the best-preserved specimens of animals such as *Neohelos stirtoni* Murray, Megirian, Rich, Plane, Black, Archer, Hand, Vickers-Rich 2000, the dromornithid *Bullockornis planei* Rich 1979, and the crocodilians *Baru darwini* Willis, Murray and Megirian 1990 and *Quinkana timara* Megirian 1994. Bullock Creek has since become an important calibration point for the continental Australian Cenozoic, lending its name to the recently defined Camfieldian Australian Land Mammal Age (Megirian et al., 2010). The Camfieldian is poorly calibrated to the Standard Chronostratigraphic Scale, but on the basis of the stage-of-evolution of the mammalian fauna and interpolation with the Wipajirian and Waitean Australian Land Mammal Ages, it may range from 12–17 Ma, making it middle Miocene (Megirian et al., 2010). The purpose of this paper is to report a significant increase in the number of mammalian taxa known from this site and to formally describe the Camfield beds, the unit in which the fossils are found.

Such an investigation is appropriate in a volume celebrating the work and contribution of Dr. Thomas H. Rich as it was Tom and his wife Pat’s work that recovered much of the fossil material described here. This study was conducted under Pat’s formal supervision, with much

interest and comment provided by Tom. Tom and Pat first visited Bullock Creek in the 1970s and 80s, and introduced numerous palaeontologists to the site, including Tim Flannery, Peter Murray and Dirk Megirian, all of whom went on to make major contributions to its study (e.g. Flannery et al., 1983; Murray and Megirian, 1992). It was a photo that hung on Pat’s office wall which was my first glimpse of the site and a box of teeth sent from the Northern Territory to Tom at Museum Victoria that formed the basis of my project – it was lucky for me that Tom hadn’t quite gotten around to having a look!

The Bullock Creek thylacinid, *Nimbacinus richi* Murray and Megirian 2000, bears Tom’s name in honour of his work at this site.

**Geology.** The Bullock Creek Local Fauna occurs in the carbonate facies of the Camfield Limestone Beds (new name). This unit is found in outcrop in the valley of Bullock Creek, a tributary of the Camfield River, located in the eastern section of the Wave Hill 1:250 000 map sheet SE/52-8 (fig. 1). The name ‘Camfield beds’ was proposed by Randal and Brown (1967), and the unit was defined by these authors as consisting of limestone, siltstone, and minor sandstone, with partially silicified limestone containing abundant chert laminae, nodules, and patches of chalcedony. The Camfield beds are part of a central Australian group of Cenozoic continental carbonate sequences, or formations with carbonate units, that contain a significant part of Australia’s Cenozoic terrestrial fossil vertebrate record. The geology of

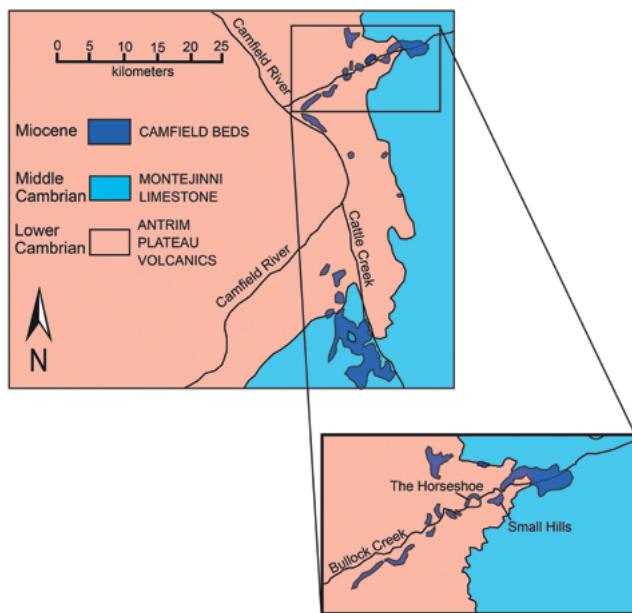


Figure 1. Regional geology of the Bullock Creek area, with inset showing the outcrops known as 'Small Hills' and 'The Horseshoe' in which most of the vertebrate fauna is found.

both the Carl Creek Limestone, containing the Riversleigh assemblage and the Ulta Limestone, in which the Kangaroo Well Local Fauna is found, have been studied in some detail (Arena, 1997; Megirian et al., 2004; Megirian, 1992). The lithostratigraphy of the Etadunna Formation has also been investigated (Woodburne et al., 1993), though this formation differs from the Carl Creek Limestone, the Ulta Limestone and the Camfield beds in containing only a single carbonate unit within an otherwise epiclastic sequence.

Randal and Brown (1967) carried out the most recent survey of the region containing the Camfield beds as part of regional mapping at the 1:250 000 scale. Plane and Gatehouse (1968) briefly summarised the geology. A study by Murray and Megirian (1992) of the vertebrate community represented at Bullock Creek is the most recent work to have been undertaken describing aspects of the Camfield beds. This paper reports the results of a detailed stratigraphic mapping project undertaken at the site in 2002, as well as sedimentological investigations of the unit.

**Palaeontology.** The mammalian faunal list of Bullock Creek has been biased towards larger mammals such as diprotodontids and palorchestids, with only a handful of the smaller mammals (macropodoids, thylacinids) described. The majority of the smaller mammal material at Bullock Creek is isolated teeth, with few fragments of jaws or skulls available and little identifiable post-cranial material. This paper reports a study of this material completed as part of the

author's PhD thesis (Schwartz, 2005). Where the fossil material is complete enough to name a new species, these have been published elsewhere (see Schwartz and Megirian, 2004; Schwartz, 2006a, 2006b).

Reported here is the material that is too incomplete to warrant naming and/or is assignable to already-described taxa. This information is critical for palaeoecological studies – the lack of publication of material that clearly demonstrates the presence of certain families, sometimes represented by multiple species, has led to the implied absences being used as evidence for palaeoenvironmental reconstructions (for example, Travouillon and Legendre, 2009), particularly the implication that the Bullock Creek Local Fauna is significantly less diverse than that of equivalent-age Riversleigh sites (see Woodhead et al., 2015 for recent work dating a number of the Riversleigh sites).

Diversity and abundance are significantly different measures, with the latter particularly problematic in palaeoecological studies, given its mediation through taphonomic and fossilisation processes. Compared with the assemblages at Riversleigh, those quarries so far sampled at Bullock Creek have shown a lower abundance of mammalian fauna, and the material is often much more fragmentary, making it more difficult to describe and interpret, and less likely to be described and published. However, caution must be used when interpreting this as the product of a less diverse assemblage.

## Materials and Methods

**Geology.** Mapping of the Camfield beds was undertaken during a field trip in 2002 using a theodolite and GPS unit. Stratigraphic relationships were observed in the field. Hand samples were collected using plug-and-feathers to separate in-situ material; split and polished in the lab, with thin-sections cut from hand samples on a diamond saw and observed under a petrographic microscope with plane and cross polarised light.

**Palaeontology.** Fossils described below were prepared through use of acid etching of the Camfield beds in approximately 10% acetic acid. Screening of indissoluble elements was conducted, dividing these into size classes. The screenings were then picked by hand, with the use of microscopes, for diagnostic remains. All measurements were conducted with a set of Mitutoyo digital callipers to the nearest 0.01 mm.

Notation and orientation terminology follows Smith and Dodson (2003) in the use of labial/buccal and lingual as descriptive terms, and the selection of lower vs. upper case letters to distinguish upper and lower tooth rows and dental homology follows Luckett (1993). The tooth type is abbreviated to its first letter (i.e. I for incisor, M for molar, etc.); and d is used as a modifier to indicate deciduous teeth that are replaced during the animal's lifetime.

**Institutional abbreviations.** NTMAG indicates specimens from the Northern Territory Museum and Art Gallery, Alice Springs, Northern Territory – where a catalogue number

beginning with P is used without a prefix, specimens are from the NTMAG; QVMAG indicates specimens from the Queen Victoria Museum and Art Gallery, Launceston, Tasmania, and NMV indicates specimens from Museum Victoria, Melbourne, Victoria.

### The geology of the Camfield beds

This study of the geology of the Camfield beds is divided into two parts. The first concentrates on the Small Hills locality, which includes the type section for the Bullock Creek Local Fauna, 'Blast Site', in addition to the majority of the other vertebrate fossil quarries (fig. 1). The second part of this study investigates other outcrops of the Camfield beds that have been noted for their vertebrate fossil concentration. This includes the quarries named 'Camp Quarry', 'Microsite' and an area known as 'The Horseshoe', which includes the quarries of Horseshoe East, West, and Centre. Investigation of these areas is included here in order to demonstrate the variety of depositional environments represented by the Camfield beds.

Names such as 'Small Hills', 'The Horseshoe', 'Blast Site', etc., are informal names used to distinguish particular outcrops of the Camfield beds (fig. 1) and the most commonly sampled vertebrate quarries. Lithological names used below (e.g., 'Blast Site beds') are similarly informal units of the Camfield beds designated by, and for, the purposes of this study. The 'Small Hills' area contains the most extensively collected quarries at Bullock Creek. This area is a single outcrop of the Camfield beds in which are contained the vertebrate fossil quarries of 'Site X', 'Site Y', 'Top Site', 'Far Site', 'Pebble Site', 'Dromornithid Mountain', and 'Blast Site' (fig. 2).

*Structure and Stratigraphy.* The Camfield beds have a thickness of approximately 25 m (Randal and Brown, 1967) and consist of laterally discontinuous beds of light-coloured calcareous sandstone, siltstone and limestone (fig. 1). They rest unconformably on either the Early Cambrian Antrim Plateau Volcanics (APV) or the Middle Cambrian Montejinni Limestone. Randal and Brown (1967), measured a composite section through the Camfield beds, but were unable to correlate stratigraphic horizons between outcrops.

Murray and Megirian (1992) recognised two distinct lithologies in the Small Hills locality: conglomeratic limestone and massive calcilutite (fig. 2). These authors also suggested a diachronous origin for the Camfield beds. This was on the basis of the presence of chalcedonic limestone clasts at Blast Site, which contain fossil gastropods. Murray and Megirian (1992) suggest that these clasts had been derived from an ancient weathered surface and incorporated into the Camfield beds as they formed.

Reported here are the results of detailed mapping of the Small Hills outcrop (fig. 2). The sequence reaches a maximum height of approximately 235 m above sea level and is distributed over a 0.5 km wide area. 'Site X' and 'Site Y' were found to be contained within the same bed, Tm1, the XY beds, as postulated by Murray and Megirian (1992). Similarly, 'Dromornithid Mountain' and 'Far Site' were also found to be

contained within a single bed, Tm4, the Dromornithid Mountain beds, which lies stratigraphically above the bed containing sites X and Y (figs. 3, 4, 5). 'Blast Site' occurs in a small-scale channel deposit incised into Tm1, and so must be younger than the XY beds but has no upper constraint; 'Top Site' occurs in a small-scale channel incised into Tm4 and so must be younger than the Dromornithid Mountain beds but also has no upper constraint. 'Pebble Site' occurs outside of the main Small Hills deposit as a small channel and no contact with a known bed was found, so its stratigraphic relationships are unknown (see fig. 5).

### Petrography of Small Hills

*Small Hills Tm1 – The XY beds.* This unit is the base of the Small Hills sequence. It consists of massive, fossiliferous calcimudstone, but contains within it a few different facies. Chert 'stringers' within the unit appear to be representative of either algal matting (they are occasionally associated with stromatolites, as shown in fig. 6B), or are perhaps features associated with the base of scours (fig. 6C). Small-scale channels, such as the Blast Site beds are incised into this unit, as is Tm5, and the unit is overlain by Tm3 (fig. 3) (though note that this unit does not directly overlie the Blast Site beds). Tm1 also appears to crop out under Quaternary alluvium, just south of the main Small Hills outcrop. No direct contact with the volcanic basement was observable – the Quaternary colluvium and alluvium concealed the area in which such a contact would be expected. A contact with the sandstone facies of the APV (fig. 6D) confines the area laterally. This contact is thought to represent the original palaeo-channel or lake margin, inside of which the XY beds were deposited.

The major facies of the XY beds is a massive fossiliferous calcimudstone. The weathered surface of this facies is generally grey in colour, with red/orange silicified chert stringers and nodules standing out against weathering. In places, weathering appears so extreme as to have resulted in the formation of whole beds of this rust-coloured chert. Stromatolites occur throughout this bed, and are similarly silicified, but with internal structure preserved (fig. 6B). Vertebrate remains are known throughout the beds, with quarries indicating areas of concentration.

In slabbed section, the calcimudstone is typically grey in colour due to the presence of dendritic pyrolusite structures in an otherwise light-yellow-coloured limestone. Occasional areas of a creamy-pink limestone are present, as are areas of sparry calcite, and both complete and fragmentary gastropod remains, including *Cupedora*, *Melanoides* (fig. 7A), and *Glyptophysa*. In thin section, the rock has a micritic, occasionally peloidal, matrix. Oogonia of charophyte algae (fig. 7B) were observed. Complete ostracods, some still unaltered, and others radially infilled with sparry calcite, were also present. Gastropod remains are quite numerous, but most of the shelly remains have been replaced by sparite. Small detrital grains of amphibole or pyroxene, probably originating from the phenocryst phase of the APV, were noted in thin-section. Small

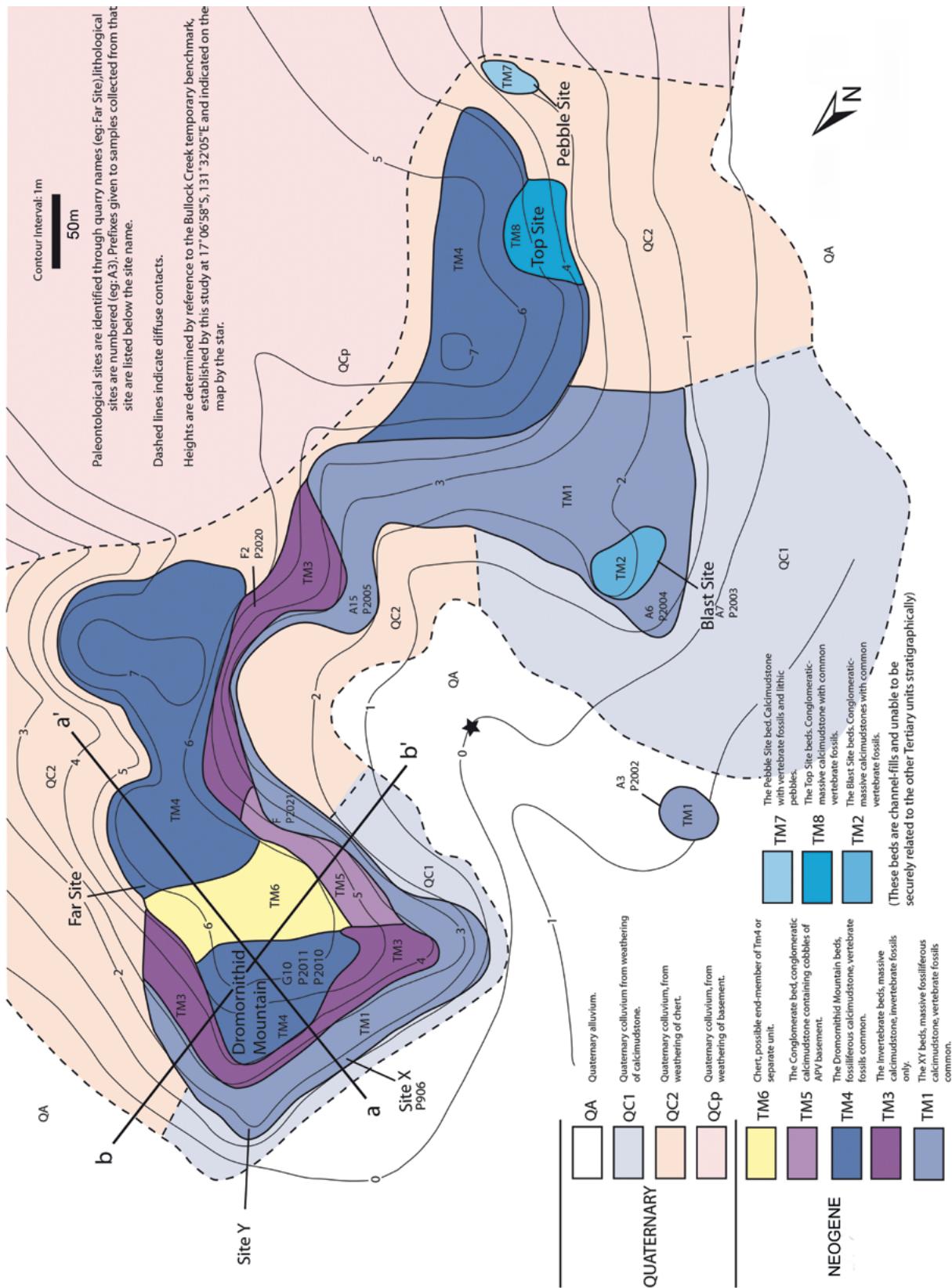


Figure 2. Detailed geological map of 'Small Hills'. Cross-sections along the lines a-a' and b-b' are shown in fig. 3.

