

Supplementary Information

The Earliest Known Eutherian Mammal

(Ms. L11309B Revised for Nature)

Research Article

Submission November 18, 2001

1st Revision January 25, 2002

2nd Revision March 8, 2002

*Qiang Ji**, *Zhe-Xi Luo^{†,¶}* *Chong-Xi Yuan**, *John R. Wible[†]*, *Jian-Ping Zhang[‡]* & *Justin A. Georgi[†]*

**The Chinese Academy of Geological Sciences, Beijing 100037, China*

[†]Carnegie Museum of Natural History, Pittsburgh, PA 15213, USA

[‡]Geoscience University of China, Beijing 100083, China

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

Table of Contents

Part I. Sources of systematic characters

Part II. Character description and systematic distribution

Part III. References to Supplementary Information

Part IV. PAUP Matrix, Search Settings and Results

Part I. Sources of systematic characters

The goals of this phylogenetic analysis are to establish the hierarchical relationships of *Eomaia scansoria* with regards to: (1) the currently known stem eutherians (such as *Montanalestes*, *Murtoilestes*, *Prokennalestes*, plus the major Late Cretaceous eutherian family-level clades) and putative “eutherians” or stem australosphenidans (*Ausktribosphenos* and *Bishops*); (2) the currently known stem metatherians and early marsupials; (3) the currently known pretribosphenic trechnotherians (sensu McKenna 1975; McKenna and Bell 1997) including stem tribosphenic mammals (or boreosphenidans); and (4) to ascertain whether (or to what extent) the proposed relationships of *Eomaia scansoria*, as proposed here, would be consistent with (or contradicted by) previously established phylogenies of all mammaliaform clades on the basis of global parsimony of all available morphological evidence (see text Figure 6).

The main systematic characters for resolving these relationships are adopted from many previous studies and are supplemented with our original observations. Many characters used in the 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 *Eomaia scansoria* in the phylogeny of all mammaliaforms. The primary sources of morphological systematic characters used here are (in chronological order): Crompton (1971), Fox (1975), McKenna (1975), Crompton and Kielan-Jaworowska (1978), Prothero (1981), Kemp (1983), Sues (1985), Clemens and Lillgraven (1986), Kielan-Jaworowska et al. (1987), Rowe (1988), Kielan-Jaworowska and Dashzeveg (1989), Lillegraven and Kruusat (1991), Wible (1991), Sigogneau-Russell et al. (1992), Cifelli (1993), Wible and Hopson (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. (1996a), 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), Horovitz (2000), Luo et al. (2001a, b), Averianov and Skuschas (2001), Archibald et al. (2001), Wible et al. (2001), Luo et al. (2002).

Part II. Character description and systematic distribution

Mandible (27 characters)

1. Post-dentary trough (behind the tooth row):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops* (incomplete, but its anterior part is visible), *Steropodon* (based on the cast and published photos, we provisionally interpret that *Steropodon* has preserved the anterior part of the postdentary trough and its associated mandibular canal opening, but it lacks the medial ridge overhanging the trough);

(1) Absent: *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not preserved: *Ambondro*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*;
unknown: *Ukhaatherium*.

2. Separate scars for the surangular/prearticular in Meckel's sulcus and the post-dentary trough:

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Shuotherium*, *Ausktribosphenos*;

(1) Absent: *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not preserved: *Ambondro*, *Bishops*, *Steropodon*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

3. Overhanging medial ridge above the post-dentary trough (behind the tooth row):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*;

(1) Absent: *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not preserved: *Ambondro*, *Bishops*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

4. Degree of development of Meckel's sulcus:

(0) Well developed: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Shuotherium*, *Ausktribosphenos*, *Steropodon*;

(1) Weakly developed: *Bishops*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Eomaia*, *Prokennalestes*;

(2) Vestigial or absent: *Hadrocodium*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Vincelestes*, *Deltatheridium*, *Didelphis*, *Erinaceus*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not preserved: *Ambondro*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

5. Curvature of Meckel's sulcus (under the tooth row) (sensu Luo 1994):

(0) Parallel to the ventral border of the mandible: tritylodontids, *Sinoconodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Bishops*, *Ausktribosphenos*, *Steropodon*, *Zhangheotherium*, *Henkelotherium*, *Kielantherium*;

(1) Convergent to the ventral border of the mandible: *Morganucodon*, *Megazostrodon*, *Shuotherium*, *Peramus*, *Eomaia*, *Prokennalestes*;

(?) Not applicable: *Hadrocodium*, *Ambondro*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Vincelestes*, *Erinaceus*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

6. Groove for the replacement dental lamina (Crompton and Luo 1993; Luo 1994):

(0) Present: *Sinoconodon*, *Morganucodon* (based on Parrington 1973, 1978), *Megazostrodon* (visible in Gow 1986: fig. 16);

(1) Absent: tritylodontids, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(?) Unknown: *Ukhaatherium*; not preserved: *Murtoilestes*.

7. Angular process of the dentary:

(0) Present but not inflected: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Weakly developed to absent: *Megazostrodon*, *Shuotherium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*;

(2) Present and transversely flaring: *Bishops*, *Ausktribosphenos* (Note on *Ausktribosphenos*: the angular process is transversely flaring. Although the angular process was not described in the holotype of *Ausktribosphenos* in Rich et al. (1997), the second specimen photographed by Rich et al. (1999) has an angle that is identical to the

transversely flaring angular process of *Teinolophos*, see Rich et al. (1999, 2001b). This is different from character state {4});

(3) Present and slightly inflected: *Hadrocodium*, *Prokennalestes*, *Asioryctes*, *Montanalestes*, *Eomaia*, *Daulestes*, *Kennalestes*, *Erinaceus*;

(4) Present, strongly inflected, and anteriorly continuing as a mandibular shelf: *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*;

(0/3 polymorphic) *Zalambdalestes* (the angular process is slightly in-turned in at least one specimen of *Zalambdalestes*, Kielan-Jaworowska and Trofimov 1981, but not in others, Wible et al. in preparation. This character is coded polymorphic based on the variation in the currently available specimens of *Zalambdalestes*).

(?) Not preserved: *Ambondro*, *Steropodon*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

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): tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ausktribosphenos*, *Bishops*;

(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): *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not applicable: *Gobiconodon*, *Jeholodens*, *Priacodon*, *Shuotherium*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium*; not preserved: *Ambondro*, *Steropodon*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

Alternative character (not used in this analysis). Characters 7 and 8 can be merged to form one multi-state character ('Compound Angular Process'). This compound and

multi-state character should be run in parsimony search algorithms as an ordered sequence for transformation (present $\Leftrightarrow$ weak $\Leftrightarrow$ absent; anterior vs. posterior).

(0) Present and anterior, with internal fossa for the angular bone: tritylodontids,

Sinoconodon, *Morganucodon*, *Haldanodon*, *Hadrocodium*;

(1) Present and anterior, but weakly developed: *Megazostrodon*;

(2) Present and posterior: *Vincelestes*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(3) Present, posterior, and inflected: *Deltatheridium*, *Didelphis*, *Asiatherium*, *Kokopellia*;

(4) Absent: *Gobiconodon*, *Jeholodens*, *Priacodon*, *Shuotherium*, *Ausktribosphenos*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium*;

(?) Not preserved: *Steropodon*, *Ambondro*, *Bishops*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

9. Vertical elevation of the angular process of the dentary relative to the molar alveolar line:

(0) Angular process is low, at or near the level of the ventral border of the mandibular horizontal ramus: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Angular process is high, at or near the level of the molar alveolar line (and far above the ventral border of the mandibular horizontal ramus): *Ausktribosphenos*, *Bishops* (the angle is at the level of the imaginary alveolar line);

(?) Not applicable: *Gobiconodon*, *Jeholodens*, *Priacodon*, *Shuotherium*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium*; not preserved: *Ambondro*, *Steropodon*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

10. Coronoid (or its attachment scar):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Shuotherium* (preserved as a partial scar, as illustrated by Chow and Rich 1984), *Ausktribosphenos*, *Gobiconodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Prokennalestes*, *Eomaia*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;

(1) Absent: *Ornithorhynchus*, *Priacodon*, cimolodontans, *Deltatheridium*, *Didelphis*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(0/1 polymorphic) plagiaulacidans (present [0] for *Kuehneodon*, but absent [1] in other plagiaulacidans);

(?) Not preserved: *Hadrocodium*, *Ambondro*, *Bishops*, *Steropodon*, *Jeholodens*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

Note: The coronoid scar is represented by only a slightly rugose area at the base of the coronoid process in *Prokennalestes* and *Eomaia*. The anatomical interpretation of this feature in these two taxa should be verified when better preserved specimens are available. Here we tentatively follow Kielan-Jaworowska and Dashzeveg's (1989) interpretation that *Prokennalestes* has the primitive condition of this character, and also the previous publications on the Mongolian asioryctitheres and zalambdalestids.

11. Position of the mandibular foramen (posterior opening of the mandibular canal) relative to the postdentary trough and Meckel's sulcus:

(0) Located within the postdentary trough and in alignment with the posterior end of Meckel's sulcus: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Steropodon* (canal is present; its aperture is shown in Archer et al. 1985: fig. 1c);

(1) Foramen is not associated with the postdentary trough but in alignment with the posterior end of Meckel's sulcus: *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*;

(2) Meckel's sulcus is offset from the mandibular foramen (the intersection of Meckel's sulcus at the pterygoid margin is ventral and posterior to the foramen): *Gobiconodon*, *Jeholodens*, *Priacodon*, *Eomaia*, *Prokennalestes*; not applicable (Meckel's sulcus and

the postdentary trough are both absent): *Hadrocodium*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Vincelestes*, *Asiatherium*, *Didelphis*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
 (?) Not preserved: *Ambondro*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

12. Concavity (fossa) for the reflected lamina of the angular bone on the medial side of the dentary angular process (Crompton and Luo 1993):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon* (based on Gow 1986), *Haldanodon*;

(1) Absent: *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Shuotherium*, *Ornithorhynchus* (the living platypus has no angular process; the fossil ornithorhynchid has a weakly developed angular process, Archer et al. 1993), plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus Ausktribosphenos*, *Bishops*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not preserved: *Ambondro*, *Steropodon*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

13. Splenial as a separate element (as indicated by its scar on the dentary):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Zhangheotherium*;

(1) Absent: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Henkelotherium* (although Krebs 1991 identified a structure as the splenial scar, this is really a part of Meckel's sulcus, and we consider the splenial scar to be absent in this taxon), *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Eomaia*, *Montanalestes*,

Prokennalestes, Zalambdalestes, Asioryctes, Kennalestes, Daulestes, Cimolestes, Gypsonictops, Protungulatum, Erinaceus;
 (?) Not preserved: *Aspanlestes, Eoungulatum, Murtoilestes*; unknown: *Ukhaatherium*.

14. Relationship of the surangular 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 in this paper as appropriate to the circumstances used in the manuscript (Rowe 1988)]:

(0) Participates in CMJ either as a separate bone or fused with the articular: tritylodontids, *Sinoconodon, Morganucodon, Megazostrodon, Haldanodon*;

(1) Surangular as bony element is absent: *Hadrocodium, Ornithorhynchus*, plagiaulacidans, cimolodontans, *Asiatherium, Didelphis, Pucadelphys, Asioryctes, Kennalestes, Zalambdalestes, Daulestes, Cimolestes, Gypsonictops, Protungulatum, Erinaceus*;

(?) Not preserved: *Ambondro, Shuotherium, Ausktribosphenos, Bishops, Steropodon, Gobiconodon, Jeholodens, Priacodon, Zhangheotherium, Peramus, Henkelotherium, Vincelestes, Kielantherium, Deltatheridium, Kokopellia, Eomaia, Prokennalestes, Montanalestes, Aspanlestes, Eoungulatum, Murtoilestes*; unknown: *Ukhaatherium*.

15. Pterygoid muscle fossa on the medial side of the mandible (Gambaryan and Kielan-Jaworowska 1995):

(0) Absent: tritylodontids, *Sinoconodon, Morganucodon, Megazostrodon, Hadrocodium, Shuotherium, Ausktribosphenos, Bishops*;

(1) Present: *Haldanodon* (a small pterygoid fossa is present, see the discussion by Krusat 1980: p. 41, fig. 10), *Gobiconodon* (shown by Kielan-Jaworowska and Dashzeveg 1998), *Jeholodens, Priacodon, Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium, Peramus, Henkelotherium, Vincelestes, Kielantherium, Deltatheridium, Asiatherium, Kokopellia* (inferred from the crushed structure in the back

of the jaw), *Didelphis*, *Pucadelphys*, *Eomaia*, *Prokennalestes*, *Asioryctes*, *Kennalestes*.
Montanalestes, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
(?) Not preserved: *Ambondro*, *Steropodon*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*;
unknown: *Ukhaatherium*.

16. Medial pterygoid ridge (shelf) along the ventral border of the coronoid part of the mandible (character definition sensu Miao 1988):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*
(this character may be coded as ‘absent 0’; the ventral ridge of Krusat’s (1980) pterygoid muscle fossa is also the ridge that overhangs the postdentary trough and differs from the typical pterygoid ridge of other more derived mammals), *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, plagiaulacidans, cimolodontans;

(1) Present: *Ornithorhynchus*, *Peramus*, *Vincelestes*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(2) Pterygoid shelf present and reaching the dentary condyle via a low crest:

Gobiconodon, *Jeholodens*, *Priacodon*, *Zhangheotherium*;

(?) Not preserved: *Ambondro*, *Steropodon*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

17. Ventral border of the masseteric fossa:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*

(*Megazostrodon* has a shallow masseteric fossa but lacks a distinctive ventral ridge, Gow 1986), *Haldanodon*, *Hadrocodium*, *Shuotherium*;

(1) Present as a low and broad crest: *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(2) Present as a well-defined and thin crest: *Ausktribosphenos*, *Bishops*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus* (from description by Simpson 1928), *Henkelotherium*;
(?) Not exposed: *Jeholodens*; not preserved: *Ambondro*, *Steropodon*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

18. Crest of the masseteric fossa along the anterior border of the coronoid process:

(0) Absent or weakly developed: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon* (*Megazostrodon* has a shallow masseteric fossa but lacks a distinctive ridge, Gow 1986), *Haldanodon*, *Hadrocodium*;

(1) Present: *Gobiconodon*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus* (from description by Simpson 1928), *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*;

(2) Present and laterally flaring: *Ausktribosphenos*, *Bishops*, *Ornithorhynchus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Steropodon*, *Jeholodens*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

19. Anteroventral extension of the masseteric muscle fossa:

(0) Below the ultimate molar or posterior to it: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) Anterior extension below the ultimate premolar: plagiaulacidans, cimolodontans;

(?) Not preserved: *Ambondro*, *Steropodon*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

20. Labial mandibular foramen inside the masseteric fossa (Kielan-Jaworowska and Dashzeveg 1989):

(0) Absent: *tritylodontids*, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *plagiaulacidans*, *cimolodontans*, *Zhangheotherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Eomaia*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Gypsonictops*, *Cimolestes*, *Protungulatum*, *Erinaceus*;

(1) Present: *Peramus*, *Vincelestes*, *Kielantherium*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*;

(0/1 polymorphic): *Zalambdalestes*;

(?) Not preserved: *Ambondro*, *Steropodon*, *Henkelotherium*, *Murtoilestes*; unknown: *Ukhaatherium*.

21. Orientation of the condylar process (dentary peduncle) and condyle:

(0) Dentary peduncle is more posteriorly directed: *tritylodontids*, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Deltatheridium*, *Asiatherium* (its condyle is broken but the peduncle is posteriorly directed), *Didelphis*, *Pucadelphys*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Eomaia*, *Prokennalestes*, *Montanalestes*;

(1) Dentary condyle is continuous with the semicircular posterior margin of the dentary; condyle is facing up due to the up-turning of the posterior-most part of the dentary: *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes* (because the peduncle is up-turned, *Vincelestes* is tentatively designated as character state '1'; but unlike 'eutricodonts' and spalacotheriids, *Vincelestes* lacks the semicircular posterior margin in the dentary);

(2) Dentary articulation extends vertically for the entire depth of the horizontal ramus of mandible; it is confluent with the horizontal ramus and without a peduncle; the dentary articulation posteriorly directed: *plagiaulacidans*;

(3) More vertically directed dentary peduncle: *Bishops*, *Ornithorhynchus*;

(1/2 polymorphic): cimolodontans, some have a slightly up-turned condyle {1}, but *Sloanbaatar* is similar to plagiaulacidans in having a posteriorly directed articulation {2});

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Kielantherium*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*, *Kennalestes*; unknown: *Ukhaatherium*.

22. Shape and relative size of the dentary articulation:

(0) Small and dorsoventrally compressed: *Megazostrodon*, *Hadrocodium*;

(1) Condyle is massive and bulbous, transversely broad in its dorsal aspect: *Sinoconodon*, *Haldanodon*, *Bishops*, *Ornithorhynchus*, *Gobiconodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Asioryctes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(2) Condyle is mediolaterally narrow and vertically deep, forming a broad arc in lateral outline, either ovoid or triangular in posterior view: *Priacodon*, *Jeholodens*, plagiaulacidans, cimolodontans;

(0/1 polymorphic): *Morganucodon*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*, *Kennalestes*; not applicable (no condyle on the dentary): tritylodontids; unknown: *Ukhaatherium*.

23. Ventral (inferior) border of the dentary peduncle (character modified from Sues 1986: p. 254; Kielan-Jaworowska 1997: p. 258)

(0) Posteriorly tapering: tritylodontids;

(1) Columnar and with lateral ridge: *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Ausktribosphenos*, *Bishops*, *Ornithorhynchus*;

(2) Ventrally flaring: *Megazostrodon* (angle of Gow 1986; neomorphic angle of Jenkins et al. 1983; Jenkins 1984);

(3) Robust and short: *Peramus*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Eomaia*, *Prokennalestes*, *Montanalestes*;

(4) Ventral part of the peduncle and condyle become continuous with the ventral border of the mandible: *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, plagiaulacidans (the peduncle is absent; the ventral border of the mandible is directly graded into the dentary condyle), cimolodontans;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Steropodon*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*, *Kennalestes*; unknown: *Ukhaatherium*.

24. Position of the dentary condyle relative to the vertical level of the postcanine alveoli:

(0) Below or about the same level as the postcanine alveoli: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Peramus*;

(1) Above the level of the postcanine alveoli: *Ausktribosphenos*, *Bishops* (inferred from the preserved part of the mandible), *Ornithorhynchus*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Didelphis*, *Asiatherium*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Asioryctes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(0/1 polymorphic): cimolodontans (below the tooth row {0} for some taxa; same as or above the tooth row {1} for others);

(?) Not applicable: tritylodontids; not preserved: *Shuotherium*, *Ambondro*, *Steropodon*, *Kokopellia*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*, *Kennalestes*; unknown: *Ukhaatherium*.

25. 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) (modified from Prothero 1981) (gradient character that can be ordered).

- (0) Coronoid process is strongly reclined and the coronoid angle is obtuse ($\geq 150^\circ$): *Sinoconodon* (150°), *Morganucodon* (150°), *Shuotherium* (155°), *Zhangheotherium* (150°);
- (1) Coronoid process less reclined (135° - 145°): *Megazostrodon* (140°), *Haldanodon* (135°), *Gobiconodon* (145°), *Jeholodens* (145°), *Priacodon* (135°), plagiaulacidans (140°),
- (2) Coronoid process less than vertical (110° - 125°): *Hadrocodium* (125°), *Ornithorhynchus* (125°), *Ausktribosphenos* (125° based on additional specimens in Rich et al. 1999), *Bishops* (115°), *Henkelotherium* (115°), *Vincelestes* (120°), *Peramus* (125°), *Eomaia* (120°), *Prokennalestes* (120°), *Zalambdalestes* (120 - 125°), *Daulestes* (115°), *Cimolestes* (120°), *Gypsonictops* (120°), *Protungulatum* (115°), *Kennalestes* (110° ~ 115°);
- (3) Coronoid process is near vertical and the coronoid angle small (95° to 105°): tritylodontids (95°), (90 ~ 100°), *Kielantherium* (100°), *Deltatheridium* (105°), *Didelphis* (105°), *Asiatherium* (100°), *Kokopellia* (105°), *Pucadelphys* (95°), *Erinaceus* (100°), *Montanalestes* ($\sim 100^\circ$), *Asioryctes* (105°);
- (1/2 polymorphic) cimolodontans (with a range of variation of 130° ~ 150°);
- (?) Not preserved: *Ambondro*, *Steropodon*, *Aspanlestes*, *Eoungulatum*, *Murtoilestes*; unknown: *Ukhaatherium*.

26. Alignment of the ultimate molar to the anterior margin of the dentary coronoid process (and near the coronoid scar if the scar is present):

- (0) Ultimate functional molar is medial to the coronoid process: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans;
- (1) Ultimate functional molar is in alignment with the coronoid process: *Shuotherium*, *Steropodon*, *Ausktribosphenos*, *Bishops*, *Ornithorhynchus*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Eomaia*, *Prokennalestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Ambondro*, *Hadrocodium*; unknown: *Aspanlestes*, *Eoungulatum*, *Murtoilestes*, *Ukhaatherium*.

27. Direction of the lower jaw movement during occlusion (Crompton and Luo 1993; Luo 1994; Gambaryan and Kielan-Jaworowska 1995):

(0) Dorsomedial movement (as inferred from teeth): *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

(1) Dorsomedial movement with a significant medial component: *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Montanalestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(2) Dorsoposterior movement: tritylodontids (Crompton 1972b), plagiaulacidans, cimolodontans (posterior movement: Krause 1982; Wall and Krause 1992; Gambaryan and Kielan-Jaworowska 1995);

(0/2 Polymorphic): *Ornithorhynchus* (Hopson and Crompton 1969 inferred from the wear patterns on the cusps of the juvenile teeth and the shape of the craniomandibular joint that the mandible of the platypus could have both dorsoposteriorly directed and the dorsomedially directed movement).

(?) Not preserved: *Murtoilestes*.

Premolars (15 characters)

28. Ultimate upper premolar - metastylar lobe:

(0) Reduced or absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*;

(1) Enlarged and wing-like: *Peramus*, *Prokennalestes*, *Eomaia*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Gypsonictops*, *Cimolestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Daulestes* (only dP4 present), *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

29. Ultimate upper premolar - metacone or metaconal swelling (modified from Archibald et al. 2001):

(0) Absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium* (metastylar lobe absent), *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Cimolestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(1) Present: *Peramus*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Gypsonictops*, *Aspanlestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Daulestes* (only dP4 present), *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

30. Ultimate upper premolar - protocone or protoconal swelling:

(0) Little or no lingual swelling: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*;

(1) Protoconal swelling: *Prokennalestes*, *Eomaia*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Daulestes* (only dP4 present), *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

31. Penultimate upper premolar - protocone or protoconal swelling (gradient character that can be ordered):

(0) Little or no lingual swelling: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*;

(1) Protoconal swelling: *Prokennalestes*, *Eomaia* (represented by a cusp impression above the lower p4), *Aspanlestes*, *Eoungulatum*, *Kennalestes*, *Daulestes*, *Erinaceus*;

(2) Distinctive and functional protocone: *Asioryctes*, *Ukhaatherium*, *Zalambdalestes*, *Gypsonictops*, *Cimolestes*, *Protungulatum*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

32. Position of the most trenchant upper premolar (Rougier et al. 1998: character 3):

(0) Absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Asiatherium*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(1) In ultimate premolar position: *Hadrocodium*, *Vincelestes*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Eomaia*;

(2) In penultimate premolar position: *Peramus*, *Prokennalestes*, *Asioryctes*, *Ukhaatherium*, *Kennalestes*, *Zalambdalestes*, *Aspanlestes*, *Gypsonictops*, *Cimolestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*, *Murtoilestes*, *Daulestes* (dP4); not applicable: tritylodontids, *Sinoconodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

33. Orientation of the first upper premolar:

(0) Erect, without diastema: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Priacodon*, *Peramus*, *Vincelestes*, *Asioryctes*, *Ukhaatherium*, *Kennalestes*;

(1) Erect, with diastema: *Gobiconodon*, *Zhangheotherium*, *Asiatherium*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(2) Procumbent, separated by diastema: *Deltatheridium*, *Pucadelphys*, *Didelphis*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*,
Henkelotherium, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*,
Murtoilestes, *Aspanlestes*, *Eoungulatum*, *Daulestes*, *Aspanlestes*, *Eoungulatum*,
Gypsonictops, *Cimolestes*, *Protungulatum*; not applicable: tritylodontids, *Sinoconodon*,
Hadrocodium, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

34. Ultimate lower premolar - symmetry of the main cusp a (= protoconid). This character is measured by the length ratio of the anterior and posterior cutting edges extending from the cusp (included because premolar symmetry was used by Simpson 1925a, 1925b, 1928 as systematic character):

(0) Asymmetrical (anterior edge of cusp a is more convex in outline than the posterior edge): *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Jeholodens*, *Priacodon*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*;

(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): *Sinoconodon* (after Zhang et al. 1998), *Hadrocodium*, *Gobiconodon*, *Shuotherium*, *Ambondro* (premolar is not complete, but the preserved part of the main cusp is symmetrical), *Ausktribosphenos*, *Bishops*, *Zhangheotherium*, *Vincelestes*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans; not preserved: *Steropodon*, *Murtoilestes*, *Daulestes* (only dp4 present), *Eoungulatum*.

35. Ultimate lower premolar - anterior cusp b (= paraconid). (Absence or reduction of anterior cusp b tends to make the premolar appear more asymmetrical. This character is included because premolar asymmetry was used by Simpson 1925a, 1925b, 1928 as a systematic character - gradient character that may be ordered):

(0) Absent or indistinctive: *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Priacodon*,

Peramus, Vincelestes, Deltatheridium, Kokopellia, Asiatherium, Pucadelphys, Didelphis, Kennalestes;

(1) Present and distinctive: *Sinoconodon, Morganucodon, Haldanodon, Shuotherium, Ausktribosphenos, Bishops, Jeholodens, Zhangheotherium, Henkelotherium, Montanalestes, Asioryctes, Cimolestes, Ukhaatherium*;

(2) Slightly enlarged: *Prokennalestes, Eomaia, Zalambdalestes, Gypsonictops, Protungulatum, Erinaceus*.

