Supporting Online Material

An Early Cretaceous Tribosphenic Mammal and Metatherian Evolution

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for

Science

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Zhe-Xi Luo[1,2*], Qiang Ji[2,3], John R. Wible[1], and Chong-Xi Yuan[4]

[1]Carnegie Museum of Natural History, Pittsburgh, PA 15213, USA
[2]Department of Earth Science, Nanjing University, Nanjing, 200017, Nanjing, China
[3]The Chinese Academy of Geological Sciences, Beijing 100037, China
[4]China University of Geosciences, Beijing 100083, China

[*]Correspondence author: Zhe-Xi Luo (luoz@carnegiemuseums.org)

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Supplementary Information

Class Mammalia
Subclass Theria
Infraclass Metatheria
Order and Family incertae sedis
Sinodelphys szalayi *gen. et sp. nov*

Etymology. *Sino* (Latin): China; *delphys* (Greek): uterus, commonly used suffix for marsupial taxa; *szalayi*: in honor of Dr. F. S. Szalay for his pioneer studies of metatherian evolution.

Holotype: CAGS00-IG03 (Text-Fig. 1. Supporting Online Material Figs. 1 and 2. Chinese Academy of Geological Sciences, Institute of Geology), an incomplete, flattened skeleton with some preserved soft tissues; parts of hindlimb, pes, and shoulder girdle preserved on fragments of a counter-slab. **Locality and age:** Lacustrine beds of the Yixian Formation at the Dawangzhangzi Locality, Lingyuan County, Liaoning, China. The locality is correlated with the main fossiliferous horizon of the Yixian at the Sihetun site that was dated as 124.6 ma in the lower Barremian stage of the Lower Cretaceous (Swisher et al. 1999).

Differential Diagnosis: *Sinodelphys szalayi* differs from Early Cretaceous eutherians in having four (instead of five) premolars (Kielan-Jaworowska and Dashzeveg 1989; Sigogneau-Russell et al. 1992; Cifelli 1999; Ji et al. 2002). *S. szalayi* differs from *Eomaia* and Late Cretaceous eutherians with preserved skeletal parts in having numerous metatherian-like skeletal apomorphies, including: enlarged hamate, scaphoid and triquetrum in the carpals, navicular facet extending on the lateral side of the astragalar head and neck, a broad navicular in the tarsals; a sigmoid profile for the ectepicondylar shelf of the humerus, and a strongly developed supraspinous fossa and a more pronounced supraspinous notch of the scapula. All of these are well-decumented features of metatherians (Szalay 1994; Marshall et al. 1995; Muizon 1998; Horovitz and Sánchez-Villagra 2003). Although similar to metatherians including deltatheroidans in having seven lower postcanine loci and four upper molars, *S. szalayi* is more plesiomorphic in lacking the fully inflected mandibular angular process of the latter (Sánchez-Villagra and Smith 1997; Rougier et al. 1998). Similar to several Asiatic Cretaceous metatherians and the North American metatherian *Kokopellia* in the approximation of the entoconid and the hypoconulid of the lower molars (Cifelli and Muizon 1997; Averianov and Kielan-Jaworowska 1999); differs from Late Cretaceous North American metatherians and crown marsupials in lacking the full twinning of these cusps (Clemens 1966; Reig et al. 1987); differs from deltatheroidans (with putative metatherian affinities) and other Cretaceous Asian metatherians (Szalay and Trofimov 1996; Rouger et al. 1998) in dental formula. It differs from deltatheroidans (Cifelli 1993; Kielan-Jaworowska and Cifelli 2001) and stem boreosphenidans (Luo et al. 2001; 2002; Sigogneau-Russell et al. 2001) in having a much larger talonid with well-developed entoconid. Differs from *Ambondro*, *Asfaltmylos*, *Ausktribosphenos*, and *Bishops* (stem autralosphenidans) and the toothed monotremes in lacking a shelf-like mesial cingulid on the lower molars (Rich et al. 1997; 1999; Flynn et al. 1999; Rauhut et al. 2002; Luo et al. 2002).

Supporting Online Materials to Text-Figure Captions

Text Fig. 2 (Supporting Online Material to the caption): the forefoot (manus) of metatherians (including *Sinodelphys*) is characterized by derived characters: hypertrophied hamate (relative to capitate), enlarged triquetrum (relative to lunate), enlarged scaphoid (relative to lunate and/or trapezium), and reduced and bean-shaped trapezium. By contrast, the manus of eutherians is characterized by plesiomorphic features: small hamate and scaphoid, and an oblong trapezium. The hindfoot (pes) of metatherians is characterized by a transversely broad but antero-posteriorly short navicular, corresponding to a navicular facet spread laterally onto the lateral side of the astragalar head and neck. By contrast, the tarsals of the known Cretaceous eutherians (including *Eomaia*) have a transversely narrow but proximodistally elongate navicular; and the navicular facet is restricted to the anterior end of the astraglar head (Kielan-Jaworowska 1977, 1978; Horovitz 2000; Ji et al. 2002).

Text Fig. 3 (Supporting Online Material to the caption): Tarsal apomorphies of major cladogram nodes. Crown therian Node (1): distinctive neck between the navicular facet ("head") and the upper ankle contact of the astragalus; medially extended sustentacular process of the calcaneus. Metatherian node (2): asymmetrical head with the navicular facet spread to the medial side of the neck, oblique calcaneocuboid facet, antero-ventral tubercle (to buttress the cuboid facet), presence of an anteriorly placed base of the peroneal process, triangular outline (in ventral view) of the sustentacular process; plus one plesiomorphy of a reduced astragalar medial plantar tubercle (present in some non-metatherians) (Szalay 1994; Muizon 1998; Szalay and Sargis 2001; this study). Eutherian node (3): well-defined crest separating the mediotibial from the laterotibial facets (Kielan-Jaworowska 1977, 1978; Horovitz 2000; Ji et al. 2002), crested astragalar medial plantar tubercle (Kielan-Jaworowska 1977, 1978), navicular facet ("head") symmetrical to the axis of the neck, shelf-like sustentacular process (in ventral view); plus the following plesiomorphies (present outside crown therians): anteriorly restricted navicular facet of the astragalus; anteriorly oriented cuboid facet of the calcaneus; flat or grooved anterior ventral surface of the calcaneus (in Cretaceous eutherians), and base of the peroneal process off-set posteriorly from the cuboid facet.

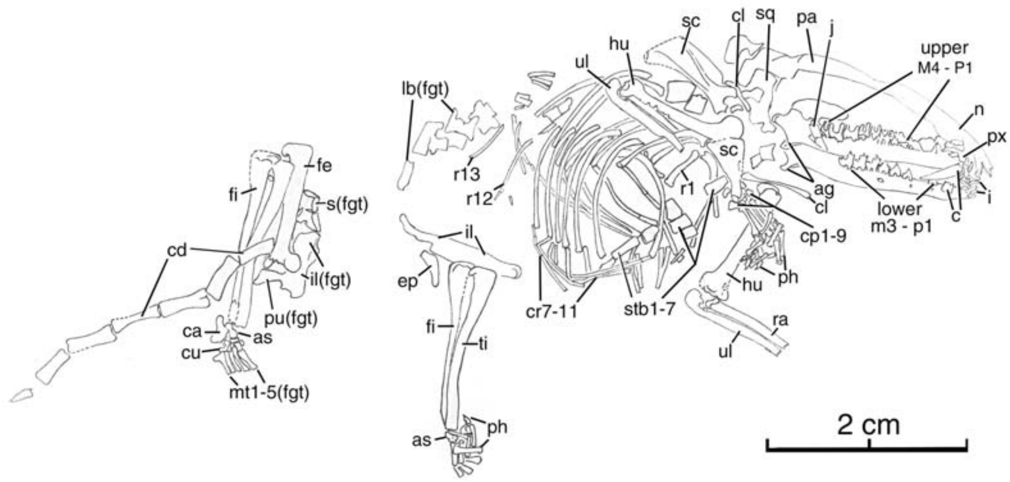
Text Fig. 4 (Supporting Online Material to the caption). The phylogenetic relationships of *Sinodelphys* to all other mammaliaforms are from PAUP4.0b10 (Swofford 2000) searches with the following parameters: Data matrix has 84 taxa, 1 taxon (*Thrinaxodon*) transferred to outgroup; number of ingroup taxa = 83. 380 characters; all characters are unordered; all characters have equal weight; number of parsimony-informative characters = 379.

Heuristic search settings: Optimality criterion = parsimony, both ACCTRAN and DELTRAN optimizations yielded the same strict consensus tree. Multistate taxa interpreted as polymorphism; starting tree(s) obtained via stepwise addition, with random addition sequence. Number of replicates of heuristic searches = 1000; branch-swapping algorithm: tree-bisection-reconnection (TBR); steepest descent option in effect; branches collapsed (creating polytomies) if maximum branch length is zero; only 1 tree was saved per replicate.

Parsimony score of each of the 224 equally parsimonious trees (EPT's): Tree length =1700; Consistency Index (CI) = 0.427; retention index (RI) = 0.805; rescaled consistency index (RC) = 0.344; homoplasy index (HI) = 0.611.

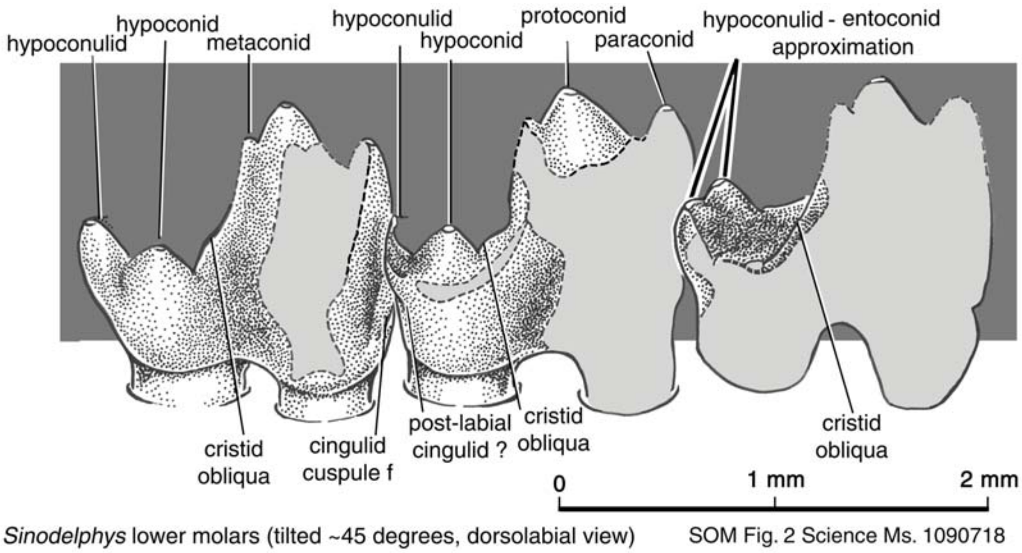
Figure 4A. The strict consensus of 224 equally parsimonious trees. Figure 4B. Time and geographic patterns of boreosphenidan taxa considered in this study. Topology in Fig. 4B is based on the Adams consensus from the 224 EPT trees resulting in a better resolution with more relax consensus criteria (A complete Adams consensus tree is provided in the PAUP output file in SOM). Geochronological distribution of boreosphenidan taxa based on Kielan-Jaworowska et al. (in press). The minimal age of *Sinodelphys* after Swisher et al. (1999); the age for the North American metatherians after Clemens (1966), Cifelli (1993), Kielan-Jaworowska and Cifelli (2001); age of the Uzbekistan metatherians after Kielan-Jaworowska and Nessov (1990), Averianov and Kielan-Jaworowska (1999); dating of the Mongolian taxa after Szalay and Trofimov (1996), Rougier et al. (1998); and dating of the South America metatherians after Muizon (1998), Muizon et al. (1997). Molecular estimate of divergence of marsupial ordinal clades after Springer (1997). Timelines for the Cretaceous Stages after Gradstein et al. (1995).

Part II. Figures for Supporting Online Material



Sinodelphys skeleton (CAGS00-IG03, Main slab of holotype) SOM-Fig. 1 (Ms. 1090718)

SOM - Fig. 1. *Sinodelphys szalayi* (Chinese Academy of Geological Sciences CAGS00-IG03) ***gen. et sp. nov***. The main slab of the holotype specimen (photograph in main-text figure 1A) and its preserved osteological features. Abbreviations: ag, mandibular angular process; as, astragalus; c, canine; ca, calcaneus; cd, caudal vertebrae; cl, clavicle; cp1-9; carpals 1 through 9; cr7-11, costal cartilages 7 through 11; cu, cuboid; ep, epipubis; fe, femur; fgt, fragmentary bones; fi, fibula; hu, humerus; i, incisors; il, ilium; j, jugal; lb, lumbar vertebrae; M/m, upper or lower molars; mt1-5, metatarsals 1-5; n, nasal; P/p upper or lower premolars; pa, parietal; ph, phalanges (either manus or pes); pu, pubis; px, premaxilla; ra, radius; r1 - r13, thoracic ribs 1 through 13; s, sacral vertebrae; sc, scapula; sq, squamosal; stb1-7, sternebrae 1 to 7 (sternebra 7 is the xiphoid); ti, tibia; ul, ulna.



SOM -Fig. 2. *Sinodelphys szalayi* (CAGS00-IG03): right molars in dorso-labial view (oblique angle of $\sim 45^{o}$). Because the specimen is laterally compressed, this is the only view in which the molar talonid structure can be seen. The lingual side of the talonid is fully exposed only on m1; it is not visible on m2 and 3 due to coverage by matrix and the left mandible. The light gray areas represent the damaged enamel surface of the molars. The dark gray background outside the teeth represents the matrix and other bone fragments that have obscured parts of the talonid. Dashed outlines of m2-m3 trigonids are based on outline of the mold or silhouette of the damaged crown. Dashed outline of m1 trigonid is a restoration. (Please note that because the teeth are tilted obliquely by about 45 degrees, the cusp proportions are different from those seen in lateral view). Quantitative comparison of the entoconid-hypoconulid distance in *Sinodelphys* and other crown therian mammals is provided in Character 83 in Part IV. Character Description.

Part III. Sources of Systematic Characters

The goals of this phylogenetic analysis are to establish the hierarchical relationships of *Sinodelphys* with regard to: (1) the currently known stem metatherians of the Cretaceous; (2) the early Tertiary metatherians with relatively complete skull and postcranium; (3) the major clades of the crown group of marsupials; (4) the currently known stem eutherians (such as *Eomaia*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, plus the major Late Cretaceous eutherian clades) and putative "eutherians" (*Ausktribosphenos* and *Bishops* discovered by Rich et al. 1997, 1999) or stem australosphenidans (sensu Luo et al. 2001a; 2002); and (5) the currently known pretribosphenic zatherians (see Sigoneau-Russell 1999; Martin 2002), and pretribosphenic trechnotherians (sensu McKenna 1975; Prothero, 1981; McKenna and Bell 1997) in which the stem boreosphenidan mammals are nested.

We also include in this analysis a wide selection of non-mammalian cynodonts and mammaliaforms, in order to ascertain whether (or to what extent) the hypotheses of relationships of *Sinodelphys*, as proposed here, would be consistent with (or contradicted by) previously established phylogenies of all mammaliaform clades on the basis of global parsimony of the available morphological evidence (see text Figure 5).

The systematic characters in this analysis are selected for the purpose of testing these hypotheses of relationships.

The main systematic characters for resolving the relationships of *Sinodelphys* to stem taxa of eutherians and metatherians are adopted from many previous studies, as summarized by Marshall et al. (1990), Cifelli (1993), Szalay (1994), Marshall and Muizon (1995), Marshall and Sigogneau-Russell (1995), Szalay and Trofimov (1996), Springer et al. (1997), Muizon et al. (1997), Muizon (1998), Rougier et al. (1998), Averianov and Kielan-Jaworowska (1999), Horovitz (2000, 2003), Kielan-Jaworowska and Cifelli (2001), Ji et al. (2002), Luo et al. (2002) and Horovitz and Sánchez-Villagra (2003). These are also supplemented with our original observations. Many characters used in previous studies are modified (e.g., modified definition of characters and character states, and reorganization of character states) in order to suit the goals of placing *Sinodelphys* in the phylogeny of all mammaliaforms.

To help explore the implications of the basal metatherian taxa for crown marsupial phylogeny, we included many characters that have been shown to be informative for modern marsupial orders (Reig et al. 1987; Wible 1990; Marshall et al. 1990; Szalay 1994; Springer et al. 1997; Muizon et al. 1997; Rougier et al. 1998; Muizon 1998; Wroe et al. 2000; Horovitz and Sánchez-Villagra 2003).

For resolving the relationships of primitive mammals outside the crown therian groups, the morphological characters used here are from a number of references: Crompton (1971), Fox (1975), McKenna (1975), Crompton and Kielan-Jaworowska (1978), Prothero (1981), Kemp (1983), Sues (1985), Clemens and Lillegraven (1986), Kielan-Jaworowska et al. (1987), Rowe (1988), Kielan-Jaworowska and Dashzeveg (1989), Lillegraven and Krusat (1991), Wible (1990, 1991, 2003), Sigogneau-Russell et al. (1992), Cifelli (1993), Wible and Hopson (1993), Rougier (1993), Kielan-Jaworowska and Gambaryan (1994), Luo (1994), Szalay (1994), Muizon (1994), Marshall and Sigogneau-Russell (1995), Marshall and Muizon (1995), Archibald (1996), Rougier et al. (1996), Cifelli and Muizon (1997), Hu et al. (1997), Kielan-Jaworowska (1997), Novacek et al. (1997), Nessov et al. (1998), Muizon (1998), Rougier et al. (1998), Sigogneau-Russell (1999), Averianov and Skuschas (1999), Ji et al. (1999), Butler (2000), Horovitz (2000, 2003), Luo et al. (2001a, b), Averianov and Skuschas (2001), Archibald et al. (2001), Wible et al. (2001, in press), Martin (2002), Luo et al. (2002).

Part IV. Character Description

Mandible (33 characters)

1. Post-dentary trough (behind the tooth row):
(0) Present; (1) Absent.

2. Separate scars for the surangular/prearticular in the post-dentary trough:
(0) Present; (1) Absent.

3. Overhanging medial ridge above the post-dentary trough (behind the tooth row):
(0) Present; (1) Absent.

4. Degree of development of Meckel's sulcus:
(0) Well developed; (1) Weakly developed; (2) Vestigial or absent.

5. Curvature of Meckel's sulcus (under the tooth row):
(0) Parallel to the ventral border of the mandible; (1) Convergent on the ventral border of the mandible.

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

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 inflected; (4) Present, strongly inflected, and continuing anteriorly as the mandibular shelf.

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).

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).

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

11. Coronoid bone (or its attachment scar):
(0) Present; (1) Absent.

12. Location of the mandibular foramen (posterior opening of the mandibular canal):
(0) Within the postdentary trough and in alignment with the posterior end 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.

13. Concavity (fossa) for the reflected lamina of the angular bone on the medial side of the dentary angular process:
(0) Present; (1) Absent.

14. Splenial bone as a separate element (as indicated by its scar on the dentary):
(0) Present; (1) Absent.

15. 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.

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

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

18. Medial pterygoid ridge (shelf) along the ventral border of the ramus of the mandible:
(0) Absent; (1) Present; (2) Pterygoid shelf present and reaching the dentary condyle via a low crest.

19. 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.

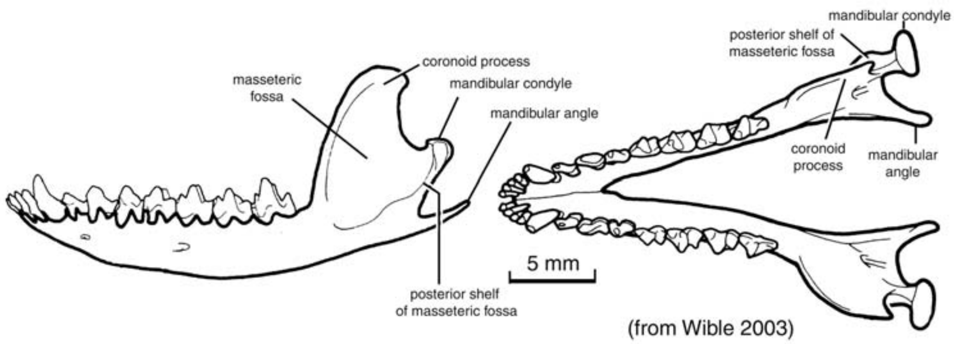
20. Crest of the masseteric fossa along the anterior border of the coronoid process:
(0) Absent or weakly developed; (1) Present and laterally flaring; (2) Hypertrophied and laterally flaring.

21. 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.

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

23. 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 the mandible; (2) Present as a thick, vertical crest. Character state definition for (2) is illustrated below.



24. Posterior-most mental foramen:
(0) In the canine and anterior premolar (premolariform) region (in the saddle behind the canine eminence of the mandible); (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.

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

26. 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.

27. Orientation of the dentary peduncle (condylar process) and condyle:
(0) Dentary peduncle more posteriorly directed; (1) Dentary condyle continuous with the semicircular posterior margin of the dentary; the condyle is facing up due to the up-turning of the posterior-most part of the dentary; (2) Dentary articulation extending vertically for the entire depth of the posterior manidbular ramus; it is confluent with the ramus and without a peduncle; the dentary articulation is posteriorly directed;
(3) More vertically directed dentary peduncle.

28. Ventral (inferior) border of the dentary peduncle:

(0) Posteriorly tapering; (1) Columnar and with a lateral ridge; (2) Ventrally flaring; (3) Robust and short; (4) Ventral part of the peduncle and condyle continuous with the ventral border of the mandible.

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

30. 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 ($\geq 150^{o}$); (1) Coronoid process less reclined (135^{o}-145^{o}); (2) Coronoid process less than vertical (110^{o}-125^{o}); (3) Coronoid process near vertical (95^{o} to 105^{o}).