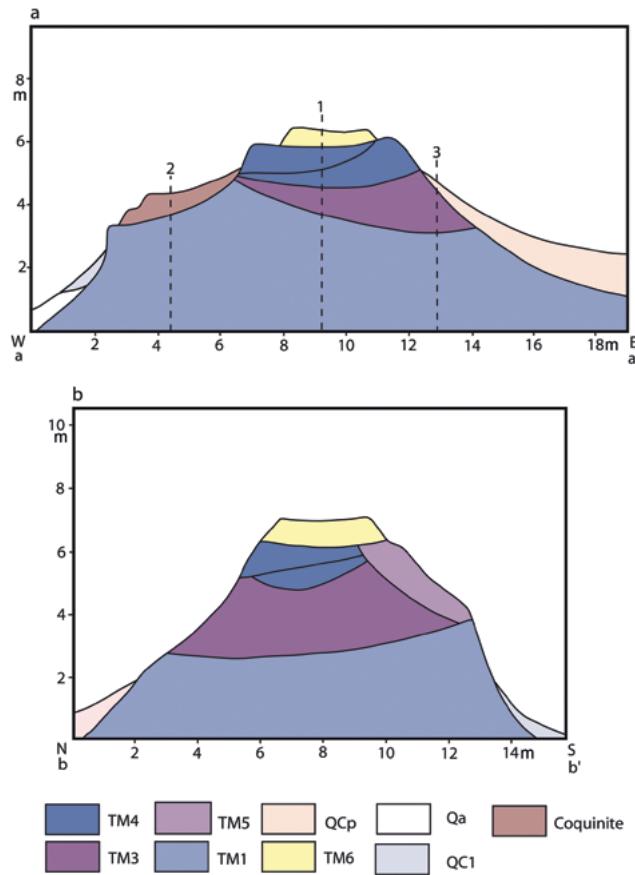


Figure 3. Schematic cross-sections along the lines a-a' and b-b' from fig. 2. Schematic logs at the points 1, 2 and 3 are shown in fig. 4. Refer to fig. 2 for descriptions of unit abbreviations.

amounts of highly angular composite quartz are also present in this facies. The occasional carbonate-coated grain is observed, with a micritic lining.

Minor facies subdivisions can be observed in the XY beds. At location A6 (fig. 2), an unusual diffuse banding of yellow-white and light pink layers occurs (fig. 8). The pink bands appear to contain slightly coarser-grained material, up to 40 mm in size, similar to the distinctive pink-orange limestone of the Dromornithid Mountain beds, or of the individual creamy-pink clasts observable in the rest of the XY beds. No lithics or obvious fossils are preserved, and only small quantities of pyrolusite (fig. 7c) are present, although it appears preferentially concentrated in the white/yellow bands. The matrix of this lithotype is predominantly micritic, with some sparry calcite replacement. At Site X, a very clean, white, highly crystalline carbonate is present. It is similar to the fine-grained facies of the Blast Site beds, but with bands of sparite throughout the sample. Just above

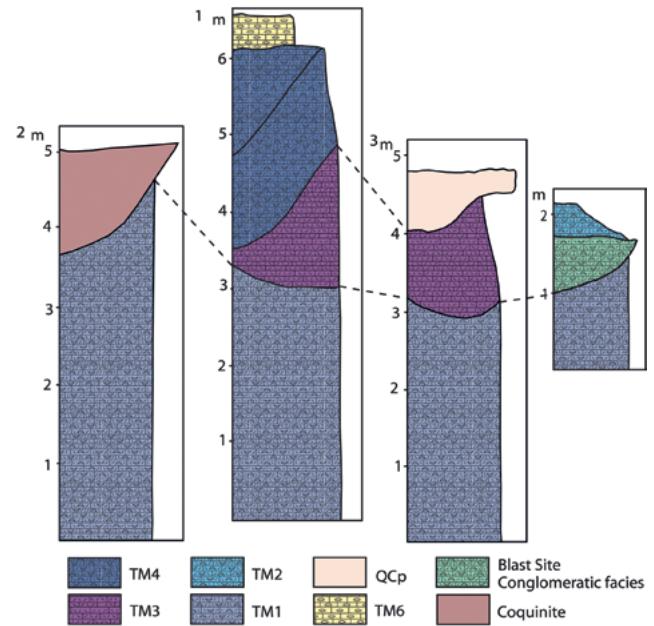


Figure 4. Schematic logs of the points 1, 2 and 3 from fig. 3. A schematic log of the stratotype, Blast Site, is also shown here at right.

Site X, of too small a scale to be included on the map shown in Figure 2, but included in Figure 3, is a small lens of a gastropod coquinite, full of *Glyptophysa* (fig. 9D) in a matrix of grey calcimudstone.

*Tm2 – The Blast Site beds.* This unit consists of two distinct facies, with the conglomeratic facies stratigraphically beneath a calcimudstone facies. The conglomeratic carbonate facies contains clasts of up to 35 mm in diameter, which have a micritic coating and appear to be mostly reworked carbonate. Slightly smaller lithic fragments and well-rounded chert pebbles are also present in this facies. The carbonate clasts are well-rounded, and occasionally contain gastropods, both whole and fragmentary, mainly *Melanoides*. Vertebrate bone fragments are also often contained within these clasts (fig. 10A), and some dendritic pyrolusite structures are also present. The micritic matrix contains angular-subangular deformed magmatic quartz grains, some small, very rounded zircons, and minor chlorite and feldspar. This suggests a quartzo-feldspathic source for at least part of the sediment contained in this sample and may imply provenance from a strained granitoid. The second, uppermost facies is a light-coloured, very fine-grained calcimudstone, which in thin section appears to consist almost entirely of micrite, with some sparite-replaced shell fragments present.

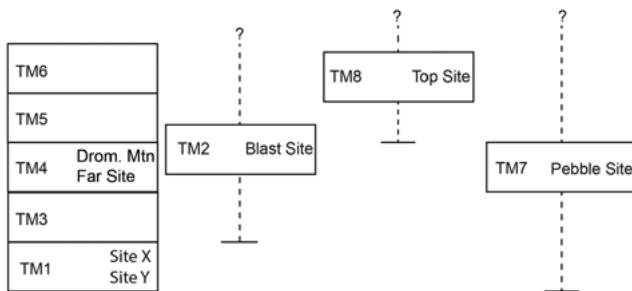


Figure 5. Stratigraphic chart for Small Hills showing units from which fossil sites derive and their relationships.

*Tm3 – The Invertebrate beds.* This is a massive, grey, fossiliferous calcimudstone. There is a marked absence of obvious vertebrate remains in this facies, but it is rich in invertebrate fossils. Quite a number of gastropods appear to be present in hand specimens, both whole *Cupedora* and fragments, often infilled with sparite. Only a small amount of dendritic pyrolusite is present. Most of the micritic matrix has been replaced with sparry calcite.

*The Dromornithid Mountain beds.* These are superimposed on Tm3, and include the units marked as Tm4 and Tm6 on the map. Tm6 is almost entirely chert, and may represent either a diagenetic alteration of Tm4 or the diagenetic end product of a bed stratigraphically on top of Tm4. The Dromornithid Mountain quarry site occurs in Tm4, and Far Site occurs east of Tm6, in what was mapped as a continuation of Tm4. In thin section, however, lithological samples from both of these quarry areas are quite different, such that the area containing Dromornithid Mountain is designated Tm4a, while the unit containing Far Side is Tm4b.

Tm4a (fig. 10B) is a pink-orange-coloured calcimudstone, which weathers to grey with some orange banding and rust-coloured siliceous nodules. It contains *Glyptophysa*, *Melanoides*, oogonia of charophyte algae and articulated ostracods radially infilled with calcite (fig. 10C). Angular bone fragments are present, both in clasts of carbonate and in the infilling micrite cement, which is occasionally peloidal. The carbonate clasts are held together with micritic cement that has been replaced by sparry calcite. The Dromornithid Mountain quarry is identified by the relative richness of large vertebrate bones in the area (fig. 9A), and the vertebrate-rich lithology appears to be characterised by an orange-pink colour on a fresh face, small carbonate clasts, articulated ostracods, and oogonia.

Tm4b is dark grey in outcrop, while the slabbed surface shows some orange-pink mottling but is mostly a light-coloured carbonate. Some lithics are present, but for the most part this unit consists of large coated carbonate clasts cemented together in a micritic matrix. This is similar to the ‘conglomeratic’ layer in the Blast Site beds. The matrix has been replaced in only a few places with sparry calcite. Some algal threads are present throughout the facies, as are peloids. The lack of ostracods and oogonia in this unit, and the presence of large carbonate clasts and lithic pebbles, distinguish it from Tm4a.

*Tm5 – The Conglomerate Bed.* This unit (fig. 9C) was originally thought to be part of the Dromornithid Mountain beds, however field relationships suggest that it is more likely to be a smaller-scale channel incised into the side of that unit (see fig. 3). Large cobble-sized clasts of APV sandstone are present (fig. 9B), implying deposition took place via a high-energy event.

*Tm7 – The Pebble Site Bed.* Like the rest of the Camfield beds, this unit is grey in outcrop; however, it also shows some ferruginous staining. A number of well-rounded lithic pebbles are present on the outcrop surface, up to 15 mm in diameter. Carbonate clasts are present, consisting mostly of denser micrite, although the occasional clast is made up of peloids. There is a high proportion of both bone and vegetation fragments scattered throughout the unit. These are generally angular and occur mostly in the micrite matrix rather than in the intraclasts. Sparry calcite is present throughout the matrix, also replacing shell fragments that tend to occur in the intraclasts and surrounding the bone and plant material. Chert occurs rarely, generally as well-rounded clasts.

### Depositional Model for Small Hills

The XY beds contain both complete and fragmentary gastropod remains, stromatolites, oogonia, articulated ostracods, and peloids. This fossil assemblage indicates quiet, standing water, such as that expected in a lacustrine environment. This is the same lithology that Murray and Megirian (1992) considered to be of lacustrine origin. Carbonate clasts found in this unit are not clasts of the Cambrian Montejinni Limestone, as they can be clearly seen to occasionally contain fragments of bone, as well as gastropod and shelly material very similar to that of the cementing matrix. This suggests that these clasts are contemporaneous, resulting from the reworking of the Camfield beds.

There are two main ways such reworking could have taken place. The first is that carbonate deposited by the systems was taken up again as a rip-up clast, upon which the micritic coating formed sub-aqueously, while the second is that the carbonate clasts represent a coated grain that formed during sub-aerial exposure, thus developing a caliche fabric. The difference in origin of these clasts is the difference in considering the Camfield beds either as a tufa or a calichlite. Subaerial formation would indicate at least seasonal dryness in the depositional environment. Given the strong similarities between the Ulta Limestone and the Camfield beds, it is likely that the Camfield beds followed a very similar diagenetic trajectory to that postulated by Megirian et al. (2004).

Small amounts of amphibole or pyroxene have also been found in the XY beds, probably originating from the phenocryst phase of the APV basement. Variable amounts of chert appear throughout the Camfield beds, either as sparry replacement of micrite, or as clasts coated with micrite and redeposited.

The base of the XY beds is obscured by Quaternary colluvium, but the contact is presumed to be with the sandstone facies of the APV due to a contact with this facies that occurs at a high topographic level within the XY beds outcrop. Thus, the contact is likely to be a curved stream-channel base, representing a cut made into this sandstone facies by the

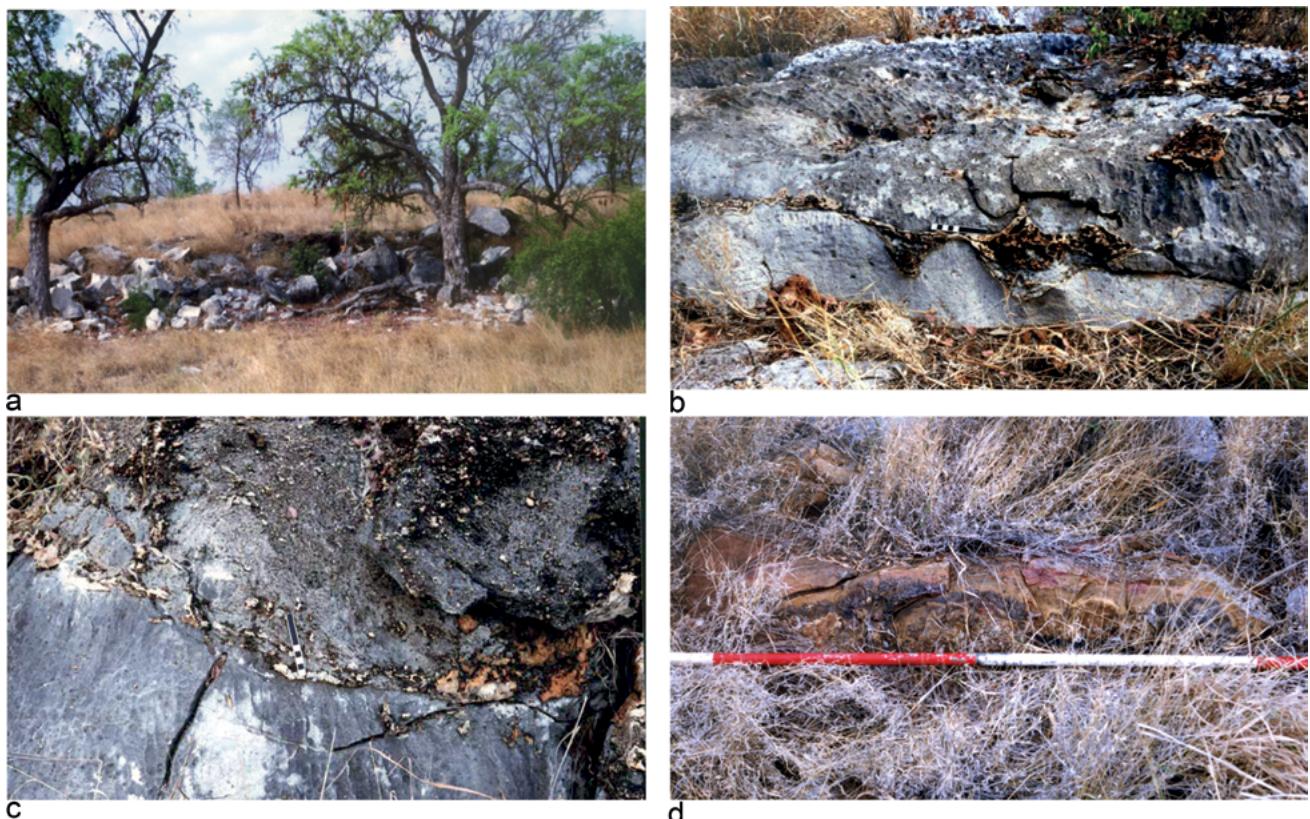


Figure 6. a, view of Site X; b, silicified stromatolites and 'stringers' (indicated with arrow) along bedding plane; c, 'stringer' along curved contact (indicated with arrow); d, contact with APV basement. Scale bar divisions in a and d are 1 m, scale bar in b and c is 10 cm.

palaeo-Bullock Creek during the deposition of the XY beds. The XY beds are themselves overprinted by a number of small-scale channel deposits, almost all of which display a curved contact with this unit (fig. 6C). No such curved contact is observed, however, between the XY beds and the Invertebrate beds, which are stratigraphically higher.

