Supplementary information

**Tip dating supports novel resolutions of controversial relationships among early mammals**

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**Effects of fossil age and branch length on tree topology**

To test the effect of taxon age on the phylogenetic position of haramiyidans, we ran an analysis without data on a partially fixed topology (based on the result from tip dating) in which only the haramiyidan taxa (i.e. *Haramiyavia*, *Thomasia* and the euaharamiyidans) were free to move around the tree. Specifically, a series of backbone constraints based on the maximum clade credibility tree from the main analysis were implemented, and haramiyidans were constrained to form two monophyletic groups (the Triassic *Haramiyavia + Thomasia*, and the Middle Jurassic euaharamiyidans) but with their phylogenetic position otherwise unconstrained. The analysis therefore tested where these two groups attached to the backbone, based purely on their stratigraphic ranges. Processing of results in R required the packages ape (Paradis et al. 2004), phangorn (Schliep 2010) and treeio (Yu et al. 2017).

Placement of the Middle Jurassic euaharamiyidans (figure S1a) based purely on stratigraphic data (referred to hereon as the stratigraphic phylogenetic position) is very different from that of the Late Triassic *Haramiyavia and Thomasia* (figure S1b). The stratigraphic phylogenetic position for *Haramiyavia and Thomasia* is concentrated around the very oldest part of the tree: the time at which *Haramiyavia and Thomasia* branch from the rest of the tree has a 95% highest posterior density (HPD) interval of 203.5 – 237.1 Ma. The stratigraphic phylogenetic position for euaharamiyidans is concentrated on younger branches (HPD 171.4 – 215.2 Ma). Notably, both groups are also more likely to attach to longer branches (figure S1). When the stratigraphic phylogenetic position is corrected for the effect of branch length, by dividing probability by branch length (figure S2), the temporal signal is more obvious. Quantification of the probability that each clade occurs above a particular node also shows that the stratigraphic phylogenetic position for *Haramiyavia* and *Thomasia* is strongly concentrated at the very base of the tree, in contrast to the euaharamiyidans (figure S1c).

These results show that there are two major factors (beyond morphology) in determining phylogenetic position in tip-dated analyses: age and branch length. Long branches tended to ‘attract’ the clades under investigation, but only long branches that occurred in an appropriate age range. This supports the suggestion of Turner et al. (2017) that Bayesian tip-dated approaches disfavour long un-sampled branches.
Supplementary Figure 1. Phylogenetic position of haramiyidans based only on stratigraphic ranges.

A-B) The tree is a fixed backbone constraint based on the maximum clade credibility tree from the main analysis, on which the branching positions for the two groups of haramiyidans are estimated. Branch colours represent the probability that the respective clade (A, Euharamiyida; B, Haramiyavia+Thomasia) was found on each branch in an analysis run without morphological data. The probabilities for Haramiyavia and Thomasia are concentrated at the base of the tree, unlike the probabilities for euharamiyidans which are more diffuse and centred in younger parts of the tree. There is also a notable preference for long branches. C) Probabilities that each group of haramiyidans is found above each node in a sequence from the base of the tree to the crown therian node. The distribution for Haramiyavia+Thomasia drops off much more quickly, representing the expectation based on their age that they are placed in a lower position on the tree than euharamiyidans.
Supplementary Figure 2. Effective topology prior for haramiyids, corrected for branch length. a-b)

The tree is a fixed topology based on the maximum clade credibility tree from the main analysis, on which the prior probabilities for the position of two groups, divided by the branch length, of haramiyids are mapped. Branch colours represent the corrected prior probability that the respective clade (a, euharamiyids; b, Triassic haramiyids) was found on that branch in an analysis run without data. The corrected prior probabilities for Triassic haramiyids are concentrated at the base of the tree, unlike the corrected prior for euharamiyids, which is more diffuse and centred in younger parts of the tree. Removing the effect of branch lengths clearly shows the temporal signal in the prior.
Relationship of *Haramiyavia, Thomasia* and tritylodontids