31. Alignment of the ultimate molar (or posteriormost postcanine) to the anterior margin of the dentary coronoid process (and near the coronoid scar if present):
(0) Ultimate molar medial to the coronoid process; (1) Ultimate molar aligned with the coronoid process.

32. Direction of lower jaw movement during occlusion (as inferred from teeth):
(0) Dorsomedial movement; (1) Dorsomedial movement with a significant medial component; (2) Dorsoposterior movement.

33. Dentary symphysis:
(0) Fused; (1) Unfused.

Premolars (16 characters)

34. Ultimate upper premolar - metastylar lobe:
(0) Reduced or absent; (1) Enlarged and wing-like.

35. Ultimate upper premolar - metacone or metaconal swelling:
(0) Absent; (1) Present.

36. Ultimate upper premolar - protocone or protoconal swelling:
(0) Little or no lingual swelling; (1) Present.

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

38. Position of the tallest posterior upper premolar within the premolar series:
(0) Absent; (1) In ultimate premolar position; (2) In penultimate premolar position.

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

40. Ultimate lower premolar - symmetry of the main 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).

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

42. 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).

43. Ultimate lower premolar - posterior (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.

44. Ultimate lower premolar - outline:
(0) Laterally compressed (or slightly angled); (1) Transversely wide (by trigonid); (2) Transversely wide (by talonid).

45. Ultimate lower premolar - labial cingulid:
(0) Absent or vestigial; (1) Present (at least along the length of more than half of the crown).

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

47. 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) Posterior cusp c distinctive but less than 30% of the primary cusp a; (1) Posterior cusp c and primary cusp a equal or subequal in height (c is 40%-100% of a).

48. Penultimate lower premolar - paraconid (=cusp b):
(0) Absent; (1) Present but not distinctive; (2) Present and distinctive.

49. 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) 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 in longitudinal row(s).

Molar Morphology (68 characters)

50. Alignment of the main cusps of the anterior lower molar(s) (justification for separating this feature from the next character on the list): Several taxa of "obtuse-angled symmetrodonts" and eutriconodont amphilestids show a gradient of variation in cusp triangulation along the molar series; the degree of triangulation may be different between the anterior and posterior molars).
(0) Single longitudinal row; (1) Reversed triangle–acute (≤90°); (2) Multiple longitudinal multicuspate rows.

51. Triangulation of cusps in posterior molars:
(0) Absent; (1) Multi-row and multi-cuspate; (2) Posterior molars slightly triangulated; (3) Posterior molars fully triangulated.

52. 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.

53. Development of postvallum shear (on the upper second molar; applicable to molars with reversed triangulation of cusps) (increasing the ranks of postvallum shear and can be ordered):
(0) Present but only by the first rank: postmetacrista; (1) Present, with the addition of a second rank (postprotocrista below postmetacrista) but the second rank does not reach labially below the base of the metacone; (2) Metacingulum/metaconule present, in addition to postprotocrista, but the metacingulum crest does not extend beyond the base of the metacone; (3) Metacingulum extended beyond metacone; (4) Metacingulum extended to the metastylar lobe; (5) Second rank postvallum shear forming a broad shelf (as in selenodonty).

54. Postcingulum:
(0) Absent or weak; (1) Present; (2) Present and reaching past the metaconule; (3) Formed by the hypoconal shelf raised to near the level of the protocone.

55. 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).

56. Relationships between the cusps of the opposing upper and lower molars:
(0) Absent; (1) Present, lower primary cusp a occludes in the groove between upper cusps A, B; (2) Present, lower main cusp a occludes in front of the upper cusp B and into the embrasure between the opposite upper tooth and the preceding upper tooth; (3) Present, parts of the talonid occluding with the lingual face (or any part) of the upper

molar; (4) Lower multicuspate rows alternately occluding between the upper multicuspate rows.

57. Protoconid (cusp a) and metaconid (cusp c) height ratio (on the lower second molar):
(0) Protoconid distinctively higher; (1) Protoconid and metaconid nearly equal in height.

58. 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.

59. Elevation of the cingulid base of the paraconid (cusp b) relative to the cingulid base of the metaconid (cusp c) on the lower molars:
(0) Absent; (1) Present.

60. Cristid obliqua (sensu Fox 1975: defined as the oblique crest anterior to, and connected with, the labial-most cusp on the talonid heel, the leading edge of facet 3): presence vs. absence and orientation (applicable only to the molar with at least a hypoconid on the talonid or a distal cingulid cuspule):
(0) Absent; (1) Present, contact closest to the middle posterior of the metaconid; (2) Present, contact closest to the lowest point of the protocristid; (3) Present, contact closest to the middle posterior of the protoconid.

61. Lower molar - medial and longitudinal crest (=‘pre-entocristid’ or ‘pre-hypoconulid’) on the talonid heel (only applicable to taxa with talonid or at least a cusp d):
(0) Talonid (or cusp d) has no medial and longitudinal crest; (1) Medial-most cristid (‘pre-entoconid cristid’) of the talonid in alignment with the metaconid or with the post-metacristid if the latter is present (the postmetacristid is defined as the posterior crest of metaconid that is parallel to the lingual border of the crown), but widely separated from the latter; (2) Medial-most cristid of the talonid (‘pre-hypoconulid’ cristid, based on cusp designation of Kielan-Jaworowska et al. 1987) is hypertrophied and in alignment with the postmetacristid and abuts the latter by a V-notch; (3) ‘Pre-entocristid’ crest is offset from the metaconid (and postmetacristid if present), and the ‘pre-entocristid’ extending anterolingually past the base of the metaconid.

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

63. Anterior internal (mesio-lingual) cingular cuspule (e) on the lower molars:
(0) Present as an anterior cuspule but not at the cingulid level; (1) Present, at the cingulid level; (2) Present, positioned above the cingulid level; (3) Absent.

64. Anterior and labial (mesio-buccal) cingular cuspule (f):
(0) Absent; (1) Present.

65. 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 protoconid and paraconid), without occlusal function; (3) Present, with occlusal contact to the upper molar.

66. 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.

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

68. Interlocking mechanism between two adjacent lower molars:
(0) Absent; (1) Present, 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; (2) Present, posterior cingular cuspule d fits between cingular cuspule e and cusp b of the succeeding molar; (3) Present, posterior cingular cuspule d of the preceding molar fits into an embayment or vertical groove of the anterior aspect of cusp b of the succeeding molar (without any involvement of distinctive cingular cuspules in interlocking).

69. Size ratio of the last three lower molars:
(0) Ultimate molar is smaller than the penultimate molar (m1≥m2≥m3; or m2≥m3≥m4; or m3≥m4≥m5; or m4≥m5≥m6); (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.

70. Paraconid position relative to the other cusps of the trigonid on the lower molars (based on the lower second molar):
(0) Paraconid in anterolingual position; (1) Paraconid lingually positioned (within lingual 1/4 of the trigonid width); (2) Paraconid lingually positioned and appressed to the metaconid; (3) Paraconid reduced in the selenodont/lophodont patterns.

71. Orientation of the paracristid (crest between cusps a and b) relative to the longitudinal axis of the molar (from Hu et al. 1998) (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 non-triangulated molars sampled in this study):
(0) Longitudinal orientation; (1) Oblique; (2) Nearly transverse.

72. Angle of the paracristid and the protocristid on the trigonid:
(0) $> 90^o$; (1) $90^o \sim 50^o$; (2) $< 35^o$.

73. Mesiolingual vertical crest of the paraconid on the lower molars (applicable only to taxa with reversed triangulation of the molar cusps):
(0) Rounded; (1) Forming a keel.

74. Anteroposterior shortening at the base of the trigonid relative to the talonid (applicable only to taxa with a talonid heel with a distal cusp d; measured at the lingual base of the lower second molar trigonid where possible):
(0) Trigonid long (extending over 3/4 of the tooth length); (1) Swelling on the side walls of the trigonid (taxa assigned to this character state have a trigonid length ratio 45%~50%; but their morphology is different from all other states in that their side walls are convex); (2) No shortening (trigonid 50-65% of tooth length); (3) Some shortening (the base of trigonid < 50% of tooth length); (4) Anteroposterior compression of trigonid (trigonid 40~45% of the tooth length).

75. 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.

76. Lower molar hypoflexid (concavity anterolabial to the hypconid or cusp d):
(0) Absent or shallow (all "triconodont-like" teeth are coded as "0" here as long as they have cuspule d); (1) Deep (40~50% of talonid width); (2) Very Deep (>65%).

77. Morphology of the talonid (or the posterior heel) of the molar:
(0) Absent; (1) Present, as an incipient heel, a cingulid, or cingular cuspule (d); (2) Present, as a transverse 'V-shaped' basin with two functional cusps; (3) Present, as an obtuse 'V-shaped' triangle; (4) Present, as a functional basin, rimmed with 3 functional cusps (if the entoconid is vestigial, there is a functional crest to define the medial rim of the basin).

78. 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, *sensu* Crompton 1971), 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, lingually positioned.

79. Hypoconulid (if there are only two functional cusps on the talonid, we assume that the second and more lingual cusp on the talonid to be the hypoconulid, following the rationale of Kielan-Jaworowska et al. 1987):
(0) Absent; (1) Present, and median (near the mid-point of the transverse talonid width); (2) Present, and placed within the lingual 1/3 of the talonid basin; (3) Absent as the result of lophodont or selenodont condition.

80. Anterior lower molar (preferably the first, or the second if the first is not available) - hypoconulid - anteroposterior orientation: procumbent vs. reclined (applicable to the taxa with at least two cusps on the talonid):
(0) Cusp tip reclined and the posterior wall of the hypoconulid is slanted and overhanging the root; (1) Cusp tip procumbent and the posterior wall of the cusp is vertical; (2) Cusp tip procumbent and the posterior wall is gibbous.

81. Hypoconulid labial postcingulid (shelf) on the lower molars (definition following Cifelli 1993; non-homologous with the postcingulid coded elsewhere in this list because of the different relationship to the talonid cusps; applicable to taxa with identifiable hypoconid and hypoconulid only):
(0) Absent; (1) Present as a crest descending mesiolabially from the apex of the hypoconulid to the base of the hypoconid.

82. Last lower molar - hypoconulid - orientation and relative size (applicable to the taxa with at least a talonid heel; scored on the third molar for *Peramus* and eutherians, the fourth molar for *Kielantherium* and metatherians; justification for separating this character from the character of the anterior molar hypoconulids is that the ultimate molar shows different morphology and distribution, especially in taxa in which there is posteriorly decreasing size gradient, e.g. *Deltatheridium*):
(0) Short and erect; (1) Tall (higher than hypoconid) and recurved.

83. Entoconid (if there are three functional cusps on the talonid, we assume that the third and the lingual-most functional cusp on the talonid is the entoconid, following the rationale given by Kielan-Jaworowska et al. 1987):
(0) Absent; (1) Present, about equal distance to the hypoconulid as to the hypoconid (85%~115%); (2) Present, with slight approximation to the hypoconulid (distance between the hypoconulid and entoconid noticeably shorter than between the hypoconulid and hypoconid) (65%~75%); (3) Present, and twinned with the hypoconulid (<60%); (4) Present and link to the "hypoconulid" crest.

Note: we estimated the distance between the hypoconulid and entoconid, vs. the distance tetween the hypoconulid and hypconid to quantify character states 1, 2, and 3 of this feature. The scoring of these states and their attendant measurements (where applicable) are as follows:
(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Steropodon* (sensu Kielan-Jaworowska et al. 1987), *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Vincelestes*, *Henkelotherium*;
(1) Present, about equal distance to hypoconulid as to hypoconid: *Ambondro* (~92%), *Deltatheridium, Montanalestes* (~110% for m1), *Murtoilestes* (113% for the only tooth), *Eomaia*, *Prokennalestes* (100% for m3), *Ukhaatherium, Asioryctes* (~100%), *Kennalestes* (~100%), *Zalambdalestes* (~100%), *Daulestes* (~105%), *Aspanlestes* (82~85% for two worn teeth), *Eoungulatum* (88% for an unworn molar), *Cimolestes* (105%), *Gypsonictops* (114%), *Protungulatum* (84% for m2), *Erinaceus* (measured from hypoconulid position 80~85%);

(2) Present, with slight approximation to hypoconulid (distance between hypoconulid and entoconid noticeably shorter than between hypoconulid and hypoconid): *Holoclemensia* (67% for an isolated lower; coded from the stereophotos of Slaughter 1971: plate 4), *Sinodelphys* (62~65% estimated from m1), *Kokopellia* (67% for m1; 72% for m2), *Marsasia* (~72% for the only tooth), *Asiatherium* (67% for m1; 69% for m2);
(3) Present and twinned with hypoconulid: *Ausktribosphenos* (44%), *Bishops* (22%), Didelphodon (50%), *Anchistodelphys* (~50%), *Turgidodon* (50%), *Pediomys* (50%), *Mayulestes* (60% on m2), *Pucadelphys* (50% on m2), *Didelphis* (43% on m2), *Marmosa* (43% on m2), *Caenolestes* (<50%), *Dasyurus* (~50% on m3), *Perameles* (~55%), *Dromiciops* (55% on m2);
(4) Present and linked to the "hypoconulid" crest: *Macropus*, *Acrobates*, *Vombatus*, *Phalanger*, *Pseudocheirus*, *Petauroides*,
(0/1 polymorphic), *Kielantherium* (character variable);
(?) Unknown: *Deltatheridium*; Not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

Comment: *Kokopellia* has an antero-posterior gradient for this feature (see photographs in Cifelli and Muizon 1997). On m1 the hypoconulid-entoconid distance is 67% of the hypconulid-hypconid distance, but but the ratio is slightly larger on m3 (73%) and m4 (73%).

84. Height ratio of the medial side of the crown (apex of the hypoconid to the base of the labial crown) vs. the most lingual cusp on the talonid to the base of the labial crown (this character can be based either on the entoconid if the entoconid is present or the hypoconulid if the entoconid cannot be scored):
(0) Entoconid absent on the talonid heel; (1) Entoconid lower than the hypoconid; (2) Entoconid near the height of the hypoconid; (3) Entoconid near the height of the hypoconid and linked to the hypoconid by a transverse crest.

85. Alignment of the paraconid, metaconid, and entoconid on the lower molars (applicable only to taxa with triangulation of the trigonid cusps and the entoconid present on the talonid):
(0) Cusps not aligned; (1) Cusps aligned.

86. 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.

87. 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.

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

89. Presence vs. absence of the ectoflexus on the upper second molar (or postcanines in the middle portion of the postcanine row). Comments: justification for separating this character from the next is that only a single upper molar is known for three taxa that are otherwise crucial for assessing the timing and biogeography of the divergence of earliest-known crown therians: *Murtoilestes*, *Atokatheridium*, and *Kokopellia*. *Nanolestes* and *Shuotherium* are also only represented by isolated upper molars. Therefore, the gradient character of the ectoflexus along the tooth row is not applicable for these taxa. Presence vs. absence of the ectoflexus alone does not exhaust the systematic distribution of the ectoflexus-related characters among taxa with isolated upper molars.
(0) Absent or weakly developed; (1) Present.

90. Ectoflexus gradient along the molar series (see the above for justification of separating presence/absence from the gradient of the ectoflexus on the upper molar(s)):
(0) Present on penultimate molar, but weakly developed or absent on the anterior molars;
(1) Present on the penultimate and preceding molars.

91. Morphological features on the labial cingulum or stylar shelf of the upper molars (excluding the parastyle and metastyle):
(0) Indistinctive; (1) Distinctive cingulum, without cuspules; (2) Individualized or even hypertrophied cuspules; (3) W-pattern on stylar shelf; (4) Cingulum crenulated with distinctive and even-sized multiple cuspules.

92. 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.

93. 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%).

94. Morphology of the protocone (applicable only to those taxa with reversed triangulation and a lingual swelling of the upper molar):
(0) Protoconal region present but no distinct protocone; (1) Protocone present, its apical portion anteroposteriorly compressed; (2) Apical portion slightly expanded; (3) Apical portion expanded; (4) Apical portion forming an obtuse triangle with the protoconal cristae.

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

96. Height and size of the paracone (cusp B) and metacone (cusp C) (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.

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

98. Base of the paracone and metacone (based on the upper second molar if available, applicable only to triangulated molars):
(0) Merged; (1) Separated.

99. Centrocrista between the paracone and the metacone of the upper molars (applicable only to taxa with well-developed metacone and distinctive wear facets 3 and 4):
(0) Straight; (1) V-shaped, with labially directed postparacrista and premetacrista.

100. 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.

101. Presence of the paraconule and metaconule on the upper molars:
(0) Absent; (1) Present.

102. Relative position of the paraconule and metaconule on the upper first and second molars (character adopted from Archibald et al. 2001):
(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.

103. Internal conular cristae:
(0) Cristae indistinctive; (1) Cristae distinctive and wing-like.

104. Parastylar groove (on upper second molar):
(0) Weak or absent; (1) Moderately to well developed.

105. Stylar cuspule “A”, the parastyle, on the upper molars (of the Bensley-Simpson system; cuspule “E” of the Crompton designation):
(0) Present (at least a swelling is present); (1) Absent.

106. Preparastyle on the upper first molar (applicable to molars with triangulation):
(0) Absent; (1) Present.

107. 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"

108. Stylar cuspule "C" (near the ectoflexus) on the penultimate upper molar:
(0) Absent; (1) Present.

109. Stylar cuspule "D" (opposite the metacone) on the penultimate upper molar:
(0) Absent; (1) Present.

110. 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”.

111. Position of the stylar cuspule “E” relative to cusp “D” or “D-position”:
(0) “E” more lingual to “D” or “D-position”; (1) “E” distal to or at same level as “D” or “D-position”.

112. Upper molar interlock:
(0) Absent; (1) Tongue-in-groove interlock; (2) Parastylar lobe of a succeeding molar lumbricated with the metastylar region of a preceding molar.

113. Size and labial extent of the metastylar lobe and parastylar lobe (based on the upper first molar if available; if not, then based on upper second):
(0) Metastylar lobe smaller than the parastylar lobe; (1) Metastylar lobe of similar size and labial extent to the parastylar lobe; (2) Metastylar lobe much larger than the parastylar lobe; (3) Metastylar lobe absent.

114. 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.

115. Selenodont molar pattern:
(0) Absent; (1) Present.

116. Outline of the lower first molar:
(0) Laterally compressed; (1) Oblong with slight labial bulge; (2) Triangular or tear-drop shaped; (3) Rectangular (or slightly rhomboidal).

117. 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.

Molar Wear Pattern (12 characters)

118. Functional development of occlusal facets on individual molar cusps:
(0) Absent; (1) Absent at eruption but developed later by crown wear; (2) Wear facets match upon tooth eruption (inferred from the flat contact surface upon eruption).

119. Topographic relationships of wear facets to the main cusps: (0) Lower cusps a, c support two different wear facets (facets 1 and 4) that contact the upper primary cusp A; (1) Lower cusps a, c support a single wear facet (facet 4) that contacts the upper primary cusp B (this facet extends onto cusp A as wear continues, but 1 and 4 do not develop simultaneous in these taxa); (2) Multicuspate series, each cusp may support 2 wear facets.

120. 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.

121. Wear facet 1 (a single facet supported by cusp a and cusp c) and facet 2 (a single facet supported by cusp a and cusp b):
(0) Absent; (1) Present.

122. Upper molars - development of facet 1 and the preprotocrista (applicable to molars with reversed triangulation):
(0) Facet 1 (prevallum crest) short, not extending to the stylocone area; (1) Facet 1 extending into the hook-like area near the stylocone; (2) Preprotocrista long, extending labially beyond the paracone.

123. 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.

124. Orientation of facet 4 (on the posterior aspect of the hypoconid):
(0) Present and oblique to the long axis of the tooth; (1) Present and forming a more transverse angle to the long axis of the tooth.

125. 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.

126. Wear pattern within the talonid basin (applicable to those taxa with triangulated molars):
(0) Absent; (1) Present; (2) Present apically on the crests of the talonid.

127. Development of the distal metacristid (applicable only to taxa with reversed triangulation):
(0) Present; (1) Absent.

128. Differentiation of wear facets 5 and 6 on the labial face of the entoconid:
(0) Absent; (1) Present.

129. Surficial features on the occluding surfaces on the talonid (only applicable to taxa with reversed triangulation):
(0) Smooth surface on the talonid heel (or on cusp d); (1) Multiple ridges within the talonid basin; (2) Talonid present, but wear occurs apically on the crests of cristid obliqua and hypoconid cristid (V-shaped talonid crests).

Other Dental Features (27 characters)

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

131. Number of upper incisors:
(0) Five; (1) Four; (2) Three; (3) Two or one; (4) No incisors.

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

133. Number of upper canine roots:
(0) One; (1) Two.

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

135. Number of lower canine roots:
(0) One; (1) Two.

136. 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.

137. Number of lower premolars:
(0) Five or more; (1) Four; (2) Three; (3) Two or one.

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

139. Number of upper molars or molariforms (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.

140. 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.

141. Number of lower postcanine loci:
(0) Eight or more; (1) Seven; (2) Six; (3) Five or less.

142. 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.

143. Diastema separating the lower first and second premolars (defined as the first and second functioning premolar or premolariform):
(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 and equal to or more than one-tooth length.

144. Ultimate premolar bladed or crenulated:
(0) Absent; (1) Present.

145. Upper first incisor:
(0) Subequal to the remaining incisors, no diastema with the second incisor; (1) Anteriorly projecting, separated from the second incisor by a diastema; (2) Absent (as evidenced by a median gap between the mesial-most incisors).

146. Ultimate and penultimate upper incisors are relatively compressed laterally:
(0) Absent; (1) Present, and spoon-shaped to rhomboid-shaped in lateral view; (2) Present, and spatulate in lateral view; (3) Ultimate and/or penultimate upper incisors bicuspate or tricuspate.