The Blast Site beds represent one of the smaller-scale channels overprinting the XY beds. They have an incised contact with that unit, and display an upward fining succession, from a conglomeratic carbonate intraclast facies to a finer-grained micritic facies resembling the XY beds. This succession suggests that the Blast Site beds may have originated from either a flood event or the abandonment of a smaller-scale channel by the river.

The Pebble Site beds are another unit superimposed on the XY beds, probably also representing a small-scale channel. This unit has a greater amount of terrigenous material than other units as represented by the lithic pebbles that give the quarry its name.

The Invertebrate beds directly overlie the XY beds, and can only be distinguished from them by the lack of vertebrate fossils. This unit may represent an upward fining continuation of the XY beds, in perhaps an even lower energy environment, such as a restricted oxbow lake.

The Dromornithid Mountain beds consist of the mapped units Tm4 and Tm6. On the basis of thin-section evidence, Tm4

has been divided into Tm4a and Tm4b. The base of the sequence here appears to be Tm4b, a clastic carbonate facies, reminiscent of the lower Blast Site facies. This sequence fines upward to Tm4a, which is micritic, with complete ostracods present. Again, this implies the probable abandonment of a channel or a flood event. Tm6 is a chert unit, and is included in the Dromornithid Mountain beds as its contact with Tm4a is unclear, and it may be the diagenetic end-product of that unit. This unit is also incised by Tm5, a conglomeratic unit of cobble-sized angular fragments of APV sandstone in a micritic matrix. This, again, suggests that these channels were deposited on top of the sandstone facies of the APV.

#### Petrography of other quarries

Beyond Small Hills, other outcrops of the Camfield beds contain significant vertebrate fossil quarries. Three vertebrate quarries are contained within the 'Horseshoe' outcrop, so named for its distinctive outline (fig. 1). Two other quarries, 'Micosite' and 'Camp Quarry', occur in other discrete outcrops of the Camfield beds, along the Bullock Creek valley.

*The Horseshoe.* This area contains three important vertebrate quarries; Horseshoe East, West, and Centre. Difficulty of access to the quarries has meant that little material has been

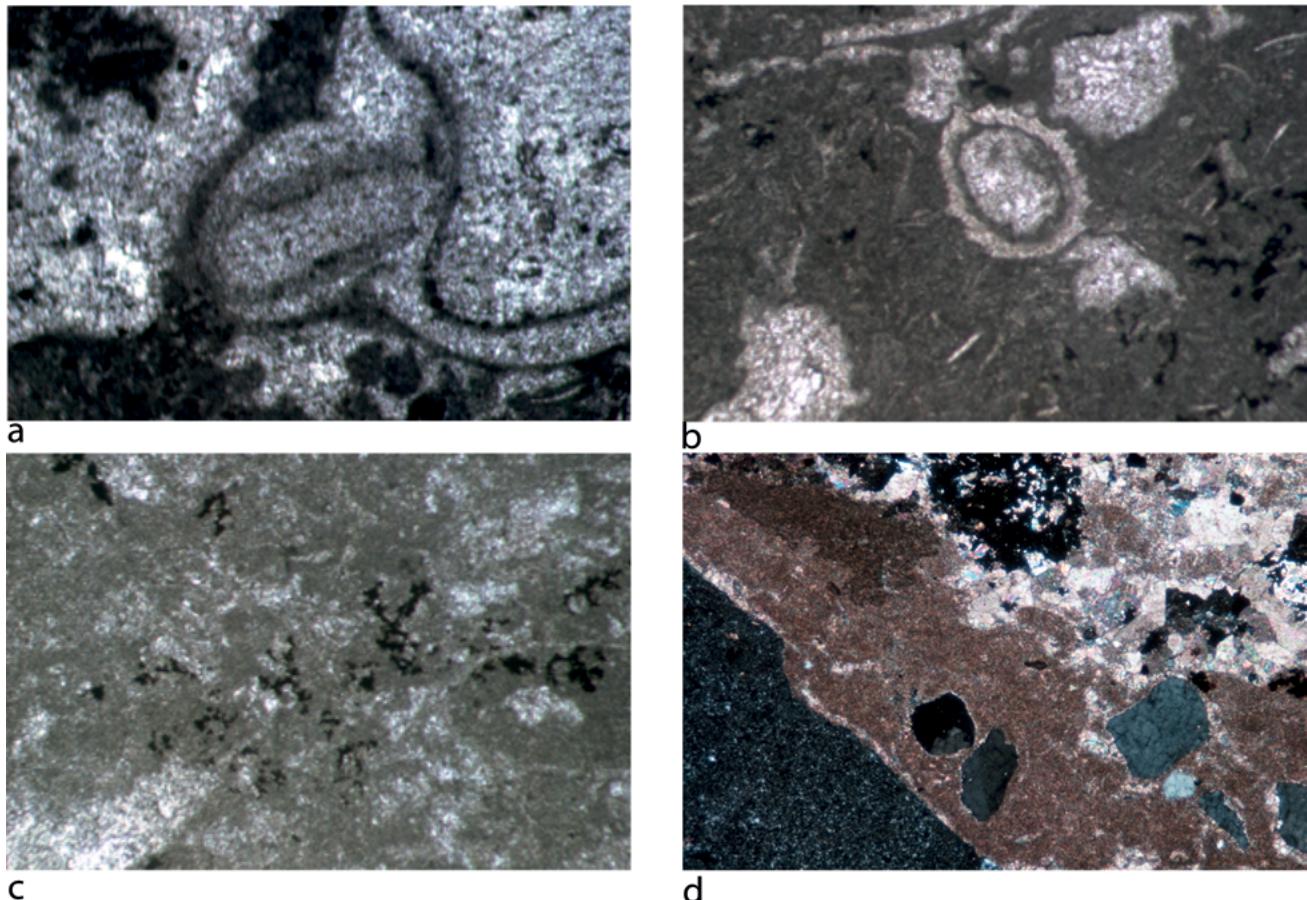


Figure 7. For all photomicrographs, vertical field of view is 2 mm. a, top portion of *Melanoides* gastropod, PPL, TS0644; b, Oogonia of charophyte algae, PPL, TS0664; c, pyrolusite structures in micritic matrix, PPL, TS0631; d, chert grain (bottom left corner) with micritic coating, XPL, TS0628.

prepared from the area, but Horseshoe East, in particular, appears much more fossiliferous than anything at Small Hills. A simplified profile of Horseshoe Centre is shown in Figure 11A. Bone fragments preserved at Horseshoe East are obvious on the weathered surface of the outcrop due to their orange-pink weathering against what is an otherwise grey calcimudstone. This colour is unusual for vertebrate bone at Bullock Creek, which tends to be black due to iron and magnesium oxides (Murray and Megirian, 1992). Horseshoe East is also unique in the Horseshoe for the three different lithologies exposed at this site.

He1 is the stratigraphically lowest calcimudstone unit exposed at Horseshoe East. The weathered surface of this unit appears grey with some ferruginous staining, and bone on the weathered surface is the typical pink-orange colour of Horseshoe East. The slabbed surface, however, shows fragments of bone that are the characteristic black colour of the Bullock Creek bone. This surface is crystalline, with large (up to 30 mm) crystals of calcite present. In thin section, it is apparent that the entire rock is sparry calcite, with no micrite present. Oxides have been exsolved, and only relict spots of

pyrolusite are recognisable. Banding, marked by concentrations of 'pyrolusite' structures, could be stromatolitic in origin – with the 'pyrolusite' indicative of bacterial activity (fig. 12). The black colour of the rock does not appear to be the result of pyrolusite concentrations, as in the grey calcimudstones from Small Hills.

He2 overlies He1 and weathers to the typical grey colour of much of the Camfield beds, with orange-pink bone fragments apparent scattered over the surface. Large carbonate intraclasts are present in the sample, as is invertebrate shell material, peloids, and quite a large number of bone fragments. The matrix is predominantly micrite, with extensive sparry calcite replacement, and much of the shell material is similarly replaced.

He3 is a unit at the top of the succession exposed at Horseshoe East. It is a much lighter white-orange colour in weathered outcrop when compared to the other units. Again a large amount of vertebrate bone is present in this unit, as is some plant material. Carbonate clasts range from 1 mm to 21 mm in diameter. The matrix is micritic with a few shell pieces, and peloids. Some sparry calcite is present in the matrix, and replacing some gastropod fragments.

**Horseshoe West.** In comparison to Horseshoe East, this site is substantially less fossiliferous. Similar to the uppermost facies at Horseshoe East, in weathered outcrop this unit appears a light white-orange colour. The slabbed surface shows it to be a very clean, yellow-coloured carbonate. A small amount of pyrolusite is present, along with articulated ostracods and fragmentary gastropod material. The matrix is almost entirely micritic, with minor spar replacement of gastropod fragments and ostracods.



Figure 8. Slabbed surface of location A6 showing pink and yellow banding. Scale bar = 1 cm.

**Horseshoe Centre.** The Camfield beds at this site are a grey colour in weathered outcrop, with some crystalline calcite standing out against weathering on the surface. Fresh faces here show very little pyrolusite, but instead are a mostly clean white limestone with large bands of calcite. Shell fragments can also be seen, as can articulated, spar-infilled ostracods. The matrix is predominantly micrite, with only a little sparite replacement, concentrated in a few bands.

**Camp Quarry.** This quarry has produced some vertebrate material, although it is not particularly rich, especially when compared to the output of Horseshoe East, or Small Hills. A profile of this quarry appears in Figure 11B.

Cq1 is a massive, grey, fossiliferous calcimudstone. It has a weathered surface in outcrop that is the typical grey colour of the Camfield beds, however bone fragments on the surface are the atypical orange/pink colour of the Horseshoe East bone. The slabbed surface reveals a fairly clean, yellow-coloured carbonate, with little dendritic pyrolusite. Medium sized (80 mm), well-rounded, carbonate clasts are present, and crystalline calcite is obvious. Bone fragments are scattered throughout. The matrix is micritic, with only some areas replaced with spar. Shell fragments are abundant, and are dominantly replaced by sparite.



a



b



c



d

Figure 9. a, dromornithid tibio-tarsus exposed at Dromornithid Mountain quarry in Tm4a, scale bar = 10 cm; b, APV cobbles in conglomeratic unit Tm5, scale bar = 10 cm; c, boulders of conglomeratic unit Tm5, scale bar divisions = 1 m; d, gastropod coquinite near Site X, scale bar = 10 cm.

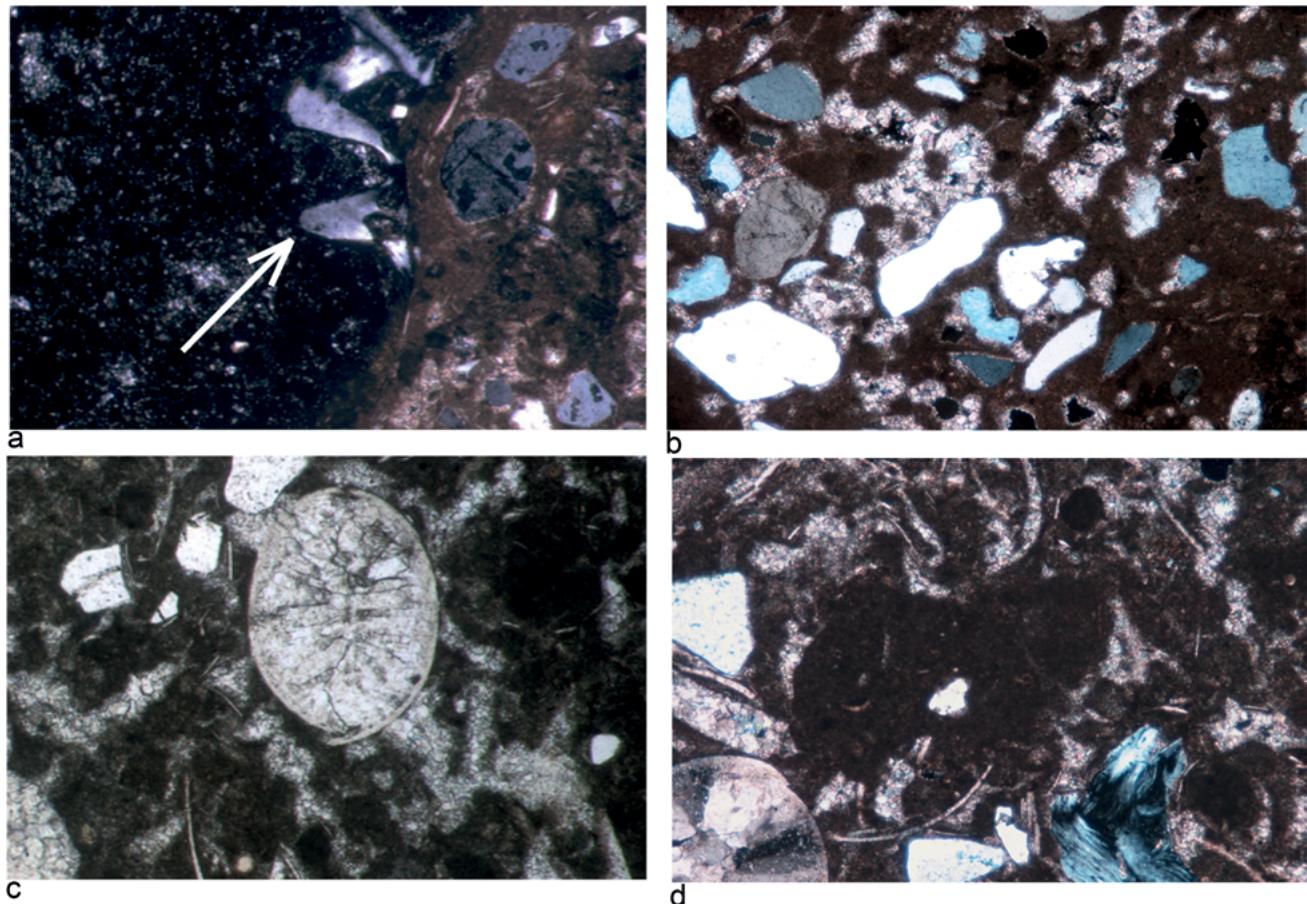


Figure 10. For all photomicrographs, vertical field of view is 2 mm. a, vertebrate bone in chert clast (indicated by arrow), XPL, TS0637; b, a view of Tm4a showing micritic matrix with some vertebrate bone (bottom right), shell fragments and portion of ostracod (bottom left corner), XPL, TS0644; c, radially infilled articulated ostracod, PPL, TS0644; d, a view of TM4b, showing chert fragments in micritic matrix, XPL, TS0693.

