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Electronic Supplementary Material

Oldest skeleton of a plesiadapiform provides additional evidence for an exclusively arboreal radiation of stem primates in the Paleocene

Stephen G. B. Chester^{a,b,c*}, Thomas E. Williamson^d, Jonathan I. Bloch^e, Mary T. Silcox^f, Eric J. Sargis^{g,h}

^aDepartment of Anthropology and Archaeology, Brooklyn College, City University of New York, 2900 Bedford Avenue, Brooklyn, NY, 11210.

^bDepartment of Anthropology, Graduate Center, City University of New York, 365 Fifth Avenue, New York, NY, 10016.

^cNew York Consortium in Evolutionary Primatology, New York, NY, 10024.

^dNew Mexico Museum of Natural History and Science, 1801 Mountain Road, NW, Albuquerque, NM 87104-1375

^eFlorida Museum of Natural History, University of Florida, 1659 Museum Road, Gainesville, FL, 32611-7800.

^fDepartment of Anthropology, University of Toronto Scarborough, 1265 Military Trail, Scarborough, ON, M1C 1A4

^gDepartment of Anthropology, Yale University, P. O. Box 208277, New Haven, CT, 06520

^hDivisions of Vertebrate Paleontology and Vertebrate Zoology, Yale Peabody Museum of Natural History, New Haven, CT, 06520.

Correspondence to: Stephen G. B. Chester. Email: stephenchester@brooklyn.cuny.edu

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Materials and Methods

Institutional Abbreviations

AMNH, American Museum of Natural History, New York, New York, U.S.A.; FMNH, Field Museum of Natural History, Chicago, Illinois, U.S.A.; MCZ, Museum of Comparative Zoology, Cambridge, Massachusetts, U.S.A.; NMMNH, New Mexico Museum of Natural History and Science, Albuquerque, New Mexico, U.S.A.; UCMP, University of California Museum of Paleontology, Berkeley, California, U.S.A.; UKMNH, University of Kansas Museum of Natural History, Lawrence, Kansas, U.S.A.; UM, University of Michigan Museum of Paleontology, Ann Arbor, Michigan, U.S.A.; UNSM, University of Nebraska State Museum, Lincoln, Nebraska, U.S.A.; USNM, United States National Museum of Natural History, Smithsonian Institution, Washington D.C., U.S.A.

Phylogenetic Analysis

The character matrix analyzed consists of 240 characters and 30 taxa (see Tables S1, S2) and was modified from that of [1], which was derived from previous analyses [2,3]; it was modified by adding the palaeochthonids *Torrejonia wilsoni* and *Plesiolestes nacimienti*, and excluding apatemyids. The new partial skeleton of *T. wilsoni* (NMMNH P-54500) was scored into this matrix, and specimens of *Plesiolestes nacimienti* (UKMNH 9557, 9558, 9559; [4-6]) were scored into this matrix because this species is the only other palaeochthonid known from more than dental fossils. Apatemyids introduced a considerable amount of missing data into the character matrix and acted as wildcard taxa. They were excluded from this dataset because they are not central to the focus of this study and their inclusion resulted in a less well-resolved hypothesis of relationships within Euarchontoglires. Additional specimens examined and

references used to score characters in the phylogenetic analysis can be found in appendix 5 of [2].

Maximum parsimony analysis was conducted using TNT (v1.5) software subsidized by the Willi Hennig Society [7], with all multistate characters treated as unordered. *Ukhaatherium* was designated as the outgroup. New Technology Search was implemented using 100 replications as the starting point for each hit, 200 parsimony ratchet iterations, 10 rounds of tree drifting, 10 rounds of tree fusing, and sectorial searching. The resulting most parsimonious tree (MPT) with a length of 997 steps was used as a starting tree in a Traditional Heuristic Search that was carried out using tree-bisection and reconnection (TBR). This resulted in a single most parsimonious tree with a consistency index (CI) of 0.318 and a retention index (RI) of 0.511 (Fig. S1). Absolute Bremer Support values were calculated using the suboptimal trees found in the search performed using the bremer.run script [8], which rigorously searches incrementally for suboptimal trees, with up to 10,000 trees held, increasing the score by 1 up to a maximum of 10 steps longer than the MPT (Fig. S1).

The same maximum parsimony analysis was conducted in TNT with a skeleton tree that forced Scandentia (*Ptilocercus* and *Tupaia*) outside a Primatomorpha grouping (*Cynocephalus* + Adapiforms + Omomyiforms):

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(Ukhaatherium, (Ptilocercus_lowii, Tupaia_glis (Cynocephalus_volans, Omomyidae, Adapidae)))
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The two resulting MPTs with a length of 998 steps were used as starting trees in a Traditional Heuristic Search that was carried out using TBR. Two resulting MPTs were used to obtain a strict consensus (CI = 0.318, RI = 0.0510) (Fig. S2). Absolute Bremer Support values were

calculated using the suboptimal trees found in the search performed using the bremer.run script [8] (Fig. S2).

Geological setting and age of locality NMMNH L-6898

The partial skeleton of *Torrejonia wilsoni* (NMMNH P-54500) was found at locality NMMNH L-6898 in the Nacimiento Formation, San Juan Basin, New Mexico (Fig. S3). Locality NMMNH L-6898 is within the Torrejonian (To3) *Mixodectes pungens* zone of the West Flank of Torrejon Wash [9], which yields part of the type fauna for the Torrejonian NALMA [10,11]. This site is located within a normal polarity zone correlated with Chron C27n, which constrains the age of the site to about 62 Ma [12-14] (Fig. S4).

All of the fossil vertebrates at this locality were found in a small area of less than 1m² of 2-3 cm thick massive muddy siltstone. Fossils were initially surface collected and then quarried from the deposit. All sediment from the quarry was processed using underwater screenwashing methods to recover the smallest bones. Some bones were articulated or associated in carbonate nodules and or encased in gypsiferous crusts. There appears to have been minimal transport before these bones were buried and this site might represent a small ephemeral pond. What is interpreted to be a partial skeleton of *Torrejonia wilsoni* was recovered mixed with partial skeletons of two other mammals [15], including a nearly complete skeleton of *Mixodectes pungens* (NMMNH P-54501) and a less complete skeleton of the eutherian mammal *Acmeodon secans* (Cimolestidae; NMMNH P-54499). Other associated fossil vertebrates include a partial skeleton of a neoavian land bird (Telluraves) [16,17], several undescribed partial skulls and postcrania of squamates, and numerous isolated mammal teeth [15].

Postcranial elements of *Torrejonia wilsoni* were readily distinguished from those of *Mixodectes pungens* by their smaller size. *Torrejonia wilsoni* is similar in size to *Acmeodon*

secans, but the morphology of many of the bones attributed to *T. wilsoni* closely resembles that of other dentally associated plesiadapiform skeletons. Also, although the skeleton of *Torrejonia* has a fully erupted adult dentition, many of the long bone epiphyses remain unfused, a pattern that has been previously documented for other plesiadapiforms (e.g. [18]). In contrast, epiphyseal fusion of postcranial elements attributed to *Acmeodon secans* indicates that this was a relatively more mature individual. For example, a right partial proximal femur attributed to *Acmeodon* has a fused greater trochanter, whereas the two associated proximal femora without proximal epiphyses were attributed to *Torrejonia* because they are very similar to those of other plesiadapiforms. Many additional elements such as fragmentary vertebrae, metapodials, and phalanges are more difficult to distinguish between these two mammals, so they are not considered further here. There are no duplicated tooth positions or skeletal elements for *T. wilsoni*, which suggests that only one individual of this species was present.

Supporting Information References

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Figure S1. Hypothesis of evolutionary relationships of *Torrejonia wilsoni* and other eutherian mammals.

