Supplementary Materials for

Earliest Evolution of Multituberculate Mammals Revealed by a New Jurassic Fossil

Chong-Xi Yuan, Qiang Ji, Qing-Jin Meng, Alan R. Tabrum, Zhe-Xi Luo*

*Corresponding author. E-mail: zxluo@uchicago.edu

Published 16 August 2013, *Science* **341**, 779 (2013)
DOI: 10.1126/science.1237970

This PDF file includes:

Earliest Evolution of Multituberculate Mammals Revealed by A New Jurassic Fossil

Supporting Online Material (Science Ms 1237970)

Chong-Xi Yuan[1], Qiang Ji[1], Qing-Jin Meng[2], Alan R. Tabrum[3], and Zhe-Xi Luo[4]

[1] Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037 CHINA

[2] Beijing Museum of Natural History, Beijing 100050 CHINA

[3] Section of Vertebrate Paleontology, Carnegie Museum of Natural History
Pittsburgh, PA 15213 USA

[4] Department of Organismal Biology and Anatomy, the University of Chicago
Chicago, IL 60637 USA

* Correspondence Author: Zhe-Xi Luo (zxluo@uchicago.edu)

Table of Contents

Part A. Illustrations and Photos for Documenting *Rugosodon* (BMNH1142)

Fig. S1. Counter-part BMNH1142B (Holotype) of *Rugosodon eurasiaticus*: identification of main features. Abbreviations: -l, left side; -r, right side; c1-c2, cervical vertebra 1 (atlas) and cervical 2 (axis); t1, t10, t13, thoracic vertebrae 1, 10, 13.

Fig. S2. Comparison of *Rugosodon* from the Tiaojishan Fm of Liaoning, China (about 160Ma according to 12-Liu et al. 2012) with *Plesiochoffatia* and other paulchoffatiid multituberculates from Guimarota Mines of Portugal (the Kimmeridgian Age of the Late Jurassic). A. *Rugosodon*: Left upper M1-2 showing M2 cusp rows lingually off-set from M1 cusp rows, a key multituberculate feature (based on SEM photos and camera lucida drawing); B. SEM photo of left M2; C-F (D-F reversed). Left M2's of the Late Jurassic paulchoffatiid multituberculate *Plesiochoffatia* from Guimarota of Portugal. G. Left lower m1-2 of *Rugosodon*. H-I. Lower m1's of known paulchoffatiid multituberculates; J-L, m2's of *Plesiochoffatia*; M-N, m2's of un-named multituberculates (but clearly very similar to *Plesiochoffatia* and *Rugosodon*) from the Late Jurassic Guimarota site. Figures on the multituberculates from the Guimarota site are used by permission of Prof. G. Hahn and Dr. R. Hahn.

Fig. S3. Comparison of *Rugosodon* with paulchoffatiid multituberculates from the Late Jurassic Guimarota mines of Portugal. A. Upper dentition of *Rugosodon* (lateral view) showing that the deciduous dP2 and dP4 are about to be replaced in BMNH1142. B. Lateral view of the paulchoffatiid *Kuehneodon* (Hahn 1969). C. Lateral view of m1's of *Plesiochoffatia* and a paulchoffatiid multituberculate. D. Type specimen of *Plesiochoffatia* (Hahn and Hahn 1998). E. m1-2 of *Rugosodon* (composite restoration in lateral view). BMNH 1142 shows no feature that would suggest the replacement of the lower premolars. Figures on the multituberculates from the Guimarota sites are reproduced by permission of Prof. G. Hahn and Dr. R. Hahn.

Notes on illustration and reconstruction of *Rugosodon* from BMNH1142A and 1142B (see Figures S4 and S5): All illustrated features have been exposed by fossil preparation and can be clearly seen with a microscope. However, it is not possible to directly photograph some of these teeth in their crown views because their occlusal surfaces, as preserved and exposed, are perpendicular to the bedding plane of the very large slabs that must be kept intact. Camera lucida drawings can be made by tilting

the fossil slabs obliquely under a microscope. ***The dash outlines represent the estimated molar width from the camera lucida drawing.*** Lower m1 occlusal features are based on the right m1's lingual half preserved on BMNH1142B and nearly the entire left m1 preserved on BMNH1142A, the occlusal surface of which is nearly completely exposed by preparation, and visible for camera lucida drawing. The m2 basin in occlusal view can be seen from the left m2 on BMNH1142A and on the right m2 of BMNH1142B; the labial row of cusps on the right m2 is partially preserved on BMNH1142B and mostly on BMNH1142A. The composite restoration of entirety of m2 as presented in Figures 2 and S2 is based the labial half of left m2, and on the lingual half reversed from right m2.

Fig. S4. Preservation of dentition and mandible on BMNH1142A (Holotype main-part) (Left) and on BMNH1142B (Holotype counter-part) (Right). Abbreviations: lf, left side; rt, right side. I/I, upper and lower incisors; C, upper canine; dP, deciduous upper premolars; P/p, upper and lower premolars; M/m, molars.

Fig. S5. Comparison of lower hind limb and the upper ankle joint of multituberculates and other Mesozoic and extant mammal clades. Nodes: 1. Crown Mammalia; 2. Theriiforms (in part); 3. Spalacotherioids; 4. Multituberculates. Cladogram simplified from Figure S6C.

Fig. S6. Summary of hypotheses of relationships of *Rugosodon* among Mesozoic mammaliaform clades and among major Mesozoic and Paleogene multituberculates, with putative outgroups. A and B. Strict and Adams consensus trees from 1000 heuristic runs on multituberculate in-group matrix, with 18 multi-state characters ordered (details in SOM Part H); C. Strict consensus tree from 1000 heuristic runs of the mammaliaform matrix with all multi-state characters un-ordered (details in SOM Part K). *Rugosodon* is unambiguously placed within the Paulchoffatiid clade in each of the 82 equally parsimonious trees from the multituberculate in-group matrix.

Fig. S7. Artistic reconstruction of *Rugosodon eurasiaticus* by April Isch (Department of Organismal Biology and Anatomy, the University of Chicago).

Part B. Systematic Paleontology

Class Mammalia

Order Multituberculata (emended by 1-Kielan-Jaworowska et al. 2004)

Family Paulchoffatiidae (emended by 3-Hahn and Hahn 2000)

Rugosodon eurasiaticus gen. et sp. nov.

Etymology: Generic name *Rugoso* - Latin "rugosus" for wrinkles and creases; -odon, Latin "tooth," for the highly wrinkled and ornamented molar occlusal surface of the new genus; specific name: *eurasiaticus*, for the broad paleobiogeographic distribution of the paulchoffatiid multituberculates in both western Europe and eastern Asia during the Late Jurassic and strong similarity of *Plesiochoffatia* from Portugal and *Rugosodon* from China, suggesting that they are closely related.