(?) Not preserved: *Ambondro, Steropodon, Kielantherium, Murtoilestes, Daulestes* (only dP4 present), *Aspanlestes, Eoungulatum*; not applicable, tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

36. Ultimate 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) Aligned in a single straight line or at a slight angle: *Sinoconodon, Morganucodon, Megazostrodon, Haldanodon* (following Hopson and Crompton 1969; Krusat 1980), *Hadrocodium, Shuotherium, Gobiconodon, Jeholodens, Priacodon, Zhangheotherium, Henkelotherium, Peramus, Vincelestes, Kielantherium, Eomaia, Prokennalestes, Montanalestes, Ukhaatherium, Asioryctes, Kennalestes, Aspanlestes, Cimolestes, Deltatheridium, Asiatherium, Didelphis, Kokopellia, Pucadelphys*;

(1) Distinctive triangulation: *Ambondro, Ausktribosphenos, Bishops, Zalambdalestes, Gypsonictops, Protungulatum, Erinaceus*;

(2) Premolar multicusps in longitudinal row(s): tritylodontids (assuming morphology of anterior postcanines), plagiaulacidans, cimolodontans;

(?) Not preserved: *Steropodon, Murtoilestes, Daulestes* (only dp4), *Eoungulatum*; not applicable: *Ornithorhynchus*.

37. 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: *Sinoconodon, Morganucodon, Megazostrodon, Haldanodon, Hadrocodium, Henkelotherium, Vincelestes, Kielantherium*;

- (1) Present: *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Cimolestes*, *Aspanlestes*, *Protungulatum*;
- (2) Present, forming a transverse talonid (for occlusion): *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Gypsonictops*, *Erinaceus*;
- (3) Presence of the continuous posterior (distal) cingulid at the base of the crown: *Ambondro*, *Ausktribosphenos*, *Bishops*;
- (?) Not preserved: *Steropodon*, *Murtoilestes*, *Daulestes* (only dp4), *Eoungulatum*; not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

Note: There are two alternative schemes to code the semimolariform premolars of the boreosphenidan taxa of this study. We optioned to designate the distal cusp or cuspule as the same character regardless whether the other cusps of the ultimate premolar are aligned or triangulated.

38. Ultimate lower premolar - outline:

- (0) Laterally compressed (or slightly angled): *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans (highly compressed and blade-like), cimolodontans (highly compressed and blade-like), *Zhangheotherium*, *Vincelestes*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*;
- (1) Transversely wide: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Zalambdalestes*, *Erinaceus*;
- (?) Not preserved: *Steropodon*, *Murtoilestes*, *Daulestes* (dp4), *Eoungulatum*; not applicable: tritylodontids, *Ornithorhynchus*.

39. Ultimate lower premolar - labial cingulid:

- (0) Absent or vestigial: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Priacodon*, plagiaulacidans (the distal labial cusps of the

premolar are part of a reduced main cusp row, not on the cingulid), cimolodontans, *Zhangheotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) Present (at least along the length of more than half of the crown): *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Gobiconodon*;

(?) Not preserved: *Bishops*, *Steropodon*, *Henkelotherium* (not exposed), *Murtoilestes*, *Daulestes* (only dp4), *Eoungulatum*; not applicable: tritylodontids, *Ornithorhynchus*.

40. Ultimate lower premolar - lingual cingulid:

(0) Absent or vestigial: tritylodontids (coded from anterior postcanines), *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Present: *Haldanodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Montanalestes*;

(?) Premolar not preserved: *Steropodon*, *Murtoilestes*, *Daulestes* (only dp4), *Eoungulatum*; not applicable: *Ornithorhynchus*.

41. 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 is indistinctive: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*;

(1) Posterior cusp c is distinctive but less than 30% of the primary cusp a: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Gobiconodon*, *Jeholodens*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Aspanlestes*, *Protungulatum*, *Asioryctes*, *Montanalestes*, *Ukhaatherium*, *Cimolestes*, *Eomaia*, *Prokennalestes*;

(2) Posterior cusp c and primary cusp a are equal or subequal in height (c is 40%-100% of a): *Priacodon*, *Gypsonictops*, *Erinaceus*, *Zalambdalestes*, *Kennalestes*;
 (?) Not preserved: *Steropodon*, *Eoungulatum*, *Daulestes* (dp4 only), *Murtoilestes*; not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

Note: Cusp a is designed as the principal (central) cusp of the premolar if the cusps are in alignment, or the protoconid if the cusps are triangulated or form a trigonid. Cusp c is designated as the distal cusp if the premolar has three main cusps in alignment. If the ultimate premolar is triangulated or has a trigonid in addition to a talonid, we optioned to designate the metaconid as cusp c.

42. Penultimate lower premolar - paraconid (=cusp b) (gradient character that may be ordered):

(0) Absent: *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Daulestes* (p3), *Kennalestes*, *Erinaceus*;
 (1) Present but not distinctive: *Haldanodon*, *Ausktribosphenos*, *Bishops*, *Asioryctes*, *Gypsonictops*, *Cimolestes*, *Protungulatum*;
 (2) Present and distinctive: *Prokennalestes*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*;
 (?) Unknown: *Sinoconodon*, *Shuotherium*, *Ambondro*, *Steropodon*, *Jeholodens*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*; not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

43. 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): *Sinoconodon*, *Megazostrodon*, *Morganucodon*, *Haldanodon*, *Shuotherium*, *Gobiconodon*, *Priacodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Eomaia*,

Prokennalestes, *Montanalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Erinaceus*;

(1) Cusps in reversed triangulation: *Ausktribosphenos*, *Bishops*;

(2) Premolar with multicusps in longitudinal row(s): tritylodontids (assuming morphology of anterior postcanines), plagiaulacidans;

(?) Not preserved: *Hadrocodium*, *Eoungulatum*, *Ambondro*, *Steropodon*, *Murtoilestes*;
not applicable: *Ornithorhynchus*, cimolodontans (reduced and peg-like p3).

Molar Morphology (54 characters)

44. Alignment of the main cusps of the lower molar(s) (m2 or more posterior if present)

(0) Single longitudinal row: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon* (Kielan-Jaworowska and Dashzeveg 1998 show that *Gobiconodon* lacks triangulate pattern on m5), *Jeholodens*, *Priacodon*;

(1) Reversed triangle–acute ($\leq 90^\circ$): *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(2) Multiple longitudinal multicuspate rows: tritylodontids, plagiaulacidans, cimolodontans;

(?) Not applicable: *Ornithorhynchus*.

Note regarding Character 44. Several taxa of “obtuse-angled symmetrodonts” and eutriconodont amphilestids show a gradient of variation in cusp triangulation along the molar series (see discussion by Luo et al. 2002). In *Tinodon* (Crompton and Jenkins 1967), the cusps are hardly triangulated in the anterior molars (e.g., m1) but distinctively triangulated in the posterior molars. There clearly is a gradient of increasing triangulation of molar cusps in *Tinodon* and in the obtuse-triangle symmetrodont *Gobiotheriodon* from Mongolia (Averianov in press). Parrington (1978: p. 202) noted that some anterior

molars of *Kuehneotherium* are linear, but posterior lower molars are triangulated; therefore, molar cusp triangulation may not be applicable to all lower molars in the same taxon, especially among “obtuse-triangle” symmetrodonts. A similar gradient of increased triangulation is present in the upper molar series of *Gobiconodon* (Kielan-Jaworowska and Dashzeveg 1998) and *Megazostrodon*. The anterior vs. posterior lower molar triangulation should be coded separately if enough “obtuse-angle” symmetrodonts are to be included in the more expanded analysis.

45. Postvallum/prevallid shearing (angle of the main trigonid shear facets, based on m2):

(0) Absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

(1) Present, weakly developed, slightly oblique: *Shuotherium*, *Henkelotherium*, *Vincelestes*, *Kielantherium*;

(2) Present, strongly developed and more transverse: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Zhangheotherium*, *Peramus*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, plagiaulacidans, cimolodontans; homology uncertain: *Ornithorhynchus*.

46. Development of postvallum shear (on M2, applicable to molars with reversed triangulation of molar cusps) (modified from Cifelli 1993 and Archibald et al. 2001) (increasing the ranks of postvallum shear and can be ordered):

(0) Postvallum shear present by post-metacanal crista but no postprotocrista: *Shuotherium*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*;

(1) Postprotocrista present as double rank shear but does not reach labially below the base of the metacone: *Deltatheridium*, *Didelphis*, *Kokopellia*, *Pucadelphys*;

(2) Metacingulum/metaconule present as double rank shear, but the metacingulum crest does not extend beyond the base of the metacone: *Murtoilestes*, *Eomaia*, *Prokennalestes*,

Ukhaatherium, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Asiatherium*, *Erinaceus*;

(3) Metacingulum extended: *Aspanlestes*, *Gypsonictops*, *Cimolestes*;

(4) Reaching the metastylar lobe: *Protungulatum*, *Eoungulatum*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Megazostrodon*, *Morganucodon*, *Haldanodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Gobiconodon*, *Jeholodens*, *Priacodon*.

47. Postcingulum (gradient character that can be ordered):

(0) Absent or weak: *Shuotherium*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Kennalestes*, *Ukhaatherium*, *Asioryctes*, *Zalambdalestes*, *Erinaceus*;

(1) Present: *Aspanlestes*, *Gypsonictops*, *Cimolestes*;

(2) Present and reaching past the metaconule: *Protungulatum*, *Eoungulatum*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

48. Precise opposition of the upper and lower molars:

(0) Absent: *Sinoconodon*;

(1) Present (either one-to-one, or occluding at the opposite embrasure or talonid):

Morganucodon, *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Erinaceus*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(2) Present (one lower molar contacts sequentially more than one upper molars):
tritylodontids, plagiaulacidans, cimolodontans (multituberculates following interpretation of Butler 2000).

49. Relationships between the cusps of the opposing upper and lower molars:

(0) Absent: *Sinoconodon*;

(1) Present, lower primary cusp a occludes in the groove between upper cusps A, B:

Morganucodon, *Haldanodon*, *Jeholodens*, *Priacodon*;

(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:

Megazostrodon, *Hadrocodium*, *Gobiconodon*, *Zhangheotherium*;

(3) Present, parts of the talonid occluding with the lingual face (or any part) of the upper molar: *Ausktribosphenos*, *Ambondro*, *Bishops*, *Steropodon*, *Peramus*, *Henkelotherium*,

Vincelestes, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*,

Pucadelphys, *Erinaceus*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*,

Ukhaatherium, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*,

Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(4) Lower multicusps rows alternately occluding between the upper multicusps rows:
tritylodontids, plagiaulacidans, cimolodontans;

(?) Not applicable: *Shuotherium* (Note: *Shuotherium* has only cuspule d posterior to the trigonid; the occlusion by the anterior pseudo-talonid to the upper molar is not homologous to other therian mammals; see relevant coding of the *Shuotherium*'s anterior occlusal features in other characters. In a far less justifiable alternative, *Shuotherium* could be coded 3 for this feature); uncertain occlusal relationships (of deciduous teeth):

Ornithorhynchus.

50. Protoconid (cusp a) and metaconid (cusp c) height ratio (on m2):

(0) Protoconid is distinctively higher: *Shuotherium*, *Ambondro*, *Bishops*,

Ausktribosphenos, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*,

Kielantherium, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Eomaia*,

Daulestes, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Cimolestes*;

(1) Protoconid and metaconid are nearly equal in height: *Steropodon*, *Ornithorhynchus* (based on deciduous tooth), *Pucadelphys*, *Didelphis*, *Gypsonictops*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Zalambdalestes*, *Erinaceus*,
 (?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Murtoilestes*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

51. Relative height and size of the base of the paraconid (cusp b) and metaconid (cusp c) (on m2) (morphocline character that may be ordered):

(0) Paraconid is distinctively higher than the metaconid: *Haldanodon*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*;

(1) Paraconid (cusp b) and metaconid (cusp c) are nearly equal in height: *Shuotherium*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Kokopellia*, *Asiatherium*, *Didelphis*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(2) Paraconid (b) is lower than metaconid (c): *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ausktribosphenos*, *Bishops*, *Henkelotherium*, *Pucadelphys*, *Murtoilestes* (the preserved part of the metaconid base is much larger than paraconid; we infer that metaconid is taller and larger), *Prokennalestes*, *Eomaia*, *Montanalestes* (see note on variation below), *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Gypsonictops*, *Cimolestes*, *Zalambdalestes*.

(?) Preservation incomplete: *Ambondro*; not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

Note: *Montanalestes* shows state 2 on m2, but its m1 and m3 show state 1 (so this character could be coded as 1/2 polymorphic; we already experimented with a coding of 1/2 polymorphism and this alternative coding would not affect our interpretation of *Eomaia* and *Montanalestes*);

52. 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: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Kokopellia*, *Asioryctes*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*, *Ukhaatherium*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) Present: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus* (based on deciduous teeth);

(?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans.

53. 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 hypconid on the talonid or a distal cingulid cuspule; morphocline character that may be ordered):

(0) Absent: *Shuotherium*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;

(1) Present and contact closest to middle posterior of metaconid: *Steropodon*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Murtoilestes*, *Prokennalestes*;

(2) Present and contact closest to the lowest point of protocristid: *Kokopellia*, *Murtoilestes*, *Montanalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Gypsonictops*, *Cimolestes*, *Aspanlestes*, *Protungulatum*;

(3) Present and contact closest to the middle posterior protoconid: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*, *Eoungulatum*, *Erinaceus*.

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans; unknown: *Eomaia*, *Ukhaatherium*.

54. 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: *Shuotherium*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*;
- (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 post-metacristid defined as the posterior crest of metaconid that is parallel to the lingual border of the crown), but widely separated from the latter: *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
- (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: *Steropodon*;
- (3) 'Pre-entocristid' crest is offset from the metaconid (and post-metacristid if present), and the 'pre-entocristid' extending anterolingually past the base of the metaconid: *Ambondro* (best developed on m2, Flynn et al.: fig. 3c), *Ausktribosphenos* (we designate the medial-most of the three cristids in its talonid basin as the pre-entocristid; other internal ridges are considered to be wear features, as proposed by Rich et al. 1997; 1999), *Bishops*;
- (?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Ornithorhynchus* (the area for the 'pre-hypoconulid' is heavily crenulated, but *Ornithorhynchus* may also be coded as state {2}), plagiaulacidans, cimolodontans.

55. Posterior lingual cingulid of the lower molars:

- (0) Absent or weak: tritylodontids, *Sinoconodon*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, plagiaulacidans, cimolodontans, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
- (1) Distinctive: *Shuotherium*, *Gobiconodon*, *Priacodon*, *Zhangheotherium*;

(2) Strongly developed, crenulated with distinctive cuspules (such as the kuhnecone): *Morganucodon*, *Megazostrodon*, *Haldanodon* (assuming the homology of cusp g of *Haldanodon* to the kuhnecone of *Morganucodon*, Krusat 1980; this cuspule is labeled as "c" by Butler 1997);

(?) Not applicable: *Ornithorhynchus*; unknown: *Hadrocodium*.

56. Anterior internal (mesio-lingual) cingular cuspule (e) on the lower molars:

(0) Present: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium* (we consider one of the cuspules on the rim of pseudotalonid to be homologous to cuspule e), *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Zhangheotherium*, *Peramus*;

(1) Absent: *Jeholodens*, *Priacodon*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
(0/1 polymorphic) *Sinoconodon* (variable in the molars of *Sinoconodon*, Zhang et al. 1998), *Kielantherium*, *Deltatheridium*;

(?) Not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

57. Anterior and labial (mesio-buccal) cingular cuspule (f):

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Vincelestes*;

(1) Present: *Shuotherium* (we assume that the single cusp in *Shuotherium kermacki*, Sigogneau-Russell 1998 is homologous to the anterior labial cingulid cuspule f, whereas one of the two cusps in the 'pseudo-talonid' of *Shuotherium dongi* is homologous to cuspule f), *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Gobiconodon*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis* (*Didelphis* may have a series of minute and individualized cuspules, but no continuous mesial cingulid), *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*,

Cimolestes, *Gypsonictops*, *Protungulatum*, *Erinaceus* (*Erinaceus* has a very reduced cuspule on the discontinuous mesial cingulid);

(?) Not exposed: *Henkelotherium*; not applicable (homology uncertain): tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

58. Mesial cingulid features above the gum:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*,

(1) Weak and discontinuous cingulid features, with individualized cuspules below the trigonid (as individual cuspule e, or f, or both, but e and f are not connected):

Kielantherium, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(2) Present in a continuous shelf below the trigonid (with no relations to the protoconid and paraconid), and without occlusal function: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus* (coded from the deciduous premolars, Simpson 1929b);

(3) A cingular area present, and with occlusal contact to the upper molar: *Shuotherium* (we assume the homology of the ‘pseudo-talonid’ of *Shuotherium* to the mesial transverse cingulids of other mammals), *Haldanodon* (we note that *Haldanodon* is similar to *Shuotherium* in possessing an anterior shelf area with occlusal contact to upper molar, but *Haldanodon* differs from *Shuotherium* in that the former’s shelf is connected to cusp b (paraconid); see Butler 1997 and references cited therein).

59. Cingulid shelf wrapping around the anterointernal corner of the molar to extend to the lingual side of the trigonid below the paraconid:

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*,

Kennalestes, *Zalambdalestes*, *Daulestes*, *Cimolestes*, *Gypsonictops*, *Aspanlestes*,
Eoungulatum, *Protungulatum*, *Erinaceus*;

(1) Present, and its lingual part without occlusal function to the upper molars:

Steropodon, *Ambondro*, *Ausktribosphenos*, *Bishops*;

(2) Present, and with occlusal function to the upper molars: *Haldanodon*, *Shuotherium*;

(?) Not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

60. Postcingulid (distal transverse cingulid above the gum level) on the lower molar:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*,
Hadrocodium, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Gobiconodon* (confirmed on all
three known species), *Priacodon*, *Jeholodens*, plagiaulacidans, cimolodontans,
Zhangheotherium, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*,
Deltatheridium, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*,
Murtoilestes, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*,
Zalambdalestes, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*,
Protungulatum, *Erinaceus*;

(1) Present, horizontal above the gum level: *Shuotherium* (assuming the positional
homology of the distal ‘cingulid’ of this taxon to the postcingulid of other therians),
Steropodon, *Ornithorhynchus* (based on deciduous p2, Simpson 1929b).

61. Interlocking mechanism between two adjacent lower molars:

(0) Absent: tritylodontids, *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*,
Ambondro, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, plagiaulacidans,
cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;

(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: *Gobiconodon*,
Peramus, *Kielantherium*; or the base of the hypoconulid interlocks with a concave area
between the irregular mesial cingulid cuspules in front of the paraconid: *Deltatheridium*
(present in some molars), *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*,
Montanalestes, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*,

Kennalestes, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(2) Present, posterior cingular cuspule d fits between cingular cuspule e and cusp b of the succeeding molar: *Morganucodon*, *Megazostrodon*;

(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 cuspsules in interlocking): *Jeholodens*, *Priacodon*.

62. Size ratio of the last three lower molars:

(0) Ultimate molar is smaller than the penultimate molar, last three molars are $m1 \geq m2 \geq m3$; or $m2 \geq m3 \geq m4$; or $m3 \geq m4 \geq m5$; or $m4 \geq m5 \geq m6$): *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus* (based on deciduous teeth), *plagiaulacidans* ($m1 \geq m2$), *cimolodontans* ($m1 \geq m2$), *Gobiconodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*, *Erinaceus*.

(1) Penultimate molar is the largest of molars ($m1 \leq m2 \leq m3 \geq m4$; or $m1 \leq m2 > m3$): *Sinoconodon*, *Bishops*, *Jeholodens*, *Priacodon*, *Deltatheridium*,

(2) Ultimate molar larger than the penultimate molar ($m1 \leq m2 \leq m3$): *Prokennalestes*, *Eomaia*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Gypsonictops*, *Cimolestes*, *Protungulatum*;

(?) Not preserved: *Ambondro*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Daulestes*; not applicable: *tritylodontids*.

63. Paraconid position relative to the other cusps of the trigonid on the lower molars (based on $m2$):

(0) Paraconid in anterolingual position and the paraconid-protoconid line forming a more oblique angle to the longitudinal axis of the tooth: *Peramus*, *Vincelestes*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*;

(1) Paraconid lingually positioned and the paraconid-protoconid line more transverse to the longitudinal axis of the tooth: *Shuotherium*, *Ambondro*, *Zhangheotherium*,

Henkelotherium, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Erinaceus*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*;

(2) Paraconid lingually positioned and appressed to the metaconid: *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus* (based on the deciduous teeth described by Simpson 1929b), *Gypsonictops*, *Cimolestes*, *Kennalestes*, *Zalambdalestes*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Eomaia* (crown view of the tooth is not available).

64. 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 paraconid] because of different distribution of the a-b crest among non-triangulated mammals sampled in this study):

(0) Longitudinal orientation: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

(1) Oblique: *Shuotherium*, *Ambondro*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(2) Nearly transverse: *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus* (coded from deciduous molars), *Kennalestes*, *Zalambdalestes*;

(?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans, *Eomaia* (crown view of the tooth is not available).

65. Mesiolingual surface of the paraconid on the lower molars (applicable only to taxa with reverse triangulation of the molar cusps):

(0) Rounded: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon* (the peculiar crest on the mesial face of the paraconid connects to the precingulid and is assumed to be non-homologous), *Ornithorhynchus*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Eomaia*, *Prokennalestes*, *Montanalestes*,

Ukhaatherium, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*,
Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) Forming a keel: *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Murtoilestes*;

(0/1 Polymorphic): *Peramus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*,
Haldanodon, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans,
cimolodontans.

66. Anteroposterior shortening at the base of the trigonid relative to the talonid
(applicable only to taxa with talonid heel with a distal cusp d; measured at the lingual
base of m2 trigonid where possible; gradient character “from-skinniest-to-fattest” that
can be ordered):

(0) Trigonid long (extending over 3/4 of the tooth length): *Shuotherium*,
Zhangheotherium, *Henkelotherium*, *Vincelestes*, *Peramus*;

(1) Swelling on the side walls of the trigonid (taxa assigned in 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): *Aspanlestes*, *Eoungulatum*, *Protungulatum*;

(2) No shortening (trigonid 50-65% of tooth length): *Ambondro*, *Ausktribosphenos*,
Bishops, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Didelphis*,
Murtoilestes (substitute from m3), *Prokennalestes*, *Montanalestes*, *Eomaia*, *Daulestes*,
Erinaceus;

(3) Some shortening (the base of trigonid < 50% of tooth length): *Ukhaatherium*,
Kennalestes, *Asioryctes*, *Cimolestes*;

(4) Anteroposterior compression of trigonid (trigonid 40~45% of the tooth length;
measured on the lingual side): *Steropodon*, *Ornithorhynchus* (based on deciduous tooth),
Gypsonictops, *Zalambdalestes*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*,
Haldanodon, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans,
cimolodontans.

67. Molar (m2 measured where possible) trigonid/talonid heel width ratio:

(0) Narrow (talonid $\leq 40\%$ of trigonid): *Shuotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*;

(1) Wide (talonid is 40-70% of the trigonid in width): *Deltatheridium*, *Prokennalestes*, *Montanalestes*, *Murtoilestes* (m2 not available; substitute from m3), *Daulestes*, *Gypsonictops*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Cimolestes*;

(2) Talonid is equal or wider than trigonid: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Zalambdalestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Eomaia* (this feature is not visible on the available teeth).

68. Lower molar hypoflexid (concavity anterolabial to the hypconid or cusp d):

(0) Absent or shallow: *Shuotherium*, *Zhangheotherium*, *Vincelestes*, *Peramus*;

(1) Deep (40~50% of talonid width): *Kielantherium*, *Ausktribosphenos*, *Bishops*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Eomaia*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Ukhaatherium*, *Daulestes*, *Gypsonictops*, *Cimolestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(2) Very Deep ($>65\%$): *Ambondro*, *Steropodon*, *Ornithorhynchus* (based on deciduous tooth);

(?) Not exposed: *Henkelotherium*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

69. Morphology of the talonid (or the posterior heel) of the molar:

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

- (1) Present as an incipient heel or a cingulid, or cingular cuspule (d): *Shuotherium* (this taxon retains a vestigial cingulid shelf posterior to the trigonid, which is positionally identical to the true talonid), *Zhangheotherium*;
- (2) Present as a heel (with at least one functional cusp): *Henkelotherium* (a large talonid heel but no basin), *Vincelestes*, *Peramus*;
- (3) Present as a transverse ‘V-shaped’ basin with two functional cusps: *Steropodon*, (Kermack et al. 1968), *Ornithorhynchus* (coded on the deciduous teeth, Simpson 1929b);
- (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):
Ausktribosphenos, *Bishops*, *Ambondro*, *Kielantherium*, *Deltatheridium*, *Asiatherium*,
Didelphis, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*,
Prokennalestes, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*,
Aspanlestes, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
- (?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans.

70. Hypoconid (we designate the distal cingulid cuspule d as the homolog to the hypoconid in the teeth with linear alignment of 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: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*;
- (1) Present (as distal cusp d, sensu Crompton 1971), elevated above the cingulid level, labially positioned (or tilted in the lingual direction): *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Ornithorhynchus* (based on deciduous teeth), *Peramus*, *Vincelestes* (see Rougier 1993; Sigogneau-Russell 1999: fig. 7), *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

- (2) Present (larger than cusp d, with occlusal contact to the upper molar), elevated above the cingulid level, lingually positioned: *Henkelotherium*;
- (?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans.

71. 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: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;
- (1) Present, posterior, median and equidistant to the entoconid and the hypoconid: *Ambondro*, *Peramus*, *Kielantherium*, *Deltatheridium* (median), *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
- (2) Present and placed on the lingual rim of the talonid basin: *Ausktribosphenos*, *Bishops*, *Steropodon*, (assuming the homology by Kielan-Jaworowska et al. 1987), *Ornithorhynchus* (coded on the deciduous teeth), *Asiatherium*, *Didelphis* (hypoconulid closer to entoconid than to hypoconid), *Pucadelphys*;
- (?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans.

72. 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: *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*;
- (1) Cusp tip procumbent and the posterior wall of the cusp is vertical: *Steropodon*, (assuming the homology proposed by Kielan-Jaworowska et al. 1987), *Ornithorhynchus* (coded on the deciduous teeth), *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(2) Cusp tip procumbent and the posterior wall is gibbous: *Ambondro*, *Ausktribosphenos*, *Bishops*,

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*.

73. Hypoconulid labial postcingulid (shelf) on the lower molars (non-homologous with postcingulid of character 55 because of different relationship to talonid cusps; applicable to taxa with identifiable hypoconid and hypoconulid only) (Cifelli 1993):

(0) Absent: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) Present as a crest descending mesiolabially from the apex of the hypoconulid to the base of the hypoconid: *Asiatherium*, *Didelphis* (weak), *Kokopellia*, *Pucadelphys*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*.