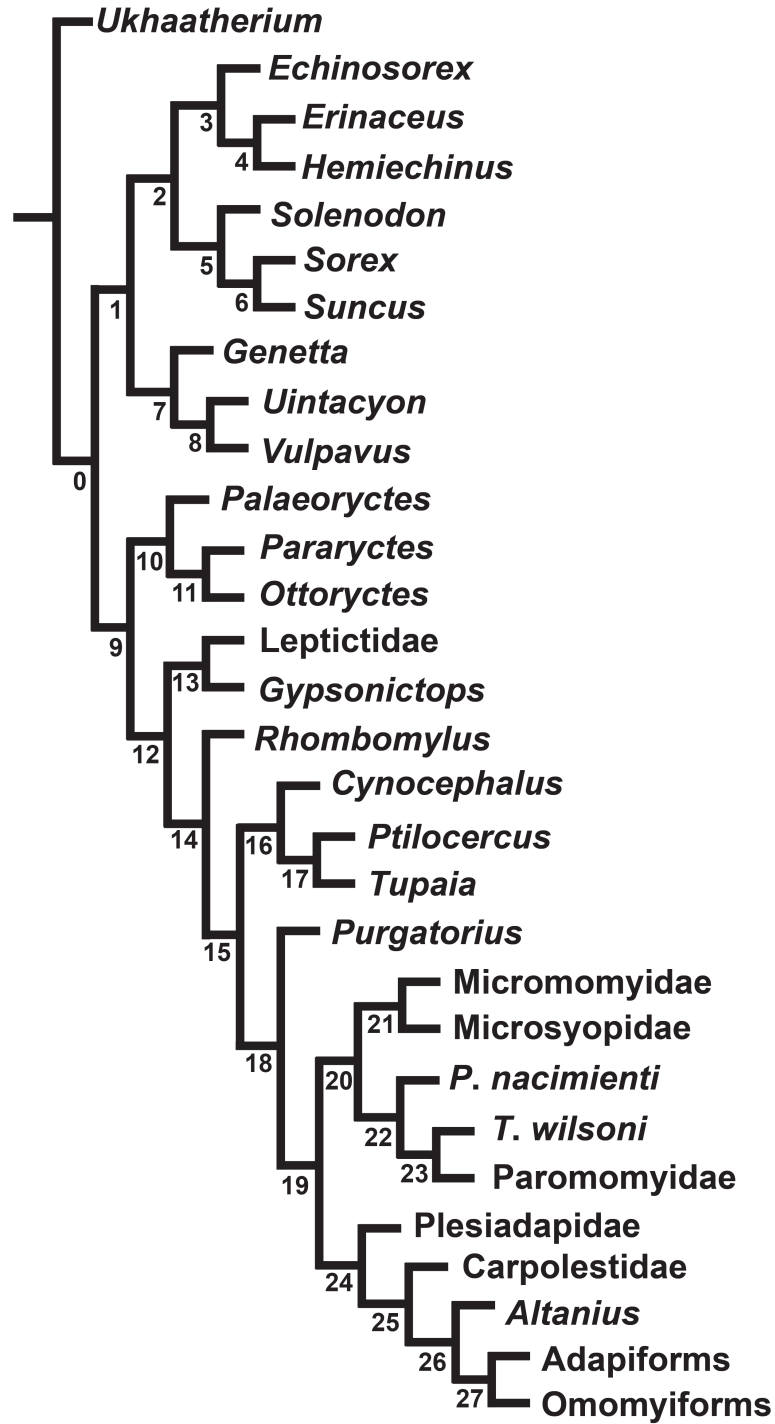


Figure S1. Hypothesis of evolutionary relationships of *Torrejonia wilsoni* and other eutherian mammals. Results of cladistic analysis based on 30 taxa and 240 morphological characters (68 postcranial, 45 cranial, 127 dental; Table S1). Resulting single most parsimonious cladogram with Bremer support indices calculated in TNT for listed nodes are as follows:

0(ingroup); 1(Laurasiatheria) = 4; 2(Eulipotyphla) = 6; 3(Erinaceomorpha) = 12; 4 = 4; 5(Soricomorpha *sensu lato*) = 4; 6(Soricidae) = 17; 7(Carnivora) = 3; 8 = 1; 9 = 1; 10(Palaeoryctidae) = 5; 11 = 2; 12 = 1; 13(Leptictida) = 2; 14(Euarchontoglires) = 2; 15(Euarchonta) = 3; 16(Sundatheria) = 1; 17(Scandentia) = 3; 18(Primates) = 2; 19 = 1; 20 = 1; 21 = 4; 22(Palomomyoidea) = 1; 23 = 1; 24(Euprimateformes) = 1; 25 = 1; 26(Euprimates) = 6; 27 = 1. Unambiguous synapomorphies calculated in TNT for listed nodes are as follows: **14(Euarchontoglires)** = 105(2), 135(1), 151(1), 158(1), 167(0), 172(1), 229(1); **15(Euarchonta)** = 11(1), 29(0), 33(0), 37(0), 40(0), 45(2), 130(0), 145(0), 207(1), 217(1); **16(Sundatheria)** = 19(1), 58(1), 142(1), 160(2), 189(0), 212(0), 221(2), 229(0), 235(3); **17(Scandentia)** = 39(1), 42(0), 52(1), 66(2), 72(2), 105(1), 129(0), 144(1), 149(1), 150(1), 153(1), 165(2), 168(0), 170(1), 175(1), 194(1), 204(1), 205(3), 218(1); **18(Primates)** = 115(1), 185(0), 201(0), 205(1); **19** = 166(1), 179(1), 190(1), 194(1); **20** = 21(1), 71(0), 88(1), 91(1), 92(1), 128(1), 132(0), 168(0), 200(1); **21** = 103(0), 121(1), 135(0), 172(0), 189(2), 192(1), 210(1), 221(1), 228(3); **22(Palomomyoidea)** = 213(1), 224 (1), 234(1); **23** = 235(2), 237(1); **24(Euprimateformes)** = 56(1), 75(0), 101(1), 143(1), 159(1), 209(1), 212(0), 214(1), 215(1), 218(1); **25** = 9(1), 12(1), 21(2), 27(1), 55(1), 57(1), 122(0), 170(1), 201(1); **26(Euprimates)** = 129(0), 144(1), 147(0), 149(1), 166(0), 171(1), 173(2), 175(1), 185(1), 187(0), 193(0), 232(0) 235(2); **27** = 218(0), 227(0).

Figure S2. Hypothesis of evolutionary relationships of *Torrejonia wilsoni* and other eutherian mammals with Primatomorpha enforced.