Holotype specimen: Beijing Museum of Natural History (BMNH) PM1142A, B: main-part and counter-part on two shale slabs split upon discovery, preserved with full dentition, broken skull, most of the postcranial skeleton, and residual soft tissues, such as halo of integument. BMNH1142 is recovered together with the *Juramaia sinensis* type specimen (BMNH1143).

Type locality and geological age: The holotype was recovered in the Daxishan site, near the Daxishan Village of the Linglongta township of Jianchang County of Liaoning Province, China. The fossil site is in the Late Jurassic Tiaojishan Formation. The Daxishan site (also known as the Daxigou site) of Liaoning was most recently dated to be 160±0.99 Ma (12-Liu et al. 2012). The Lanqi Formation, a stratigraphic equivalent of the Tiaojishan in the adjacent Beipiao area, is dated to be 160 Ma in a recent geochronological study (34-Chang et al. 2009) (more discussion on "Geological Age of Tiaojishan Formation"). The Daxishan site is of the Oxfordian age of the Late Jurassic.

Diagnosis: Dental formula I3, C1, P5, M2/i1, c0, p4, m2. P5, M1 with two longitudinal multicusp rows; M1 without posterolingual wing; M2 with a lingual cusp row (of five cusps) and a labial (central) row (of two cusps), plus a shelf-like anterobuccal ridge (= crista anterobuccalis); M2's two cusp rows are lingually off-set from the cusp rows of M1. Lower incisor enlarged, procumbent, and elongate with a root extending into dentary below premolars, and incisor separate from premolars by a diastema. Last lower premolar (p4) is bladed, with seven serrations on the main crest, although the anteriormost and posteriormost serrations are represented only by cusps. The m1 with two cusp rows of four cusps each, and the second lingual and second labial cusps taller than the other cusps of the row; m2 with trenchant, hypertrophied anterior cusp on the lingual row, the remaining labial and lingual cusps are small and coalesced to form a crenulated margin encircling the entire tooth basin. The dentary has a laterally compressed articular condyle and a round angular region without an angular process, and a masseteric fossa extending anteriorly to below the p4-m1 junction. All of the above are multituberculate synapomorphies, or paucholffatiid synapomorphies, or shared derived features otherwise known only in some other (but not all) paulchoffatiid

multituberculates (1-Kielan-Jaworowska et al. 2004; 3-Hahn and Hahn 2000; 4 – Butler 2000).

Differential diagnosis: *Rugosodon* differs from all pre-mammalian mammaliamorphs (including tritylodontids) in having the dentary condyle and the squamosal glenoid in the temporomandibular joint. Among all mammaliamorph cynodonts (including mammaliaforms) with multi-row and multicusped postcanines, *Rugosodon* differs from tritylodontids and *Haramiyavia* (35-Jenkins et al. 1997) in the absence of the postdentary trough for accommodating the mandibular middle ear. It differs from all non-multituberculate mammaliaforms in the masseteric fossa extending anteriorly onto the lateral surface of mandibular body directly below m1 (a multituberculate apomorphy), which also occurs in some rodents. It differs from all pre-mammalian mammaliaforms (including sinoconodontids, morganucodontans, and docodontans) and cladotherians (dryolestoids through crown therians) in lack a mandibular angle; from the majority of mammaliaforms (including eutriconodonts) in having a laterally compressed dentary condyle (a multituberculate apomorphy). Among mammals with a rounded angular region of the mandible, *Rugosodon* differs from eutriconodonts in lacking mediolaterally compressed molars with a single row of three main cusps, from tinodontid and spalacotherioid symmetrodonts in lacking triangulation of the molar cusps. It differs from cladotherians in lacking a lower molar heel-like or basin-like talonid.

In dental features *Rugosodon* differs from the majority of mammaliaforms (including clades of living mammals) in having at least two cusp rows, except haramiyidans; differs from all cynodonts (inclusive of crown mammals) with multiple cusp-rows in M2 cusp rows lingually offset from M1 cusp rows. Within the Order Multituberculata, *Rugosodon* differs from the "plagiaulacid" and eobaatarid multituberculates in I2 being tricuspid and enlarged, I3 being bicuspid, and in upper canine having more than two cusps (autapomorphic).

Rugosodon is more plesiomorphic than and differs from plagiaulacids (sensu 1-Kielan-Jaworowska et al. 2004) that are abundant in the Late Jurassic Morrison Formation of North America and the earliest Cretaceous Purbeck sites of Great Britain in a basined lower m2, and in m2 lacking a complete middle valley fully separating the lingual from the labial cusp row. *Rugosodon*, along all other paulchoffatiids, differs from eobaatarids (including *Sinobaatar*) (20-Kusuhashi et al. 2009; 36-Kielan-Jaworowska et al. 1987; 37-Kusuhashi 2008) in lacking the posterolingual wing in upper M1 (plesiomorphic) (*Sinobaatar* has a single cusp or cingulum in the posterolingual wing of M1) and in having a shorter labial cusp row than the lingual row on lower m2 than eobaatarids. *Rugosodon* has seven serrations (five with ridges, two represented only by cusps) on the blade-like ultimate lower premolar, in contrast to eight or more (*Sinobaatar xiei* and *Sinobaatar fuxinensis*) up to ten (*Sinobaatar lingyuanensis*) cuspule-ridge serrations on ultimate premolar among *Sinobaatar* species (38-Hu and Wang 2002; 20-Kusuhashi et al. 2009). Moreover, *Sinobaatar* has no canine (according to 20-Kusuhashi et al. 2009) and fewer lower premolars than *Rugosodon*. *Rugosodon* differs from all taxa of the Cimolodonta clade in retaining an upper canine and the anterior upper and lower premolars (plesiomorphous).

Rugosodon is similar in dental formula (plesiomorphic) to those paulchoffatiid genera for which the full dentition is known (except for *Henkelodon*); similar to paulchoffatiids but different from most non-paulchoffatiid multituberculates in the presence of a crenulated anterobuccal ridge/shelf and middle valley posteriorly closed by a cusp or ridge on M2; the anterior end of the middle valley of m1 and m2 rimmed by a crest (also known in some haramiyidans) and posterior end of the valley rimmed by a crenulated crest (apomorphic), and in m2 with a full basin encircled by a crenulated rim (apomorphic).

Among paulchoffatiid multituberculates, BMNH1142 is similar in lower molar features to *Kuehneodon*, *Paulchoffatia,* and *Meketibolodon* in the anteriormost cusp being the largest and most trenchant cusp in the lingual cusp row of the lower molars, but differs from these paulchoffatiids in the basin rim having more crenulations with smaller and denser cuspules (Abb. 39 of 18-Hahn and Hahn 1998; fig. 8.28 of 1-Kielan-Jaworowska et al. 2004). *Rugosodon* differs from *Xenachoffatia* in that the tall and trenchant cusp is anterolingual, but not centrally positioned as in *Xenachoffatia*.