74. Entoconid (if there are three functional cusps on the talonid, we assume that the third and the lingual-most functional cusp on the talonid to be the entoconid, following the rationale given by Kielan-Jaworowska et al. 1987):

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Steropodon* (sensu Kielan-Jaworowska et al. 1987), *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Vincelestes*, *Henkelotherium*;

(1) Present: *Ambondro*, *Asiatherium*, *Kokopellia*, *Deltatheridium*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(2) Present and twinned with hypoconulid: *Ausktribosphenos*, *Bishops*, *Pucadelphys*, *Didelphis*;

(0/1 polymorphic), *Kielantherium* (character variable);

(?) Not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

75. Height ratio of the hypoconid (to the base of the labial crown) vs. entoconid (to the base of labial crown) (character modified from Rougier et al. 1998):

(0) Entoconid absent on the talonid heel: *Shuotherium*, *Steropodon* (sensu Kielan-Jaworowska et al. 1987), *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;

(1) Entoconid is lower than the hypoconid: *Ambondro*, *Deltatheridium*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Aspanlestes*;

(2) Entoconid is near the height of the hypoconid: *Ausktribosphenos*, *Bishops*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Gypsonictops*, *Cimolestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*.

(0/1 polymorphic): *Peramus* (see Clemens and Mills 1971; Sigogneau-Russell 1999), *Kielantherium*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

76. 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) (Clemens 1979):

(0) Cusps not aligned: *Deltatheridium*, *Kielantherium*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Cusps aligned: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Zalambdalestes*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*,

Henkelotherium, *Vincelestes*, *Eomaia* (crown view is not visible); unknown from the published illustration: *Ukhaatherium*.

77. The length vs. width ratio of the functional talonid basin of lower molar (in occlusal view, measured at the cingulid level, and based on m2):

(0) Longer than wide (or narrows posteriorly): *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*;

(1) Length equals width: *Ambondro*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Protungulatum*, *Erinaceus*;

(2) Wider than long: *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus* (based on deciduous p2 as described by Simpson 1929b; and illustrated by Woodburne and Tedford 1975);

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Shuotherium*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Eomaia* (crown view is not visible).

78. 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 triangle):

(0) Hypoconid/protoconid height ratio less than 20% (hypoconid or cusp d is on the cingulid): *Shuotherium*, *Zhangheotherium*;

(1) Hypoconid/protoconid height ratio between 25% and 35% (talonid cusp elevated above the cingulid level): (~33%), *Henkelotherium* (~25%), *Peramus* (~25%), *Vincelestes* 35%~40%, *Kielantherium* (~37%), *Deltatheridium* (37%);

(2) Hypoconid/protoconid height ratio between 40% and 60%: *Ambondro* (estimated ~57%), *Asiatherium* (60%), *Didelphis* (~59%), *Kokopellia* (50%), *Pucadelphys* (60%), *Erinaceus* (56%), *Ukhaatherium* (50%), *Asioryctes* (~55%), *Kennalestes* (47%), *Eomaia*

(<55%), *Prokennalestes* (average 57%), *Montanalestes* (~53%), *Zalambdalestes* (58%), *Daulestes* (60%), *Aspanlestes* (60%), *Cimolestes* (~40%), *Gypsonictops* (50%);
 (3) Hypoconid/protoconid height ratio between >60% and 80%: *Ausktribosphenos* (~61%) *Bishops* (~62%), *Steropodon* (67%), *Ornithorhynchus* (sub-equal height ~80%); *Eoungulatum* (65%~70%), *Protungulatum* (70%~75%);
 (?) Incomplete preservation of the protoconid: *Murtoilestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

79. Width of the upper molar labial styler shelf (the area labial to the paracone/metacone) (Prothero 1980; as modified by Hu et al. 1997, 1998):

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;
 (1) Present and narrow: *Henkelotherium*;
 (2) Present and broad: *Shuotherium*, *Ornithorhynchus* (juvenile teeth), *Zhangheotherium*, *Vincelestes*, *Pucadelphys*, *Didelphis*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;
 (3) Present, broad, and with a hypertrophied ectoflexus (on M2): *Peramus*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Zalambdalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Cimolestes*, *Gypsonictops*;
 (?) Unknown: *Ausktribosphenos*, *Bishops*, *Ambondro*, *Steropodon*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, plagiaulacidans, cimolodontans.

80. Cuspule morphology of the labial cingulum labial to the paracone and metacone of the upper molars (excluding the parastyle and metastyle):

(0) Absent or weak: tritylodontids, *Sinoconodon*, *Hadrocodium*, plagiaulacidans, cimolodontans, *Henkelotherium*;
 (1) Distinctive cingulum, without cuspules (excluding the parastyle): *Haldanodon*, *Gobiconodon*, *Priacodon*, *Shuotherium*, *Ornithorhynchus* (deciduous teeth),

Zhangheotherium, *Vincelestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum* *Erinaceus*;

(2) Wide cingulum with individualized or even hypertrophied cusps (in addition to the parastyle): *Peramus*, *Deltatheridium*, *Kokopellia*, *Didelphis*, *Pucadelphys*, *Asiatherium*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(3) Cingulum crenulated with distinctive and even-sized multiple cusps:
Morganucodon, *Megazostrodon*;

(0/1 polymorphic) *Jeholodens*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*.

81. Upper molar with a functional lingual protocone or pseudoprotocone that grinds against a basin on the lower:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes* (has a lingual enlargement of the upper molar, but no functional cusp to fit into the lower molar basin, Bonaparte and Rougier 1987; Rougier 1993);

(1) Present: *Haldanodon* (MCL of Kermack et al. 1987; cusp X of Krusat 1973, 1980; Butler 1997), *Shuotherium* ('pseudoprotocone' of Wang et al. 1998; Sigogneau-Russell 1998), *Deltatheridium*, *Asiatherium*, *Didelphis*, *Kokopellia*, *Pucadelphys*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Steropodon*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; uncertain: *Ornithorhynchus*.

82. Degree of labial shift of the protocone (distance from the protocone apex to the lingual border versus the entire tooth width, in %) (applicable only to those taxa with reversed triangles; gradient character that can be ordered):

(0) No protoconal swelling: *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*;
 (1) Protocone present but no labial shift (10%-20%): *Deltatheridium*, *Asiatherium*,
Kokopellia, *Pucadelphys*, *Didelphis*, *Murtoilestes*, *Eomaia*, *Prokennalestes*,
Ukhaatherium, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*;
 (2) Moderate labial shift (25%-30%): *Cimolestes*, *Gypsonictops*, *Erinaceus*;
 (3) Substantial labial shift ($\geq 40\%$): *Eoungulatum*, *Protungulatum*;
 (?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Kokopellia*,
Montanalestes; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*,
Megazostrodon, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Steropodon*,
Ornithorhynchus, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans,
 cimolodontans.

83. Morphology of the protocone (applicable only to those taxa with reversed triangles and a lingual swelling of the upper molar; may be ordered):

(0) Protoconal region present but no distinct protocone: *Henkelotherium*, *Vincelestes*,
Peramus;
 (1) Protocone present, its apical portion anteroposteriorly compressed: *Deltatheridium*,
Asioryctes, *Kennalestes*, *Zalambdalestes*, *Ukhaatherium*, *Cimolestes*, *Gypsonictops*;
 (2) Apical portion slightly expanded: *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Didelphis*,
Murtoilestes, *Prokennalestes*, *Eomaia*, *Daulestes*, *Erinaceus*;
 (3) Apical portion expanded: *Aspanlestes*, *Eoungulatum*, *Protungulatum*;
 (?) Not preserved: *Montanalestes*, *Kielantherium*; not applicable: tritylodontids,
Sinoconodon, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*
 (an alternative coding of *Shuotherium* would be to code this taxon for state 2),
Ambondro, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*,
Jeholodens, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*.

84. Height of the protocone relative to the paracone and metacone (whichever is highest of the latter two):

(0) Protocone is markedly lower (less than 70%): *Deltatheridium*, *Kokopellia*, *Eomaia*,
Murtoilestes, *Prokennalestes*;

(1) Protocone of intermediate height (70%~80%): *Asiatherium*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Gypsonictops*, *Cimolestes*;
 (2) Protocone is near the height of paracone and metacone (within 80%): *Didelphis*, *Pucadelphys*, *Zalambdalestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;
 (?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Ukhaatherium*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*.

85. Anteroposterior width of the conular region 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; M2 measured where possible):

(0) Narrow (anteroposterior distance medial to the paracone and metacone less than 0.30 of total tooth length): *Peramus*, *Vincelestes*, *Deltatheridium* (0.29);
 (1) Moderate development (distance between position of conules = 0.31—0.50 of total tooth length): *Kokopellia* (0.50), *Murtoilestes* (0.47), *Eomaia*, *Prokennalestes* (0.46), *Ukhaatherium*, *Asioryctes* (0.44), *Kennalestes*, *Zalambdalestes*, *Daulestes*;
 (2) Wide (distance between conules greater than 0.51 of total tooth length): *Asiatherium*, *Pucadelphys* (0.59), *Didelphis* (0.55), *Erinaceus* (lophate crown);
 (?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium* (lingual portion of the docodont upper molar has different shape and connecting crests; so there is uncertainty in how to apply this character to *Shuotherium*), *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*.

86. Height and size of the paracone (cusp B) and metacone (cusp C) (on M2; see Clemens and Lillegraven 1986; Cifelli 1993; Rougier et al. 1998):

(0) Paracone higher and larger at the base than metacone: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Deltatheridium*, *Kokopellia*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Gypsonictops*, *Cimolestes*;

(1) Paracone and metacone are of equal size: *Vincelestes*, *Asiatherium*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(2) Paracone is lower than metacone: *Pucadelphys*, *Didelphis*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Steropodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

87. Base of the paracone and metacone (on M2, applicable only to triangulated molars):

(0) Merged: *Shuotherium*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Deltatheridium*, *Kokopellia*, *Eomaia*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Gypsonictops*, *Cimolestes*;

(1) Separate: *Asiatherium*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*, *Eoungulatum*, *Protungulatum*, *Aspanlestes*, *Erinaceus*.

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

88. 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: *Shuotherium*, *Peramus*, *Vincelestes*, *Deltatheridium*, *Kokopellia*, *Ukhaatherium*, *Asioryctes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) V-shaped, with labially directed postparacrista and premetacrista: *Asiatherium*, *Didelphis*, *Pucadelphys*;
 (?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*.

89. Presence of the paraconule and metaconule (modified from Rougier et al. 1998, character 35):

(0) Absent: *Shuotherium*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Didelphis*, *Erinaceus*;
 (1) Present: *Deltatheridium*, *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Eomaia*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Gypsonictops*, *Cimolestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*;
 (?) Not preserved: *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

90. Relative position of the paraconule and metaconule on M1-2 (character adopted from Archibald et al. 2001) (gradient character that can be ordered):

(0) Paraconule and metaconule closer to the protocone: *Deltatheridium*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Protungulatum*;
 (1) Both positioned near the midpoint of the protocone-metacone: *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Daulestes*, *Gypsonictops* (metaconule is very weak in *Gypsonictops*), *Cimolestes*;
 (2) Paraconule and metaconule are labial to the midpoint: *Eoungulatum*, *Aspanlestes*;
 (?) Not well preserved on the available fossils: *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*,

Hadrocodium, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Kielantherium*, *Didelphis*, *Montanalestes*, *Erinaceus*.

91. Internal conular cristae:

(0) Conule present with indistinct and continuous convex surface: *Deltatheridium*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Zalambdalestes*, *Protungulatum*;

(1) Distinctive and wing-like: *Daulestes*, *Kennalestes*, *Gypsonictops*, *Cimolestes*, *Aspanlestes*, *Eoungulatum*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Steropodon*, *Shuotherium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

92. Parastylar groove (on M2):

(0) Weak or absent: *Shuotherium*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*, *Gypsonictops*, *Cimolestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(1) Moderately to well developed: *Deltatheridium*, *Kokopellia*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

93. Upper molar cuspule E (an enlarged version of E would be the parastyle; a reduced version of this forms the corner of the tooth on the cingulum):

(0) Present (at least a cuspule swelling is present): *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*,

Henkelotherium, *Peramus*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Asioryctes*, *Kennalestes*, *Eomaia* (visible only on M3), *Prokennalestes*;

(1) Absent: tritylodontids, *Priacodon*, plagiaulacidans, cimolodontans;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Kielantherium*, *Montanalestes*.

94. Upper molar interlock:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Didelphis*, *Eoungulatum*, *Protungulatum*, *Erinaceus*;

(1) Tongue-in-groove interlock: *Priacodon*;

(2) Parastylar lobe of succeeding molar lumbricated with the metastylar region of a preceding molar: *Henkelotherium*, *Peramus*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Asiatherium*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*.

95. Size and labial extent of the metastylar lobe and parastylar lobe (on M2, character modified from Archibald et al. 2001) (morphocline character that can be ordered):

(0) Metastylar lobe is smaller than the parastylar lobe: *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Gypsonictops*, *Cimolestes*;

(1) Metastylar lobe of similar size and labial extent to the parastylar lobe: *Shuotherium*, *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Protungulatum*, *Aspanlestes*, *Eoungulatum*, *Erinaceus*;

(2) Metastylar lobe is much larger than the parastylar lobe: *Deltatheridium*, *Didelphis*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Montanalestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Steropodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans.

96. Outline of the lower m1:

(0) Laterally compressed: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

(1) Oblong with slight labial bulge: *Shuotherium*, *Ambondro*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Asioryctes*, *Kennalestes*;

(2) Triangular or tear-drop shaped: *Zhangheotherium*, *Henkelotherium* (near triangular);

(3) Rectangular (or slightly rhomboidal): tritylodontids, *Haldanodon*, *Steropodon*, *Ausktribosphenos* (anterior part rhomboidal), *Bishops* (anterior part rhomboidal), *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Erinaceus*.

97. Aspect ratio and outline of the upper M1:

(0) Laterally compressed: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

(1) Longer than transversely wide (oval-shaped or spindle shaped): *Peramus*, *Vincelestes*;

(2) Transversely wider than long (triangular outline): *Shuotherium* (the single upper molar from China has almost equal length to width, Wang et al. 1998; *Shuotherium* upper molar from Bathonian of England is wider than long, Sigogneau-Russell 1998), *Haldanodon* (dumbbell shaped), *Zhangheotherium*, *Henkelotherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Murtoilestes*, *Prokennalestes*, *Eomaia*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(3) Rectangular or nearly so: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Erinaceus*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*, *Montanalestes*.

Molar Wear Pattern (12 characters)

98. Functional development of occlusal facets on individual molar cusps:

(0) Absent for lifetime: *Sinoconodon*;

(1) Absent at eruption but developed later by wearing of the crown: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*;

(2) Wear facets match upon the eruption of teeth (inferred from the flat contact surface upon eruption): tritylodontids, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not applicable: *Ornithorhynchus* (uncertain for juvenile teeth, not applicable to adult teeth).

99. Topographic relationship of wear facets to the main cusps:

(0) Wear facet absent or a simple longitudinal facet that extends the entire length of the crown: *Sinoconodon*;

(1) Lower cusps a, c support two different wear facets (facets 1 and 4) that contact the upper primary cusp A: *Morganucodon*, *Megazostrodon*, *Haldanodon* (according to Hopson and Crompton 1969), *Hadrocodium*, *Jeholodens*, *Priacodon*;

(2) Lower cusps a, c support a single wear 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): *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon* (Kielan-Jaworowska and Dashzeveg 1998),

Zhangheotherium, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*,
Deltatheridium, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*,
Murtoilestes, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*,
Zalambdalestes, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*,
Protungulatum, *Erinaceus*;

(3) Multicuspate series, each cusp may support 2 wear facets: tritylodontids;
plagiaulacidans, cimolodontans;

(?) Homology uncertain: *Ornithorhynchus*.

100. Development and orientation of prevallum/postvallid shearing:

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*,
Gobiconodon, *Jeholodens*, *Priacodon*;

(1) Present and obtuse: *Shuotherium*, *Ambondro*, *Peramus*, *Henkelotherium*, *Vincelestes*;

(2) Present, hypertrophied and transverse: *Ausktribosphenos*, *Bishops*, *Steropodon*,
Zhangheotherium, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*,
Pucadelphys, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*,
Ukhaatherium, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*,
Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans; homology uncertain:
Ornithorhynchus.

101. 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: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*,
Jeholodens, *Priacodon*;

(1) Present: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Gobiconodon*,
Zhangheotherium, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*,
Deltatheridium, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*,
Murtoilestes, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*,
Zalambdalestes, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*,
Protungulatum, *Erinaceus*;

(?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans; homology uncertain: *Ornithorhynchus*.

102. Upper molars - development of facet 1 and the preprotocrista (applicable to molars with reversed triangulation of molar cusps) (modified from Cifelli 1993):

(0) Facet 1 (prevallum crest) is short, and does not extend to the stylocone area:

Shuotherium, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;

(1) Wear facet 1 extends beyond into the hook-like area near the stylocone: *Peramus*;

(2) A long preprotocrista (below the paracone-stylocone crest) is added to the prevallum shear and extends labially beyond the paracone: *Deltatheridium*, *Asiatherium*,

Kokopellia, *Pucadelphys*, *Didelphis*, *Murtoilestes*, *Eomaia*, *Prokennalestes*,

Ukhaatherium, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*,

Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Kielantherium*,

Montanalestes; not applicable: tritylodontids, *Sinoconodon*, *Megazostrodon*,

Morganucodon, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Priacodon*, *Gobiconodon*,

Ornithorhynchus, plagiaulacidans, cimolodontans, *Montanalestes*.

103. Differentiation of wear facet 3 (on the anterolabial aspect of the talonid) and facet 4 (on the posterolabial aspect of the talonid):

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Vincelestes*, *Henkelotherium*;

(1) Present: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(2) Facets 3 and 4 hypertrophied on the flanks of the strongly V-shaped talonid:

Steropodon, *Ornithorhynchus*;

(?) Not applicable: tritylodontids, plagiaulacidans, cimolodontans.

104. Orientation of facet 4 (on the posterior aspect of the hypoconid):

(0) Present and oblique to the long axis of the tooth: *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Present and forming a more transverse angle to the long axis of the tooth: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*.

105. Morphology of the posterolateral aspect of the talonid (the labial face of the hypoconid, applicable to the taxa with fully basined talonid):

(0) Gently rounded: *Ambondro*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Angular: *Ausktribosphenos*, *Bishops*, *Steropodon*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*; homology uncertain (on the deciduous teeth): *Ornithorhynchus*.

106. Wear pattern within the talonid basin (applicable to those taxa with triangulated molars):

(0) Absent: *Shuotherium*, *Steropodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*;

(1) Present: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Eomaia* (inferred from the obvious contact of the protocone and talonid), *Prokennalestes*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
 (?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans; homology uncertain: *Ornithorhynchus*.

107. Development of the distal metacristid (applicable only to taxa with reversed triangulation cusp pattern):

(0) Present: *Ambondro*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes* (Sigogneau-Russell 1999: fig. 7), *Kielantherium*, *Deltatheridium*;
 (1) Absent: *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Ornithorhynchus*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;
 (?) Not preserved: *Murtoilestes*; not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, plagiaulacidans, cimolodontans, *Gobiconodon*, *Jeholodens*, *Priacodon*.

108. Differentiation of wear facets 5 and 6 on the labial face of the entoconid:

(0) Absent: *Shuotherium*, *Steropodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*;
 (1) Present: *Ambondro*, *Ausktribosphenos* (the areas in talonid basin corresponding to facets 5 and 6 have multiple ridges), *Bishops* (talonid basin corresponding to facets 5 and 6 have fewer ridges), *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Eomaia* (not visible in the crown view); homology uncertain: *Ornithorhynchus*.

109. Surficial features on the occluding surfaces of facets 5 and 6 in the talonid (only applicable to taxa with reversed triangulation):

(0) Smooth surface on the talonid heel (or on cusp d): *Shuotherium*, *Ambondro*, *Steropodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;

(1) Multiple ridges within the talonid basin: *Ausktribosphenos* (the areas in talonid basin corresponding to facets 5 and 6 have multiple ridges and differ from the northern tribosphenidans), *Bishops* (talonid basin has fewer ridges);

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon* (the posterior part of the tooth is not homologous to the tribosphenic talonid, so *Haldanodon* is coded '?'); *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Eomaia* (not visible in the crown view).

Other Dental Features (13 characters)

110. Number of lower incisors:

(0) Three or more: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Zalambdalestes*;

(1) Two or fewer: tritylodontids, *Ornithorhynchus*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Montanalestes*, *Murtoilestes*.

111. Upper canine - presence vs. absence, and size:

(0) Upper canine present and enlarged: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes* (based on deciduous tooth), *Aspanlestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Present and small: *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Erinaceus*;

(2) Absent: tritylodontids, *Ornithorhynchus*, cimolodontans;

(1/2 polymorphic): plagiaulacidans (present {1} in *Kuehneodon*, *Pinheirodon*; absent {2} in other plagiaulacidans);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Peramus*, *Kielantherium*, *Montanalestes*, *Aspanlestes*, *Murtoilestes*, *Eoungulatum*, *Prokennalestes*.

112. Lower canine -- presence vs. absence and size:

(0) Present and enlarged: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Eomaia*, *Prokennalestes*;

(1) Present and small: *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Daulestes* (based on deciduous tooth), *Zalambdalestes*, *Erinaceus*;

(2) Absent: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Asiatherium*, *Aspanlestes*, *Eoungulatum*, *Montanalestes*, *Murtoilestes*.

113. Number of upper and lower premolars (gradient character that can be ordered):

(0) 5/5 or more: *Morganucodon*, *Megazostrodon*, *Bishops*, *Peramus*, *Prokennalestes*, *Eomaia*, *Aspanlestes*;
 (1) 4/4: *Gobiconodon*, *Priacodon*, *Henkelotherium*, *Kielantherium*, *Ukhaatherium*, *Asioryctes*, *Cimolestes*, *Gypsonictops*, *Daulestes*, *Eoungulatum*, *Protungulatum*;
 (2) 3/3: *Haldanodon*, *Zhangheotherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*;
 (3) 2 or less: *Sinoconodon*, *Hadrocodium*, *Ornithorhynchus*, *Jeholodens*, cimolodontans, *Vincelestes*, *Erinaceus*;
 (1/2 polymorphic - either 3 or 4 premolars): plagiaulacidans, *Zalambdalestes*; (0/1 polymorphic - either 4 or 5): *Kennalestes*;
 (?) Unknown: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Murtoilestes*, *Montanalestes*; not applicable: tritylodontids.

114. Diastema separating the lower p2 and p1 (defined as the first functioning premolar):

(0) Absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Priacodon*, *Peramus*, *Vincelestes*, *Daulestes*, *Zalambdalestes*, *Erinaceus*;
 (1) Present: *Sinoconodon*, *Jeholodens*, *Henkelotherium*, *Asiatherium*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Eomaia*;
 (?) Not-applicable: tritylodontids, *Hadrocodium*, plagiaulacidans, cimolodontans, *Ornithorhynchus*; not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Zhangheotherium*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*.

115. The p2-p3 diastema (or between penultimate lower premolar and its preceding tooth)

(0) Absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ausktribosphenos*, *Bishops*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Henkelotherium*, *Vincelestes*, *Peramus*, *Deltatheridium*, *Kokopellia*, *Asiatherium*, *Prokennalestes*, *Montanalestes*, *Daulestes* (based on dp2, p3), *Zalambdalestes*, *Gypsonictops*, *Cimolestes*, *Protungulatum*;

(1) Present: *Sinoconodon*, *Hadrocodium*, cimolodontans, *Eomaia*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Erinaceus*;
 (?) Unknown: *Shuotherium*, *Ambondro*, *Steropodon*, *Zhangheotherium*, *Kielantherium*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, not applicable: tritylodontids, *Ornithorhynchus*.

116. Number of lower molars or molariform postcanines:

(0) 6 or more: *Zhangheotherium*, *Henkelotherium*;
 (1) 4 to 5 molars (or molariforms): *Sinoconodon* (= molariform loci, Zhang et al. 1998); *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Shuotherium* (sensu Chow and Rich 1984), *Gobiconodon* (= molariform loci, see Jenkins and Schaff 1988), *Jeholodens*, *Priacodon*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*;
 (2) 3 molars: *Ausktribosphenos*, *Bishops* (based on Rich et al. 2001a), *Steropodon*, *Ornithorhynchus* (based on milk teeth, Simpson 1929b), *Vincelestes*, *Peramus*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
 (3) 2 molars: *Hadrocodium*, plagiaulacidans, cimolodontans;
 (0/1 polymorphic): tritylodontids;
 (?) incompletely preserved (missing the posterior molar{s}): *Ambondro*, *Murtoilestes*.

117. Number of upper canine roots (Rougier et al. 1998, character 10):

(0) One: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Deltatheridium*, *Eomaia*., *Montanalestes*, *Daulestes* (dC), *Ukhaatherium*, *Gypsonictops*, *Cimolestes*, *Protungulatum*, *Erinaceus*;
 (1) Two: *Prokennalestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Henkelotherium*, *Kielantherium*, *Murtoilestes*, *Montanalestes*, *Aspanlestes*,

Eoungulatum; not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

118. Number of lower canine roots (Rougier et al. 1998, character 44):

(0) One: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Deltatheridium*, *Eomaia*, *Montanalestes*, *Daulestes* (p3), *Ukhaatherium*, *Gypsonictops*, *Cimolestes*, *Protungulatum*, *Erinaceus*;

(1) Two: *Prokennalestes*, *Asioryctes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Henkelotherium*, *Kielantherium*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*; not applicable: tritylodontids, *Ornithorhynchus*, plagiaulacidans, cimolodontans.

119. Replacement of at least some posterior functional molariforms:

(0) Present: *Sinoconodon*, *Megazostrodon* (after Gow 1986), *Gobiconodon*;

(1) Absent: tritylodontids, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Priacodon*, *Ornithorhynchus* (the deciduous teeth are lost early and replaced by functional horny pads), plagiaulacidans, cimolodontans, *Zhangheotherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Prokennalestes*, *Eomaia*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(?) Unknown: *Shuotherium*, *Steropodon*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Montanalestes*, *Murtoilestes*.

120. Procumbency and enlargement of the anterior-most lower incisor:

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Priacodon*, *Vincelestes*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Protungulatum*;

(1) Present (at least 50% longer than second functional incisor): tritylodontids, *Gobiconodon*, *Jeholodens*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Peramus*, *Asiatherium*, *Henkelotherium*, *Kielantherium*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Cimolestes*, *Gypsonictops*, *Aspanlestes*, *Eoungulatum*; not applicable: *Ornithorhynchus*.