147. Staggered lower incisor (Hershkovitz 1982):
(0) Absent; (1) Present.

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

149. Replacement of at least some posterior functional molariforms:
(0) Present; (1) Absent.

150. Procumbency and enlargement of the lower anterior-most incisor:
(0) Absent; (1) Present (at least 50% longer than the adjacent incisor).

151. 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.

152. U-shaped ridge in the lower multi-rowed molars:
(0) Absent; (1) Present.

153. Single-aligned and the labial row of multi-cusp or multi-rowed lower molar - Cusp ratio:
(0) Second mesial cusp (b2 of Butler 2000) highest; (1) Mesial cusp (b1 of Butler 2000) highest.

154. Multi-rowed upper premolar/molar - cusp ratio in the labial row of multi-cusp row:
(0) Distal cusp highest, with a gradient of anteriorly decreasing height;
(1) Cusps in same row of equal height.

155. Alignment of multi-cuspate upper first and second molars:
(0) Second lingually offset from the first so that the lower second molar lingual row occludes with the lingual side of the upper second labial row; (1) lower second molar labial row occludes with the labial side of the upper second labial row.

156. Enamel microstructure (character state definition following Wood et al. 1999; distribution following Clemens 1997; Sander 1997; Wood and Stern 1997):
(0) Synapsida columnar enamel (prismless); (1) 'Transitional' (sheath indistinct, 'prismatic' crystallites inclined at less than 45^{o} to the 'interprismatic' matrix).

Vertebrae (6 characters)

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

158. Atlas rib:
(0) Present; (1) Absent.

159. Fusion of dens to the axis:
(0) Absent; (1) Present.

160. Axis rib:

(0) Present; (1) Absent (rib fused to form the transverse process).

161. Postaxial cervical ribs:
(0) Unfused; (1) Fused.

162. Number of thoracic vertebrae:
(0) 13 or less; (1) 15 or more.

Shoulder Girdle (18 characters)

163. Interclavicle:
(0) Present; (1) Absent.

164. Contact relationships between the interclavicle (embryonic membranous element) and the sternal manubrium (embryonic endochondral element) (assuming the homologies of these elements by Klima 1973, 1987):
(0) Two elements distinct from each other, posterior end of the interclavicle abuts with the anterior border of manubrium; (1) Two elements distinct from each other, the interclavicle broadly overlaps the ventral side of the manubrium; (2) Complete fusion of the embryonic membranous and endochondral elements resulting in a single and enlarged manubrium.

165. Cranial margin of the interclavicle/manubrium (assuming the interclavicle is fused to the sternal manubrium in living therians, Klima 1987):
(0) Emarginated or flat; (1) With a median process.

166. Sternoclaviclular joint (assuming that homologous elements of the interclavicle and the manubrium are fused to each other in therians, Klima 1973, 1987):
(0) Immobile; (1) Mobile.

167. Acromioclavicular joint:
(0) Extensive articulation; (1) Limited articulation (either pointed acromion, pointed distal end of clavicle, or both).

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

169. Scapula - supraspinous fossa: degree of development along the length:
(0) Absent (acromion extending from the 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).

170. 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 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.

171. Scapula - acromion process:
(0) Short stump, level with or behind the glenoid; (1) Hook-like and extending below the glenoid.

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

173. Procoracoid:
(0) Present; (1) Fused to the sternal apparatus (Klima 1973) .

174. Procoracoid foramen:
(0) Present; (1) Absent (assuming the procoracoid is fused to the sternal apparatus in living therians, Klima 1973).

175. Coracoid:
(0) Large, with posterior process; (1) Small, without posterior process.

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

177. 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.

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

179. Medial surface of the scapula:
(0) Convex; (1) Flat.

180. Suprascapular incisure (defined as the prominent emargination on the cranial border of the supraspinus fossa):
(0) Absent; (1) Present.

Forelimb and Manus (14 characters)

181. Humeral head:
(0) Subspherical, weakly inflected; (1) Spherical, strongly inflected.

182. Intertubercular groove of the humerus:
(0) Shallow and broad; (1) Narrow and deep.

183. Size of the lesser tubercle of the humerus relative to the greater tubercle:
(0) Wider; (1) Narrower.

184. Torsion between the proximal and distal ends of the humerus:
(0) Strong ($\geq 30^{o}$); (1) Moderate (30^{o} –15^{o}); (2) Weak.

185. Ventral extension of the deltopectoral crest or the position of the deltoid tuberosity:
(0) Not extending beyond the midpoint of the humeral shaft; (1) Extending ventrally (distally) beyond the midpoint of the shaft.

186. 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).

187. 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).

188. Entepicondyle and ectepicondyle of the humerus:
(0) Robust; (1) Weak.

189. Sigmoidal shelf for the supinator ridge extending proximally from the ectepicondyle:
(0) Absent; (1) Present.

190. Styloid process of the radius:
(0) Weak; (1) Strong.

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

192. 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.

193. Trapezium morphology and proportion:

(0) Elongate to cuboidal, larger than or subequal to the trapezoid; (1) Bean-shaped or fusiform, smaller than the trapezoid.

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

Pelvic Girdle (7 characters)

195. Anterior process of the ilium:
(0) Short (less than the diameter of the acetabulum); (1) Long, 1-1.5 times the diameter of the acetabulum (following Hopson and Kitching 2001); (2) Elongate, more than 1.5 times the diameter of the acetabulum.

196. Posterior process of the ilium:
(0) Present; (1) Reduced; (2) Absent.

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

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

199. 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.

200. Posterior spine of the ischium:
(0) Elongate; (1) Short and blunt.

201. Epipubic bone:
(0) Present; (1) Absent.

Hindlimb and Pes (47 characters)

202. 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.

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

204. Orientation of the greater trochanter:
(0) Directed dorsolaterally; (1) Directed dorsally.

205. Position of the lesser trochanter:

(0) On medial side of the shaft; (1) On the ventromedial or ventral side of the shaft.

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

207. Patellar facet (‘groove’) of the femur:
(0) Absent; (1) Shallow and weakly developed; (2) Well-developed.

208. Proximo-lateral tubercle or tuberosity of the tibia:
(0) Large and hook-like; (1) Indistinct.

209. Distal tibial malleolus:
(0) Weak; (1) Distinct.

210. Fibula contacting the distal end of the femur:
(0) Present; (1) Absent; (2) Fibula fused with the tibia.

211. Distal fibular styloid process:
(0) Weak or absent; (1) Distinct.

212. Fibula contacting the calcaneus (= ‘tricontact in upper ankle joint’ of Szalay 1994):
(0) Extensive contact; (1) Reduced; (2) Absent.

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

214. Astragalar neck:
(0) Absent; (1) Weakly developed (asymmetrical: present only on the lateral side of the “neck region”, or Szalay’s [1994] comment on “necklessness”).

215. Astragalar neck basal width (justification for separating this character from the navicular facet expansion is that the latter concerns symmetry, whereas this character deals with proportion; the distributions of these two character are different in some stem eutherians and crown marsupials):
(0) Neck narrower than the head; (1) Neck about same width as the head (with parallel sides, constricted posterior to navicular facet); (2) Widest point of neck at mid-length (widening is not developed near the base of the neck); (3) Astragalar neck widest at the base.

216. Astragalonavicular facet aspect ratio:
(0) Navicular facet transversely wider than dorsoventrally thick; (1) Navicular facet dorsoventrally thicker than transversely wide.

217. Navicular facet expansion in the astragalar head region:
(0) Restricted anteriorly; (1) Asymmetrical spread only to the medial side of the astragalar “head-neck region”; (2) Astragalar head supersedes navicular so the navicular facet shifted

ventrally; (3) 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).

218. 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.

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

220. Astragalar medial plantar tuberosity (AMPT of Szalay 1994 and Horovitz 2000):
(0) Absent; (1) Present, but weakly developed; (2) Present, and ventrally flaring or protruding.

221. Distal end of the calcaneal tubercle:
(0) Short, without a terminal swelling; (1) Elongate, vertically deep, and mediolaterally compressed, with a terminal swelling.

222. 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).

223. 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.

224. 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.

225. Alignment of the cuboid to the main axis of the calcaneus:
(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).

226. Orientation of the calcaneocuboid joint:

(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.

227. 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).

228. Lower ankle joint - orientation of the sustentacular facet of the calcaneus in relation to the horizontal plane:
(0) Nearly vertical; (1) Oblique ($\leq 70^{o}$) to nearly horizontal.

229. Antero-posterior placement of the sustentacular facet relative to the astragalar facet on the calcaneus:
(0) Directly anterior to the astragalar facet and vertically oriented on the medial edge of the calcaneus; (1) On the dorsal aspect and positioned anteromedial to the astragalar facet on the calcaneus; (2) On the dorsal aspect, medial to the astragalar facet; (3) On the dorsal aspect, anterior to the astragalar facet.

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

231. Ventral outline of the sustentacular process of the calcaneus:
(0) Indistinctive; (1) Medially directed shelf, with rounded outline; (2) Protruding triangle, posteromedially directed;

232. 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.

233. Shape of posterior calcaneo-astragalar process/protuberance and its contiguous fibular contact (if the fibula contact is present) on the calcaneus:
(0) Confluent with fibular contact and kidney-shaped (best viewed medially); (1) Oblong to ellipsoidal; (2) Nearly spherical and bulbous, more transversely developed than character state 1; (3) Transversely confluent with the sustentacular facet.

234. Placement of the CAF structure (structure of the calcaneoastragalar contact):
(0) On the medial side of the body of the calcaneus; (1) On the dorsal side of the body of the calcaneus, but bordering on the body's medial margin (without a protruding outline); (2) On the dorsal side of the body of the calcanues and protruding beyond the body's medial margin; (3) Withdrawn and separated from the medial margin and placed along the lateral margin of the body of the calcaneus.

235. Anterior ventral (plantar) tubercle of the calcaneus:

(0) Absent; (1) Present, at the anterior edge (just lateral to the cuboid facet); (2) Present, set back from the anterior edge.

236. Anteroventral groove or depression of the calcaneus:
(0) Absent; (1) Present.

237. Cross-sectional shape of the body of the calcaneus at the level of the posterior calcaneoastragalar facet:
(0) Dorso-ventrally compressed; (1) Mediolaterally compressed.

238. Ventral curvature of the calcaneal tubercle:
(0) Present; (1) Absent.

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

240. 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.

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

242. Prehallux:
(0) Absent; (1) Present.

243. Side-by-side contact of metatarsal V and the peroneal process of the calcaneus:
(0) Absent; (1) Present.

244. Relationships of the proximal end of metatarsal V to the cuboid:
(0) Metatarsal V is off-set to the medial 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 the anterior end of the cuboid.

245. Ventrolateral tubercle at the proximal end of metatarsal V:
(0) Absent; (1) Present,at the anterior edge of the calcaneus; (2) Present, off-set posteriorly from the anterior edge of the calcaneus.

246. 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.

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

248. Opposable hallux:
(0) Absent; (1) Present.

Other Postcranial Characters (4 characters)

249. Ossified patella:
(0) Absent; (1) Present.

250. Sesamoid bones in the flexor tendons:
(0) Absent; (1) Present, unpaired; (2) Present, paired.

251. External pedal (tarsal) spur:
(0) Absent; (1) Present.

252. Pes digital grouping:
(1) Didactylous; (1) Syndactylous.

Basicranium (66 characters)

253. External size of the cranial moiety of the squamosal:
(0) Narrow; (1) Broad; (2) Expanded posteriorly to form the skull roof table.

254. Participation of the cranial moiety of the squamosal in the endocranial wall of the braincase:
(0) Absent; (1) Present.

255. 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 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.

256. Postglenoid depression on the squamosal:
(0) Present as the post-craniomandibular joint sulcus ("external auditory meatus" on the zygoma); (1) Absent; (2) Present on the skull base.

257. Squamosal - entoglenoid process:
(0) Absent or vestigial; (1) Present, but separated from the postglenoid process; (2) Present, enlarged and connected to the postglenoid process.

258. Position of the craniomandibular joint:

(0) Posterior or lateral to the level of the fenestra vestibuli; (1) Anterior to the level of the fenestra vestibuli.

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

260. 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.

261. Postglenoid foramen position:
(0) Posterior to the glenoid area; (1) Medial to the postglenoid process; (2) Anterior to the postglenoid process.

262. Postglenoid foramen presence vs. absence and composition:
(0) Absent; (1) Present, in the squamosal; (2) Present, between the squamosal and petrosal; (3) Present, between the squamosal and ectotympanic.

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

264. Squamosal - epitympanic recess (this character may be ordered):
(0) No contribution to the "epitympanic area" of the petrosal; (1) Small contribution to the posterolateral wall of the epitympanic recess; (2) Large contribution to the lateral wall of the epitympanic recess; (3) Squamosal forming a large part of enlarged epitympanic sinus.

265. Contribution of the basisphenoid wing (parasphenoid ala) to the external bony housing of the cochlea:
(0) Participates in the rim of the fenestra vestibuli; (1) Does not reach the rim of the fenestra vestibuli; (2) Absent or excluded from the cochlear housing.

266. Relationship of the cochlear housing to the lateral lappet of the basioccipital:
(0) Entirely covered by the basioccipital; (1) Partially (~about half width on the medial side) covered by the basioccipital; (3) Fully exposed as the promontorium.

267. Thickened rim of the fenestra vestibuli:
(0) Present; (1) Absent.

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

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

270. 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.

271. Cochlea:
(0) Cochlear recess (without a canal); (1) Short canal; (2) Elongate canal, to the fullest extent of the promontorium; (3) Curved; (4) Elongate and partly coiled; (5) Elongate and coiled to at least 360˚.

272. Internal acoustic meatus - cribriform plate:
(0) Absent; (1) Present.

273. Internal acoustic meatus depth:
(0) Deep with thick prefacial commissure; (1) Shallow with thin prefacial commissure.

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

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

276. Crista interfenestralis:
(0) Horizontal, broad, and extending to the base of the paroccipital process; (1) Vertical, delimiting the back of the promontorium; (2) Horizontal, narrow, and connecting to the caudal tympanic process.

277. Post-promontorial tympanic recess:
(0) Absent; (1) Present.

278. 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.

279. Caudal tympanic process of the petrosal:
(0) Absent; (1) Present; (2) Present, notched; (3) Present, hypertrophied and buttressed against the exoccipital paracondylar process.

280. Petrosal - tympanic process (Kielan-Jaworowska- 1981):
(0) Absent; (1) Present.

281. Rear margin of the auditory region:
(0) Marked by a steep wall; (1) Extended onto a flat surface.

282. Prootic canal:
(0) Absent; (1) Present, vertical; (2) Present, horizontal and reduced.

283. Position of the sulcus for the anterior distributary of the transverse sinus relative to the subarcuate fossa.
(0) Anterolateral; (1) Posterolateral.

284. Lateral trough floor anterior to the tympanic aperture of the prootic canal and/or the primary facial foramen:
(0) Open lateral trough, no bony floor; (1) Bony floor present; (2) Lateral trough absent.

285. Anteroventral opening of the cavum epiptericum:
(0) Present; (1) Present, with reduced size (due to the anterior expansion of the lateral trough floor); (2) Present, partially enclosed by the petrosal; (3) Present, enclosed by the alisphenoid and petrosal; (4) Present, as large piriform fenestra.

286. Enclosure of the geniculate ganglion by the bony floor of the petrosal in the cavum supracochleae:
(0) Absent; (1) Present.

287. Position of the hiatus Fallopii for the greater petrosal nerve:
(0) Absent; (1) In the roof through the petrosal; (2) At the anterior edge of the petrosal.

288. Foramen ovale - composition:
(0) Between the petrosal and alisphenoid; (1) Secondary foramen partially or fully enclosed by the alisphenoid, in addition to the primary foramen between the petrosal and alisphenoid; (2) In the petrosal (anterior lamina); (3) Between the alisphenoid and squamosal; (4) Within the alisphenoid.

289. Foramen ovale - position:
(0) On the lateral wall of the braincase; (1) On the ventral surface of the skull.

290. Number of exit(s) for the mandibular branch of the trigeminal nerve (V3):
(0) One; (1) Two.

291. Quadrate ramus of the alisphenoid:
(0) Forming a rod underlying the anterior part of the lateral flange; (1) Absent.

292. Anterior lamina exposure on the lateral braincase wall:
(0) Present; (1) Reduced or absent.

293. Orientation of the anterior part of the lateral flange:
(0) Horizontal shelf; (1) Ventrally directed; (2) Medially directed and contacting the promontorium; (3) Vestigial or absent.

294. Vertical component of the lateral flange (‘L-shaped’ and forming a vertical wall to the pterygoparoccipital foramen):
(0) Present; (1) Absent.

295. Vascular foramen in the posterior part of the lateral flange (and anterior to the pterygoparoccipital foramen):
(0) Present; (1) Absent.

296. Relationship of the lateral flange to the crista parotica (or the anterior paroccipital process that bears the crista):
(0) Widely separated; (1) Narrowly separated; (2) Continuous.

297. Pterygoparoccipital foramen (for the ramus superior of the stapedial artery):
(0) Laterally open notch; (1) Foramen enclosed by the petrosal or squamosal; (2) Absent.

298. Position of the pterygoparoccipital foramen relative to the level of the fenestra vestibuli:
(0) Posterior or lateral; (1) Anterior.

299. "Bifurcation of the paroccipital process" - presence vs. absence (this is modified from the character used in several previous studies):
(0) Absent; (1) Present.

300. Posterior paroccipital process of the petrosal:
(0) No ventral projection below the level of the surrounding structures; (1) Projecting below the surrounding structures.

301. Morphological differentiation of the anterior paroccipital region:
(0) Anterior paroccipital is bulbous and distinctive from the surrounding structures;
(1) Anterior paroccipital region has a distinct crista parotica.

302. Epitympanic recess lateral to the crista parotica:
(0) Absent; (1) Present.

303. Tympanohyal contact with the petrosal:
(0) Absent; (1) Present.

304. Relationship of the squamosal to the paroccipital process:
(0) Squamosal covers the entire paroccipital region; (1) No squamosal cover on the anterior paroccipital region; (2) Squamosal covers a part of the paroccipital region, but not the crista parotica (the squamosal wall and the crista parotica are separated by the epitympanic recess).

305. Medial process of the squamosal reaching toward the tympanic cavity:
(0) Absent; (1) Present (near or bordering on the foramen ovale).

306. Stapedial artery sulcus on the petrosal:
(0) Absent; (1) Present.

307. Transpromontorial sulcus for internal carotid artery on the cochlear housing:

(0) Absent; (1) Present.

308. Deep groove on the anterior pole of the promontorium (Muizon 1994):
(0) Absent; (1) Present.

309. Epitympanic wing medial to the promontorium:
(0) Absent; (1) Present.

310. Ectopterygoid process of the alisphenoid:
(0) Absent; (1) Present.

311. Tympanic process of the alisphenoid:
(0) Absent; (1) Present, but limited to the “piriform” region of the basicranium; (2) Intermediate; (3) Well-developed, extending to near the jugular foramen.

312. Hypotympanic recess in the junction of the alisphenoid, squamosal, and petrosal:
(0) Absent; (1) Present.

313. Separation of the fenestra cochleae from the jugular foramen:
(0) Absent; (1) Separate but within the same depression; (1) Separate (not within the same depression).

314. Channel of the perilymphatic duct:
(0) Open channel and sulcus; (1) At least partially enclosed channel.

315. Jugular foramen size relative to the fenestra cochleae (applicable only to those taxa with a jugular foramen fully separated from the fenestra cochleae):
(0) Jugular subequal to the fenestra cochleae; (1) Jugular larger than the fenestra cochleae.

316. Relationship of the jugular foramen to the opening of the inferior petrosal sinus:
(0) Confluent; (1) Separate.

317. Stapedial muscle fossa:
(0) Absent; (1) Present, aligned with the crista interfenestralis; (2) Present, lateral to the crista interfenestralis, and small; (3) Present, lateral to crista interfenestralis, and twice the size of the fenestra vestibuli; (4) Present, lateral to crista interfenestralis, shallow and small.

318. Hypoglossal foramen:
(0) Indistinct, either confluent with the jugular foramen or sharing a depression with the jugular foramen; (1) Separated from the jugular foramen; (2) Separated from the jugular foramen; the latter has a circular, raised external rim.

Middle Ear Ossicle Characters (15 Characters)

319. Geometry (shape) of the incudo-mallear contact:
(0) Trochlear (convex and cylindrical) surface of the incus; (1) Trough; (2) Saddle-shaped contact on the incus; (2) Flat surface.

320. Alignment of the incus and malleus:
(0) Posterior-anterior; (1) Posterolateral to anterior medial; (2) Dorsoventral.

321. Twisting of the dorsal plate relative to the trochlea on the quadrate:
(0) Dorsal plate aligned with the trochlea; (1) Dorsal plate twisted relative to the trochlea, (2) Dorsal plate twisted and elevated from the trochlea; (3) Dorsal plate reduced to a conical process (crus longum).

322. Presence of a quadrate/incus neck (slightly constricted region separating the dorsal plate or crus brevis from the trochlea; this represents the differentiation between the 'body' and crus brevis of the incus):
(0) Absent; (1) Present.

323. Dorsal plate (= crus brevis) of the quadrate/incus:
(0) Broad plate; (1) Pointed triangle; (2) Reduced.

324. Incus - angle of the crus brevis to crus longum of the incus (this is equivalent to the angle between the dorsal plate and the stapedial process of the quadrate):
(0) Alignment of the stapedial process (crus longum) and the dorsal plate (crus brevis) (or an obtuse angle between the two structure) (distinctive process is lacking, stapes/incus contact is on the medial side of the quadrate trochlea); (1) Perpendicular or acute angle of the crus brevis and crus longum ("A-shaped" incus).

325. Primary suspension of the incus/quadrate on the basicranium:
(0) By quadratojugal in addition to at least one other basicranial bone; (1) By squamosal only; (2) By petrosal (either by the preserved direct contact of the incus or by inference from the presence of a well-defined crista parotica).