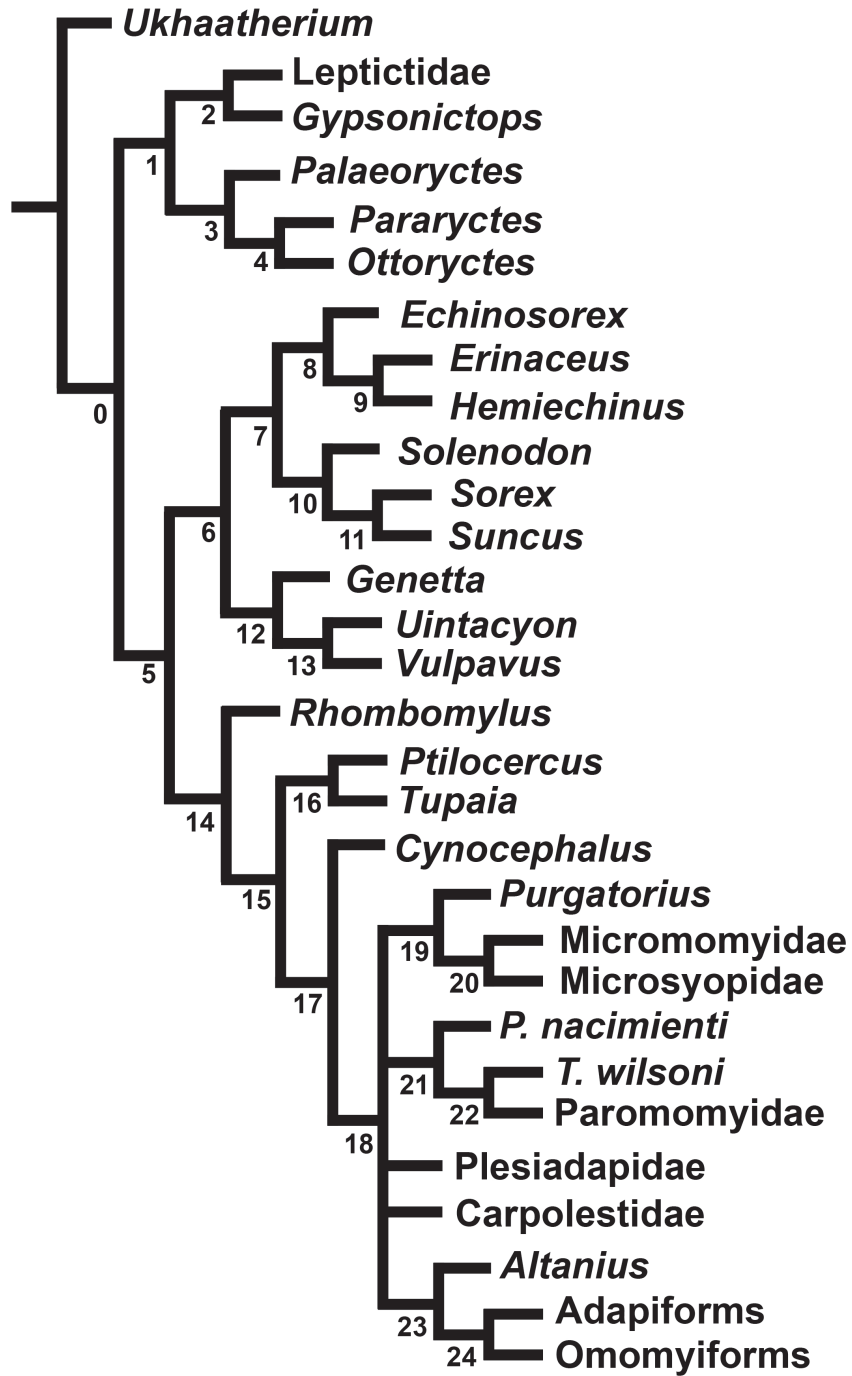


Figure S2. Hypothesis of evolutionary relationships of *Torrejonia wilsoni* and other eutherian mammals with Primatomorpha enforced. Results of cladistic analysis based on 30 taxa and 240 morphological characters (68 postcranial, 45 cranial, 127 dental; Table S1) with a skeleton tree that forced Scandentia (*Ptilocercus* and *Tupaia*) outside a Primatomorpha grouping (*Cynocephalus* + Adapiforms + Omomyiforms). Resulting strict consensus of two most parsimonious trees with Bremer support indices calculated in TNT for listed nodes are as follows: **0(ingroup)**; **1** = 1; **2(Leptictida)** = 2; **3(Palaeoryctidae)** = 5; **4** = 2; **5** = 4; **6(Laurasiatheria)** = 6; **7(Eulipotyphla)** = 15; **8(Erinaceomorpha)** = 4; **9** = 1; **10(Soricomorpha sensu lato)** = 4; **11(Soricidae)** = 19; **12(Carnivora)** = 3; **13** = 1; **14(Euarchontoglires)** = 2; **15(Euarchonta)** = 1; **16(Scandentia)** = 3; **17(Primatomorpha)** = 3; **18(Primates)** = 1; **19** = 2; **20** = 1; **21(Paromomyoidea)** = 1; **22** = 1; **23(Euprimates)** = 1; **24** = 4. Unambiguous synapomorphies calculated in TNT for listed nodes are as follows: **14(Euarchontoglires)** = 42(1), 69(1), 120(1), 122(1), 135(1), 151(1), 158(1), 193(1), 208(0), 233(1); **15(Euarchonta)** = 29(0), 33(0), 40(0), 45(2), 76(1), 130(0), 145(0), 197(1); **16(Scandentia)** = 39(1), 42(0), 52(1), 66(2), 72(2), 105(1), 149(1), 153(1), 168(0), 175(1), 199(3); **17(Primatomorpha)** = 51(1), 81(1), 163(0), 165(0), 227(1), 231(2); **18(Primates)** = 73(0), 78(1), 107(1), 156(0), 179(1), 219(0), 226(1), 228(2), 229(1); **19** = 116(2), 135(0), 172(0), 176(1), 227(0), 228(1), 231(01); **20** = 189(2), 192(1), 210(1), 220(1), 221(1), 229(3); **21(Paromomyoidea)** = 213(1), 224(1), 234(1); **22** = 206(1), 235(2), 237(1); **23(Euprimates)** = 147(0), 149(1), 175(1), 187(0), 193(0); **24** = 206(1), 227(0).

Figure S3. Map showing the location of NMMNH fossil locality L-6898 in relation to the outcrop belt of the Nacimiento Formation, San Juan Basin, New Mexico.

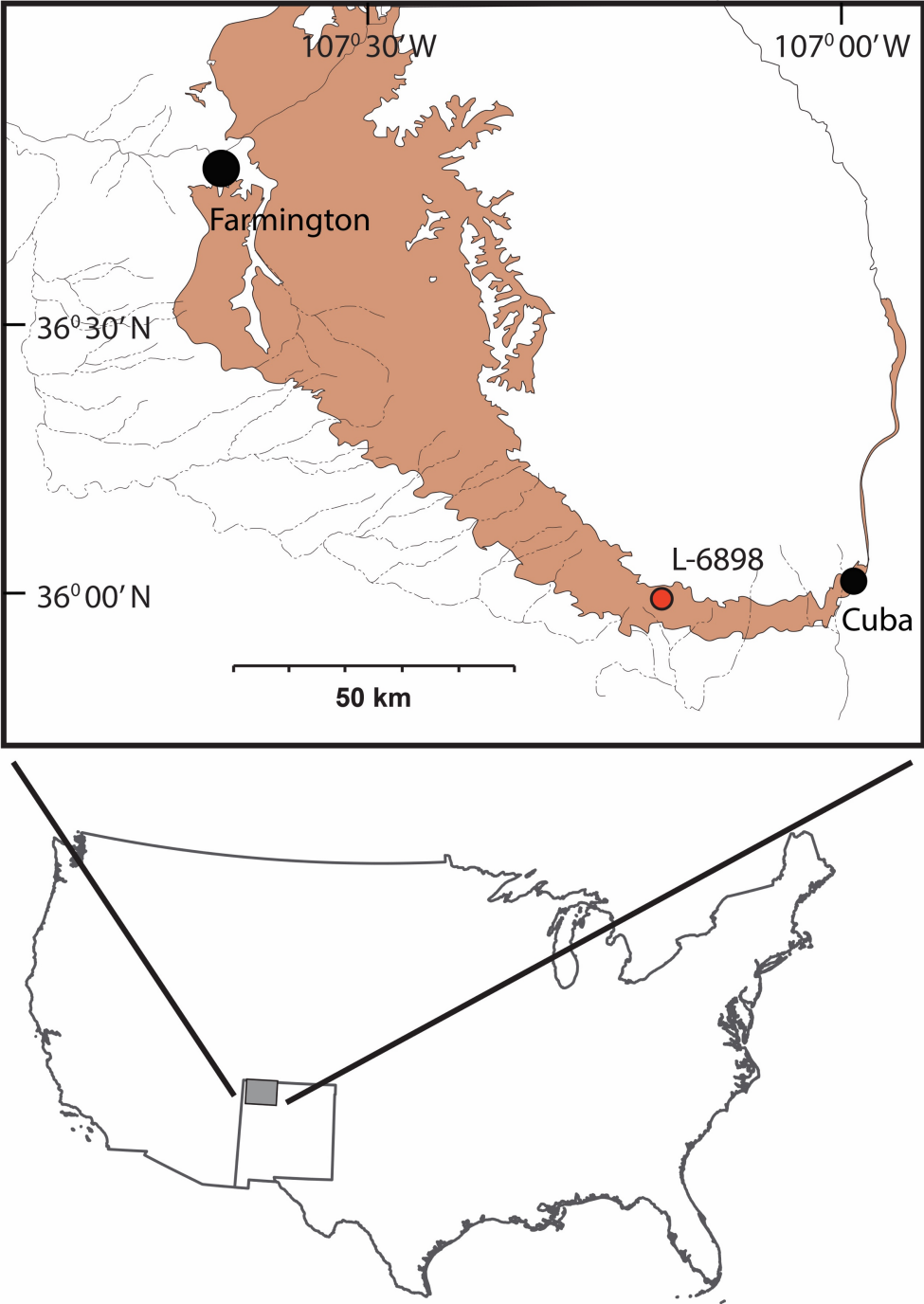
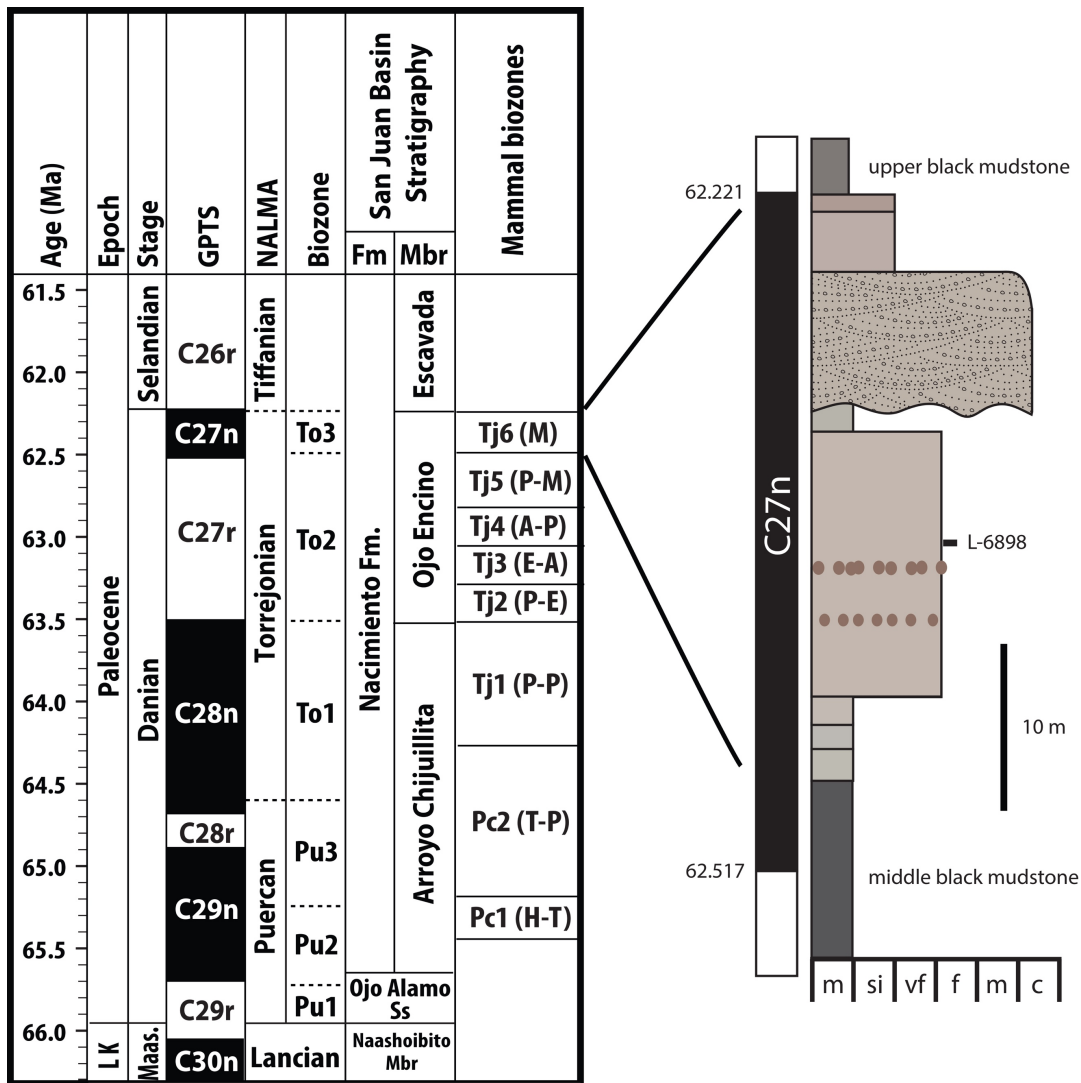