121. Enlarged diastema in the lower incisor-canine region (better developed in older individuals, see Parrington 1978; Gow 1986; Crompton and Luo 1993):

(0) Absent: *Haldanodon*, *Gobiconodon*, (large diastema between i3 and i4, but there is no diastema behind the canine), *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;

(1) Present and behind the canine: *Sinoconodon*, *Morganucodon* (in older individuals), *Megazostrodon*, *Hadrocodium*, *Jeholodens*, *Priacodon*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(2) Present and behind the posterior incisor: tritylodontids, plagiaulacidans, cimolodontans;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Asiatherium*, *Montanalestes*, *Murtoilestes*; not applicable: *Ornithorhynchus*.

122. Enamel microstructures (character state definition following Wood et al. 1999; distribution following Clemens 1997; Sander 1997; Wood and Stern 1997):

(0) Synapsida columnar enamel (prismless): tritylodontids, (coded from unidentified haramiyids), *Morganucodon*, *Haldanodon*, plagiaulacidans (from Fosse et al. 1985), *Ornithorhynchus*;

(1) 'Transitional' character state (sheath indistinct, 'prismatic' crystallites inclined at less than 45° to 'interprismatic' matrix): *Sinoconodon*, *Priacodon* (coded from the 'Cloverly triconodontine' as determined by Wood et al. 1999);

(2) Plesiomorphic prismatic enamel: *Megazostrodon*, *Gobiconodon*, cimolodontans, *Zhangheotherium* (coded from ‘spalacotheriids’ as determined by Wood et al. 1999), *Deltatheridium* (Wood 2000), *Kokopellia*, *Pucadelphys*, *Didelphis*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Erinaceus*;
 (?) Unknown: *Hadrocodium*, *Jeholodens*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Asiatherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Murtoilestes*, *Ukhaatherium*, *Asioryctes*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*.

Vertebrae (6 characters)

123. Fusion of the atlas neural arch and intercentrum (Rowe 1988, character 93):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon* (unfused, based on Gow 1986: fig. 14), *Jeholodens*, cimolodontans, *Vincelestes*, *Asioryctes*;
 (1) Present: *Ornithorhynchus*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*;
 (?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*; unknown: *Ukhaatherium*, *Zalambdalestes*.

124. Atlas rib in adults (Jenkins and Parrington 1976; Rowe 1988: char. 96; Kielan-Jaworowska 1977; Kielan-Jaworowska and Gambaryan 1994 observed this

independently and interpreted this feature as absence of transverse foramen in the atlas):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Jeholodens*, cimolodontans;
 (1) Absent: *Ornithorhynchus*, *Zhangheotherium*, *Vincelestes*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Asioryctes* (atlas has a stump for a transverse process, although the distal part of the transverse process is broken);
 (?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Ambondro*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Henkelotherium*, *Peramus*,

Kielantherium, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*,
Montanalestes, *Murtoilestes*; unknown: *Ukhaatherium*, *Zalambdalestes*.

125. Fusion of dens to the axis:

(0) Absent: tritylodontids, *Morganucodon*, *Megazostrodon* (round anterior margin of the axis, as described by Gow 1986, is characteristic of an unfused dens), *Jeholodens*;

(1) Present: *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

126. Rib of the axis:

(0) Present: tritylodontids, *Morganucodon* (Jenkins and Parrington 1976 showed the attachment facet), *Megazostrodon* (Gow 1986: fig. 14 illustrates the rib facets on the neural arch), *Ornithorhynchus*, *Jeholodens*, cimolodontans, *Zhangheotherium*;

(1) Absent (rib fused to become the transverse process): *Vincelestes*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Vincelestes*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

127. Postaxial cervical ribs in adults (Rowe 1988, character 101):

(0) Present: tritylodontids, *Sinoconodon* (on one specimen, although poorly preserved), *Morganucodon*, *Megazostrodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*;

(1) Absent: *Ornithorhynchus*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

128. Number of thoracic vertebrae:

(0) 13: *Gobiconodon* (after the reconstruction by Jenkins and Schaff 1988), cimolodontans, *Zhangheotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*;

(1) 15 or more: *Ornithorhynchus* (16), *Jeholodens* (15);

(?) Unknown: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

Shoulder Girdle (16 characters)

129. Interclavicle (Rowe 1988; character 110 merged with character 113, modified by Hu et al. 1997):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Ornithorhynchus*, *Jeholodens*, cimolodontans, *Zhangheotherium*;

(1) Absent: *Vincelestes*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Gobiconodon*, *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*,

Aspanlestes, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

130. Contact relationships in adults between the interclavicle (embryonic membranous element) and the sternal manubrium (embryonic endochondral element) (assuming the homologies of these elements by Klima 1973, 1987) (Hu et al. 1997, 1998):

(0) Two elements distinct from each other, posterior end of interclavicle abuts anterior border of manubrium: tritylodontids (Sun and Li 1985), *Sinoconodon*, *Ornithorhynchus* (Klima 1987), cimolodontans (Meng and Miao 1992; Sereno and McKenna 1995);

(1) Two elements distinct from each other, the interclavicle broadly overlaps the ventral side of the manubrium: *Jeholodens*, *Zhangheotherium* (Hu et al. 1997);

(2) Complete fusion of the embryonic membranous and endochondral elements resulting in a single and enlarged manubrium (Klima 1987): *Vincelestes*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*;

(?) Not preserved: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

131. Cranial margin of the interclavicle/manubrium:

(0) Anterior border is emarginated or flat: tritylodontids (*Bienotheroides*, Sun and Li 1985), *Sinoconodon*, *Ornithorhynchus*, cimolodontans (*Bulganbaatar* 'clover-shaped interclavicle' Sereno and McKenna 1995; see also Meng and Miao 1992), *Zhangheotherium* (Hu et al. 1997);

(1) With a median process (assuming interclavicle is fused to the sternal manubrium in living therians, Klima 1987): *Morganucodon* (based on a specimen courtesy of Dr. Susan Evans), *Jeholodens*, *Vincelestes*, *Didelphis*, *Pucadelphys*;

(2) Cranial border of the sternal manubrium has an emargination: *Eomaia*, *Erinaceus*;

(?) Not preserved: *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

132. Clavicle-sternal apparatus joint (assuming that homologous elements of the interclavicle and the manubrium are fused to each other in therians, Klima 1973, 1987; Sereno and McKenna 1995; Hu et al. 1997):

(0) Immobile: tritylodontids (Sun and Li 1985), *Sinoconodon*, *Ornithorhynchus*;

(1) Mobile: *Jeholodens*, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Eomaia*, *Erinaceus*, *Didelphis*, *Pucadelphys*;

(?) Not preserved: *Morganucodon* (Evans 1981; pers. comm. from Drs F. A. Jenkins and S. E. Evans), *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ausktribosphenos*, *Bishops*, *Ambondro*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

133. Acromioclavicular joint:

(0) Extensive articulation: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*;

(1) Limited articulation (either pointed acromion, or pointed distal end of clavicle, or both): *Gobiconodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Asioryctes*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*,

Daulestes, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;
unknown: *Ukhaatherium*.

134. Curvature of the clavicle (Ji et al. 1999):

(0) Boomerang-shaped: tritylodontids (Sun and Li 1985), *Sinoconodon*, *Morganucodon* (Jenkins and Parrington 1976), *Ornithorhynchus*;

(1) Slightly curved: *Jeholodens*, cimolodontans, *Zhangheotherium* (Hu et al. 1997), *Henkelotherium* (Krebs 1991: Abb. 7), *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*;

(?) Not preserved: *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

135. Scapula - supraspinous fossa (Jenkins and Schaff 1988; Rowe 1988, character 114; new definition of character states by Hu et al. 1997):

(0) Absent (acromion extending from the dorsal border of the scapula and positioned anterior to the glenoid): tritylodontids, *Sinoconodon*, *Ornithorhynchus*;

(1) Weakly developed (present only along a part of the scapula and positioned lateral to the glenoid): *Morganucodon* (sensu Sereno and McKenna 1995), *Megazostrodon*, *Haldanodon* (Henkel and Krusat 1980; Krusat 1980), cimolodontans;

(2) Fully developed (present along the entire dorsal border of scapula): *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Kuehneotherium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

136. Scapula - acromion process (Rowe 1988; Hu et al. 1997; modified here):

(0) Short stump, level with or behind the glenoid: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*;

(1) Hook-like and extending below the glenoid: *Gobiconodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Henkelotherium*, *Didelphis*, *Asiatherium*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

137. Scapula - a distinctive fossa for the teres muscle on the lateral aspect of the scapular plate (new):

(0) Absent: tritylodontids (Sun and Li 1985), *Sinoconodon*, *Megazostrodon*, *Haldanodon*, cimolodontans (Sereni and McKenna 1995), *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(1) Present: *Ornithorhynchus*, *Jeholodens*, *Zhangheotherium* (Hu et al. 1997), *Henkelotherium* (Krebs 1991: Abb. 7);

(?) Not preserved: *Morganucodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

138. Procoracoid (as a separate element in adults) (Klima 1973; Rowe 1988, character 117):

(0) Present: tritylodontids, *Sinoconodon* (as indicated by the facet on the scapula), *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*;

(1) Fused to the sternal apparatus (Klima 1973) and absent in adult: *Gobiconodon* (on a well preserved proximal portion of the scapula, there is no indication for contact for procoracoid), *Jeholodens*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Erinaceus*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Zalambdalestes*;

(?) Not preserved: *Haldanodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

139. Procoracoid foramen:

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*;

(1) Absent (assuming the procoracoid is fused to the sternal apparatus in living therians, Klima 1973): *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Eomaia*, *Zalambdalestes*, *Erinaceus*, *Asiatherium*, *Pucadelphys*, *Didelphis*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

140. Coracoid (Rowe 1988, character 118; revised by Hu et al. 1997):

(0) Large, with posterior process: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon* (inferred from the contacting border on the scapula by Jenkins and Parrington 1976), *Ornithorhynchus*;

(1) Small, without posterior process: *Gobiconodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Zalambdalestes*, *Eomaia*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

141. Size of the anterior-most element ('manubrium') relative to the subsequent sternebrae in the sternal apparatus:

(0) Large: tritylodontids, *Sinoconodon*, *Ornithorhynchus*, *Jeholodens*, cimolodontans (Kielan-Jaworowska 1989 described this in a taeniolabidoid; also see Meng and Miao 1992), *Zhangheotherium* (in *Zhangheotherium* the sternebrae are secondarily fused; the proximal part of the fused sternebrae, as evidenced by the first thoracic rib facet, indicating the anterior-most sternebrae is larger than the subsequent segments), *Vincelestes*, *Eomaia*;

(1) Small: *Didelphis*, *Pucadelphys*, *Erinaceus*;

(?) Not preserved: *Morganucodon* (Evans 1981; pers. comm. from Drs. F. A. Jenkins and S. E. Evans), *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

142. Orientation ('facing' of the articular surface) of the glenoid (relative to the plane or the axis of the scapula) (Rougier 1993; Hu et al. 1997):

(0) Nearly parallel to the long axis of the scapula and facing posterolaterally: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*;

(1) Oblique to the long axis of the scapula and facing more posteriorly: *Gobiconodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;
 (2) Perpendicular to the main plane of the scapular plate: *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;
 (?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

143. Shape and curvature of the glenoid (Jenkins 1973; Rowe 1988; Hu et al. 1997):

(0) Saddle-shaped, oval and elongate: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*;
 (1) Uniformly concave and more rounded in outline: *Jeholodens*, *Gobiconodon*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;
 (?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Deltatheridium*, *Kokopellia*; unknown: *Ukhaatherium*.

144. Medial surface of the scapula (Sereno and McKenna 1995; Hu et al. 1997):

(0) Convex: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus* (if the curvature of the medial surface near the anterior scapular border is taken into account), cimolodontans;
 (1) Flat: *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Eomaia*, *Zalambdalestes*, *Erinaceus*, *Asiatherium*, *Pucadelphys*, *Didelphis*;
 (?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*,

Kennalestes, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

Forelimb (12 characters)

145. Humeral head (Rowe 1988, character 120; new definition of character states by Hu et al. 1997):

(0) Subspherical, weakly inflected: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*;

(1) Spherical and strongly inflected: cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Deltatheridium*, *Kokopellia*; unknown: *Ukhaatherium*.

146. Intertubercular groove of the humerus (modified from Rowe 1988, characters 121, 122, 123):

(0) Shallow and broad: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, cimolodontans, *Vincelestes*;

(1) Narrow and deep: *Zhangheotherium*, *Henkelotherium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

147. Size of the lesser tubercle of the humerus relative to the greater tubercle (Gambaryan and Kielan-Jaworowska 1997):

(0) Wider: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *Gobiconodon*, cimolodontans;
 (1) Narrower: *Zhangheotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;
 (?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;
 unknown: *Ukhaatherium*.

148. Torsion between the proximal and distal ends of the humerus (Rougier et al. 1996b; Gambaryan and Kielan-Jaworowska 1997; Kielan-Jaworowska 1998):

(0) Strong ($\geq 30^\circ$): tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Vincelestes*;
 (1) Moderate ($30^\circ - 15^\circ$): *Zhangheotherium*, *Henkelotherium*;
 (2) Weak: *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;
 (1/2 polymorphic): cimolodontans (coded 1, see Kielan-Jaworowska and Qi 1990; Kielan-Jaworowska and Gambaryan 1994; Kielan-Jaworowska 1998; coded 2, see Sereno and McKenna 1995).
 (?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

149. Ventral extension of the deltopectoral crest or position of the deltoid tuberosity (Hu et al. 1997, 1998):

(0) Not extending beyond the midpoint of the humeral shaft: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, cimolodontans, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(1) Extending ventrally (distally) past the midpoint of the shaft: *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon* (Engelmann and Callison, 1998); *Zhangheotherium*;
 (0/1 polymorphic) tritylodontids (*Oligokyphus*, 0; *Kayentatherium*, 1);
 (?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

150. Ulnar articulation on the distal humerus (after Rowe 1988, with new definitions of character states):

(0) Bulbous ulnar condyle: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, cimolodontans;

(1) Cylindrical trochlea in posterior view with vestigial ulnar condyle in anterior view: *Jeholodens*, *Gobiconodon* (Jenkins and Schaff 1988 described this character state, and it is confirmed by a new partial humerus of *Gobiconodon* from Gansu, China), *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes* (Rougier, pers. comm.);

(2) Cylindrical trochlea without ulnar condyle (cylindrical trochlea has extended to the anterior/ventral side): *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*.

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

151. Radial articulation on the distal humerus:

(0) Distinct and rounded condyle in both anterior (ventral) and posterior (dorsal) aspects of the structure (that does not form continuous synovial surface with the ulnar articulation in the ventral/anterior view of the humerus): tritylodontids, *Sinoconodon*,

Morganucodon, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*,
Jeholodens, *Priacodon*, cimolodontans,

(1) Radial articulation forms a rounded condyle anteriorly but its posterior surface is near cylindrical: *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;

(2) Capitulum (radial articulating structure that forms continuous synovial surface with the ulnar trochlea and the surface is cylindrical in both anterior and posterior aspects): *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia* (inferred from incomplete preservation), *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

152. Entepicondyle and ectepicondyle of the humerus (Rowe 1988, character 124):

(0) Robust: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*;

(1) Weak: *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Erinaceus*;

(0/1 polymorphic) cimolodontans (1 for weak epicondyles in most taxa, 0 for the hypertrophies in *Lambdopsalis*, see Kielan-Jaworowska and Qi 1990; Gambaryan and Kielan-Jaworowska 1997);

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

153. Rectangular shelf for the supinator ridge extended from the ectepicondyle:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Ornithorhynchus*, cimolodontans,

Zhangheotherium, *Henkelotherium*, *Vincelestes*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(1) Present: *Asiatherium*, *Didelphis*, *Pucadelphys*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

154. Styloid process of the radius (Rowe 1988, character 129):

(0) Weak: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Vincelestes*;

(1) Strong: cimolodontans, *Henkelotherium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

155. Enlargement of the scaphoid with a distomedial projection (Szalay and Trofimov 1996):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Jeholodens*, *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Eomaia*, *Erinaceus*, *Asioryctes*;

(1) Present: *Asiatherium*, *Didelphis*, *Pucadelphys*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Gobiconodon*, *Priacodon*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

156. Size and shape of the hamate (unciform) in the wrist:

(0) Anteroposteriorly compressed (wider than long in dorsal view): *Megazostrodon*, *Jeholodens*, *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Erinaceus*, *Asioryctes*, *Eomaia*;

(1) Hypertrophied with mediolateral compression (longer than wide): *Asiatherium*, *Didelphis*;

(?) Not preserved: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Gobiconodon*, *Priacodon*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Pucadelphys*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

Pelvic Girdle (3 characters)

157. Acetabular dorsal emargination (cotyloid notch of Kühne 1956; Rowe 1988, character 134; modified by Hu et al. 1997):

(0) Open (emarginated): tritylodontids, *Morganucodon*, *Megazostrodon*, *Gobiconodon* (inferred from the incomplete iliac circumference of the acetabulum), *Jeholodens*, cimolodontans, *Vincelestes*, *Asiatherium*;

(1) Closed (with a complete rim): *Ornithorhynchus*, *Zhangheotherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Zalambdalestes*, *Ukhaatherium*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

158. Sutures of the ilium, ischium, and pubis within the acetabulum in adults (Ji et al. 1999):

(0) Unfused: tritylodontids (*Oligokyphus*, Kühne 1956), *Morganucodon*, *Megazostrodon*, *Jeholodens*, *Gobiconodon*, *Zhangheotherium*, *Henkelotherium*;

(1) Fused: *Ornithorhynchus*, cimolodontans, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia* (fused at the ischo-pubic suture), *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*.

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

159. Ischiatic dorsal margin and tuberosity:

(0) Dorsal margin concave (emarginated) and ischiatic tuberosity present: tritylodontids, *Morganucodon*, *Megazostrodon*;

(1) Dorsal margin concave and ischiatic tuberosity hypertrophied: *Ornithorhynchus*, cimolodontans;

(2) Dorsal margin straight and ischiatic tuberosity small: *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, *Shuotherium*, *Steropodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Asioryctes*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Hindlimb (11 characters)

160. Inflected head of the femur set off from the shaft by a neck (Rowe 1988, characters 141, 142; modified by Hu et al. 1997):

(0) Neck absent and head oriented dorsally: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Jeholodens*, *Gobiconodon*;

(1) Neck present, head spherical and inflected medially: cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

161. Fovea for the acetabular ligament on the femoral head (Gambaryan and Averianov 2001; data from Jenkins 1971; Jenkins and Parrington 1976; Kielan-Jaworowska and Gambaryan 1994):

(0) Absent: tritylodontids (Kühne 1956; Sues 1983), *Sinoconodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*;

(1) Present: *Morganucodon*, *Megazostrodon*, cimolodontans, *Henkelotherium*, *Vincelestes*, *Didelphis*, *Pucadelphys*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Asioryctes*, *Prokennalestes*, *Kennalestes*, *Daulestes*, *Montanalestes*, *Murtoilestes*, *Eomaia* (not exposed), *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

162. Greater trochanter (Rowe 1988, character 143):

(0) Directed dorsolaterally: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Jeholodens*, *Gobiconodon*;

(1) Directed dorsally: cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

163. Orientation of the lesser trochanter (Rowe 1988, character 144):

- (0) On medial side of the shaft: *tritylodontids*, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Jeholodens*, *Gobiconodon*, *Vincelestes*;
- (1) On the ventromedial or ventral side of the shaft: *cimolodontans*, *Zhangheotherium*, *Henkelotherium*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*, *Asiatherium*, *Pucadelphys*, *Didelphis*;
- (?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *plagiaulacidans*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

164. Size of the lesser trochanter (Rowe 1988):

- (0) Large: *tritylodontids*, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *cimolodontans*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;
- (1) Small: *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*;
- (?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *plagiaulacidans*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

165. Patellar facet ('groove') of the femur (Rowe 1988, character 145; distribution modified):

- (0) Absent: *tritylodontids*, *Sinoconodon*;
- (1) Shallow and weakly developed: *Morganucodon* (Jenkins and Parrington 1976), *Jeholodens*, *Gobiconodon* (Jenkins and Schaff 1988), *Asiatherium*, *Didelphis*, *Pucadelphys* (metatherians coded after the interpretation by Szalay and Trofimov 1996);

(2) Well developed: *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*;
(?) Not preserved: *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

166. Proximo-lateral tubercle or tuberosity of the tibia (Jenkins and Parrington 1976; Kielan-Jaworowska and Gambaryan 1994):

(0) Large and hook-like: tritylodontids, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *Ornithorhynchus*, cimolodontans;
(1) Indistinctive: *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Erinaceus*;
(?) Not preserved: *Sinoconodon*, *Hadrocodium*, *Shuotherium*, *Steropodon*, *Priacodon*, plagiaulacidans, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Asioryctes*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

167. Distal tibial malleolus:

(0) Weak: tritylodontids, *Megazostrodon*, *Jeholodens*, *Gobiconodon*, *Zhangheotherium*;
(1) Distinct: *Ornithorhynchus*, cimolodontans, *Henkelotherium*, *Vincelestes*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;
(?) Not preserved: *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

168. Fibula contacting the distal end of the femur (Szalay and Trofimov 1996):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, cimolodontans, *Henkelotherium*, *Vincelestes*, *Erinaceus*, *Eomaia*, *Ukhaatherium*, *Asioryctes*;

(1) Absent: *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Zalambdalestes* (fibula reduced and fused to the tibia);

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Priacodon*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

169. Distal fibular styloid process:

(0) Weak or absent: tritylodontids, *Megazostrodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*, *Eomaia*, *Asioryctes*, *Ukhaatherium*, *Pucadelphys*, *Didelphis*;

(1) Distinct: *Henkelotherium*, *Vincelestes*, *Erinaceus*;

(?) Not preserved: *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable: *Zalambdalestes* (tibia and fibula fused distally).

170. Fibula contacting the calcaneus (= 'tricontact in upper ankle joint' of Szalay 1994):

(0) Extensive contact: tritylodontids, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *Jeholodens*, *Gobiconodon*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*;

(1) Reduced: *Deltatheridium* (Horovitz 2000), *Asiatherium*, *Pucadelphys*, *Didelphis*, *Ukhaatherium*, *Eomaia*, *Zalambdalestes* (completely absent);

(2) Mortise and tenon contact of fibula to the ankle (Szalay 1994): *Erinaceus*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Ankle Joint (10 characters)

171. Superposition (overlap) of the astragalus over the calcaneus (lower ankle joint)

(Jenkins 1971; Rowe 1988; Kielan-Jaworowska 1997):

(0) Little or absent: tritylodontids, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *Jeholodens*;

(1) Weakly developed: cimolodontans, *Zhangheotherium*;

(2) Present: *Vincelestes*, *Deltatheridium*, *Didelphis*, *Pucadelphys*, *Erinaceus*, *Eomaia*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

172. Lower ankle joint – orientation of the sustentacular facet of the calcaneus in relation to the horizontal plane (Szalay 1994; Horovitz 2000):

(0) Nearly vertical: tritylodontids, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *Jeholodens*, cimolodontans;

(1) Oblique ($\leq 70^\circ$) to nearly horizontal: *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

173. Astragalar neck (Ji et al. 1999):

(0) Absent: tritylodontids, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*,

Jeholodens, cimolodontans, *Zhangheotherium*, *Vincelestes*;

(1) Weakly developed: *Didelphis*, *Pucadelphys*;

(2) Present: *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*,
Ausktribosphenos, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans,
Henkelotherium, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*,
Prokennalestes, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*,
Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

174. Astragalar trochlea:

(0) Absent: tritylodontids, *Morganucodon*, *Megazostrodon*, *Jeholodens*, cimolodontans,
Zhangheotherium (new GMV specimen);

(1) Trochlea present, but weak (defining crest on the medial astragalo-tibial facet weakly
developed): *Vincelestes*, *Pucadelphys*, *Didelphis*;

(2) Trochlear crest well developed on the medial side (defining crest on the medial
astragalo-tibial facet well developed): *Eomaia*, *Erinaceus*, *Ukhaatherium*,
Zalambdalestes, *Asioryctes*,

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*,
Bishops, *Ausktribosphenos*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans,
Henkelotherium, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*,
Prokennalestes, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*,
Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable:

Ornithorhynchus (The platypus has a condyle on the dorsomedial aspect of the astragalus
for the trough on the distal end of the tibia. It serves to allow the tibio-astraglar joint to
rotate with respect to the transverse axis of the foot for extension and flexion, Szalay
1994. However, the astragalus lacks a true trough as in the astragalar trochlea of extant
therians. For these reasons we coded *Ornithorhynchus* as ‘?’).

175. Calcaneal tubercle (Rowe 1988: character 151):

(0) Short, without terminal swelling: tritylodontids, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *Jeholodens*;

(1) Elongate, vertically deep, and mediolaterally compressed, with terminal swelling: cimolodontans, *Zhangheotherium*, *Vincelestes*, *Henkelotherium*, *Deltatheridium* (Horovitz 2000), *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

176. Peroneal process and groove of the calcaneus (modified from Kielan-Jaworowska and Gambaryan 1994):

(0) Forming laterally directed shelf, without a distinct process: tritylodontids, *Morganucodon*, *Megazostrodon*, *Gobiconodon*, *Jeholodens*;

(1) Weakly developed with shallow groove on the lateral side of the process: *Zhangheotherium*, *Vincelestes*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(2) With a distinct peroneal process: *Ornithorhynchus* (after the homology proposed by Szalay 1994), cimolodontans (with a distinct peroneal process: demarcated by a deep peroneal groove at the base);

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Steropodon*, *Priacodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

177. Contact of the cuboid on the calcaneus (following the orientation identified by Lewis 1983; Szalay 1994) (new character, modified from Kielan-Jaworowska 1997):

(0) On the anterior (distal) end of the calcaneus (the cuboid is aligned with the long axis of the calcaneus): tritylodontids (*Oligokyphus* as illustrated by Szalay 1994),

Morganucodon (inferred from the orientation of the cuboid facet on the calcaneus), *Zhangheotherium*, *Vincelestes* (Rougier 1993), *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(1) On the anteromedial aspect of the calcaneus (the cuboid is skewed to the medial side of the long axis of the calcaneus): *Ornithorhynchus* (Grassé 1955; Szalay 1994, pers. obs. of AMNH 65831), *Jeholodens*, cimolodontans (Krause and Jenkins 1983; Kielan-Jaworowska and Gambaryan 1994);

(?) Not preserved: *Sinoconodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

178. Orientation and placement of the sustentacular facet on the calcaneus (modified from Szalay 1994):

(0) Vertically oriented on the medial edge of the calcaneus: tritylodontids, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus* (ankle orientation and identification of facet in the platypus following Szalay 1994), *Jeholodens*;

(1) On the dorsal aspect of the calcaneus and positioned medial to anteromedial to the astragalar facet on the calcaneus: cimolodontans (medial, for identification of facets see Krause and Jenkins 1983), *Vincelestes*, *Deltatheridium* (anteromedial), *Pucadelphys*, *Didelphis*;

(2) On the dorsal aspect of calcaneus and positioned anterior to the astragalar facet on the calcaneus: *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;

(?) Not preserved: *Sinoconodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*,

Murtoilestes, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

179. Relationships of the proximal end of metatarsal V to the cuboid:

- (0) Metatarsal V is off-set to the medial side of the cuboid: *Megazostrodon*, *Jeholodens*;
- (1) Metatarsal V is so far off-set to the side of the cuboid that it contacts the calcaneus: *Ornithorhynchus* (metatarsal V is bound by ligament to the peroneal tubercle of calcaneus, Szalay 1994, and confirmed by our pers. obs. of AMNH 65831), cimolodontans (after Kielan-Jaworowska and Gambaryan 1994);
- (2) Metatarsal V is level with the anterior end of the cuboid: *Vincelestes*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;
- (?) Not preserved: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

180. 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 is aligned with (or parallel to) the long axis of the calcaneus: *Megazostrodon*, *Vincelestes*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*;
- (1) Metatarsal III is arranged obliquely from the long axis of the calcaneus: *Ornithorhynchus*, *Jeholodens*, cimolodontans;
- (?) Not preserved: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Prokennalestes*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Other Postcranial Characters (2 characters)

181. Sesamoid bones in the flexor tendons (Rowe 1988, character 158):

(0) Absent: tritylodontids, *Megazostrodon*, *Jeholodens*;

(1) Present and unpaired: *Ornithorhynchus*;

(2) Present and paired: cimolodontans, *Zhangheotherium*, *Didelphis*, *Eomaia*, *Erinaceus*;

(?) Not preserved: *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Zalambdalestes*.