326. Quadratojugal:
(0) Present; (1) Absent.

327. Morphology of the stapes:
(0) Columelliform–macroperforate; (1) Columelliform–imperforate (or microperforate); (2) Bicrurate–perforate.

328. Stapedial ratio:
(0) Less than 1.4; (1) 1.4-1.8;(2) $\geq$1.8.

329. Bullate stapedial footplate:
(0) Absent; (1) Present.

330. Malleolar neck:

(0) Absent; (1) Present.

331. Ectotympanic ring (may be ordered):
(0) Plate-like; (1) Curved and rod-like; (2) Ring-shaped; (3) Slightly expanded (fusiform); (4) Expanded; (5) Tube-like.

332. Position/orientation of the incisura tympanica:
(0) Posteroventral; (1) Posterior; (2) Postero-dorsal; (3) Dorsal.

333. Fusion of the ectotympanic to other bones:
(0) Absent; (1) Fused to other bones.

Other Cranial Characters (40 characters)

334. Posterior extent of the bony secondary palate:
(0) Anterior to the posterior end of the tooth row; (1) Level with the posterior end of the tooth row; (2) Extending posterior to the tooth row; (3) Extending to the basisphenoid-basioccipital suture.

335. Pterygopalatine ridges:
(0) Present; (1) Absent.

336. Transverse process of the pterygoid:
(0) Present and massive; (1) Present but reduced (as the hamulus); (2) Greatly reduced (with a vestigial crest on pterygoid) or absent.

337. Pterygoids contact on midline:
(0) Present; (1) Absent.

338. Ventral opening of the minor palatine foramen:
(0) Encircled by the pterygoid (and ectopterygoid if present) in addition to the palatine; (1) Encircled by the palatine and maxilla, separated widely from the subtemporal margin; (2) Encircled completely by the palatine, large, with thin bony bridge from the subtemporal margin; (3) Large, posterior fenestration.

339. Transverse canal foramen:
(0) Absent; (1) Present.

340. Carotid foramen position:
(0) Within the basisphenoid; (1) Within the basisphenoid/basioccipital suture; (2) Within the basisphenoid/petrosal suture; (3) Through the opening of the cavum epiptericum.

341. Overhanging roof of the orbit:
(0) Absent; (1) Present, formed by the frontal.

342. Exit(s) of the infraorbital canal:

(0) Single; (1) Multiple.

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

344. 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 a narrow strap; (4) Absent from the facial portion of the rostrum.

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

346. Number of lacrimal foramina:
(0) One; (1) Two.

347. Lacrimal foramen composition:
(0) Within the lacrimal; (1) In the maxilla or between the maxilla and frontal.

348. 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%.

349. Frontal/alisphenoid contact:
(0) Dorsal plate of the alisphenoid contacting the frontal at the anterior corner; (1) Dorsal plate of the alisphenoid with more extensive contact with the frontal (~50% of its dorsal border); (2) Absent.

350. Frontal-maxilla facial contact:
(0) Absent; (1) Present.

351. Nasal-frontal suture - medial process of the frontals wedged between the two nasals:
(0) Absent; (1) Present.

352. Pila antotica:
(0) Present; (1) Absent.

353. Fully ossified medial orbital wall of the orbitosphenoid:
(0) Absent; (1) Present, forming the ventral floor of the braincase but not the entire orbital wall; (2) Present, forming both the braincase floor and the medial orbital wall.

354. Separation of the optic foramen from the sphenorbital fissure:
(0) Absent; (1) Present.

355. Separate opening for the minor palatine nerve inside the orbit:
(0) Absent; (1) Present.

356. 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.

357. Maxillary in the sub-temporal margin of the orbit:
(0) Absent; (1) Present; (2) Present and extensive.

358. Orbital process of the frontal borders on the maxilla within orbit:
(0) Absent; (1) Present.

359. Anterior ascending vascular channel (for the arteria diploëtica magna) in the temporal region:
(0) Open groove; (1) Partially enclosed in a canal; (2) Completely enclosed in a canal or endocranial; (3) Absent.

360. Posttemporal canal for the arteria and vena diploëtica:
(0) Present, large; (1) Small; (2) Absent.

361. Lambdoidal crest:
(0) Overhanging the concave or straight supraoccipital; (1) Weak developed with convex supraoccipital.

362. Sagittal crest:
(0) Prominently developed; (1) Weakly developed; (2) Absent.

363. Tabular bone:
(0) Present; (1) Absent.

364. Occipital slope:
(0) Occiput sloping posterodorsally (or vertically oriented) from the occipital condyle; (1) Occiput sloping anterodorsally from the occipital condyle (such that the lambdoidal crest is leveled anterior to the occipital condyle and condyle is fully visible in dorsal view of the skull).

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

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

367. Internarial process of the premaxilla:

(0) Present; (1) Absent.

368. Posterodorsal process of the premaxilla:
(0) Does not extend beyond canine ("short or absent"); (1) extends beyond canine ("long").

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

370. 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.

371. Palatal vacuities:
(0) Absent; (1) Present; (2) Present, either positioned near or extended to the posterior edge of bony palate.

372. Ossified ethmoidal cribriform plate of the nasal cavity:
(0) Absent; (1) Present.

373. Posterior excavation of the nasal cavity into the bony sphenoid complex:
(0) Absent; (1) Present; (2) Present and partitioned from the nasal cavity.

Cranial Vault and Brain Endocast Characters (7 characters)

374. External bulging of the braincase in the parietal region:
(0) Absent; (1) Expanded (the parietal part of the cranial vault is wider than the frontal part, but the expansion does not extend to the lambdoidal region); (2) Greatly expanded (expansion of the cranial vault extends to the lambdoidal region).

375. Anterior expansion of the vermis (central lobe of the cerebellum):
(0) Absent; (1) Present.

376. Overall size of the vermis:
(0) Small; (1) Enlarged.

377. Lateral cerebellar hemisphere (excluding the paraflocculus):
(0) Absent; (1) Present.

378. External division on the endocast between the olfactory lobe and the cerebral hemisphere (well-defined transverse sulcus separating the olfactory lobes from the cerebrum):
(0) Absence of external separation of the olfactory lobe from cerebral hemisphere; (1) Enlarged olfactory lobes; (2) Clear division of transverse sulcus.

379. Anterior expansion of the cerebral hemisphere:
(0) Absent; (1) Present.

380. Expansion of the posterior cerebral hemisphere (for each hemisphere, not the combined width of the posterior hemispheres):
(0) Absent; (1) Present.

Part V. Matrix Table (Character Distribution)

(1) Key to polymorphic multi-state characters:

A = 0 & 1
B = 0 & 2
C = 1 & 2
D = 1 & 3
E = 2 & 3
F = 3 & 4

(2) PAUP Version of the matrix is available in Part VII. PAUP Search Settings and Results.

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Jeholodens
1??1010??0 ?1111?12?? 010?221401 0010000000 1010000000 00??11?10? ?02000031?
00???0000? ??0????00? A0???0???? ????0????? ?0??000010 0?0??????1 1101033223
2000000111 1?????0000 0101111121 111?101110 0??0110100 0001210021 0000001001
0000?00000 0000100000 0000000000 0000010000 000012?011 ?00?2?11?1 30100??0??
?10??11??? ?????????? ????0??00? ?????????? ??21?????? 2????????? 00?10??1??
?????12??? 011?01??0? ???1??????

Priacodon
1??1010??0 1111??1221 0100221401 0010000000 0010001000 00??11?10? ?12000031?
00???0000? ??0????00? 10???0???? ????1????? ?1??000010 0?0??????3 ?000012222
1000??0110 1????1???? ?????????? ?????????? ????110100 ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????1 ??00211111 301??00000
0101?11100 ?0111100?? 100??000?0 ??110021?? ????2??0?? ???2?????0 ?0????????
?????12?10 ?????????0 ???1??????

Trioracodon
1??10?0??0 1111??1221 0100221401 0010000?0 1010001000 00??11?10? ?1B000031?
00???0000? ??0????00? 10???????? ????1????? ?1??000010 0?0??????3 ?000012332
1000??0110 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ???02?11?? ???????0??
0?0??1110? ?0???????? ???????0?0 ???1?????? ???????0?? ?????????0 ??????????
?????????0 ?????????? ??????????

Plagiaulacidans
1??2?10??0 A311101021 1100222401 021?????0? ?2?000??22 1???24???? ?0??0?000?
?????????? ????????0? 00???????? ????1????? ?0??03313? ?????????4 2C02?CC44F
202103?111 210010???? ??00011111 1011101100 1002000101 000121?111 011110?010
001??00?00 1211120?10 0011000000 0001010012 ?0?0110110 ?000211111 301??00000
0101211101 10211???01 11?10?0000 00100021?? ????21?0?? 2?00020100 10020001?0
0020112020 0010A11010 0?21??????

Cimolodontans
1??2?10??0 1311101021 110022C4AC 021?????0? ?2?000??22 1???24???? ?0??0?000?
?????????? ????????0? 00???????? ????1????? ?0??03313? ?????????4 32??33444
302123?111 2011120010 0000011111 1011101100 100C000A01 00??210111 0111102010
0010?00000 1211120010 0A1100A000 0001010012 1000110A10 ?000211111 30100C00A0
0101211101 1021121A01 1A010AA000 001A002132 312121C000 21000C0100 1002000120
002A112020 0110121010 0021110233

Tinodon
1??11????? 0111??121? 0?0??10413 00???????0 101000?001 21??12?100 010100010?
110000100? ??00??0100 11???00??? 0???0????0 ?000021021 1?0??????? ???1??22??
1??0?????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Zhangheotherium
1??1010??0 0210??1221 010?211410 1110000011 101001?001 3100120100 0100000001
1100?0100? ??00??0200 11???000?? 0??0000000 ?000022122 100??00002 2101022000
0010000111 0????2?110 0001011121 1111101110 111111110? 0001211022 01?1102101
0010?00000 1302010110 0011000000 000?0?0002 10??120111 ?001211111 2????11010
01?1?1?10? ?0??121001 1102000000 001?0?2??? ????21???? ????????0? ?1?????1??
??????2??2 ???????0?? ??????????

Dryolestes
1??1011100 0210??1121 00?1211312 1110000010 000001?001 3100130200 0020000001
110000220? ?000??1100 01???000?? 0??0001000 ?200022121 100?001001 1000011000
0000030111 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?1???10???
?????????? ???????0?? 0?????????

Henkelotherium
1??1011100 0211??1121 0?1?211312 1110000?0 0000?0?001 3100130200 002?000001
110000220? ?000??1100 01???000?? 0??0001000 ?200022121 100?00100? ?0?0?11000
0000??0??? 0????????? ??????1121 111?1?1110 11?1011101 000121?022 0111002110
10???????? 1????????? ?????????? ????0???0? 101?120?11 ?00?2?111? 3?????????
?????????? ?????????? ????0????? ?????????? ?????????? ???????1?? ???20001??
1?????20?? ?????????? ??????????

Amphitherium
1??1111100 0211??1121 00?1210312 11111?0?00 000001?001 3100130001 0020000000
110000210? 0000??1111 01???000?? 0??0001000 ?200021121 1110000001 ???0??000?
0?00?????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Peramus
1??1111100 0211??1121 0011210312 1111100200 002000?001 3100130001 0001000100
11A0002110 000A?01211 21?0?01000 0??0001002 0200011121 1110000002 ??00000331
0?00??0??? 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Vincelestes
1??2?11100 A211??1111 0011211312 1110000101 000000?001 3100130000 0020000000
110000210? ?000?01200 11?0?01000 0??0001012 0000011121 100?000003 1010033334
2000030??0 0?????0111 1012111?21 1011101110 1010011100 0001210122 0111002110
1020?00100 1302010110 00110100?? ???210??0? 0011220011 ?00121?112 400?111010
0101111100 1011A21101 1102011000 00110031?? ????21?0?? ???1110100 0102010000
1120102020 0010111000 0??1??????

Nanolestes
1??1011100 0211??112? 0??1210312 111??????0 000000?001 3100130001 0021000100
1100002100 0?00?0121? 11?0?0?000 0??1013012 0200011121 1110000001 1?001?02??
0?00??0??? 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Kielantherium
1??101110? 0211??1111 0?12????13 11???????0 000000?001 31??130001 1021100101
1102015110 000A001??? ?????????? ?????????? ????01?122 1?1001000? ???0??12??
0??0?????? 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????0
?????????? ?????????? ??????????

Aegialodon
?????????? ?????????? ?????????? ?????????? ?????????1 ?1??130001 10211001?1
1102015110 0?11001??? ?????????? ?????????? ?????1?122 1?1001000? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ??????????

Montanalestes
1??2?13100 0411??1112 0013210313 111??????1 2020010001 32??130102 1021100120
1202115110 0111002??? ?????????? ?????????? ????0??122 1?1001110? ??????03??
0?00?????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ???1??????

Prokennalestes
1??1113100 0111??1112 0012210312 1111A112?1 2020000201 3220130201 1011100120
1202115110 0111002211 2202001001 1001011010 0200012122 121001110? ??1010033?
0000?00?1? 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ????211112 51111110C0
0102?11??? ?13?1?1100 11???1201? ??110?3??? ????2??0?? ?????????? ?0????????
?1???????1 ?????????? 0?????????

Murtoilestes
?????????? ?????????? ?????????? ?????????? ?????????1 322013?202 10111001?0
1202115110 0?1100?210 220200?001 1001011000 0200012122 121001?10? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Eomaia
1??1113100 0111??1112 0012210312 1111011111 2010000201 322013020? 101110012?
?202?15110 0111??2211 2202001001 10010??000 ?200012122 1210011??1 0000000331
0010000?10 0????11?1 1012011122 1011102110 1112022101 0001211122 01?1112110
0122100212 1302010130 1111010000 1002100012 0011?????2 ??0????1?? 51?11?????
?????11??? ?????????? ?????????? ??11?????? ?????????? ?????????? 00??0??1?0
??2?1020?? ????02??1? ???1??????

Kennalestes
1??2?13100 0411101112 00022????2 1111111201 0020001001 3220130202 1021100122
2203115110 0111002210 2201101001 1011010000 ?200012122 1210011102 101011A332
0010000110 1?????01?? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ???2?????? ?????????? ?????????? ??11222112 2102211112 511??21021
1002F1?200 113?????00 1102010011 00110031?? ????21?1?? 330?110200 000200???0
1121102022 0111021010 0??1011233

Asioryctes
1??2?13100 0411101112 0002210313 1111112201 1020000101 3220130202 1021100120
1203115110 0111002210 2201101001 1001000000 ?200012122 1210011101 0010111332
1010000?10 1?????0111 1????????? ?????????0 ????????01 1000?????2 ????????10
0122100212 1302010130 1111010000 0?0200001? 0011222112 2102211112 5?1??21021
10?2411200 113???1100 1102010011 00110031?? ????21?1?? 3302110200 000200?110
1?21102022 0111021010 0??1011233

Ukhaatherium
?????????0 ?4???????? ?0?22????? ?111112201 1020000201 322013020? 1021100120
1203115110 0111?02210 2201101001 1001000000 ?200012122 1210011101 0000011332
1010030?10 1??????1?? 1??????122 10111?2110 1112022101 00?1210?22 01?1112110
0122100212 1302010130 1111010000 ???200??1? ?0????2??2 21???????? ?????2??21
????4????? ?????????? ?????????? ?????????? ?????????? ?????????0 ?????????0
1????????? ?????????? ??????????

Zalambdalestes
1??2?1D100 A411101112 00A2210312 1111112210 2122001201 3220131203 1021100102
2204205110 001110220? 1201201101 1000000000 ?200012122 1210011102 E0110CC33E
1010200?11 1???????11 10????1?22 10111?2110 1112022101 0001211122 01?1112112
?122100212 13?201013? 0113000000 000200001? 0011322112 2102211112 5?1??21021
1002412200 113???1100 1102010011 00110031?? ????21?1?? 3302110200 000201?110
1121102021 0110021010 0??1011233

Daulestes
1??2?13100 1411101112 0002210312 111???1??? ???????001 3220130202 1021100?1
1202115110 011100220? 1202101001 1111010000 ?200012122 1210011101 ?001011332
00?0??0?10 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ??11220112 0102211112 511???10??
???2?????0 113??????? 11?20120?? 001??????1 ????2??0?? 3?0?1?1??0 00?100?1?0
0?211020?? ?1??0????? 0??2??????

Aspanlestes

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?????1???? ?????????? ??1??????? ?1?11112?1 ?010000?01 3231131102 10211001?1
1201215110 001100220? 1203211103 12100?0000 ?210012122 121001110? ??????033?
0??0????1? 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????1?0?0
?1???????? ?1???????? ??????001? ?????????? ???????1?? ?????????? ?0????????
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Eoungulatum

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?????1???? ?????????? ??1??????? ?1?10110?? ?????????1 3242131103 10211001?1
1201215111 001200320? 1223211103 1210010000 ?010012122 121001110? ??????1332
???0????1? 0????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????1???0
?1???????? ?????????? ?????000?? ?????????? ???????1?? ?????????? ??????????
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Cimolestes

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1??2?1010? 14111?1112 0?02210312 11110122?1 1010000101 3231130202 1021100122
1203115110 0112002210 1211101001 1110000000 ?200012122 1210011102 ?000011332
1?00????1? 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????0???? ?????????? ?????????? ?????????? ??????????
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Gypsonictops

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1??2?10100 14111?1112 0?02210312 11111122?1 2120001101 3231131202 1021100122
1204115110 0112002210 1211101001 1110000000 ?200012122 121001110? ?000011332
0?00????1? 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
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?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Protungulatum

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1??2?10100 14111?1112 0002210312 11110120?1 2110000101 3242131102 1021100121
1201215111 001201320? 1223211103 1000000000 ?010012122 121001110? ?000011332
1?00????10 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
?222003212 1312?10130 11132011?? ?????????? ?????????? ????2?1112 5?1??1?0?0
?00??A1??? ?1???????? ?????1201? ???1?????? ???????1?? ?????????? ??????????
?????????1 ?????????? ??????????
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Erinaceus

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1??2?13100 1411101112 0002210313 1111011011 2122001001 3220131103 1021100101
1202215111 001211220? 1212211102 0??0000000 ?010033122 1211111103 2101033334
2000200111 0????21111 101201112C 1011112110 1112022101 0001211122 1111112102
1222003212 1512010130 1113201100 0002001012 0011321112 0102211112 5111121021
1002311300 113???1100 1102012011 0011003121 3111212100 4302111200 0002001111
0121112121 0111021110 0122011233
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Leptictis

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1??2?13100 1411101112 0002210313 1111112211 2122001001 3222131103 1021100121
1204115110 001101220? 1211111001 1110000000 ?010012122 1211111102 2001011332
1000200?10 0????????? ??12011?22 ??11112110 1112022101 ????211122 1111112112
1222003212 1312010130 1113201100 ??0200?01? ?011321112 0102211112 5111111020
1002312300 113???1100 1102012011 00110031?? ????21?10? 3302111200 0003000111
0121112021 0111021010 0122011233
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Holoclemensia
?????????? ?????????? ?????????? ?1???????? ?????????1 3210130201 1021100111
1102115110 0?2100120? 1201111000 1001001112 1200012122 121001000? ??????????
???0?????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Sinodelphys
1????13101 ?411??111? 0??2210313 11100??11? 1010?00?01 32??130101 1001100111
11?2115110 0121??1211 22???110?? ????002012 12100??122 1?10010001 1000011321
1120?10?10 0????????? ?012?11123 1011112?11 1112?22111 111021???? 01?1???100
0121201??1 1422020110 21?2100011 1102100002 001??????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? 0??????1??
??2??02?3? ????0????? ???1??????

Deltatheridium
1??2?14101 1211??1111 0004210313 1110000110 0010000001 3210130001 1001100111
1102115110 0001001211 2201011000 1001002001 0222012122 1210010001 1000022222
11100?1210 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
?12??????? 1??????110 212???00?? ?????????? ??11?20112 ???211112 510??11010
0212310??? 113????2?00 11?2?0001? ??110141?? ????2??1?? ???211?2?0 00?20101?0
0121?02031 ????02?011 0?????????

Atokatheridium
?????????? ?????????? ?????????? ?????????? ?????????1 ?210130001 1001100?1
1102115110 0?0??0121? 2201011000 1001002001 0222012122 121001000? ??????????
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Sulestes
?????????? ?????????? ?????????? ?????????? ?????????1 3210130001 10011001?1
1112115110 0?11102211 2201011000 1001002111 0222012122 121001010? ??????????
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Marsasia
1??2?14101 1211??1111 2104??1?13 ?????????? ?????????1 3???130?02 ?0011001?1
1112115110 0?22112??? ?????????? ?????????? ????0????? ?????????? ???????2??
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Asiatherium
1??1?14101 14111?1111 01042?0?13 1110000110 0010000001 3220130103 1021100101
1112215110 1122112210 2202111112 11?0001001 0210012122 121001110? ?00?022222
1010?????0 ?????????? 10????1123 10111?2110 1112022111 1110210122 01?1111101
01???????? 1????????? ?????????? ????????0? 0011320112 010?211112 5????1111?
0??23??410 113?????00 ?1?2????10 1111???1?? ????2????? ???211?2?0 0??21??1??
??2??020?? ?1100????? 1??2??????

Kokopellia
???1?1410? 12?1??1?11 0?0F?????3 111????1?0 0010000001 3210130102 1021100100
1112215110 112210221? 2202011001 11?1002111 0210012122 1210011101 ?0000?222?
1?10??0?10 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
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Anchistodelphys
?????????? ?????????? ?????????? ?????????? ?????????1 ?210130203 10211001?0
1112205110 1132102211 2202212102 1010102111 0?20012122 111001110? ??????????
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Albertatherium
?????????? ?????????? ?????????? ?????????? ?????????? 322013???? ??????????
?1???????? ???????211 2202221102 1011002111 12200?2122 111??????? ????????2?
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
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Didelphodon
1??2?14101 1111??1111 010421131? 111001???0 0011000001 3220130003 1021100121
1112205120 1?32112211 2202222102 0101003011 0221012122 111001110? ???0022222
1?00????1? 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
??21201101 1311010110 21221011?? ?????????? ???1320112 0102211112 ???????1??
0?1??12??? ?1???????? ????0??01? ????01???? ?????1?1?? ?????????? ??????????
?????????1 ?????????? 1?????????