A surprising aspect of our results is the placement of *Haramiyavia* and *Thomasia* with tritylodontids (fig. 2). This has been found in some previous analyses (e.g. Gurovich and Beck 2009), but it should be noted that these two groups show marked dental differences (Kemp 1982; Jenkins et al. 1997; Kielan-Jaworowska et al. 2004; Luo et al. 2004; Kemp 2005; Luo et al. 2015a; Velazco et al. 2017). The upper postcanines of tritylodontids comprise three major rows of cusps arranged labiolingually, whereas those of *Haramiyavia* and *Thomasia* have only two. Tritylodontids show a specialised type of postcanine dental replacement, in which worn teeth shed from the anterior end of the tooth row and new teeth are added at the posterior end, whereas this is absent in *Haramiyavia* (the pattern of dental replacement in *Thomasia* is unknown). *Haramiyavia* also retains the upper and lower canines, whilst these teeth have been lost by tritylodontids. Based on these striking morphological differences (only some of which were used as characters by Huttenlocker et al. (2018)), this relationship should be viewed cautiously, pending description of additional cranial and postcranial material of *Haramiyavia, Thomasia*, and improved taxon and character sampling of non-mammaliaform cynodonts. As discussed above, the recovery of this relationship is likely driven by the relatively long branch leading to tritylodontids, which also means that morphological differences between tritylodontids and *Haramiyavia* and *Thomasia* are penalised less.

Effect of fossil sampling on age estimates of *Juramaia* and *Rugosodon*

The result of the age estimate of *Juramaia* is striking (Fig. 3). However, it is possible that poor sampling of eutherians in the Early Cretaceous drives this result. In order to test this idea, we manufactured an equivalent situation for the multituberculate *Rugosodon* by deleting *Kuehneodon* and plagiaulacids from the dataset. This produces an approximately 40 million-year gap between *Rugosodon* from the Yanliao biota and *Sinobaatar* from the Jehol biota, equivalent to the temporal difference between *Juramaia* and *Eomaia*. We then estimated the age of *Rugosodon* using the same laplace distribution prior as used for other taxa from the Yanliao biota (main text: Material and Methods).

Estimating the age of *Rugosodon* following deletion of *Kuehneodon* and plagiaulacids resulted a younger age estimate (Fig. S12), suggesting that sampling issues may indeed affect the age estimate for *Juramaia*. However, the results are not entirely equivalent. For *Rugosodon*, the upper bound of the HPD (114.4–164.5) still overlaps with the correct age, whereas the upper bound of the HPD for *Juramaia* is much younger (106.3–137.6). Deletion of taxa results in a loss of precision for the age estimate of *Rugosodon*, representing a lack of information in the data. In contrast, the age estimation for *Juramaia* results in a distinct Early Cretaceous peak (Fig. 3), showing a strong signal in the morphological data. Nevertheless, these results show the importance of fossil sampling to constrain estimates of taxon age, and suggest the implications of the morphology of *Juramaia* may be subject to change if additional Early Cretaceous eutherian fossils are discovered.
Supplementary Figure 3. 50% majority rule consensus tree using craniodental data only. Tip-dated analysis from BEAST2 on the dataset of Huttenlocker et al. (2018). ‘Allotherian’ taxa in green. In contrast to the full dataset, this analysis has increased support for haramiyidan monophyly.
Supplementary Figure 4. 50% majority rule consensus tree using dental data only. Tip-dated analysis from BEAST2 on the dataset of Huttenlocker et al. (2018). ‘Allotherian’ taxa in green. This analysis shows support for allotherian monophyly.
**Supplementary Figure 5.** 50% majority rule consensus tree using postcranial data only. Tip-dated analysis from BEAST2 on the dataset of Huttenlocker *et al.* (2018). ‘Allotherian’ taxa in green. This analysis separates euharamiyids from multituberculates, but cannot be used to investigate the position of Triassic haramiyidans.
Supplementary Figure 6. 50% majority rule consensus tree using the dataset of Wang et al (2019). Tip-dated analysis from BEAST2. ‘Allotherian’ taxa in green. This analysis separates euharamiyids from Haramiyavia and Thomasia, while euharamyiids and multituberculates form a clade.
Supplementary Figure 7. Twin likelihood peaks in the tip-dated analysis on the Krause et al. (2014) dataset. Boxplots represent the calculated prior (tree model likelihood), likelihood and posterior probabilities within the two likelihood peaks, which correspond to alternative phylogenetic positions for the Triassic haramiyids. An un-nested position has a higher prior probability (due to improved stratigraphic fit of the resulting phylogenies), but a lower likelihood (due to lower congruence with the morphological data, particularly the dental data). The contradictory effects of the prior and likelihood on the two topologies lead to approximately equal posterior probabilities, and both were therefore sampled during the analysis.
Supplementary Figure 8. 50% majority rule consensus tree for the Krause et al. (2014) dataset. Tip-dated analysis from BEAST2. ‘Allotherian’ taxa in green.
Supplementary Figure 9. 50% majority rule consensus tree for the Krause et al. (2014) dataset, using only the trees from the posterior sample that recovered Triassic haramiyids in a nested position. Tip-dated analysis from BEAST2. ‘Allotherian’ taxa in green.
Supplementary Figure 10. 50% majority rule consensus tree for the Krause et al. (2014) dataset, using only the trees from the posterior sample that recovered Triassic haramiyids in an un-nested position. Tip-dated analysis from BEAST2. ‘Allotherian’ taxa in green.
Supplementary Figure 11. 50% majority rule consensus tree for the Huttenlocker et al. (2018) dataset, where the age of Juramaia was allowed to vary. Tip-dated analysis from BEAST2. ‘Allotherian’ taxa in green.
Supplementary Figure 12. Age estimate for Rugosodon after removal of Kuehneodon and plagiaulacids. This leads to a younger and much less precise age estimate, and suggests that the young age estimate for Juramaia could be partly driven by the lack of sampling of eutherians in the Early Cretaceous.