182. External pedal (tarsal) spur present in the male (modified from Hu et al. 1997, 1998):

(0) Absent: tritylodontids, *Megazostrodon*, *Jeholodens*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*;

(1) Present: *Gobiconodon*, *Ornithorhynchus*, cimolodontans (Wible and Rougier 2000), *Zhangheotherium*, *Henkelotherium* (pers. observation J. R. Wible).

(?) Not preserved: *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Bishops*, *Ausktribosphenos*, *Steropodon*, *Priacodon*, plagiaulacidans, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

Note: The ankle (external pedal) spur is a sexually dimorphic character in living platypus and echidna (present only in adult males, but absent in females or juveniles). In a separate study (Luo and Kielan-Jaworowska, ms in prep.), we have documented the presence of the external pedal spur in some multituberculate specimens but not in other individuals of the same species. A similar pattern also occurs in *Zhangheotherium* (the

holotype has a spur, but the second specimen of the same taxon lacks it). The best available biological interpretation is that the spur was a (sexually) dimorphic feature in fossils as in extant monotreme families. Alternative, this character can be coded as (0/1) polymorphic: 0—absent for females and juveniles; 1—present for males.

Basicranium (49 characters)

183. External size of the cranial moiety of the squamosal (Rowe 1988; Wible 1991; Luo 1994):

(0) Narrow: *tritylodontids*, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *cimolodontans*;

(1) Broad: *Hadrocodium*, *Henkelotherium* (Krebs 1991: Abb. 1), *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *plagiaulacidans*, *Zhangheotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

184. Participation of the cranial moiety of the squamosal in the braincase (Wible 1991; Luo 1994):

(0) Does not participate in the endocranial wall of the braincase: *tritylodontids*, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Gobiconodon*, *Ornithorhynchus*, *plagiaulacidans*, *cimolodontans* (based on Hurum, 1998);

(1) Participates in the endocranial wall of the braincase: *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

185. Entoglenoid constriction (neck) between the craniomandibular joint (or glenoid) and the cranial moiety of the squamosal (only applicable to taxa with the dentary - squamosal joint; this character is best seen in the ventral view) (modified from Luo 1994; Hu et al. 1998):

(0) Absent: *tritylodontids*, *Sinoconodon*, *Hadrocodium*, *Ornithorhynchus*, *Vincelestes*, *Zalambdalestes*;

(1) Present: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *plagiaulacidans*, *cimolodontans*, *Zhangheotherium*, *Henkelotherium*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Kennalestes*, *Daulestes* (note that among other eutherians this feature is polymorphic constriction absent in *zalambdalestids* and *leptictids*, but present in other eutherians);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Daulestes* (anatomical interpretation is uncertain due to distorted preservation).

186. Postglenoid depression on the squamosal:

(0) Present as the post-cranio-mandibular joint sulcus ('external auditory meatus' on the zygoma): *tritylodontids*;

(1) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *plagiaulacidans*, *cimolodontans*;

(2) Present on the skull base: *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

187. Squamosal – entoglenoid process:

(0) Absent or vestigial: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Daulestes* (vestigial), *Erinaceus*;

(1) Present and enlarged: *Asioryctes*, *Ukhaatherium*, *Kennalestes*, *Zalambdalestes*;

(?) Not applicable: tritylodontids; not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Priacodon*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Asiatherium*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

188. Position of the craniomandibular joint (Rowe 1988; Wible 1991):

(0) Posterior or lateral to the level of the fenestra vestibuli: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*;

(1) Anterior to the level of the fenestra vestibuli: *Hadrocodium*, plagiaulacidans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Erinaceus*;

(0/1 polymorphic) cimolodontans: ptilodontoids and taeniolabidoids (0); *Chulsanbaatar* and *Nemegtbaatar* (1);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Prokennalestes*, *Eomaia*, *Montanalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

189. Orientation of the glenoid on the squamosal:

(0) On the inner side of the zygoma and facing ventromedially: *Sinoconodon*, *Hadrocodium*;

(1) On platform of the zygoma and facing ventrally: *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, plagiaulacidans, cimolodontans, *Zhangheotherium*,

Henkelotherium, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*,
Erinaceus, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;
 (0/1 polymorphic): *Morganucodon*;
 (?) Not-applicable: tritylodontids; not preserved: *Shuotherium*, *Ambondro*,
Ausktribosphenos, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Kielantherium*,
Kokopellia, *Eomaia*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, *Aspanlestes*,
Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

190. Postglenoid process of the squamosal:

(0) Absent: *Sinoconodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans;
 (1) Present as a distinctive process: *Haldanodon*, *Hadrocodium*, *Gobiconodon*,
Jeholodens, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*,
Asiatherium, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Ukhaatherium*,
Zalambdalestes, *Asioryctes*, *Kennalestes*;
 (1/2 polymorphic): *Morganucodon*;
 (?) Not applicable: tritylodontids, (have a dentary-squamosal contact on the inner side of
 the zygoma but lack a distinctive glenoid fossa); not preserved: *Megazostrodon*,
Shuotherium, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*,
Kielantherium, *Kokopellia*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, *Aspanlestes*,
Eoungulatum, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

191. Postglenoid foramen within the squamosal:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*,
Ornithorhynchus, plagiaulacidans, cimolodontans, *Gobiconodon*, *Jeholodens*,
Zhangheotherium, *Vincelestes*, *Henkelotherium*;
 (1) Present posterior to the glenoid area: *Asiatherium*, *Pucadelphys*, *Didelphis*,
Erinaceus,
 (2) Present within the glenoid area: *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Daulestes*,
Zalambdalestes;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

192. Relationship of the pars cochlearis to the lateral lappet of the basioccipital (Crompton 1995; Luo 2001):

(0) Pars cochlearis is entirely or partially covered by the basioccipital: tritylodontids (Luo 2001), *Sinoconodon* (partially covered by basioccipital Luo et al. 2001b);

(1) Pars cochlearis fully exposed as the promontorium: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Prokennalestes*, *Asioryctes*, *Zalambdalestes*, *Kennalestes*, *Daulestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

193. Medial surface of the promontorium of the pars cochlearis:

(0) Flat: *Sinoconodon*, *Megazostrodon*, *Haldanodon*;

(1) Inflated and convex: *Morganucodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Prokennalestes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Gobiconodon*, *Peramus*, *Kokopellia*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable: tritylodontids (the pars cochlearis is concealed medially by the basioccipital); unknown: *Ukhaatherium*.

194. External outline and morphology of promontorium (Rougier et al. 1996a):

(0) Triangular, with steep and slightly concave lateral wall: *Sinoconodon*, *Haldanodon*;
 (1) Elongate and cylindrical petrosal cochlear housing: *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, *Jeholodens* (not exposed but based on CT scans), *plagiaulacidans*, *cimolodontans* (slightly curved), *Zhangheotherium*;
 (2) Bulbous and oval shaped promontorium: *Hadrocodium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Prokennalestes*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Erinaceus*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;
 not applicable: tritylodontids (pars cochlearis does not have an external exposure);
 unknown: *Ukhaatherium*.

195. Cochlea (Rowe 1988; Wible 1991; Luo 1994; Rougier et al. 1996a; Hurum 1998b):

(0) Short and uncoiled: tritylodontids (Luo 2001), *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon* (partially preserved in the Chinese materials), *Jeholodens* (as inferred from CT scan and the internal aspect of the pars cochlearis), *Priacodon*, *plagiaulacidans*, *cimolodontans*, *Zhangheotherium*, *Henkelotherium* (Krebs 2000);
 (1) Elongate and partly coiled: *Ornithorhynchus*, *Vincelestes*;
 (2) Elongate and coiled to at least 360°: *Didelphis*, *Asiatherium*, *Pucadelphys*, *Deltatheridium*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Peramus*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

196. Internal acoustic meatus – cribriform plate:

(0) Absent: tritylodontids, *Sinoconodon*, *Megazostrodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium* (based on CT scan), *Jeholodens*, *Priacodon*, plagiaulacidans (see Hahn 1988; Lillegraven and Hahn 1993), cimolodontans, *Vincelestes*;

(1) Present: *Ornithorhynchus*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Eomaia* (as inferred from the preserved portion of the cochlear canal), *Prokennalestes*, *Daulestes*, *Kennalestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Murtoilestes*, *Prokennalestes*, *Montanalestes*, *Zalambdalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Asioryctes*, *Daulestes*; unknown: *Ukhaatherium*.

197. Internal acoustic meatus depth:

(0) Deep with thick prefacial commissure: tritylodontids, *Sinoconodon*, *Gobiconodon*, *Vincelestes*, *Deltatheridium*;

(1) Shallow with thin prefacial commissure: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium* (based on CT), *Ornithorhynchus*, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans, *Pucadelphys*, *Didelphis*, *Prokennalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Protungulatum*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Aspanlestes*, *Eoungulatum*, *Gypsonictops*, *Cimolestes*; unknown *Ukhaatherium*.

198. Primary bony lamina within the cochlear canal (Meng and Fox 1995b; Fox and Meng 1997):

(0) Absent: tritylodontids (Luo 2001), *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Ornithorhynchus*, *Gobiconodon*, cimolodontans;

(1) Present (Meng and Fox 1995a): *Didelphis*, *Erinaceus*, *Eomaia*, *Prokennalestes*;

(?) Preserved but not exposed: *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Daulestes*, *Asioryctes*. Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*; unknown: *Ukhaatherium*, *Zalambdalestes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*.

199. Secondary bony lamina for the basilar membrane within the cochlear canal (Meng and Fox 1995a; Rougier et al. 1996a; Wible et al. 2001):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium* (based on CT scan), *Jeholodens* (based on CT scan), *Ornithorhynchus*, cimolodontans;

(1) Present: *Vincelestes* (Rougier et al. 1996a), *Didelphis* (Meng and Fox 1995a), *Erinaceus*, *Eomaia*, *Prokennalestes*;

(?) Not preserved or unknown (in the intact specimens): *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Gobiconodon*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Asioryctes*, *Ukhaatherium*, *Daulestes*, *Zalambdalestes*, *Kennalestes*.

200. Crista interfenestralis (Rougier et al. 1996a):

(0) Horizontal, broad, and extending to the base of the paroccipital process: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*; plagiaulacidans;

(1) Vertical, delimiting the back of the promontorium: cimolodontans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Didelphis*, *Asiatherium*, *Pucadelphys*, *Erinaceus*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*;

(2) Horizontal, narrow, and connecting to the caudal tympanic process: *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens* (not exposed), *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Eomaia*, *Daulestes*, *Montanalestes*, *Cimolestes*, *Gypsonictops*.

201. Post-promontorial tympanic recess (Rougier et al. 1996a):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, plagiaulacidans, cimolodontans;

(1) Present: *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Prokennalestes*, *Zalambdalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Murtoilestes*, *Montanalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

202. Caudal tympanic process of the petrosal (Rougier et al. 1996a):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, plagiaulacidans;

(1) Present: *Zhangheotherium*, *Vincelestes*, *Asiatherium*, *Didelphis*, *Pucadelphys*, *Deltatheridium*;

(2) Present and notched (after Wible 1990): *Erinaceus*, *Asioryctes*, *Kennalestes*, *Ukhaatherium*, *Zalambdalestes*;

(0/1) Polymorphic: cimolodontans (present in some, but not all Cretaceous cimolodontans), *Prokennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Daulestes*, *Montanalestes*; unknown: *Jeholodens*, *Murtoilestes*, *Cimolestes*, *Gypsonictops*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*.

203. Petrosal - Tympanic process (sensu Kielan-Jaworowska 1981):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*;

(1) Present: *Asioryctes*, *Ukhaatherium*, *Zalambdalestes*, *Kennalestes*, *Erinaceus*.
(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*,
Jeholodens, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Asiatherium*,
Montanalestes, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Cimolestes*,
Gypsonictops.

204. Prootic canal (modified from Crompton and Sun 1985; Kielan-Jaworowska et al. 1986; Lucas and Luo 1993; Luo 1994; Wible and Hopson 1995; Rougier et al. 1996a):

(0) Absent: tritylodontids, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Protungulatum*,
Erinaceus;

(1) Present, vertical: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*,
Hadrocodium, *Jeholodens*, *Priacodon*, plagiaulacidans, cimolodontans,
Zhangheotherium, *Vincelestes*, *Ornithorhynchus*, *Prokennalestes*, *Aspanlestes*,
Eoungulatum;

(2) Present, horizontal and reduced: *Deltatheridium*, *Pucadelphys*, *Didelphis*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*,
Gobiconodon, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*,
Eomaia, *Montanalestes*, *Murtoilestes*, *Cimolestes*, *Gypsonictops*; unknown: *Daulestes*,
Ukhaatherium.

205. Lateral trough floor anterior to the tympanic aperture of the prootic canal and/or the primary facial foramen (modified from Lucas and Luo 1993; Luo 1994):

(0) Open lateral trough but no bony floor: tritylodontids (tritylodontids lack the prootic canal; the primary facial foramen is used as a landmark for assessment of the lateral trough floor);

(1) Present: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*,
Ornithorhynchus, *Priacodon*, *Gobiconodon*, plagiaulacidans, cimolodontans,
Zhangheotherium, *Vincelestes*;

(2) Lateral trough absent: *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*,
Erinaceus, *Asioryctes*, *Daulestes*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*; preserved but not exposed: *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

206. Anteroventral opening of the cavum epiptericum:

(0) Present: tritylodontids;

(1) Present with reduced size (due to the anterior expansion of the lateral trough floor): *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Ornithorhynchus*, *Vincelestes*;

(2) Present and partially enclosed by the petrosal: *Haldanodon*, *Gobiconodon*, plagiaulacidans, cimolodontans;

(3) Enclosed by both the alisphenoid and the petrosal: *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*;

(4) Present as large piriform fenestra: *Asioryctes*, *Ukhaatherium*, *Zalambdalestes*;

(3/4 polymorphic): *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Gypsonictops*, *Cimolestes*, *Protungulatum*; unknown: *Priacodon*, *Daulestes*, *Prokennalestes*.

207. Anterior lamina of the petrosal and ascending process of the alisphenoid and their relationships to the exit of mandibular branch (V3) of the trigeminal nerve;

(0) V3 trigeminal foramen at the suture of the alisphenoid ascending process and the anterior lamina of petrosal: *Haldanodon*;

(1) V3 trigeminal foramen within the enlarged anterior lamina of the petrosal: tritylodontids, *Megazostrodon*, *Priacodon* (anterior lamina is large, but V3 foramen is not preserved), *Ornithorhynchus*, *Vincelestes*;

(2) Double trigeminal foramina within the anterior lamina (foramina masticatorium vs. inferiorium) in addition to the trigeminal foramen at the anterior lamina border with the alisphenoid: *Sinoconodon*, *Morganucodon*, plagiaulacidans;

(3) V3 trigeminal foramen within the ascending process of the alisphenoid (or between it and squamosal): *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;

(2/3 polymorphic): state {2} for most cimolodontans, state {3} for *Lambdopsalis* (Miao 1988);

(?) Not preserved (or not exposed): *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Eomaia*, *Montanales*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Gypsonictops*, *Cimolestes*, *Protungulatum*; unknown: *Ukhaatherium*.

208. Quadrate ramus of the alisphenoid:

(0) Forming a rod overlapping with the anterior part of the lateral flange: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon* (Gow 1986), *Haldanodon*;

(1) Quadrate ramus absent: *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, plagiaulacidans, cimolodontans (from Hurum 1998a), *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Eomaia*, *Montanales*, *Murtoilestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

209. Orientation of the anterior part of the lateral flange (modified from Luo 1994; Rougier et al. 1996a):

(0) Horizontal shelf: tritylodontids, *Sinoconodon*;

(1) Ventrally directed: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, *Vincelestes*;

(2) Medially directed and contacting the promontorium: plagiaulacidans, cimolodontans;
 (3) Vestigial or absent: *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Prokennalestes*, *Daulestes*, *Zalambdalestes*, *Kennalestes*;
 (?) Not exposed: *Haldanodon* (damaged on the specimens illustrated by Lillegraven and Krusat 1991), not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Zhangheotherium* (present but damaged on the type specimen), *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;
 unknown: *Ukhaatherium*.

210. Vertical component of the lateral flange ('L-shaped' and forming a vertical wall to the pterygoparooccipital foramen) (modified from Luo 1994):

(0) Present: tritylodontids, *Sinoconodon*;
 (1) Absent: *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, plagiaulacidans, cimolodontans, *Vincelestes*;
 (?) Not preserved: *Haldanodon* (damaged on the specimen illustrated by Lillegraven and Krusat 1991), *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Zhangheotherium* (damaged on the type specimen), *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable: *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Kennalestes*, *Eomaia*, *Prokennalestes*, *Zalambdalestes*; unknown: *Daulestes*, *Ukhaatherium*.

211. Vascular foramen in the posterior part of the lateral flange (and anterior to the 'pterygoparooccipital or the ramus superior foramen'):

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Hadrocodium*;
 (1) Absent: *Ornithorhynchus*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Kennalestes*, *Prokennalestes*, *Daulestes*, *Zalambdalestes*;
 (0/1 polymorphic) *Vincelestes*;

(?) Uncertain: *Megazostrodon*, *Haldanodon* (unknown due to damage in the relevant area on the specimen illustrated by Lillegraven and Krusat 1991); not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Protungulatum*; unknown: *Ukhaatherium*.

212. Relationship of the petrosal lateral flange to the crista parotica (or the anterior paroccipital process that bears the crista) (modified from Rougier et al. 1996a: character 30):

(0) Widely separated: tritylodontids, *Sinoconodon*;

(1) Narrowly separated: *Morganucodon*, *Megazostrodon*, *Priacodon*;

(2) Continuous bone formed by petrosal: *Hadrocodium*, *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Vincelestes*;

(?) Uncertain: *Haldanodon* (damaged on the specimens illustrated by Lillegraven and Krusat 1991); not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable (the lateral flange of the petrosal is reduced to absent): *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Eomaia*, *Asioryctes*, *Prokennalestes*, *Daulestes*, *Zalambdalestes*, *Kennalestes*; unknown: *Ukhaatherium*.

213. Morphology of the pterygoparoccipital foramen (for the ramus superior of the stapedia artery):

(0) Laterally open notch: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Priacodon*;

(1) Foramen enclosed by the petrosal or squamosal: *Hadrocodium*, *Ornithorhynchus*, cimolodontans, *Zhangheotherium*, *Vincelestes* ('ascending canal' of Rougier et al. 1992), *Erinaceus*, *Asioryctes*, *Prokennalestes*, *Zalambdalestes*;

(2) Absent: *Deltatheridium*, *Didelphis*, *Pucadelphys*;

(?) Not preserved: *Haldanodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Asiatherium*, *Daulestes*, *Ukhaatherium*, *Kennalestes*.

214. Position of the pterygoparoccipital foramen relative to the fenestra vestibuli (adapted from Wible et al. 1995):

(0) Posterior or lateral to the level of the fenestra vestibuli: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, *Zhangheotherium*;

(1) Anterior to the level of the fenestra vestibuli: *Vincelestes*, *Erinaceus*, *Asioryctes*, *Prokennalestes*, *Zalambdalestes*;

(0/1 polymorphic): cimolodontans;

(?) Not applicable: *Deltatheridium*, *Pucadelphys*, *Didelphis*; not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, plagiaulacidans, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Daulestes*, *Ukhaatherium*.

215. “Bifurcation of the paroccipital process” – presence vs. absence (this is modified from the character used in several previous studies):

(0) Bifurcation absent: *Hadrocodium*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Prokennalestes*, *Erinaceus*, *Kennalestes*, *Asioryctes*, *Zalambdalestes*;

(1) Bifurcation present: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

216. Posterior paroccipital process of the petrosal:

(0) No ventral projection below the level of its surrounding structures: tritylodontids, *Sinoconodon*, *Haldanodon* (posteromedial condyle of main body of crista parotica, as described by Lillegraven and Krusat 1991), *Hadrocodium*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*;

(1) Projecting below the surrounding structures: *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Daulestes*; unknown: *Ukhaatherium*.

217. Morphological differentiation of the anterior paroccipital region:

(0) Anterior paroccipital is bulbous and distinctive from the surrounding structures: tritylodontids, *Sinoconodon*;

(1) Anterior paroccipital region has a distinct crista parotica: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Daulestes*, *Asioryctes*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Daulestes*; unknown: *Ukhaatherium*.

218. Epitympanic recess lateral to the crista parotica:

(0) Absent: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*;

(1) Present: *Hadrocodium*, *plagiaulacidans*, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*, *Daulestes*;
 (0/1 polymorphic) cimolodontans (Rougier et al. 1996a);
 (?) Not applicable for those taxa in which the crista parotica is not differentiated: tritylodontids, *Sinoconodon*; not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

219. Relationship of the squamosal to the paroccipital process (modified from Luo 1989; Rougier et al. 1996a, character 23):

(0) Squamosal covers the entire paroccipital region: *Sinoconodon*;
 (1) No squamosal cover on the anterior paroccipital region: tritylodontids, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *plagiaulacidans*, cimolodontans;
 (2) Squamosal covering a part of the paroccipital region, but not on the crista parotica (the squamosal wall and the crista parotica are separated by the epitympanic recess): *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

220. Medial process of the squamosal reaching toward the tympanic cavity (Muizon 1994):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Jeholodens*, *plagiaulacidans*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Zalambdalestes*;

(1) Present: *Didelphis*, *Pucadelphys*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Cimolestes*, *Gypsonictops*, *Aspanlestes*, *Eoungulatum*, *Protungulatum*; unknown: *Ukhaatherium*.

221. Stapedial artery sulcus on the petrosal (Wible 1990; Rougier et al. 1998):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, *Zhangheotherium*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Aspanlestes*, *Eoungulatum*;

(1) Present: *Vincelestes* (Rougier et al. 1992), *Prokennalestes*, *Kennalestes*, *Daulestes*, *Asioryctes*, *Zalambdalestes*, *Protungulatum*, *Erinaceus*;

(0/1 polymorphic) cimolodontans (conditions are variable);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, plagiaulacidans, *Henkelotherium*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*; unknown: *Ukhaatherium*.

222. Transpromontorial sulcus for internal carotid artery on pars cochlearis (Wible 1987; Rougier et al. 1998):

(0) Absent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Asioryctes*, *Zalambdalestes*, *Aspanlestes*, *Eoungulatum*, *Kennalestes*;

(1) Present: *Vincelestes*, *Erinaceus*, *Daulestes*, *Prokennalestes*, *Protungulatum*;

(0/1 polymorphic) cimolodontans;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Cimolestes*, *Gypsonictops*; not applicable: tritylodontids (promontorium is absent because the pars cochlearis is not exposed externally); unknown: *Ukhaatherium*.

223. Bullar process of the alisphenoid:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Erinaceus*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Pucadelphys* (coded after Muizon 1994; Marshall and Muizon 1995);

(1) Present: *Asiatherium*, *Didelphis*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Priacodon*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*,.

224. Hypotympanic recess in the junction of the alisphenoid, squamosal, and petrosal (Muizon 1994):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, plagiaulacidans, cimolodontans, *Gobiconodon*, *Zhangheotherium*, *Vincelestes*, *Erinaceus*, *Asioryctes*, *Daulestes*, *Zalambdalestes*, *Kennalestes*;

(1) Present: *Asiatherium*, *Didelphis*, *Pucadelphys* (coded from a depression posteromedial to the foramen ovale, Marshall and Muizon 1995: fig. 18);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Priacodon*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Deltatheridium*, *Montanalestes*, *Eomaia*, *Prokennalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

225. Separation of the fenestra cochleae from the jugular foramen:

(0) Within the same depression: tritylodontids, *Ornithorhynchus*;

(1) Separate (do not share the same depression): *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Prokennalestes*, *Zalambdalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

226. Channel of the perilymphatic duct (Zeller 1989; Wible and Hopson 1993; Rougier et al. 1996a: division of characters modified to suit this study):

(0) Open channel and sulcus: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, plagiaulacidans;

(1) Channel partially or fully enclosed: *Haldanodon*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Eomaia*, *Prokennalestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(0/1) cimolodontans (cimolodontans may have open or partially enclosed perilymphatic channel, but this group never develops fully enclosed channel, polymorphic conditions following Rougier et al. 1996a);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Daulestes*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

227. Relationship of the jugular foramen to the opening of the inferior petrosal sinus (Rougier et al. 1998, character 150)

(0) Confluent: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Priacodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Erinaceus*,

(1) Separate: *Deltatheridium*, *Pucadelphys*, *Didelphis*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Prokennalestes*, *Murtoilestes*, *Eomaia*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Gypsonictops*, *Cimolestes*,

Protungulatum; unknown: *Ukhaatherium*; not applicable: tritylodontids, *Ornithorhynchus*.