Pediomys
???2?14101 1111??1111 010421131? 111??????? ????????01 3220130103 1021100111
1112205120 1132112211 2202222102 1100001111 0210012122 111001110? ???0022222
1100?????? 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
??21201101 1422020110 21221011?? ?????????? ?????????? ???121111? ???????0??
0?1???2??? ?1???????? ???????01? ????01???? ???????1?? ???????2?? ?0????????
?????????1 ?????????? 1?????????

Turgidodon
???2?14101 11111?1111 0?04?1131? 111??????0 0010000001 3210130103 1021100111
1113215120 1132112211 2202221102 1100001111 0220012122 111001110? ???0022222
1?00???21? 0????2???? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? 2????????? ?????????? ?????????? ???221111? ???????0??
0?1??12??? ?1???????? ???????01? ????0????? ???????1?? ?????????? ??????????
?????????1 ?????????? ??????????

Mayulestes
1??2?14101 1411101111 0104210313 1110000100 0010000001 3210130103 1021100111
1112215120 1131102211 2202222002 1100003011 0221012122 1110011101 0000022222
1100111?10 0????1111 1012111123 1011112111 1112022111 ?1??211122 0111111110
0121301101 1422020110 21211011?? ???210??0? 0011320112 0111211112 5?1??11010
0??2412010 113????00 1102101110 01111141?? ????21???? ???2110200 0002110110
0?201020?? 0110021111 0??2??????

Pucadelphys
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1??2?14101 1411101111 0104210313 1110000100 0010000001 3210131203 1021100101
1112215120 1132102210 2202222112 1110003111 1210012122 1110011101 0000022222
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Vombatus
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Pseudocheirus

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Petauroides

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Part VII. PAUP Search Settings and Results

```
P A U P *
Version 4.0b10 for Macintosh (PPC)
Monday, October 27, 2003  3:05 PM

This copy registered to: Zhe-Xi Luo
                         Carnegie Museum of Natural History
                         (serial number = B414746)

      -----------------------------NOTICE-----------------------------
        This is a beta-test version.  Please report any crashes,
        apparent calculation errors, or other anomalous results.
        There are no restrictions on publication of results obtained
        with this version, but you should check the WWW site
        frequently for bug announcements and/or updated versions.
        See the README file on the distribution media for details.
      ----------------------------------------------------------------

Processing of file "Luo-Matrix(Ms.1090718).dat" begins...

Data matrix has 84 taxa, 380 characters
Valid character-state symbols: 012345
Missing data identified by '?'
Gaps identified by '-'

2 trees read from TREES block
   Time used = 0.00 sec

2 trees converted from rooted to unrooted.

Warning: The following taxa were omitted from one or more trees:
            Thrinaxodon,      Massetognathus,   Probainognathus, Pachygenelus,
            Adelobasileus,    Asfaltomylos,     Teinolophos,     Obdurodon,
            Tachyglossus,     Amphilestes,      Trioracodon,     Tinodon,
            Dryolestes,       Amphitherium,     Nanolestes,      Aegialodon,
            Murtoilestes,     Eomaia,           Kennalestes,     Ukhaatherium,
            Zalambdalestes,   Daulestes,        Aspanlestes,     Eoungulatum,
            Cimolestes,       Gypsonictops,     Protungulatum,   Leptictis,
            Holoclemensia,    Sinodelphys,      Atokatheridium,  Sulestes,
            Marsasia,         Anchistodelphys,  Albertatherium,  Didelphodon,
            Pediomys,         Turgidodon,       Mayulestes,      Andinodelphys,
            Marmosa,          Caenolestes,      Dasyurus,        Perameles,
            Dromiciops,       Thylacomyidae,    Macropus,        Acrobates,
            Phascolarctos,    Vombatus,         Phalanger,       Pseudocheirus,
            Petauroides
         (They have been connected to the base of the tree according to the rooting
         implied by the tree description.)

*** Skipping "MacClade" block

Processing of file "Luo-Matrix(Ms.1090718).dat" completed.

Outgroup status changed:
  1 taxon transferred to outgroup
  Total number of taxa now in outgroup = 1
  Number of ingroup taxa = 83

Input data matrix:

                              111111111122222222223333333333444444444455555555556666666666777
Taxon/Node          123456789012345678901234567890123456789012345678901234567890123456789012
----------------------------------------------------------------------------------------------
Thrinaxodon         0000000000000000000000000?0??0100??????0?00000???00???00?????0000000??0?
Massetognathus      0000010000000001000000000?0??0100????????20000???20???00?????0000000????
Probainognathus     0000000000000001000000000?00?0100????????00000???00???00?????0000000??0?
Tritylodontids      0000010000000000000000010?00?3020????????20?00??221???24?????0000000????
Pachygenelus        0000000000000000000000000000?2001??????1?00000???00???00?????0000000?000
```

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Adelobasileus       ??????????????????????????????????????????????????0?????0?????0000000?000
Sinoconodon         0000001000000000000000000110100001?????01100000?0000???00?20??00000001000
                                                                                   2
Morganucodon        0000101000000000000000000200100001000000010000?00000??11?20??20000020000
                                             1
Megazostrodon       0000100000000000000000000200201001000000000000?00000??12?20??20000020000
Haldanodon          0000011000000000100000002101010010000000100001?10000??11?00???0032000000
Hadrocodium         1??2?13001?4111000000000200102?0100001010000000?0?000??12?20???0000000000
Shuotherium         0010110??00011??000?0?00?????0101??????1101011??0132001?0103010132100111
Asfaltomylos        00121121100011??0022000021311210???????11011?????132??13??13?0210000?111
Ambondro            ?????1???0???1???????0?????????0???????12131110??132??130?1330012100?111
Ausktribosphenos    00100120100011??0022000002??112101??????1213111011132??130213300121000221
Bishops             01?1012010?011??0022000021311210???????12131?1011132??130213300121001221
Teinolophos         1???2120101311??0022000?21311210??????????????????32??1311112001201 0?222
Steropodon          011001???0?0?1?????????????????10??????????????????132??1311112001211 00222
Obdurodon           1??2?1201013111011220001213112101??????1013100???132??131111200120100222
Ornithorhynchus     1??2?1001013111011220001213112101????????????????132??1?1?1?????20100222
                                                   2
Tachyglossus        1??2?10??01411100000000?21311??01?????????????????????????????????????????
Gobiconodon         1??1010??001111?12210101211401001000001100101000000 0??12?10??10100010?00
Amphilestes         1??11?0??0111???122???0?211402201??????1101000000000??12?10??10100010?00
Jeholodens          1??1010??0?1111?12??010?22140100100000001010000000000??11?10??02000031?00
Priacodon           1??1010??01111??12210100221401001000000000100010000 0??11?10??12000031?00
Trioracodon         1??10?0??01111??122101002214010010000 0?0101000100000??11?10??10000031?00
                                                                                   2
Plagiaulacidans     1??2?10??003111010211100222401021?????0??2?000??221???24?????0??0?000???
                              1
Cimolodontans       1??2?10??013111010211100221401021?????0??2?000??221???24?????0??0?000???
                                          2 12
Tinodon             1??11????0111??121?0?0??1041300???????0101000?00121??12?100010100010?11
Zhangheotherium     1??1010??00210??1221010?2114101110000011101001?001310012010001000000 0111
Dryolestes          1??10111000210??112100?121131211100000100000 01?0013100130200002000000111
Henkelotherium      1??10111000211??11210?1?211312111000 00?00000?0?00131001302000 02?00000111
Amphitherium        1??11111000211??112100?12103121111 1?0?00000001?0013100130001002000000011
Peramus             1??11111000211??11210011210312111110020000 2000?0013100130001000100010011
Vincelestes         1??2?111000211??11110011211312111000010100000 0?0013100130000002000000011
                              1
Nanolestes          1??10111000211??112?0??121031 2111??????0000000?0013100130001002100010011
Kielantherium       1??101110?0211??11110?12????1311???????0000000?00131??1300011021100 10111
Aegialodon          ?????????????????????????????????????????????????1?1??1300011021100 1?111
Montanalestes       1??2?131000411??111200132103131 11??????1202001000132??1301021021100 12012
Prokennalestes      1??11131000111??1112001221031211110112?12020000201322013020110111001 2012
                                                     1
Murtoilestes        ?????????????????????????????????????????????????1322013?20210111001?012
Eomaia              1??11131000111??1112001221031211110111112010000201322013020?101110012??2
Kennalestes         1??2?1310004111011120002 2????2111111120100200010013220130202102110012222
Asiorycte           1??2?131000411101112000221031311111122011020000101322013020210211001 2012
Ukhaatherium        ?????????0?4?????????0?22??????111112201102000020132201302 0?102110012012
Zalambdalestes      1??2?111000411101112000221031211111122102122001201322013120310211001 0222
                          3   1           1
Daulestes           1??2?13100141110111200022103121 11???1??????????0013220130202102110 01?112
Aspanlestes         ?????1??????????????????1?????????1?11112?1?010000?01323113110210211001?112
Eoungulatum         ?????1??????????????????1?????????1?10110???????????13242131103102110 01?112
Cimolestes          1??2?1010?14111?11120?022103121111 0122?11010000101323113020210211001 2212
Gypsonictops        1??2?10100141 11?11120?0221031211111122?12120001101323113120210211001 2212
Protungulatum       1??2?1010014111?1112000221031211110120?12110000101324213110210211001 2112
Erinaceus           1??2?131001411101112000221031311110110112122001001322013110310211001 0112
Leptictis           1??2?131001411101112000221031311111122112122001001322213110310211001 2112
Holoclemensia       ?????????????????????????????????1??????????????????13210130201102110011111
Sinodelphys         1????13101?411??111?0??22103131110 0??11?1010?00?0132??1301011001100 11111
Deltatheridium      1??2?141011211??11110004210313111000011000100000013210130001100110 011111
Atokatheridium      ?????????????????????????????????????????????????1?2101300011001 1001?111
Sulestes            ?????????????????????????????????????????????????13210130001100 11001?111
Marsasia            1??2?141011211??11112104??1?13????????????????????13???130?02?0011001?111
Asiatherium         1??1?1410114111?111101042?0?131110000110001000000132201301031021100 10111
Kokopellia          ???1?1410?12?1??1?110?032????3111????1?0001000000132101301021021100 10011
                                        4
Anchistodelphys     ?????????????????????????????????????????????????1?2101302031021100 1?011
Albertatherium      ??????????????????????????????????????????????????322013????????????????1
```

Didelphodon	1??2?141011111??1111010421131?111001???0001100000132201300031021100121 11
Pediomys	???2?141011111??1111010421131?111???????????????013220130103102110011111
Turgidodon	???2?1410111111?11110?04?1131?111??????000100000013210130103102110011111
Mayulestes	1??2?141011411101111010421031311100001000010000001321013010310211001111 1
Pucadelphys	1??2?141011411101111010421031311100001000010000001321013120310211001011 1
Andinodelphys	1??2?141011411101111010421031311100001000010000001321013120310211001211 1
Didelphis	1??2?141011411101111010421031311100002100010000001321013020310211001011 1
Marmosa	1??2?141011411101111010421031311100002100010000001321013020310211001111 1
Caenolestes	1????14101141110111101042 1?313111???????????????0?321013020310211001111 1
Dasyurus	1??2?141011411101111010421031311100002100010000001321013020310211001111 1
	1
Perameles	1????1410114111011110104 21?313111???????????????0?321013020210211001211 1
Dromiciops	1?12?141011411101111010421031311100002100010000001321013020310211001101 1
Thylacomyidae	1?1??1410114111011110104 21?313111???????????????0?3??????????????001??11
Macropus	1?1??1410114111011110104 21?313111???????????????0?3253131303002000013301
Acrobates	1?1??1410114111011110104 21?313111???????????????0?3353131302102000010101
Phascolarctos	1?1??1310114111011110104 21?313110???????????????0?3353131303202000013301
Vombatus	1?1??1410114111011110104 21?313110???????????????0?3353131303202000013301
Phalanger	1?1??1410114111011110104 21?313111???????????????0?3353131303202000013300
Pseudocheirus	1?1??1410114111011110104 21?313111?????????????????3353131303202000013300
Petauroides	1?1??1410114111011110104 21?313111?????????????????3353131303202000013300

Input data matrix (continued):

```
                                             111111111111111111111111111111111111111111111
                  777777788888888889999999999000000000011111111112222222222333333333344444
Taxon/Node        345678901234567890123456789012345678901234567890123456789012345678901234
--------------------------------------------------------------------------------------------
Thrinaxodon       ???????????????00?????????????????????????0???0??????????000000????00?0?
Massetognathus    ???????????????00?????????????????????????0??01??????????000000????00?0?
Probainognathus   ???????????????00?????????????????????????0???0??????????000000????00?0?
Tritylodontids    ???????????????00?00????????????1??????0??03313??????????332?2???0000?2?
Pachygenelus      ???????????????00?????????????????????????0???0??????????331000??0000?1?
Adelobasileus     ??????????????????????????????????????????????0?????????????????????????
Sinoconodon       ???0000???0????00?00???0????????0??????0??000?0?0?0??????000000331122020
Morganucodon      ???0000???0????00?40???0????????0??????0??0000100?0??????000000002100000
                                                                           11      32
Megazostrodon     ???0000???0????00?40???0????????0??????0??0000100?0??????110000001100000
Haldanodon        ???0000???0????00?11???0????????0??????0??0320100?0??????100000220000000
Hadrocodium       ???0000???0????00?00???0????????0??????0??0000100?0??????000100334443000
Shuotherium       0000110???00??020?11???0?00?0??000?????01001212110 0??0100????????3?????0
Asfaltomylos      02214110001111 2????????????????????????????01?1211?1101??0??????????????0
Ambondro          022241120?11112????????????????????????????01?1211?1101010??????????????0
Ausktribosphenos  022141220032123????????????????????????????03?1221?1112111????????3????00
Bishops           022141220032123????????????????????????????03?1221?1112111???????03??0?00
Teinolophos       042231210?02?23?????????????????????????????3?1222?211310 2???????????????
Steropodon        042231210?02?23????????????????????????????03?1221?2113102????????3??3???
Obdurodon         042231210?02?2320?1??????????????0????????0331221?2113102542?2?333443??0
Ornithorhynchus   042231210??2?2320?1?????????????????????0??033?????2?1?1?2542?2?334443??0
Tachyglossus      ?????????????????????????????????????????????????????????542?2?334443???
Gobiconodon       ???0000???0????00?10???0????????0??????0??0000201?0??????321010111100000
                                                                                  2
Amphilestes       ???0000???0????00???????????????????????????00?0201?0??????????00?21??0000
Jeholodens        ???0000???0????00?00???0????????0??????0??0000100?0??????111010332232000
                                    1
Priacodon         ???0000???0????00?10???0????????1??????1??0000100?0??????3?0000122221000
Trioracodon       ???0000???0????00?10?????????????1??????1??0000100?0??????3?0000123321000
Plagiaulacidans   ????????????????0?00?????????????1??????0??03313??????????42102?114432021
                                                                             2   22  4
Cimolodontans     ????????????????0?00?????????????1??????0??03313??????????432?2?334443021
Tinodon           0000100???00??010011???00???0???0????0?0000210211?0??????????1??22??1??0
Zhangheotherium   00?0100???00??020011???000??0??0000000?000022122100??000022101022000001 0
Dryolestes        0000220??000??110001???000??0??0001000?200022121100?00100110000110000000
Henkelotherium    0000220??000??110001???000??0??0001000?200022121100?00100??0?0?110000000
Amphitherium      0000210?0000??111101???000??0??0001000?2000211211110000001???0??000?0?00
Peramus           000021100000?0121121?0?010000??0001002020001112111100000 02??000003310?00
                  1          1
Vincelestes       0000210??000?0120011?0?010000??000101200000111211 00?0000031010033334200 0
Nanolestes        000021000?00?0121?11?0?0?0000??10130120200011121111000000 11?001?02??0?00
Kielantherium     020151100000001????????????????????????????01?1221?1001000????0??12??0??0
                             1
Aegialodon        020151100?11001?????????????????????????????1?1221?1001000???????????????
Montanalestes     021151100111002????????????????????????????0??1221?1001110???????03??0?00
Prokennalestes    021151100111002211220200100110010110100200012122121001110???1010033?0000
Murtoilestes      021151100?1100?210220200?001100101100002000121221210 01?10??????????????
Eomaia            02?151100111??2211220200100110010??000?2000121221210011??100000003310010
Kennalestes       031151100111002210220110100110110100 00?2000121221210011102101011033200 10
                                                                                1
Asiorycts         031151100111002210220110100110010000 00?20001212212100111010010111332101 0
Ukhaatherium      031151100111?0221022011010011001000000?20001212212100111010000011332101 0
Zalambdalestes    042051100011102 20?1201201101100000000?20001212212100111022011011332101 0
                                                                            3    22  3
Daulestes         021151100111002 20?120210100111101000 0?20001212212100111 01?00101133200?0
Aspanlestes       012151100011002 20?1203211103121 00?0000?21001212212100111 0???????033?0??0
Eoungulatum       012151110012003 20?1223211103121001000 0?01001212212100111 0???????1332???0
Cimolestes        031151100112002210121110100111100000 00?20001212212100111 02?000011 3321?00
Gypsonictops      041151100112002210121110100111100000 00?20001212212100111 0??000011 3320?00
Protungulatum     012151110012013 20?1223211103100000000 0?01001212212100111 0??000011 3321?00
Erinaceus         022151110012112 20?12122111020??0000000?010033122121111111032101033334200 0
```

Leptictis	04115110001101220?12111110011110000000?010012122121111110220010113321000
Holoclemensia	021151100?2100120?120111100010010011121200012122121001000??????????????0
Sinodelphys	?21151100121??121122???110??????00201212100??1221?1001000110000113211120
Deltatheridium	021151100001001211220101100010010020010222012122121001000110000222221110
Atokatheridium	021151100?0??0121?22010110001001002001022201212212100100 0???????????????
Sulestes	121151100?1110221122010110001001002111022201212212100101 0???????????????
Marsasia	121151100?22112???????????????????????????0??????????????????????2??????
Asiatherium	12215110112211221022021111211?000100102100121221210011 10??00?0222221010
Kokopellia	1221511011221022 1?22020110011 1?1002111021001212212100111 01?0000?222?1?10
Anchistodelphys	122051101132102211220221210210101021110?20012122111001110???????????????
Albertatherium	???????????????21122022211021011002111122 00?2122111???????????????2?????
Didelphodon	122051201?32112211220222210201010030110221012122111001110????00222221?00
Pediomys	122051201132112211220222210211000011110210012122111001110????00222221100
Turgidodon	132151201132112211220222110211000011110220012122111001110????00222221?00
Mayulestes	122151201131102211220222200211000030110221012122111001110100000222221100
Pucadelphys	122151201132102210220222211211100031111210012122111001110100000222221110
Andinodelphys	122151201032112210220222211211100031111210012122111001110100000222221110
Didelphis	122151201032112210220222211 20??00031111220012122111001110100000222221110
Marmosa	121151201032122210220222211 20??00031111210012122111001110100010222221000
Caenolestes	132151201032122210220222211 20??010310102100121221110 0111?110000222221010
Dasyurus	122151201032122211220222211 20??01031010220012122111001110210000332231100
Perameles	132151200032122210220222211 20??010310102200121221110 0111?200000222221010
Dromiciops	132051201032122211220222211 20??00000011210012122111001110100010222221010
Thylacomyidae	132??1????3???4????2042??1120??0100001?2?0112122101???110200???222221??0
Macropus	13204131004312400?32042211120??0100000?23001212210111011 0421???332232?11
Acrobates	13215120004212420?32042211120??010000112100121221010011 10300010222231000
Phascolarctos	13204130004312420?32042211120??0100100?23011212210111011 0421???332233?20
Vombatus	13204131004312420?32032211120??0100000?23011212210111011 0432???332233?20
Phalanger	13215120004312420?32042211120??0100100?230012122101110110320010222222021
Pseudocheirus	13204130004212420?32042211120??0100100?230112122101110110321010332232000
Petauroides	13204130004212420?32042211120??0100100?230012122101110110320010332232000

Input data matrix (continued):