Cq2, another massive, grey, fossiliferous calcimudstone, weathers in outcrop to a slightly darker grey colour than does Cq1. The slabbed surface reveals a white-grey coloured face, with more magnesium oxide dendritic material than Cq1. Black bone fragments are present, as are areas of crystalline calcite. Oogonia of charophyte algae are present, as are shell fragments, in a micritic matrix, which has been largely replaced by sparry calcite.

**Microsite A** A profile of this quarry area appears in Figure 11C. The weathered outcrop here shows internal moulds of *Melanooides*, standing out against a grey calcimudstone with occasional rust-coloured areas, possibly the result of chert replacement of original material. Some worn oncoids and pebbles are also apparent. On the polished face of the specimen (fig. 13), both *Glyptophysa* and *Melanooides* are present, infilled with sparite. White-cream carbonate intraclasts have a black outline, and some dendritic magnesium oxide material inside. Layers of black material coat *Glyptophysa*, carbonate, and bone clasts, producing oncoids. A single, well-rounded clast of chert is present and algal threads can also be identified. A high

proportion of the micritic matrix (approximately 40%) has been replaced by calcite spar.

#### A depositional model for other quarries

The Horseshoe quarries are situated west of the Small Hills area (see fig. 1). The shape of the outcrop is suggestive of a stream meander, or oxbow lake, and the geology of the deposit supports this. Again, low-energy, lacustrine sedimentation appears to have dominated the area, with ostracods present at Horseshoe West and Centre, algal threads at Horseshoe Centre, and peloids dominant in the micritic matrix of He2 at Horseshoe East. Differences in the lithologies at Horseshoe East appear attributable to differential diagenesis, with He1 the most altered of any of the Camfield beds material examined for this study. The first two lithologies at Horseshoe East appear to be fairly typical Camfield beds, with the high concentration of bones, and their unusual colour the only difference to the Small Hills lithologies. He1, however, is far more crystalline, and altered in colour. Only relicts of the

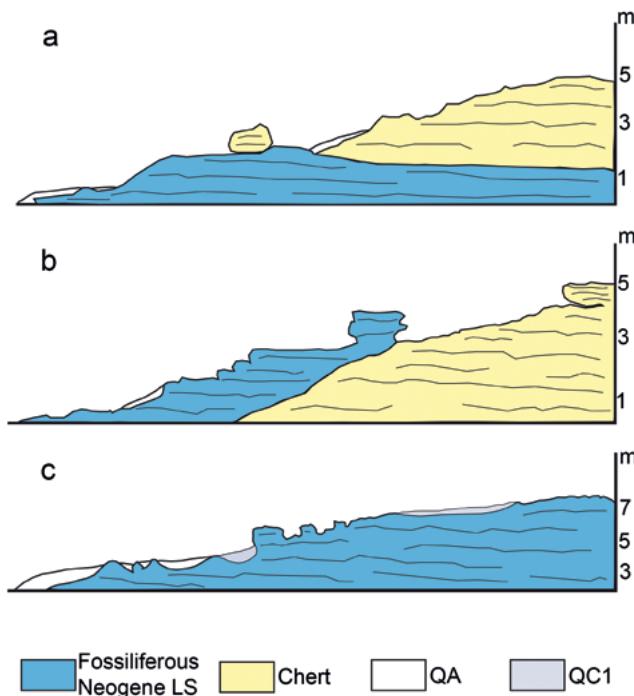


Figure 11. Profiles of a, Horseshoe Centre; b, Camp Quarry; and c, Microsite.

bacterial shrubs remain, and oxides appear to have been exsolved. Neither invertebrate nor vertebrate fossils are present, nor is there any micritic matrix, the entire sample having been recrystallised to sparry calcite.

At Camp Quarry, low-energy sedimentation is again indicated by the presence of the micritic matrix and charophyte algae. Microsite appears to have been deposited in quiet water, although probably shallower water than many of the other deposits, as it is only here that oncoids, which are presumed to be formed by biogenic blue-green algae on the grain surface, are present. Complete gastropods are more common than shell fragments, and algal threads and peloids are also found.

Overall, the Camfield beds are best described as a series of facies of differing energy and limited lateral extent. Facies associations, such as those observed at Blast Site and Dromornithid Mountain, are typical of channels of meandering or braided rivers. These two types of rivers are best considered as end units of a continuous spectrum, rather than mutually exclusive types. The Camfield beds are, therefore, interpreted to represent a braided or meandering river system that was formed by the palaeo-Bullock Creek. This creek had its source in the north-east, and was saturated in carbonate from the Montejinni Limestone along its path. Deposition of the Camfield beds took place via channel migration, with stream meanders and oxbow lakes on many different scales, varyingly overprinting and reworking each other.

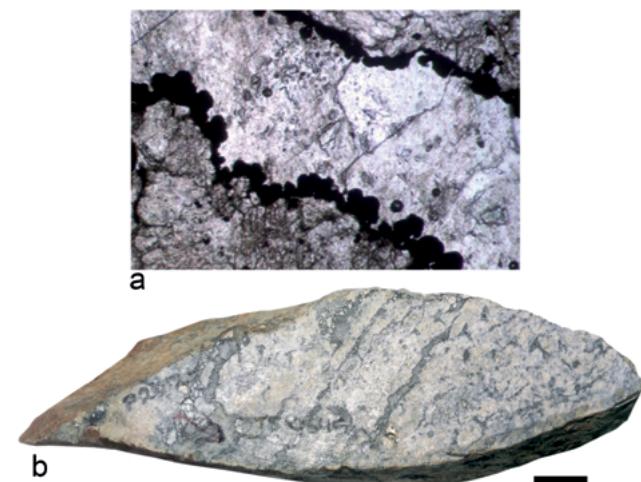


Figure 12. a, stromatolitic banding, PPL, TS0645, vertical field of view is 2 mm; b, slabbed face showing banding, scale bar = 1 cm.

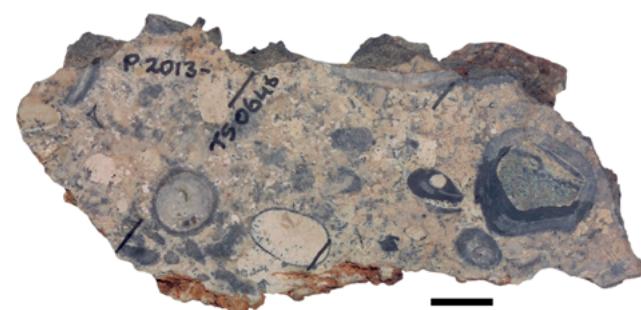


Figure 13. Slabbed face of Microsite sample, showing oncoids and cross-sections of the gastropods *Glyptophysa* and *Melanoides*. Scale bar is 1 cm.

### Systematic palaeontology

Order DASYUROMORPHIA (Gill 1872) Aplin and Archer, 1987

Superfamily DASYUROIDEA (Goldfuss 1820) Simpson, 1930

Family ?DASYURIDAE (Goldfuss, 1820) Waterhouse 1838

(Fig. 14, tables 1, 2)

Referred Material – NTMAG P9215-4 Right dentary cont. p2-m2; NTMAG P215-6 left m; NTMAG P8663-4, right m.

Locality and Horizon – Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

*Determination.* P9215-4 is considered referable to Dasyuridae on the basis of Wroe (1996, 1997a), who suggested that a p3 larger than p2 was a plesiomorphic feature of outgroups to Dasyuromorphia. Reduction of the p3 relative to p2 is found amongst thylacinids in only *Badjocinus* from the late Oligocene

Table 1. Measurements for P9215-4 (in mm). Length is measured along the lingual edge of the tooth, height is measured for premolars from the cervix of the tooth to the tallest point, and width is the distance from the protoconid to the metaconid on the molars.

Tooth Position	Length	Height	Width
p2	0.95	0.77	
p3	0.89	0.58	
m1	1.11		
m2	1.37		0.78

White Hunter site at Riversleigh. Most dasyurids have a p3 that is shorter and lower crowned than p2, with the exception of *Murexia* and most sminthopsines (Wroe, 1997a). The absence of the entoconid also implies that this may be a relatively derived dasyurid, as large entoconids are plesiomorphic for dasyuromorphian outgroups (Wroe, 1997a).

The other two molars referred here to ?Dasyuridae, P9215-6 and P8663-4 differ enough from each other and from P9215-4 as to suggest the presence of at least three different species. Thus, these elements suggest that three species of ?dasyurid forms are present at Bullock Creek, along with a possible third ?thylacinid species (see below). However, assignment to Dasyuridae, for all teeth except P9215-4, is mostly on the basis of size. There are no dental synapomorphies for the family (see, for example, Wroe, 1996, 1997a, 1997b) and so these teeth could also be considered Dasyuromorphia *incertae sedis* as other authors have done with forms such as *Ankotarinja* and *Keeuna* (Godthelp et al., 1999).

More certain determination of affinities of these dasyuromorphian forms is dependent upon discovery of cranial material, given that features of the skull are the only remaining synapomorphies for Dasyuridae. In the absence of this material, and any synapomorphies uniting the forms described here with extant units of the family, these cannot be strictly placed within the family.

#### Family ?THYLACINIDAE Bonaparte, 1938

(Fig. 15, table 3)

Referred Material – NTMAG P9464-4, Right M2/3.

Locality and Horizon – Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

**Determination.** P9464-4 is considered ‘thylacinid-like’ based on its resemblance to *Maximucinus muiheadae* Wroe 2001 from the middle Miocene Ringtail site of Riversleigh. Wroe (2001) considered *M. muiheadae* to have the following thylacinid synapomorphies, which are shared with P9464-4: reduction of

Table 2. Measurements for ?dasyurid isolated teeth (in mm). Length is measured along the lingual edge of the tooth and width is measured from the protoconid to the metaconid.

Specimen	Length	Width
P9215-6	1.89	1.00
P8663-4	3.30	1.79

the protocone and stylar shelf, elongation of the postmetacrista, and reduction of stylar cusps B and D without the paracone and metacone moving closer together. In addition, P9464-4 has a straight centrocrista, recognised by Wroe (2001) and others as a generalised thylacinid character, and stylar cusp D is not anterior to the metacone, a shift that is characteristic of dasyurids.

P9464-4 does not appear to belong to one of the two previously described thylacines from Bullock Creek, *Mutpuracinus archibaldi* Murray and Meigirian 2000 or *Nimbacinus richi*, being separated from these forms by its much smaller size, and in fact, is much smaller than other known thylacines (see Wroe, 2001 for sizes of fossil and modern thylacinids). Using the body mass estimates of Myers (2001), this animal would be approximately 180 g in weight, significantly smaller than the smallest known thylacinid, *Mutpuracinus archibaldi*, which is over 1 kg, and much closer in size to dasyurids.

Order PERAMELEMORPHIA (Kirsch, 1968) Aplin and Archer 1987

Superfamily YARALOIDEA Muirhead, 2000

Family YARALIDAE Muirhead 2000

(Fig. 16, table 4)

Referred Material – NTMAG P8688-12 right m2; NTMAG P925-15 left m1; NTMAG P87106-46 left M2.

Locality and Horizon – P8688-12 is from an unrecorded quarry at Bullock Creek; P925-15 and P87106-46 are both from Site Y, Small Hills, Tm1 the XY beds of the Camfield beds.

**Determination.** For P8688-12, the position of the hypoconulid, directly posterior to the entoconid (figs. 16A, B), unites this tooth with the Peramelemorphia. The size of the entoconid, presence of a pronounced preentocristid, and the subsequent ‘bladed’ appearance of the entoconid, separate this tooth from *Yarala burchfieldi* Muirhead and Filan 1995 from Upper Site, Riversleigh. The termination point of the cristid obliqua on the buccal side of the metacristid notch implies yaralid affinities. The size of this tooth is, however, much larger than those of

Table 3. Measurements of P9464-4 (in mm). Para-Met is the distance from the paracone to the metacone, Para-Proto from the paracone to the protocone, Proto-Met from the protocone to the metacone. Width is measured along the anterior edge from the anterobuccal corner of the tooth to the protocone, and length is measured along the buccal edge of the tooth.

Specimen	Para-Met	Para-Proto	Proto-Met	Width	Length
P9464-4	1.21	1.18	1.74	2.77	3.31

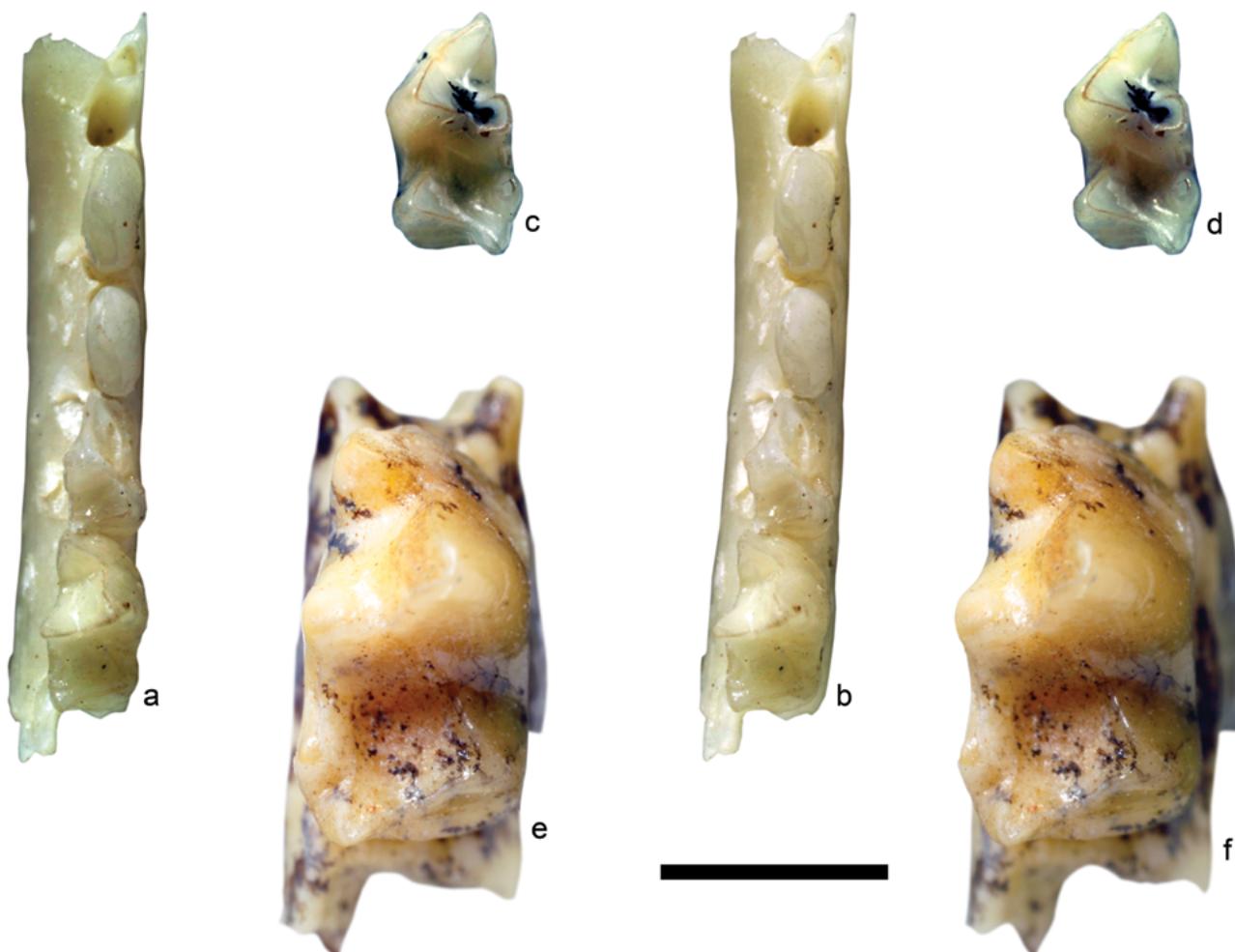


Figure 14. Occlusal stereopair of ?dasyurid dentary and isolated teeth. a, b, NTMAG P9215-4, right ?dasyurid dentary containing p2-m2; c, d, NTMAG P9215-6, ?dasyurid left lower molar; e, f, NTMAG P8663-4, ?dasyurid right lower molar. Scale bar = 2 mm.