Figure S4. Stratigraphic section of a part of the Nacimiento Formation as measured at the West Flank of Torreon Wash showing the position of NMMNH locality L-6898 relative to marker beds and magnetic polarity zonations [9, 19]. The stratigraphic section is correlated to Nacimiento Formation biostratigraphic zonation [9], mammal biochronology (Paleocene North American Land Mammal Ages [NALMA] and interval zones; ref. 11), and the geomagnetic polarity time scale (GPTS; ref. 14). The precise ages of the polarity reversals at the bottom and top of chron C27n are from [14].



Supplementary Tables

Table S1. Descriptions of morphological characters used in the cladistic analysis modified from that of [1], which was derived from previous analyses [2, 3]. Each character is listed with one or two letters that refer to the larger partition to which they belong (i.e., PC = postcranial; Cr = cranial; D = dental).

1. PC, Scapula, Metacromion form: (0) absent; (1) small but present; (2) very large - larger than acromion.
2. PC, Humerus, Projection of greater tuberosity: (0) small tuberosity that does not extend superior to head; (1) even with or slightly above head; (2) extends far superior to head.
3. PC, Humerus, Projection of lesser tuberosity: (0) not projecting, small; (1) large and medially projecting.
4. PC, Humerus, Deltopectoral crest form: (0) sharp and elevated; (1) broad and elevated.
5. PC, Humerus, Deltopectoral crest tip form: (0) crest tapers to a point; (1) crest has broad, rounded, shelf-like distal end.
6. PC, Humerus, Deltopectoral crest proportional length: (0) less than 50% humerus length; (1) between 50% and 67% humerus length; (2) greater than 67% humerus length.
7. PC, Humerus, Olecranon fossa depth: (0) shallow, or slit-like; (1) deep and pit-like; (2) deep, pit-like, and perforated.
8. PC, Humerus, Medial epicondyle projection: (0) makes up less than 25% of entire distal end width; (1) makes up 25% or more of entire distal end width.
9. PC, Humerus, Supinator crest development: (0) present as a distinct ridge; (1) projects prominently posterolaterally; (2) absent - rounded lateral surface of distal humeral shaft.
10. PC, Humerus, Prominence of teres tubercle on medial side: (0) small or indistinct; (1) prominent and crest-like.
11. PC, Humerus, Capitulum shape: (0) spindle-shaped; (1) ovoid or spherical.

12. PC, Humerus, Humeral trochlear morphology: (0) medial keel only; (1) medial and lateral keels, trochlea and capitulum well-separated.
13. PC, Radius, Radial head shape: (0) minimum diameter greater than 70% maximum diameter; (1) minimum diameter between 70% and 60% maximum diameter; (2) minimum diameter less than or equal to 60% maximum diameter.
14. PC, Radius, Bicipital tuberosity presence: (0) present; (1) absent.
15. PC, Radius, Distal radius-ulna contact: (0) ligamentous or synovial; (1) synostosis.
16. PC, Radius, Ridge on dorsal surface of distal end presence: (0) absent; (1) present.
17. PC, Ulna, Olecranon relative length: (0) less than 20% total ulna length; (1) between 20% and 25% of total ulna length; (2) greater than 25% total ulna length.
18. PC, Ulna, Olecranon tip form: (0) straight, with no flare beyond more proximal part of olecranon; (1) tip flares somewhat medially; (2) tip flares prominently medially.
19. PC, Carpals, Scaphoid-lunate fusion: (0) unfused; (1) fused.
20. PC, Metapodial, MCIII dorsal surface form: (0) smooth; (1) with distinct extensor tubercle.
21. PC, Phalanges, Digit elongation index ($[(\text{Intermediate phalanx length} + \text{proximal phalanx length}) / \text{humerus length}]$) of digit III or IV: (0) less than 35%; (1) 35%-50%; (2) greater than 50%.
22. PC, Phalanges, Prehensility index of digit III of the manus: (0) intermediate phalanx less than 80% of metacarpal length; (1) greater than or equal to 80%.
23. PC, Innominate, Anterior inferior iliac spine development: (0) absent; (1) distinct but small; (2) pronounced and laterally projecting.
24. PC, Innominate, Ilium shape: (0) rod-like; (1) blade-like.