```
                    111111111111111111111111111111111111111111111111111111122222222222222222
                    444445555555555666666666677777777778888888888999999999900000000001111111
Taxon/Node          567890123456789012345678901234567890123456789012345678901234567890123456
--------------------------------------------------------------------------------------------
Thrinaxodon         0000001?0??0000001000000000?000000000000000000????000000?0000000000000?0
Massetognathus      000000100??0?????????????0?????????00000000000????10???0????????????????
Probainognathus     000000??0??0?????????????0????????????????????????10???0????????????????
Tritylodontids      10??1120100000000?0000000000000000000000000000????200010000000000000000?0
                                                            1
Pachygenelus        2000001?1??0000?0?001000000?00000000000000000001000210001?00000?????????
Adelobasileus       ????????????????????????????????????????????????????????????????????????
Sinoconodon         0000001????100??0?0000000000000000000000000000???????????000000??0??????
Morganucodon        0001101????000000?0?1?00100?000?00000000000000????21000100100010?0?000?0
Megazostrodon       0001001????200000?????0?1000000?0000000000000??0??210001001000?0000000?0
Haldanodon          0001100????0????????????1000????00?000?0100000???????????0?000?0????????
Hadrocodium         0001101?????????????????????????????????????????????????????????????????
Shuotherium         ????????????????????????????????????????????????????????????????????????
Asfaltomylos        ????????????????????????????????????????????????????????????????????????
Ambondro            ????????????????????????????????????????????????????????????????????????
Ausktribosphenos    ????????????????????????????????????????????????????????????????????????
Bishops             ????????????????????????????????????????????????????????????????????????
Teinolophos         ????????????????????????????????????????????????????????????????????????
Steropodon          ????????????????????????????????????????????????????????????????????????
Obdurodon           ????1?????????????????????????????????????????????21???1????????????????
Ornithorhynchus     ????1??????01110110000000001010000000001000001001211111000000020100000?0
Tachyglossus        ????????????1110110000000001010000000001000001001211111000000020100000?0
Gobiconodon         0001010????2?????1????1?211?1?1?11100000110000????210021000000100100????
Amphilestes         ??????0?????????????????????????????????????????????????????????????????
Jeholodens          0001111?????00000101111121111?1011100??0110100000121002100000010010000?0
Priacodon           ??01101????1???????????????????????????110100???????????????????????????
Trioracodon         ??01100?????????????????????????????????????????????????????????????????
Plagiaulacidans     03?111210010??????000111111011101100100200010100012 1?111011110?010001??0
Cimolodontans       23?111201112001000000111111011101100100100000100??21011101111020100010?0
                                                           2   1
Tinodon             ????????????????????????????????????????????????????????????????????????
Zhangheotherium     0001110????2?11000010111211111101110111111110?000121102201?11021010010?0
Dryolestes          0301110????2????????????????????????????????????????????????????????????
Henkelotherium      ??0???0???????????????1121111?1?111011?1011101000121?022011100211010????
Amphitherium        ????????????????????????????????????????????????????????????????????????
Peramus             ??0???0?????????????????????????????????????????????????????????????????
Vincelestes         030??00?????01111012111?2110111011101010011100000121012201110021101020?0
Nanolestes          ??0???0?????????????????????????????????????????????????????????????????
Kielantherium       ??????0?????????????????????????????????????????????????????????????????
Aegialodon          ????????????????????????????????????????????????????????????????????????
Montanalestes       ????????????????????????????????????????????????????????????????????????
Prokennalestes      ?00?1?0?????????????????????????????????????????????????????????????????
Murtoilestes        ????????????????????????????????????????????????????????????????????????
Eomaia              000?100?????11?1101201112210111021101112022101000121112201?1112110012210
Kennalestes         0001101?????01??????????????????????????????????????????????????????????
Asioryctes          000?101????01111???????????????????0????????011000?????2????????10012210
Ukhaatherium        030?101??????1??1??????12210111?2110111202210100?1210?2201?1112110012210
Zalambdalestes      200?111???????1110????1?2210111?21101112022101000121112201?1112112?12210
Daulestes           ??0?100?????????????????????????????????????????????????????????????????
Aspanlestes         ????1?0?????????????????????????????????????????????????????????????????
Eoungulatum         ????1?0?????????????????????????????????????????????????????????????????
Cimolestes          ????1?0????2????????????????????????????????????????????????????????????
Gypsonictops        ????1?0????2????????????????????????????????????????????????????????????
Protungulatum       ????100????2???????????????????????????????????????????????????????22200
Erinaceus           2001110????2111110120111211011112110111202210100012111221111112102122200
                                             2
Leptictis           200?100???????????12011?22??11112110111202210 1????2111221111112112122200
Holoclemensia       ????????????????????????????????????????????????????????????????????????
Sinodelphys         ?10?100??????????012?111231011112?111112?22111111021????01?1???100012120
Deltatheridium      0?12100????2???????????????????????????????????????????????????????12???
Atokatheridium      ????????????????????????????????????????????????????????????????????????
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Sulestes	??
Marsasia	??
Asiatherium	?????0?????????10????112310111?21101112022111111021012201?111110101????
Kokopellia	??0?100????2??
Anchistodelphys	??
Albertatherium	??
Didelphodon	????1?0????2??2120
Pediomys	??????0????2??2120
Turgidodon	???21?0????2??
Mayulestes	111?100????1111101211112310111121111112022111?1??2111220111111110012130
Pucadelphys	1112100????1111101211112310111121111112122 11?????2111220111111110012130
Andinodelphys	111?100???
Didelphis	1112100???21111101211112310111121111112022111211021112201111111100 12130
	1
Marmosa	1112100????11111012111123101111211111120221112110211122011111111 0012130
Caenolestes	0202100???0?11111012111123101111211111120221112110211122011111111 0012130
Dasyurus	0112100????11111012111123101111211111120221112110211122011111111 0012131
Perameles	0212101????11111012111123101111211111120221112110211122011111110 1012130
Dromiciops	0212100????11111012111123101111211111120221112110211122011111111 0012130
Thylacomyidae	?2?210?????11111012111123101111211?11120221111110211122011111111 0012130
Macropus	020211 2?110?11111012111123101111211111120221111110211122011111111 0012131
Acrobates	020211 0????11111012111123101111211111120221111110211122011111111 0012130
Phascolarctos	010211 1????11111012111123101111211111120221111110211122011111111 0012130
Vombatus	1?0211 2????11111012111123101111211111120221111110211122011111110 1012130
Phalanger	020211 1????11111012111123101111211111120221111110211122011111111 0012130
Pseudocheirus	020211 1????11111012111123101111211111120221111110211122011111111 0012130
Petauroides	020211 1????11111012111123101111211111120221111110211122011111111 0012131

Input data matrix (continued):

```
                  222222222222222222222222222222222222222222222222222222222222222222222222
                  111222222222233333333334444444444555555555566666666667777777777888888888
Taxon/Node        789012345678901234567890123456789012345678901234567890123456789012345678
------------------------------------------------------------------------------------------
Thrinaxodon       0000000000000?0000000011000000??000000?0????????0000??000??00?0?00?00000
Massetognathus    ????????????????????????????????0??????0????????1000??000??00?0?00?00000
Probainognathus   ???????????????????????????????????????0?????0??1000??000??00?0?00?00000
Tritylodontids    00000000000000000000001?000?0?00000000?0?0???0?01011??1000000?0000000000
Pachygenelus      ????????????????????????????????????000100?0?0?01011??1?00000?0000?00000
Adelobasileus     ????????????????????????????????????000????????0201100?????0000001?11??1
Sinoconodon       ????????????????????????????????????00010000?00020110010000000001011111
Morganucodon      0000000000000000000000??0???????0??000110000?00021111120100000000 1011111
                                                            11
Megazostrodon     0000000000?00??0??0?0?1?0000000000000?1100???0002111012010?0000001011111
Haldanodon        ????????????????????????????????0???00120011?000211100201000000001?12111
Hadrocodium       ????????????????????????????????????10020101?000211112301000000001?11111
Shuotherium       ????????????????????????????????????????????????????????????????????????
Asfaltomylos      ????????????????????????????????????????????????????????????????????????
Ambondro          ????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ????????????????????????????????????????????????????????????????????????
Bishops           ????????????????????????????????????????????????????????????????????????
Teinolophos       ????????????????????????????????????????????????????????????????????????
Steropodon        ????????????????????????????????????????????????????????????????????????
Obdurodon         ????????????????????????????????????00210110?000211111?????0000001?11111
Ornithorhynchus   000001011000000000000?1000110100110000210010?000211111411000000001011111
                                                    1
Tachyglossus      000001011000000000000?1000110100110000210010?000211111411000000001011111
                                                    1
Gobiconodon       ?????000??0???0?????????????????0?1?00120011?0002111?13?00?0000001?121?1
Amphilestes       ????????????????????????????????????????????????????????????????????????
Jeholodens        000000001000000000000000000001000000001 2?011?00?2?11?130100??0???10??11?
Priacodon         ???????????????????????????????????????????1??00211111301??000000101?111
Trioracodon       ???????????????????????????????????????????????02?11?????????0??0?0??111
Plagiaulacidans   0?001211120?1000110000000001010012?0?0110110?000211111301??0000001012111
Cimolodontans     000012111200100011000000000101001210001100 10?000211111301001000001012111
                                 1    1                    1                 2  1
Tinodon           ????????????????????????????????????????????????????????????????????????
Zhangheotherium   000013020101100011000000000?0?000210??120111?0012111112????1101001?1?1?1
Dryolestes        ????????????????????????????????????????????????????????????????????????
Henkelotherium    ????1???????????????????????0???0?101?120?11?00?2?111?3?????????????????
Amphitherium      ????????????????????????????????????????????????????????????????????????
Peramus           ????????????????????????????????????????????????????????????????????????
Vincelestes       0100130201011000110100?????210??0?0011220011?00121?112400?11101001011111
Nanolestes        ????????????????????????????????????????????????????????????????????????
Kielantherium     ????????????????????????????????????????????????????????????????????????
Aegialodon        ????????????????????????????????????????????????????????????????????????
Montanalestes     ????????????????????????????????????????????????????????????????????????
Prokennalestes    ????????????????????????????????????????????????21111251111110100102?11?
                                                                                2
Murtoilestes      ????????????????????????????????????????????????????????????????????????
Eomaia            02121302010130111101000010021000120011?????2??0????1??51?11??????????11?
Kennalestes       ???????2????????????????????????????112221122102211112511??21021100231?2
                                                                                      4
Asioryctes        0212130201013011110100000?0200001?001122211221022111125?1??2102110?24112
Ukhaatherium      021213020101301111010000???200??1??0????2??221?????????????2??21????4???
Zalambdalestes    021213?201013?0113000000000200001?001132211221022111125?1??2102110024122
Daulestes         ????????????????????????????????????112201120102211112511???10?????2????
Aspanlestes       ???????????????????????????????????????????????????????????1?0?0?1??????
Eoungulatum       ???????????????????????????????????????????????????????????1???0?1??????
Cimolestes        ????????????????????????????????????????????????????????????????????????
Gypsonictops      ????????????????????????????????????????????????????????????????????????
Protungulatum     32121312?1013011132011??????????????????????????2?11125?1??1?0?0?00??01?
                                                                                       1
Erinaceus         321215120101301113201100000200101200113211120102211112511112102110023113
Lepictis          321213120101301113201100??0200?01??0113211120102211112511111102010023123
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Holoclemensia     ????????????????????????????????????????????????????????????????????????
Sinodelphys       1??1142202011021?21000111102100002001???????????????????????????????????
Deltatheridium    ????1??????110212???00??????????????11?20112????211112510??110100212310?
Atokatheridium    ????????????????????????????????????????????????????????????????????????
Sulestes          ????????????????????????????????????????????????????????????????????????
Marsasia          ????????????????????????????????????????????????????????????????????????
Asiatherium       ????1????????????????????????????0?0011320112010?2111125???1111?0??23??4
Kokopellia        ????????????????????????????????????????????????????????????????????????
Anchistodelphys   ????????????????????????????????????????????????????????????????????????
Albertatherium    ????????????????????????????????????????????????????????????????????????
Didelphodon       1101131101011021221011???????????????13201120102211112???????1??0?1??12?
Pediomys          1101142202011021221011?????????????????????????121111????????0??0?1???2?
Turgidodon        ??????????????2????????????????????????????????221111????????0??0?1??12?
Mayulestes        1101142202011021211011?????210??0?0011320112011121111125?1??110100??24120
Pucadelphys       1101142202011021221011?11?0210??0?00113201120111211112511??1101002124120
Andinodelphys     ????????????????????????????????0???1132011201122111125?1??1101002?24120
Didelphis         110114220211102123201111110210010200113201120111211112511111111002123120
                                                                                         1
Marmosa           110114220211102122201111110210010200113201120111211112511111111002123121
Caenolestes       2?0114220101102122101111000210100200113201120?11211112511111113002?23120
Dasyurus          210115100101212I3?1011110002101002001132011201132111125111111130021231111
Perameles         2?1115100201212I3?101111100200100201113201120211211112511111113002?23124
Dromiciops        2?1115100201212I3?201111100210010200113201120111211112511111113002?23124
Thylacomyidae     ????15100201212I3???11???002?0?002011132?112?11321111251111111300 2?2312?
Macropus          2?11151001012121 3?101111100200000201113211131303211112511111113002?23104
Acrobates         2?11151002012121 3?2?1111100 2?0?10201113211131303211112511111113002?23104
Phascolarctos     2?1115100201212I3?1011111002100102012132111001032111125111111130 02?23104
Vombatus          2?11151002012121 3?10111110021001020121321110?0032111125111111130 02?23003
Phalanger         2?1115100201212I3?201111100210010201213211131303211112511111113002?23104
Pseudocheirus     2?1115100201212I3?201111100210010201213211131303211112511111113002?23104
Petauroides       2?1115100201212I3?201111100210010201213211131303211112511111113002?23104
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Input data matrix (continued):

                  2222222222223333333333333333333333333333333333333333333333333333333333
                  8999999999900000000000111111111122222222223333333333444444444455555555556
Taxon/Node        9012345678901234567890123456789012345678901234567890123456789012345678890
----------------------------------------------------------------------------------------
Thrinaxodon       00010?1000000??0?????00?00??000000000000000000000000000000000000000000
Massetognathus    0001001000000??0?????00?00??0010100000000001000000003000000000000010000000
Probainognathus   0001001100000??0?????00?00??00001000000?00100000000000000000000010000000
Tritylodontids    000100000100??00000?00000?0100021000000001000000103010000000000020001000
                                                                1
Pachygenelus      0001011000000??00000?000100001002100110000100001000001010101000010001000
Adelobasileus     01000100100000???000000000100001?????????0??????0?0?000??????00?020????00
Sinoconodon       0100000000100?00000000000100011102100110000100101010001010001000020102000
Morganucodon      0100110100111001000000000100011002100210000100101010001010101000020102000
Megazostrodon     000011?1001110?1000000000100011002 10?21???01001?1??000101010100 0?2?102000
Haldanodon        00?01????0101001000000000010001100????21000???0212?1000101010000000201 02010
Hadrocodium       0?1011021000110100000000100?11??????21?0??1??212?103010100010001 2?102010
Shuotherium       ??????????????????????????????????????????????????????????????????????
Asfaltomylos      ??????????????????????????????????????????????????????????????????????
Ambondro          ??????????????????????????????????????????????????????????????????????
Ausktribosphenos  ??????????????????????????????????????????????????????????????????????
Bishops           ??????????????????????????????????????????????????????????????????????
Teinolophos       ??????????????????????????????????????????????????????????????????????
Steropodon        ??????????????????????????????????????????????????????????????????????
Obdurodon         101011121001 10?10000000000?000???????1?0?????312?10000?40??1211120112?00
Ornithorhynchus   1010111210011011000000000000?000323121211000210311010000240011211120112100
Tachyglossus      1010111210011011000000000010?000323121211000210312110200240011211120112100
Gobiconodon       001011110001100000000000011??21???????1?0????0201010?00010000?0??2??12020
Amphilestes       ??????????????????????????????????????????????????????????????????????
Jeholodens        ????????????????0??00??????????????21??????2?????????00?10??1???????12???
Priacodon         00?0111100??100??000?0??110021??????2??0?????2?????0?0??????????????12?10
Trioracodon       0??0????????????????0?0???1??????????????0????????????0?????????????????0
Plagiaulacidans   0110211???0111?10?000000100021??????21?0??2?000201001002 0001?00020112020
Cimolodontans     0110211210011001000000000100021323121211000210001010010020001200020112020
                           1   1   11      1           2        2                 1
Tinodon           ??????????????????????????????????????????????????????????????????????
Zhangheotherium   0??0??121001110200000000 1?0?2????????21?????????????0??1?????1?????????2??2
Dryolestes        ?????????????????????????????????????????????????????1???10?????????????
Henkelotherium    ????????????????0????????????????????????????????1?????20001??1?????20??
Amphitherium      ??????????????????????????????????????????????????????????????????????
Peramus           ??????????????????????????????????????????????????????????????????????
Vincelestes       00101102110111020110000011003 1??????21?0?????11101000102010000 1120102020
                        1
Nanolestes        ??????????????????????????????????????????????????????????????????????
Kielantherium     ????????????????????????????????????????????????????????????0?????????
Aegialodon        ??????????????????????????????????????????????????????????????????????
Montanalestes     ??????????????????????????????????????????????????????????????????????
Prokennalestes    ???13?1?110011???1201???110?3???????2??0?????????????0?????????1???????1
Murtoilestes      ??????????????????????????????????????????????????????????????????????
Eomaia            ????????????????????????11??????????????????????????00??0??1?0??2?1020??
Kennalestes       00113?????0011020100110011003 1??????21?1??330?110200000200???01121102022
Asioryctes        00113???110011020100110011003 1??????21?1??3302110200000200?1101?21102022
Ukhaatherium      ?????????????????????????????????????????????????0?????????01?????????
Zalambdalestes    00113???110011020100110011003 1??????21?1??3302110200000201?1101121102021
Daulestes         ?0113???????11?20120??001??????1????2??0??3?0?1?1??000?100?1?00?211020??
Aspanlestes       ???1???????????????001???????????????????1??????????????0??????????????????
Eoungulatum       ?????????????????000???????????????????1??????????????????????????????????
Cimolestes        ?????????????????0????????????????????????????????????????????????????
Gypsonictops      ??????????????????????????????????????????????????????????????????????
Protungulatum     ???1??????????????1201????1??????????????1?????????????????????????????1
Erinaceus         00113???11001102012011001100312131112121004302111200000200111101211121 21
Leptictis         00113???11001102012011001100 31??????21?10?33021112000003000111012111 2021
Holoclemensia     ??????????????????????????????????????????????????????????????????????
Sinodelphys       ??????????????????????????????????????????????????????0??????1????2??02?3?
Deltatheridium    ??113???2?0011?2?0001???110141??????2??1?????211?2?000?20101?00121?02031
Atokatheridium    ??????????????????????????????????????????????????????????????????????
Sulestes          ??????????????????????????????????????????????????????????????????????
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Marsasia	??
Asiatherium	10113?????00?1?2????101111???1??????2????????211?2?00??21??1????2??020??
Kokopellia	??
Anchistodelphys	??
Albertatherium	??
Didelphodon	???1????????????0??01?????01?????????1?1???????????????????????????????1
Pediomys	???1???????????????01?????01???????????1?????????2???0?????????????????1
Turgidodon	???1???????????????01?????0????????????1???????????????????????????????1
Mayulestes	10113?????00110210111001111141??????21???????211020000021101100?201020??
Pucadelphys	10113?????00110210111001111141??????21?1??2??211?20000021101111120102031
Andinodelphys	10113?????00110210111000111141??????21?1?????2111?1000021?01110120102031
Didelphis	10113?????00110200001011110141213111212101220211121000021001110120102031
Marmosa	10113?????00110200001011110141213111212101220211121000021001110120102031
Caenolestes	10113?????00?102000000211101412131??211101320211131000021?0111?120102032
Dasyurus	10113?????00110200001021110142?131??211101420211111200021101110120102032
Perameles	10113?????001102000010211101412131??211101420211121000021001110120102032
Dromiciops	10113?????001102000010211100412131??212201330211111000031101110120102032
Thylacomyidae	10113?????001102?000102?1???4?2131??21??0?4?02111?1000021?0111?12?1?20?2
Macropus	10113?????001102000010311100412131??212201530211111100131101110120103032
Acrobates	10113?????001102000010111101422131??212?115312111?1000031101110120102032
Phascolarctos	10113?????001102000010211101412131??211201330211131100141001111120103032
Vombatus	10113?????001102000010111100412131??211201530211131000141101110120103032
Phalanger	10113?????001102000010311100412131??212211531211131100131001110120103032
Pseudocheirus	10113?????001102000010311100422131??212211531211121000031101110120102032
Petauroides	10113?????001102000010311100422131??212211531211121000021101110120102032

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Input data matrix (continued):

                  33333333333333333333
                  66666666667777777778
Taxon/Node        12345678901234567890
--------------------------------------
Thrinaxodon       00000000000000000000
Massetognathus    00000?00000000000000
Probainognathus   00000?00000000000111
Tritylodontids    000000000000100?0110
                          1          1
Pachygenelus      000000000000000?????
Adelobasileus     0110?????????0??????
Sinoconodon       00001000000010000121
Morganucodon      01101100000010000122
Megazostrodon     01?0??????0??0??????
Haldanodon        01111100000000???222
Hadrocodium       121101?00?00?2??1233
Shuotherium       ????????????????????
Asfaltomylos      ????????????????????
Ambondro          ????????????????????
Ausktribosphenos  ????????????????????
Bishops           ????????????????????
Teinolophos       ????????????????????
Steropodon        ????????????????????
Obdurodon         1211011?0?0002????33
Ornithorhynchus   1211011?0?0002111233
Tachyglossus      1211011?0?0102111233
Gobiconodon       0010?1?00?0??0??????
Amphilestes       ????????????????????
Jeholodens        011?01??0????1??????
Priacodon         ?????????0???1??????
Trioracodon       ????????????????????
Plagiaulacidans   00100110100?21??????
                      1
Cimolodontans     01101210100021110233
Tinodon           ????????????????????
Zhangheotherium   ???????0????????????
Dryolestes        ???????0??0?????????
Henkelotherium    ????????????????????
Amphitherium      ????????????????????
Peramus           ????????????????????
Vincelestes       00101110000??1??????
Nanolestes        ????????????????????
Kielantherium     ????????????????????
Aegialodon        ????????????????????
Montanalestes     ?????????????1??????
Prokennalestes    ??????????0?????????
Murtoilestes      ????????????????????
Eomaia            ????02??1????1??????
Kennalestes       01110210100??1011233
Asioryctes        01110210100??1011233
Ukhaatherium      ????????????????????
Zalambdalestes    01100210100??1011233
Daulestes         ?1??0?????0??2??????
Aspanlestes       ????????????????????
Eoungulatum       ????????????????????
Cimolestes        ????????????????????
Gypsonictops      ????????????????????
Protungulatum     ????????????????????
Erinaceus         01110211100122011233
Leptictis         01110210100122011233
Holoclemensia     ????????????????????
Sinodelphys       ????0????????1??????
Deltatheridium    ????02?0110?????????
Atokatheridium    ????????????????????
Sulestes          ????????????????????
Marsasia          ????????????????????
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Asiatherium       ?1100?????1??2??????
Kokopellia        ????????????????????
Anchistodelphys   ????????????????????
Albertatherium    ????????????????????
Didelphodon       ??????????1?????????
Pediomys          ??????????1?????????
Turgidodon        ????????????????????
Mayulestes        01100211110??2??????
Pucadelphys       01100210110?21??????
Andinodelphys     01100210111?21??????
Didelphis         00100211111121011233
Marmosa           12110211111121011233
Caenolestes       ??1002111?2121???233
Dasyurus          01100211111121011233
Perameles         12100211101121???233
Dromiciops        12110210111121011233
Thylacomyidae     ??1?021?1??121???233
Macropus          121102101?2121???233
Acrobates         12110211111121???233
Phascolarctos     01100211112121???233
Vombatus          02100211112121???233
Phalanger         02100211112121???233
Pseudocheirus     12100211112121???233
Petauroides       1211021011121?1???233

Heuristic search settings:
  Optimality criterion = parsimony
    Character-status summary:
      Of 380 total characters:
        All characters are of type 'unord'
        All characters have equal weight
        1 character is parsimony-uninformative
        Number of parsimony-informative characters = 379
    Gaps are treated as "missing"
    Multistate taxa interpreted as polymorphism
  Starting tree(s) obtained via stepwise addition
  Addition sequence: random
    Number of replicates = 1000
    Starting seed = 1981555018
  Number of trees held at each step during stepwise addition = 1
  Branch-swapping algorithm: tree-bisection-reconnection (TBR)
  Steepest descent option in effect
  Initial 'MaxTrees' setting = 2000 (will be auto-increased by 1000)
  Branches collapsed (creating polytomies) if maximum branch length is zero
  'MulTrees' option not in effect; only 1 tree will be saved per replicate
  Topological constraints not enforced
  Trees are unrooted

Heuristic search completed
   Total number of rearrangements tried = 3.2195e+09
   Score of best tree(s) found = 1700
   Number of trees retained = 224
   Time used = 01:04:41.5

Tree-island profile:
                     First      Last                     First   Times
Island      Size*     tree      tree         Score   replicate     hit
----------------------------------------------------------------------
     1         1         1         1          1700           7       1
     2         1         2         2          1700          11       1
     3         1         3         3          1700          15       1
     4         1         4         4          1700          28       1
     5         1         5         5          1700          37       1
     6         1         6         6          1700          39       1
     7         1         7         7          1700          42       1
     8         1         8         8          1700          44       1
     9         1         9         9          1700          55       1
    10         1        10        10          1700          56       1
    11         1        11        11          1700          64       1
```

