Dataset S1 for

Bone microstructure supports a Mesozoic origin for a semi-aquatic burrowing lifestyle in monotremes (Mammalia)

Suzanne J. Hand[1]*, Laura A.B. Wilson[1,2,3]*, Camilo López-Aguirre[4,5,6], Alexandra Houssaye[7], Michael Archer[1], Joseph J. Bevitt[8], Alistair R. Evans[9,10], Amalia Y. Halim[11], Tzong Hung[12], Thomas H. Rich[10], Patricia Vickers-Rich[13], and Robin M.D. Beck[14]

[1]School of Biological, Earth and Environmental Sciences, UNSW Sydney, 2052, Australia

[2]School of Archaeology and Anthropology, College of Arts and Social Sciences, The Australian National University, ACT 2601, Australia

[3]ARC Training Centre for Multiscale 3D Imaging, Modelling and Manufacturing, Research School of Physics, The Australian National University, ACT 2601, Australia

[4]University of Toronto Scarborough, M1C 1A4, Scarborough, ON, Canada

[5]Universidad de La Salle, Museo de La Salle, Bogotá 111711, Colombia

[6]Escuela de Biología, Universidad Industrial de Santander, Bucaramanga, Colombia

[7]UMR 7179 Mécanismes adaptatifs et Évolution (MECADEV), Centre National de la Recherche Scientifique, Muséum National d'Histoire Naturelle, Paris, France

[8]Australian Centre for Neutron Scattering, Australian Nuclear Science and Technology Organisation, Lucas Heights, NSW 2234, Australia

[9]School of Biological Sciences, Monash University, Melbourne, Victoria, 3800, Australia

[10]Museums Victoria Research Institute, Museums Victoria, P.O. Box 666, Melbourne, Victoria 3001, Australia

[11]Tyree X-ray Micro-CT Laboratory, Mark Wainwright Analytical Centre, UNSW Sydney, 2052, Australia

[12]Biological Resources Imaging Laboratory, Mark Wainwright Analytical Centre, UNSW Sydney, 2052, Australia

[13]School of Earth, Atmosphere and Environment, Monash University, Melbourne, Victoria 3800, Australia

[14]School of Science, Engineering, and Environment, University of Salford, Salford, UK

* Corresponding: Suzanne J Hand and Laura A.B. Wilson

Email: s.hand@unsw.edu.au; laura.wilson@anu.edu.au

CLASSIFICATION: Evolutionary Biology

KEYWORDS: bone microstructure, Mesozoic, monotreme, mammal, semi-aquatic burrowing, Gondwana

This PDF file includes:

Dataset S1

SOURCES FOR SCORING THE HUMERUS FOR PHYLOGENETIC ANALYSIS (WITH TAXON INDICATED)

F. Abdala, Elementos postcraneanos de *Cynognathus* (Synapsida-Cynodontia) del Triasico Inferior de la provincia de Mendoza, Argentina. Consideraciones sobre la morfologfa del humero en cinodontes. *Span. J. Palaeont.* **14**, 13–24 (1999). (***Probainognathus***)

C. Argot, Functional-adaptive anatomy of the forelimb in the Didelphidae, and the paleobiology of the Paleocene marsupials *Mayulestes ferox* and *Pucadelphys andinus*. *J. Morphol.* **247**, 51–79 (2001). (***Mayulestes, Pucadelphys***)

S. Bi, Y. Wang, J. Guan, X. Sheng, J. Meng, Three new Jurassic euharamiyidan species reinforce early divergence of mammals. *Nature* **514**, 579–584 (2014). (***Xianshou linglong, Xianshou songae, Shenshou***)

C. E. Gow, A partial skeleton of the tritheledontid *Pachygenelus* (Therapsida: Cynodontia) *Palaeontol. Afr.* **37**, 93–97 (2001). (***Pachygenelus***)

M. L. Guignard, A. G. Martinelli, M. B. Soares, The postcranial anatomy of *Brasilodon quadrangularis* and the acquisition of mammaliaform traits among non-mammaliaform cynodonts. *PLOS ONE* **14**, e0216672 (2019). (***Brasilodon***)

S. Hoffmann, Y. Hu, D. W. Krause, Postcranial morphology of *Adalatherium hui* (Mammalia, Gondwanatheria) from the Late Cretaceous of Madagascar. *J. Vertebr. Paleontol.* **40**, 133–212 (2020). (***Adalatherium***)

I. Horovitz, Postcranial skeleton of *Ukhaatherium nessovi* (Eutheria, Mammalia) from the Late Cretaceous of Mongolia. *J. Vertebr. Paleontol.* **23**, 857–868 (2003). (***Ukhaatherium***)

Y. Hu, *Postcranial morphology of Repenomamus (Eutriconodonta, Mammalia): Implications for the higher-level phylogeny of mammals*. PhD thesis, (The City University of New York, 2006). (***Repenomamus***)

K. R. K. Jäger, Z. X. Luo, T. Martin, Postcranial skeleton of *Henkelotherium guimarotae* (Cladotheria, Mammalia) and locomotor adaptation. *J. Mamm. Evol.* **27**, 349–372 (2020). (***Henkelotherium***)

F. A. Jenkins Jr., F. R. Parrington, The postcranial skeletons of the Triassic mammals *Eozostrodon*, *Megazostrodon* and *Erythrotherium*. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **273**, 387–431 (1976). (***Morganucodon, Megazostrodon***)

F. A. Jenkins Jr., C. R. Schaff, The Early Cretaceous mammal *Gobiconodon* (Mammalia, Triconodonta) from the Cloverly Formation in Montana. *J. Vertebr. Paleontol*. **8**, 1–24 (1988). (***Gobiconodon***)

F. A. Jenkins Jr., The Chañares (Argentina) Triassic reptile fauna. VII. The postcranial skeleton of the traversodontid *Massetognathus pascuali* (Therapsida, Cynodontia). *Breviora* **352**, 1–28 (1970). (***Massetognathus***)

F. A. Jenkins Jr., The postcranial skeleton of African cynodonts: Problems in the early evolution of the mammalian postcranial skeleton. *Yale Univ. Peabody Mus. Nat. Hist. Bull.* **36**, 1–216 (1971). (***Thrinaxodon***)

Q. Ji, Z. X. Luo, S. A. Ji, A Chinese triconodont mammal and mosaic evolution of the mammalian skeleton. *Nature* **398**, 326–330 (1999). (***Jeholodens***)

Q. Ji, Z.-X. Luo, C.-X. Yuan, A. R. Tabrum, A swimming mammaliaform from the Middle Jurassic and ecomorphological diversification of early mammals. *Science* **311**, 1123–1127 (2006). (***Castorocauda***)

Q. Ji *et al.*, The earliest known eutherian mammal. *Nature* **416**, 816–822 (2002). (***Eomaia***)

Q. Ji, Z. X. Luo, X. Zhang, C. X. Yuan, L. Xu, Evolutionary development of the middle ear in Mesozoic therian mammals. *Science* **326**, 278–281 (2009). (***Maotherium***)

Z. Kielan-Jaworowska, R. L. Cifelli, Z.-X. Luo, *Mammals from the Age of Dinosaurs: Origins, Evolution, and Structure* (Columbia University Press, 2004). (Cimolodontans, *Zalambdalestes*)

W. G. Kühne, *The Liassic therapsid Oligokyphus*. British Museum (Natural History), 1956). (**Tritylodontids**)

J. Liu, M. B. Soares, M. Reichel, *Massetognathus* (Cynodontia, Traversodontidae) from the Santa Maria Formation of Brazil. *Rev. Bras. Paleontol.* **11**, 27–36 (2008). (***Massetognathus***)

Z.-X. Luo, Q. Ji, New study on dental and skeletal features of the Cretaceous “symmetrodontan” mammal *Zhangheotherium*. *J. Mamm. Evol.* **12**, 337–357 (2005). (***Zhangheotherium***)

Z.-X. Luo *et al.*, New evidence for mammaliaform ear evolution and feeding adaptation in a Jurassic ecosystem. *Nature* **548**, 326–329 (2017). (***Vilevolodon***)

Z.-X. Luo, J. R. Wible, A Late Jurassic digging mammal and early mammalian diversification. *Science* **308**, 103–107 (2005). (***Fruitafossor***)

Z.-X. Luo, C. X. Yuan, Q. J. Meng, Q. Ji, A Jurassic eutherian mammal and divergence of marsupials and placentals. *Nature* **476**, 442–445 (2011). (***Juramaia***)

M. W. Maisch, A. T. Matzke, G. Sun, A new tritylodontid from the Upper Jurassic Shishugou Formation of the Junggar Basin (Xinjiang, NW China). *J. Vertebr. Paleontol.* **24**, 649–656 (2004). (**Tritylodontids**)

L. G. Marshall, D. Sigogneau-Russell, "Part III: Postcranial skeleton" in *Pucadelphys andinus* (Marsupialia, Mammalia) from the early Palaeocene of Bolivia (Mémoires du Muséum national d'Histoire naturelle 165)*,* C. de Muizon, Ed. (Muséum national d'Histoire naturelle, 1995), pp. 91–164. (***Pucadelphys***)

T. Martin *et al.*, A Cretaceous eutriconodont and integument evolution in early mammals. *Nature* **526**, 380–384 (2015). (***Spinolestes***)

T. Martin, Postcranial anatomy of *Haldanodon exspectatus* (Mammalia, Docodonta) from the Late Jurassic (Kimmeridgian) of Portugal and its bearing for mammalian evolution. *Zool. J. Linn. Soc.* **145**, 219–248 (2005). (***Haldanodon***)

T. Martin, Mammalian postcranial bones from the Late Jurassic of Portugal and their implications for forelimb evolution. *J. Vertebr. Paleontol***. 33**, 1432–1441 (2013). (***Dryolestes***)

Q. J. Meng *et al.*, New gliding mammaliaforms from the Jurassic. *Nature* **548**, 291–296 (2017). (***Maiopatagium***)

Q. J. Meng *et al.*, An arboreal docodont from the Jurassic and mammaliaform ecological diversification. *Science* **347**, 764–768 (2015). (***Agilodocodon***)

Muizon, C. de, *Mayulestes ferox*, a borhyaenoid (Metatheria, Mammalia) from the early Palaeocene of Bolivia: phylogenetic and palaeobiologic implications. *Geodiversitas* **20**, 19–142 (1998). (***Mayulestes***)

A. E. B. Pavanatto, R. T. Müller, Á. A. S. Da Rosa, S. Dias da Silva, New information on the postcranial skeleton of *Massetognathus ochagaviae* Barberena, 1981 (Eucynodontia, Traversodontidae), from the Middle Triassic of Southern Brazil. *Hist. Biol.* **28**, 978–989 (2015). (***Massetognathus***)

A. Romer, A. Lewis, The Chañares (Argentina) Triassic reptile Fauna. XIX. Postcranial materials of the cynodonts *Probelesodon* and *Probainognathus*. *Breviora* **407**, 1–26 (1973). (***Probainognathus***)

K. D. Rose, The postcranial skeleton of early Oligocene *Leptictis* (Mammalia: Leptictida), with a preliminary comparison to *Leptictidium* from the middle Eocene of Messel. *Palaeontogr. Abt. A* **278**, 37–56 (2006). (***Leptictis***)

G. W. Rougier, Q. Ji, M. J. Novacek, A new symmetrodont mammal with fur impressions from the Mesozoic of China. *Acta Geol. Sin.* **77**, 7–14 (2003). (***Maotherium***)

G. W. Rougier, Vincelestes neuquenianus *Bonaparte (Mammalia, Theria) un primitivo mamífero del Cretácico Inferior de la Cuenca Neuquina.* Ph.D. dissertation (Universidad Nacional de Buenos Aires, 1993). (***Vincelestes***)

H.-D. Sues, F. A. Jenkins Jr., "The postcranial skeleton of *Kayentatherium wellesi* from the Lower Jurassic Kayenta Formation of Arizona and the phylogenetic significance of postcranial features in tritylodontid cynodonts" in *Amniote Paleobiology: Perspectives on the Evolution of Mammals, Birds, and Reptiles,* M. T. Carrano, T. J. Gaudin, R. W. Blob, J. R. Wible, Eds. (University of Chicago Press, 2006), pp. 269–311. (**Tritylodontids**)

A. Sun, Y. Li, The postcranial skeleton of the late tritylodont *Bienotheroides*. *Vert. PalAs.* **23**, 135–151 (1985). (**Tritylodontids**)

F. S. Szalay, B. Trofimov, The Mongolian Late Cretaceous *Asiatherium*, and the early phylogeny and paleobiogeography of Metatheria. *J. Vertebr. Paleontol.* **16**, 474–509 (1996). (***Asiatherium***)

C. X. Yuan, Q. Ji, Q. J. Meng, A. R. Tabrum, Z. X. Luo, Earliest evolution of multituberculate mammals revealed by a new Jurassic fossil. *Science* **341**, 779-783 (2013). (***Rugosodon***)

C. F. Zhou, S. Wu, T. Martin, Z. X. Luo, A Jurassic mammaliaform and the earliest mammalian evolutionary adaptations. *Nature* **500**, 163-167 (2013). (***Megaconus***)

SCORES FOR THE PHYLOGENETIC DATA MATRIX

Numbering for the morphological characters used in our phylogenetic analysis follows Huttenlocker et al. (2018: supplementary information) for characters 1-538, with characters 539-546 representing new additions. (See also SI Appendix.)