Rugosodon bears some resemblance to *Pinheirodon* (Pinheirodontidae, Paulchoffattoidea) in the elevated crown height of ultimate lower premolar but the upper M1-2 are more pitted and ornamented in *Rugosodon* than those of *Pinheirodon* (39-Hahn and Hahn 1999b); M1 is longer and M2 is distinctly triangular in *Rugosodon* in contrast to the shorter M1 and much narrower M2 of pinheirodontids (39-Hahn and Hahn 1998b; 40-Badiola et al. 2008).

Of all known paulchoffatiid multituberculates, *Rugosodon* is most similar and nearly identical to *Plesiochoffatia* (18-Hahn and Hahn 1998c, emended by 41-Hahn and Hahn 1999) in overall morphology: highly corrugated m1 middle valley and m2 basin with coalesced cuspules forming the basin rim. But by size, *Rugosodon* is about 170% the size of *Plesiochoffatia* by m2, and 150% to 200% by size of m1, because m1's referred to *Plesiochoffatia* have a wide range of sizes (inclusive of specimens formerly assigned to "plesiochoffatiid genus D" see Taxonomic note on *Plesiochoffatia*) by the size of upper M2 (Figures S2, S3). *Rugosodon* is autapomorphic among paulchoffatiids in its densely wrinkled and creased lower m2, M1, and M2. M2 is extensively wrinkled and pitted on occlusal surface, more so than in *Plesiochoffatia* (including the specimens of un-named paulchoffatiid Genus D of Hahn and Hahn 1998a).

Taxonomic note on *Plesiochoffatia*: G. Hahn and R. Hahn (18-1998, nomenclature emended 1999) established *Plesiochoffatia* on five isolated m2's, diagnosed by the molar occlusal basin encircled by labial, anterior, and posterior rims ornamented with small, distinctive although coalesced cuspules. This lower-tooth-based genus has not been assigned with isolated upper teeth due to the disassociated preservation of upper and lower teeth in the Guimarota mammal assemblage. Hahn and Hahn (18-1998) also recognized a very distinctive paulchoffatiid Genus D based on M2's among the isolated upper teeth of the Guimarota multituberculates. Very prudently, these authors did not assign M2's of "Genus D" to any multituberculate taxa based on the lower dentition from the same assemblage. The difficulty in correlating the "upper dental taxa" with "lower dental taxa" is a widely discussed issue of the multituberculates from the Guimarota mines (3-Hahn and Hahn 2000; 1-Kielan-Jaworowska et al. 2004; 2-Wilson et al. 2012).

The associated upper and lower teeth of *Rugosodon* (BMNH1142) show that its m2 is nearly identical to m2's of *Plesiochoffatia* (notwithstanding some relatively minor morphological differences and a major size difference) and its M2 is also nearly identical to M2's of "paulchoffatiid Genus D" (with minor distinguishing features). This provides strong evidence that "paulchoffatiid Genus D" represents the disassociated upper teeth of *Plesiochoffatia* that was originally established on lower molars. The upper dental specimens of "Genus D" can now be reliably assigned to *Plesiochoffatia* on the unambiguous association of the upper and lower teeth in the type specimen (BMNH1142) of *Rugosodon*.

In general, it is the consensus of all workers of multituberculates (see recent reviews by 3-Hahn and Hahn 2000; 1-Kielan-Jaworowska et al. 2004; 2-Wilson et al. 2012 – supplementary information) that although there are several genera by associated upper and lower teeth, many Jurassic genera and species of multituberculates are most likely over-split, because most taxa are based exclusively on upper teeth, or exclusively on lower teeth, which are from the same faunas or from the same site. By comparison to *Rugosodon*, several un-named upper and lower teeth of different tooth positions can be assigned to *Plesiochoffatia* from the same Guimarota site. This represents a useful step toward clarifying a widespread, historical problem.

In summary, *Rugosodon* bears resemblance to other paulchoffatiid multituberculates of the Lower Jurassic (Kimmeridgian) Guimarota site, and can be reliably assigned to the family Paulchoffatiidae. Within paulchoffatiids, it is most closely related to *Plesiochoffatia*.

Authentication of the Fossil

Verification of provenance – the specimen was acquired from a third party by three co-authors (Q. Ji, C.-X. Yuan and Z.-X. Luo) during fieldwork onsite near the Daxishan Village in May 2009, along with two other mammal fossils (including type specimen of *Juramaia*). The authors were able to confirm the quarries yielding these fossils. Subsequently these fossils were curated into the collection of Beijing Museum of Natural History. During the study of BMNH1142 at the museum's lab, three co-authors (Q.-J. Meng, Q. Ji and Z.-X. Luo) carried the original fossils to the fieldsite near the Daxishan Village in September 2011, to verify the lithology with the stratigraphic section at the site, and to obtain GPS coordinates of the quarries. Photos of May 2009 and September 2011 fieldworks by the research team, and GPS coordinates of the site may be released to scientists with proper credentials and justification on request.

Verification of intact fossils - The type specimen BMNH1134 consists of the main part (BMNH1134A: SOM Fig. S1) and the counterpart (BMNH1142B, main text Fig. 1), already split when found. During the preliminary study and fossil preparation in July 2009, it became clear that this fossil was well preserved and it represented a multituberculate mammal. During the exhaustive preparation and morphological research in September 2011 in Beijing Museum of Natural History, all features of teeth, skull, and postcranium were exposed through manual preparation by one of the co-authors (Alan Tabrum) while other authors did photography and camera lucida drawings of the main

part and counterpart. Because the specimen was frail, the research team decided to reinforce the backsides of the main part and counterpart by placing these on thin plywood boards with frame, so that the fossil can withstand handling during the study and preparation. Features on the main part can match vis-à-vis with features on counterpart, as exposed during mechanical preparation (Fig 1 and S1 on skeletal features; Fig. S4 on dentition). During the preparation, the left upper M1 and M2 (contiguous with each other) were bound by some fractures, and easily amenable for extraction. The reach team extracted Left M1-2 on BMNH1142A for scanning electron microscopy photography at the Beijing Museum of Natural History. Exposing the original features by preparation and the matching features of the main part and counterpart authenticate the original intact nature of the fossil.

Part C. Geological Age of Tiaojishan Formation & Its Vertebrate Fauna

The fossiliferous horizon of the Daxishan site in the Tiaojishan Formation is directly dated to be 160±0.99 million years (Ma) by the Prof. Yong-Qing Liu's team (12-Liu et al. 2012). Therefore, the age estimate for the holotype specimen (BMNH1142) and the associated mammals (including *Juramaia sinensis*) is about 160Ma. This age estimate is consistent with the following field stratigraphic observation and geochronological correlations.