12	1	12	12	1700	66	1
13	1	13	13	1700	69	1
14	1	14	14	1700	71	1
15	1	15	15	1700	73	1
16	1	16	16	1700	75	1
17	1	17	17	1700	78	1
18	1	18	18	1700	80	1
19	1	19	19	1700	81	1
20	1	20	20	1700	89	1
21	1	21	21	1700	92	1
22	1	22	22	1700	99	1
23	1	23	23	1700	110	1
24	1	24	24	1700	111	1
25	1	25	25	1700	113	1
26	1	26	26	1700	117	1
27	1	27	27	1700	122	1
28	1	28	28	1700	123	1
29	1	29	29	1700	125	1
30	1	30	30	1700	129	1
31	1	31	31	1700	136	1
32	1	32	32	1700	139	1
33	1	33	33	1700	151	1
34	1	34	34	1700	158	1
35	1	35	35	1700	180	1
36	1	36	36	1700	183	1
37	1	37	37	1700	184	1
38	1	38	38	1700	189	1
39	1	39	39	1700	190	1
40	1	40	40	1700	191	1
41	1	41	41	1700	196	1
42	1	42	42	1700	199	1
43	1	43	43	1700	205	1
44	1	44	44	1700	212	1
45	1	45	45	1700	214	1
46	1	46	46	1700	215	1
47	1	47	47	1700	216	1
48	1	48	48	1700	217	1
49	1	49	49	1700	223	1
50	1	50	50	1700	224	1
51	1	51	51	1700	229	1
52	1	52	52	1700	238	1
53	1	53	53	1700	242	1
54	1	54	54	1700	243	1
55	1	55	55	1700	246	1
56	1	56	56	1700	251	1
57	1	57	57	1700	252	1
58	1	58	58	1700	258	1
59	1	59	59	1700	263	1
60	1	60	60	1700	267	1
61	1	61	61	1700	268	1
62	1	62	62	1700	270	1
63	1	63	63	1700	276	1
64	1	64	64	1700	278	1
65	1	65	65	1700	283	1
66	1	66	66	1700	293	1
67	1	67	67	1700	294	1
68	1	68	68	1700	303	1
69	1	69	69	1700	307	1
70	1	70	70	1700	308	1
71	1	71	71	1700	310	1
72	1	72	72	1700	312	1
73	1	73	73	1700	314	1
74	1	74	74	1700	316	1
75	1	75	75	1700	318	1
76	1	76	76	1700	322	1
77	1	77	77	1700	323	1
78	1	78	78	1700	331	1
79	1	79	79	1700	334	1
80	1	80	80	1700	345	1

81	1	81	81	1700	348	1
82	1	82	82	1700	349	1
83	1	83	83	1700	358	1
84	1	84	84	1700	363	1
85	1	85	85	1700	366	1
86	1	86	86	1700	367	1
87	1	87	87	1700	368	1
88	1	88	88	1700	373	1
89	1	89	89	1700	380	1
90	1	90	90	1700	381	1
91	1	91	91	1700	387	1
92	1	92	92	1700	391	1
93	1	93	93	1700	394	1
94	1	94	94	1700	395	1
95	1	95	95	1700	397	1
96	1	96	96	1700	399	1
97	1	97	97	1700	418	1
98	1	98	98	1700	421	1
99	1	99	99	1700	423	1
100	1	100	100	1700	433	1
101	1	101	101	1700	445	1
102	1	102	102	1700	447	1
103	1	103	103	1700	448	1
104	1	104	104	1700	461	1
105	1	105	105	1700	466	1
106	1	106	106	1700	469	1
107	1	107	107	1700	470	1
108	1	108	108	1700	478	1
109	1	109	109	1700	481	1
110	1	110	110	1700	486	1
111	1	111	111	1700	490	1
112	1	112	112	1700	492	1
113	1	113	113	1700	493	1
114	1	114	114	1700	496	1
115	1	115	115	1700	498	1
116	1	116	116	1700	509	1
117	1	117	117	1700	510	1
118	1	118	118	1700	513	1
119	1	119	119	1700	516	1
120	1	120	120	1700	525	1
121	1	121	121	1700	526	1
122	1	122	122	1700	531	1
123	1	123	123	1700	543	1
124	1	124	124	1700	545	1
125	1	125	125	1700	549	1
126	1	126	126	1700	551	1
127	1	127	127	1700	552	1
128	1	128	128	1700	561	1
129	1	129	129	1700	564	1
130	1	130	130	1700	577	1
131	1	131	131	1700	584	1
132	1	132	132	1700	590	1
133	1	133	133	1700	591	1
134	1	134	134	1700	598	1
135	1	135	135	1700	600	1
136	1	136	136	1700	617	1
137	1	137	137	1700	623	1
138	1	138	138	1700	634	1
139	1	139	139	1700	636	1
140	1	140	140	1700	639	1
141	1	141	141	1700	641	1
142	1	142	142	1700	646	1
143	1	143	143	1700	647	1
144	1	144	144	1700	658	1
145	1	145	145	1700	660	1
146	1	146	146	1700	665	1
147	1	147	147	1700	671	1
148	1	148	148	1700	673	1
149	1	149	149	1700	674	1

150	1	150	150	1700	679	1
151	1	151	151	1700	686	1
152	1	152	152	1700	702	1
153	1	153	153	1700	706	1
154	1	154	154	1700	708	1
155	1	155	155	1700	713	1
156	1	156	156	1700	715	1
157	1	157	157	1700	716	1
158	1	158	158	1700	724	1
159	1	159	159	1700	727	1
160	1	160	160	1700	728	1
161	1	161	161	1700	729	1
162	1	162	162	1700	734	1
163	1	163	163	1700	735	1
164	1	164	164	1700	741	1
165	1	165	165	1700	743	1
166	1	166	166	1700	747	1
167	1	167	167	1700	748	1
168	1	168	168	1700	751	1
169	1	169	169	1700	758	1
170	1	170	170	1700	759	1
171	1	171	171	1700	762	1
172	1	172	172	1700	763	1
173	1	173	173	1700	767	1
174	1	174	174	1700	774	1
175	1	175	175	1700	777	1
176	1	176	176	1700	779	1
177	1	177	177	1700	781	1
178	1	178	178	1700	782	1
179	1	179	179	1700	785	1
180	1	180	180	1700	789	1
181	1	181	181	1700	797	1
182	1	182	182	1700	800	1
183	1	183	183	1700	819	1
184	1	184	184	1700	825	1
185	1	185	185	1700	826	1
186	1	186	186	1700	828	1
187	1	187	187	1700	833	1
188	1	188	188	1700	844	1
189	1	189	189	1700	854	1
190	1	190	190	1700	856	1
191	1	191	191	1700	860	1
192	1	192	192	1700	864	1
193	1	193	193	1700	866	1
194	1	194	194	1700	870	1
195	1	195	195	1700	874	1
196	1	196	196	1700	883	1
197	1	197	197	1700	884	1
198	1	198	198	1700	892	1
199	1	199	199	1700	895	1
200	1	200	200	1700	899	1
201	1	201	201	1700	901	1
202	1	202	202	1700	907	1
203	1	203	203	1700	913	1
204	1	204	204	1700	915	1
205	1	205	205	1700	917	1
206	1	206	206	1700	923	1
207	1	207	207	1700	931	1
208	1	208	208	1700	932	1
209	1	209	209	1700	933	1
210	1	210	210	1700	939	1
211	1	211	211	1700	941	1
212	1	212	212	1700	947	1
213	1	213	213	1700	948	1
214	1	214	214	1700	954	1
215	1	215	215	1700	961	1
216	1	216	216	1700	962	1
217	1	217	217	1700	964	1
218	1	218	218	1700	971	1

219	1	219	219	1700	972	1
220	1	220	220	1700	974	1
221	1	221	221	1700	977	1
222	1	222	222	1700	982	1
223	1	223	223	1700	989	1
224	1	224	224	1700	997	1
225	1	-	-	1701	4	275**
226	1	-	-	1702	14	211**
227	1	-	-	1703	1	103**
228	1	-	-	1704	2	38**
229	1	-	-	1705	145	5**
230	1	-	-	1706	84	13**
231	1	-	-	1707	33	13**
232	1	-	-	1708	70	3**
233	1	-	-	1709	3	40**
234	1	-	-	1710	88	31**
235	1	-	-	1711	98	22**
236	1	-	-	1712	48	10**
237	1	-	-	1713	165	6**
238	1	-	-	1714	443	2**
239	1	-	-	1715	232	2**
240	1	-	-	1716	326	1
241	1	-	-	1739	408	1

Note(s):
 * Only one tree was saved per island; island structure is undetermined
 ** Multiple observations of the same score do not imply identity of the corresponding trees

Lengths and fit measures of trees in memory:
 Character-status summary:
  Of 380 total characters:
   All characters are of type 'unord'
   All characters have equal weight
   1 character is parsimony-uninformative
   Number of parsimony-informative characters = 379
 Gaps are treated as "missing"
 Multistate taxa interpreted as polymorphism ("min" values for CI, RI, and RC are minimum-possible character lengths)

 Sum of min. possible lengths = 726
 Sum of max. possible lengths = 5726

Tree #	1
Length	1700
CI	0.427
RI	0.805
RC	0.344
HI	0.611
G-fit	-241.825

```
Strict consensus of 224 trees:

/------------------------------------------------------------------------ Thrinaxodon
| /---------------------------------------------------------------------- Massetognathus
| | /-------------------------------------------------------------------- Probainognathus
\-+ |  /----------------------------------------------------------------- Tritylodontids
  \-+  | /--------------------------------------------------------------- Pachygenelus
    \--+ | /------------------------------------------------------------- Adelobasileus
       \-+ +------------------------------------------------------------- Sinoconodon
         | |                                                          /-- Morganucodon
         \-+  /-------------------------------------------------------+-- Megazostrodon
           |  | /-------------------------------------------------------- Haldanodon
           |  | | /------------------------------------------------------ Hadrocodium
           \--+ | |                                                 /---- Shuotherium
              | | |                                                 +---- Asfaltomylos
              \-+ |                                                 +---- Ambondro
                | |                                                 +---- Ausktribosphenos
                | |                                                 +---- Bishops
                \-+ /-----------------------------------------------+---- Teinolophos
                  | |                                               +---- Steropodon
                  | |                                               +---- Tachyglossus
                  | |                                               | /-- Obdurodon
                  | |                                               \-+-- Ornithorhynchus
                  | | /-------------------------------------------------- Gobiconodon
                  \-+ +-------------------------------------------------- Amphilestes
                    | +-------------------------------------------------- Jeholodens
                    | +-------------------------------------------------- Tinodon
                    | |                                               /-- Priacodon
                    | +-----------------------------------------------+-- Trioracodon
                    \-+                                               /-- Plagiaulacidans
                      +-----------------------------------------------+-- Cimolodontans
                      |  /----------------------------------------------- Zhangheotherium
                      |  | /--------------------------------------------- Dryolestes
                      |  | +--------------------------------------------- Henkelotherium
                      \--+ | /------------------------------------------- Amphitherium
                         | | +------------------------------------------- Peramus
                         \-+ +------------------------------------------- Vincelestes
                           | +------------------------------------------- Nanolestes
                           | |  /---------------------------------------- Kielantherium
                           | |  +---------------------------------------- Aegialodon
                           \-+  |                         /-------------- Montanalestes
                             |  |                         +-------------- Daulestes
                             |  |                         |           /-- Prokennalestes
                             |  |                         +-----------+-- Murtoilestes
                             |  |                         |           \-- Eomaia
                             \--+ /-----------------------+           /-- Kennalestes
                                | |                       |  /--------+-- Asioryctes
                                | |                       |  |        \-- Ukhaatherium
                                | |                       |  |        /-- Cimolestes
                                | |                       \--+ /------+-- Gypsonictops
                                | |                          | | /------- Zalambdalestes
                                | |                          \-+ |  /---- Erinaceus
                                \-+                            \-+  +---- Leptictis
                                  |                              \--+ /-- Aspanlestes
                                  |                                 \-+-- Eoungulatum
                                  |                                   \-- Protungulatum
                                  | /------------------------------------ Holoclemensia
                                  | +------------------------------------ Sinodelphys
                                  | |                                 /-- Deltatheridium
                                  \-+ /-------------------------------+-- Atokatheridium
                                    | | /-------------------------------- Sulestes
                                    \-+ |  /----------------------------- Marsasia
                                      \-+  | /--------------------------- Kokopellia
                                        |  | | /------------------------- Asiatherium
                                        \--+ | +------------------------- Anchistodelphys
                                           | | +------------------------- Albertatherium
                                           \-+ +------------------------- Didelphodon
```

```
| +------------------------- Pediomys
| +------------------------- Turgidodon
\-+------------------------- Mayulestes
  +------------------------- Pucadelphys
  +------------------------- Andinodelphys
  |                      /-- Didelphis
  |  /-------------------+-- Marmosa
  |  | /-------------------- Caenolestes
  \--+ | /------------------ Dasyurus
     \-+ | /---------------- Perameles
       \-+ | /-------------- Dromiciops
         \-+ |  /----------- Thylacomyidae
           \-+  | /--------- Acrobates
             \--+ | /------- Phalanger
                \-+ +------- Pseudocheirus
                  \-+------- Petauroides
                    |  /---- Macropus
                    \--+ /-- Phascolarctos
                       \-+-- Vombatus
```

Adams consensus of 224 trees:

```
/------------------------------------------------------------------------- Thrinaxodon
| /----------------------------------------------------------------------- Massetognathus
| | /--------------------------------------------------------------------- Probainognathus
\-+ | /------------------------------------------------------------------- Tritylodontids
  \-+ | /----------------------------------------------------------------- Pachygenelus
    \-+ | /--------------------------------------------------------------- Adelobasileus
      \-+ +--------------------------------------------------------------- Sinoconodon
        | |                                                            /-- Morganucodon
        \-+ /----------------------------------------------------------+-- Megazostrodon
          | | /----------------------------------------------------------- Haldanodon
          \-+ | /--------------------------------------------------------- Hadrocodium
            | | |                                          /-------------- Shuotherium
            \-+ |                                          +-------------- Tachyglossus
              | |  /---------------------------------------+ /------------ Asfaltomylos
              | |  |                                       | | /---------- Ambondro
              \-+  |                                       \-+ | /-------- Ausktribosphenos
                |  |                                         \-+ +-------- Bishops
                |  |                                           \-+ /------ Steropodon
                |  |                                             \-+ /---- Teinolophos
                |  |                                               \-+ /-- Obdurodon
                \--+                                                 \-+-- Ornithorhynchus
                   | /---------------------------------------------------- Tinodon
                   | |                                                 /-- Plagiaulacidans
                   | +-------------------------------------------------+-- Cimolodontans
                   | |                                               /---- Gobiconodon
                   | |                                               +---- Amphilestes
                   \-+-----------------------------------------------+---- Jeholodens
                     |                                               | /-- Priacodon
                     |                                               \-+-- Trioracodon
                     | /-------------------------------------------------- Zhangheotherium
                     | | /------------------------------------------------ Dryolestes
                     \-+ +------------------------------------------------ Henkelotherium
                       | | /---------------------------------------------- Amphitherium
                       \-+ +---------------------------------------------- Vincelestes
                         | | /-------------------------------------------- Peramus
                         | | +-------------------------------------------- Nanolestes
                         \-+ | /------------------------------------------ Kielantherium
                           | | +------------------------------------------ Aegialodon
                           | | |                             /------------ Montanalestes
                           \-+ |                             +------------ Daulestes
                             | |                             |         /-- Prokennalestes
                             | |                             +---------+-- Murtoilestes
                             | |                             |         \-- Eomaia
                             \-+ /---------------------------+         /-- Kennalestes
                               | |                           | /-------+-- Asioryctes
                               | |                           | |       \-- Ukhaatherium
                               | |                           | |       /-- Cimolestes
                               | |                           \-+ /-----+-- Gypsonictops
                               | |                             | | /------ Zalambdalestes
                               | |                             \-+ | /---- Erinaceus
                               \-+                               \-+ +---- Leptictis
                                 |                                 \-+ /-- Aspanlestes
                                 |                                   \-+-- Eoungulatum
                                 |                                     \-- Protungulatum
                                 | /-------------------------------------- Holoclemensia
                                 | +-------------------------------------- Sinodelphys
                                 | |                                   /-- Deltatheridium
                                 \-+ /---------------------------------+-- Atokatheridium
                                   | | /---------------------------------- Sulestes
                                   \-+ | /-------------------------------- Marsasia
                                     \-+ | /------------------------------ Kokopellia
                                       \-+ | /---------------------------- Asiatherium
                                         \-+ +---------------------------- Albertatherium
                                           | | /-------------------------- Anchistodelphys
                                           \-+ |                       /-- Didelphodon
```

```
| +----------------------+-- Pediomys
| |                      \-- Turgidodon
\-+ /----------------------- Mayulestes
  | |                    /-- Pucadelphys
  | +--------------------+-- Andinodelphys
  \-+                    /-- Didelphis
    | /------------------+-- Marmosa
    | | /------------------- Caenolestes
    \-+ |  /---------------- Dasyurus
      \-+  | /-------------- Perameles
        \--+ | /------------ Dromiciops
           \-+ | /---------- Thylacomyidae
             \-+ | /-------- Acrobates
               \-+ | /------ Phalanger
                 \-+ +------ Pseudocheirus
                   \-+------ Petauroides
                     | /---- Macropus
                     \-+ /-- Phascolarctos
                       \-+-- Vombatus
```