228. Stapedial muscle fossa (modified from Rowe 1988; Wible 1991; Luo 1994; Rougier et al. 1996a):

(0) Absent: *Ornithorhynchus*;

(1) Present and in alignment with the crista interfenestralis: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*;

(2) Present and lateral to the crista interfenestralis: *Priacodon*, plagiaulacidans, cimolodontans, *Zhangheotherium*;

(3) Present, lateral to crista interfenestralis and twice the size of the fenestra vestibuli: *Vincelestes*, *Erinaceus*, *Asioryctes*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*;

(4) Present, lateral to crista interfenestralis, shallow and small: *Deltatheridium*, *Pucadelphys*, *Didelphis*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Daulestes*, *Ukhaatherium*.

229. Shape of the fenestra vestibuli (defined as the articulating rim for the stapedial footplate, not the larger depression in which the fenestra vestibuli is located; Archibald 1979; modified by many subsequent studies):

(0) Rounded: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*;

(1) Oval: *Eomaia* (based on the cast of inner ear), *Prokennalestes* (Wible et al. 2001), *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Protungulatum*, *Erinaceus*, *Aspanlestes*, *Eoungulatum* (*Aspanlestes* and *Eoungulatum* are coded from the “zhelestid petrosals” from the same locality, described in Supplementary Information Page 15 of Archibald et al. 2001);

(0/1 polymorphic): cimolodontans (variable among different taxa: Kielan-Jaworowska et al. 1986; Miao 1988; Luo 1989);

(?) Not preserved, or not exposed: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Cimolestes*, *Gypsonictops*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*; unknown: *Daulestes*, *Ukhaatherium*.

230. Hypoglossal foramen (Lucas and Luo 1993; as modified by Rougier et al. 1996a):

(0) Indistinct, either confluent with the jugular foramen or sharing a depression with the jugular foramen: tritylodontids (confluent), *Ornithorhynchus*;

(1) Separated from the jugular foramen: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Asioryctes*, *Zalambdalestes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*; unknown: *Daulestes*, *Ukhaatherium*.

Incus (Quadrate) Characters (8 Characters)

231. Geometry (shape) of the incudo-malleal contact (Zeller 1993; Luo and Crompton 1994; Meng and Wyss 1995):

(0) Trochlear (convex and cylindrical) surface of the incus: tritylodontids, *Morganucodon*, *Megazostrodon* (based on an isolated quadrate), *Haldanodon* (inferred from the articulating facet of articular, Lillegraven and Krusat 1991);

(1) Trough or saddle-shaped contact on the incus: *Sinoconodon*, *Didelphis*, *Erinaceus*;

(2) Flat surface (following Zeller 1993; Meng and Wyss 1995): cimolodontans, *Ornithorhynchus*;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Zalambdalestes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

232. Alignment of the incus and malleus (Zeller 1989, 1993; Meng and Wyss 1995; Hurum et al. 1996; as modified by Rougier et al. 1996b) by the ‘center of mass’:

(0) Posterior-anterior (Luo and Crompton 1994): tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon* (inferred from the articulating facet of articular, Lillegraven and Krusat 1991);

(1) Posterolateral to anterior medial: *Didelphis*, *Erinaceus*, *Daulestes*;

(2) Dorsoventral (Zeller 1993; Meng and Wyss 1995; Hurum et al. 1996):

Ornithorhynchus, cimolodontans;

(?) Not preserved: *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Kennalestes*, *Zalambdalestes*, *Asioryctes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

233. Presence of a quadrate/incus neck (separation of the dorsal plate and the trochlea; this represents the differentiation between the ‘body’ and crus brevis of the incus) (distributions modified from Luo 1994; Luo and Crompton 1994):

(0) Absent: tritylodontids, *Sinoconodon*;

(1) Present: *Morganucodon*, *Megazostrodon*, *Didelphis*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*,

plagiaulacidans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable: cimolodontans (Hurum et al. 1995, 1996), *Ornithorhynchus*, *Zalambdalestes*.

234. Dorsal plate (= crus brevis) of the quadrate/incus:

(0) Broad plate: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*;

(1) Pointed triangle: *Didelphis*, *Erinaceus*;

(2) Reduced: *Ornithorhynchus*, *Jeholodens*, cimolodontans;

(?) Not preserved: *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Kennalestes*, *Zalambdalestes*, *Asioryctes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

235. Incus - angle of the crus brevis to crus longum of the incus (this is equivalent to the angle between the dorsal plate and the stapedia process of the quadrate, modified from Hurum et al. 1996):

(0) Alignment of the stapedia 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): tritylodontids,

Sinoconodon, *Morganucodon*;

(1) Perpendicular or acute angle of the crus brevis and crus longum (A-shaped incus of Hurum et al. 1996; Rougier et al. 1996b): *Ornithorhynchus* (assuming the top of the flat 'T' is homologous to crus brevis, see Zeller 1993), *Jeholodens*, cimolodontans,

Didelphis, *Erinaceus*;

(?) Unknown: *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*,

Deltatheridium, *Asiatherium*, *Pucadelphys*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Kennalestes*, *Daulestes*, *Zalambdalestes*, *Asioryctes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

236. Primary suspension of the incus/quadrato on the basicranium:

(0) By squamosal and quadratojugal: tritylodontids, *Sinoconodon* (by squamosal only);

(1) By petrosal (either by the preserved direct contact of incus, or by the inference from the presence of a well defined crista parotica): *Morganucodon*, *Megazostrodon*,

Haldanodon (no squamosal pit for quadrato, Lillegraven and Krusat 1991),

Hadrocodium (inferred from the crista parotica), *Ornithorhynchus*, *Priacodon*,

plagiaulacidans, cimolodontans, *Zhangheotherium* (the incus is not preserved; its suspension structure inferred from the correlated epitympanic features), *Vincelestes* (incus not preserved, its suspension structure inferred to the epitympanic features),

Deltatheridium, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Asioryctes*, *Daulestes*,

Zalambdalestes, *Erinaceus*, *Prokennalestes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*,

Gobiconodon, *Jeholodens*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*,

Eomaia, *Montanalestes*, *Murtoilestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*,

Cimolestes, *Gypsonictops*, *Protungulatum*.

237. Morphology of the stapes (descriptive terms modified from Novacek and Wyss 1986b; Meng 1992; Hurum et al. 1995; Rougier et al. 1996b):

(0) Columniform–macroperforate: tritylodontids, *Sinoconodon* (Luo and Crompton, unpublished data), *Morganucodon*, *Haldanodon* (tentative interpretation; *Haldanodon* has preserved the footplate and proximal parts of the crura, so it can not be ruled out that it could be character state 3);

(1) Columelliform–imperforate (or microperforate): *Ornithorhynchus*;

(2) Bicurrate–perforate: *Didelphis*, *Erinaceus* (Doran 1878);

(1/2 polymorphic): 1 for cimolodontans (most djadochtatherians and *Lambdopsalis*), 2 for *Kryptobaatar*;

(?) Not preserved: *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Prokennalestes*, *Asioryctes*, *Daulestes*, *Eomaia*, *Montanalestes*, *Murtoilestes* *Ukhaatherium*, *Zalambdalestes*, *Kennalestes*, *Asioryctes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

238. Ectotympanic (applicable to those taxa with the ectotympanic suspended in the basicranium, not on the mandible):

(0) Ring-like: cimolodontans, *Ornithorhynchus*, *Didelphis*;

(1) Ectotympanic expanded laterally: *Daulestes*, *Asioryctes*, *Zalambdalestes*, *Kennalestes*, *Erinaceus*;

(?) Not applicable: tritylodontids, *Sinoconodon*, *Morganucodon*; not preserved: *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Asiatherium*, *Montanalestes*, *Prokennalestes*, *Murtoilestes*, *Eomaia*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Palatal, Orbital and Zygomatic Characters (11 characters)

239. Bony secondary palate:

(0) Ending anterior to the posterior end of the tooth row: tritylodontids, plagiaulacidans, cimolodontans;

(1) Level with the posterior end of the tooth row: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Vincelestes*, *Zalambdalestes*;

(2) Extending posterior to the tooth row: *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, *Priacodon*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Daulestes*, *Asioryctes*, *Zalambdalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Daulestes*, *Kennalestes*.

240. Pterygopalatine ridges:

(0) Present: tritylodontids, *Sinoconodon*, *Morganucodon*, plagiaulacidans, cimolodontans;

(1) Absent: *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Daulestes*, *Zalambdalestes*, *Kennalestes*, *Asioryctes*, *Erinaceus*;

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

241. Transverse process of the pterygoid:

(0) Present and massive (see below the polymorphic states):

(1) Present but reduced (as the hamulus): *Sinoconodon*, *Morganucodon*, *Megazostrodon* (Gow 1986: fig. 5), *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Daulestes*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;

(2) Greatly reduced or absent: *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, plagiaulacidans;

(0/1 polymorphic) tritylodontids (enlarged for some tritylodontids, see Sues 1985; but not in others, see Kemp 1983);

(1/2 polymorphic): cimolodontans (present in *Kryptobaatar*, absent in others, Wible and Rougier 2000).

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*,

Kielantherium, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

242. Overhanging roof of the orbit:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Ornithorhynchus*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;

(1) Present, formed by the frontal: plagiaulacidans, cimolodontans;

(?) Not preserved: *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

243. Outline of the facial part of the lacrimal:

(0) Large, triangular and pointed anteriorly: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Gobiconodon*, *Eomaia*, *Daulestes*, *Zalambdalestes*, *Asioryctes*;

(1) Small and rectangular or crescentic, or absent: *Ornithorhynchus* (absent), plagiaulacidans (based on reconstruction by Hahn 1978), *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Erinaceus*;

(0/1 polymorphic) cimolodontans;

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Zhangheotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Murtoilestes*, *Ukhaatherium*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

244. Pila antotica:

(0) Present: tritylodontids, *Sinoconodon* (Luo and Crompton, unpublished data), *Morganucodon* (Crompton and Luo, unpublished data), *Haldanodon* (based on photos in

Lillegraven and Krusat 1991: fig. 15), cimolodontans (Hurum 1998a; Wible and Rougier 2000)

(1) Absent (in adult): *Hadrocodium* (based on CT scan), *Ornithorhynchus*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Prokennalestes*, *Zalambdalestes*, *Kennalestes*;

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Daulestes*, *Ukhaatherium*, *Asioryctes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

245. Frontal/alisphenoid contact (modified from Rowe 1988; Wible 1991; Luo 1994):

(0) Dorsal plate of alisphenoid contacting the frontal by the anterior corner: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon* (based on Lillegraven and Krusat 1991: fig. 15), *Hadrocodium*, *Vincelestes*;

(1) Dorsal plate of the alisphenoid has more extensive contact with the frontal (~50% of its dorsal border): *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*;

(2) Contact of alisphenoid and frontal absent: *Ornithorhynchus*, cimolodontans;

(?) Not applicable: *Ukhaatherium*; not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

246. Frontal-maxilla contact:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Deltatheridium*, *Eomaia*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(1) Present: *Pucadelphys*, *Didelphis*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Asiatherium*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

247. Separation of optic foramen from sphenoorbital fissure:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Ornithorhynchus*, plagiaulacidans, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*;

(1) Present: *Asioryctes*, *Zalambdalestes*, *Daulestes*, *Kennalestes*, *Erinaceus*;

(0/1 polymorphic): cimolodontans;

(?) Not preserved: *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Asiatherium*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

248. Jugal on the zygoma (Hopson et al. 1986):

(0) Anterior part of the jugal extends to the facial part of the maxilla and forms a part of the anterior orbit: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Henkelotherium*, *Vincelestes*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;

(1) Anterior part of jugal does not reach the facial part of the maxilla and is excluded from the anterior orbit: *Ornithorhynchus*, *Jeholodens*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

249. 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) (distribution modified from Luo 1994):

(0) Between 10-20%: tritylodontids; *Haldanodon*, *Gobiconodon*, *Vincelestes*;
 (1) Between 5-7%: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Hadrocodium*, *Ornithorhynchus*, *Jeholodens*, plagiaulacidans, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Peramus*, *Kielantherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

Occipital and Other Skull characters (12 characters)

250. Anterior ascending vascular channel (for the arteria diploetica magna) in the temporal region:

(0) Open groove: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Ornithorhynchus*;
 (1) Partially enclosed in a canal: *Haldanodon*, *Hadrocodium*, *Priacodon*;
 (2) Completely enclosed in a canal or endocranial: *Gobiconodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Erinaceus* (as the endocranial part of the superior ramus of the stapedial artery), *Zalambdalestes*, *Asioryctes*, *Kennalestes*;
 (3) Absent: *Pucadelphys*, *Deltatheridium*, *Didelphis*;
 (?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Eomaia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Daulestes*, *Ukhaatherium*.

251. Lambdoidal crest:

(0) Crest overhanging the concave or straight supraocciput: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*, *Jeholodens*, *Vincelestes*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;

(1) Weak crest with convex supraocciput: *Hadrocodium*, *Ornithorhynchus*;
(0/1 polymorphic) cimolodontans (e.g., *Chulsanbaatar* and *Nemegtbaatar* 1; e.g., *Ptilodus* 0);
(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Daulestes*, *Ukhaatherium*.

252. Sagittal crest:

(0) Prominently developed: tritylodontids, *Sinoconodon*, *Gobiconodon*, *Vincelestes*, *Didelphis*;
(1) Weakly developed: *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Jeholodens*, *Asiatherium*, *Pucadelphys*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;
(2) Absent: *Hadrocodium*, *Ornithorhynchus*;
(1/2 polymorphic) cimolodontans;
(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

253. Tabular bone:

(0) Present: tritylodontids, *Sinoconodon* (Luo and Crompton, unpublished data);
(1) Absent: *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Jeholodens*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Didelphis*, *Asiatherium*, *Pucadelphys*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;
(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*,

Aspanlestes, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown:
Daulestes, *Ukhaatherium*.

254. Occipital slope:

(0) Occiput is sloping posterodorsally (or vertically oriented) from the occipital condyle: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Gobiconodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Zalambdalestes*;

(1) Occiput is 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): *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Erinaceus*, *Asioryctes*, *Kennalestes*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*; unknown: *Daulestes*, *Ukhaatherium*.

255. Foramina on the dorsal surface of the nasals:

(0) Absent: tritylodontids, *Sinoconodon*, *Jeholodens*, *Hadrocodium*, *Ornithorhynchus*, *Deltatheridium*, *Asiatherium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*;

(1) Present: *Morganucodon*, *Haldanodon*, cimolodontans, *Vincelestes*;

(0/1 polymorphic) plagiaulacidans;

(?) Not preserved: *Megazostrodon*, *Gobiconodon*, *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Prokennalestes*, *Montanalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

256. Septomaxilla (Wible et al. 1990):

(0) Present and with the ventromedial shelf: tritylodontids, *Sinoconodon*;

(1) Present and without ventromedial shelf: *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Jeholodens*, *Gobiconodon*, *Ornithorhynchus* (fused to the premaxillary secondarily, Wible et al. 1990), *Vincelestes*;

(2) Absent: plagiaulacidans, cimolodontans, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

257. Internarial process of premaxilla:

(0) Present: tritylodontids (Sues 1986), *Sinoconodon* (Crompton and Luo 1993), *Morganucodon*, *Haldanodon* (Lillegraven and Krusat 1991);

(1) Absent: plagiaulacidans, cimolodontans, *Ornithorhynchus*, *Vincelestes*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;

(?) Not preserved: *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Eomaia*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*, *Daulestes*.

258. Facial part of premaxilla borders on the nasal:

(0) Absent: *Sinoconodon*, *Morganucodon*, *Haldanodon*, *Hadrocodium*, *Gobiconodon*, *Jeholodens*, *Ornithorhynchus* (following Wible et al. 1990 to regard the ‘embryonic’ septomaxillary as fused to ‘embryonic premaxillary’ in adult), *Vincelestes*;

(1) Present: plagiaulacidans, cimolodontans, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Eomaia*, *Erinaceus*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*;

(0/1 polymorphic) tritylodontids (*Kayentatherium* 0: Sues 1986; *Bocatherium* 1: Hopson 1994);

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

259. Premaxilla – palatal process relative to the canine alveolus:

(0) Does not reach to the level of the canine alveolus: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon*, *plagiaulacidans*, *Priacodon*, *Vincelestes*, *Asioryctes*, *Zalambdalestes*, *Kennalestes*, *Erinaceus*;

(1) Reaches the level of the canine alveolus: *Deltatheridium*, *Pucadelphys*, *Didelphis*;

(?) Not preserved (not exposed): *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, cimolodontans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Kokopellia*, *Asiatherium*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; not applicable: *Ornithorhynchus*, cimolodontans; unknown: *Ukhaatherium*.

260. Ossified ethmoidal cribriform plate of the nasal cavity:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon* (Lillegraven and Krusat 1991 reported the presence of only a fragment ethmoid), *Hadrocodium*, *Ornithorhynchus*, cimolodontans (Hurum 1998a);

(1) Present: *Didelphis*, *Erinaceus*;

(?) Unknown: *Megazostrodon*, *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *plagiaulacidans*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Vincelestes*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*; unknown: *Ukhaatherium*, *Zalambdalestes*, *Daulestes*, *Asioryctes*, *Kennalestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Note: Zeller (1989) documented a cartilaginous cribriform plate in early ontogenetic stage of *Ornithorhynchus* but it is secondarily lost in adults. Zeller (1988, 1989) considered the absence of the ossified cribriform plate in adult *Ornithorhynchus* to be a secondary condition of monotremes due to the aquatic adaptation of the platypus. *Tachyglossus* has a well-developed cribriform plate. Miao (1988), Hurum (1994), and Wible and Rougier (2000) have shown that this structure is absent in various cimolodontans. The unpublished serial sectioning data (Luo et al) show no sign of the cribriform plate in *Yunnanodon*, *Sinoconodon*, and *Morganucodon*.

261. Posterior excavation of the nasal cavity into the bony sphenoid complex (modified from Hurum 1994; Luo 1997; Wible and Rougier 2000):

(0) Absent: *Ornithorhynchus*, *Haldanodon*;

(1) Present: tritylodontids (Luo 1997), *Sinoconodon*, *Morganucodon*;

(2) Present and partitioned from the nasal cavity: plagiaulacidans (inferred from Hahn's 1981 illustration), cimolodontans (following Hurum 1994), *Didelphis*, *Pucadelphys*, *Erinaceus*;

(?) Not preserved: *Megazostrodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*; unknown: *Ukhaatherium*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Note: This character is defined as a blind space in the ethmoido-sphenoid complex that opens into the nasal cavity anteriorly; it can be considered to be the posterior extension of the nasal cavity, or a precursor to the sphenoid sinus; the posterior extension of nasal cavity can be transformed into the sphenoidal sinus if the space is partially partitioned from the nasal cavity proper.

Cranial Vault and Brain Endocast Characters (6 characters)

262. External bulging of the braincase in the parietal region:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Gobiconodon*;

(1) Expanded (the parietal part of the cranial vault is wider than the frontal part, but expansion does not extend to the lambdoidal region): *Jeholodens*, *Priacodon*, *Vincelestes*, *Didelphis*, *Pucadelphys*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*;

(2) Greatly expanded (expansion of cranial vault extends to the lambdoidal region): *Hadrocodium*, *Ornithorhynchus*, *Asiatherium*, *Daulestes*, *Erinaceus*;

(1/2 polymorphic): cimolodontans;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Kielantherium*, *Deltatheridium*, *Kokopellia*, *Prokennalestes*, *Eomaia*, *Montanalestes*, *Murtoilestes*, , *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

263. Anterior expansion of the vermis (central lobe of the cerebellum):

(0) Absent: tritylodontids, *Sinoconodon* (based on Luo and Crompton, unpublished data), *Morganucodon*, *Didelphis*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Erinaceus*;

(1) Present, covers and conceals the mesencephalon (midbrain) on the endocast (= the cryptomesencephalic condition of Kielan-Jaworowska 1997): *Ornithorhynchus*, cimolodontans;

(?) Not preserved: *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Priacodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

264. Overall size of the vermis:

(0) Small: *Sinoconodon*, *Morganucodon*;

(1) Enlarged: *Ornithorhynchus*, cimolodontans, *Didelphis*, *Asioryctes*, *Kennalestes*, *Zalambdalestes*, *Erinaceus*.

(?) Not preserved: tritylodontids, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

265. Lateral cerebellar hemisphere (excluding the paraflocculus):

(0) Absent: tritylodontids (based on Kühne 1956), *Sinoconodon*, *Morganucodon*, cimolodontans;

(1) Present: *Hadrocodium*, *Ornithorhynchus*, *Didelphis*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Erinaceus*;

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*; unknown: *Ukhaatherium*.

266. External division on the endocast between the olfactory lobe and the cerebral hemisphere (presence vs. absence of the circular sulcus that defines the external aspect of the olfactory lobe):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*;

(1) Present: *Haldanodon* (described by Lillegraven and Krusat 1991 on the underside of the frontal bone), *Hadrocodium*, *Ornithorhynchus*, cimolodontans, *Didelphis*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Erinaceus*;

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Asiatherium*, *Kokopellia*,

Pucadelphys, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Daulestes*, *Prokennalestes*;
unknown: *Ukhaatherium*.

267. Anterior expansion of the cerebral hemisphere:

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, *Haldanodon* (inferred from the olfactory demarcation on the frontal);

(1) Present: *Hadrocodium*, *Ornithorhynchus*, cimolodontans, *Didelphis*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Erinaceus*;

(?) Not preserved: *Megazostrodon*, *Shuotherium*, *Ausktribosphenos*, *Ambondro*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*;
unknown: *Ukhaatherium*.

268. Expansion of the posterior cerebral hemisphere (for each hemisphere, not the combined width of the posterior hemispheres):

(0) Absent: tritylodontids, *Sinoconodon*, *Morganucodon*, cimolodontans;

(1) Present: *Hadrocodium*, *Ornithorhynchus*, *Didelphis*, *Zalambdalestes*, *Asioryctes*, *Kennalestes*, *Erinaceus*;

(?) Not preserved: *Haldanodon*, *Megazostrodon*, *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Jeholodens*, *Gobiconodon*, *Priacodon*, plagiaulacidans, *Zhangheotherium*, *Henkelotherium*, *Peramus*, *Vincelestes*, *Kielantherium*, *Deltatheridium*, *Asiatherium*, *Kokopellia*, *Pucadelphys*, *Montanalestes*, *Murtoilestes*, *Eomaia*, *Prokennalestes*, *Daulestes*, *Ukhaatherium*, *Aspanlestes*, *Eoungulatum*, *Cimolestes*, *Gypsonictops*, *Protungulatum*.

Optional character: this character is parsimoniously uninformative for our current dataset. It is listed here for the purpose of documenting our interpretation of *Eomaia* on this character, but it is not used in our parsimony analysis.

(?)269. Enclosure of the geniculate ganglion by the bony floor of the petrosal (modified from Crompton and Sun 1985; Wible and Hopson 1993; Luo 1994; Rougier et al. 1996a):

(0) Absent: tritylodontids (with possible exception of *Oligokyphus*);

(1) Present: *Sinoconodon*, *Morganucodon*, *Megazostrodon*, *Haldanodon*, *Hadrocodium*, *Ornithorhynchus*, *Priacodon*, plagiaulacidans, cimolodontans, *Vincelestes*, *Deltatheridium*, *Pucadelphys*, *Didelphis*, *Erinaceus*, *Eomaia*, *Asioryctes*, *Kennalestes*, *Prokennalestes*, *Zalambdalestes*;

(0/1 polymorphic) *Protungulatum* (coded on the Bug Creek isolated petrosals in which this feature is variable);

(?) Not preserved: *Shuotherium*, *Ambondro*, *Ausktribosphenos*, *Bishops*, *Steropodon*, *Gobiconodon*, *Jeholodens*, *Zhangheotherium*, *Peramus*, *Henkelotherium*, *Kielantherium*, *Asiatherium*, *Kokopellia*, *Montanalestes*, *Murtoilestes*, *Aspanlestes*, *Cimolestes*, *Gypsonictops*; unknown: *Daulestes*, *Ukhaatherium*.

Part III. References to Supplementary Information

- Archibald, J. D. 1979. Oldest known eutherian stapes and a marsupial petrosal bone from the Late Cretaceous of North America. *Nature* 281, 669-670.
- Archibald, J. D. 1996. Fossil evidence for a Late Cretaceous origin of "hoofed" mammals. *Science* 272, 1150-1153.
- Archibald, J. D., Averianov, A. O. & Ekdale, E. G. 2001. Late Cretaceous relatives of rabbits, rodents, and other extant eutherian mammals. *Nature* 414, 62-65.
- Averianov, A. O. in press. Early Cretaceous symmetrodont mammal *Gobiotheriodon* and the systematics of Symmetrodonta. *Acta Palaeontologica Polonica*.
- Averianov, A. O. & Skutschas, P. P. 1999. Phylogenetic relationships within basal tribosphenic mammals. *Proceedings of the Zoological Institute, Russian Academy of Sciences* 281, 55-60.
- Averianov, A. O. & Skutschas, P. P. 2001. A new genus of eutherian mammal from the Early Cretaceous of Transbaikalia, Russia. *Acta Palaeontologica Polonica* 46, 431-436.
- Bonaparte, J. F. & Rougier, G. W. 1987. Mamíferos del Cretácico Inferior de Patagonia. *IV Congreso Latinoamericano de Paleontología* 1, 343-359
- Butler, P. M. 1997. An alternative hypothesis on the origin of docodont molar teeth. *Journal of Vertebrate Paleontology* 17, 435-439.
- Butler, P. M. 2000. Review of the early allotherian mammals. *Acta Palaeontologica Polonica* 45, 317-342.
- Cifelli, R. L. 1993. Theria of metatherian-eutherian grade and the origin of marsupials. In: F. S. Szalay, M. J. Novacek & M. C. McKenna (eds.), *Mammal Phylogeny: Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials*, 205-215. Springer-Verlag, New York.