25. PC, Innominate, Buttressing of acetabulum: (0) no buttressing; (1) cranial buttressing; (2) caudal buttressing.
26. PC, Innominate, Ischiopubic symphysis presence and form: (0) absent; (1) present but narrow craniocaudally (2) robust - long craniocaudally.
27. PC, Femur, Greater trochanter projection: (0) below femoral head (ratio of femoral length including greater trochanter to that length not including trochanter, but measured to the superior surface of the head, is less than 1); (1) even with femoral head (ratio is between 1 and 1.05); (2) prominent, extending above femoral head (ratio is greater than 1.05).
28. PC, Femur, Greater trochanter relative anteroposterior (AP) expansion: (0) trochanter AP dimension less than 120% midshaft AP dimension; (1) trochanter AP dimension 120% or greater midshaft AP dimension.
29. PC, Femur, Lesser trochanter orientation: (0) medially projecting; (1) posteromedially or posteriorly projecting.
30. PC, Femur, Third trochanter position: (0) far distal to lesser trochanter; (1) slightly distal to lesser trochanter; (2) proximal to lesser trochanter.
31. PC, Femur, Third trochanter lateral projection: (0) small, not projecting; (1) prominently projecting.
32. PC, Femur, Patellar groove form: (0) proximodistal length less than 150% of mediolateral dimension; (1) proximodistal length greater than or equal to 150% of mediolateral dimension.
33. PC, Tibia-Fibula, Relative shaft length: (0) tibia no longer than femur; (1) tibia longer than femur.
34. PC, Tibia-Fibula, Tibia shaft shape: (0) straight; (1) bowed and thus laterally concave.

35. PC, Tibia-Fibula, Popliteal tuberosity (process on the anteromedial surface of the proximal tibia) presence: (0) present; (1) absent.
36. PC, Tibia-Fibula, Distal contact form: (0) ligamentous or synovial; (1) synostosis - fused.
37. PC, Tibia-Fibula, Tibial posterior process development: (0) small or absent; (1) prominently distally projecting.
38. PC, Tibia-Fibula, Medial malleolus form: (0) well-developed; (1) small; (2) absent.
39. PC, Tibia-fibula, Medial malleolus relation to sustentaculum tali (scored as inapplicable if medial malleolus was scored as “absent” in the preceding character): (0) no posterior contact; (1) posterior contact.
40. PC, Astragalus, Form of trochlea of body: (0) shallowly grooved; (1) deeply grooved.
41. PC, Astragalus, Regions of trochlea of body: (0) not clearly separated into regions or regions equal in mediolateral width; (1) lateral region wider than medial region; (2) medial region wider than lateral region.
42. PC, Astragalus, Relative height of trochlear borders: (0) medial border less than 90% height of lateral border; (1) medial border 90% to 110% height of lateral border; (2) medial border greater than 110% height of lateral border.
43. PC, Astragalus, Astragalar body medial aspect: (0) flat; (1) deeply concave, cotylar fossa.
44. PC, Astragalus, Astragalar medial border of body crimped (medial margin is relatively deeper dorsoventrally than long proximodistally): (0) absent; (1) present.
45. PC, Astragalus, Sustentacular and navicular facet contact: (0) no contact; (1) contact on lateral side; (2) contact on medial side; (3) contact on ventral side.

46. PC, Astragalus, Fibular facet form and orientation: (0) flat and faces laterodorsally; (1) faces laterally but has laterally-flaring, dorsally-facing shelf; (2) flat and faces laterally with no shelf.
47. PC, Astragalus, Ectal facet form (0) evenly concave, (1) unevenly concave or "peaked."
48. PC, Astragalus, Head shape: (0) maximum diameter less than 140% of minimum diameter; (1) greater than or equal to 140%.
49. PC, Astragalus, Flexor fibularis groove presence: (0) present, separate from trochlea; (1) absent.
50. PC, Calcaneum, Fibular facet orientation: (0) large and lateral; (1) large and distal; (2) small or absent.
51. PC, Calcaneum, Plantar pit on cuboid facet presence: (0) absent; (1) present.
52. PC, Calcaneum, Peroneal tubercle position: (0) distal; (1) proximal.
53. PC, Calcaneum, Ectal facet proximal margin shape: (0) convex; (1) concavoconvex.
54. PC, Calcaneum, Shaft (body and tuber) shape: (0) straight or laterally bowed; (1) medially bowed (= laterally convex).
55. PC, Entocuneiform, Plantodistal process presence: (0) present; (1) absent.
56. PC, Entocuneiform, Proximal extension of medial metatarsal 1 facet presence: (0) absent; (1) present.
57. PC, Metapodial, Metatarsal I torsion: (0) absent; (1) present.
58. PC, Metapodial, Bifurcate keel on metatarsal I presence: (0) absent; (1) present.
59. PC, Metapodial, Cylindrical (instead of spherical) metapodial heads presence (score from the central metapodials of either the manus or pes): (0) absent; (1) present.
60. PC, Phalanges, Distal phalanx of pedal digit I shape: (0) claw shaped; (1) flattened as a nail.

61. PC, Phalanges, Ungual pedal phalanx of digit III-IV relative length: (0) greater than 110% length of respective intermediate phalanges; (1) less than or equal to 110%.
62. PC, Phalanges, Asymmetrical manual or pedal intermediate phalanx distal ends presence: (0) absent; (1) present.
63. PC, Phalanges, Flexor sheath attachments on proximal phalanges of the manus or pes: (0) reduced or present as bony processes; (1) present as long ridges but not substantially ventrally projecting; (2) substantially ventrally projecting.
64. PC, Axial, Axis spinous process orientation: (0) caudal; (1) cranial.
65. PC, Axial, Anapophysis number: (0) present on all or all but ultimate lumbar vertebrae; (1) lacking on all or all but first lumbar vertebrae.
66. PC, Axial, Sacral vertebra spinous process: (0) all equal; (1) first reduced or absent; (2) first two reduced or absent.
67. PC, Axial, Manubrium sterni form: (0) not enlarged; (1) enlarged with ventral keel that extends to anterior margin; (2) dorsoventrally thickened with ventral keel poorly developed; (3) with prominent anterior process and short posterior process.
68. PC, Axial, Rib morphology: (0) narrow; (1) broad.
69. Cr, Snout, Length: (0) long; (1) moderate; (2) very short.
70. Cr, Nasal, Posterior extension: (0) extends to M³; (1) extends to M¹; (2) extends to P⁴.
71. Cr, Nasal, Frontonasal contact relative size: (0) broad, nasals reach lacrimal and maxilla is separated from frontal; (1) semi expanded - nasals flare posteriad but do not touch lacrimal; (2) restricted - nasals narrow posteriad.
72. Cr, Jugal, Zygomatic arch form: (0) incomplete - jugal absent; (1) complete without postorbital bar; (2) complete with postorbital bar.

73. Cr, Lacrimal, Tubercle development: (0) distinctly present; (1) poorly defined or absent.
74. Cr, Premaxilla, Frontal contact: (0) absent; (1) present.
75. Cr, Maxilla, Orbital mosaic maxillary contacts: (0) frontal; (1) palatine excludes from frontal contact; (2) non-palatine bone prevents maxillary-frontal contact.
76. Cr, Maxilla, Infraorbital foramen size: (0) larger than 15% maximum breadth between cheek tooth arcades; (1) 15% or less.
77. Cr, Maxilla, Infraorbital foramen position: (0) above M¹; (1) above P⁴; (2) above P³.
78. Cr, Palatine, Postpalatine spine presence: (0) large; (1) small or absent.
79. Cr, Alisphenoid, Tympanic process development: (0) small or absent; (1) substantial - may form anterior margin of bulla.
80. Cr, Alisphenoid, Ectopterygoid crest development: (0) no alisphenoid-tipped ectopterygoid crest; (1) alisphenoid-tipped crest equal or smaller than entopterygoid crest; (2) alisphenoid-tipped crest much larger than entopterygoid crest.
81. Cr, Alisphenoid, Canal for ramus infraorbitalis presence: (0) present; (1) absent.
82. Cr, Alisphenoid, Foramen rotundum presence: (0) present; (1) absent.
83. Cr, Alisphenoid, Borders of foramen ovale: (0) foramen ovale contained by alisphenoid; (1) between alisphenoid and squamosal and/or petrosal.
84. Cr, Alisphenoid, Transverse canal (foramen subovale) presence: (0) absent; (1) present.
85. Cr, Basisphenoid, Tympanic process development: (0) small to absent; (1) substantial - may form much of anteromedial wall and floor of bulla.
86. Cr, Basisphenoid, Morphology relating to vidian nerve: (0) foramen for vidian nerve in basisphenoid in tympanic cavity; (1) groove leads to foramen outside of tympanic cavity; (2) no morphological evidence of vidian nerve.