Supplementary Figure 13. The Jurassic age of Juramaia necessitates highly heterogenous rates of evolution. a) Rates of evolution on each branch from the majority rule consensus tree of the main analysis (Juramaia assigned a Jurassic age). Rates from three key branches are highlighted: 1, the branch leading to the therian crown node; 2, the branch leading to the common ancestor of eutherians; and 3, the branch leading to eutherians excluding Juramaia. There is a large reduction in the rate of evolution following the divergence of Juramaia from the rest of the eutherians. b) Rates of evolution on each branch from the majority rule consensus tree of the analysis in which the age of Juramaia was allowed to vary (and was estimated to be Early Cretaceous). The rates on the same three branches are much more similar.
Further details on priors used for tip-dated analysis

The analyses did not use a diversified sampling model (Zhang et al. 2016), as this is only relevant when extant taxa are sampled. The datasets were modified so that extant taxa and recent fossils were removed.

Details of parameters and priors. Lognormal distributions are in log space.

| Parameter          | Value                                   |
|--------------------|-----------------------------------------|
| Removal probability| Fixed (0.0)                             |
| Origin time        | Uniform (0, 2000)                       |
| Birth Rate         | Lognormal (mean -2, sd 1)               |
| Death Rate         | Exponential (mean 0.1)                  |
| Sampling Rate      | Exponential (mean 0.1)                  |
| Gamma shape        | Uniform (0, 10)                         |
| Clock Rate         | Lognormal (mean -5, sd 1.4)             |
| Clock standard deviation | Exponential (mean 1)          |
Tip ages

Here we give the ages of each taxon, with references. These were assigned as uniform priors in the analysis. Occurrences are taken from the literature, or from the Paleobiology Database (accessed through Fossilworks http://www.fossilworks.org). Occurrences using the Paleobiology database are referenced with “PBDB”. Occurrences from the literature and the PBDB are recorded according to Geological stage, and for standardisation were converted to age using the International Chronostratigraphy Chart (Cohen et al. 2018). Occurrences on the PBDB listed as cf. Taxon were not included. Regional stages were converted to international stages based on the Geowhen database (http://www.stratigraphy.org/bak/geowhen/index.html). When sources referenced subdivisions of stages (e.g. early, middle, late Campanian), the stage was divided into three equal-sized intervals. Radiometric dates are used, when available.