1. SCORED and ORDERED. Post-dentary trough (behind the tooth row): (0) Full presence of the postdentary trough; (1) Reduced postdentary trough in angular region and below dentary peduncle; (2) Absence of the postdentary trough.
Steropodon = ? (0 in Huttenlocker et al. 2018)
Ausktribosphenos = 2 (0 in Huttenlocker et al. 2018)
Bishops = 2 (0 in Huttenlocker et al. 2018)
Adalatherium = 2
Notes: Scoring of *Steropodon* follows Ramírez-Chaves et al. (2016). Scoring of *Ausktribosphenos* and *Bishops* follows Rougier et al. (2007), Ramírez-Chaves et al. (2016), and Rich et al. (2016).

2. EXCLUDED. Separate scars for surrangular/prearticular in the mandible: (0) Present; (1) Absent.
Ausktribosphenos: 1 (0 in Huttenlocker et al. 2018)
Notes: Character excluded following Rougier et al. (2007).

3. EXCLUDED. Overhanging medial ridge above the post-dentary trough (behind the tooth row): (0) Present; (1) Absent.
Notes: Character excluded following Rougier et al. (2007).

4. SCORED and ORDERED. Degree of development of Meckel's sulcus: (0) Well developed; (1) Short, and limited to the mandibular foramen; (2) Vestigial or absent.
Steropodon = ? (0 in Huttenlocker et al. 2018)
Adalatherium = 2
Notes: Scoring of *Steropodon* follows Ramírez-Chaves et al. (2016).

5: SCORED. Curvature of Meckel's sulcus: (0) Parallel to the ventral border of the mandible; (1) Convergent on the ventral border of the mandible.
Steropodon = ? (0 in Huttenlocker et al. 2018)
Adalatherium = -
Notes: Scoring of *Steropodon* follows Ramírez-Chaves et al. (2016).

6. Groove for the replacement dental lamina (Crompton's groove): (0) Present; (1) Absent.
Adalatherium = 1

7. Angular process of the dentary: (0) Weakly developed to absent; (1) Present, distinctive but not inflected; (2) Present and transversely flaring (This is different from character state {4} in having a lateral expansion of the angle and in lacking the anterior shelf); (3) Present and slightly medially inflected; (4) Present, strongly inflected, and continuing anteriorly as the mandibular shelf.
Adalatherium = 0

8. Position of the angular process of the dentary relative to the dentary condyle: (0) Anterior position (the angular process is below the main body of the coronoid process, separated widely from the dentary condyle); (1) Posterior position (the angular process is positioned at the level of the posterior end of the coronoid process, either close to, or directly under the dentary condyle).
Adalatherium = -

9. Vertical elevation of the angular process of the dentary relative to the molar alveoli: (0) Angular process low, at or near the level of the ventral border of the mandibular horizontal

ramus; (1) Angular process high, at or near the level of the molar alveolar line (and far above the ventral border of the mandibular horizontal ramus).
Adalatherium = -

10. Flat ventral surface of the mandibular angle: (0) Absent; (1) Present.
Adalatherium = -

11. Exoflection of the angular process of mandible: (0) Absent; (1) Present.
Adalatherium = -

12. SCORED and ORDERED. Coronoid bone (or its attachment scar): (0) Present and significant; (1) Vestigial; (2) Absent.
Teinolophos = ? (2 in Huttenlocker et al. 2018)
Adalatherium = 2
Notes: Rich et al. (2016) identified a possible contact area for the coronoid bone in multiple specimens of *Teinolophos* (see also Celik and Phillips 2018).

13. EXCLUDED. Location of the mandibular foramen (posterior opening of the mandibular canal): (0) Within the postdentary trough or in the posterior part of Meckel's sulcus; (1) In the pterygoid fossa and offset from Meckel's sulcus (the intersection of Meckel's sulcus at the pterygoid margin is ventral and posterior to the foramen); (2) In the pterygoid fossa and in alignment with the posterior end of Meckel's sulcus; (3) In the pterygoid fossa but not associated with Meckel's sulcus; (4) Not associated with any of the above structures.
NOTES: Character excluded following Rougier et al. (2007).

14. Vertical position of the mandibular foramen: (0) Below the alveolar plane; (1) At or above the alveolar plane.
Adalatherium = 0

15. Concavity (fossa) for the reflected lamina of the angular bone on the dentary: (0) Present the medial side; (1) Present on the posterior aspect; (2) Absent.
Adalatherium = 2

16. EXCLUDED. Splenial bone as a separate element (as indicated by its scar on the dentary): (0) Present; (1) Absent.
NOTES: Character excluded following Rougier et al. (2007).

17. Relationship of the "postdentary" complex (surangular-articular-prearticular) to the craniomandibular joint (CMJ) [CMJ is made of several bones in the stem groups of mammals or mammaliaforms, whereas the temporomandibular joint (TMJ) is the medical and veterinary anatomical term applicable to living mammals in which the jaw hinge is made only of the temporal (squamosal) bone and the dentary. CMJ and TMJ are used interchangeably here as appropriate to the circumstances]: (0) Participating in CMJ; (1) Excluded from CMJ.
Adalatherium = 1

18. Contact of the surangular bone (or associated postdentary element) with the squamosal: (0) Absent; (1) Present.
Adalatherium = 0

19. Pterygoid muscle fossa on the medial side of the ramus of the mandible: (0) Absent; (1) Present.
Adalatherium = 1

20. EXCLUDED. Medial pterygoid ridge (shelf) along the ventral border of the body of the mandible: (0) Absent; (1) Present; (2) Pterygoid shelf present and reaching the dentary condyle via a low crest.
NOTES: Character excluded following Rougier et al. (2007).

21. Ventral border of the masseteric fossa: (0) Absent; (1) Present as a low and broad crest; (2) Present as a well-defined and thin crest.
Adalatherium = 1

22. ORDERED. Crest of the masseteric fossa along the anterior border of the coronoid process: (0) Absent or weakly developed; (1) Present and distinctive; (2) Hypertrophied and laterally flaring.
Adalatherium = 0

23. ORDERED. Anteroventral extension of the masseteric fossa: (0) Absent; (1) Extending anteriorly onto the body of the mandible; (2) Further anterior extension below the ultimate premolar/first molar.
Adalatherium = 1

24. Labial mandibular foramen inside the masseteric fossa: (0) Absent; (1) Present.
Adalatherium = 0

25. ORDERED. Posterior vertical shelf of the masseteric fossa connected to the dentary condyle: (0) Absent; (1) Present as a thin crest along the angular margin of mandible; (2) Present as a thick, vertical crest.

26. ORDERED. Posterior-most mental foramen: (0) In the canine and anterior premolar (premolariform) region (in the saddle behind the canine eminence of the mandible or behind incisor if canine is absent); (1) Below the penultimate premolar (under the anterior end of the functional postcanine row); (2) Below the ultimate premolar; (3) At the ultimate premolar and the first molar junction; (4) Under the first molar.
Adalatherium = 1
NOTES: Assuming a dental formula for *Adalatherium* of I2 C1 P1 M4 / i1 c0 p1 m3 (as in Krause et al., 2020).

27. ORDERED. Articulation of the dentary and the squamosal: (0) Absent; (1) Present, but without condyle/glenoid; (2) Present, with condyle/glenoid.
Adalatherium = 2

28. Shape and relative size of the dentary articulation: (0) Condyle small or absent; (1) Condyle massive, bulbous, and transversely broad in its dorsal aspect; (2) Condyle mediolaterally narrow and vertically deep, forming a broad arc in lateral outline, either ovoid or triangular in posterior view.
Adalatherium = 1

31. Gracile and elongate dentary peduncle: (0) Absent; (1) Present.
Adalatherium = 0

32. Position of the dentary condyle relative to the level of the postcanine alveoli: (0) Below or about the same level; (1) Above.
Adalatherium = 1

33. ORDERED. Tilting of the coronoid process of the dentary (measured as the angle between the anterior border of the coronoid process and the horizontal alveolar line of all molars): (0) Coronoid process strongly reclined and the coronoid angle obtuse (≥150 degrees); (1) Coronoid process less reclined (135-145 degrees); (2) Coronoid process less than vertical (110-125 degrees); (3) Coronoid process near vertical (95-105 degrees).

Adalatherium = 1

34. Gracile base of the coronoid process: (0) Absent; (1) Present.
Adalatherium = 0

35. Height of the coronoid process of the dentary: (0) Not reduced; (1) reduced.
UMNH 16771 = ?
Adalatherium = 0

36. Alignment of the ultimate lower molar (or posterior-most postcanine) to the anterior margin of the dentary coronoid process (and near the coronoid scar if present): (0) Ultimate lower molar medial to the coronoid process; (1) Ultimate lower molar aligned with the coronoid process.
Adalatherium = 0

37. Direction of lower jaw movement during occlusion (as inferred from teeth): (0) Dorsal movement; (1) Dorsomedial movement with a significant medial component; (2) Dorsoposterior or dorsal-posterior movement.
Adalatherium = 2

38. Dentary symphysis: (0) Fused; (1) Unfused.
Adalatherium = 1

39. Rostral mandibular spout: (0) Absent; (1) Present.
Adalatherium = 0

40. Relative dentary depth in relation to the length: (0) Shallow; (1) Deep.
Adalatherium = 1

41. Ultimate upper premolar with two rows of multiple cusps: (0) Absent; (1) Present.
Adalatherium = 0

42. Upper ultimate and penultimate premolars basined (with main cusps located peripherally surrounding a shallow and broad central basin): (0) absent; (1) present.
Adalatherium = 0

43. Upper ultimate and penultimate premolars central valley: (0) the mesial end open; (1) the mesial end closed (trenched when deeply worn).
Adalatherium = -

44. Ultimate upper premolar width relative to the first upper molar: (0) Ultimate upper premolar transversely narrower than, or subequal to, the first upper molar; (1) Ultimate upper premolar transversely wider than the first upper molar; (2) Ultimate upper premolar with a protruding lingual lobe (wider than M1 by about 50% or more).
Adalatherium = 0

45. Enamel ridges or flutings on cusps of upper premolars: (0) absent; (1) present.
Adalatherium = 0

46. Ultimate upper premolar with multi-rows of cusps - Labial row of cuspules: (0) Absent; (1) Present.
Adalatherium = -

50. ORDERED. Penultimate upper premolar - protocone or protoconal swelling: (0) Little or no lingual swelling; (1) Protoconal swelling; (2) Distinctive and functional protocone.