Table 4. Measurements of peramelemorphian teeth (in mm). Length is measured along the midline of the lower teeth and along the buccal edge of the upper molar. Widths are measured at the widest points of the trigonid and talonid on lower molars. On the upper molar, anterior width is measured from the anterobuccal corner of the tooth to the protocone, and posterior width is measured from the protocone to the posterobuccal corner.

Specimen	Tooth Position	Length	Anterior Width	Posterior Width
P8688-12	m1	2.2	1.2	1.2
P925-15	m2	1.8	1	1.1
P87110-24	m3	1.7	1.1	0.9
P87106-47	M2	1.5	1.6	2.1

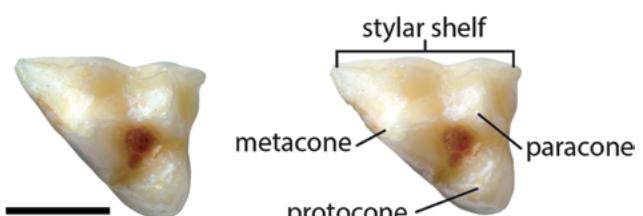


Figure 15. Stereopair of occlusal view of NTMAG P9464-4, right M2/3 referred to ?Thylacindae. Scale bar = 2 mm.

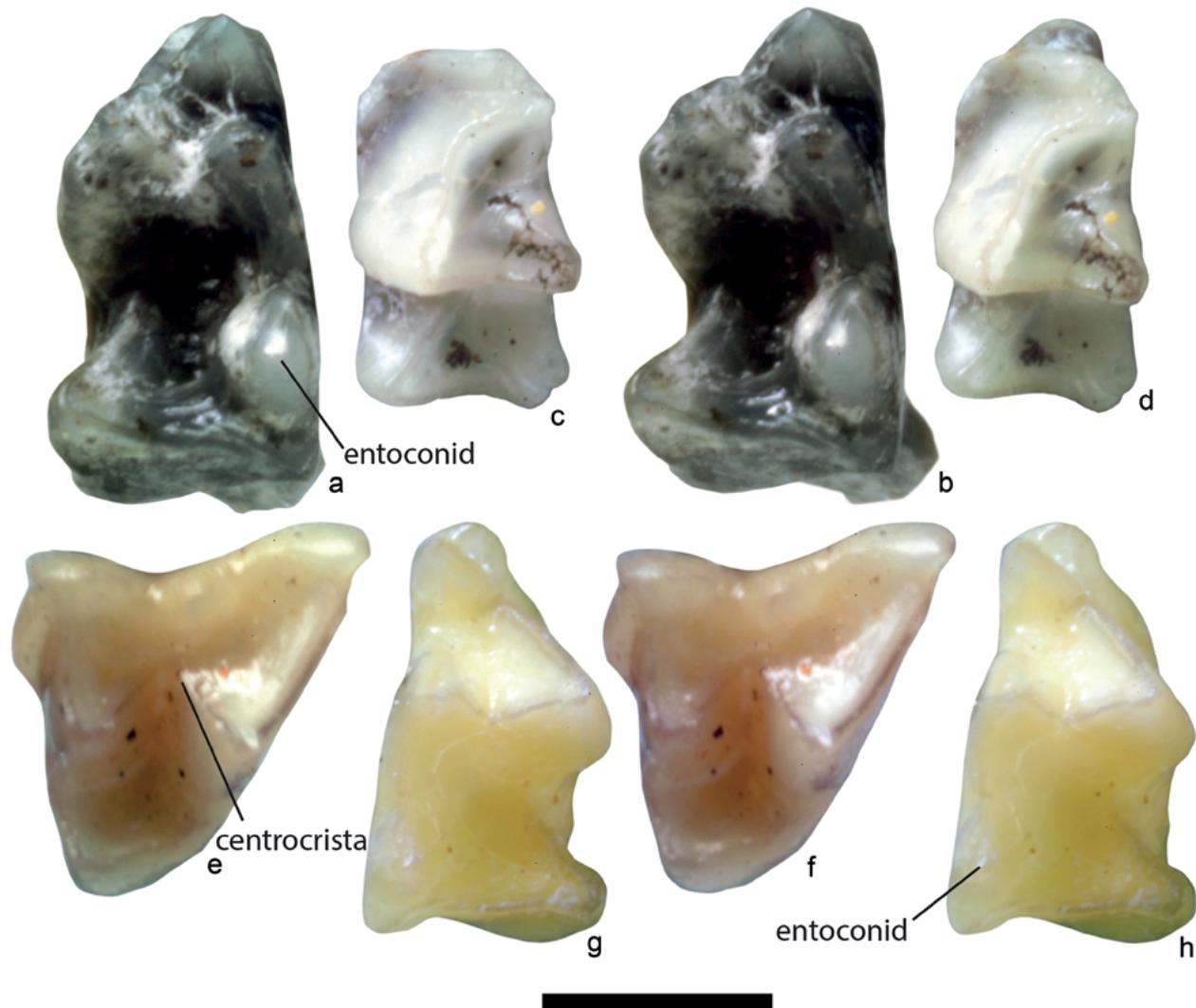


Figure 16. Stereopairs of occlusal views of peramelemorphian teeth from Bullock Creek. a,b, NTMAG P8688-12 Rm2; c,d, NTMAG P87110-24, Lm3 referred to *Yarala* sp.; e,f, NTMAG P87106-46 LM2; g, h, NTMAG P925-15 Lm1. Scale bar = 1 mm.

*Yarala burchfieldi* from Riversleigh, *Yarala kida* Schwartz 2006a, from Kangaroo Well and *Yarala* sp. material listed here.

P925-15, on the other hand, lacks a strong preentocristid which may suggest affinities with *Yarala burchfieldi*, but this tooth differs from that species in that the entoconid (figs. 16G, H) is more robust. It differs from *Yarala kida* in the relative heights of the entoconid and the hypoconid, and in the lack of a strong postmetacristid. Like P8688-12, the termination of the cristid obliqua on the buccal side of the metacristid notch implies yaralid affinities.

P87106-46, is assigned to the Yaraloidea on the basis of a complete centrocrista (figs. 16E, F). While a complete centrocrista is a character shared between yaraloid bandicoots and dasyuromorphs, in yaralids, a smaller angle is formed between the postparacrista and the premetacrista, such as is

observed here. The centrocrista is also more buccally positioned than in dasyuromorphs (Muirhead and Filan, 1995). This tooth, although quite worn, appears most similar to *Yarala kida*, allowing for the removal of stylar cusp B through wear.

#### **YARALA Muirhead and Filan 1995**

##### **YARALA sp. nov.**

(Figs. 16C, D, table 4)

Referred Material – NTMAG P87110-24 left m3.

Locality and Horizon – Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

**Determination.** The tallest cuspid on this tooth is the protoconid, followed by the metaconid. The entoconid appears to have been the taller than the paraconid, though the tips of these two cusps are missing, and also taller than the hypoconid. The hypoconulid is positioned directly posterior to the entoconid, which is ‘spire-like’ with an only very weakly developed pre-entocristid. The cristid obliqua contacts the trigonid very nearly on the midline of the tooth, directly below the metacristid notch, and the taloned is antero-posteriorly reduced relative to the trigonid. P87110-24 is therefore considered to belong to a third, undescribed species of *Yarala*, due to its strong similarities to both *Y. kida* and *Y. burchfieldi*.

**Comment.** It is surprising that only a single superfamily of the Peramelemorphia, the Yaraloidea, is found at Bullock Creek and any crown-group Peramelemorphia (sensu Travouillon et al., 2014) are so far lacking. This is particularly surprising given that Travouillon et al. (2014) report both thylacomyids and peramelids from middle Miocene sites at Riversleigh.

The Bullock Creek record, however, consists mostly of lower molars. The lower teeth of peramelemorphians are not easily assigned, particularly where isolated teeth are concerned. This makes the identifications of those teeth above as yaraloid bandicoot, on the basis of their similarities to *Yarala kida* from Kangaroo Well (Schwartz, 2006a) and *Y. burchfieldi* from Riversleigh (Muirhead and Filan, 1995), less certain than the identification that is based on the upper molar. Gurovich et al. (2014) have questioned the monophyly of the Yaraloidea, suggesting that instead that this group represents a grade of stem-peramelemorphians.

#### Order DIPROTODONTIA Owen 1866

##### Suborder PHALANGERIDA Aplin and Archer 1987

##### Family PHALANGERIDAE Thomas, 1888

##### Genus WYULDA

cf. ASHERJOELI sp. Crosby, Nagy and Archer 2001

(Fig. 17, table 5)

Referred Material – NTMAG P87110-36 left P3; NTMAG P87110-37 right M1/2; NTMAG P87110-38 right M2/3.

Locality and Horizon – Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

**Determination.** P87110-36, which is a left P3, is nearly identical to that described for *Wyulda asherjoeli* Crosby, Nagy and Archer 2001 from the Mike’s Menagerie site at Riversleigh. It differs from this species only in having a more acute angle to the buccal cingulum. P87110-37, a right M1/2, and P87110-38, a right M2/3 are phenetically similar and nearly identical, in both structure and wear pattern. Like P87110-36, these teeth most closely resemble *Wyulda asherjoeli*.

Table 5. Measurements of teeth (in mm) referred to *Wyulda* sp. cf. *asherjoeli*. Length is measured along the midline of the tooth. Anterior width is measured across the protoloph and posterior width along the metaloph.

Specimen	Length	Anterior Width	Posterior Width
P87110-36	4.3	3.5	
P87110-37	4.3	4.2	3.7
P87110-38	3.5	3.3	2.8

##### Family PETAURIDAE (Bonaparte, 1838) Archer 1984

##### PETAURIDAE indet.

(Figs. 18A, B, table 6)

Referred Material – NTMAG P8697-7 left M1?

Locality and Horizon – Dromornithid Mountain, Small Hills, Tm4 the Dromornithid Mountain beds of the Camfield beds.

**Determination.** P8697-7 is assigned to the Petauridae due to its near-square occlusal outline, low-crowned nature, and the indistinctness of the cusps, all of which are petaurid characteristics. It differs from the modern *Petaurus australis* Shaw 1791 in the absence of an enlarged stylar shelf, and from *Petaurus norfolkensis* Kerr 1792 in its possession of a metaloph. This structure however, unites it with the petaurids known from the Pliocene Hamilton Local Fauna (Victoria) (Turnbull et al., 1987), although in P8697-7 both the protocone and hypocone (figs. 18A, B) are significantly smaller than the buccal cusps. No crenulations are present in the central basin of the tooth, although these may have been removed by wear.

Table 6. Measurements (in mm) of the petaurid molar from Bullock Creek. Length is measured along the buccal edge of the tooth, anterior width from the paracone to the protocone and posterior width from the metacone to the hypocone.

Specimen	Length	Anterior Width	Posterior Width
P8697-7	3.5	2.8	2.4

##### Family PSEUDOCHEIRIDAE (Winge, 1893) Archer (1984)

##### PSEUDOCHEIRIDAE indet.

(Figs. 18C–F, table 7)

Referred Material – NTMAG P9464-249 right M2; NTMAG 9276-1 right M2; NTMAG P9464-245 left m2/3.

Locality and Horizon – Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

**Determination.** P9276-1 and P9464-249 are identical except that P9276-1 is less worn than P9464-249. These teeth display the characteristic offset of the postprotocrista and premetaconule



Figure 17. Stereopairs of occlusal views of teeth referred to *Wyulda* sp. cf. *asherjoeli*. a, b, NTMAG P87110-36 LP3; c, d, NTMAG P87110-37 RM1/2; e, f, NTMAG P87110-38 RM2/3. Scale bar = 3 mm.

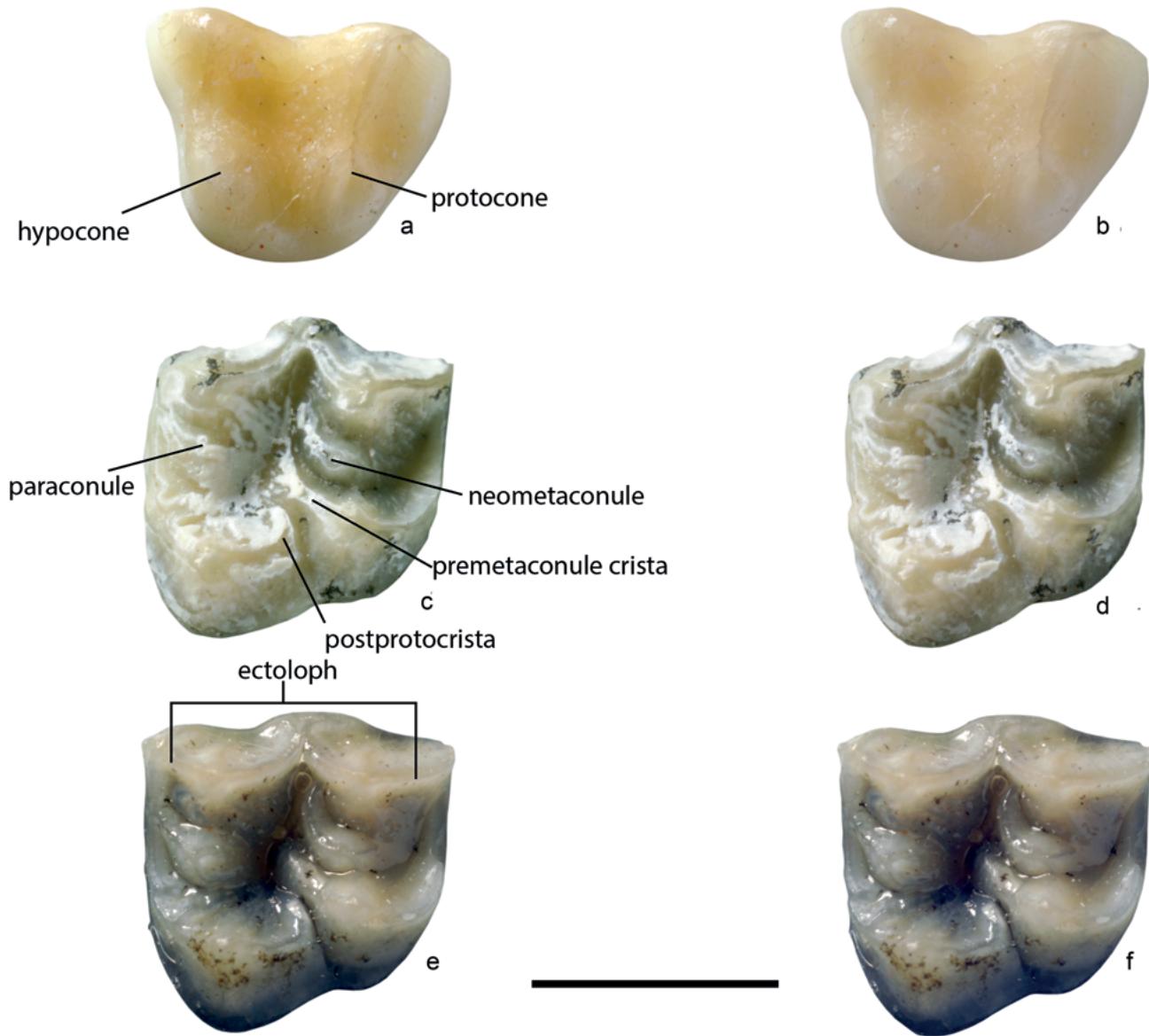


Figure 18. Occlusal stereopairs of petauroid upper molars. a, b, NTMAG P8697-7, petaurid LM1; c, d, NTMAG P9464-249, pseudocheirid RM2; e, f, NTMAG P9276-1, pseudocheirid RM2. Scale bar = 2 mm.

crista that Woodburne et al. (1987) suggested was synapomorphic for Pseudocheiridae (figs. 18 C-F). They differ from species of *Pildra* in having a more pronounced paraconule and neometaconule, and in being lower-crowned. They differ from species of *Marlu* in having a paraconule that does not extend to the midpoint of the tooth's occlusal surface, and in the arcuate shape of the neometaconule. They differ from species of *Paljara* in having a much less 'W-shaped' ectoloph.