Taxa from Huttenlocker et al. dataset

**Adelobasileus**
Tecovas formation. Norian.
(Lucas and Luo 1993; Parker et al. 2008)

**Aegialodon**
Cliff end, Wadhurst formation. Early Valanginian.
(Kielan-Jaworowska et al. 2004)

**Agilodocodon**
Daohugou locality, Tiaojishan formation
(Meng et al. 2015)

**Akidolestes**
Yixian formation. Radiometric date 129.7 (base), and 122.1 (top)
(Li and Luo 2006; Chang et al. 2009)

**Albertatherium**
Deadhorse Coulee Member (Milk River Formation). Late Santonian
Deadhorse Coulee Member (Eagle Formation). Santonian
PBDB

**Ambondro**
Isalo group. Bathonian.
(Flynn et al. 1999)

**Amphilestes**
Taynton Limestone formation (Stonesfield slate), Middle Bathonian.
(Butler and Sigogneau-Russell 2016)
**Amphitherium**
Taynton limestone formation (stonesfield slate), Middle Bathonian.
(Butler and Clemens 2001)

**Anchistodelphys**
Smoky Hollow Member (Straight Cliffs Formation). Late Turonian
Wahweap Formation, Early/Lower Campanian

**Andinodelphys**
Tiupampan mammal zone, Santa Lucía Formation, Danian
PBDB

**Arboroharamiya**
Yanliao biota, 166-159
(Zhou and Wang 2017)

**Asfaltomylos patagonicus**
Canadon asfalto formation, Toarcian.
(Rauhut et al. 2002; Cúneo and Bowring 2010)

**Asiatherium**
Barun Goyot formation equivalent. Campanian-Maastrichian.
(Szalay and Trofimov 1996; Longrich et al. 2010)

**Asioryctes**
Barun Goyot formation. Campanian-Maastrichian.
(Kielan-Jaworowska 1975)

**Aspanlestes**
Darbasa Formation, Early/Lower Campanian
Aitym Formation, Late/Upper Turonian to Late/Upper Turonian
Bissekty Formation, Coniacian
PBDB

**Atokatheridium**
Middle Member (Antlers Formation), Late/Upper Aptian to Late/Upper Aptian
Little Sheep Mudstone Member (Cloverly Formation), Aptian to Aptian
PBDB

**Ausktribosphenos**
Wonthaggi formation, Flat rocks, early-middle Aptian.
(Rich et al. 1997; Benson et al. 2012)

**Bishops**
Wonthaggi formation, Flat rocks, Aptian.
(Rich et al. 2001a)

**Brasilitherium**
Caturrita Formation, Rosario del Sul Group. Norian
(Bonaparte et al. 2003; Langer and Ferigolo 2013)

**Brasilodon**
As Brasilitherium

**Castorocauda**
Daohugou locality, Tiaojishan formation
(Ji et al. 2006)

**Cifelliodon**
Yellow cat member, Cedar mountain formation.
Two different U/Pb ages: 124.2±2.6 and 139.7±2.2
(Huttenlocker et al. 2018)

**Cimolestes**
Hainin Formation, Danian
Tiupampan mammal zone, Santa Lucía Formation, Danian
Ravenscrag Formation, Puercan
Frenchman Formation, Puercan
Jbel Guersif Formation (Subatlas Group), Thanetian
Hell Creek Formation, Puercan
Bear Formation, Puercan
Frenchman Formation, Lancian
Ravenscrag Formation, Lancian
Hell Creek Formation, Lancian
Lance Formation, Lancian
Ferris Formation, Lancian
PBDB

**Cimolodontans**
Age of *Kryptobaatar* used.
Djadochta formation. Campanian
(Wible and Rougier 2000)

**Daulestes**
Bissekty Formation, Middle Turonian
PBDB

**Deltatheridium**
Djadokhta Formation, Campanian, Mongolia.
(Butler and Kielan-Jaworowska 1973; Godefroit et al. 2008)
Didelphodon
(Horseshoe Canyon Formation), Edmontonian
Scollard Formation, Lancian
Frenchman Formation
Lancian of Montana
Hell Creek Formation, Lancian
Lancian, South Dakota
Lancian of Wyoming
PBDB

Docofossor
Nanshimen site, Hebei, Tiaojishan formation
(Nuo et al. 2015b)

Dryolestes
Morrison formation.
148-155 Mya
(Kowallis et al. 1998)

Eleutherodon
Forest Marble Formation (Great Oolite Group), Late/Upper Bathonian
(Kielan-Jaworowska et al. 2005)

Eomaia
Yixian formation. 129.7-122.1
(Ji et al. 2002; Chang et al. 2009)

Eoungulatum
Bissekty Formation, Middle Turonian
Aitym Formation, Late/Upper Turonian
PBDB