51. Position the upper premolar with the tallest cusp within the premolar series: (0) No premolar standing out; (1) In ultimate premolar position; (2) In penultimate premolar position.
Adalatherium = -

52. Diastema posterior to the first upper premolar (applicable to taxa with premolar-molar differentiation): (0) Absent; (1) Present.
Adalatherium = -

53. Penultimate upper premolar: tallest cusp position within longitudinal cusp row: (0) Central; (1) Tallest cusp anterior with posterior cusps (if existing) with decreasing heights; (2) Tallest cusp on buccal row; (3) Cusps even.
Adalatherium = -

54. Hypertrophic mesial cusp on ultimate lower premolar: (0) absent; (1) present.
UMNH 16771 = ?
Adalatherium = 1

55. Ultimate lower premolar - symmetry of the main (middle) cusp a (= protoconid): (0) Asymmetrical (anterior edge of cusp a is more convex in outline than the posterior edge); (1) Symmetrical (anterior and posterior cutting edges are equal or subequal in length; neither edge is more convex or concave than the other in lateral profile).
Adalatherium = 0

56. ORDERED. Ultimate lower premolar - anterior cusp b (= paraconid): (0) Absent or indistinctive; (1) Present and distinctive; (2) Enlarged.
Adalatherium = 0

57. Ultimate lower premolar - arrangement of principal cusp a, cusp b (if present), and cusp c (assuming the cusp to be c if there is only one cusp behind the main cusp a): (0) Aligned in a single straight line or at a slight angle; (1) Distinctive triangulation; (2) Premolar multicuspate in longitudinal row(s).
Adalatherium = -

58. Ultimate lower premolar – posterior-most (distal) cingulid or cingular cuspule (in addition to cusp c or the metaconid if the latter cusp is present on a triangulated trigonid): (0) Absent or indistinctive; (1) Present; (2) Present, in addition to cusp c or the c swelling; (3) Presence of the continuous posterior (distal) cingulid at the base of the crown.
Adalatherium = 0

60. Posterior upper premolar – single enlarged anterior (mesial) sectorial cusp (scored on anterior postcanine in taxa without differentiation of premolars from molars): (0) Absent; (1) Present.
Adalatherium = 0

61. Penultimate or ultimate lower premolar with carnassial shearing notch in the middle of the tooth (score on anterior postcanines in taxa where premolars undifferentiated from molars): (0) Absent (single cusp shearing); (1) Present.
Adalatherium = 0

62. ORDERED. Lower premolars – basined heel (score on anterior postcanines in taxa in which premolars are not differentiated from molars): (0) Absent; (1) Weakly developed; (2) Full molarization of posterior premolars.
Adalatherium = 1

63. Lower premolar: presence of a distinctive distal cingulid with cuspules or crenulated cingulid, and their topographic relation to the main cusp row: (0) Absence of crenulation or cuspules on cingulid row; (1) Present and labially positioned; (2) Present and lingually positioned.
Adalatherium = 0

64. Ultimate lower premolar - labial cingulid: (0) Absent or vestigial; (1) Present (at least along the length of more than half of the crown); (2) cuspate distal cingulid.
Adalatherium = 0

65. Ultimate lower premolar - lingual cingulid: (0) Absent or vestigial; (1) Present.
Adalatherium = 0

66. ORDERED. Ultimate lower premolar - relative height of primary cusp a to cusp c (measured as the height ratio of a and c from the bottom of the valley between the two adjacent cusps): (0) Indistinctive; (1) Posterior cusp c distinctive but less than 30% of the primary cusp a; (2) Posterior cusp c and primary cusp a equal or subequal in height (c is 40%-100% of a).

67. ORDERED. Penultimate lower premolar - paraconid (=cusp b): (0) Absent; (1) Present but not distinctive; (2) Distinctive and slightly enlarged.
Adalatherium = -

68. Penultimate lower premolar - arrangement of principal cusp a, cusp b (if present), and cusp c (we assume the cusp to be c if there is only one cusp behind the main cusp a): (0) Individual cusps in straight alignment (for a tooth with a single cusp, the anterior and posterior crests from the main cusp are in alignment): (1) Cusps in reversed triangulation; (2) With multicusps or multi-serrations in a single longitudinal row; (3) With multicusps or multi-serrations rows.
Adalatherium = -

69. Penultimate lower premolar – labial cingulid: (0) Absent; (1) Present.
Adalatherium = -

70. Gradation of elongation of posterior penultimate premolars: (0) Absent; (1) Present.
UMNH 16771 = ?
Adalatherium = -

71. The mesial U-ridge of upper molars with multi-rows of cusps: (0) Absent; (1) Present; (2) Closed by the cuspules.
Adalatherium = -

74. ORDERED. M1 cusp formula (A row relative to B row): (0) 4:4 or lower; (1)5:4; (2) 6:4 or higher.
Adalatherium = -

78. EXCLUDED. Postvallum/prevallid shearing (angle of the main trigonid shear facets, based on the second lower molar): (0) Absent; (1) Present, weakly developed, slightly oblique; (2) Present, strongly developed and more transverse; (3) Present, strongly developed, short and slightly oblique.
NOTES: Character excluded following Rougier et al. (2007).

81. Precise opposition of the upper and lower molars: (0) Absent; (1) Present (either one-to-one, or occluding at the opposite embrasure or talonid); (2) Present (one lower molar contacts sequentially more than one upper molar).
Adalatherium = 2

83. Lower m1 with multicuspate rows- lingual row occlude into the basin of upper molar:

(0) Absent; (1) Present.
Adalatherium = -

84. Lower m2 with multicuspate rows – the lingual cusp row occlude into the basin of upper molar: (0) Absent; (1) Present.
Adalatherium = -

85. The distal end of lower molars with multi-rows of cusps: (0) Absent; (1) Closed by the ridge;(2) Closed by the cuspules.
Adalatherium = -

88. ORDERED. m1 main lingual row cusp count (distribution revised): (0) 4 or fewer; (1) 5; (2) 6 or more.
Adalatherium = -

91. ORDERED. Relative height and size of the base of the paraconid (cusp b) and metaconid (cusp c) (on the lower second molar): (0) Paraconid distinctively higher than the metaconid; (1) Paraconid and metaconid nearly equal in height; (2) Paraconid lower than metaconid; (3) Paraconid reduced or absent.

95. ORDERED. Posterior lingual cingulid of the lower molars: (0) Absent or weak; (1) Distinctive; (2) Strongly developed, crenulated with distinctive cuspules (such as the kuhneocone).
Adalatherium = 0

97. ORDERED. Anterior and labial (mesio-buccal) cingular cuspule (f): (0) Absent; (1) Present; (2) Hypertrophied to form pseudo-hypoconid.

98. ORDERED. Mesial cingulid features above the gum: (0) Absent; (1) Weak and discontinuous, with individualized cuspules below the trigonid (as individual cuspule e, f, or both, but e and f are not connected); (2) Present, in a continuous shelf below the trigonid (with no relations to the
Adalatherium = 0

100. ORDERED. Cingulid shelf wrapping around the anterolingual corner of the molar to extend to the lingual side of the trigonid below the paraconid: (0) Absent; (1) Present, without occlusal function to the upper molars; (2) Present, with occlusal function to the upper molars.

101. Postcingulid (distal transverse cingulid above the gum level) on the lower molars: (0) Absent; (1) Present, horizontal above the gum level.
Adalatherium = 0

102. Lower molars interlocking: (0) Absent; (1) Present.
Adalatherium = 0

103. Lower molars interlocking - types of interlocking mechanisms: (0) Posterior cingular cuspule d (or the base of the hypoconulid) of the preceding molar fits in between cingular cuspules e and f of the succeeding molar; (1) posterior cingular cuspule d fits between cingular cuspule e and cusp b of the succeeding molar; (2) posterior cingular cuspule d or cingulum of the preceding molar fits into an embayment or vertical groove of the anterior aspect of the succeeding molar (without any involvement of distinctive cingular cuspules in interlocking). (3) Anterior corner of succeeding lower molar overlapping posterior corner of preceding lower molar.
Adalatherium = -

104. Size ratio of the last three lower postcanines: (0) Ultimate molar is smaller than the

penultimate molar (m1≥m2≥m3; or m2≥m3≥m4; or m3≥m4≥m5; or m4≥m5≥m6; or p4≥m1≥m2); (1) Penultimate molar is the largest of the molars (m1≤m2≤m3≥m4; or m1≤m2>m3); (2) Ultimate molar is larger than the penultimate molar (m1≤m2≤m3); (3) Equal size.
Adalatherium = 1

106. ORDERED. Orientation of the paracristid (or the crest between cusps a and b) relative to the longitudinal axis of the molar (This is separated from the previous character ["lingual" vs. "labial" position of the paraconid] because of the different distribution of the a-b crest among mammals with nontriangulated molars sampled here): (0) Longitudinal orientation; (1) Oblique; (2) Nearly transverse.

107. ORDERED. Angle of the paracristid (b-a crest) and the protocristid (a-c crest) on the lower molar: (0) > 90 degrees; (1) 90 ~ 50 degrees; (2) < 35 degrees.

110. ORDERED. Molar (the lower second molar measured where possible) trigonid/talonid heel width ratio: (0) Narrow (talonid ≤40% of trigonid); (1) Wide (talonid is 40-70% of the trigonid in width); (2) Talonid is equal or wider than trigonid.

113. ORDERED. Hypoconid (we designate the distal cingulid cuspule d as the homolog to the hypoconid in the teeth with linear alignment of the main cusps; we assume the cusp to be the hypoconid if there is only a single cusp on the talonid in the teeth with reversed triangulation): (0) Present, but not elevated above the cingulid level; (1) Present (as distal cusp d), elevated above the cingulid level, labially positioned (or tilted in the lingual direction); (2) Present (larger than cusp d, with occlusal contact to the upper molar), elevated above the cingulid level, labially positioned.

121. ORDERED. The length vs. width ratio of the functional talonid basin of the lower molars (in occlusal view, measured at the cingulid level, and based on the second molar): (0) Longer than wide (or narrows posteriorly); (1) Length equals width; (2) Wider than long.

122. ORDERED. Elevation of the talonid (measured as the height of the hypoconid from the cingulid on the labial side of the crown) relative to the trigonid (measured as the height of protoconid from the cingulid) (applicable only to the teeth with reversed triangulation): (0) Hypoconid/protoconid height ratio less than 20% (hypoconid or cusp d is on the cingulid); (1) Hypoconid/protoconid height ratio between 25% and 35% (talonid cusp elevated above the cingulid level); (2) Hypoconid/protoconid height ratio between 40% and 60%; (3) Hypoconid/protoconid height ratio between >60% and 80%; (4) Equal height.

123. ORDERED. Size (labiolingual width) of the upper molar labial stylar shelf on the penultimate molar: (0) Absent; (1) Present and narrow; (2) Present and broad.

127. Distinctive lingual cingulum on upper molariforms: (0) Absent; (1) Present.
Adalatherium = 0

128. ORDERED. Upper molar protocone: (0) Functional cusp and lingual swelling absent; (1) Functional cusp absent, but the lingual side is more swollen than the labial side at the cingular level; (2) Functional cusp present.

129. ORDERED. Degree of labial shift of the protocone (distance from the protocone apex to the lingual border vs. the total tooth width, in %) (applicable only to those taxa with reversed triangulation): (0) Protocone present but no labial shift (10%-20%); (1) Moderate labial shift (25%-30%); (2) Substantial labial shift (≥ 40%).

131. ORDERED. Height of the protocone/pseudoprotocone relative to the paracone and metacone

(whichever is highest of the latter two): (0) Protocone/pseudoprotocone markedly lower (less than 70%); (1) Protocone of intermediate height (70%~80%); (2) Protocone/pseudoprotocone near the height of paracone and metacone (within 80%).

132. ORDERED. Height and size of upper molar cusp B and cusp C of triconodont-type molariform (based on the upper second molar if available): (0) Paracone noticeably higher and larger at the base than metacone; (1) Paracone slightly larger than metacone; (2) Paracone and metacone of equal size or paracone lower than metacone.

133. ORDERED. Height and size of the paracone and metacone (applicable only to molars with cusps of triangular arrangement; based on the upper second molar if available): (0) Paracone noticeably higher and larger at the base than metacone; (1) Paracone slightly larger than metacone; (2) Paracone and metacone of equal size or paracone lower than metacone.