- Clemens, W. A. 1979. Marsupialia. In: J. A. Lillegraven, Z. Kielan-Jaworowska & W. A. Clemens (eds.), *Mesozoic Mammals: The First Two-thirds of Mammalian History*, 192-220. University of California Press, Berkeley.
- Clemens, W. A. 1997. Characterization of enamel microstructure and application of the origins of prismatic structures in systematic analyses. In: W. v. Koenigswald & P. M. Sander (eds.), *Tooth Enamel Microstructure*, 267-280. A. A. Balkema, Rotterdam.
- Clemens, W. A. & Mills, J. R. E. 1971. Review of *Peramus tenuirostris*. *Bulletin of the British Museum (Natural History), Geology* 20, 89-113.
- Crompton, A. W. 1971. The origin of the tribosphenic molar. In: D. M. Kermack & K. A. Kermack (eds.), *Early Mammals*, 65-87. Zoological Journal of the Linnean Society 50, supplement 1, London.
- Crompton, A. W. 1972a. Evolution of the jaw articulation in cynodonts. In: K. A. Joysey & T. S. Kemp (eds.), *Studies in Vertebrate Evolution*, 231-253. Oliver & Boyd, Edinburgh.
- Crompton, A. W. 1972b. Postcanine occlusion in cynodonts and tritylodonts. *Bulletin of the British Museum (Natural History), Geology* 21, 30-71.
- Crompton, A. W. & Jenkins, F. A., Jr. 1967. American Jurassic symmetrodonts and Rhaetic "pantotheres". *Science* 155, 1006-1009.
- Crompton, A. W. & Luo, Z.-X. 1993. Relationships of the Liassic mammals *Sinoconodon*, *Morganucodon*, and *Dinnetherium*. In: F. S. Szalay, M. J. Novacek & M. C. McKenna (eds.), *Mammal Phylogeny: Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials*, 30-44. Springer-Verlag, New York.
- Crompton, A. W. & Kielan-Jaworowska, Z. 1978. Molar structure and occlusion in Cretaceous therian mammals. In: P. M. Butler & K. A. Joysey (eds.), *Studies in*

the Development, Function and Evolution of Teeth, 249-287. Academic Press, London.

- Crompton, A. W. & Sun, A.-L. 1985. Cranial structure and relationships of the Liassic mammal *Sinoconodon*. *Zoological Journal of the Linnean Society* 85, 99-119.
- Evans, S. E. 1981. The postcranial skeleton of the Lower Jurassic eosuchian *Gephyrosaurus bridensis*. *Zoological Journal of Linnean Society* 73, 81-116.
- Flynn, J.J., Parrish, J.M., Rakotosamimanana, B., Simpson, W.F., and Wyss, A.E. 1999. A Middle Jurassic mammal from Madagascar. *Nature* 401: 57-60.
- Fosse, G., Kielan-Jaworowska, Z. & Skaale, S. G. 1985. The microstructure of tooth enamel in multituberculate mammals. *Palaeontology* 28, 438-449.
- Fox, R. C. 1975. Molar structure and function in the Early Cretaceous mammal *Pappotherium*: evolutionary implications for Mesozoic Theria. *Canadian Journal of Earth Sciences* 12, 412-442.
- Fox, R. C. & Meng, J. 1997. An X-radiographic and SEM study of the osseous inner ear of multituberculates and monotremes (Mammalia): implications for mammalian phylogeny and evolution of hearing. *Zoological Journal of the Linnean Society* 121, 249-291.
- Gambaryan, P. P. & Averianov, A. O. 2001. Femur of a morganucodontid mammal from the Middle Jurassic of central Russia. *Acta Palaeontologica Polonica* 46, 99-112.
- Gambaryan, P. P. & Kielan-Jaworowska, Z. 1995. Masticatory musculature of Asian taeniolabidid multituberculate mammals. *Acta Palaeontologica Polonica* 40, 45-108.
- Gambaryan, P. P. & Kielan-Jaworowska, Z. 1997. Sprawling versus parasagittal stance in multituberculate mammals. *Acta Palaeontologica Polonica* 42, 13-44.

- Gow, C. E. 1986. A new skull of *Megazostrodon* (Mammalia: Triconodonta) from the Elliot Formation (Lower Jurassic) of southern Africa. *Palaeontologia Africana* 26, 13-23.
- Grassé, P.-P. 1955. Ordre des Monotremes. In, Grassé, P.-P. (ed.), *Traité de Zoologie: Anatomie, Systématique, Biologie*. Tome XVII, Mammifères, 47-92.
- Hahn, G. 1981. Zum Bau der Schädel-Basis der Paulchoffatiidae (Multituberculata, Ober-Jura). *Senckenbergiana lethaea* 61, 227-245.
- Henkel, S. & Krusat, G. 1980. Die Fossil-lagerstätte in der Kohlengrube Guimarota (Portugal) und der erste Fuld eines Docodontiden-skelettes. *Berliner geowissenschaftliche Abhandlungen A* 20, 209-214.
- Hopson, J. A. 1994. Synapsid evolution and the radiation of non-eutherian mammals. In: R. S. Spencer (ed.) *Major Features of Vertebrate Evolution*, 190-219. The Paleontological Society, Knoxville.
- Hopson, J. A. & Crompton, A. W. 1969. Origin of mammals. In: T. Dobzhansky, M. K. Hecht & W. C. Steere (eds.), *Evolutionary Biology, volume 3*, 15-72. Appleton-Century-Crofts, New York.
- Hopson, J. A., Kielan-Jaworowska, Z. & Allin, E. F. 1989. The cryptic jugal of multituberculates. *Journal of Vertebrate Paleontology* 9, 201-209.
- Horovitz, I. 2000. The tarsus of *Ukhaatherium nessovi* (Eutheria, Mammalia) from the Late Cretaceous of Mongolia: an appraisal of the evolution of the ankle in basal therians. *Journal of Vertebrate Paleontology* 20, 547-560.
- Hu, Y.-M., Wang, Y.-Q., Li, C.-K. & Luo, Z.-X. 1998. Morphology of dentition and forelimb of *Zhangheotherium*. *Vertebrata Palasiatica* 36, 102-125.
- Hu, Y.-M., Wang, Y.-Q., Luo, Z.-X. & Li, C.-K. 1997. A new symmetrodont mammal from China and its implications for mammalian evolution. *Nature* 390, 137-142.

- Hurum, J. H. 1994. The snout and orbit of Mongolian multituberculates studied by serial sections. *Acta Palaeontologica Polonica* 39, 181-221.
- Hurum, J. H. 1998a. The braincase of two Late Cretaceous Asian multituberculates studied by serial sections. *Journal of Vertebrate Paleontology* 43, 21-52.
- Hurum, J. H. 1998b. The inner ear of two Late Cretaceous multituberculate mammals, and its implications for multituberculate hearing. *Journal of Mammalian Evolution* 5, 65-94.
- Hurum, J. H., Presley, R. & Kielan-Jaworowska, Z. 1995. Multituberculate ear ossicles. In: A.-L. Sun & Y. Wang (eds.), *Sixth Symposium on Mesozoic Terrestrial Ecosystems and Biota, Short Papers*, 243-246. China Ocean Press, Beijing.
- Hurum, J. H., Presley, R. & Kielan-Jaworowska, Z. 1996. The middle ear in multituberculate mammals. *Acta Palaeontologica Polonica* 41, 253-275.
- Jenkins, F. A., Jr. 1971. The postcranial skeleton of African cynodonts. *Peabody Museum of Natural History Bulletin* 36, 1-216.
- Jenkins, F. A., Jr. 1973. The functional anatomy and evolution of the mammalian humero-ulnar joint. *American Journal of Anatomy* 137, 281-296.
- Jenkins, F. A., Jr., Gatesy, S. M., Shubin, N. H. & Amaral, W. W. 1997. Haramiyids and Triassic mammalian evolution. *Nature* 385, 715-718.
- Jenkins, F. A., Jr. & Parrington, F. R. 1976. The postcranial skeletons of the Triassic mammals *Eozostrodon*, *Megazostrodon* and *Erythrotherium*. *Philosophical Transactions of the Royal Society of London* 273, 387-431.
- Jenkins, F. A., Jr. & Schaff, C. R. 1988. The Early Cretaceous mammal *Gobiconodon* (Mammalia, Triconodonta) from the Cloverly Formation in Montana. *Journal of Vertebrate Paleontology* 8, 1-24.

- Ji, Q., Luo, Z.-X. & Ji, S. 1999. A Chinese triconodont mammal and mosaic evolution of the mammalian skeleton. *Nature* 398, 326-330.
- Kemp, T. S. 1983. The relationships of mammals. *Zoological Journal of the Linnean Society* 77, 353-384.
- Kermack, K. A., Lee, A. J., Lees, P. M. & Mussett, F. 1987. A new docodont from the Forest Marble. *Zoological Journal of the Linnean Society* 89, 1-39.
- Kielan-Jaworowska, Z. 1977. Evolution of the therian mammals in the Late Cretaceous of Asia. Part II. Postcranial skeleton in *Kennalestes* and *Asioryctes*. *Palaeontologia Polonica* 37, 65-83.
- Kielan-Jaworowska, Z. 1981. Evolution of the therian mammals in the Late Cretaceous of Asia. Part IV. Skull structure in *Kennalestes* and *Asioryctes*. *Palaeontologia Polonica* 42, 25-78.
- Kielan-Jaworowska, Z. 1997. Characters of multituberculates neglected in phylogenetic analyses of early mammals. *Lethaia* 29, 249-266.
- Kielan-Jaworowska, Z. & Dashzeveg, D. 1989. Eutherian mammals from the Early Cretaceous of Mongolia. *Zoologica Scripta* 18, 347-355.
- Kielan-Jaworowska, Z. & Dashzeveg, D. 1998. Early Cretaceous amphilestid ("triconodont") mammals from Mongolia. *Acta Palaeontologica Polonica* 43, 413-438.
- Kielan-Jaworowska, Z. & Gambaryan, P. P. 1994. Postcranial anatomy and habits of Asian multituberculate mammals. *Fossils & Strata* 36, 1-92.
- Kielan-Jaworowska, Z. & Kermack, K. A. 1971. Therian and non-therian mammals. In: D. M. Kermack & K. A. Kermack (eds.), *Early Mammals*, 103-115. Zoological Journal of the Linnean Society 50, supplement 1, London.

- Kielan-Jaworowska, Z. & Qi, T. 1990. Fossorial adaptations of a taeniolabidoid multituberculate mammal from the Eocene of China. *Vertebrata Palasiatica* 28, 81-94.
- Kielan-Jaworowska, Z. & B. A. Trofimov. 1981. A new occurrence of Late Cretaceous eutherian mammal *Zalambdalestes*. *Acta Palaeontologica Polonica* 26, 3-7.
- Kielan-Jaworowska, Z., Crompton, A. W. & Jenkins, F. A., Jr. 1987. The origin of egg-laying mammals. *Nature* 326, 871-873.
- Kielan-Jaworowska, Z., Presley, R. & Poplin, C. 1986. The cranial vascular system in taeniolabidoid multituberculate mammals. *Philosophical Transactions of the Royal Society of London* 313, 525-602.
- Klima, M. 1973. Die Frühentwicklung des Schultergürtels und des Brustbeins bei den Monotremen (Mammalia: Prototheria). *Advances in Anatomy, Embryology and Cell Biology* 47, 1-80.
- Klima, M. 1987. Early development of the shoulder girdle and sternum in marsupials (Mammalia: Metatheria). *Advances in Anatomy, Embryology and Cell Biology* 109, 1-91.
- Krause, D. W. 1982. Jaw movement, dental function, and diet in the Paleocene multituberculate *Ptilodus*. *Paleobiology* 8, 265-281.
- Krause, D. W. & Jenkins, F. A. Jr. 1983. The postcranial skeleton of North American multituberculates. *Bulletin of the Museum of Comparative Zoology* 150, 199-246.
- Krebs, B. 1991. Das Skelett von *Henkelotherium guimarotae* gen. et sp. nov. (Eupantotheria, Mammalia) aus dem Oberen Jura von Portugal. *Berliner geowissenschaftliche Abhandlungen A* 133, 1-110.
- Krusat, G. 1973. Beiträge zur Kimmeridge-Fauna der Kohlengrube Guimarota (Leira, Portugal): *Haldanodon exspectatus* Kühne and Krusat 1972 (Mammalia, Docodonta). *Memórias dos Serviços Geológicos de Portugal* 27, 1-79.

- Krusat, G. 1980. Contribuição para o conhecimento da fauna do Kimeridgiano da mina de lignito Guimarota (Leiria, Portugal). IV Parte. *Haldanodon exspectatus* Kühne & Krusat 1972 (Mammalia, Docodonta). *Memórias dos Serviços Geológicos de Portugal* 27, 1-79.
- Kühne, W. G. 1956. *The Liassic therapsid Oligokyphus*. 149 pp. British Museum (Natural History), London.
- Lewis, O. J. 1983. The evolutionary emergence and refinement of the mammalian pattern of foot architecture. *Journal of Anatomy* 137:21-45.
- Lillegraven, J. A. & Krusat, G. 1991. Cranio-mandibular anatomy of *Haldanodon exspectatus* (Docodonta; Mammalia) from the Late Jurassic of Portugal and its implications to the evolution of mammalian characters. *Contributions to Geology, University of Wyoming* 28, 39-138.
- Lucas, S. G. & Luo, Z.-X. 1993. *Adelobasileus* from the Upper Triassic of western Texas: the oldest mammal. *Journal of Vertebrate Paleontology* 13, 309-334.
- Luo, Z.-X. 1989. *Structure of the petrosal of Multituberculata (Mammalia) and the morphology of the molars of early arctocyonids*. Unpublished Ph.D. dissertation. 426 pp. University of California, Berkeley.
- Luo, Z.-X. 1994. Sister-group relationships of mammals and transformations of diagnostic mammalian characters. In: N. C. Fraser & H.-D. Sues (eds.), *In the Shadow of the Dinosaurs--Early Mesozoic Tetrapods*, 98-128. Cambridge University Press, Cambridge.
- Luo, Z.-X. 1997. Sphenoidal sinus in advanced and early mammals, and its implications on mammalian skull evolution. *Journal of Morphology* 232(3): 290. (Abstract to International Congress of Vertebrate Morphology V, Bristol, UK).
- Luo, Z.-X. 2001. Inner ear and its bony housing in tritylodonts and implications for evolution of mammalian ear. In: F. A. Jenkins, Jr., T. Owerkowicz & M. D. Shapiro (eds.), *Studies in Organismal and Evolutionary Biology in Honor of A. W.*

- Crompton, 81-97. *Bulletin of the Museum of Comparative Zoology* 156, Cambridge.
- Luo, Z.-X., Cifelli, R. L. & Kielan-Jaworowska, Z. 2001a. Dual origin of tribosphenic mammals. *Nature* 409, 53-57.
- Luo, Z.-X. & Crompton, A. W. 1994. Transformation of the quadrate (incus) through the transition from non-mammalian cynodonts to mammals. *Journal of Vertebrate Paleontology* 14, 341-374.
- Luo, Z.-X., Crompton, A. W. & Lucas, S. G. 1995. Evolutionary origins of the mammalian promontorium and cochlea. *Journal of Vertebrate Paleontology* 15, 113-121.
- Luo, Z.-X., Crompton, A. W. & Sun, A.-L. 2001b. A new mammal from the Early Jurassic and evolution of mammalian characteristics. *Science* 292, 1535-1540.
- Luo, Z.-X., Kielan-Jaworowska, Z. & Cifelli, R. L. 2002. In quest for a phylogeny of Mesozoic mammals. *Acta Palaeontologica Polonica* 47(1), 1-78.
- Marshall, L. G. & de Muizon, C. 1995. Part II: The skull. *In*: C. de Muizon, (ed.) *Pucadelphys andinus (Marsupialia, Mammalia) from the early Paleocene of Bolivia*, 21-90. Mémoires du Muséum national d'Histoire naturelle 165, Paris.
- Marshall, L. G. & Sigogneau-Russell, D. 1995. Part III: Postcranial skeleton. *In*: C. de Muizon, (ed.) *Pucadelphys andinus (Marsupialia, Mammalia) from the early Paleocene of Bolivia*, 91-164. Mémoires du Muséum national d'Histoire naturelle 165, Paris.
- McKenna, M. C. 1975. Toward a phylogenetic classification of the Mammalia. *In*: W. P. Luckett & F. S. Szalay (eds.), *Phylogeny of the Primates*, 21-46. Plenum Publishing Corporation, New York.
- McKenna, M. C. & Bell, S. K. 1997. *Classification of Mammals Above the Species Level*. 631 pp. Columbia University Press, New York.

- Meng, J. 1992. The stapes of *Lambdopsalis bulla* (Multituberculata) and transformational analyses on some stapedial features in Mammaliaformes. *Journal of Vertebrate Paleontology* 12, 459-471.
- Meng, J. & Fox, R. C. 1995. Osseous inner ear structures and hearing in early marsupials and placentals. *Zoological Journal of the Linnean Society* 115, 47-71.
- Meng, J. & Miao, D. 1992. The breast-shoulder apparatus of *Lambdopsalis bulla* (Multituberculata) and its systematic and functional implications. *Journal of Vertebrate Paleontology* 12, 43A.
- Meng, J. & Wyss, A. R. 1995. Monotreme affinities and low-frequency hearing suggested by multituberculate ear. *Nature* 377, 141-144.
- Miao, D. 1988. Skull morphology of *Lambdopsalis bulla* (Mammalia, Multituberculata). *Contributions to Geology, University of Wyoming, Special Paper* 4, 1-104.
- Muizon, C., de. 1994. A new carnivorous marsupial from the Palaeocene of Bolivia and the problem of marsupial monophyly. *Nature* 370, 208-211.
- Muizon, C., de. 1998. *Mayulestes ferox*, a borhyaenoid (Metatheria, Mammalia) from the early Palaeocene of Bolivia. Phylogenetic and palaeobiologic implications. *Geodiversitas* 20, 19-142.
- Novacek, M. J., Rougier, G. W., Wible, J. R., McKenna, M. C., Dashzeveg, D. & Horovitz, I. 1997. Epipubic bones in eutherian mammals from the Late Cretaceous of Mongolia. *Nature* 389, 483-486.
- Novacek, M. J. & Wyss, A. R. 1986b. Origin and transformation of the mammalian stapes. *Contributions to Geology, University of Wyoming, Special Paper* 3, 35-54.
- Parrington, F. R. 1973. The dentitions of the earliest mammals. *Zoological Journal of the Linnean Society* 52, 85-95.

- Parrington, F. R. 1978. A further account of the Triassic mammals. *Philosophical Transactions of the Royal Society of London B* 282, 177-204.
- Prothero, D. R. 1981. New Jurassic mammals from Como Bluff, Wyoming, and the interrelationships of non-tribosphenic Theria. *Bulletin of the American Museum of Natural History* 167, 277-326.
- Rich, T. H., Flannery, T. F., Trusler, P., Kool, L., van Klaveren, N. & Vickers-Rich, P. 2001a. A second placental mammal from the Early Cretaceous Flat Rocks site, Victoria, Australia. *Records of the Queen Victoria Museum* 110, 1-9.
- Rich, T. H., Vickers-Rich, P., Constantine, A., Flannery, T. F., Kool, L. & van Klaveren, N. 1997. A tribosphenic mammal from the Mesozoic of Australia. *Science* 278, 1438-1442.
- Rich, T. H., Vickers-Rich, P., Constantine, A., Flannery, T. F., Kool, L. & van Klaveren, N. 1999. Early Cretaceous mammals from Flat Rocks, Victoria, Australia. *Records of the Queen Victoria Museum* 106, 1-35.
- Rich, T. H., Vickers-Rich, P., Trusler, P., Flannery, T. F., Cifelli, R. L., Constantine, A., Kool, L. & van Klaveren, N. 2001b. Monotreme nature of the Australian Early Cretaceous mammal *Teinolophos trusleri*. *Acta Palaeontologica Polonica* 46, 113-118.
- Rougier, G. W. 1993. *Vincelestes neuquenianus Bonaparte (Mammalia, Theria) un primitivo mamífero del Cretácico Inferior de la Cuenca Neuquina*. Unpublished Ph.D. dissertation. 720 pp. Universidad Nacional de Buenos Aires, Buenos Aires.
- Rougier, G. W., Wible, J. R. & Hopson, J. A. 1992. Reconstruction of the cranial vessels in the Early Cretaceous mammal *Vincelestes neuquenianus*: implications for the evolution of the mammalian cranial system. *Journal of Vertebrate Paleontology* 12, 188-216.
- Rougier, G. W., Wible, J. R. & Hopson, J. A. 1996a. Basicranial anatomy of *Priacodon frutaensis* (Triconodontidae, Mammalia) from the Late Jurassic of Colorado, and

a reappraisal of mammaliaform interrelationships. *American Museum Novitates* 3183, 1-38.

- Rougier, G. W., Wible, J. R. & Novacek, M. J. 1996b. Middle-ear ossicles of *Kryptobaatar dashzevegi* (Mammalia, Multituberculata): implications for mammaliomorph relationships and evolution of the auditory apparatus. *American Museum Novitates* 3187, 1-43.
- Rougier, G. W., Wible, J. R. & Novacek, M. J. 1998. Implications of *Deltatheridium* specimens for early marsupial history. *Nature* 396, 459-463.
- Rowe, T. B. 1988. Definition, diagnosis, and origin of Mammalia. *Journal of Vertebrate Paleontology* 8, 241-264.
- Sander, P. M. 1997. Non-mammalian synapsid enamel and the origin of mammalian enamel prisms: the bottom-up perspective. In: W. v. Koenigswald & P. M. Sander (eds.), *Tooth Enamel Microstructure*, 41-62. A. A. Balkema, Rotterdam.
- Sereno, P. C. & McKenna, M. C. 1995. Cretaceous multituberculate skeleton and the early evolution of the mammalian shoulder girdle. *Nature* 377, 144-147.
- Sigogneau-Russell, D. 1999. Réévaluation des Peramura (Mammalia, Theria) sur la base de nouveaux spécimens du Crétacé inférieur d'Angleterre et du Maroc. *Geodiversitas* 21, 93-127.
- Sigogneau-Russell, D., Dashzeveg, D. & Russell, D. E. 1992. Further data on *Prokennalestes* (Mammalia, Eutheria inc. sed.) from the Early Cretaceous of Mongolia. *Zoologica Scripta* 21, 205-209.
- Simpson, G. G. 1925a. Mesozoic Mammalia. I. American triconodonts, part 1. *American Journal of Science* 10, 145-165.
- Simpson, G. G. 1925b. Mesozoic Mammalia. I. American triconodonts: part 2. *American Journal of Science* 10, 334-358.

- Simpson, G. G. 1928. *A Catalogue of the Mesozoic Mammalia in the Geological Department of the British Museum*. 215 pp. Trustees of the British Museum, London.
- Simpson, G. G. 1929. The dentition of *Ornithorhynchus* as evidence of its affinities. *American Museum Novitates* 390, 1-15.
- Sues, H.-D. 1985. The relationships of the Tritylodontidae (Synapsida). *Zoological Journal of the Linnean Society* 85, 205-217.
- Sues, H.-D. 1986. The skull and dentition of two tritylodontid synapsids from the Lower Jurassic of western North America. *Bulletin of the Museum of Comparative Zoology* 151, 217-268.
- Sun, A.-L. & Li, Y.-H. 1985. The postcranial skeleton of Jurassic tritylodonts from Sichuan Province. *Vertebrata Palasiatica* 23, 135-151.
- Szalay, F. S. 1994. *Evolutionary History of the Marsupials and an Analysis of Osteological Characters*. 481 pp. Cambridge University Press, Cambridge.
- Wible, J. R. 1987. The eutherian stapedia artery: character analysis and implications for superordinal relationships. *Zoological Journal of the Linnean Society* 91, 107-135.
- Wible, J. R. 1990. Petrosals of Late Cretaceous marsupials from North America and a cladistic analysis of the petrosal in therian mammals. *Journal of Vertebrate Paleontology* 10, 183-205.
- Wible, J. R. 1991. Origin of Mammalia: the craniodental evidence reexamined. *Journal of Vertebrate Paleontology* 11, 1-28.
- Wible, J. R. & Hopson, J. A. 1993. Basicranial evidence for early mammal phylogeny. In: F. S. Szalay, M. J. Novacek & M. C. McKenna (eds.), *Mammal Phylogeny: Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials*, 45-62. Springer-Verlag, New York.

- Wible, J. R., Miao, D. & Hopson, J. A. 1990. The septomaxilla of fossil and recent synapsids and the problem of the septomaxilla of monotremes and armadillos. *Zoological Journal of the Linnean Society* 98, 203-228.
- Wible, J. R. & Rougier, G. W. 2000. The cranial anatomy of *Kryptobaatar dashzevegi* (Mammalia, Multituberculata), and its bearing on the evolution of mammalian characters. *Bulletin of the American Museum of Natural History* 247, 1-124.
- Wible, J. R., Rougier, G. W., Novacek, M. J. & McKenna, M. C. 2001. Earliest eutherian ear region: a petrosal referred to *Prokennalestes* from the Early Cretaceous of Mongolia. *American Museum Novitates* 3322, 1-44.
- Wible, J. R., Rougier, G. W., Novacek, M. J., McKenna, M. C. & Dashzeveg, D. 1995. A mammalian petrosal from the Early Cretaceous of Mongolia: implications for the evolution of the ear region and mammalian relationships. *American Museum Novitates* 3149, 1-19.
- Wood, C. B. 2000. Tooth enamel microstructure in *Deltatheridium* (Metatheria, Late Cretaceous of Mongolia), with comparison to some other Mesozoic mammals. *Bulletin of the Paleontological Society of Korea, Special Publication* 4, 127-152.
- Wood, C. B., Dumont, E. R. & Crompton, A. W. 1999. New studies of enamel microstructure in Mesozoic mammals: a review of enamel prisms as a mammalian synapomorphy. *Journal of Mammalian Evolution* 6, 177-213.
- Wood, C. B. & Stern, D. N. 1997. The earliest prisms in mammalian and reptilian enamel. In: W. v. Koenigswald & P. M. Sander (eds.), *Tooth Enamel Microstructure*, 63-83. A. A. Balkema, Rotterdam.
- Woodburne, M. O. & Tedford, R. H. 1975. The first Tertiary monotreme from Australia. *American Museum Novitates* 2588, 1-11.
- Zeller, U. 1989. Die Entwicklung und Morphologie des Schädels von *Ornithorhynchus anatinus* (Mammalia: Prototheria: Monotremata). *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft* 545, 1-188.

- Zeller, U. 1993. Ontogenetic evidence for cranial homologies in monotremes and therians, with special reference to *Ornithorhynchus*. In: F. S. Szalay, M. J. Novacek & M. C. McKenna (eds.), *Mammal Phylogeny, Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials*, 95-107. Springer-Verlag, New York.
- Zhang, F.-K., Crompton, A. W., Luo, Z.-X. & Schaff, C. R. 1998. Pattern of dental replacement of *Sinoconodon* and its implications for evolution of mammals. *Vertebrata Palasiatica* 36, 197-217.

Part IV. PAUP Matrix, Search Settings and Results

Treatment of Characters

Ordered vs. unordered multi-state characters. We have run two separate searches with regards to ordered vs. unordered multi-state characters.

(1) Search with all multi-state characters run as unordered in searches. The strict consensus tree (Text-Fig. 6a.) from the unordered searches is our preferred tree, as unordered multi-state characters requires the fewest assumptions on the sequence and direction of character transformation. The search with all multi-state characters unordered has yielded 50 equally parsimonious trees; each tree has Tree Length = 919, Consistency index CI = 0.508, and Retention Index RI = 0.740 (details of the search is provided below).