87. Cr, Basisphenoid, Anterior carotid foramen composition: (0) piriform fenestra; (1) basisphenoid.
88. Cr, Basioccipital, Tympanic process development: (0) absent; (1) distinctly present.
89. Cr, Basioccipital, Central stem breadth: (0) mediolaterally broad central stem, tympanic cavities well separated; (1) mediolaterally narrow central stem, tympanic cavities nearly in contact.
90. Cr, Basioccipital, Dorsum sellae presence: (0) absent; (1) present, with prominent posterior clinoid processes.
91. Cr, Occipital, Tentorium cerebelli condition: (0) unossified; (1) ossified.
92. Cr, Occipital, Nuchal crest development: (0) poorly developed or absent; (1) distinct and large.
93. Cr, Squamosal, Postglenoid process form: (0) absent; (1) present rostral to postglenoid foramen; (2) present lateral or caudal to postglenoid foramen.
94. Cr, Squamosal, Entoglenoid process form: (0) absent; (1) present but small (smaller than postglenoid process - if present); (2) present and large.
95. Cr, Squamosal, Pathway for the ramus inferior of the stapedia artery location: (0) separate from chorda tympani nerve and Glaserian fissure; (1) within Glaserian fissure with chorda tympani nerve.
96. Cr, Squamosal/Petrosal, Epitympanic recess size: (0) small (less than half the width of the promontorium); (1) large (more than half the width of the promontorium).
97. Cr, Ectotympanic, Degree to which it is covered by other bones: (0) phaneric; (1) completely covered by bony bulla.

98. Cr, Ectotympanic, Shape: (0) very narrow ring; (1) moderately expanded ring; (2) vastly expanded - may form much or all of ossified bulla.
99. Cr, Petrosal, Caudal tympanic process development: (0) absent or very small; (1) present and not very small (small to extensive *sensu* ref. 20).
100. Cr, Petrosal, Rostral tympanic process presence: (0) small or absent; (1) present.
101. Cr, Petrosal, Bulla presence (score as inapplicable if rostral tympanic process is absent): 0 absent; (1) present.
102. Cr, Petrosal, Piriform fenestra development: (0) expansive medially, laterally, and/or caudally; (1) reduced or absent
103. Cr, Petrosal, Facial nerve pathway: (0) open sulcus; (1) fully closed canal.
104. Cr, Petrosal, Expression of promontory branch of ICA on promontorium: (0) groove; (1) tube; (2) no expression.
105. Cr, Petrosal, Stapedial branch of internal carotid artery (ICA) on promontorium expression: (0) distinct groove; (1) tube; (2) little or no expression.
106. Cr, Petrosal Bony tube for stapedial artery condition (1.0) (score as inapplicable if bony tube is absent): (0) stops at fenestra vestibule; (1) continues through fenestra vestibuli
107. Cr, Petrosal, Fenestra cochleae visibility: (0) visible (when bulla, if present, is removed); 1 shielded by petrosal.
108. Cr, Entotympanic, Presence and degree of development: (0) absent; (1) present, small; (2) present and contributes to much of an ossified bulla.
109. Cr, Parietal/Occipital, Foramina in the lateral braincase (likely for the rami temporales; ref. 21; =sinus canal; ref. 22) presence: (0) absent; (1) one or two present; (2) many present, proliferated.

110. Cr, Parietal, Temporal lines or crest form: (0) single sagittal crest; (1) parallel parasagittal crests or temporal lines.
111. Cr, Parietal, Orbitotemporal canal (*sensu* ref. 21; =sinus canal, ref. 23; =ophthalmic sulcus, ref. 22) for ramus supraorbitalis of ramus superior presence: (0) present - groove on internal aspect of braincase; (1) absent.
112. Cr, Dentary, Internal ridge caudal to toothrow development: (0) incomplete, reduced or absent ridge between M₃ and condyle; (1) prominent ridge between M₃ and condyle.
113. Cr, Dentary, Posteriormost mental foramen position: (0) beneath m1 or farther distal; (1) beneath P₄; (2) beneath P₃ or farther mesial.
114. D, I¹, Size: (0) similar in size to other incisors or premolars (if I²⁻³ are missing); (1) much larger than other incisors or premolars (if I²⁻³ are missing); (2) tooth absent.
115. D, I¹, Tip strongly recurved presence: (0) absent; (1) present.
116. D, I¹, Accessory cuspules presence: (0) no accessory cuspules; (1) posterocone present but no apical cuspules; (2) posterocone and small cuspules developed around the tip; no strong apical division; (3) strong apical division into an anterocone and laterocone in addition to the presence of a protocone.
117. D, I¹, Restricted enamel presence and distribution: (0) absent (enamel surrounds the entire tooth); (1) restricted to an anterior band; (2) bands of enamel present on both anterior and posterior surfaces.
118. D, I², Presence: (0) present; (1) absent.
119. D, I², Size: (0) tooth absent; (1) present but small (2) large.
120. D, I³, Presence: (0) present; (1) absent.
121. D, C¹, Upper canine root number: (0) single rooted; (1) double rooted; (2) tooth absent.

122. D, P¹, Presence: (0) present; (1) absent.
123. D, P², Root number: (0) tooth absent; (1) double rooted; (2) single rooted, (3) triple rooted.
124. D, P², Parastyle (anterior basal cusp) presence: (0) poorly developed or absent; (1) distinct.
125. D, P³, Root number: (0) triple rooted; (1) double rooted; (2) single rooted; (3) tooth absent.
126. D, P³, Shape (buccal length/lingual length): (0) less than 1.8; (1) 1.8-2.0; (2) more than 2.0.
127. D, P³, Size relative to P⁴ based on $(\ln(\text{buccal length} \times \text{width})P^3)/(\ln(\text{buccal length} \times \text{width})P^4)$: (0) less than 0.6; (1) 0.6-1.2; (2) more than 1.2.
128. D, P³, Parastyle (anterior basal cusp) presence: (0) distinct; (1) absent.
129. D, P³, Metacone presence: (0) absent; (1) present.
130. D, P³, Metastyle presence: (0) absent; (1) present.
131. D, P³, Conules presence and number: (0) absent; (1) one present; (2) two present.
132. D, P³, Protocone presence: (0) absent; (1) present.
133. D, P³, Hypocone presence: (0) absent; (1) present.
134. D, P⁴, Number of roots: (0) one; (1) two; (2) three.
135. D, P⁴, Shape (buccal length/lingual length): (0) more than 1.8; (1) less than or equal to 1.8.
136. D, P⁴, Cusp acuteness: (0) acute; (1) bulbous.
137. D, P⁴, Carnassial shear with m1 presence: (0) absent; (1) present.
138. D, P⁴, Size relative to M¹ based on $(\ln(\text{buccal length} \times \text{width})P^4)/(\ln(\text{buccal length} \times \text{width})M^1)$: (0) less than 0.9; (1) 0.90-0.98; (2) more than 0.98.
139. D, P⁴, Width relative to M¹: (0) P⁴ not as wide transversely as M¹; (1) P⁴ as wide as or wider transversely as M¹.
140. D, P⁴, Cusp height in lateral view relative to M¹: (0) P⁴ lower than M¹; (1) P⁴ equal to or greater in height than M¹.

141. D, P⁴, Styler shelf development: (0) wide laterally and very narrow in the middle because of a strong ectoflexus; (1) ectoflexus weak with little or no styler shelf.
142. D, P⁴, Parastyle presence: (0) present; (1) absent.
143. D, P⁴, Parastylar lobe morphology: (0) large, projecting; (1) small, not projecting.
144. D, P⁴, Metacone presence: (0) present; (1) absent.
145. D, P⁴, Metastyle presence: (0) absent; (1) present.
146. D, P⁴, Conules presence and size: (0) absent; (1) one large conule present located near the midline of the tooth mesiodistally; (2) small paraconule present; (3) both conules present, strong; (4) metaconule present, no paraconule.
147. D, P⁴, Protocone lobe shape: (0) shorter mesiodistally than wide; (1) equally long and wide.
148. D, P⁴, Preprotocrista presence: (0) present; (1) absent.
149. D, P⁴, Protocone position: (0) not mesial to paracone; (1) mesial to paracone.
150. D, P⁴, Postprotocrista presence: (0) present; (1) absent.
151. D, P⁴, Postprotocingulum presence: (0) absent; (1) present.
152. D, P⁴, Hypocone presence: (0) totally absent; (1) present, at least incipiently.
153. D, M¹, Length relative to transverse width compared to M² or M³: (0) M¹ similarly elongate relative to transverse width than M² or M³; (1) M¹ more elongate relative to transverse width than M² or M³.
154. D, M¹, Ectoflexus depth: (0) deep with the styler shelf wide at the corners and almost disappearing in the middle; (1) shallow.
155. D, M¹, W-shaped ectoloph presence: (0) absent; (1) present.
156. D, M¹, Precingulum presence: (0) present, doesn't connect to postcingulum; (1) present, connects to postcingulum in at least some specimens; (2) precingulum absent.