The Tiaojishan Formation was dated to be 164Ma by SHRIMP U-Pb method on zircons in the Qiaomailiang Locality in the neighboring Ningcheng area of the Inner Mongolia Region (42-Liu et al. 2006: fig. 2). At the Qiaomailiang locality the Tiaojishan Formation can be as old as164-165Ma, but it is stratigraphically above the Jiulongshan Formation, best known in the Daohugou site of the Ningcheng area (42-Liu et al. 2006; 43-Ren et al. 2002). The Lanqi Formation in the adjacent Beipiao area of Liaoning is generally considered to be a stratigraphic equivalent of the Tiaojishan Formation. The lower part of the Lanqi Formation in the Beipiao area near Jianchang County is recently dated to range to 160.7±0.4Ma to158.7±0.6Ma by high-precision Ar40/Ar39 geochronological method on sanidines and plagioclases (34-Chang et al. 2009).

An earlier estimate postulated the geological age of the Tiaojishan Formation to be from 161Ma to 151Ma (44-Hu et al. 2009). Another geological study estimated that the top part of Tiaojishan ranged from 162Ma to 154Ma (45-Zhang et al. 2008). A recent study on a feathered troodontid dinosaur from the Tiaojishan Formation (44 - Hu et al. 2009) adopted the median age of 155Ma from Zhang et al. (2008) (45) for the Tiaojishan Formation from the range of 161Ma to 151Ma by the earlier studies) but this appears to be an underestimate of the age. The indirect range estimates published before 2008 are now superseded by the recent direct dating on the Daxishan fossil site and the dates with the higher geochronological precision on the equivalent Lanqi Formation (34 - Chang et al. 2009; 12-Liu et al. 2012).

These estimates have placed the Daxishan site and the Tiaojishan Formation to be early Oxfordian (161 – 156Ma sensu 46-Gradstein et al. 2004 and the published timescale by Geological Society of America). Thus, the fossil locality for *Rugosodon* (BMNH1142), *Juramaia sinensis* (BMNH1143), and other associated mammals should be placed in the lowest part of the Late Jurassic.

For faunal correlation, the Tiaojishan Formation of the Jianchang County also yielded the pterosaur *Darwinopterus modularis* (47-Lü et al. 2009) and the troodontid dinosaur *Anchiornis huxleyi*. Hu et al. (43- 2009) pointed out that the invertebrate and plant fossils from the Tiaojishan Formation differ from, and are generally more plesiomorphous than those of the Early Cretaceous Yixian Formation. Hu et al. (44 - 2009) (also shows that *Anchiornis huxleyi* is phylogenetically close to the Late Jurassic archaeopterids from Germany. We concur with their assessment that the dinosaurs, pterosaurs, invertebrates, and plants from the Tiaojishan are distinctively older than the elements of the Jehol biota of the Yixian Formation. Elsewhere in the Daohugou site, the Tiaojishan Formation yielded docodont mammaliaform *Castorocauda* (48 -Ji et al. 2006), the triconodontid

Volaticotherium (49 - Meng et al. 2006) and the shuotheriid *Pseudotribos* (14-Luo et al. 2007)

Part D. Body Mass Estimate of *Rugosodon eurasiaticus* (Type specimen BMNH PM1142)

BMNH1142 estimated mandibular length: 28 mm

BMNH 1142 estimated skull length: 36 mm

First we adopt a common method of estimating body mass from the skull size by scaling the relationship of skull length and body mass. This empirical regression is based on a dataset of extant placental insectivores and primates developed by Gingerich and Smith (1984) (50) and used previously for estimating body mass of Mesozoic mammals (e.g., 48 -Ji et al. 2006; 51-Luo et al. 2001b):

$$\text{Lg10 (Body-Mass [g])} = 3.68 \times \text{Lg10 (skull-length[mm])} - 3.83.$$

On the basis of skull length at 36 mm, body mass is estimated here at 78.95 grams for BMNH1142.

Alternatively, we also used the estimate developed by Foster (2009) (52) on regression between body mass to mandibular length, and the Foster dataset from placental insectivores and marsupials:

$$\text{Ln (body-mass [g])} = 2.9677 \times \text{Ln (mandible-length[mm])} - 5.6712$$

By this mandible-body mass scaling, we estimated that the body mass is about 67.95 grams for BMNH1142, on the mandibular length of 28 mm.

Multituberculate mammals have shorter mandibles and shorter lower dentition than the upper jaw and upper teeth, consistent with the palinal movement of the lower jaw relative to the upper (53 - Krause, 1982; 54 - Lazarri et al. 2010). Therefore, the estimate of body mass by the mandible length, while effective for other mammals (52 - Foster 2009), may be an underestimate for multituberculates, but it can provide an estimated lower limit of the body mass.

Part E. Hypothesis on Habits and Substrate Preference of *Rugosodon*

& Notes on Morphology of Postcranial Skeleton

Rugosodon is therian-like in the vertebral column. It has seven cervicals, with fused neural arch and centrum of the atlas (C1) and fused dens to the centrum of the axis (C2), and fused ribs with centrum for post-axial cervicals. It has thirteen thoracic vertebrae, and thoracic 10 is the anticlinal vertebra, as in Cretaceous multituberculates (9-Kielan-Jaworowska and Gambaryan 1994). There are six lumbar vertebrae, the last four of which show anterolaterally oriented transverse process. The thoraco-lumbar boundary is distinctive, as in Cretaceous multituberculates (9-Kielan-Jaworowska and Gambaryan 1994) and most trechnotherians (28-Ji et al. 2009). A distinctive thoraco-lumbar boundary suggests that the epaxial vertebral muscles are well differentiated between the thoracic region and the lumbar-sacral region in multituberculates. The relatively tall dorsal spines and the transverse processes of the lumbars indicate that the epaxial muscles associated with these bony structures are well developed in the lumbar region. These skeleton-muscle features suggest a significant capacity of lumbar movement in the sagittal plane, either for climbing (8-Krause and Jenkins 1983) or for jumping (9-Kielan-Jaworowska and Gambaryan 1994). There are three sacral vertebrae.

The scapula is not complete but the preserved scapular blade is relatively narrow, and has a trough-like infraspinous fossa. The acromial process is positioned on the cranial border of the scapular blade. Overall, the preserved scapular parts are similar to those of Late Cretaceous and Paleogene multituberculates (29-Sereno 2006). The interclavicle has a triangular outline and the clavicle is a slightly curved bone. These two bones appear to have a mobile articulation, again as in Cretaceous multituberculates (Figs. 1 and S1) (29-Sereno 2006).