For un-ordered multistate characters, the bootstrap 50% majority-rule consensus tree is less resolved than the strict consensus of the 50 most parsimonious and shortest trees. In the bootstrap tree, *Eomaia* is still a part of the eutherian clade, but the “asioryctitherians” are collapsed. Outside the therian crown group, the formerly pinnate clades of “eutricodonts” are also collapsed into a basal polytomy.

(2) The second search was to set 37 multi-state characters as ordered. These 37 multi-state characters have morphoclines or gradients that represent ordinal transformational sequences of character states. These characters are: 25, 30, 31, 34, 40-42, 44-47, 50-54, 57, 58, 62, 63, 65-69, 76-78, 81-83, 89, 90, 94, 95, 99, and 110. Searching with ordering of these multi-state characters is justified by our empirical anatomical assessment.

In the searches with the above 37 characters ordered, the strict consensus of the three equally parsimonious trees is presented below. Each of the three equally parsimonious trees has Tree Length = 953, Consistency index CI = 0.490, and Retention Index RI = 0.740 (Topology from these searches are provided below). If all multi-state characters were set as ordered in the searches, the topology in the trechnotherians, the therian crown group and eutherians are the same as the search with 37 ordered multi-state characters.

Therefore, our decision to make a sub-set of multi-state characters ordered did not introduce any bias in the tree topologies.

Both ordered and unordered searches have upheld our main phylogenetic conclusions that *Eomaia scansoria* is a eutherian, and that *Eomaia* is nested with the basal eutherians. Therefore permutation of character types for multi-state characters does not affect our main conclusions.

If all multi-state characters are unordered in searches, *Eomaia* is placed with *Murtoilestes* and *Prokennalestes* at the basal node of all eutherians in an unresolved multichotomy (Text-Fig. 6a; also see the PAUP search printouts below). However, *Eomaia*, *Murtoilestes*, and *Prokennalestes* form a clade if searches are ordered (either for the 37 ordinal transformation characters or for all of the multi-state characters). This clade would be more deeply nested within eutherians than in the trees from unordered searches. *Montanalestes* is the first divergent clade within Eutheria if searches are ordered (either for the 37 ordinal transformation characters or for all of the multi-state characters). The ordered searches also give a strong support for the clade of asioryctitherians by providing better resolution among the asioryctitherian taxa.

Outside asioryctitherians and *Eomaia*, all other Cretaceous eutherians are still very incomplete. Many taxa are represented only by dental characters that show discordant (or homoplastic) distributions. Thus the differences in placements of *Montanalestes* is attributable to a very common cause (discordant distributions of the relevant characters that happen to be preserved in an incomplete fossil) that would also affect all other phylogenies.

For the ordered multistate characters, the bootstrap 50% majority-rule consensus tree is less resolved than the strict consensus of the 3 most parsimonious and shortest trees. In the bootstrap consensus tree, *Eomaia* is still a part of the eutherian clade, but the “asioryctitherians” are collapsed. Outside the therian crown group, the formerly pinnate clades of “eutricodonts” are also collapsed into a basal polytomy. A monophyletic group of *Murtoilestes*, *Prokennalestes* and *Eomaia* is weakly supported by the bootstrap results, if 37 multistate characters are ordered.

Polymorphic characters. Multi-state polymorphic characters of the terminal taxa here are run as polymorphisms in PAUP search.

Not-preserved vs. non-applicable characters. PAUP and other currently available softwares for phylogenetic analyses treat both missing and inapplicable characters as “missing.” Therefore the “not preserved” characters and the “not applicable” characters are both coded as “?” in the matrix and are treated the same by the phylogenetic algorithms, although the two categories of absence of data are clearly different in the empirical anatomical survey. We the authors are aware of the limit of PAUP in this regard, but we have to rely on it for the lack of a better and feasible alternative algorithm.

PAUP Search

PAUP V.4.0b. No topological constraint is imposed in any of the searches of this study. Tritylodontids are allocated to the outgroup in the algorithm. Limited by our computing capacity, our phylogeny is based on the strict consensus tree (Fig. 6a, also see PAUP printouts below) from the parsimonious and shortest trees by 1000 runs of heuristic search of PAUP.

P A U P *

Version 4.0b10 for Macintosh (PPC)

Saturday, March 8, 2002 9:26 AM

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 "Ji-Luo(L11309C).mtx" begins...

Data matrix has 42 taxa, 268 characters

Valid character-state symbols: 01234

Missing data identified by '?'

Gaps identified by '-'

1 tree read from TREES block

Time used = 0.00 sec

1 tree converted from rooted to unrooted.

Warning: The following taxa were omitted from one or more trees:

Murtoilestes,	Eomaia,	Kennalestes,	Ukhaatherium,
Zalambdalestes,	Daulestes,	Aspanlestes,	Eoungulatum,
Cimolestes,	Gypsonictops,	Protungulatum	

(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 "Ji-Luo(Ms-L11309C).mtx" completed.

Outgroup status changed:

1 taxon transferred to outgroup

Total number of taxa now in outgroup = 1

Number of ingroup taxa = 41

	111111111222222222333333333344444444455555555566666666777
Taxon/Node	12345678901234567890123456789012345678901234567890123456789012
Tritylodontids	0000010000000000000000?0?302??????????2???0??22???24?????0?0?00?????????
Sinoconodon	000000000000000000000110000?????11000000?00???00?20???00000010?0???000?
	1
Morganucodon	000010000000000000000001000000000010000000000?11?20???20000020?0???000?
	1
Megazostrodon	000010100000000000000002010000000000000000000?12?20???20000020?0???000?
Haldanodon	00000100000000100000011010000000010000101000?11?00???70032000?0?0???000?
Hadrocodium	0112?1300??11100000000102?000000?100000000?00?12?20???0000000?0?0???00?
Shuootherium	0010111?0001?000?00?00?010?0?????11010110?011001?01000101321000110000110?
Ambondro	?????1?????1?????????????0?0?????1?131111?12??130?1330012100?1102224112
Ausktribosphenos	0010012010011?002200?011210?????111311111112??13021330012100022021214122
Bishops	0??102010?011?0022003111210?????11131?11112??13021330012100122021214122
Steropodon	0?1001????0?1?0????????????10????????????12??1311112001211002204223121
Ornithorhynchus	1112?11??1?1111122003111210????????????????????1?1?1?????2?1002204223121
	2
Gobiconodon	1111011???021111221001140100000001100101010000?12?10??10100010?0????000?
Jeholodens	1111011???211112???00124010000000?01010001?000?11?10??01000031?0????000?
Priacodon	1111011???2121?122100124010000000000100020000?711?10??11000031?0????000?
Plagiaulacidans	1112?11???0?1111021102240102?????????2?000??22??10?24?????0?0?000?????????
	1
Cimolodontans	1112?11??1?1111021101240102?????????2?000??22??10?24?????0?0?000?????????
	2 12
Zhangheotherium	1111011???0110?122100114101100000111010000012001201000100000001100?0100?
Peramus	111111010011?112101113121111002000100000012001300010001000100100002110
	1
Henkelotherium	1111010100111?11210?113121100000?01000?0000110013020000?10000011000?220?
Vincelestes	1112?10100?11?11110111312110000101000000001100130000001000000010000210?
Kielantherium	1111010100111?111101???1311?????0?0000000011?13000110011001011020114110
	1
Deltatheridium	1112?14101111?1111000131311000012000100010012101300011001100111102114110
	1
Asiatherium	1111?14101?1111111000??13110000010001000100122013010310011100101112214120
Kokopellia	?1?1?14??11?1?1?1100????311????1?000100010012101301021011100100112214110
Pucadelphys	1111?1410111111110001313110000120001000100012101312031011100100112214120
Didelphis	1112?14101?1111111000131311000012000100010012101311031011100101112214120
Montanalestes	1112?13100?11?1112000131311?????110100110012??1302102101100120102114110
Murtoilestes	??122013?20110111001?0102114110
Prokennalestes	1111113100211?11120101312111112?120100012012201302011011100120102114110
Eomaia	111113100211?111200013121110111120001201100012013020?101110012?02?14110
Kennalestes	1112?13100?111111200????211111120100200020012201302021011100122203114110
Asioryctes	1112?13100?111111200013131111220110200011012201302021011100120103114110
Ukhaatherium	????????????????????????????1112201102000120122013020?1011100120103114110
Zalambdalestes	1112?10100?111111200013121111221021210022012201312031011100102204204110
	3 1
Daulestes	1112?13101?1111112000131211???1?????????000122013020210111001?1102114110
Aspanlestes	?????1????????????1?????111112?1?01000?01231131021011001?1101214110
Eoungulatum	?????1????????????1?????1011001?????????12421310310111001?1101214111
Cimolestes	1112?10101?111111200013121110122?110100011012311302021011100122103114110
Gypsonictops	1112?10101?111111200013121111122?1212000210012311312021011100122104114110
Protungulatum	1112?10101?111111200013121110120?121100011012421311021011100121101214111
Erinaceus	1112?13101?111111200013131101101121210020012201311031011100101102214111

[illegible]


```

Eomaia      ???????11??1????????????00??0?01?????02?1??????????
Kennalestes 11201000110311?????1?1?110?1?010?2011102110??1011111
Asioryctes  11201000110311?????1?121100?101012011102110??1011111
Ukhaatherium ?????????????????????????????????????????????
Zalambdalestes 11201000110311?????1?1211001101012011002110??1011111
Daulestes   112011001?????1?????1?1?1?00??0101??1??0??????2?????
Aspanlestes ?????0?????1????????????????????????????????????
Eoungulatum ?????0?????1????????????????????????????????????
Cimolestes  ?????0????????????????????????????????????????????
Gypsonictops ?????????????????????????????????????????????
Protungulatum ?????11?????1????????????????????????????????
Erinaceus   112011001103111111121211011111112011102110122011111

```

```

Heuristic search settings:
  Optimality criterion = parsimony
  Character-status summary:
    Of 268 total characters:
      All characters are of type 'unord'
      All characters have equal weight
      All characters are parsimony-informative
    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 = 196120166
  Number of trees held at each step during stepwise addition = 1
  Branch-swapping algorithm: tree-bisection-reconnection (TBR)
  Steepest descent option not in effect
  Initial 'MaxTrees' setting = 10000 (will be auto-increased by 1000)
  Branches collapsed (creating polytomies) if maximum branch length is zero
  'MulTrees' option in effect
  Topological constraints not enforced
  Trees are unrooted

```

```

Heuristic search completed
  Total number of rearrangements tried = 92442682
  Score of best tree(s) found = 919
  Number of trees retained = 50
  Time used = 00:04:49.6

```

Tree-island profile:

Island	Size	First tree	Last tree	Score	First replicate	Times hit
1	50	1	50	919	1	979
2	1	-	-	921	193	9*
3	0	-	-	921	244	1
4	9	-	-	923	876	1
5	1	-	-	923	367	6*
6	0	-	-	923	74	4*

Note(s):

* Multiple hits on islands of unsaved trees may in fact represent different islands

Strict consensus of 50 trees:

```

/----- Tritylodontids
+----- Sinoconodon
|
| /----- Morganucodon
| /----- Megazostrodon
| /----- Haldanodon
\--+ | /----- Hadrocodium
| | /----- Shuotherium
\--+ | /----- Ambondro
| | /----- Ausktribosphenos
\--+ | \--+ /----- Bishops
| | \--+ /----- Steropodon
| | \--+ /----- Ornithorhynchus
\--+ | /----- Jeholodens
| /----- Priacodon
| | /----- Gobiconodon
\--+ | /----- Plagiaulacidans
| | /----- Cimolodontans
| | /----- Zhangheotherium
\--+ | /----- Henkelotherium
| | /----- Vincelestes
\--+ | /----- Peramus
| | /----- Kielantherium
\--+ | /----- Deltatheridium
| | /----- Kokopellia
| | \--+ /----- Asiatherium
| | \--+ /----- Pucadelphys
\--+ | \--+ /----- Didelphis
| /----- Murtoilestes
| +----- Prokennalestes
| +----- Eomaia
| /----- Montanalestes
\--+ | /----- Kennalestes
| | +----- Asioryctes
| | +----- Ukhaatherium
\--+ | \----- Zalambdalestes
| /----- Daulestes
| | /----- Cimolestes
\--+ | /----- Gypsonictops
| | \--+ /----- Aspanlestes
| | \--+ /----- Eoungulatum
| | \--+ /----- Protungulatum
\--+ | \--+ /----- Erinaceus

```

Lengths and fit measures of trees in memory:

Character-status summary:

Of 268 total characters:

All characters are of type 'unord'

All characters have equal weight

All characters are parsimony-informative

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 = 467

Sum of max. possible lengths = 2204

Tree # 1

Length 919

CI 0.508

RI 0.740

Bootstrap method with heuristic search:

Number of bootstrap replicates = 100

Starting seed = 1879607707

Optimality criterion = parsimony

Character-status summary:

Of 268 total characters:
 All characters are of type 'unord'
 All characters have equal weight
 All characters are parsimony-informative
 Gaps are treated as "missing"
 Multistate taxa interpreted as polymorphism
 Starting tree(s) obtained via stepwise addition
 Addition sequence: simple (reference taxon = Tritylodontids)
 Number of trees held at each step during stepwise addition = 1
 Branch-swapping algorithm: tree-bisection-reconnection (TBR)
 Steepest descent option not in effect
 Initial 'MaxTrees' setting = 10000 (will be auto-increased by 1000)
 Branches collapsed (creating polytomies) if maximum branch length is zero
 'MulTrees' option in effect
 Topological constraints not enforced
 Trees are unrooted

100 bootstrap replicates completed
 Time used = 00:18:26.6

Bootstrap 50% majority-rule consensus tree

```

/----- Tritylodontids(1)
+----- Sinoconodon(2)
|
| /----- Morganucodon(3)
| /----- Megazostrodon(4)
| /----- Haldanodon(5)
\100-+ /----- Hadrocodium(6)
| | /----- Shuotherium(7)
| | \94-+ /----- Gobiconodon(13)
| | | /----- Jeholodens(14)
| | \92-+ +----- Priacodon(15)
| | | /----- Plagiaulacidans(16)
| | | +----- Cimolodontans(17)
| | | /----- Ambondro(8)
| | \68-+ | /----- Ausktribosphenos(9)
| | | +----- Bishops(10)
| | | /----- Steropodon(11)
| | | \84-+ /----- Ornithorhynchus(12)
| | | /----- Zhangheotherium(18)
| | | \75-+ | /----- Henkelotherium(20)
| | | | /----- Vincelestes(21)
| | | \79-+ | /----- Peramus(19)
| | | | \60-+ | /----- Kielantherium(22)
| | | | | /----- Deltatheridium(23)
| | | | | \67-+ | /----- Kokopellia(25)
| | | | | | \90-+ /----- Asiatherium(24)
| | | | | | \80-+ | \94-+ /----- Pucadelphys(26)
| | | | | | | \80-+ /----- Didelphis(27)
| | | | | | | /----- Montanalestes(28)
| | | | | | | +----- Murtoilestes(29)
| | | | | | \56-+ +----- Prokennalestes(30)
| | | | | | | +----- Eomaia(31)
| | | | | | | +----- Kennalestes(32)
| | | | | | | +----- Asioryctes(33)
| | | | | | | +----- Ukhaatherium(34)
| | | | | \-----80-----+----- Zalambdalestes(35)
| | | | | +----- Daulestes(36)
| | | | | | /----- Cimolestes(39)
| | | | | +68-+ /----- Gypsonictops(40)
| | | | | | /----- Aspanlestes(37)
| | | | | | +----- Eoungulatum(38)
| | | | | \61-+ /----- Protungulatum(41)
| | | | | | \----- Erinaceus(42)

```

Bipartitions found in one or more trees and frequency of occurrence (bootstrap support values):

1 2 3 4 4

123456789012345678901234567890123456789012	Freq
.....**.....	100.00
.,*****	100.00
.....**.....	99.52
..**.....	94.40
.....*.....	94.25
.....**.....	93.50
.....*****	92.00
.....*****	90.30
.....**.....	84.49
.....*****	80.33
.....**.....	80.23
.....*****	80.23
.....*****	79.02
.....*****	74.84
.....*****	72.66
.....*****	72.53
.....**.....	71.85
.....*****	71.02
.....**.....	68.09
.....*****	67.90
.....*.....	66.80
.....**.....	61.05
.....*****	59.69
.....*****	56.35
.....*****	49.43
.....**.....	49.40
.....**.....	47.60
.....*****	46.40
.....*****	42.86
.....*****	42.15
.....*.....	40.33
.....**.....	36.65
.....**.....	36.13
.....**.....	35.18
.....*****	34.19
.....**.....	33.89
.....*****	32.85
.....*****	32.75
.....*****	31.91
.....**.....	31.18
.....*****	29.19
.....**.....	26.95
.....*.....	23.36
.....*****	22.88
.....*.....	22.39
.....*****	20.02
.....**.....	19.84
.....**.....	19.31
.....**.....	19.10
.....*****	18.93
.....**.....	18.83
.....**.....	18.54
.....*.....	18.53
.....*****	18.45
.....**.....	18.41
.....*.....	16.91
.....**.....	16.77
.....*****	16.63
.....*****	15.85
.....*****	15.10
.....*****	14.89
.....*.....	14.32
.....*.....	14.02
.....**.....	13.60
.....*****	13.45
.....*.....	13.06
.....*.....	12.63

```

.....*****..... 11.50
.....*..... 11.38
.....*** 11.25
.....***** 11.12
.....***** 11.02
.....***** 10.24
.....*..** 10.19
.....**..** 9.92
.....*** 9.58
.....** ***** 9.50
.....*..** 9.36
.....*** ***** 9.31
.....***** ** 9.26
.....*..** 9.18
.....** ***** 9.06
.....*..***** 8.75
.....***** ** 8.71
.....***** ***** 8.50
.....***** 8.50
.....** 8.50
.....*** ***** 8.30
.....*** ** 8.04
.....*..* 7.44
.....*** ***** 7.31
.....*** * ***** 7.08
.....*..** 7.00
.....*..** ** 6.91
.....*..* 6.83
.....*..* 6.64
.....***** ** 6.61
.....* ***** 6.50
.....*** * ***** 6.31
.....*** ***** 6.26
.....*..* 6.25
.....** 6.01
.....***** * 6.00
.....*** ***** 5.96
.....***** 5.89
.....***** ** * 5.86
.....*..* 5.70
.....***** ***** 5.60
.....*..* ***** 5.50
.....*..* 5.42
.....*** 5.41
.....*** ***** 5.40
.....*** 5.35
.....*** ***** 5.31
.....*** * 5.31
.....***** *..* 5.21
.....*** **..** 5.05
.....***** 5.00

```

454 groups at (relative) frequency less than 5% not shown

Heuristic search settings:

Optimality criterion = parsimony

Character-status summary:

Of 268 total characters:

37 characters are of type 'ord' (Wagner)

231 characters are of type 'unord'

All characters have equal weight

All characters are parsimony-informative

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 = 1010731978

Number of trees held at each step during stepwise addition = 1

Branch-swapping algorithm: tree-bisection-reconnection (TBR)
 Steepest descent option not in effect
 Initial 'MaxTrees' setting = 10000 (will be auto-increased by 1000)
 Branches collapsed (creating polytomies) if maximum branch length is zero
 'MulTrees' option in effect
 Topological constraints not enforced
 Trees are unrooted

Heuristic search completed

Total number of rearrangements tried = 109679880
 Score of best tree(s) found = 953
 Number of trees retained = 3
 Time used = 00:05:22.6

Tree-island profile:

Island	Size	First tree	Last tree	Score	First replicate	Times hit
1	3	1	3	953	1	798
2	3	-	-	955	49	13*
3	9	-	-	957	15	45*
4	8	-	-	957	59	17*
5	7	-	-	957	116	17*
6	6	-	-	957	5	28*
7	3	-	-	957	687	1
8	1	-	-	957	16	28*
9	0	-	-	957	6	5*
10	1	-	-	966	31	44*
11	0	-	-	966	127	4*

Note(s):

* Multiple hits on islands of unsaved trees may in fact represent different islands

Strict consensus of 3 trees:

```

/----- Tritylodontids
+----- Sinoconodon
| /----- Morganucodon
| /----- Megazostrodon
| /----- Haldanodon
\--+ | /----- Hadrocodium
| | /----- Shuotherium
\--+ | /----- Ambondro
| | /----- Ausktribosphenos
\--+ | /----- Bishops
| | /----- Steropodon
\--+ | /----- Ornithorhynchus
| | /----- Jeholodens
\--+ | /----- Priacodon
| | /----- Gobiconodon
\--+ | /----- Plagiaulacids
| | /----- Cimolodontans
\--+ | /----- Zhangheotherium
| | /----- Henkelotherium
\--+ | /----- Vincelestes
| | /----- Peramus
\--+ | /----- Kielantherium
| | /----- Deltatheridium
\--+ | /----- Kokopellia
| | /----- Asiatherium
| | /----- Pucadelphys
\--+ | /----- Didelphis
| | /----- Montanalestes
| | /----- Ukhaatherium
\--+ | /----- Asioryctes
| | /----- Kennalestes
| | /----- Zalambdalestes
\--+ | /----- Murtoilestes
| | /----- Prokennalestes
| | /----- Eomaia
\--+ | /----- Daulestes
| | /----- Cimolestes
\--+ | /----- Gypsonictops
| | /----- Aspanlestes
| | /----- Erinaceus
\--+ | /----- Eoungulatum
\--+ | /----- Protungulatum

```

Lengths and fit measures of trees in memory:

Character-status summary:

Of 268 total characters:

37 characters are of type 'ord' (Wagner)

231 characters are of type 'unord'

All characters have equal weight

All characters are parsimony-informative

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 = 467

Sum of max. possible lengths = 2333

```

Tree #      1
Length    953
CI        0.490
RI        0.740

```

Bootstrap method with heuristic search:

Number of bootstrap replicates = 100

Starting seed = 77720946

Optimality criterion = parsimony
 Character-status summary:
 Of 268 total characters:
 37 characters are of type 'ord' (Wagner)
 231 characters are of type 'unord'
 All characters have equal weight
 All characters are parsimony-informative
 Gaps are treated as "missing"
 Multistate taxa interpreted as polymorphism
 Starting tree(s) obtained via stepwise addition
 Addition sequence: simple (reference taxon = Tritylodontids)
 Number of trees held at each step during stepwise addition = 1
 Branch-swapping algorithm: tree-bisection-reconnection (TBR)
 Steepest descent option not in effect
 Initial 'MaxTrees' setting = 10000 (will be auto-increased by 1000)
 Branches collapsed (creating polytomies) if maximum branch length is zero
 'MulTrees' option in effect
 Topological constraints not enforced
 Trees are unrooted

100 bootstrap replicates completed
 Time used = 00:11:45.4

Bootstrap 50% majority-rule consensus tree

```

/----- Tritylodontids(1)
+----- Sinoconodon(2)
|
| /-----100-----+----- Morganucodon(3)
| | /----- Megazostrodon(4)
| | | /----- Haldanodon(5)
\100+ | | /----- Hadrocodium(6)
      | | | /----- Gobiconodon(13)
      \96+ | | | /----- Jeholodens(14)
           | | | +----- Priacodon(15)
           \81+ | | /----- Shuotherium(7)
                | | | /----- Ambondro(8)
                | | | +----- Ausktribosphenos(9)
                \63+ | | | /93+----- Bishops(10)
                     | | | \50+----- Steropodon(11)
                     | | | \87+----- Ornithorhynchus(12)
                     | | | /----- Plagiaulacidans(16)
                     | | | +----- Cimolodontans(17)
                     | | | /----- Zhangheotherium(18)
                     \64+ | | | /----- Henkelotherium(20)
                          | | | \77+----- Vincelestes(21)
                          \76+ | | | /----- Peramus(19)
                               | | | \59+----- Kielantherium(22)
                               | | | | /----- Deltatheridium(23)
                               \74+ | | | /69+----- Kokopellia(25)
                                    | | | | \84+----- Asiatherium(24)
                                    \79+ | | | | \95+----- Pucadelphys(26)
                                         | | | | | \82+----- Didelphis(27)
                                         | | | | | /----- Montanalestes(28)
                                         \58+ | | | | +----- Kennalestes(32)
                                              | | | | +----- Asioryctes(33)
                                              | | | | +----- Ukhaatherium(34)
                                              | | | | +----- Zambdalestes(35)
                                              | | | | +----- Daulestes(36)
                                              \75+ | | | | /----- Cimolestes(39)
                                                  +-----60-----+----- Gypsonictops(40)
                                                  | /----- Murtoilestes(29)
                                                  +-----54-----+----- Prokennalestes(30)
                                                  | \----- Eomaia(31)
                                                  | /----- Aspanlestes(37)
                                                  \61+ | /----- Erinaceus(42)
                                                       \52+ | /----- Eoungulatum(38)
                                                            \64+----- Protungulatum(41)
  
```

Bipartitions found in one or more trees and frequency of occurrence (bootstrap support

values):

1	2	3	4 4	
123456789012345678901234567890123456789012				Freq
.....**.....				100.00
*****				100.00
..**.....				99.50
.....*****				96.50
.....*..*				94.77
.....**.....				92.61
.....**.....				86.69
.....*****				83.79
.....**.....				82.26
.....*****				80.99
.....*****				79.08
.....*****				78.75
.....*****				76.83
.....*****				75.93
.....**.....				75.82
.....*****				75.44
.....*..*****				74.00
.....*****				71.52
.....*****				69.08
.....*..*				64.50
.....*****				63.85
.....*****				63.29
.....**..*				60.97
.....**.....				60.13
.....*..*****				59.27
.....*****				57.68
.....***.....				53.52
.....*..**				51.74
.....***.....				50.28
.....***.....				47.75
.....***.....				46.28
.....*****				45.67
.....*****				44.67
.....*****				42.23
.....**.....				39.59
.....**.....				35.67
.....**..*				34.39
.....***.....				34.33
.....*****				30.24
.....*..*****				30.04
.....*****				27.15
.....*****				26.32
.....**.....				26.26
.....**.....				24.87
.....*****				24.44
.....*..*****				24.02
.....*..*				22.35
.....*****				22.25
.....*..*				21.15
.....***..**				20.67
.....**.....				19.52
.....*****				18.75
.....**..*				18.29
.....*****				17.06
.....*..*				16.24
.....*****				16.01
.....**..*****				15.99
.....*****				14.81
.....**..**				14.55
.....**..*****				14.07
.....*..*****				13.29
.....**..*****				13.07
.....**..*****				13.07
.....*.....*				12.72

420 groups at (relative) frequency less than 5% not shown