157. D, M¹, Pre- and paracingula continuity: (0) not continuous; (1) continuous; (2) no paracingulum.
158. D, M¹, Parastylar lobe morphology: (0) projecting beyond the plane of the mesiolingual corner of the tooth; (1) not projecting.
159. D, M¹, Preparacrista orientation: (0) angled buccally; (1) straight; (2) crest absent.
160. D, M¹, Paracone and metacone relative sizes: (0) paracone larger than metacone or metacone absent; (1) cusps are subequal; (2) metacone larger than paracone.
161. D, M¹, Paracone and metacone bases relationship (0) M¹ paracone and metacone clearly separated at their bases; (1) M¹ paracone and metacone connate (no separation at the bases of the cusps).
162. D, M¹, Metastylar region buccal projection: (0) greater than parastylar region; (1) less than or equal to parastylar region.
163. D, M¹, Metastyle presence: (0) absent; (1) present.
164. D, M¹, Post- and metacingula continuity: (0) not continuous; (1) continuous.
165. D, M¹, Conules presence: (0) both conules present; (1) metaconule absent; (2) both weak or absent; (3) paraconule absent.
166. D, M¹, Conules position: (0) central or closer to protocone than to paracone and metacone; (1) appressed to paracone and metacone.
167. D, M¹, Protocone size relative to the buccal half of the tooth: (0) large; (1) small.
168. D, M¹, Protocone position: (0) skewed mesiobuccally; (1) central on the tooth.
169. D, M¹, Protoloph presence: (0) absent; (1) present.
170. D, M¹, Hypocone presence: (0) absent; (1) present (true hypocone, coming off the cingulum); (2) present (pseudohypocone, budding off the postprotocingulum).

171. D, M¹ or M², Postprotocingulum presence: (0) absent; (1) weak; (2) pronounced.
172. D, M², Ectoflexus depth: (0) deep with the styler shelf wide at the corners and almost disappearing in the middle; (1) shallow.
173. D, M², Hypocone size: (0) small, distinctly smaller than the protocone; (1) large, similar in size to the protocone; (2) hypocone absent.
174. D, M³, Presence: (0) present; (1) absent.
175. D, M³, Relative size based on $(\ln(\text{buccal L} \times \text{W})M^3) / (\ln(\text{buccal L} \times \text{W})M_1)$: (0) more than 0.9; (1) less than or equal to 0.9.
176. D, M³, Prominent parastylar lobe presence: (0) not prominent or absent; (1) prominent.
177. D, M³, Metacone presence: (0) metacone present as a well-developed cusp; (1) metacone absent.
178. D, M³, Hypocone size: (0) very small or absent; (1) large.
179. D, Upper Molar, Styler shelf morphology: (0) broad; (1) narrow (buccal cingulum only) or absent.
180. D, Upper Molar, Mesostyles presence (0) absent; (1) one or more present.
181. D, Upper Molar, Centrocrista morphology: (0) moderate; (1) strong and straight; (2) absent or very weak; (3) strong and V-shaped.
182. D, Antermost Lower Incisor, Continuous growth presence: (0) absent; (1) present.
183. D, Antermost Lower Incisor, Enamel restricted to an anterior band: (0) not restricted; (1) restricted.
184. D, Antermost Lower Incisor, Root extent relative to M₃: (0) does not extend below M₃; (1) extends below M₃.

185. D, I₁, Size: (0) much larger than other incisors (or premolars if I₂₋₃ are lost); (1) comparable to other incisors (or premolars if I₂₋₃ are lost); (2) very reduced; (3) tooth absent
186. D, I₁, Form: (0) simple, not laterally compressed; (1) laterally compressed with no broad, flattened surface; (2) as 1, with flattened dorsal surface; (3) as 2, but rotated medially.
187. D, I₁, Orientation: (0) essentially vertical (between vertical and 45 degrees); (1) procumbent-horizontal (greater than 45 degrees).
188. D, I₁, Margoconid presence: (0) absent; (1) present.
189. D, I₂, Presence: (0) present, large and/or larger than i₁; (1) present, small; (2) absent.
190. D, I₃, Presence: (0) present; (1) absent.
191. D, C₁, Lower canine root number: (0) one; (1) two; (2) tooth absent.
192. D, C₁, Lower canine relative size: (0) larger than adjacent teeth; (1) smaller than adjacent teeth; (2) tooth absent.
193. D, P₁, Presence: (0) present; (1) absent.
194. D, P₂, Alveoli number: (0) two; (1) one; (2) tooth absent.
195. D, P₂, Crown, Large, procumbent, with a hatchet-like slicing anterior projection: (0) absent; (1) present.
196. D, P₃, Root number: (0) two; (1) one; (2) tooth absent.
197. D, P₃, Paraconid (anterior basal cusp) presence: (0) present; (1) absent.
198. D, P₄, Number of roots: (0) one; (1) two roots fused with apical division; (2) two.
199. D, P₄, Mesiodistal length relative to M₁: (0) P₄ somewhat shorter than M₁; (1) P₄ and M₁ subequal in length; (2) P₄ much longer than M₁; (3) M₁ much longer than P₄.

200. D, P₄, Paraconid presence: (0) paraconid distinct, cuspsate; (1) cusp indistinct but paracristid present, not markedly elongate; (2) paraconid and paracristid absent or weak; (3) paracristid elongate with or without a distinct cusp.
201. D, P₄, Metaconid presence: (0) absent; (1) present.
202. D, P₄, Cristid obliqua position: (0) joins postvallid near midline of tooth or more lingually; (1) joins postvallid near buccal margin of trigonid; (2) cristid obliqua absent.
203. D, P₄, Hypoflexid morphology: (0) distinct, deep; (1) not distinct, shallow.
204. D, P₄, Talonid morphology: (0) basined; (1) not basined.
205. D, P₄, Talonid cusp number: (0) three well defined; (1) two well defined; (2) one solo distinct cusp; (3) all poorly defined.
206. D, M₁, Crown height (M₁ trigonid height over tooth length): (0) high crowned (index value more than 0.79); (1) moderate (index value 0.60-0.78); (2) low crowned (index value less than 0.6).
207. D, M₁, Trigonid degree of mesiodistal compression: (0) strongly compressed mesiodistally; (1) longer, with the paraconid positioned more mesially relative to the metaconid.
208. D, M₁, Trigonid height: (0) taller than the talonid but less than two times the height of the talonid; (1) of a similar height to talonid; (2) trigonid two times taller than the talonid or more.
209. D, M₁, Trigonid basal: (0) not swollen at the base; (1) swollen basally.
210. D, M₁, Mesiobuccal projection presence: (0) absent; (1) present.
211. D, M₁, Paraconid distinctiveness from paracristid: (0) indistinct from paracristid; (1) distinct from paracristid.