134. ORDERED. Metacone position relative to paracone: (0) Metacone labial to paracone; (1) Metacone about the same level as paracone; (2) Metacone lingual to paracone.

137. ORDERED. Anteroposterior width of the conular region (with or without conules) on the upper molars (applicable only to taxa with reversed triangulation and an occluding lingual portion of the upper molar; for the taxa with conules, this is measured between the paraconule and metaconule; for those taxa without conules, this is measured as the length of the tooth medial to the base of paracone; the upper second molar measured where possible): (0) Narrow (anteroposterior distance medial to the paracone and metacone less than 0.30 of total tooth length); (1) Moderate development (distance between position of conules = 0.31—0.50 of total tooth length); (2) Wide (distance between conules greater than 0.51 of total tooth length); (3) Expanded.

139. ORDERED. Relative position of the paraconule and metaconule on the upper first and second molars: (0) Paraconule and metaconule closer to the protocone; (1) Both positioned near the midpoint of the protocone-metacone; (2) Paraconule and metaconule labial to the midpoint.

144. ORDERED. Stylar cuspule “B” (opposite the paracone) (based on the upper second molar if available): (0) Vestigial to absent; (1) Small but distinctive; (2) Subequal to the parastyle; (3) Large (subequal to parastyle), with an extra "B-1" cuspule in addition to "B".

147. ORDERED. Absence vs. presence and size of the stylar cuspule “E” (Bensley-Simpson designation; not the Crompton cusp E): (0) Absent or poorly developed; (1) Present, less developed than or subequal to stylar cuspule “D”; (2) Present and better developed than cuspule “D”.

150. ORDERED. Salient postmetacrista on the upper molars (applicable to taxa with reversed triangulation): (0) Absent or weakly developed; (1) Well-developed but no longer than the metacone-protocone distance; (2) Hypertrophied and longer than the metacone-protocone distance.

151. Selenodont molar pattern: (0) Absent; (1) Present.
Adalatherium = 0

152. Outline of the lower first molar crown (in crown view): (0) Laterally compressed; (1) Oblong with slight labial bulge; (2) Triangular or tear-drop shaped; (3) Rectangular (or rhomboidal); (4) circular.
Adalatherium = 1

153. Outline of the lower second molar crown (in crown view): (0) Laterally compressed; (1) Oblong with slight labial bulge; (2) Triangular or tear-drop shaped; (3) Rectangular (or rhomboidal); (4) circular.
Adalatherium = 1

154. Aspect ratio and outline of the upper first molar: (0) Laterally compressed; (1) Longer than transversely wide (oval-shaped or spindle shaped); (2) Transversely wider than long (triangular outline); (3) Rectangular or nearly so; (4) circular.
Adalatherium = 3

155. Carnassial shearing blades on posterior aspect of the ultimate upper premolar and anterior aspect of the first lower molar: (0) Absent; (1) Present.
Adalatherium = 0

156. Upper molar interlock: (0) Absent; (1) Present.
Adalatherium = 0

157. Anterior molar(s) - types of upper molar interlock: (0) Notch interlock (with cingular cusps involved or without); (1) Tongue-in-groove interlock; (2) Parastylar lobe of a succeeding molar lumbricated with the metastylar region of a preceding molar.
Adalatherium = -

158. Posterior upper molar(s) - types of upper molar interlock: (0) Posterior end of preceding molar lumbricating anterolabial side of ultimate upper molar; (1) Parastylar lobe of a succeeding molar lumbricated with the metastylar region of a preceding molar: cladotherians; boreosphenidans; (2) Tongue-in-groove interlock.
Adalatherium = -

163. ORDERED. Development and orientation of prevallum/postvallid shearing (based on either upper or the lower molar structures): (0) Absent; (1) Present and obtuse; (2) Present, hypertrophied and transverse.

166. ORDERED. Differentiation of wear facet 3 and facet 4 (applicable to taxa with a distal cusp d or "hypoconulid"): (0) Absent; (1) Present; (2) Facets 3 and 4 hypertrophied on the flanks of the strongly V-shaped talonid.

168. EXCLUDED. Morphology of the posterolateral aspect of the talonid (the labial face of the hypoconid or equivalent area of Crompton facet 4, applicable to taxa with fully basined talonid): (0) Gently rounded; (1) Angular.
NOTES: Character excluded following Rougier et al. (2007).

171. EXCLUDED. Differentiation of wear facets 5 and 6 on the labial face of the entoconid: (0) Absent; (1) Present.
NOTES: Character excluded following Rougier et al. (2007).

176. ORDERED. Number of upper incisors: (0) Five; (1) Four; (2) Three; (3) Two; (4) One; (5) No incisors.
Adalatherium = 3

177. I2 enlargement: (0) absent; (1) present.
Adalatherium = 1

179. ORDERED. Number of lower incisors: (0) Five or more; (1) Four; (2) Three; (3) Two; (4) One; (5) No incisors.
Adalatherium = 4

180. Lower anterior-most incisor enamel: (0) Covers the whole incisor; (1) Restricted anteriorly.
Adalatherium = 1

181. Lower anterior-most incisor with open root: (0) Absent; (1) Present.
Adalatherium = 1

182. Upper anterior-most incisor enamel: (0) Covers the whole incisor; (1) Restricted anteriorly.
Adalatherium = 1

183. Upper anterior-most incisor with open root: (0) Absent; (1) Present.
Adalatherium = 1

184. ORDERED. Upper canine - presence vs. absence, and size: (0) Present and enlarged; (1) Present and small; (2) Absent.
Adalatherium = 1

186. Number of upper canine roots: (0) One; (1) Two.
Adalatherium = 0

187. ORDERED. Lower canine - presence vs. absence and size: (0) Present and enlarged; (1) Present and small; (2) Absent.
Adalatherium = 2

188. Number of lower canine roots: (0) One; (1) Two.
Adalatherium = -

189. Orientation of lower canine: (0) Erect; (1) Procumbent.
Adalatherium = -

190. ORDERED. Number of upper premolars (only applicable to taxa with premolar vs. molar differentiation): (0) Five or more; (1) Four; (2) Three; (3) Two or less.
Adalatherium = 3

191. ORDERED. Number of lower premolars: (0) Five or more; (1) Four; (2) Three; (3) Two or less.
Adalatherium = 3

192. ORDERED. Number of lower molars or molariform postcanines: (0) Six or more; (1) Five; (2) Four; (3) Three; (4) Two or less.
Adalatherium = 3

193. ORDERED. Number of upper molars or molariform postcanines (applicable only to those taxa that do not have multiple dental replacements): (0) Six or more; (1) Five; (2) Four; (3) Three; (4) Two or less.
Adalatherium = 2

194. ORDERED. Total number of upper postcanine loci: (0) More than 8 (including the loci plus the alveoli of shed anterior postcanines); (1) Eight; (2) Seven, (3) Six; (4) Five or less.
Adalatherium = 4

195. ORDERED. Total number of lower postcanine loci: (0) Eight or more; (1) Seven; (2) Six; (3) Five or fewer.
Adalatherium = 3

196. Procumbency and diastema of first (functional) upper premolar or postcanine in relation to

the upper canine: (0) Not procumbent and without diastema; (1) Procumbent and with diastema.
Adalatherium = -

197. ORDERED. Diastema separating the lower first and second premolars (defined as the first and second functioning premolar or premolariform postcanine): (0) Absent (gap less than one tooth root for whichever is smaller of the adjacent teeth); (1) Present, subequal to one tooth-root diameter or more; (2) Present, equal to or more than one-tooth length.
Adalatherium = -

198. Ultimate lower premolar bladed or crenulated: (0) Absent; (1) Present.
Adalatherium = 0

199. Upper anterior-most incisor (I1): (0) Subequal to the remaining incisors, no diastema with the second incisor; (1) Anteriorly projecting, separated from the second incisor (or any following teeth if posterior incisors are absent) by a diastema; (2) Absent (as evidenced by a small median gap between the mesial-most incisors).
Adalatherium = 0

201. Staggered lower incisor: (0) Absent; (1) Present.
Adalatherium = -

202. ORDERED. Replacement pattern of incisors and canines: (0) More than one replacement; (1) One replacement; (2) No replacement.

204. Enlargement of the lower anterior-most incisor: (0) Absent; (1) Present (at least 50% longer than the adjacent incisor).
Adalatherium = 1

205. Enlarged diastema in the lower incisor-canine region (better developed in older individuals): (0) Absent; (1) Present and behind the canine; (2) Present and behind the posterior incisor.
Adalatherium = 2

206. U-shaped transverse ridge in the lower multi-rowed molars: (0) Absent; (1) Present, at second anterior cusp: (2) Present, at the anterior rim.
Adalatherium = -

208. Cusp ratio on lingual row of multi-rowed lower molar: (0) Cusps are of subequal height; (1) Mesial cusp on the lingual row the highest.
Adalatherium = -

210. Cusp ratio on buccal row of multi-rowed lower molar: (0) All cusps are of equal height; (1) The middle cusps higher than the mesial and distal cusps.
Adalatherium = -

211. Enlarged and more centrally placed second cusp of lingual row on lower m1 (applicable only to molars with multi-rows of multiple cusps): (0) Absent; (1) Present.
Adalatherium = -

212. ORDERED. Upper premolar/molar with multi-cusped rows - cusp ratio in the labial row of multi-cusp row on ultimate upper molar: (0) Distal cusp highest, with a gradient of anteriorly decreasing height; (1) Cusps in same row of equal height; (2) Mesial cusp is slightly higher than distal cusp.
Adalatherium = -

213. Antero-lingual wing (in addition to two main cusp rows) on M1: (0) Absent; (1) Present.
Adalatherium = -

214. Last (ultimate) upper molar - alignment of multi-cusped rows: (0) Absence of lingual offset of ultimate molar to penultimate molar; (1) Presence of offset of ultimate molar from the penultimate molar: the lower ultimate molar lingual row occludes with the lingual side of the upper second labial row, or the labial side of the lower ultimate molar occluding with the labial side of the upper ultimate molar.
Adalatherium = -

215. Complete middle valley between lingual cusp row and labial cusp row on lower m2: (0) Absent; (1) Present.
Adalatherium = -

216. Multi-rowed ultimate lower molar, row length difference: (0) Labial cusp row about equal as lingual cusp row; (1) Labial row is shorter at the anterior end (by at least half-cusp length) than lingual row; (2) Labial row is longer at the posterior end than lingual row (by at least halfcusp length).
Adalatherium = -

217. Enamel microstructure: (0) Synapsida columnar enamel (prismless); (1) 'Transitional' (sheath indistinct, 'prismatic' crystallites inclined at less than 45o to the 'interprismatic' matrix); (2) Full prismatic enamel; (3) Enamel absent.
Adalatherium = 2

218. Hypsodonty roots of cheek teeth: (0) Absent; (1) Present.
Adalatherium = 0

219. Open root end of the postcanines: (0) Absent; (1) Present.
Adalatherium = 0

220. Degrees of postcanine root division: (0) Single root; (1) divided roots connected by dentine sheets; (2) two or three complete divided roots or more; (3) multiple roots coalesced.
Adalatherium = 2

222. Fusion of the atlas neural arch and intercentrum: (0) Absent; (1) Present.
Adalatherium = 0

228. Postaxial cervical ribs: (0) Unfused; (1) Fused.
Adalatherium = 0

229. Number of vertebrae bearing ribs: (0) 13 or less; (1) 14 or more.
Adalatherium = 1

230. Overlapping ventral costal plates: (0) Absent; (1) Present.
Adalatherium = 0

231. Overlapping lumbar or posterior thoracic ribs: (0) Present; (1) Absent.
Adalatherium = 1

232. Anticlinal vertebra: (0) Absent; (1) Present.
Adalatherium = 1

233. Anticlinal vertebra position (not applicable for vertebral column without an anticlinal vertebra): (0) Anticlinal absent; (1) More posterior position (within last 4 lumbar vertebrae); (2) Anteriorly positioned (within the anterior 13 dorsal and the thoracic vertebral region if thoracolumbar boundary is distinctive)
Adalatherium = 1