The humerus has a pectodeltoid crest extending more than half of the humeral shaft. The distal end of the humerus has distinctive and well-separated radial and ulnar condyles, but no trochlea structure like that of crown therian mammals. The large but unfused parafibula process in *Rugosodon* (Fig 3A), previously known from some Paleogene and Late Cretaceous multituberculates (8-Krause and Jenkins 1983), represents a common condition of all multituberculates, thus a plesiomorphic feature of their common ancestor. The large parafibula adds a greater area for origins of major muscles (M. gastrocnemius lateralis and M. tibialis posterior) joining the Achilles tendon on the calcaneal tubercle for plantarflexion of the pes (9-Kielan-Jaworowska and Gambaryan 1994, 31-Chen and Luo 2012), and for the peroneal muscles (especially peroneus longus) for rotating and everting the foot via the peroneal shelf of the calcaneus (9-Kielan-Jaworowska and Gambaryan 1994, 25-Szalay and Sargis 2005). The parafibula also augments muscles for extending (e.g., extensor hallucis longus) and flexing pedal digits (8-Krause and Jenkins 1983; 9-Kielan-Jaworowska and Gambaryan 1993; 10-Szalay 1994). These inferred muscular patterns of the lower hind limb were correlated with the highly mobile tarsal bones and their joints, as follows:

(1) The upper ankle joint of *Rugosodon* (Fig. 3A-D) consists of two facets of the astragalus, respectively articulating with a peg-like medial condyle and a spiral lateral condyle in the distal end of the tibia. The exposed features of the upper ankle joint are identical to those of the Paleogene *Eucosmodon* and *Ptilodus* (7-Jenkins and Krause, 1983; 8-Krause and Jenkins 1983) and Late Cretaceous forms (9-Kielan-Jaworowska and Gambaryan 1994 and 10-Szalay

1994). The medial astragalar facet pivots on the medial tibial condyle, while the lateral astragalar facet glides along the curved lateral tibial condyle (Fig. 4A, B: curved arrow), facilitating an easy rotation of the upper ankle joint, for a wide abduction and eversion of the hind foot (7-Jenkins and Krause, 1983: fig. 1).

(2) At the lower ankle joint between the astragalus and the calcaneus (Fig. 3B), the calcaneus and the astragalus are slightly dislocated, exposing the calcaneo-astragalar contact. The shape of this contact is similar to what was characterized on the isolated calcaneus and astragalus of other multituberculates (7-Jenkins and Krause, 1983; 8 -Krause and Jenkins, 1983). Jenkins and Krause 1983 (7) interpreted that this joint was capable of translational movement for the calcaneus relative to the astragalus, facilitating plantarflexion and inversion of the foot relative to the ankle joint in Paleogene multituberculates. The same pattern also holds for *Rugosodon*.

(3) The contact between the astragalus and the navicular is a saddle-shaped joint, as well characterized for Cretaceous and Paleogene multituberculates (8-Krause and Jenkins 1983; 9 – Kielan-Jaworowska and Gambaryan 1994; 10-Szalay 1994). This joint permitted not only side-to-side but also dorsi- and plantar-flexion of the navicular to the astragalus (Fig. 4C). This enhances the mobility of the mid-tarsal joint of the hind foot in general.

(4) The entocuneiform-metatarsal joint (Fig. 4A) is formed by a deep saddle of the entocuneiform, reciprocated by a curved groove on metatarsal 1 (Fig. 4D), identical in the Jurassic *Rugosodon* as in all later multituberculates (8-Krause and Jenkins 1983; 10-Szalay 1994). This joint facilitates rotation of metatarsal 1 to the entocuneiform (Fig. 4E), amplifying to an even greater dorsoventral excursion for phalanges of the hallux (pedal digit 1), as would be pulled by the peroneus longus and the extensor digitorium hallucis, both originating near the enlarged parafibula at the knee joint (Fig. 3A). The saddle on the entocuneiform allowed abduction of metatarsal 1, although the metatarsal 1 is not habitually abducted as preserved *in situ* in *Rugosodon* (Fig. 3B, D), as interpreted for Paleogene multituberculates (7-Jenkins and Krause 1983). The mobility of metatarsal 1 in multituberculates is a unique condition, not seen in other Mesozoic mammals.

The intrinsic hand proportions and morphology of the terminal phalanges suggest that *Rugosodon eurasiaticus* is most probably a terrestrial mammal, or more likely a terrestrial mammal than an arboreal form. We developed this inference based on the broader comparative analyses by Kirk et al. (26-2008), Weisbecker and Wharton (27-2006), and Weisbecker and Schmid (55-2007). Other features of the skeleton are generalized, and not informative about likely substrate preference of *Rugosodon*.

****

Manual Ray III Phalangeal Proportion:
Metacarpal III = 6.8mm (Length) 2mm (Width)
Proximal phalanx III = 4.4mm (Length) 1.85mm (Width)
Intermediate phalanx III = 3.6mm (Length) 1.7mm (Width)

Ray III - Phalangeal (Length) Index:
(IP[3.6]+PP[4.4])/MC[6.8] x 100% = 117%

Ray III - Inter-Phalangeal (Length) Index = 82%

Phalangeal Slenderness Index (PSI) (Length/Width x100%) (Manual Ray III):

Metacarpal III:	MPSI(L/W)=340%
Proximal Phalanx:	PPSI(L/W)=238%
Intermediate Phalanx:	IPSI(L/W)=211%

Phalangeal Slenderness Index (PSI) (Length/Width x100%) for Manual Ray V:

Metacarpal V (estimate):	L6.7mm W2.1mm	MPSI(L/W)=219%
Proximal Phalanx:	L3.6mm W1.8mm	PPSI(L/W)=200%
Intermediate Phalanx:	L2.9mm W1.6mm	IPSI(L/W)=181%

****

The intrinsic hand proportions reflect habits and substrate preference among extant mammals (26-Kirk et al. 2008; 27-Weisbecker and Wharton 2006; 55 - Weisbecker and Schmid 2007). These recent analyses on proportions of phalanges and metacarpals have demonstrated that differences in substrate preference can be distinguished for various species within hystricognath rodents (55 - Weisbecker and Schmid 2007), within diprotodontian marsupials (27-Weisbecker and Wharton 2006), or among species of different habits within a clade across multiple clades of diverse placentals and marsupials on a broader scale (26-Kirk et al. 2008).

The phalangeal length index (PLI) of manual digit ray III is a major index for distinguishing terrestrial versus arboreal substrate preference among small euarchontan placentals, sciuromorph rodents, and didelphid marsupials. PLI of the manual ray III is 117% for *Rugosodon* (measured on the right manus as preserved on BMNH1142), which places *Rugosodon* among the middle of the top quartile for terrestrial species but near the lower limit of arboreal species of didelphids, sciuromorphs, and euarchontans studied by Kirk et al. (26-2008: fig. 6). Among sciuromorph rodents sampled by Kirk et al. (26-2008) that are more similar in feeding specialization to multituberculates including *Rugosodon*, the PLI of *Rugosodon* is more comparable to the terrestrial rodents than to those arboreal rodents. However, if compared to a different hystricognath rodent clade sampled by Weisbecker and Schmid (55-2007; also see 26-Kirk et al. 2008), the PLI value at 117% for *Rugosodon* would place it among the scansorial chinchillids and some arboreal erethizontid rodents, and above relatively shorter phalanges of the terrestrial species of other hystricognathan rodents (55-Weisbecker and Schmid 2007). Among placental carnivorans, most taxa with PLI comparable to that of *Rugosodon* are arboreal (Kirk et al. 2008) (26).