Fruitafossor
Morrison formation
(Luo and Wible 2005)

Gobiconodon
Cloverly formation. Aptian-Albian.
(Jenkins Jr and Schaff 1988)

Gypsonictos
Judithian – Lancian
(Kielan-Jaworowska et al. 2005)
**Hadrocodium**
Zhangjiawa member (dark red beds), Lower Lufeng formation, Sinemurian.
(Luo et al. 1994; Luo et al. 2001)

**Hahnodon**
Ksar Metlili Formation, Berriasian
PBDB

**Haldanodon**
Guimarota coal mine. Kimmeridgian.
(Martin and Nowotny 2000)

**Haramiyavia**
Tait Bjerg Beds of the Fleming Fjord formation. Norian-Rhaetian.
(Clemmensen et al. 2016)

**Henkelotherium**
Guimarota Coal mine. Kimmeridgian.
(Ruf et al. 2009)

**Holoclemensia**
Middle Member (Antlers Formation), Late/Upper Aptian
Middle Member (Antlers Formation), Albian
Paluxy Formation, Albian
PBDB

**Jeholodens**
Yixian formation.
(Qiang et al. 1999)

**Juramaia**
Tiaojishan formation.
(Luo et al. 2011; Gao and Shubin 2012)

**Kennalestes**
Djadokhta Formation, Campanian (*Kennalestes gobiensis*)
PBDB

**Kielantherium**
Höövör locality, Mongolia. Aptian-Albian.
(Lopatin and Averianov 2007)

**Kokopellia**
Mussentuchit, Cedar mountain formation. 97-98 Mya
(Cifelli and de Muizon 1997; Garrison et al. 2007)
**Kuehneodon**  
Alcobaça Formation, Kimmeridgian  
Sobral Formation, Late/Upper Kimmeridgian  
Praia Azul Member (Lourinhã Formation), Late/Upper Kimmeridgian
PBDB

**Maiopatagium**  
Daxishan, Tiaojishan formation  
(Meng et al. 2017)

**Maotherium**  
Lujiatun Locality, Yixian formation.  
(Ji et al. 2009)

**Massetognathus**  
Chañares formation  
PBDB, (Marsicano et al. 2016)

**Megaconus**  
Daohugou, Tiaojishan Formation  
(Zhou et al. 2013)

**Megazostrodon**  
Upper Elliot formation, Pokane, Lesotho. Hettangian-Sinemurian  
(Gow 1986; Butler 2005)

**Millsodon**  
Forest Marble Formation. Late Bathonian  
PBDB

**Montanalestes**  
Cloverly formation  
(Cifelli 1999)

**Morganucodon**  
Zhangjiawa member, Lower Lufeng formation, Sinemurian.  
Glamorgan fissure fills, particularly St Brides island. Rhaetian-Sinemurian  
(Luo et al. 1994; Kielan-Jaworowska et al. 2004)

**Murtoilestes**  
Murtoi formation. Late Barremian-Middle Aptian  
PBDB

**Nanolestes**
Guimarota coal mine and Qigu formation, China (Oxfordian).
(Martin et al. 2010)

**Pachygenelus**
Upper Elliot formation. Hettangian-Sinemurian
(Gow 2001)

**Pediomys**
Age for *P. elegans*
Scollard formation. Lancian
Hell Creek formation. Lancian
Lance Formation. Lancian
Frenchman formation. Lancian
Ravenscrag formation. Lancian
PBDB

**Peramus**
Durlston Bay, Lulworth formation. Middle Berriasian
(Riboulleau et al. 2007; Davis 2012)

**Plagiaulacidae**
Durlston Bay, Lulworth formation, Middle Berriasian
(Kielan-Jaworowska et al. 2004)

**Priacodon**
Morrison formation.
(Rasmussen and Callison 1981)

**Probainognathus**
Chañares formation. 236-234 Mya
(Romer 1970; Marsicano et al. 2016)

**Prokennalestes**
Khoobur locality. Aptian-Albian
(Wible et al. 2001)

**Protungulatum**
Frenchman formation. Lancian
Ravenscrag formation. Lancian
Denver Formation. Puercan
Hell Creek Formation. Puercan (*P. donnae*)
Hell Creek Formation. Late Maastrichtian (*P. gorgun, coombsi*)
Ferris formation. Puercan
China Butte Member (Fort Union Formation). Puercan
PBDB
Pseudotribos
Daohugou locality, Tiaojishan formation
(Luo et al. 2007b)