Part VIII. Apomorphy List for Cladogram Nodes

```
P A U P * Version 4.0b10 for Macintosh (PPC)

Processing of file "Luo-Matrix(Ms.1090718).dat" completed.

Outgroup status changed:
  1 taxon transferred to outgroup
  Total number of taxa now in outgroup = 1
  Number of ingroup taxa = 83

Lengths and fit measures of trees in memory:
  Character-status summary:
    Of 380 total characters:
      All characters are of type 'unord'
      All characters have equal weight
      1 character is parsimony-uninformative
      Number of parsimony-informative characters = 379
  Gaps are treated as "missing"
  Multistate taxa interpreted as polymorphism ("min" values for CI, RI, and RC are
    minimum-possible character lengths)

   Sum of min. possible lengths = 726
   Sum of max. possible lengths = 5726

Tree #         1
Length      1700
CI         0.427
RI         0.805
RC         0.344
HI         0.611
G-fit   -241.825

Strict consensus of 224 trees:

/------------------------------------------------------------------------ Thrinaxodon
| /---------------------------------------------------------------------- Massetognathus
| | /-------------------------------------------------------------------- Probainognathus
\-+ |  /----------------------------------------------------------------- Tritylodontids
  \-+  | /--------------------------------------------------------------- Pachygenelus
    \--+ | /------------------------------------------------------------- Adelobasileus
       \-+ +------------------------------------------------------------- Sinoconodon
         | |                                                          /-- Morganucodon
         \-+  /-------------------------------------------------------+-- Megazostrodon
           |  | /-------------------------------------------------------- Haldanodon
           |  | | /------------------------------------------------------ Hadrocodium
           \--+ | |                                                 /---- Shuotherium
              | | |                                                 +---- Asfaltomylos
              \-+ |                                                 +---- Ambondro
                | |                                                 +---- Ausktribosphenos
                | |                                                 +---- Bishops
                \-+ /-----------------------------------------------+---- Teinolophos
                  | |                                               +---- Steropodon
                  | |                                               +---- Tachyglossus
                  | |                                               | /-- Obdurodon
                  | |                                               \-+-- Ornithorhynchus
                  | | /-------------------------------------------------- Gobiconodon
                  \-+ +-------------------------------------------------- Amphilestes
                    | +-------------------------------------------------- Jeholodens
                    | +-------------------------------------------------- Tinodon
                    | |                                               /-- Priacodon
                    | +-----------------------------------------------+-- Trioracodon
                    \-+                                               /-- Plagiaulacidans
                      +-----------------------------------------------+-- Cimolodontans
                      |  /----------------------------------------------- Zhangheotherium
                      |  | /--------------------------------------------- Dryolestes
                      |  | +--------------------------------------------- Henkelotherium
                      \--+ | /------------------------------------------- Amphitherium
                         | | +------------------------------------------- Peramus
                         \-+ +------------------------------------------- Vincelestes
                           | +------------------------------------------- Nanolestes
                           | |  /---------------------------------------- Kielantherium
                           | |  +---------------------------------------- Aegialodon
                           \-+  |                         /-------------- Montanalestes
                             |  |                         +-------------- Daulestes
                             |  |                         |           /-- Prokennalestes
                             |  |                         +-----------+-- Murtoilestes
                             |  |                         |           \-- Eomaia
                             \--+ /-----------------------+           /-- Kennalestes
                                | |                       |  /--------+-- Asioryctes
                                | |                       |  |        \-- Ukhaatherium
```

```
| |                       |  |        /-- Cimolestes
| |                       \--+ /------+-- Gypsonictops
| |                          | | /------- Zalambdalestes
| |                          \-+ |  /---- Erinaceus
\-+                            \-+  +---- Leptictis
  |                              \--+ /-- Aspanlestes
  |                                 \-+-- Eoungulatum
  |                                   \-- Protungulatum
  | /------------------------------------ Holoclemensia
  | +------------------------------------ Sinodelphys
  | |                                 /-- Deltatheridium
  \-+ /-------------------------------+-- Atokatheridium
    | | /-------------------------------- Sulestes
    \-+ |  /----------------------------- Marsasia
      \-+  | /--------------------------- Kokopellia
        |  | | /------------------------- Asiatherium
        \--+ | +------------------------- Anchistodelphys
           | | +------------------------- Albertatherium
           \-+ +------------------------- Didelphodon
             | +------------------------- Pediomys
             | +------------------------- Turgidodon
             \-+------------------------- Mayulestes
               +------------------------- Pucadelphys
               +------------------------- Andinodelphys
               |                      /-- Didelphis
               |  /-------------------+-- Marmosa
               |  | /-------------------- Caenolestes
               \--+ | /------------------ Dasyurus
                  \-+ | /---------------- Perameles
                    \-+ | /-------------- Dromiciops
                      \-+ |  /----------- Thylacomyidae
                        \-+  | /--------- Acrobates
                          \--+ | /------- Phalanger
                             \-+ +------- Pseudocheirus
                               \-+------- Petauroides
                                 |  /---- Macropus
                                 \--+ /-- Phascolarctos
                                    \-+-- Vombatus
```

```
Tree description:

  Unrooted tree(s) rooted using outgroup method
  Optimality criterion = parsimony
    Character-status summary:
      Of 380 total characters:
        All characters are of type 'unord'
        All characters have equal weight
        1 character is parsimony-uninformative
        Number of parsimony-informative characters = 379
    Gaps are treated as "missing"
    Multistate taxa interpreted as polymorphism ("min" values for CI, RI, and RC are
      minimum-possible character lengths)

    Character-state optimization: Delayed transformation (DELTRAN)

Tree number 1 (rooted using user-specified outgroup)

Tree length = 1700
Consistency index (CI) = 0.4271
Homoplasy index (HI) = 0.6106
CI excluding uninformative characters = 0.4267
HI excluding uninformative characters = 0.5733
Retention index (RI) = 0.8052
Rescaled consistency index (RC) = 0.3439

/------------------------------------------------------------------------ Thrinaxodon
| /---------------------------------------------------------------------- Massetognathus
| |/--------------------------------------------------------------------- Probainognathus
166| /------------------------------------------------------------------- Tritylodontids
 165 |/------------------------------------------------------------------ Pachygenelus
   164| /---------------------------------------------------------------- Sinoconodon
    163 | /-------------------------------------------------------------- Adelobasileus
      162 |                                                           /-- Morganucodon
        161/---------------------------------------------------------85-- Megazostrodon
          || /----------------------------------------------------------- Haldanodon
         160 |/---------------------------------------------------------- Hadrocodium
           | ||                                           /-------------- Tachyglossus
           159| /----------------------------------------94/------------- Shuotherium
             || |                                         93 /----------- Asfaltomylos
             || |                                          \92/---------- Ambondro
            158 |                                            91 /-------- Ausktribosphenos
              | |                                             \90 /------ Bishops
              | |                                               \89/----- Steropodon
              | |                                                 88 /--- Teinolophos
              157                                                  \87/-- Obdurodon
                |                                                    86-- Ornithorhynchus
                |                                                 /------ Gobiconodon
                | /----------------------------------------------98/----- Amphilestes
                | |                                               97 /--- Jeholodens
                | |                                                \96/-- Priacodon
                | |                                                  95-- Trioracodon
                156                                                   /-- Plagiaulacidans
                  |/-------------------------------------------------99-- Cimolodontans
                  || /--------------------------------------------------- Tinodon
                 155 |/-------------------------------------------------- Zhangheotherium
                   154| /------------------------------------------------ Henkelotherium
                    153 | /---------------------------------------------- Dryolestes
                      152 |/--------------------------------------------- Vincelestes
                        151| /------------------------------------------- Amphitherium
                         150 |/------------------------------------------ Nanolestes
                           149| /---------------------------------------- Peramus
                            148 | /-------------------------------------- Kielantherium
                              | | |/------------------------------------- Aegialodon
                              147 ||                              /------ Daulestes
                                | ||                         /--103/----- Montanalestes
                               146|                          |   102 /--- Murtoilestes
                                  ||                         |     101/-- Prokennalestes
                                  ||                         |      100-- Eomaia
                                  || /---------------------114       /--- Ukhaatherium
                                 145 |                       |/----105/-- Kennalestes
                                   | |                       ||     104-- Asioryctes
                                   | |                       ||       /-- Cimolestes
                                   | |                      113 /---111-- Gypsonictops
                                   | |                        | | /------ Zalambdalestes
                                   | |                        112 |   /-- Erinaceus
                                   144                          110/108-- Leptictis
                                     |                           109 /--- Aspanlestes
                                     |                             107/-- Eoungulatum
                                     |                              106-- Protungulatum
                                     |/---------------------------------- Holoclemensia
```

```
 || /-------------------------------- Sinodelphys
143 |                             /-- Deltatheridium
  142 /-------------------------115-- Atokatheridium
    | |/----------------------------- Sulestes
    141| /--------------------------- Marsasia
     140 |/-------------------------- Kokopellia
       139| /------------------------ Asiatherium
        138 |                      /--- Turgidodon
          | | /----------------135/-- Didelphodon
          137 |                 134-- Pediomys
            | |                /----- Mayulestes
            | |                |  /-- Anchistodelphys
            136/-------------119116-- Albertatherium
              ||                118/-- Pucadelphys
              ||                 117-- Andinodelphys
             133                  /-- Didelphis
              | /--------------120-- Marmosa
              132/------------------ Caenolestes
               131 /---------------- Dasyurus
                 130 /-------------- Perameles
                   129/------------- Dromiciops
                    128 /----------- Thylacomyidae
                      127/---------- Acrobates
                       126 /-------- Petauroides
                         125 /------ Pseudocheirus
                           124/----- Phalanger
                            123 /--- Macropus
                              122/-- Phascolarctos
                               121-- Vombatus
```

Apomorphy lists for major cladogram nodes

A. Refer to the nodes in Text-Fig. 4A and the equally parsimonious tree EPT #1 (figured in SOM)

B. Refer to character list (in SOM) for full description of characters and their states.

➔ Bold arrow: unambiguous synapmorphies (regardless of scheme of optimization)
→ Thin arrow: optimized by DELTRAN option of PAUP

Character	Character CI	State Change
Node 1 of Text-Fig. 4A (= EPT #1 node 147 → node 146) The boreosphenidan clade (common ancestor of Kielantherium, Erinaceus, and Vombatus)		
	Unambiguous apomorphies:	
19 (Masse fossa ventral)	0.400	2 **➔** 1
24 (Post mental foramen)	0.625	1 **➔** 2
61 (M Pre-entocristid)	0.600	0 **➔** 1
65 (Mesial cingulid)	0.600	0 **➔** 1
70 (trigonid pattern)	0.231	0 **➔** 1
74 (Trigonid shortening)	0.364	0 **➔** 2
76 (Hypoflexid)	0.200	0 **➔** 1
77 (Talonid morphology)	0.625	2 **➔** 5
120 (Prevallum/postvalid)	0.400	1 **➔** 2
126 (wear in tln basin)	0.600	0 **➔** 1
137 (# of lw premolars)	0.286	0 **➔** 1
Node 2 of Text-Fig 4A (= EPT #1: node 145 → node 144) The crown therian clade (common ancestor of Erinaceus and Vombatus, excluding Kielantherium)		
	Unambiguous apomorphies:	
52 (angle postvlm/prevallid)	0.600	1 **➔** 2
75 (m2 trg/ta wid ratio)	0.333	0 **➔** 1
	Ambiguous apomorphies (DELTRAN optimization):	
4 (M-groove width)	0.167	1 → 2
7 (Dent angl presence)	0.385	1 → 3
23 (Labial mand foramen)	0.333	1 → 0
39 (Up P1-P2 diastema)	0.167	0 → 1
82 (Ultimate-l-m hpcld)	0.200	0 → 1
92 (Upper protocone)	0.500	1 → 2
94 (Protocone compress)	0.571	0 → 1
101 (Para/meta conule)	0.250	0 → 1
104 (Parastylar groove)	0.167	0 → 1
117 (outline of upper M1)	0.300	1 → 2
122 (Preprotocrista)	0.500	1 → 2
140 (# Upper PC Loci)	0.353	0 → 2
157 (Atlas intercentrum)	0.333	0 → 1
177 (Glenoid orientation)	1.000	1 → 2
184 (Humeral torsion)	0.600	0 → 2
186 (Hu ulnar condyle)	0.667	1 → 2
187 (Hu radial condyle)	1.000	1 → 2
205 (Less troch orient)	0.333	0 → 1
206 (Less troch size)	1.000	0 → 1
212 (Fibo-calcaneus)	1.000	0 → 1
232 (Relative Pos. Sust.)	1.000	0 → 1
260 (SQ Postglenoid process)	0.571	1 → 2
262 (PG for composition)	0.600	0 → 1
271 (Cochlear canal)	0.714	3 → 5
272 (IAM cribriform plt)	0.500	0 → 1
284 (Lateral trough)	1.000	1 → 2
292 (Anterior lamina PE)	0.500	0 → 1
293 (Lateral flange PE)	1.000	1 → 3
300 (Ventral Proj PPP)	0.333	1 → 0
309 (Prom epitymp wing)	0.500	0 → 1
319 (Incus troch/saddle)	0.750	3 → 2
320 (Inc/Mal alignment)	1.000	2 → 1
323 (D-plate/crus brevis)	1.000	2 → 1
338 (Minor pal on palate)	0.375	1 → 2
342 (infr-orb foramen)	0.250	1 → 0
349 (Fr/Al contact)	0.667	0 → 1
360 (PTC size)	0.500	0 → 1
366 (Septomaxilla)	0.667	1 → 2
369 (Pmx facial/nasal)	0.667	0 → 1
372 (Ossified cribriform)	0.500	0 → 1

Node 3 of Text-Fig. 4A (= EPT#1 node 144 → node 114)
The eutherian clade (common ancestor of Eomaia and Erinaceus, including all taxa more closely related to Erinaceus than to Vombatus)

Unambiguous apomorphies:

36 (U Ulti Pm protocone)	0.667	0 → 1
40 (Sym last low p)	0.111	0 → 1
41 (Ultimate l pm pacd)	0.167	0 → 2
60 (Cristid obliqua)	0.250	1 → 2
72 (Paratd/protid anglem2-3)	0.333	1 → 2
87 (Talonid elevation)	0.571	1 → 2
100 (Conular width)	0.600	0 → 1
110 (Size of Stylar E)	0.400	2 → 0
127 (Dist metacristid)	0.200	0 → 1
128 (Facets 5 vs. 6)	0.250	0 → 1
131 (# upper incisors)	0.333	1 → 0
20 (Ant border msseter)	0.667	1 → 2
218 (Astragalar trochlea)	1.000	1 → 2
219 (Astra M-D crest)	0.500	0 → 1
229 (Cal-Sus-fac place)	1.000	1 → 3
249 (Ossified patella)	0.333	0 → 1
331 (Ectotymp size/shape)	0.556	2 → 3
346 (# lacrimal foramina)	0.100	1 → 0

Ambiguous apomorphies (DELTRAN Optimization):

12 (Man for post)	0.364	2 → 4
43 (Last Pm dist cingulid)	0.333	0 → 2
53 (Rank of postvallum)	0.556	0 → 2
58 (M Pacd-mecd ratio)	0.188	0 → 2
69 (Lower m size ratio)	0.188	0 → 2
170 (with ratio s-sp/i-sp)	1.000	1 → 2
214 (Astragalar neck)	1.000	0 → 2
220 (Astragalus AMPT)	1.000	0 → 2
231 (Sust-vent-outline)	0.667	0 → 1
264 (SQ epitymp portion)	0.429	1 → 2
306 (Stapedial sulcus)	0.400	0 → 1
354 (Optical foramen)	0.667	0 → 1

Node 4 (equivalent) of Text-Fig. 4A (= EPT #1 node 144 → node 143)
The metatherian clade (including all taxa more closely related to Vombatus than Erinaceus; common ancestor of Vombatus and Sinodelphys).

Note of discussion: The apomorphy list below is contingent on the inclusion of Holoclemensia (as in text Fig. 4A), and that, as in some (but not all) EPT's, Holoclemensia is resolved to a more ancestral position than Sinodelphys. For other EPT's in which Sinodelphys may be resolved to a position ancestral to Holoclemensia, the list of apomorphies would differ accordingly. In the strict consensus, Holoclemensia and Sinodelphys are collapsed into a trichotomy, the apomorphies listed separately for Nodes 4A and 4B may be used to diagnose all metatherians. If Holoclemensia is excluded from the analysis, then the apomorphies of characters 82 and 109 will become synapomorphies of the next node.

Unambiguous apomorphies:

83 (Entoconid)	0.444	1 → 2
96 (Up Pcn/mtn height)	0.500	0 → 1
109 (Stylar cuspule D)	0.143	0 → 1

Ambiguous apomorphies (DELTRAN Optimization):

53 (Rank of postvallum)	0.556	0 → 1
69 (Lower m size ratio)	0.188	0 → 1

Node 4 (equivalent) of Tex-Fig. 4A (= EPT #1 node_143 → node 142)
The metatherian clade (common ancestor of Vombatus and Sinodelphys)

Unambiguous apomorphies
(two more unambiguous synapomorphies will be added to this node if Holoclemensia is excluded from this analysis, or collapsed in polytomy with Sinodelphys in a strict consensus)

63 (Ant-Ling cusp e)	0.444	2 → 0
107 (Stylar cuspule "B")	0.300	1 → 2

Ambiguous apomorphies (DELTRAN Optimization):

10 (Ang ventral surface)	0.500	0 → 1
30 (Angle of coron proc)	0.235	2 → 3
34 (U ulti Pm metasty)	0.500	1 → 0
38 (Trenchant U premol)	0.250	2 → 1
43 (Last Pm dist cingulid)	0.333	0 → 1

91 (stylar shelf morphology)	0.385	1 → 2
139 (# Upper Molars)	0.545	3 → 2
141 (# of low pc loci)	0.167	0 → 1
142 (Procumbent P1/C)	0.200	0 → 1
146 (Spoon Up post incisor)	0.375	0 → 1
170 (with ratio s-sp/i-sp)	1.000	1 → 3
176 (Manubrium size)	0.500	0 → 1
189 (S-shape supinat shelf)	1.000	0 → 1
191 (scaphoid size/shape)	0.400	0 → 1
192 (Hamate (unciform))	1.000	0 → 1
193 (Trapezium proportion)	1.000	0 → 1
194 (Triq-lunate ratio)	0.333	1 → 0
214 (Astragalar neck)	1.000	0 → 1
215 (As-neck width ratio)	1.000	1 → 2
217 (Navi facet spread)	1.000	0 → 1
220 (Astragalus AMPT)	1.000	0 → 1
222 (Pero-Proc-Morph)	0.714	3 → 4
223 (Peron base extension)	0.400	0 → 2
226 (Cal-Cu joint orient)	0.286	1 → 2
231 (Sust-vent-outline)	0.667	0 → 2
234 (CA facet/Medial)	0.600	1 → 2
235 (Ant-plant tuber)	0.400	0 → 1
239 (Nav-Cuboid ratio)	0.500	0 → 1
240 (Cuneiform ratios)	0.500	0 → 1
241 (Cuboid notch)	0.250	0 → 1
359 (Ascending channel)	0.600	2 → 3

Node 5 of Text-Fig. 4A (= EPT #1 node 142 → node 141)
Unnamed clade (common ancestor of Deltatheridium and Vombatus)

Unambiguous apomorphies:

7 (Dent angl presence)	0.385	3 → 4
24 (Post mental foramen)	0.625	2 → 4
110 (Size of Stylar E)	0.400	2 → 1
136 (# upper premolar)	0.312	1 → 2
137 (# of lw premolars)	0.286	1 → 2

Ambiguous apomorphies (DELTRAN Optimization):

11 (Coronoid fossa)	0.400	0 → 1
95 (Protocone height)	0.333	1 → 0
113 (Metastylar size)	0.250	0 → 2
138 (# lower molar)	0.294	3 → 2
143 (p1-p2 diastema)	0.118	0 → 1
148 (Multi-replace i/c)	1.000	1 → 2
233 (Post CAF structure)	1.000	1 → 2
282 (Prootic canal)	0.400	1 → 2
283 (trans sinus SA)	1.000	0 → 1
285 (Vent open Ca Ep)	0.556	1 → 3
316 (inf pe si jugular)	0.250	0 → 1
317 (Stapedial fossa)	0.571	3 → 4
328 (Stapedial ratio)	0.667	0 → 1
370 (Pmx palate extension)	0.500	0 → 1

EPT#1 node 141 → node 115
Putative clade of "Deltatheroidans"

Unambiguous apomorphies:

83 (Entoconid)	0.444	2 → 0
109 (Stylar cuspule D)	0.143	1 → 0

Ambiguous synapomorphies (DELTRAN Optimization):

114 (Salient mtcrista)	0.500	0 → 2

EPT#1 node 141 → node 140
Unnamed clade (including all taxa more closely related to Vombatus than Deltatheridium):

Unambiguous synapomorphies:

73 (Pcd mes-lin crest)	1.000	0 → 1
85 (para/ento align)	0.250	0 → 1
87 (Talonid elevation)	0.571	1 → 2
108 (Stylar cuspule C)	0.111	0 → 1
128 (Facets 5 vs. 6)	0.250	0 → 1

Node 6 of Text-Fig. 4A (= EPT #1 node 139 → node 138)
Unnamed clade (common ancestor of Kokopellia and Vombatus; members of this clade are primarily North and South American; members of this clade are all un-contested metatherians as they possess well-established marsupial-like dental and mandibular apomorphies)

Unambiguous apomorphies:

63 (Ant-Ling cusp e)	0.444	0 → 2
75 (m2 trg/ta wid ratio)	0.333	1 → 2
81 (Hypcld labial shelf)	0.333	0 → 1

Ambiguous apomorphies (DELTRAN Optimization):

58 (M Pacd-mecd ratio)	0.188	0 → 1
94 (Protocone compress)	0.571	1 → 2
102 (Conule distance)	0.286	0 → 1
127 (Dist metacristid)	0.200	0 → 1

Node 7 of Text-Fig. 4A (EPT #1. node 137 → node 136)
Unnamed clade (Common ancestor of Asiatherium and crown marsupials)

Unambiguous apomorphies:

79 (Hypoconulid)	0.429	1 → 2
83 (Entoconid)	0.444	2 → 3
96 (Up Pcn/mtn height)	0.500	1 → 2
122 (Preprotocrista)	0.500	2 → 1

Ambiguous apomorphies (DELTRAN Optimization)

95 (Protocone height)	0.333	0 → 2
237 (Cal body compress)	0.667	0 → 1
238 (Cal-tuber curvature)	0.500	0 → 1
287 (Hiatus fallop position)	0.286	1 → 2

Node 8 of Text-Fig. 4A (=EPT#1 node 133 → node 132)
Clade of Marsupialia (common ancestor of the extant marsupials)

Unambiguous synapomorphies:

38 (Trenchant U premol)	0.250	1 → 2
82 (Ultimate-l-m hpcld)	0.200	1 → 0
99 (Centrocrista)	0.333	0 → 1
101 (Para/meta conule)	0.250	1 → 0
278 (Rost tymp process)	0.333	0 → 1
339 (Trans canal)	0.500	0 → 1
111 (Posit of stylar E)	0.167	0 → 1
227 (Saddle cu-ca contact)	1.000	0 → 1
235 (Ant-plant tuber)	0.400	1 → 2
248 (Hullax opposable)	0.250	0 → 1
346 (# lacrimal foramina)	0.100	1 → 0

Ambiguous synapomorphies (DELTRAN Optimization):

58 (M Pacd-mecd ratio)	0.188	1 → 2
86 (Talonid L/W ratio)	0.200	0 → 2
191 (scaphoid size/shape)	0.400	1 → 2
330 (Malleolar neck)	1.000	0 → 1
332 (Incisura tymp posit)	0.750	1 → 2
337 (Ptgd meet midline)	0.200	0 → 1
350 (Frontal-max contact)	0.250	0 → 1
368 (Pmx P-D process)	0.167	0 → 1