1. INTRODUCTION

The earliest history of Metatheria, the group including extant marsupials and all extinct mammals more closely related to marsupials than to placentals, is becoming increasingly well known due to the discovery of exceptional skeletons from the Cretaceous of Asia (Luo et al. 2003). North America also has a diverse history of metatherians from the Cretaceous through the Miocene, but this record is mainly based on isolated skeletal remains, especially teeth (Kielan-Jaworowska et al. 2004). The two living species of opossum in North America are geologically recent immigrants from South America.

The Miocene fossil record of South America and Australia contains well-preserved skeletons that document the diversification of crown Marsupialia in these continents, but the only detailed record between these geologically recent fossils and Cretaceous forms are the Paleocene skeletons of basal metatherians from Bolivia (Muizon et al. 1997) and the two-dimensional ones from the Middle Eocene of Messel in Germany (Kurz 2005). Several additional metatherian clades are known from the ca 45 Myr time-interval ranging from the Early Miocene to the Late Cretaceous, but most taxa are based on isolated skeletal remains, especially teeth (Luo et al. 2003).

One of these groups is the Herpetotheriidae (Herpetotheriinae of McKenna & Bell 1997), consisting of superficially opossum-like species distributed from the Late Cretaceous (Martin et al. 2005) to the Miocene. Herpetotheriids are known from North America, Europe, Asia, Africa and possibly South America (Goin & Candela 2004). They are usually placed with the Didelphidae and Caluromyidae in the ‘Didelphimorpha’, together with other superficially primitive-looking and opossum-like forms (Kirsch et al. 1997). The phylogenetic placement of Herpetotheriidae has been informal and based on inferences made from the study of just teeth. The dental similarity of herpetotheriids to modern forms led Simpson (1942, p. 39) to refer to opossums as ‘little changed… since [the] Late Cretaceous’. To test this association in a cladistic framework, we studied exceptionally well-preserved three-dimensional cranial and postcranial bones of Herpetotherium from the Early Oligocene, which allowed us to study its adaptations and relationships among metatherians.

2. MATERIAL AND METHODS

Two fairly complete skulls and associated postcranial bones from the White River Formation, ca 33 Myr old (Evanoff et al. 1992) were identified as Herpetotherium fugax based on dental features (electronic supplementary material).

We conducted a phylogenetic analysis of basal metatherian taxa with mostly complete skeletons. The matrix of 245 characters and 568 character states results from our extensive examination of craniodental and postcranial characters (electronic supplementary material). Twenty-seven metatherian taxa were coded, with representatives of all major living clades, the three Triamphidae metatherians known from almost complete skeletons (Muizon et al. 1997), two additional stem metatherians and five non-metatherian taxa as outgroups. We excluded Smoedelphys szalaya from the analysis because its preservation prevents coding more than 80% of the characters.

3. RESULTS AND DISCUSSION

(a) Anatomy

The dental formula is the plesiomorphic one for metatherians: 3134/4134. In an M3, a single layer of radial enamel (with parallel prism orientation) was
detected, the plesiomorphic therian condition and the most common enamel type among marsupials. Enamel tubules and Hunter–Schreger bands are absent (figures 1 and 2).

The overall morphology of the cranial endocast is similar to that of didelphids. The endocranial volume is 25% smaller than that of a 57-day-old Monodelphis of comparable skull length. The cerebral...
hemisphere casts are lissencephalic and a rhinal fissure is not visible.

The most remarkable aspect of the bony labyrinth is that the posterior arm of the lateral semicircular canal and the inferior arm of the posterior semicircular canal build a second common crus, present in several basal marsupials. The 1.6 cochlear turns is a low number, similar to that of basal metatherians and less than the typical 2.4 of didelphids (Meng & Fox 1995).

The femur bears a robust third trochanter, absent in didelphids and in australidelphians (Szalay & Sargis 2001). Several features suggest a powerful M. quadriceps, usual in agile scansorial and terrestrial taxa. These include a distinct pelvic tuberosity for the rectus femoris, the anterior protrusion of the greater trochanter and the presence of a crest for the vastus lateralis on the femur, a distal femoral epiphysis slightly deeper than wide in distal view, a well-defined femoral trochlea between sharp crests and a triangular cross-section of the tibia due to a sharp anterior crest.