Pucadelphys
Tiupamapa, Santa Lucia formation. 65MyA
(Macrini et al. 2007; Muizon et al. 2015)

Repenomamus
Yixian formation
(Li et al. 2001)

Rugosodon
Tiaojishan formation
(Yuan et al. 2013)

Shenshou
Daxishan, Tiaojishan formation, Oxfordian
(Bi et al. 2014)

Shuotherium
Shangshaximiao formation. Oxfordian.
(Kielan-Jaworowska et al. 2004)

Sineleutherus
Qigu Formation, Oxfordian
Upper Member (Itat Formation), Bathonian
PBDB

Sinobaatar
Yixian formation. Fuxin formation. Aptian-Albian
(Hu and Wang 2002; Kusuhashi et al. 2009)

Sinoconodon
Zhangjiawa member (dark red beds), Lower Lufeng formation, Sinemurian
(Luo et al. 1994)

Sinodelphys
Yixian formation.
(Luo et al. 2003)

Spalacotherium
Purbeck limestone group and Wealden supergroup. Berriasian-Valanginian.
(Kielan-Jaworowska et al. 2004)
Spinoleses
La Huérguina Formation, Late/Upper Barremian
PBDB

Steropodon
Lightning ridge. Early-Mid Albian
(Archer et al. 1985; Kear and Godthelp 2008)

Sulestes
Bissekty formation. Middle–Upper Turonian
(Kielan-Jaworowska et al. 2004)

Teinolophos
Flat rocks, Victoria
(Rich et al. 2001b)

Thomasia
Early Rhaetian, Lorraine
? norian, Holwell, Britain
Late Rhaetian, Wurttemberg, Germany
(Kielan-Jaworowska et al. 2004)

Thrinaxodon
Lystrosaurus assemblage zone, Karoo. Induan-early Olenekian
(Estes 1961; Ezcurra et al. 2013)

Tinodon
Morrison formation and Purbeck limestone.
(Kielan-Jaworowska et al. 2004)

Trioracodon
Morrison formation and Purbeck limestone
(Kielan-Jaworowska et al. 2004)

Tritylodontidae
Age of Bienotherium and Oligokyphus used.

Bienotherium
Shawan member, Lower Lufeng formation, Hettangian.
(Luo et al. 1994)

Oligokyphus
Shawan member (Dull purplish) Lower Lufeng formation. Hettangian.
Windsor Hill fissure fill. Pleinsbachian
(Kühne 1956; Luo and Sun 1994)
**Turgidodon**
Oldman formation. Judithian
Dinosaur Park formation. Judithian
St. Mary River Formation, Edmontonian
Scollard Formation. Lancian
Foremost formation. Middle Campanian
Oldman Formation, Middle–Late Campanian
Frenchman Formation. Lancian
Judith River Formation. Middle Campanian
Hell Creek Formation. Lancian
Upper Shale Member (Aguja Formation), Judithian
Kaiparowits Formation, Late/Upper Campanian
Wahweap Formation, Judithian
Mesaverde Formation, Judithian
Lance Formation. Lancian
PBDB

**Ukhaatherium**
Djadocinha formation. Campanian
(Horovitz 2003)

**Vilevolodon**
Nanshimen site, Tiaojishan formation
(Luo et al. 2017)

**Vincelestes**
La Amarga formation. Barremian
(Apesteguía 2007)

**Vintana**
La Kinkoky member, Maevarano formation. Maastrichian
(Krause et al. 2014)

**Xianshou linglong**
Daxishan, Tiaojoshan formation, Oxfordian
(Bi et al. 2014)

**Xianshou songae**
Daxishan, Tiaojoshan formation, Oxfordian
(Bi et al. 2014)

**Yanoconodon**
Yixian formation.
(Luo et al. 2007a)
Zhangheotherium
Yixian formation
(Hu et al. 1997)

Additional taxa for the Krause et al. matrix

Bharattherium
Intertrappean beds, Maastrichian.
(Prasad et al. 2007)

Bienotherium
Shawan member, Lower Lufeng formation, Hettangian.
(Luo et al. 1994)