For P9464-245, the presence of a hypoconulid, a larger entostyloid, and a mostly linear (rather than arcuate) entostyloid ridge separate this tooth from *Pildra antiquus* Woodburne, Tedford and Archer 1987 from the Pinpa Local Fauna of the

Namba Formation which has been correlated with the middle Oligocene Zone A of the Etadunna Formation of South Australia. The entoconid here is developed in a more blade-like fashion than in *Pildra secundus* Woodburne, Tedford and Archer 1987, from the Etadunna Formation late Oligocene Zone B, and the entostylid ridge is here directed almost transversely, rather than antero-buccally.

This tooth appears most similar to *Pildra tertius* Woodburne, Tedford and Archer 1987, from the early Miocene Kutjumarpu Local Fauna, however it is significantly larger and somewhat more ornate in its crenulations. Like species of *Pildra*, it differs from *Marlu* in possessing an entostyloid ridge; having an

indistinct paraconid; lacking an entoconid that is aligned en echelon with the metastylid; and the absence of a cusp-like structure on the lingual side of the anterior end of the cristid obliqua. It differs from species of *Paljara* in having a strongly developed entostyloid ridge, and in being larger. This tooth could be considered a larger, more derived species of *Pildra*.

Table 7. Measurements (in mm) of pseudocheirid molars. Length is measured along the buccal margin for the uppers, along the midline for the lower. Anterior width is measured from the paracone-protocone for the uppers, and from the protoconid to the metaconid on the lower. Posterior width is measured along the metacone to the metaconule on the uppers and from the entoconid to the hypoconid on the lowers.

Specimen	Length	Anterior Width	Posterior Width
P9276-1	3.5	2.9	3.1
P9464-249	3.3	2.9	3.3
P9464-245	4.0	2.1	2.2
P9464-246	2.6	2.2	

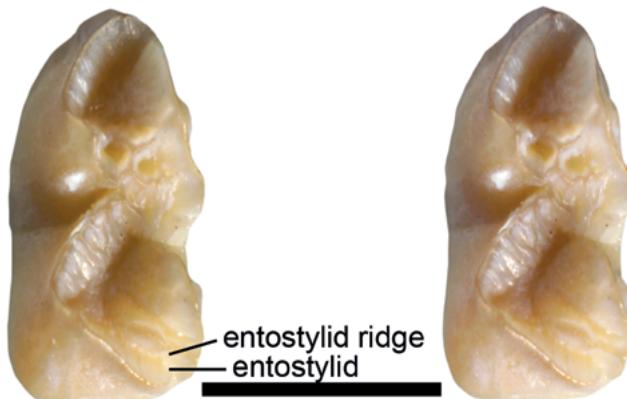


Figure 19. Occlusal steropair of NTMAG P9464-245, pseudocheirid Lm2/3. Scale bar = 3 mm.

#### PHALANGERIDA indet.

(Fig. 20, table 8)

Referred Material – NTMAG P9215-12 right m1; NTMAG P9215-11 right m2.

Locality and Horizon – Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

**Determination.** P9215-12 is similar to that of *Djaludjangi yadjana* Brammal 1998, however it also shows affinities to the pilkipildridids. No protostyloid is present on this tooth, separating it from *Djilgaringa gillespiei* Archer, Tedford and Rich 1987; however, like that species, there is a short ‘flattened’ section to the trigonid extending anteriorly from the protoconid. This feature is not present in *D. yadjana*. The lack of a metaconid separates this tooth from both species of *Djilgaringa* and those

of *Pilkipildra*. This tooth further differs from both species of *Pilkipildra* in that the cristid obliqua does not ascend the flank of the trigonid, and there is no notch in the anterior cingulum for articulation of the p3. It differs from *D. yadjana* in the presence of the deep fissure between the trigonid and the talonid observed on the lingual side of the tooth; not possessing a ‘complete’ hypolophid as well as the posterior cingulid; and having much more crenulate enamel. This tooth is assigned to Phalangerida incertae sedis, pending review of this group.

On P9215-11, the trigonid and talonid are equal widths, implying, by comparison with *Djilgaringa gillespiei*, that this is an m2. This tooth is very similar to P9215-12, and fits together with it in such a way as to imply that these teeth are from the same individual. No comparisons of this tooth with *Djilgaringa thompsoni* Archer, Tedford and Rich 1987 or with *Pilkipildra taylori* Archer, Tedford and Rich 1987 are possible as these species are known only from m1s. It differs from *D. gillespiei* in having a distinct paraconid; in the transverse ridge from the metaconid not contacting the protoconid; in lacking a metastylid and possessing an entostyloid; and in having a continuous cristid obliqua. This tooth also differs from *Pilkipildra handi* in its possession of a transverse cristid on the talonid and the presence of crenulations on the trigonid basin.

P9215-11 differs from *Djaludjangi yadjana* in not having complete ‘lophids’, and in being less ‘pinched in’ at the ‘waist’ (between the talonid and trigonid) of the tooth than that *D. yadjana*. The position of the entoconid in P9215-11 also differs slightly from that of *D. yadjana*, being slightly posterior of that cuspid. *D. yadjana* also lacks an entostyloid or the secondary accessory stylid on the entoconid, in both of which features it is similar to *Djilgaringa gillespieae*. However, the presence of a paraconid separates this tooth from both *D. yadjana* and *D. gillespieae*, although on the latter species there is a small ‘wobble’ in the anterior cingulid, discernible in buccal view, that could be interpreted to represent this cuspid. Like P9215-12, this tooth is assigned to the Phalangerida incertae sedis, pending review of this group.

**Comment.** A large diversity of ‘possum’ groups is recorded at Bullock Creek. Unfortunately, many of the groups described here are in dire need of review, a problem that extends even to the living pseudocheirid species. Changes in organisation of many of the groups discussed may affect the familial interrelationships presented here, and in some cases, may synonymise the groups

Table 8. Measurements (in mm) of molars referred to Phalangerida incertae sedis. Length is measured along the midline of the tooth, anterior width on P9215-12 is measured across the base of the talonid at the point of attachment of the anterior root. Posterior width on both teeth is measured from the entoconid to the hypoconid, and anterior width on P9215-11 is measured from the metaconid to the protoconid.

Specimen	Length	Anterior Width	Posterior Width
P9215-12	2.0	1.2	1.2
P9215-11	1.9	1.3	1.3

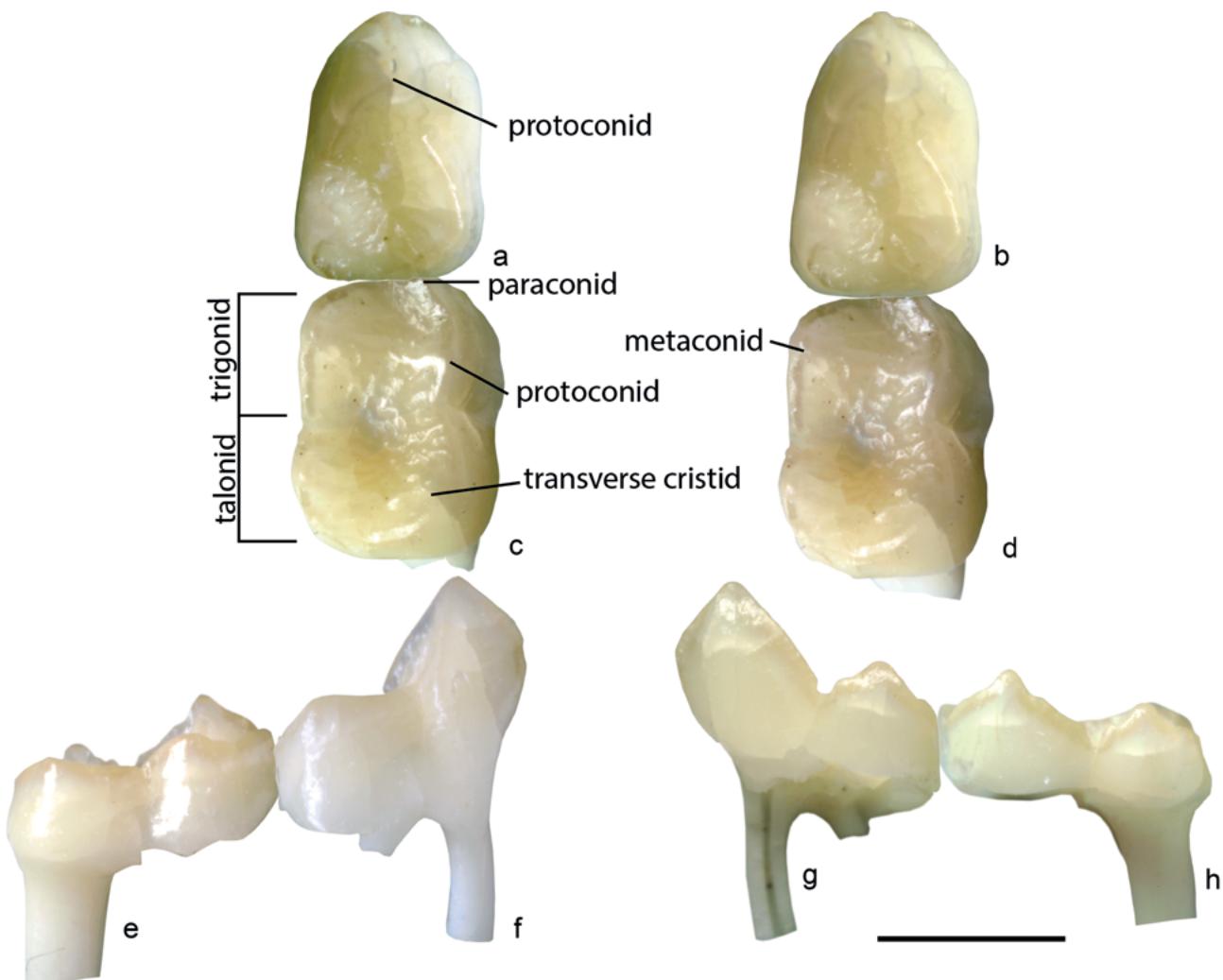


Figure 20. Molars referred to Phalangerida *incertae sedis*. a, b, occlusal stereopair of NTMAG P9215-12, Rm1; c, d, occlusal stereopair of NTMAG 9215-11, Rm2; e, lingual view of NTMAG P9215-11; f, lingual view of NTMAG P9215-12; g, buccal view of NTMAG P9215-11. Scale bar = 2 mm.

used here. For example, Flannery et al. (1987) synonymised *Wyulda* with *Trichosurus*, although this has not been followed by subsequent authors (Crosby et al., 2001).

The presence of *Wyulda* sp. cf *asherjoeli* at Bullock Creek suggests a possible correlation between this site and the early Miocene Camel Sputum Riversleigh site in which it is found (Crosby et al., 2001; Woodhead et al., 2015). However, there is only one other species of *Wyulda* known, an extant form, *Wyulda squamicaudata*, which implies that either that the genus is fairly conservative, or that those features recognised as ‘trichosurine’ are plesiomorphic for Phalangeridae (Beck, pers. comm.).

The absence of the final phalangeroid family, the Ektopodontidae, from the Bullock Creek local fauna is puzzling. While this family is known to be relatively rare in the Cenozoic deposits of Australia, its continued absence from this

site contrasts with its otherwise widespread occurrences.

What may be the oldest petaurid is also recorded here at Bullock Creek, though Tedford and Kemp (1998) referred material from the late Oligocene Geilston Bay site to Petauroidea *incertae sedis*. However, the association of the Bullock Creek tooth with the Petauridae is tentative. The only other fossil record of this family is the similarly tentatively assigned Hamilton petaurids (Turnbull et al., 1987). Unfortunately, as it is only an isolated tooth and already simplified along petaurid lines, very little information as to its phylogenetic affinities may be obtained without further material.

The pseudocheirid upper molars listed here are likely to represent a new genus, however they are unlikely to be associated with the lower molar, as the uppers are clearly separate to both *Pildra* and *Paljara*, genera with which the

Table 9. Measurements of teeth referred to *cf. Palaeopotorous*. Length is measured along the midline of the tooth. Anterior width is measured across the protoloph and posterior width across the metaloph. No width measurements are shown for P8670-22 as the specimen is missing its lingual edge.

Specimen	Length	Anterior Width	Posterior Width
P8670-22	5.7		
P908-78	5.4	5.0	5.1
P87106-2	5.3	5.0	5.1
P9464-243	4.6	3.8	3.8

lower shows some similarity. The use of the presence of the entostyloid ridge to separate *Marlu* and *Pildra* species has been thrown into some doubt by Roberts et al. (2009), who identified an entostyloid ridge on the m1 of *Marlu praecursor* and noted the probable paraphyly of that genus. Further, Roberts et al. (2008) noted that features distinguishing the posterior molars of *Pildra* and *Paljara* species are minor and often removed by wear. There is some possibility, then, than the lower molar reported here belongs to either *Pildra* or *Paljara*, but such a determination will have to wait on further material.

Therefore, it is probable that at least two separate species of pseudocheirid are present at Bullock Creek. Up to nine undescribed species have apparently been found in a single Riversleigh site (Archer, 1992), and co-existence of pseudocheirid species has been recorded at Riversleigh, in zone D, latest Oligocene, of the Etadunna Formation, and in the early Miocene Wipajiri Formation (Woodburne et al., 1993). Thus, the co-existence of two pseudocheirid species in the Bullock Creek Local Fauna is not surprising.