234. Mobile lumbar ribs: (0) Present; (1) Absent.
Adalatherium = 1

235. Orientation of lumbar ribs or transverse processes: (0) Posterolaterally directed; (1) Laterally or anterolaterally directed.
Adalatherium = 1

236. Xenarthrous articulation in addition to the pre- and post-zygapophyses of lumbar vertebrae: (0) Absent; (1) Present.
Adalatherium = 0

237. Expanded dorsal end (“flat top”) of neural spine of posterior dorsal vertebrae: (0) Absent; (1) Present.
Adalatherium = 1

238. Interclavicle: (0) Present; (1) Absent.
Adalatherium = 1

240. Interclavicle distal expansion: (0) Absent; (1) Present.
Adalatherium = -

241. Cranial margin of the interclavicle/manubrium (assuming the interclavicle is fused to the sternal manubrium in living therians): (0) Emarginated or flat; (1) With a median process.
Adalatherium = 0

242. Interclavicle to sternal manubrium length ratio: (0) Interclavicle twice the length of manubrium; (1) Interclavicle nearly equal to manubrium in length.
Adalatherium = -

243. Sternoclaviclular joint (assuming that homologous elements of the interclavicle and the manubrium are fused to each other in therians): (0) Immobile; (1) Mobile.
Adalatherium = 1

246. Curvature of the clavicle: (0) Boomerang-shaped; (1) Slightly curved.
Adalatherium = 1

248. ORDERED. Scapula - supraspinous fossa: degree of development along the length: (0) Present only in the “acromional region” of the scapula, and on the cranial (dorsal) border of the scapula and positioned anterior to the glenoid); (1) Weakly developed (present only along a part of the scapula and positioned lateral to the glenoid); (2) Fully developed (present along the entire dorsal border of the scapula).
Adalatherium = 2

249. ORDERED. Proportion of supraspinous vs. infraspinous fossae (width measured across the "saddle region" of the spine, or near the mid-length of the scapula): (0) Supraspinous “fossa” on the

cranial aspect of the scapula and much narrower than infraspinous fossa; (1) Supraspinous width is 50% to 80% that of infraspinous fossa; (2) Fossae subequal; (3) Supraspinous over 150% that of infraspinous fossa.
Adalatherium = 2

251. Scapula - a distinctive fossa for the teres major muscle on the lateral aspect of the scapular plate: (0) Absent; (1) Present.
Adalatherium = 0

252. Procoracoid: (0) Present and distinct; (1) Fused to the sternal apparatus.
Adalatherium = 1

254. Coracoid: (0) Large, with posterior process; (1) Small, without posterior process.
Adalatherium = 0

255. ORDERED. Anterior process of the coracoid: (0) Indistinctive; (1) Distinctive; (2) Distinctive and forming a broad plate.

257. Size of the anterior-most element ('manubrium') relative to the subsequent sternebrae in the sternal apparatus: (0) Large; (1) Small.
Adalatherium = 1

258. Orientation ('facing' of the articular surface) of the glenoid (relative to the plane or the long axis of the scapula): (0) Nearly parallel and facing posterolaterally; (1) Oblique and facing more posteriorly; (2) Perpendicular.
Adalatherium = 2

259. Shape and curvature of the glenoid: (0) Saddle-shaped, oval and elongate; (1) Uniformly concave and more rounded in outline.
Adalatherium = 0

260. Medial surface of the scapula: (0) Convex; (1) Flat.
Adalatherium = 1

262. SCORED. Humeral head: (0) Subspherical, weakly inflected; (1) Spherical, strongly inflected.
Ornithorhynchus = 0
Tachyglossus = 0
Zaglossus = 0
Megalibgwilia = 0
Adalatherium = 1

263. SCORED. Intertubercular groove of the humerus: (0) Shallow and broad; (1) Narrow and deep.
Zhangheotherium = 0 (1 in Huttenlocker et al. 2018)
Henkelotherium = 0 (1 in Huttenlocker et al. 2018)
Ornithorhynchus = 0
Tachyglossus = 0
Zaglossus = 0
Megalibgwilia = 0
Kryoryctes= 0
Adalatherium = 0

Notes: Scoring of *Zhangheotherium* and *Henkelotherium* follows Rougier et al. (2007). Scoring of *Kryoryctes* agrees with Celik and Phillips (2018).

264. SCORED. Size of the lesser tubercle of the humerus relative to the greater tubercle: (0) Wider; (1) Narrower.
Ornithorhynchus = 0
Tachyglossus = 0
Zaglossus = 0
Kryoryctes = 0
Notes: Scoring of *Kryoryctes* agrees with Celik and Phillips (2018).

265. MODIFIED, SCORED, and ORDERED. Torsion between the proximal and distal ends of the humerus: (0) Very strong (>60°); (1) Strong (30-60°); (2) Moderate (30° –15°); (3) Weak (<15°).
Thrinaxodon = 1
Massetognathus = 1
Tritylodontids: 1
Brasilodon = 2
Morganucodon = 1
Haldanodon = 1
Xianshou linglong = 2
Xianshou songae = 2
Senshou = 2
Vilevolodon = 2
Maiopatagium = 2
Cimolodontans = 2/3
Ornithorhynchus= 0
Tachyglossus= 1
Kryoryctes= 1
Zaglossus= 1
Megalibgwilia= 1
Fruitafossor = 1
Gobiconodon = 1
Akidolestes = 1
Zhangheotherium = 2
Dryolestes = 2
Vincelestes = 2
Eomaia = 3
Ukhaatherium = 3
Zalambdalestes = 3
Erinaceus = 3
Leptictis = 3
Canis = 3
Felis = 3
Rattus = 3
Bradypus = 3
Tamandua = 3
Glyptotherium = 3
Dasypus = 3
Chaetophractus = 3

Euphractus = 3
Sinodelphys = 3
Mayulestes = 3
Pucadelphys = 3
Didelphis = 3
Marmosa = 3
Caenolestes = 3
Dasyurus = 3
Perameles = 3
Dromiciops = 3
Thylacomyidae = 3
Macropus = 3
Acrobates = 3
Phascolarctos = 3
Vombatus = 3
Phalanger = 3
Pseudocheirus = 3
Petauroides = 3
Adalatherium = 2
ALL OTHER TAXA = ?
Notes: We have added an additional state (state 0) for very strong humeral torsion (defined as >60°), which in our matrix is seen only in *Ornithorhynchus*. We rescored all taxa present in the Huttenlocker et al. (2018) matrix according to the literature (see references below) and/or firsthand observation of specimens; taxa that we could not score based on this information were specified as unknown ('?') for this character, even if they had been originally scored by Huttenlocker et al. (2018).

266. SCORED. Ventral extension of the deltopectoral crest or the position of the deltoid tuberosity: (0) Short and limited to the proximal part of the humeral shaft; (1) Extending ventrally (distally) at least one-third the length of the shaft.
Ornithorhynchus= 1
Tachyglossus = 1
Zaglossus= 1
Megalibgwilia= 1
Kryoryctes= 1
Adalatherium = 1

267. SCORED and ORDERED. Teres tuberosity on medial side of humerus: (0) Absent; (1) Present; (2) Hypertrophied.
Ornithorhynchus= 2
Tachyglossus = 2
Zaglossus= 2
Kryoryctes= 2
Adalatherium = 0/1

268. SCORED and ORDERED. Ulnar articulation on the distal humerus: (0) Bulbous ulnar condyle; (1) Cylindrical trochlea in posterior view with a vestigial ulnar condyle in anterior view; (2) Cylindrical trochlea without an ulnar condyle (cylindrical trochlea extending to the anterior/ventral side).
Ornithorhynchus= 0
Tachyglossus = 0

Zaglossus= 0
Megalibgwilia= 0
Kryoryctes=1
Adalatherium = 2

269. SCORED and ORDERED. Radial articulation on the distal humerus: (0) Distinct and rounded radial condyle in both anterior (ventral) and posterior (dorsal) aspects (that does not form a continuous synovial surface with the ulnar articulation in the ventral/anterior view of the humerus); (1) Rounded radial condyle anteriorly but cylindrical posteriorly; (2) Capitulum (forming a continuous synovial surface with the ulnar trochlea; cylindrical in both anterior and posterior aspects).
Ornithorhynchus= 0
Tachyglossus = 0
Zaglossus= 0
Megalibgwilia= 0
Kryoryctes= 0
Dryolestes = 1 (was ? in Huttenlocker et al., 2018).
Adalatherium = 2
Notes: Our scoring of *Kryoryctes* agrees with Celik and Phillips (2020). Scoring of *Dryolestes* is based on Martin (2013).

270. SCORED. Entepicondyle and ectepicondyle of the humerus: (0) Robust; (1) Weak.
Cimolodontans = 1 (0 & 1 in Huttenlocker et al., 2018)
Ornithorhynchus= 0
Tachyglossus = 0
Zaglossus= 0
Megalibgwilia= 0
Kryoryctes= 0
Adalatherium = 1
Notes: Scoring of cimolodontans follows Rougier et al. (2007)

271. SCORED. Sigmoidal shelf for the supinator ridge extending proximally from the ectepicondyle: (0) Absent; (1) Present.
Ornithorhynchus = 0
Tachyglossus = 0
Zaglossus = 0
Kryoryctes = 0
Adalatherium = 0

272. ORDERED. Coronoid process of semilunar notch of ulna: (0) Absent; (1) Present and level to olecranon
process; (2) Present and higher than olecranon process.
Adalatherium = 2

273. Styloid process of the radius: (0) Weak; (1) Strong.
Adalatherium = 1

274. Enlargement of the scaphoid: (0) Not enlarged (scaphoid ≤150% of the lunate); (1) Enlarged (scaphoid twice the size of the lunate); (2) Enlarged with a distolateral process.
Adalatherium = 1

275. Size and shape of the hamate (unciform): (0) About equal size to the triquetrum, anteroposteriorly compressed; (1) Hypertrophied, much larger than the triquetrum, mediolaterally compressed.
Adalatherium = 0

276. Trapezium morphology and proportion:
(0) Elongate to cuboidal, larger than or subequal to the trapezoid; (1) Bean-shaped or fusiform, smaller than the trapezoid.
Adalatherium = 0

277. Triquetrum-lunate proportion: (0) Triquetrum nearly twice the size of the lunate; (1) Triquetrum subequal to the lunate.
Adalatherium = 1

278. Relative length of metacarpals (MC) to proximal phalanx (PP) of digit III: (0) PP shorter than MC; (1) PP longer than MC.
Adalatherium = 0

280. Posterior process of the ilium: (0) Present; (1) Reduced or absent.
Adalatherium = 1

281. Acetabular dorsal emargination: (0) Open (emarginated); (1) Closed (with a complete rim).
Adalatherium = 1

282. Sutures of the ilium, ischium, and pubis within the acetabulum: (0) Present; (1) Fused.
Adalatherium = 1

283. Ischiatic dorsal margin and tuberosity: (0) Dorsal margin concave (emarginated) and ischiatic tuberosity present; (1) Dorsal margin concave and ischiatic tuberosity hypertrophied; (2) Dorsal margin straight and ischiatic tuberosity small.
Adalatherium = 1

285. Epipubic bone: (0) Present; (1) Absent.
Adalatherium = 0

289. Preacetabular tubercle on the ilium for M. rectus femoris: (0) Absent; (1) Present.
Adalatherium = 1

291. Lesser psoas tuberosity or process on the pubis: (0) Absent; (1) Present.
Adalatherium = 0

292. Inflected head of the femur set off from the shaft by a neck: (0) Neck absent and head oriented dorsally; (1) Neck present, head spherical and inflected medially.
Adalatherium = 1

293. Fovea for the acetabular ligament on the femoral head: (0) Absent; (1) Present.
Adalatherium = 1

294. Orientation of the greater trochanter: (0) Directed dorsolaterally; (1) directed dorsally.
Adalatherium = 1

295. Level of greater trochanter relative to femoral head: (0) mid-level of femoral head; (1) top level of femoral head.
Adalatherium = 1