Bienotheroides
Upper Xiashaximiao formation. Middle Jurassic.
(Sun and Li 1985; Danilov and Parham 2008)

Bocatherium
La Boca formation. Pleinsbachian.
(Montellano et al. 2008)

Catopsbaatar
Barungoyot Formation equivalent. Campanian-Maastrichian.
(Hurum and Kielan-Jaworowska 2008)

Chulsanbaatar
Barun Goyot formation.
(Hurum 1998)

Cronopio
Candeleros Formation. Cenomanian.
(Rougier et al. 2011)

Cynognathus
Early to middle Triassic Burgersdorp formation (Karoo), and Mendoza. Cynognathus assemblage zone. Olenekian-Anisian.
(Abdala et al. 2005; Lucas 2010)

Diademodon
As Cynognathus
(Botha et al. 2005)

Gomphos
Nomogen formation and Arshanto formations, inner Mongolia. Palaeocene-Eocene boundary. (Meng et al. 2004)

**Gondwanatherium**
Los Alamitos formation, Argentina. Campanian. (Bonaparte 1986)

**Greniodon**
La Barba, Andesitas Huancache Formation, Argentina. Early Lutetian. (Goin et al. 2012)

**Guimarota Paulchoffatiidae**
Guimarota coal mine. Kimmeridgian. (Schwarz and Salisbury 2005)

**Exaeretodon**
Ischigualasto formation Argentina, and Santa Maria formation Brazil. Ladinian-Carnian. (Abdala et al. 2002)

**Ferugliotherium**
Los Alamitos formation, Argentina. Campanian. (Krause et al. 1992)

**Henosferus**
Canadon asfalto formation. (Rougier et al. 2007)

**Kayentatherium**
Kayenta formation. Sinemurian-Pleinsbachian. (Kermack 1982; Tykoski et al. 2002)

**Kryptobaatar**
Djadochta formation. Campanian (Wible and Rougier 2000)

**Lambdopsalis**
Nomogen formation. Late Palaeocene (Mao et al. 2015)

**Lavanify**
Maevarano Formation. Maastrichian (Krause et al. 1997; Rogers et al. 2007)

**Nemegtbaatar**
Barun Goyot formation
**Oligokyphus**
Shawan member (Dull purplish) Lower Lufeng formation. Hettangian.
Windsor Hill fissure fill. Pleinsbachian
(Kühne 1956; Luo and Sun 1994)

**Pappotherium**
Butler farm local fauna, Albian
(Fox 1975)

**Ptilodus**
New Mexico, Torrejonian (Late Danian)
Fort Union, Montana, Torrejonian
Washakio basin, Wyoming, Torrejonian
Williston Basin Saskatchewan, Tiffanian (Selandian-Thanetian)
Cochrane, Alberta. Tiffanian
(Granger and Simpson 1929; Szalay 1965; Krause 1982; Scott et al. 2002)

**Sudamerica**
Punto Perigro, Salamanca formation. Danian
(Koenigswald et al. 1999; Woodburne et al. 2014)

**Taeniolabis**
Nacimiento formation (Puercan)
Ludlow formation and Tullock formation, Montana. 65.5 Mya
(Simmons 1987; Greenwald 1988; Williamson et al. 2008)

**Trapalcotherium**
Allen formation. ? Maastrichian
(Rougier et al. 2009)

**Tribosphenomys**
Subeng, Inner Mongolia and Zhigden member, Naran Bulak formation, Mongolia. Thanetian
(Lopatin et al. 2004)

**Tritheledontidae**
Pachygenelus: Upper Elliot formation.
Brasilitherium and Brasilodon from the Caturrita Formation, Rosario del Sul Group. Norian
(Gow 2001; Bonaparte et al. 2003; Langer and Ferigolo 2013)

**Yunnanodon**
Zhangjiawa member (dark red beds), Lower Lufeng formation, Sinemurian.
(Fraser and Sues 1997)
Zalambdalestes
Djadokhta formation.
(Wible et al. 2004)

Additional taxa for the Wang et al. matrix

Jeholbaatar
Jiufotang formation. 120.3+0.7
(He et al. 2004; Wang et al. 2019)

Liaoconodon
Jiufotang formation.
(Meng et al. 2011)

Mayulestes
Tiupampan mammal zone, Santa Lucía Formation, Danian
PBDB
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