#### Superfamily MACROPODOIDEA Gray 1821

#### Family MACROPODIDAE Gray 1821

#### cf. PALAEOPOTOROUS Flannery and Rich 1986

(Figs. 21, 22)

Referred Material – NTMAG P8670-22 left M2/3; NTMAG P908-78 left M2/3; NTMAG P87106-2 right M2/3; NTMAG P9464-243 right M2.

Locality and Horizon – P8670-22 unrecorded quarry in the Camfield beds; P908-78 Blast Site, Small Hills, Tm2 the Blast Site beds of the Camfield beds; P87106-2 Site Y, Small Hills, Tm1 the XY beds of the Camfield beds; P9464-243 Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds.

**Determination.** P87106-2 shows strong resemblance to NMV P172995, except that it is slightly larger. Similarly, P908-78 resembles NMV P172999. Both these teeth were described by Flannery and Rich (1986) as belonging to *Palaeopotorous priscus* Flannery and Rich 1986, from the late Oligocene Namba Formation of South Australia. These teeth differ from

Table 10. Measurements (in mm) of bulungamayine teeth. Length is measured along the midline of the tooth. For premolars, anterior width is measured at the first cusp and posterior width at the last. For molars, anterior width is measured across the protoloph/id and posterior width across the metaloph or the hypolophid.

Specimen	Length	Anterior Width	Posterior Width
P87105-29	3.9	2.3	2.8
P9464-218	3.6	2.4	2.8
P2786-1	12.0	3.1	6.9
P9272-11	8.8	1.9	3.1
P8697-8	5.2	4.9	4.3
P874-1	5.7	5.5	5.5
P9272-10	5.1	3.9	4.1
P9464-217	6.3	4.7	4.3
P9464-190	4.4	2.9	3.2

the upper molar figured by those authors, which has both complete lophs that incorporate a third cusp. Either *P. priscus* shows a large amount of variation along the molar row in terms of numbers and expression of stylar cusps, and the form of the protoloph, in which case these teeth could be considered to belong to a closely related species with a similar level of variation; or, both the material referred to *P. priscus*, and these teeth, represent a number of closely related species.

P9464-243 contains three cusps in the metaloph, a characteristic of those teeth described above and referred to *Palaeopotorous*. Like P908-78, and species of *Ekaltadeta*, it also shows a stylar crest. This tooth is therefore included with the other teeth referred to *Palaeopotorous* and considered to represent a possible link between this genus and units of the Propleopinae. It is also similar to the upper teeth described for *Wanburoo hilarus* Cooke 1999, a bulungamayine, except that *W. hilarus* possesses a stylar cusp C.

#### Subfamily BULUNGAMAYINAE Flannery, Archer and Plane 1983

(Figs. 23–25, table 10)

Referred Material – NTMAG P9464-192 left i1; NTMAG P87105-29 left p2; NTMAG P9464-218 right p2; NTMAG P9272-10 left dp3; NTMAG P2786-1 left P3 and partial palate; NTMAG P9272-11 left p3; NTMAG P8697-8 right M2/3; NTMAG P874-1 left M3; NTMAG P9464-217 right m2; NTMAG P9464-190 left m2.

Locality and Horizon – P9464-192, P9464-218, P9464-217, P9464-190 Top Site, Small Hills, in Tm8 the Top Site beds of the Camfield beds; P87105-29, P9272-10, P9272-11, P874-1 unrecorded quarry of the Camfield beds; P2786-1 Horseshoe West, unnamed unit of the Camfield beds; P8697-8 Dromornithid Mountain, Small Hills, in Tm4 Dromornithid Mountain beds of the Camfield beds.

**Determination.** Incisors. i1 is unknown in most Miocene kangaroos, and so comparison with P9464-192 is difficult. Confinement of enamel to the buccal surface of the tooth,

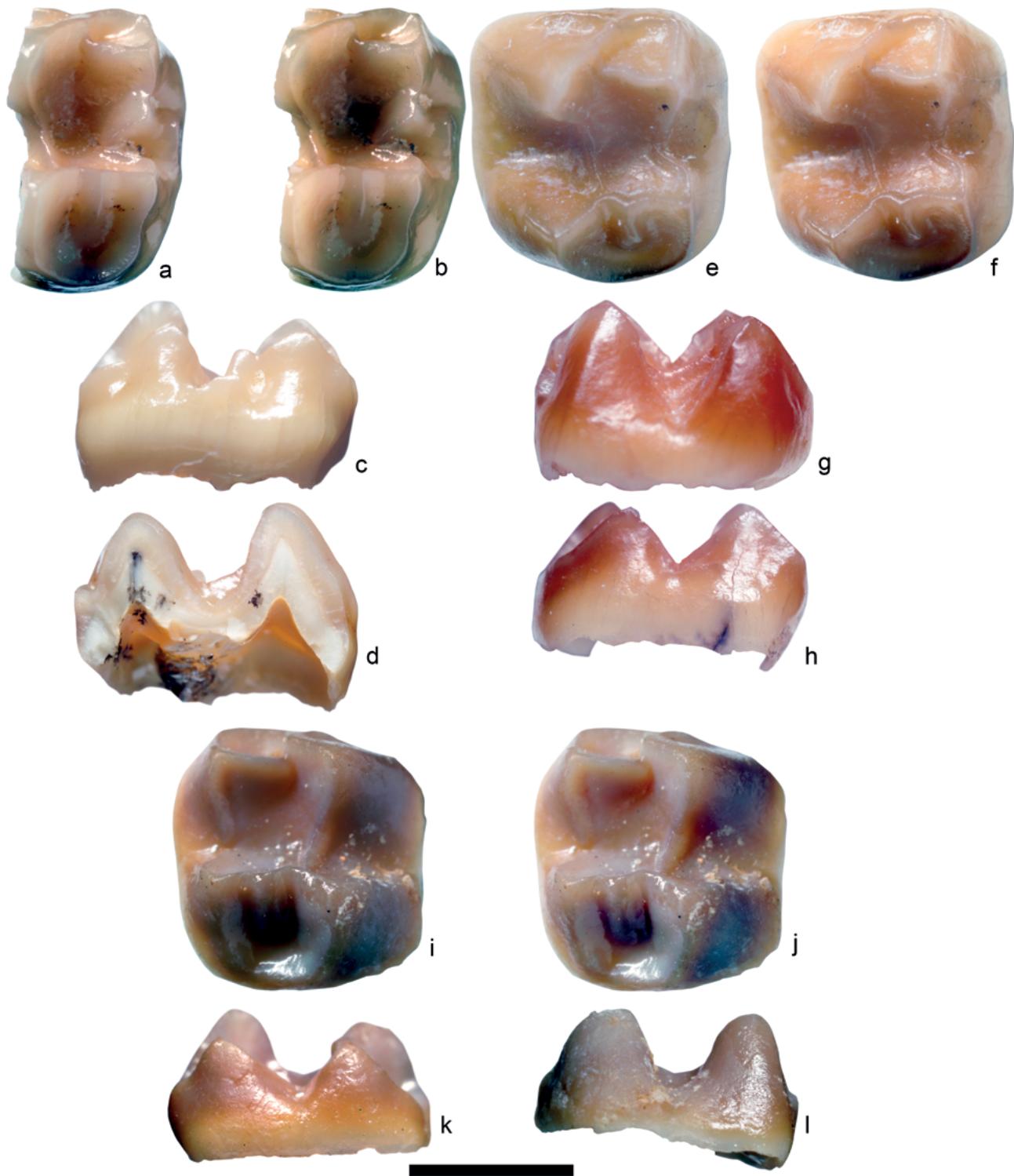


Figure 21. Upper molars referred to *cf. Palaeopotorous*. a, b, occlusal stereopair of NTMAG P8670-22, LM2/3; c, buccal view; d, lingual view; e, f, occlusal stereopair of NTMAG P908-78, LM2/3; g, buccal view; h, lingual view; i, j, occlusal stereopair of NTMAG P87106-2, RM2/3; k, buccal view; l, lingual view. Scale bar = 3 mm.

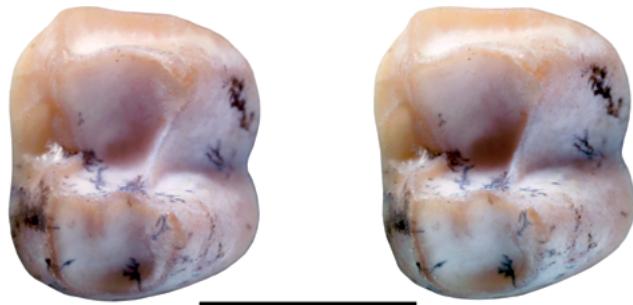


Figure 22. Occlusal stereopair of NTMAG P9464-243, RM2 of *cf. Paleotorous*. Scale bar = 3 mm.



Figure 23. Occlusal stereopair of NTMAG P9464-218, bulungamayne Rp2. Scale bar = 3 mm.

combined with the presence of dorsal and enamel flanges, and the absence of enamel ridges suggests that this tooth may belong to the Bulungamayinae (Cooke, 1997a).

Premolars. P87105-29 and P9464-218 are most similar to bulungamayne premolars, in that they are finely ridged and not ‘bulbous’ in the same way as the premolars of balbarines and hypsiprymnodontids, with transcristds that continue to the base of the tooth. They are broadly similar to dp2s known for *Wanburoo hilarus*, a bulungamayne kangaroo. P2786-1 is assigned to the Bulungamayinae on the basis of its length as it is much longer than premolars known for Balbarinae. The presence of a posterolingual cuspule also unites this tooth with the bulungamayines, although this is also a feature of macropodines (Cooke, 1999). If, as Kear and Cook (2001) and Prideaux and Warburton (2010) contend, Bulungamayinae is best considered a paraphyletic grade of macropodids, including forms closer to Stenurinae and to Macropodinae, this is unsurprising.

For P9272-11, both the curvature and length of this premolar unite it with the bulungamayines. Short bulbous premolars, such as those seen in hypsiprymnodontids and balbarines are considered plesiomorphic for macropodoids, with elongate premolars a derived condition displayed in bulungamayines and macropodines (Cooke, 1999).

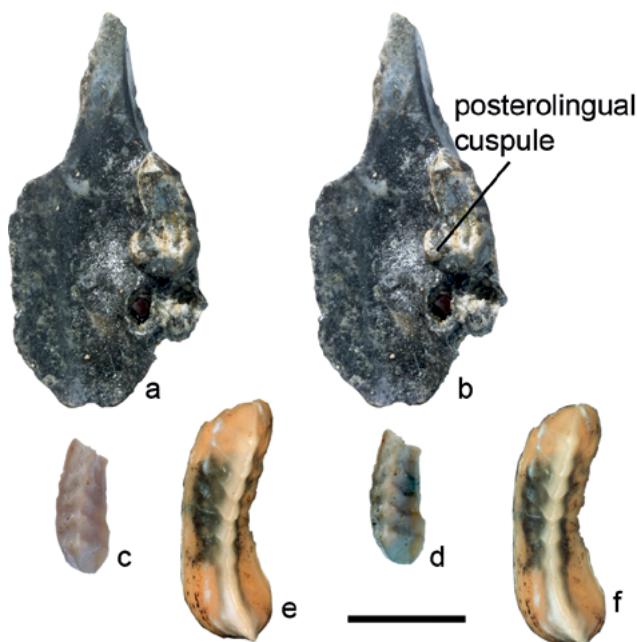


Figure 24. Bulungamayne P3s and p3s. a, b, occlusal stereopair of NTMAG P2786-1, LP3; c, d, occlusal stereopair of NTMAG P8663-3, Rp3; e, f, occlusal stereopair of NTMAG P9272-11, Lp3. Scale bar = 12 mm for a and b, 6 mm for c-f.

Molars. P8697-8, P874-1 and P9272-10 are all tentatively referred to the Bulungamayinae on the basis of the ‘bulbous’ base of the molar relative to those of balbarines. ‘Bulbous’ molars appear so because the loph/ids of the tooth do not extend to the edges of the tooth. This is not the case in balbarines, however it is seen in bulungamayines. On P9272-10 there is also a buccally directed crest from the entoconid that unites it with bulungamayines. On P9464-217 there is a well-developed cristid obliqua, which originates at the hypoconid, heads antero-lingually until flexing in the interlophid valley to contact the base of the protoconid. This is reminiscent of that seen in potoroids, but on P9464-217, the cristid obliqua intersects the protolophid, rather than being continuous with the anterior cingulid as it is in potoroids.

The presence of an anterobuccally directed ridge on the entoconid unites P9464-217 with the Bulungamayinae, as its presence indicates a bulungamayne-style formation of the hypolophid, as per Cooke (1997b). This tooth also shows the ‘bulbous’ characteristic of bulungamayne molars.

P9464-190 is also ‘bulbous’ which indicates it may belong to the Bulungamayinae. A pre-entocristid, such as is present on this tooth, can be found in both balbarine and bulungamayne molars, however it is somewhat more common in the bulungamayne, being present at every stage of Cooke’s (1997b) hypothesis of hypolophid development, rather than simply at one stage, as is the case in balbarines (Cooke, 1997c).



Figure 25. Bulungamayine molariform teeth. a, b, occlusal stereopair of NTMAG P8697-8, RM2/3; c, d, occlusal stereopair of NTMAG P874-1, LM3; e, f, occlusal stereopair of NTMAG P9464-190, Lm2; g, h, occlusal stereopair of NTMAG P9464-217, Rm2; i, j, occlusal stereopair of NTMAG P9272-10, Ldp3. Scale bar = 3 mm.

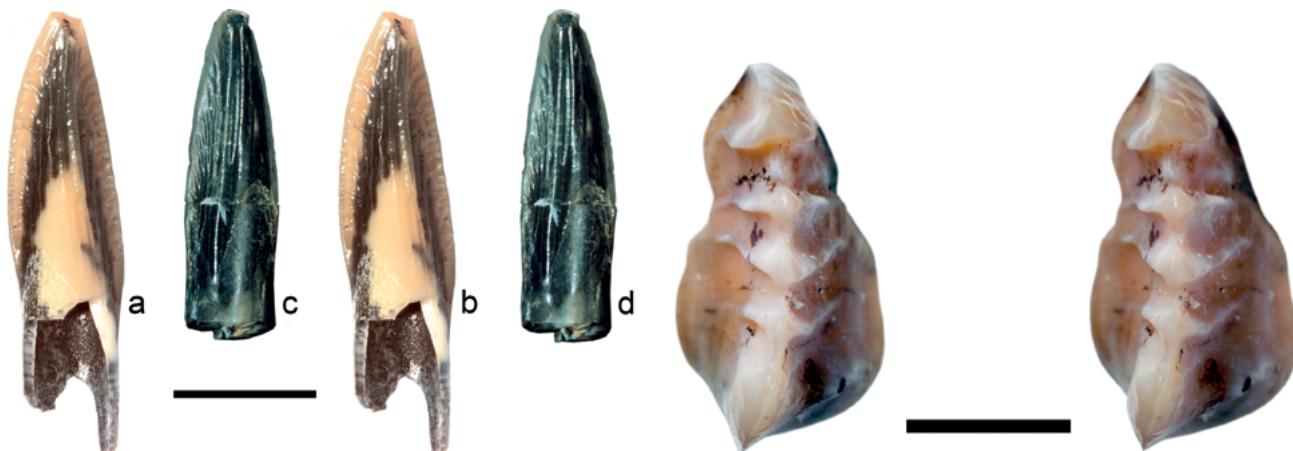


Figure 26. Stereopair of ventral view of balbarine incisors. a, b, QVMAG.17, Ri1; c, d, NTMAG P907-57, Ri1. Scale bar = 10 mm.