296. Position of the lesser trochanter: (0) On medial side of the shaft; (1) On the ventromedial or ventral side of the shaft.
Adalatherium = 1

297. Size of the lesser trochanter: (0) Large; (1) Small to absent.
Adalatherium = 1

298. The third trochanter of femur: (0) Absent; (1) Present; (2) Present as a continuous ridge connected to the greater trochanter.
Adalatherium = 0

299. Patellar facet ('groove') of the femur: (0) Absent; (1) Shallow and weakly developed; (2) Well-developed.
Adalatherium = 1

300. Proximo-lateral tubercle or tuberosity of the tibia: (0) Large and hook-like; (1) Indistinct; (2) Fused to fibula
Adalatherium = 1

301. Distal tibial malleolus: (0) Weak; (1) Distinctive.
Adalatherium = 1

302. Diferentiation of lateral tibio-astragalar condyle from the medial tibio-astragalar condyle: (0) Absent; (1) Present.
Adalatherium = 1

303. Fibula contacting the distal end of the femur: (0) Present; (1) Absent; (2) Fibula contacting through fusion with the tibia.
Adalatherium = 0

304. Fused distal portions of the tibia and fibula: (0) Absent; (1) Present.
Adalatherium = 0

305. Enlarged parafibular structure of the fibula: (0) Absent; (1) Present.
Adalatherium = 1

306. Parafibula types: (0) Separate bone and unfused to the fibular; (1) fused to fibula as an enlarged process:
Adalatherium = 0

307. Distal fibular styloid process: (0) Weak or absent; (1) Distinct.
Adalatherium = 1

308. Fibula contacting the calcaneus (= 'tricontact in upper ankle joint'): (0) Extensive contact; (1) Reduced; (2) Absent.
Adalatherium = 0

309. Superposition (overlap) of the astragalus over the calcaneus (lower ankle joint): (0) Little or absent; (1) Weakly developed; (2) Present.
Adalatherium = 1

310. Astragalo-navicular articulation – symmetry to the neck: (0) Articulating facet indistinctive; (1) Asymmetrical: present only on the lateral side of the “neck region”; (2) Symmetrical with regard to the astragalar neck.
Adalatherium = 2

313. Expansion of navicular contact in the astragalar head region: (0) Restricted anteriorly; (1) Asymmetrical spread only to the medial side of the astragalar “head-neck region”; (2) Symmetrical spread of the navicular facet to both the lateral and the medial sides of the neck (symmetrical with regards to the main axis of the neck).
Adalatherium = 2

314. Astragalo-navicular contact shape: (0) Flat to convex; (1) Crest-in-groove: Transverse groove on astralar head to receive crest from navicular.
Adalatherium = 1

315. Astragalar trochlea (defined as a saddle-shaped upper ankle joint): (0) Absent; (1) Present, but weak (defining crest on the medial astragalo-tibial facet weakly developed); (2) Present, with clear separation of the medial and lateral tibial facets.
Adalatherium = 0

316. Well-defined medio-tibial crest (more or less parallel to the tibio-fibular crest) on the astragalus: (0) Absent; (1) Present.
Adalatherium = 1

317. Astragalar medial plantar tuberosity: (0) Absent; (1) Present, but weakly developed; (2) Present, and ventrally flaring or protruding.
Adalatherium = 2

318. Distal end of the calcaneal tubercle: (0) Short, dorso-ventrally compressed, without a terminal swelling; (1) doro-ventrally compressed, with a terminal swelling; (2) Elongate, vertically deep, and mediolaterally compressed, with terminal swelling.
Adalatherium = 2

319. Ventral orientation of terminal swelling of calcaneal tuber: (0) Absent; (1) Present.
UMNH 16771 = ?
Adalatherium = 0

320. Morphology of the peroneal process of the calcaneus: (0) Laterally expanded shelf, larger than the combined length of the sustentacular and astragalar facets, lateral to the astragalar facet; (1) With a distinct and long peroneal process, laterally projecting; (2) With a distinct peroneal process, demarcated by a deep peroneal groove at the base; (3) Laterally directed, small peroneal shelf demarcated from the anterior (cuboidal) edge of the calcaneus; (4) Anterolaterally directed, hypertrophied peroneal process/shelf; (5) Peroneal structure laterally reduced (lateral surface is straight from the calcaneal tubercle).
Adalatherium = 3

321. Placement of the base of the peroneal process relative to the level of the cuboid facet of the calcaneus: (0) Peroneal structure posterior to the level of the cuboid facet; (1) Peroneal structure developed anteriorly at the same level as the cuboid facet; (2) Peroneal structure hypertrophied, extending anteriorly beyond the level of the cuboid facet.
Adalatherium = 0

322. Peroneal groove of the calcaneus: (0) Indistinct, on the anterolateral aspect of the lateral

shelf; (1) Distinct, deep separation of the peroneal process; (2) Weakly developed, with shallow groove on the lateral side of the process; (3) Distinct, on the anterolateral corner of the peroneal process.
Adalatherium = 2

323. Alignment of the cuboid to the main axis of the calcaneus (horizontal plane): (0) On the anterior (distal) end of the calcaneus (the cuboid is aligned with the long axis of the calcaneus); (1) On the anteromedial aspect of the calcaneus (the cuboid is skewed to the medial side of the long axis of the calcaneus):
Adalatherium = 1

324. Orientation of the calcaneocuboid joint in dorso-ventral plane: (0) Calcaneocuboid facet on the calcaneus oriented ventrally (more visible in the plantar view than in dorsal view); (1) Calcaneocuboid facet oriented anteriorly (distally); (2) Calcaneocuboid facet oriented ventromedially or medio-obliquely.
Adalatherium = 2

325. Saddle-shaped calcaneocuboid joint: (0) Calcaneocuboid facet on the calcaneus relatively flat to slightly concave; (1) Saddle-shaped (differentiation of dorsal vs. proximal calcaneocuboid "facets" so that the whole calcaneocuboidal joint is saddle-shaped).
Adalatherium = 0

326. Lower ankle joint - orientation of the sustentacular facet of the calcaneus in relation to the horizontal plane: (0) Nearly vertical; (1) Oblique (≤70 degrees) to nearly horizontal.
Adalatherium = 0

328. Confluence of the sustentacular facet and the astragalar facet on the calcaneus: (0) Absent; (1) Present.
Adalatherium = 0

330. Antero-posterior position of the sustentacular facet/process (using the most salient point of the facet/process in ventral view as landmark) relative to the length of the calcaneus: (0) Near the mid-point; (1) Near the anterior (proximal) one-third.
Adalatherium = 1

331. Shape of posterior calcaneo-astragalar process/protuberance and its contiguous fibular contact (if the fibula contact is present in medial view) on the calcaneus: (0) Indistinctive (boundary not defined and confluent with fibular contact); (1) Well defined, and oblong to ellipsoidal; (2) Nearly spherical and bulbous, more transversely developed than character state 1; (3) Transversely confluent with the sustentacular facet.
Adalatherium = 1

333. Orientation of Calcaneo-Astraglo-Facet (CAF) relative to Calcaneo-Fibulo-Facet (CFF): (0) CAF anterior to CFF; (1) CAF medial to CFF.
Adalatherium = 1

337. Ventral curvature of the calcaneal tubercle: (0) Present; (1) Absent.
Adalatherium = 1

338. Proportion of the navicular and cuboid (transverse width measured in dorsal view): (0) Navicular narrower than or subequal to cuboid; (1) Navicular wider than cuboid.
Adalatherium = 1

339. Proportion of the entocuneiform, mesocuneiform, and ectocuneiform (in ventral view): (0)

Mesocuneiform and ectocuneiform small, their combined width smaller than the width of the entocuneiform; (1) Mesocuneiform and ectocuneiform large, their combined width (in dorsal view) exceeding the width of the entocuneiform.
Adalatherium = 0

341. Medio-plantar aspect of the cuboid deeply notched by the peroneus longus tendon: (0) Absent; (1) Present.
Adalatherium = 1

342. Prehallux: (0) Absent; (1) Present.
Adalatherium = 0

344. Relationships of the proximal end of metatarsal V to the cuboid: (0) Metatarsal V is off-set from the lateral side of the cuboid; (1) Metatarsal V is so far off-set to the side of the cuboid that it contacts the calcaneus; (2) Metatarsal V is level with (not offset from) the anterior end of the cuboid.
Adalatherium = 0/1

345. Ventrolateral tubercle at the proximal end of metatarsal V: (0) Absent or indistinctive; (1) Present, at or anterior to the anterior edge of the calcaneus; (2) Present, off-set posteriorly from the anterior edge of the calcaneus.
Adalatherium = 1/2

346. Angle of metatarsal III to the calcaneus (which indicates how much the sole of the foot is 'bent' from the long axis of the ankle): (0) Metatarsal III aligned with (or parallel to) the long axis of the calcaneus; (1) Metatarsal III arranged obliquely from the long axis of the calcaneus.
Adalatherium = 0

347. Metatarsal II and metatarsal III proximal ends: (0) II and III even or II more proximal than III; (1) III more proximal than II.
Adalatherium = 0

348. Opposable hallux: (0) Absent; (1) Present.
Adalatherium = 0

349(B336). Relative length of metatarsals and proximal phalanx of digit III: (0) PP shorter than MT; (1) PP longer than MT.
Adalatherium = 0

351. Sesamoid bones in the digital flexor tendons: (0) Absent; (1) Present, unpaired; (2) Present, paired.
Adalatherium = 1&2

353. Pes digital grouping: (0) Didactylous; (1) Syndactylous.
Adalatherium = 0

354. SCORED. Epiphyses in long bones: (0) Absent; (1) Present.
Ornithorhynchus= 1
Tachyglossus = 1
Zaglossus= 1
Megalibgwilia= 1
Kryoryctes= 1
Adalatherium = 1

357. Multiple vascular foramina (for rami temporales) in the squamosal and parietal: (0) Absent; (1) Present.
Adalatherium = 0

359. Topographic relationships of the dentary-squamosal contact (or glenoid) and the cranial moiety of the squamosal (only applicable to taxa with the dentary-squamosal joint; this character is best seen in ventral view): (0) Contact on the internal aspect of the zygoma, without a constricted neck; (1) Contact on the zygoma, with a constricted neck; (2) Contact on the cranial moiety of squama; (3) On zygoma, without a constricted neck.
Adalatherium = 1

364. Orientation of the glenoid on the squamosal: (0) On the inner side of the zygoma and facing ventromedially; (1) On the platform of the zygoma and facing ventrally.
Adalatherium = 1

365. Postglenoid process of the squamosal: (0) Absent; (1) Postglenoid crest raised below the fossa, but without a distinctive process; (2) Distinctive process; (3) Distinctive process buttressed by ectotympanic.
Adalatherium = 0

368. Medial margin of the glenoid fossa: (0) Formed by the squamosal; (1) Formed by the alisphenoid.
Adalatherium = 0

373. Cochlear housing fully formed by the petrosal: (0) Absent; (1) Present.
Adalatherium = 1

374. Ventromedial surface of the promontorium: (0) Flat; (1) Inflated and convex.
Adalatherium = 1

375. Lateral wall and overall external outline of the promontorium: (0) Triangular, with a steep and slightly concave lateral wall; (1) Elongate and cylindrical; (2) Bulbous and oval shaped.
Adalatherium = 1

376. Cochlea: (0) Cochlear recess (without a canal); (1) Short canal; (2) Elongate canal, to the fullest extent of the promontorium; (3) slightly curved; (4) Elongate and partly coiled; (5) Elongate and coiled to at least 360°.
Adalatherium = 3

377. Internal acoustic meatus - cribriform plate: (0) Absent; (1) Present.
Adalatherium = 1

379. Primary bony lamina within the cochlear canal: (0) Absent; (1) Present.
Adalatherium = 1

380. Secondary bony lamina for the basilar membrane within the cochlear canal: (0) Absent; (1) Present.
Adalatherium = 1

383. Rostral tympanic process of the petrosal: (0) Absent or low ridge; (1) Tall ridge, but restricted to the posterior half of the promontorium; (2) Well-developed ridge reaching the

anterior pole of the promontorium.
Adalatherium = 1/2

400. EXCLUDED. Vertical component of the lateral flange ('L-shaped' and forming a vertical wall to the pterygoparoccipital foramen): (0) Present; (1) Absent.
NOTES: Character excluded following Rougier et al. (2007).