If compared to diprotodontian marsupials (27-Weisbecker and Wharton 2006), PLI at 117% for *Rugosodon* places it within the range of terrestrial herbivorous diprotodontians, and well below the lower limit of the arboreal diprotodontians (27- Weisbecker and Wharton 2006: table 6). Among didelphid marsupial, the terrestrial and semiaquatic *Chironectes* with PLI at 106 (26-Kirk et al. 2008) is the closest match to *Rugosodon*.

The phalangeal slenderness ratio (SR) (27-Weisbecker and Wharton 2006) is metric for the robustness vs. slenderness of metacarpals and phalanges. This has been used to discriminate among modes of locomotor adaptation of hands and substrate preferences of mammals among diprotodontian marsupials (27-Weisbecker and Wharton 2006). For manual ray III of *Rugosodon*, the metacarpal slenderness ratio is 340, below the mean of terrestrial diprotodontians and near the lower limit of arboreal diprotodontians (ranging from 318 to 581 with a mean at 450). *Rugosodon*'s proximal phalangeal slenderness is 200%, below the mean (217) for Proximal Phalangeal SR from terrestrial diprotodontians and well below the lower limit of the arboreal forms (range of 262–657 with a mean at 461) (27-Weisbecker and Wharton 2006: tables 5 and 6). The intrinsic hand bone proportion of *Rugosodon* suggests that it is certainly a terrestrial form by comparison to diprotodontian marsupials of similar habits (27-Weisbecker and Wharton 2006), which are herbivorous like multituberculates, and some (but not the majority of) diprotodontians even have developed convergent plagiaulacoid premolar patterns as multituberculates.

The terminal phalanx of *Rugosodon* has a low dorsoventral profile in the proximal part and a dorsoventrally flattened and bilaterally wide distal part. This is similar to the phalanges of terrestrial or fossorial multituberculates (Kielan-Jaworowska and Gambaryan 1994) (9), to those of most eutriconodonts that are interpreted as terrestrial forms (56 - Ji et al. 1999; 57 - Hu 2006; 58 - Luo et al. 2007), with exception of *Volaticotherium*, which is an arboreal and gliding species (49 - Meng et al. 2006). Most diagnostically, the profile of the two preserved terminal phalanges (III and V) of *Rugosodon* is similar to the generalized or terrestrial terminal phalangeal profiles of placentals (24-MacLeod and Rose, 1993) and marsupials (25-Szalay and Sargis 2005), but not arboreal placentals or marsupials.

In summary, the intrinsic hand proportions and the profile of terminal phalanges suggest that *Rugosodon* is more likely a terrestrial, than an arboreal mammal.

Part F. Systematic Characters for placing the new multituberculate mammal *Rugosodon eurasiaticus* (BMNH1142) among major clades of Mesozoic mammaliaforms and cynodont outgroups (expanded from Luo et al. 2011 character list)

Mandible

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

2. Separate scars for the surangular/prearticular in the mandible:
(0) Present; (1) Absent.
Rugosodon = 1

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

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

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

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

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

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

9. Vertical elevation of the angular process of the dentary relative to the molar alveoli:
(0) Angular process low, at or near the level of the ventral border of the mandibular horizontal ramus; (1) Angular process high, at or near the level of the molar alveolar line (and far above the ventral border of the mandibular horizontal ramus).
Rugosodon = ?

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

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

12. Coronoid bone (or its attachment scar):
(0) Present; (1) Absent.
Rugosodon = ?

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

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

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

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

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

(0) Participating in CMJ; (1) Excluded from CMJ.
Rugosodon = 1

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

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

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

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

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

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

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

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

26. Posterior-most mental foramen:
(0) In the canine and anterior premolar (premolariform) region (in the saddle behind the canine eminence of the mandible or behind incisor if canine is absent); (1) Below the penultimate premolar (under the anterior end of the functional postcanine row); (2)

Below the ultimate premolar; (3) At the ultimate premolar and the first molar junction; (4) Under the first molar.
Rugosodon = 0

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

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

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

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

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

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

33. Tilting of the coronoid process of the dentary (measured as the angle between the anterior border of the coronoid process and the horizontal alveolar line of all molars):
(0) Coronoid process strongly reclined and the coronoid angle obtuse ($\geq 150^{o}$); (1) Coronoid process less reclined (135^{o}-145^{o}); (2) Coronoid process less than vertical (110^{o}-125^{o}); (3) Coronoid process near vertical (95^{o} to 105^{o}).
Rugosodon = 1

34. Gracile base of the coronoid process:

(0) Absent; (1) Present.
Rugosodon = 0

35. Height of the coronoid process of the dentary:
(0) Not reduced; (1) reduced.
Rugosodon = 0

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

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

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

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

Premolars

40. Ultimate upper premolar with multi-rows of cusps - Labial row of cuspules:

(0) Absent; (1) Present.
Sinobaatar = 0

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

42. Ultimate upper premolar - metacone or metaconal swelling:
(0) Absent; (1) Present.
Rugosodon = ?

43. Ultimate upper premolar - protocone or protoconal swelling:
(0) Little or no lingual swelling; (1) Present.
Rugosodon = ?

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

Rugosodon = ?

45. Position of the tallest posterior upper premolar within the premolar series:
(0) No premolar standing out; (1) In ultimate premolar position; (2) In penultimate premolar position.
Rugosodon = ?

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

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

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

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

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

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

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

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

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

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

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

57. Penultimate lower premolar – labial cingulid:
(0) Absent; (1) Present.
Rugosodon = ?

58. Elongation of posterior premolars:
(0) Absent; (1) Present.
Rugosodon = 1

Molar Morphology

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

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

61. B1 cusp on the upper molar (applicable to molars with triangulation):

(0) Absent; (1) Present:
Rugosodon = ?

62. Postvallum/prevallid shearing (angle of the main trigonid shear facets, based on the second lower molar):
(0) Absent; (1) Present, weakly developed, slightly oblique; (2) Present, strongly developed and more transverse; (3) Present, strongly developed, short and slightly oblique.
Rugosodon = ?

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

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

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

66. Relationships between the cusps of the opposing upper and lower molars:
(0) Absent; (1) Present, lower primary cusp a occludes in the groove between upper cusps A, B; (2) Present, lower main cusp a occludes in front of the upper cusp B and into the embrasure between the opposite upper tooth and the preceding upper tooth; (3) Present, parts of the talonid occluding with the lingual face (or any part) of the upper molar; (4) Lower multicuspate rows alternately occluding between the upper multicuspate rows; (5) Columnar tooth without cusps and with beveled wear across the entire crown contact surface.
Rugosodon = 4

67. Protoconid (cusp a) and metaconid (cusp c) height ratio (on the lower second molar):

(0) Protoconid distinctively higher; (1) Protoconid and metaconid nearly equal in height.
Rugosodon = ?