Figure 27. Occlusal stereopair of NTMAG P9464-216, Rp3. Scale bar = 3 mm.

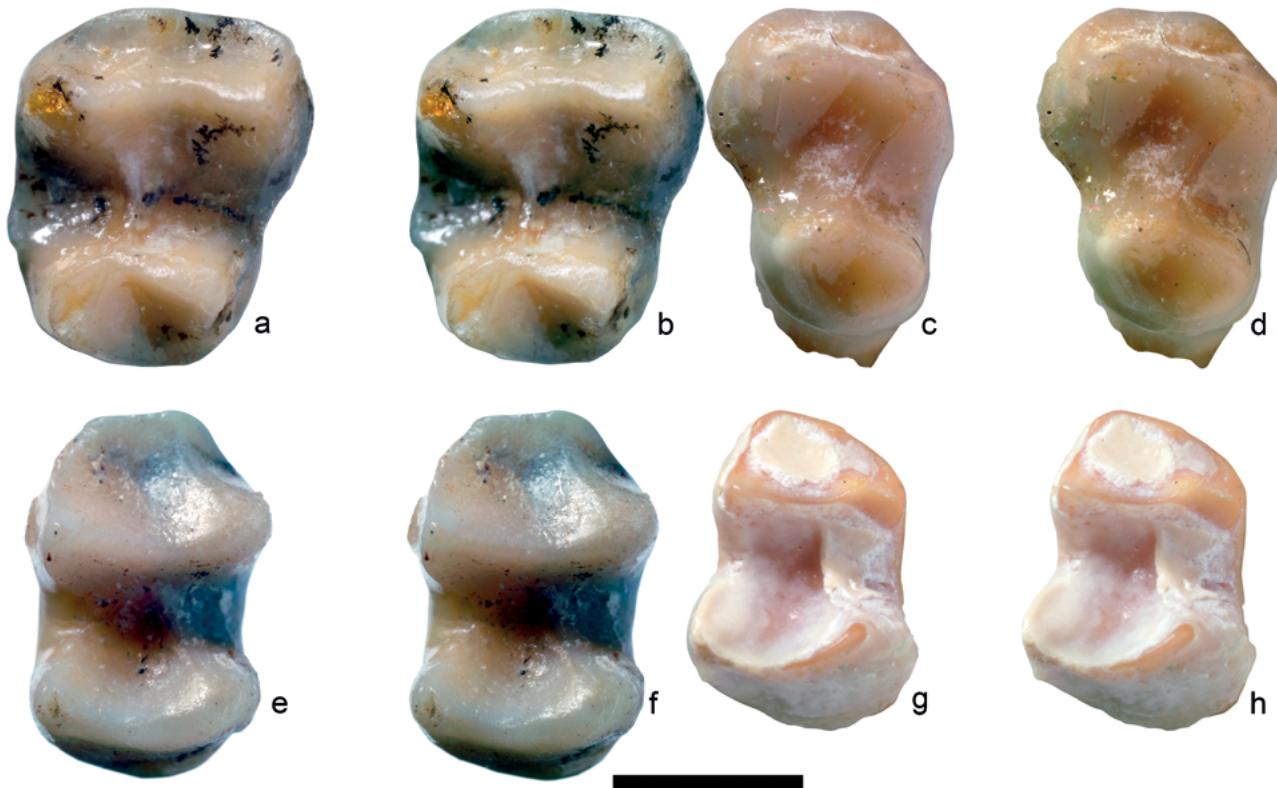


Figure 28. Occlusal stereopairs of balbarine molars. a, b, NTMAG P8692-5, RM4; c, d, NTMAG P925-13, LM4; e, f, occlusal stereopair of NTMAG P8612-4, Rm3; g, h, NTMAG P9464-2, Rm2. Scale bar = 3 mm.

Table 11. Measurements (in mm) of balbarid teeth. Length is measured along the midline of the tooth. For incisors and the premolar, width is measured at the widest point. For molars, anterior width is measured across the protoloph/id and posterior width across the metaloph or hypolophid.

Specimen	Length	Anterior Width	Posterior Width
QVMAG.17	16.1	6.1	
P907-57	13.5	5.2	
P9464-216	7.8	2.8	
P8692-5	5.1	3.5	5.1
P925-13	4.2	3.3	2.5
P8612-4	5.2	3.6	3.2
P9464-2	4.4	2.7	3.2

Family BALBARIDAE (Flannery, Archer and Plane, 1983)  
Cooke and Kear 1999

(Figs. 26–28, table 11)

Referred Material – QVMAG.17 right i1; NTMAG P907-57 right i1; NTMAG P9464-3 right i1, partial; NTMAG P9464-216 right p3; NTMAG P8695-80 left p3, partial; NTMAG P8692-5 right M4; NTMAG P925-13 left M4; NTMAG P8612-4 right m3; NTMAG P9464-2 right m2.

Locality and Horizon – QVMAG.17, unrecorded quarry of the Camfield beds; P907-57, P9464-3, P9464-216, P9464-2, Top Site, Small Hills, Tm8 the Top Site beds of the Camfield beds; P925-13 Site Y, Small Hills, Tm1 the XY Beds of the Camfield beds; P8695-80, P8692-5, P8612-4 Blast Site, Small Hills, Tm2 the Blast Site beds of the Camfield beds.

*Determinations.* Incisors. QVMAG.17, P907-57 and P9464-3 are referred to the Balbaridae on the basis of possessing branching enamel ridges (see Cooke, 1992 and discussion below). QVMAG.17 is quite a robust tooth, and quite a bit larger in size than the others (table 11). P907-57 is unique from the other two in preserving both dorsal and ventral enamel flanges.

Premolars. P9464-216 is relatively short antero-posteriorly, and has quite coarse ridges. The smaller number of ridges and lack of occlusal convexity precludes its referral to the Hypsiprymnodontidae. This tooth is therefore fairly confidently assigned to the Balbaridae. The relatively large size of this tooth (see table 11) excludes it from any of the species for which the known premolars have the same number of ridges as this tooth (4). However it is smaller and more gracile than the premolars known for *Balbaroo* and *Wururoo*, and resembles those of *Nambaroo/Ganawamaya* more closely. The large size of P8695-80, its robustness and small number of cusps relative to its size and length determines its assignment to the Balbaridae. Unlike P9464-216, this is quite a robust

tooth, and so possibly of *Balbaroo/Wururoo* affinities, rather than *Nambaroo/Ganawamaya*.

Molars. There are no obvious features to unite P8692-5 with Balbaridae. However, the lophs extend the full width of the tooth, and it does not display the anterior-posterior compression characteristic of bulungamayine uppers. It is therefore tentatively considered to be a balbarine upper. Like P8692-5, no features of P925-13 clearly place it in any subfamily; however, it does have lophs that extend the full width of the tooth, and does not show any features that would preclude it belonging to the Balbaridae.

Like the M4s described above, P8612-4 shows no features that clearly unite it with any subfamily; however, it does appear similar to other balbarine lowers described here. It is fully lophodont, but lacking the 'bulbous' appearance that would unite it with Bulungamayinae, and so it is tentatively assigned to the Balbaridae.

P9464-2 is interpreted as balbarine on the basis of the postentocristid, which is possibly a remnant of the structure seen in *Nambaroo* that bounds the posterior 'pocket' on the hypolophid of that genus.

*Comment.* Most of the macropodoid teeth identified above belong to either the Balbaridae or Bulungamayinae. The exception are those teeth referred to *Palaeopotorous*. This genus was originally described as a new subfamily, but subsequent authors have assigned it to either the Bulungamayinae (Kear and Cooke, 2001) the Propelopinae (Ride, 1993), or the Potoroinae (Prideaux, 2004) and it is considered here to be of indeterminate subfamily. No material referable to *Palaeopotorous* has been found outside of the Namba Formation.

Distinguishing balbarid molars from bulungamayine molars required the use of some new criteria. For lower molars other than m1, the only characters that have been considered to differentiate balbarids from bulungamayines are: a small cuspid - possibly a rudimentary paraconid positioned on the lingual side of the anterior cingulum (Flannery et al., 1983); the presence of a posterior cingulid; and a 'generally plesiomorphic morphology' (Cooke, 1992).

The presence of a posterior cingulid distinguishes the Balbaridae from the Bulungamayinae, however the absence of one does not preclude inclusion with the Balbaridae, as some plesiomorphic balbarids lack a posterior cingulid. Cooke's (1997a) observation that bulungamayine molars retain a remnant of the bunolophodont hypolophid in the form of an antero-buccally directed cristid on the anterior face of the entoconid provides another criterion for recognising bulungamayines. However, this is only true of plesiomorphic bulungamayines, with other, advanced bulungamayines having lost this cristid.

For the upper molars of the two groups, there are even fewer synapomorphies that can be used to distinguish them. Cooke (1999) suggested that bulungamayines as a general rule retain only stylar cusp C on the upper molars, while balbarids retain both stylar cusps C and D. More apomorphic members of both groups show no stylar cusps at all. However, a single stylar cusp is a characteristic of teeth referred to Propelopinae and *Palaeopotorous*. Under Kear and Cooke's (2001) classification, this genus is a member of Bulungamayinae.

Stylar cusps are a plesiomorphic feature of the australidelphian, and the diprotodontian tooth. Cooke (1997b) suggests that the bulungamayine ancestor had lost stylar cusp D, and was therefore, in this aspect, more derived than the balbarid ancestor. However, stylar cusp D also appears to have been lost in the ancestor of the propleopines.

During the course of this study, it was observed that balbarid uppers are generally more elongate than those belonging to bulungamayines, and that, along with the 'bulbous' nature of the molar in question, was used to assign upper teeth. 'Bulbous' is used to describe the condition in which the loph/ids of the tooth, whether lower or upper, do not extend for the full width of the molar. This is the condition observed universally in bulungamayines (as defined here). In balbarids, by contrast, the loph/ids extend fully to the buccal and lingual edges of the tooth.

Incisors have previously been used to distinguish between balbarid and bulungamayines, with the concentration of enamel on the buccal side of the tooth considered a bulungamayine character, while thick enamel over both sides is considered a balbarid character. The presence of branching enamel ridges on the dorsolingual side of i1 was described by Cooke (1992) on *Ganawamaya ornata*. Two different incisors are described here, both of which display branching enamel ridges in the position described by Cooke. Neither of these incisors can be referred to *G. ornata*, as they are less gracile than those described for that species. These ridges are consistently present in undescribed material from both the Kutjumarpu Local Fauna and Riversleigh (pers. obs.), and always occur in balbarids.

## Discussion and Conclusion

Combining the results of this study with those of previously published studies, the revised mammalian faunal list for the Bullock Creek Local Fauna is given below.

### Order Dasyuromorpha

#### Superfamily Dasyuroidea

##### Family Dasuridae

indet.

##### Family ?Thylacinidae

*Nimbacinus richi* Murray and Megirian 2000

*Mutpuracinus archibaldi* Murray and Megirian 2000

indet.

### Order Peramelemorpha

#### Superfamily Yarloidea

##### Family Yaralidae

*Yarala sp.*

indet.

Order Diprotodontia  
 Family Diprotodontidae  
 Subfamily Zygomaturinae  
*Neohelos stirtoni* Murray et al. 2000  
 Family Thylacoleonidae  
 Subfamily Wakaleoninae  
*Wakaleo vanderleueri* Clemens and Plane 1974  
 Family Palorchestidae  
*Propalorchestes novaculcephalus* Murray 1986  
 Suborder Phalangerida  
 incertae sedis  
 Family Miralinidae  
 Subfamily Miralininae  
*Barguru kayir* Schwartz 2006b  
*Barguru maru* Schwartz 2006b  
 Family Phalangeridae  
*Wyulda sp. cf. asherjoeli*  
 Family Petauridae  
 indet.  
 Family Pseudocheiridae  
 indet.  
 Superfamily Macropodoidea  
*cf Palaeopotorous*  
 Subfamily Bulungamayinae  
 indet.  
 Family Balbaridae  
*Balbaroo camfieldensis* Flannery et al. 1983  
*(Nambaroo bullockensis* Schwartz and Megirian 2004)  
 indet.

Randal and Brown (1967) interpreted the depositional environment of the Camfield beds as being marine, shallow, and near-shore. They suggested that gastropods in the assemblage were perhaps introduced through freshwater flooding and considered that the environment may have been lacustrine, or associated with lagoons or estuaries that were frequently flooded with freshwater. However, Murray and Megirian (1992) considered the lithoclastic carbonate deposits and evaporites to be of non-marine origin, and instead indicative of periods of relatively dry, even semi-arid, climatic conditions. The presence of obligate freshwater fish, as well as freshwater gastropods led to these authors interpreting the depositional environment as freshwater.

This study provides further support for interpretation of this deposit as freshwater, as the gastropods found throughout the area are freshwater taxa (McMichael, 1968). Although the gastropod fauna is yet to be fully described, these are preliminarily identified as belonging predominantly to the genera *Glyptophysa*, *Cupedora*, and *Melanoides* (Murray and Megirian, 1992; Schwartz pers. obs.).

Dendritic pyrolusite material was observed in most thin sections examined from the Camfield beds. This likely implies an at least partly biogenic origin for the Camfield beds. Similar structures were observed in the Carl Creek Limestone by Megirian (1992) and interpreted to be the 'bacterial shrubs' of Chafetz and Folk (1984).

Algae were also present, and are seen at the macroscopic level, in the form of fossilised stromatolites and algal matting, as well as oncoids, such as those seen at Microsite. At the microscopic level, this is reflected in the presence of the oogonia of charophyte algae, and occasional preserved algal threads. Ostracods also form part of the fauna, with both articulated and fragmentary remains observed throughout the deposit. That articulated ostracods are often preserved suggests little transport, and along with the oogonia and stromatolites, indicates the presence of standing water.

The likely source of the carbonate saturation that produced the Camfield beds is dissolution of the basement Montejinni Limestone. The distribution of the Camfield beds close to the contact between the Montejinni Limestone and the APV suggests that before this point the river may not have reached sufficient saturation to precipitate carbonate.

At present, there is no faunal evidence that suggests a significant time difference between quarries, despite the stratigraphy mapped in this study. The Bullock Creek Local Fauna has previously been conservatively treated as a single Local Fauna despite being spread among multiple different quarries and outcrops of the Camfield beds. Over the 40 years of collection at Bullock Creek by various workers, associated collection data that indicates localities below the level of 'Bullock Creek', 'the Horseshoe' or 'Small Hills' has not always been consistently kept, however, which makes it difficult to confirm. Certainly the stratigraphy demonstrated here should be an encouragement to workers to keep such information in future.

Of the fauna described for the Bullock Creek Local Fauna, there is a low abundance of peramelemorphians when compared with the Late Oligocene Kangaroo Well Local Fauna. Notably, however, Kangaroo Well is missing dasyromorphians. Similarities in ecological niche between the yaraloid peramelemorphians and dasyromorphians have been noted elsewhere (Gurovich et al., 2014; Muirhead, 2000) and it is possible that what can be seen at Bullock Creek is the beginnings of the competitive replacement of yaraloids by dasyromorphians.

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