413. Stapedial artery sulcus on the petrosal: (0) Absent; (1) Present.
Adalatherium = 0

414. Transpromontorial sulcus for the internal carotid artery on the cochlear housing: (0) Absent; (1) Present.
Adalatherium = 0

432. EXCLUDED. Alignment of the incus and the malleus: (0) Posterior-anterior; (1) Posteromedial to anterolateral; (2) Dorsoventral.
NOTES: Character excluded following Rougier et al. (2007).

462. Exit(s) of the infraorbital canal: (0) numerous small foramina of similar size; (1) at least a single large, with smaller, anteroventral accessory foramina; (2) one large foramen.
Adalatherium = 0

463. Composition of the posterior opening of the infraorbital canal (maxillary foramen): (0) Between the lacrimal, palatine, and maxilla; (1) Exclusively enclosed by the maxilla; (2) Enclosed by the maxilla, frontal and palatine.
Adalatherium = 0

464. Size and shape of the lacrimal: (0) Small, oblong-shaped on the facial part of the rostrum; (1) Large, triangle-shaped on the facial portion of rostrum; (2) Crescent shaped on the facial portion of the rostrum; (3) Reduced to an anteroposteriorly narrow strap confined to the antorbital margin; (4) Absent from the facial portion of the rostrum.
Adalatherium = 1

465. Location of the lacrimal foramen: (0) Within the orbit; (1) On the facial side of the lacrimal (anterior to or on the anterior orbital margin).
Adalatherium = 1

466. Number of lacrimal foramina: (0) One; (1) Two.
Adalatherium = 0

467. Lacrimal foramen composition: (0) Within the lacrimal; (1) Bordered by or within the maxilla.
Adalatherium = 0

468. Maximum vertical depth of the zygomatic arch relative to the length of the skull (this character is designed to indicate the robust vs. gracile nature of the zygomatic arch): (0) Between 10-20%; (1) Between 5-7%; (2) Zygoma incomplete.
Adalatherium = 0

469. Ultimate upper molar implanted in the anterior root of zygoma: (0) Absent. (1) Present.
Adalatherium = 0

481. Anterior part of the jugal on the zygoma: (0) Anterior part of the jugal extends to the facial part of the maxilla and forms a part of the anterior orbit; (1) Anterior part of the jugal does not reach the facial part of the maxilla and is excluded from the anterior orbit margin.
Adalatherium = 0

482. Jugal lateral exposure on zygoma: (0) Long, extending to at least 2/3 of the zygoma; (1) short, limited to anterior 1⁄2 of the zygoma; (2) not exposed on lateral aspect of zygoma.
Adalatherium = 0

483. Posterior part of the jugal: (0) Contributes to the squamosal glenoid; (1) Borders on but does not contribute to the squamosal glenoid; (2) Terminates anterior to the squamosal glenoid.
Adalatherium = 1

493. Foramina on the dorsal surface of the nasals: (0) Absent; (1) Present.
Adalatherium = 1

494. Septomaxilla: (0) Present, with the ventromedial shelf; (1) Present, without the ventromedial shelf; (2) Absent.
Adalatherium = 0

495. Internarial/dorsal process of the premaxilla: (0) Present on nasal midline suture; (1) Absent/extremely reduced.
Adalatherium = 0

496. Posterodorsal process of the premaxilla length: (0) Short (i.e, does not extend beyond level of anterior maxillary tooth); (1) intermediate (i.e., extends beyond level of anterior maxillary tooth); (2) long (i.e., contacts frontal posteriorly).
Adalatherium = 0/1

497 Facial part of the premaxilla borders on the nasal: (0) Absent; (1) Present.
Adalatherium = 0

498. Premaxilla - palatal process relative to the canine alveolus: (0) Does not reach to the level of the canine alveolus; (1) Reaches the level of the canine alveolus.
Adalatherium = 1

499. Incisive foramina size: (0) Small (one or two incisors); (1) Intermediate (three or four incisors); (2) Large (more than half the palatal length).
Adalatherium = 1

514. Multi-row and multicuspate molar opposition - Lower molar lingual row tallest anterior cusp a1 occluding into lingual embrasure between upper molars: (0) Absent; (1) Present.
Adalatherium = -

515. Multi-row and multicuspate molar crown: saddle transverse crest between lingual cusp row (usually the tallest a1 on lowers, or A1 on uppers) and buccal cusp row (usually the talliest b2, or B2 on uppers): (0) Absent; (1) Present.
Adalatherium = -

516 Frontal anterior extent location: (0) Posterior to anterior border of orbit; (1) Anterior to orbit but posterior to anterior tip of lacrimal; (2) Anterior to lacrimal.

Adalatherium = 1

518. Contact between nasals and parietals: (0) Absent; (1) Present.
Adalatherium = 0

519. Upper incisor alveolus depth: (0) Shallow (approximately 1.5x the alveolar diameter or less); (1) Deep (at least 2x the alveolar diameter or more).
Adalatherium = 1

520. Upper incisor alveolus orientation: (0) Vertical; (1) Procumbent.
Adalatherium = 1

521. PMX facial process-nasal suture length (only applicable to taxa coded as '1' for char 497): (0) Less than 75% of maxilla-nasal suture length; (1) 75% to subequal to that of the maxilla.
Adalatherium = -

532. Klinorhynchy: (0) Absent; (1) Present, anterior portion of skull is flexed anteroventrally.
Adalatherium = 1

534. Mesiolateral divergence of left and right maxillary tooth rows: (0) Absent; (1) Present.
Adalatherium = 0

537. Stepwise pattern ("en echelon" pattern of Jenkins et al. 1997) in the profile of upper premolar-molar series (applicable only to molars with more than one rows of multiple cusps).
Adalatherium = -

538. Relative width of calcaneus as measured in length-width ratio.
(0) Longer than wide, L/W ratio equal or greater than 150%; (1) Length sub-equal to width, L/W is 140%, or less.
Adalatherium = 0

New characters

539. Olecranon fossa on dorsal face of humerus: (0) Present; (1) Absent.
Thrinaxodon = 0
Massetognathus = 1
Probainognathus = 1
Tritylodontids = 0
Brasilodon = 0
Morganucodon = 0
Haldanodon = 1
Cimolodontans = 0
Ornithorhynchus= 1
Tachyglossus = 1
Zaglossus = 1
Megalibgwilia= 1
Kryoryctes= 0
Repenomamus = 0
Yanoconodon = 0
Priacodon = 0
Akidolestes = 0
Dryolestes = 0

Henkelotherium = 0
Vincelestes = 0
Ukhaatherium = 0
Zalambdalestes = 0
Protungulatum = 0
Erinaceus = 0
Leptictis = 0
Canis = 1
Felis = 1
Rattus = 0
Oryctolagus = 0
Bradypus = 0
Glyptotherium = 0
Dasypus = 0
Chaetophractus = 0
Euphractus = 0
Sulestes = 0
Didelphodon = 0
Mayulestes = 0
Pucadelphys = 0
Didelphis = 0
Marmosa = 0
Caenolestes = 0
Dasyurus = 0
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 0
Acrobates = 0
Phascolarctos = 0
Vombatus = 0
Phalanger = 0
Pseudocheirus = 0
Petauroides = 0
Adalatherium = 0

540. ORDERED. Proximo-distal position of teres major tubercle: (0) Positioned ~25% the total length of the humerus from the proximal end; (1) Positioned ~33% the total length of the humerus from the proximal end; (2) Positioned ~50% the total length of the humerus from the proximal end.
Thrinaxodon = 1
Massetognathus = 2
Probainognathus = 1/2
Tritylodontids = 1
Brasilodon = 2
Morganucodon = 1
Haldanodon = 2
Cimolodontans = 2
Ornithorhynchus = 1
Tachyglossus = 0
Kryoryctes = 1
Zaglossus = 0

Fruitafossor = 2
Gobiconodon = 1/2
Repenomamus = 2
Yanoconodon = 1/2
Priacodon = 1
Akidolestes = 1/2
Dryolestes = 1
Henkelotherium = 1/2
Vincelestes = 1
Erinaceus = 1
Leptictis = 0
Canis = 1
Felis = 0/1
Rattus = 0
Oryctolagus = 0
Bradypus = 1
Tamandua = 1
Dasypus = 1
Chaetophractus = 1
Euphractus = 1
Mayulestes = 0
Pucadelphys = 0
Didelphis = 1
Marmosa = 0
Dasyurus = 1
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 1
Phascolarctos = 1/2
Vombatus = 2
Phalanger = 1
Pseudocheirus = 1
Petauroides = 1

541. Location of entepicondylar foramen: (0) Marginal; (1) Not marginal, closer to centre of entepicondyle.
Thrinaxodon = 0
Massetognathus = 0
Probainognathus = 0
Tritylodontids = 0
Pachygenelus = 0
Brasilodon = 1
Morganucodon = 0
Haldanodon = 0
Shenshou = 1
Cimolodontans = 0
Ornithorhynchus = 0
Tachyglossus = 1
Kryoryctes = 0
Zaglossus = 1
Megalibgwilia = 1

Fruitafossor = 0
Gobiconodon = 0
Repenomamus = 0
Priacodon = 0
Akidolestes = 0
Zhangheotherium = 1
Dryolestes = 0
Vincelestes = 0
Zalambdalestes = 0
Protungulatum = 0
Erinaceus = -
Leptictis = 0
Canis = 0
Felis = 0
Rattus = -
Oryctolagus = -
Tamandua = 1
Glyptotherium = 0
Dasypus = 0
Chaetophractus = 0/1
Euphractus = 1
Sulestes = 0
Didelphodon = 0
Mayulestes = 0
Pucadelphys = 0
Didelphis = 0
Marmosa = 0
Caenolestes = 0
Dasyurus = 0
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 0
Acrobates = 1
Phascolarctos = 0
Vombatus = 0
Phalanger = 0
Pseudocheirus = 0
Petauroides = 0
Adalatherium = 0

542. Orientation of the inter-epicondylar axis with respect to long axis of humerus: (0) ~90°; (1) 75-80°.
Thrinaxodon = 0
Massetognathus = 0
Probainognathus = 0
Tritylodontids = 0
Pachygenelus = 0
Brasilodon = 0
Morganucodon = 1
Haldanodon = 0

Agilodocodon = 0
Shenshou = 0
Maiopatagium = 0
Cimolodontans = 0
Ornithorhynchus = 1
Tachyglossus = 1
Kryoryctes = 0
Zaglossus = 1
Megalibgwilia = 1
Fruitafossor = 1
Repenomamus = 0
Yanoconodon = 0
Priacodon = 0
Akidolestes = 0
Zhangheotherium = 0
Dryolestes = 0
Henkelotherium = 0
Vincelestes = 0
Juramaia = 0
Zalambdalestes = 0
Protungulatum = 0
Erinaceus = 0
Leptictis = 0
Canis = 0
Felis = 0
Rattus = 0
Oryctolagus = 0
Bradypus = 0
Tamandua = 0
Glyptotherium = 0
Dasypus = 0
Chaetophractus = 0
Euphractus = 0
Sulestes = 0
Mayulestes = 0
Pucadelphys = 0
Didelphis = 0
Marmosa = 0
Caenolestes = 0
Dasyurus = 0
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 0
Acrobates = 0
Phascolarctos = 0
Vombatus = 0
Phalanger = 0
Pseudocheirus = 0
Petauroides = 0
Adalatherium = 0

543. Position of humeral contribution to elbow joint: (0) Central/medial position (more closely aligned with long axis of humerus); (1) Laterally positioned.