212. D, M₁, Paraconid size: (0) large; (1) small, markedly smaller than metaconid; (2) paraconid absent.
213. D, M₁, Protoconid and metaconid relative height: (0) protoconid higher; (1) subequal; (2) metaconid higher.
214. D, M₁, Metaconid position relative to protoconid: (0) metaconid and protoconid in line or metaconid in front of protoconid; (1) metaconid positioned well behind the level of the protoconid.
215. D, M₁, Stepped postvallid presence: (0) absent; (1) present.
216. D, M₁, Talonid basin form: (0) talonid with well defined basin surrounded by ridges continuous with or comprised of the entoconid, hypoconid, and or hypoconulid; (1) talonid basin reduced or absent.
217. D, M₁, Talonid width near cusp apices: (0) somewhat narrower than trigonid; (1) wider than trigonid; (2) much narrower than trigonid (the distance between the lingual margin and the point at which the cristid obliqua contacts the postvallid is less than half the width of the trigonid).
218. D, M₁, Talonid cusps relative height: (0) hypoconid taller than entoconid; (1) entoconid taller than hypoconid.
219. D, M₁, Entoconid notch presence (between the entoconid and hypoconulid): (0) absent; (1) present.
220. D, M₁, Hypoconulid notch presence (between the hypoconulid and hypoconid): (0) absent-weak; (1) present.
221. D, M₁, Hypoconulid and entoconid relative positions (see ref. 24: fig. 3.18): (0) unpaired; (1) paired (hypoconulid lingual of the central axis of the tooth but not directly appressed

- to the entoconid); (2) twinned (hypoconulid appressed to the entoconid in the distolingual corner of the tooth).
222. D, M₁, Hypoconulid position relative to the central axis of the tooth: (0) hypoconulid centrally placed or lingual of the central axis of the tooth; (1) hypoconulid buccal of central axis; (2) cusp absent.
223. D, M₂, Mesiobuccal projection presence: (0) absent; (1) present.
224. D, M₂, Paraconid distinctiveness compared to M₁: (0) comparably distinct to the paraconid on m₁; (1) less distinct than the paraconid on M₁.
225. D, M₃, Presence: (0) present; (1) absent.
226. D, M₃, Length relative to M₂: (0) M₃ less than or equal to M₂; (1) M₃ greater than M₂.
227. D, M₃, Talonid width: (0) much narrower than trigonid; (1) similar in breadth to trigonid or wider; (2) talonid absent.
228. D, M₃, Hypoconulid size: (0) similar to that cusp on M₁₋₂; (1) larger than on M₁₋₂ but not developed into a lobe; (2) developed into a lobe.
229. D, Lower Molar, Relative sizes: (0) lower molars get progressively smaller distally from M₁₋₃; (1) lower molars get progressively larger from M₁₋₃; (2) all lower molars similar in size; (3) M₂ is the smallest lower molar; (4) M₂ is the largest lower molar.
230. D, Lower Molar, Lingual curvature (“sweeps smoothly from the paraconid to the rear of the talonid”; McKenna, 1963: p. 17): (0) absent; (1) present.
231. D, Lower Molar, Trigonid length along the tooth row: (0) trigonids become less mesiodistally compressed from M₁₋₃; (1) no change; (2) trigonids become more mesiodistally compressed from M₁₋₃.

232. D, Lower Molar, Trigonid mesial inflection presence (in mesially oriented trigonids the postvallid is at a greater than ninety degree angle to the floor of the talonid basin; see ref. 24: fig. 3.13): (0) absent; (1) weak; (2) pronounced.
233. D, Lower Molar, Curving paracristids presence: (0) absent; (1) present.
234. D, Lower Molar, Protoconid-metaconid notch morphology: (0) strong and sharp; (1) more rounded; (2) fold of enamel bridges notch.
235. D, Lower Molar, Buccal cingulid(s) presence: (0) anterobuccal "precingulid" only; (1) separate anterior and posterior cingulids; (2) continuous buccal cingulid; (3) absent (no buccal cingulid or "precingulid").
236. D, Lower Molar, Hypoflexid distinctiveness: (0) distinct, invaginated; (1) not distinct
237. D, Molar, Enamel roughness: (0) smooth; (1) crenulated.
238. D, Molar, Cusp acuteness: (0) relative acute; (1) blunter (more bunodont).
239. D, Diastema, Large upper diastema presence: (0) diastema absent or shorter than the molar tooththrow; (1) diastema longer than the molar tooththrow.
240. D, Diastema, Diastema between the lower incisors and the cheek teeth presence: (0) absent; (1) present.

Table S2. Taxon-character matrix formatted facilitating importation to a parsimony computer program, such as TNT [7].

```
#NEXUS

BEGIN TAXA;
  DIMENSIONS NTAX=30;
  TAXLABELS
    Ukhaatherium Leptictidae Erinaceus Echinossorex Hemiechinus
Ottoryctes Pararyctes Paleoryctes Uintacyon '''Vulpavus profectus'''
Solenodon '''Sorex cinereus sorex sp.''' '''Suncus murinus''' Rhombomylus
'''Ptilocercus lowii''' '''Tupaia glis''' Genetta '''Cynocephalus
volans''' Gypsonictops Purgatorius Carpolestidae Plesiadapidae
Paromyiidae Microsyopidae Micromomyidae '''Altanius orlovi''' Adapidae
Omomyiidae Torrejonia_wilsoni Plesiolestes_nacimienti
  ;

END;

BEGIN CHARACTERS;
  DIMENSIONS NCHAR=240;
  FORMAT DATATYPE = STANDARD GAP = - MISSING = ? SYMBOLS = " 0 1 2 3
4";
  MATRIX
    Ukhaatherium
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?0210?11100?101??021?00110?0000?00000000000100020021001010200010000011000
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    Leptictidae
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    Erinaceus
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    Echinossorex
210101112000?10012000011002110011001??010200021100001100001000000010012100
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1101110011110011300011011010011000000010000001001200001032110010100011???2
000000002000200000
    Hemiechinus
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Ottoryctes
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10000000000000011110101100002001000000002000000011000210000120020011000020
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Pararyctes
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Paleoryctes
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10000102?000111?00110000200100000?0020000000110002100001200200010000200000
000000211000000000

Uintacyon
??0??1??
??0??1??
10000000000001101010000120????000000????100000000200011110120010000020????
000000012000000000

''Vulpavus profectus''
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?11000??0?01000?1112000?00?0002?0010?0?00000100020001101000200100110011010
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Solenodon
1011011101100000120000011010001010111101120101010000000001000001010012010
000100010100 (0 1)00001020?011100000?001001 (0 1
2)1000010100?10110000020102010001101011011002?000?11?2?0101001001?000?0002
01110000002?23012113012001100012????2000100201000000000

''Sorex cinereus sorex
sp.''
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1)0000110000101000002000001000010010000?0000000200011100000?00110001110010
011020010000021001111001101010010110010200110000010100111001300?0111210112
?2?0311211301000100000111020000000101100200000

''Suncus murinus''
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0001001100010000010200011100000?001100?11100210110200100000200010110011010
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Rhombomylus
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00200201000??01?0000?1021100122?0010?0120?1101210?0010 (0
1)10102110101101 (0
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''Ptilocercus lowii''
10100001101100010010??10110?0000000000100000200102010001010010110211112210
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111 (0 1)1101011200112?00010100110000000010100000110112301 (0
2)01301000100000011020000000001010200000

''Tupaia glis''
100100010000000000100021022100110000001000002201020100000100100002?0022210
11200200000000110011101010?111110210001100002101200210000 (0

1)020001011101000011101112?00201102?00010000110001300010100000110012301(0
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Genetta

2010001100001000011000110210100100100001120001110200000000001000030122100
101(0 1)0100010(0

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00000000

''Cynocephalus volans''

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11200211000000010002?10200?1022?01011010000020110?021110000210020111100310
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Gypsonictops

??
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1)000101110001??00000000201010000000

Purgatorius

??001002001021000????????????
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Carpolestidae

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000112302110000000

Plesiadapidae

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Paromomyidae

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1)00000000?102?01?0120100?0211211??0??1111121?1101101112?12200011130011012
?001?000002100(0 2)011(0 1)0100100110010001000001110000210010001000000(1
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Microsyopidae

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Micromomyidae

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?02?????????????1???21?1101??002?1??0?0111200211120021100000200010110000010
0000010000000000010000000010010000001102101100012230000(1 3)(0
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''Altanius orlovi''

??
??002?0210000102000?0110010001
11?001000111010000010111201000100?01?0?1100000012001000101010100110110000
000112102010200000

Adapidae

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01110210000000110021101011111111010?0100000(1
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1)11201000100000100011000000120(0 1)1(0 1)(0 1)(0
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Omomyidae

?01100011?11000????????????1112111000000001002200021101???1???1?????????2?220?
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1)1120(0 1)0001000001(0 1)0011000100120010001110101001(0 1)010000000010(1
2)302(0 1)10200000

Torrejonia_wilsoni

?01???011?11000??0???1?1???110??0?000000000?00?021000?????????2?????????????
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3)10000001000111010101000021000000100000021011001100121(0 1)(0
1)1001110101110001000000101121021112011?0

Plesiolestes_nacimienti

??0?
?02??0?????????01100(0 2)(0 1)1100(0
1)0210000110000(0 2)101(0 1)100100000(0 1)000(0 1)0100002120(0
1)000100??00?1?00001100120?(0 1)000101000111000100100010112202111(0
1)00000

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END;