The orientation of the sustentacular facet of the calcaneum indicates that the astragalus was not superimposed on the calcaneum in its distal region. The sustentacular facet is oriented mediodorsally in its proximal region and ends distally, practically mediadly directed. Therefore, the astragalar head lies medial to the distal area of the calcaneum. Other metatherians that display this primitive therian condition are Mayulestes, Pucadelphys and Deltatheridium. Crown group marsupials and eutherians display convergently a completely superimposed astragalus and calcaneum (Horovitz 2000). Astragalar shape is consistent with terrestrial habits (electronic supplementary material).

**Phylogenetic relationships**

The phylogenetic analyses placed *Herpetotherium* as the sister group to crown marsupials, not as a basal didelphid (figure 3).

The oldest known fossil record of opossums (Didelphidae) is from the Early Miocene of Patagonia (Goin et al. in press), but molecular divergence date estimates suggest that Didelphidae diverged from the rest of crown marsupials during the Late Cretaceous (Nilsson et al. 2004). Therefore, our conclusions that the pre-Pleistocene metatherians of North America are not referable to the Didelphidae, suggest that there is a long gap in the fossil record of opossums extending for ca 45 Myr.

Since the Paleogene fossil record of small mammals in North America is well studied, the supposed absence of didelphids at this time in North America may be relevant. Despite informal statements describing opossums as living fossils (cf. Simpson 1942), there are not yet any unequivocal records of pre-Miocene didelphids. They are also absent from Paleogene rocks of South America, although the record there is largely confined to the southern cone. We suspect that stem group didelphids inhabited northern South America in the Paleogene. The highest diversity of living didelphids is in the northern neotropics; a region reported to have served as a cradle for other lineages that were extirpated elsewhere in their range (Jablonski et al. 2006).

**Functional anatomy and character evolution**

Comparisons of extant opossums with basal opossum-like metatherians like *Herpetotherium* reveal that the living forms are characterized by a series of derived features in their cranial and postcranial anatomy. This includes a subterminal position of the calcaneal sustentaculum, the absence of a calcaneal facet for the fibula, the presence of a notch for the cuboid pivot, a reduction of the mastoid tympanic process and an increased number of cochlear turns, among others.

The clade containing *Herpetotherium* and Marsupialia is supported by seven unambiguous synapomorphies from the skull, dentition and postcranial skeleton (electronic supplementary material). Within the herpetotheriid clade, *Herpetotherium* has lost the staggered condition of the lower i3. This has also happened in the microbiotheriid clade, suggesting that the absence of a staggered i3 in *Dromiciops* is apomorphic.

Figure 3. Strict consensus tree based on parsimony analysis of 245 characters to study the phylogenetic relationships of *Herpetotherium*. There are three most parsimonious tress at 868 steps (CI=0.370; RI=0.649). Numbers at nodes are the Bremer (above) and bootstrap values (below). The crown-group Marsupialia, in the shaded box, is the sister group of *Herpetotherium*.
Terrestrial habitat use, reconstructed here for *Herpetotherium*, is in congruence with data from the only other herpetotheriids known from significant skeletal material (Kurz 2005). The oldest metatherian *Sinodelphys szalayi* is reported to have been arboreal (Luo et al. 2003). Terrestrial habitats reconstructed for *Herpetotherium* suggests that multiple evolutionary transformations occurred along the stem leading to the crown, or less likely, that *Sinodelphys* is derived in its arboreal habits and basal metatherians were terrestrial.

4. CONCLUSION

Since herpetotheriids are opossum-like and have a distribution from the Late Cretaceous to the Miocene, they were first deemed to be stem didelphids and fill that gap in the fossil record. However, the position of *Herpetotherium* outside of Marsupialia contradicts this and suggests instead that there is a major gap in the fossil record of opossums extending for nearly 45 Myr.

At the time *H. fugax* was alive in Wyoming, the extant clades of didelphids had probably not yet fully radiated in South America according to molecular divergence date estimates (Steiner et al. 2005). Didelphids eventually reached a sizeable diversification of approximately 85 species in the Americas today. Whereas in tropical South America and Australia, marsupials attained considerable taxonomic and ecological diversity (Goin & Candela 2004), the diversity of metatherians across the Northern Hemisphere remained limited throughout the Early Cenozoic and was capped by their extinction in the Miocene.

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