Thrinaxodon = 1
Massetognathus = 0
Tritylodontids = 0
Pachygenelus = 0
Brasilodon = 0
Morganucodon = 0
Haldanodon = 0
Castorocauda = 1
Agilodocodon = 1
Shenshou = 0
Cimolodontans = 0
Ornithorhynchus = 1
Tachyglossus = 1
Kryoryctes = 0
Zaglossus = 1
Megalibgwilia = 1
Fruitafossor = 1
Repenomamus = 0
Yanoconodon = 0
Priacodon = 0
Akidolestes = 0
Zhangheotherium = 0
Dryolestes = 0
Henkelotherium = 0
Vincelestes = 0
Juramaia = 0
Ukhaatherium = 1
Zalambdalestes = 0
Protungulatum = 0
Erinaceus = 0
Leptictis = 0
Canis = 0
Felis = 0
Rattus = 0
Oryctolagus = 0
Bradypus = 0
Tamandua = 0
Glyptotherium = 0
Dasypus = 0
Chaetophractus = 0
Euphractus = 0
Sulestes = 0
Mayulestes = 0
Pucadelphys = 0
Didelphis = 0
Marmosa = 0
Caenolestes = 0

Dasyurus = 0
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 0
Acrobates = 0
Phascolarctos = 0/1
Vombatus = 0
Phalanger = 0
Pseudocheirus = 0
Petauroides = 0
Adalatherium = 0

544. Width of distal humerus: (0) <50% humerus length; (1) >50% humerus length.
Thrinaxodon = 0
Massetognathus = 0
Probainognathus = 0
Tritylodontids = 0
Pachygenelus = 0
Brasilodon = 0
Sinoconodon = 0
Morganucodon = 0
Megazostrodon = 0
Haldanodon = 1
Agilodocodon = 0
Xianshou linglong = 0
Xianshou songae = 0
Shenshou = 0
Vilevolodon = 0
Maiopatagium = 0
Plagiaulacids = 0
Cimolodontans = 0
Ornithorhynchus = 1
Tachyglossus = 1
Kryoryctes = 1
Zaglossus = 1
Megalibgwilia = 1
Fruitafossor = 1
Gobiconodon = 0
Repenomamus = 0
Spinolestes = 0
Yanoconodon = 0
Jeholodens = 0
Priacodon = 0
Akidolestes = 0
Zhangheotherium = 0

Dryolestes = 0
Henkelotherium = 0
Vincelestes = 0
Juramaia = 0
Ukhaatherium = 0
Zalambdalestes = 0
Protungulatum = 0
Erinaceus = 0
Leptictis = 0
Canis = 0
Felis = 0
Rattus = 0
Oryctolagus = 0
Bradypus = 0
Tamandua = 0
Glyptotherium = 0
Dasypus = 0
Chaetophractus = 0
Euphractus = 0
Sinodelphys = 0
Asiatherium = 0
Mayulestes = 0
Pucadelphys = 0
Didelphis = 0
Marmosa = 0
Caenolestes = 0
Dasyurus = 0
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 0
Acrobates = 0
Phascolarctos = 0
Vombatus = 0
Phalanger = 0
Pseudocheirus = 0
Petauroides = 0
Adalatherium = 0

545. Estimated body mass: (0) <500g; (1) >500g.
Thrinaxodon = 1
Massetognathus = 1
Probainognathus = 1
Tritylodontids = 1
Brasilitherium = 0
Brasilodon = 0
Sinoconodon = 1

Morganucodon = 0
Megazostrodon = 0
Haldanodon = 0
Castorocauda = 1
Docofossor = 0
Agilodocodon = 0
Megaconus = 0
Cifelliodon = 1
Haramiyavia = 0
Arboroharamiya = 0
Xianshou linglong = 0
Xianshou songae = 0
Shenshou = 0
Vilevolodon = 0
Maiopatagium = 0
Vintana = 1
Rugosodon = 0
Kuehneodon = 0
Sinobaatar = 0
Plagiaulacids = 0
Cimolodontans = 1
Hadrocodium = 0
Shuotherium = 0
Pseudotribos = 0
Asfaltomylos = 0
Ambondro = 0
Ausktribosphenos = 0
Bishops = 0
Kollikodon = 1
Teinolophos = 0
Steropodon = 1
Obdurodon = 1
Ornithorhynchus = 1
Tachyglossus = 1
Kryoryctes = 1
Zaglossus = 1
Megalibgwilia = 1
Fruitafossor = 0
Gobiconodon = 0
Repenomamus = 1
Spinolestes = 0
Amphilestes = 0
Yanoconodon = 0
Jeholodens = 0
Priacodon = 0
Tinodon = 0
Spalacotherium = 0

Zhangheotherium = 0
Maotherium = 0
Dryolestes = 0
Henkelotherium = 0
Vincelestes = 1
Nanolestes = 0
Kielantherium = 0
Aegialodon = 0
Montanalestes = 0
Prokennalestes = 0
Murtoilestes = 0
Eomaia = 0
Juramaia = 0
Kennalestes = 0
Asioryctes = 0
Ukhaatherium = 0
Zalambdalestes = 0
Daulestes = 0
Aspanlestes = 0
Eoungulatum = 0
Cimolestes = 0+1
Gypsonictops = 0
Protungulatum = 0
Erinaceus = 1
Leptictis = 1
Canis = 1
Felis = 1
Rattus = 0
Oryctolagus = 1
Bradypus = 1
Tamandua = 1
Glyptotherium = 1
Dasypus = 1
Chaetophractus = 1
Euphractus = 1
Holoclemensia = 0
Sinodelphys = 0
Deltatheridium = 0
Atokatheridium = 0
Sulestes = 0
Asiatherium = 0
Kokopellia = 0
Anchistodelphys = 0
Albertatherium = 0
Didelphodon = 1
Pediomys = 0
Turgidodon = 0

Mayulestes = 0
Pucadelphys = 0
Didelphis = 1
Marmosa = 0
Caenolestes = 0
Dasyurus = 1
Perameles = 0+1
Dromiciops = 0
Thylacomyidae = 1
Macropus = 1
Acrobates = 0
Phascolarctos = 1
Vombatus = 1
Phalanger = 1
Pseudocheirus = 1
Petauroides = 1
Adalatherium = 1
NOTES: This character is taken from Phillips et al. (2009: character 440). Body mass in mammals shows high phylogenetic signal (Capellini et al. 2010: table 1), and similar characters have been used in phylogenetic analyses of different mammalian clades (e.g. Yates 2014, Cramb et al. 2023); we therefore feel it is suitable for use as a phylogenetic character.

546. Mandibular aspect ratio for most of the length of the dentary below the tooth row, or homologous section (0) depth at least equal to width; (1) depth less than width.
Thrinaxodon = 0
Massetognathus = 0
Probainognathus = 0
Tritylodontids = 0
Pachygenelus = 0
Brasilitherium = 0
Brasilodon = 0
Sinoconodon = 0
Morganucodon = 0
Megazostrodon = 0
Haldanodon = 0
Castorocauda = 0
Docofossor = 0
Agilodocodon = 0
Megaconus = 0
Haramiyavia = 0
Arboroharamiya = 0
Xianshou linglong = 0
Xianshou songae = 0
Shenshou = 0
Vilevolodon = 0
Rugosodon = 0
Kuehneodon = 0

Sinobaatar = 0
Plagiaulacids = 0
Cimolodontans = 0
Hadrocodium = 0
Shuotherium = 0
Pseudotribos = 0
Asfaltomylos = 0
Ambondro = 0
Ausktribosphenos = 0
Bishops = 0
Kollikodon = 0
Teinolophos = 0
Steropodon = 0
Obdurodon = 0
Ornithorhynchus = 1
Tachyglossus = 1
Zaglossus = 1
Fruitafossor = 0
Gobiconodon = 0
Repenomamus = 0
Spinolestes = 0
Amphilestes = 0
Yanoconodon = 0
Jeholodens = 0
Trioracodon = 0
Priacodon = 0
Tinodon = 0
Akidolestes = 0
Spalacotherium = 0
Zhangheotherium = 0
Maotherium = 0
Dryolestes = 0
Henkelotherium = 0
Amphitherium = 0
Peramus = 0
Vincelestes = 0
Nanolestes = 0
Kielantherium = 0
Montanalestes = 0
Prokennalestes = 0
Eomaia = 0
Juramaia = 0
Kennalestes = 0
Asioryctes = 0
Ukhaatherium = 0
Zalambdalestes = 0
Daulestes = 0

Aspanlestes = 0
Eoungulatum = 0
Cimolestes = 0
Gypsonictops = 0
Protungulatum = 0
Erinaceus = 0
Leptictis = 0
Canis = 0
Felis = 0
Rattus = 0
Oryctolagus = 0
Bradypus = 0
Tamandua = 0
Glyptotherium = 0
Dasypus = 0
Chaetophractus = 0
Euphractus = 0
Sinodelphys = 0
Deltatheridium = 0
Sulestes = 0
Asiatherium = 0
Kokopellia = 0
Didelphodon = 0
Pediomys = 0
Turgidodon = 0
Mayulestes = 0
Pucadelphys = 0
Andinodelphys = 0
Didelphis = 0
Marmosa = 0
Caenolestes = 0
Dasyurus = 0
Perameles = 0
Dromiciops = 0
Thylacomyidae = 0
Macropus = 0
Acrobates = 0
Phascolarctos = 0
Vombatus = 0
Phalanger = 0
Pseudocheirus = 0
Petauroides = 0
Adalatherium = 0

References

I. Capellini, C. Venditti, R. A. Barton, Phylogeny and metabolic scaling in mammals. *Ecology* **91**, 2783–2793 (2010).

M. A. Celik, M. J. Phillips, Conflict resolution for Mesozoic mammals: Reconciling phylogenetic incongruence among anatomical regions. *Front. Genet.* **11**, 0651 (2020).

J. Cramb, S. Hocknull, R. M. D. Beck, S. Kealy, G. J. Price, *Urrayira whitei* gen. et sp. nov.: a dasyuromorphian (Mammalia: Marsupialia) with incipient zalambdodonty from the Middle Pleistocene of Queensland, Australia. *Alcheringa* **47**, 551–561 (2023).

A. K. Huttenlocker, D. M. Grossnickle, J. I. Kirkland, J. A. Schultz, Z. X. Luo, Late-surviving stem mammal links the lowermost Cretaceous of North America and Gondwana. *Nature* **558**, 108–112 (2018).

F. A. Jenkins, Jr., S. M. Gatesy, N. H. Shubin, W. W. Amaral, Haramiyids and Triassic mammalian evolution. *Nature* **385**, 715–718 (1997).

D. W. Krause *et al.*, Skeleton of a Cretaceous mammal from Madagascar reflects long-term insularity. *Nature* **581**, 421–427 (2020).

T. Martin, Mammalian postcranial bones from the Late Jurassic of Portugal and their implications for forelimb evolution. *J. Vertebr. Paleontol.* **33**, 1432–1441 (2013).

M. J. Phillips, T. H. Bennett, M. S. Y. Lee, Molecules, morphology, and ecology indicate a recent, amphibious ancestry for echidnas. *Proc. Natl. Acad. Sci. U.S.A.* **106**, 17089–17094 (2009).

H. E. Ramirez-Chaves, V. Weisbecker, S. Wroe, M. J. Phillips, Resolving the evolution of the mammalian middle ear using Bayesian inference. *Front. Zool.* **13**, 39 (2016).

T. H. Rich *et al.*, The mandible and dentition of the Early Cretaceous monotreme *Teinolophos trusleri*. *Alcheringa* **40**, 475-501 (2016).

G. W. Rougier, A. G. Martinelli, A. M. Forasiepi, M. J. Novacek, New Jurassic mammals from Patagonia, Argentina: a reappraisal of australosphenidan morphology and interrelationships. *Amer. Mus. Novit.* **3566**, 1-54 (2007).

A. M. Yates, New craniodental remains of *Thylacinus potens* (Dasyuromorphia: Thylacinidae), a carnivorous marsupial from the late Miocene Alcoota Local Fauna of central Australia. *PeerJ* **2**, e547 (2014).