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

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

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

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

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

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

(0) Present as an anterior cuspule but not at the cingulid level; (1) Present, at the cingulid level; (2) Present, positioned above the cingulid level; (3) hypertrophied cusp e = pseudo-hypoconulid; (4) Absent.
Rugosodon = ?

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

75. Mesial cingulid features above the gum:
(0) Absent; (1) Weak and discontinuous, with individualized cuspules below the trigonid (as individual cuspule e, f, or both, but e and f are not connected); (2) Present, in a continuous shelf below the trigonid (with no relations to the protoconid and paraconid), without occlusal function; (3) Present, with occlusal contact to the upper molar.
Rugosodon = 0

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

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

78. Interlocking mechanism between two adjacent lower molars:
(0) Absent; (1) Present, posterior cingular cuspule d (or the base of the hypoconulid) of the preceding molar fits in between cingular cuspules e and f of the succeeding molar; (2) Present, posterior cingular cuspule d fits between cingular cuspule e and cusp b of the succeeding molar; (3) Present, posterior cingular cuspule d of the preceding molar fits into an embayment or vertical groove of the anterior aspect of cusp b of the succeeding molar (without any involvement of distinctive cingular cuspules in interlocking). (4) Anterior corner of succeeding lower molar overlapping posterior corner of preceding lower molar.
Rugosodon = 0

79. Size ratio of the last three postcanines:
(0) Ultimate molar is smaller than the penultimate molar (m1≥m2≥m3; or m2≥m3≥m4; or m3≥m4≥m5; or m4≥m5≥m6; or p4≥m1≥m2); (1) Penultimate molar is the largest of the molars (m1≤m2≤m3≥m4; or m1≤m2>m3); (2) Ultimate molar is larger than the penultimate molar (m1≤m2≤m3); (3) Equal size.
Rugosodon = 0

80. Paraconid position relative to the other cusps of the trigonid on the lower molars (based on

the lower second molar):
(0) Paraconid in anterolingual position; (1) Paraconid lingually positioned (within lingual 1/4 of the trigonid width); (2) Paraconid lingually positioned and appressed to the metaconid; (3) Paraconid reduced in the selenodont/lophodont patterns.
Rugosodon = ?

81. Orientation of the paracristid (or the crest between cusps a and b) relative to the longitudinal axis of the molar (from Hu et al. 1998) (This is separated from the previous character ["lingual" vs. "labial" position of the paraconid] because of the different distribution of the a-b crest among mammals with non-triangulated molars sampled here):
(0) Longitudinal orientation; (1) Oblique; (2) Nearly transverse.
Rugosodon = ?

82. Angle of the paracristid (b-a crest) and the protocristid (a-c crest) on the lower molar:
(0) > 90^{o}; (1) 90^{o} ~ 50^{o}; (2) < 35^{o}.
Rugosodon = ?

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

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

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

86. Lower molar hypoflexid (concavity anterolabial to the hypconid or cusp d):
(0) Absent or shallow (all "triconodont-like" teeth are coded as "0" here as long as they have cuspule d); (1) Deep (40~50% of talonid width); (2) Very Deep (>65%); (3) Pseudo-hypoflexid (40% to 65% of the pseudo-talonid width).
Rugosodon = ?

87. Morphology of the talonid (or the posterior heel) of the molar:
(0) Absent; (1) Present, as an incipient heel, a cingulid, or cingular cuspule (d); (2) Present, as a transverse 'V-shaped' basin with two functional cusps; (3) Present, as an obtuse 'V-shaped' triangle; (4) Present as a basin (rimmed with 3 functional cusps with at leas is a functional crest to define the medial rim of the basin if the entoconid is not already present) with wear occurs only crests but absent from the bottom of the basin (following Martin and Rauhut 2005); (5) as a functional basin (rimmed by 3 cusps) with wear occurs inside the basin.
Rugosodon = ?

88. Hypoconid (we designate the distal cingulid cuspule d as the homolog to the hypoconid in the teeth with linear alignment of the main cusps; we assume the cusp to be the hypoconid if there is only a single cusp on the talonid in the teeth with reversed triangulation):
(0) Present, but not elevated above the cingulid level; (1) Present (as distal cusp d, *sensu* Crompton 1971), elevated above the cingulid level, labially positioned (or tilted in the lingual direction); (2) Present (larger than cusp d, with occlusal contact to the upper molar), elevated above the cingulid level, labially positioned.
Rugosodon = ?

89. 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):
(0) Absent; (1) Present, and median (near the mid-point of the transverse talonid width); (2) Present, and placed within the lingual 1/3 of the talonid basin; (3) Incorporated into the crest of lophodont or selenodont conditions.
Rugosodon = ?

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

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

92. Last lower molar - hypoconulid - orientation and relative size (applicable to the taxa with at least a talonid heel; scored on the third molar for *Peramus* and eutherians, the fourth molar for *Kielantherium* and metatherians; justification for separating this

character from the character of the anterior molar hypoconulids is that the ultimate molar shows different morphology and distribution, especially in taxa in which there is posteriorly decreasing size gradient, e.g. *Deltatheridium*):
(0) Short and erect; (1) Tall (higher than hypoconid) and recurved.
Rugosodon = ?

93. Entoconid (if there are three functional cusps on the talonid, we assume that the third and the lingual-most functional cusp on the talonid is the entoconid, following the rationale given by Kielan-Jaworowska et al. 1987):
(0) Absent; (1) Present, about equal distance to the hypoconulid as to the hypoconid; (2) Present, with slight approximation to the hypoconulid (distance between the hypoconulid and entoconid noticeably shorter than between the hypoconulid and hypoconid); (3) Present, and twinned with the hypoconulid.
Rugosodon = ?

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

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

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

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

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

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

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

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

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

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

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

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

106. Height and size of the paracone (cusp B) and metacone (cusp C) (based on the upper second molar if available):
(0) Paracone noticeably higher and larger at the base than metacone; (1) Paracone slightly larger than metacone; (2) Paracone and metacone of equal size or paracone lower than metacone.
Rugosodon = ?

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

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

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

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

conules = 0.31—0.50 of total tooth length); (2) Wide (distance between conules greater than 0.51 of total tooth length); (3) Expanded.
Rugosodon = ?

111. Presence of the paraconule and metaconule on the upper molars:
(0) Absent; (1) Present.
Rugosodon = ?

112. Relative position of the paraconule and metaconule on the upper first and second molars (character adopted from Archibald et al. 2001):
(0) Paraconule and metaconule closer to the protocone; (1) Both positioned near the midpoint of the protocone-metacone; (2) Paraconule and metaconule labial to the midpoint.
Rugosodon = ?

113. Internal conular cristae (conular wing):
(0) Cristae indistinctive; (1) Cristae distinctive and wing-like.
Rugosodon = ?

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

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

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

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

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

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

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

121. Position of the stylar cuspule "E" relative to cusp "D" or "D-position":
(0) "E" more lingual to "D" or "D-position"; (1) "E" distal to or at same level as "D" or "D-position".
Rugosodon = ?

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

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

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

125. Selenodont molar pattern:
(0) Absent; (1) Present.
Rugosodon = 0

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

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

128. Carnassial shearing blades on last upper premolar and first lower molar:
(0) Absent; (1) Present.

Rugosodon = 0

Molar Wear Pattern

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

130. Topographic relationships of wear facets to the main cusps:
(0) Wear pattern across the entire crown; (1) Lower cusps a, c support two different wear facets (facets 1 and 4) that contact the upper primary cusp A; (2) Lower cusps a, c support a single wear facet (facet 4) that contacts the upper primary cusp B (this facet extends onto cusp A as wear continues, but 1 and 4 do not develop simultaneous in these taxa); (3) Multicuspate series, each cusp may support 2 wear facets.
Rugosodon = 3

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

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

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

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

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

136. Morphology of the posterolateral aspect of the talonid (the labial face of the hypoconid or equivalent area of Crompton facet 4, applicable to taxa with fully basined talonid):

(0) Gently rounded; (1) Angular.
Rugosodon = ?

137. Wear pattern within the talonid basin (applicable to those taxa with triangulated molars):
(0) Absent; (1) Present; (2) Present apically on the crests of the talonid; (3) Apical wear on crest and lophodont.
Rugosodon = ?

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

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

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

141. Molar wear facets pseudo-3 and pseudo-4:
(0) Absent; (1) Present.
Rugosodon = ?

142. Molar wear facets pseudo-5 and pseudo-6:
(0) Absent; (1) Present.
Rugosodon = ?

143. Pseudo cusp e and f hypertrophied:
(0) Absent; (1) Present.
Rugosodon = ?

Other Dental Features

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

145. Number of cusps on posterior upper incisors
(0) One; (1) two or more
Rugosodon = 1

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

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

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

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

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

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

152. Upper canine – number of cusps:
(0) Peg-like with single cusp; (1) two or more cusps.
Rugosodon = 1

153. Number of upper canine roots:
(0) One; (1) Two.
Rugosodon = 0

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

155. Number of lower canine roots:
(0) One; (1) Two.
Rugosodon = ?

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

157. Number of lower premolars:

(0) Five or more; (1) Four; (2) Three; (3) Two or less.
Rugosodon = 1

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

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

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

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

162. Procumbency and diastema of first (functional) upper premolar or postcanine in relation to the upper canine:
(0) Not procumbent and without diastema; (1) Procumbent and with diastema.
Rugosodon = 0

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

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

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

166. Ultimate and penultimate upper incisors - morphology:

(0) Absent (peg-like); (1) Present, and spoon-shaped to rhomboid-shaped in lateral view; (2) Present, and spatulate in lateral view; (3) Ultimate and/or penultimate upper incisors bicuspate or tricuspate.
Rugosodon = 3

167. Staggered lower incisor (Hershkovitz 1982):
(0) Absent; (1) Present.
Rugosodon = ?

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

169. Replacement of at least some posterior functional molariform postcanines:
(0) Present; (1) Absent.
Rugosodon = 1

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

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

172. U-shaped transverse ridge in the lower multi-rowed molars:
(0) Absent; (1) Present.
Rugosodon = 1

173. Single-aligned and the buccal row of multi-cusp or multi-rowed lower molar - Cusp ratio:
(0) Second mesial cusp (b2 of Butler 2000) highest; (1) Mesial cusp (b1 of Butler 2000) highest; (2) all cusps are of equal height.
Rugosodon = 0

174. Enlarged and more centrally placed second cusp of either labial row on lower m1 (applicable only to molars with multi-rows of multiple cusps)
(0) Absent; (1) Present.
Rugosodon = 1

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

Rugosodon = 0

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

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

178. Multi-rowed ultimate lower molar:
(0) labial cusp row about equal as lingual cusp row; (1) labial row is longer (by at least half-cusp length) than lingual row.
Tritylodontids = 0
Haramiyidans = 0
Rugosodon = 0
Kuehneodon = 0
Sinobaatar = 1
Plagiaulacids = 1
Cimolodontants = 1

179. Enamel microstructure (character state definition following Wood et al. 1999; distribution following Clemens 1997; Sander 1997; Wood and Stern 1997):
(0) Synapsida columnar enamel (prismless); (1) 'Transitional' (sheath indistinct, 'prismatic' crystallites inclined at less than 45^{o} to the 'interprismatic' matrix); (2) Full prismatic enamel; (3) Enamel absent.
Rugosodon = ?

180. Open root end of the postcanines
(0) Absent; (1) Present.
Rugosodon = 0

Vertebrae and Ribs

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

182. Atlas rib:
(0) Present; (1) Absent.
Rugosodon = 1

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

Rugosodon = 1

184. Axis rib:
(0) Present; (1) Absent (rib fused to form the transverse process).
Rugosodon = 1

185. Postaxial cervical ribs:
(0) Unfused; (1) Fused.
Rugosodon = 1

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

187. Overlapping ventral costal plates:
(0) Absent; (1) Present.
Rugosodon = ?

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

189. Anticlinal vertebra:
(0) Absent; (1) Present.
Rugosodon = 1

190. Mobile lumbar ribs:
(0) Present; (1) Absent.
Rugosodon = 1

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

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

Shoulder Girdle

193. Interclavicle:
(0) Present; (1) Absent.
Rugosodon = 0

194. Contact relationships between the interclavicle (embryonic membranous element) and the sternal manubrium (embryonic endochondral element)

(0) Two elements distinct from each other, posterior end of the interclavicle abuts with the anterior border of manubrium; (1) Two elements distinct from each other, the interclavicle broadly overlaps the ventral side of the manubrium; (2) Complete fusion of the embryonic membranous and endochondral elements resulting in a single and enlarged manubrium**.**
Rugosodon = 0

195. Inverclavicle distal expansion:
(0) Absent; (1) Present.
Rugosodon = 0

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

197. Interclavicle to sternal manubrium length ratio
(0) Interclavicle twice the length of manubrium; (1) Interclavicle nearly equal to manubrium in length.
Rugosodon = 1

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

199. Interclavico-manubrial craniolateral process:
(0) Absent; (1) Present.
Rugosodon = 0

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

201. Curvature of the clavicle:
(0) Boomerang-shaped; (1) Slightly curved**.**
Rugosodon = 1

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

203. Proportion of supraspinous vs. infraspinous fossae (width measured across the "saddle region" of the spine, or near the mid-length of the scapula):
(0) Supraspinous “fossa” on the cranial aspect of the scapula and much narrower than infraspinous fossa; (1) Supraspinous width is 50% to 80% that of infraspinous fossa; (2) Fossae subequal; (3) Supraspinous over 150% that of infraspinous fossa.
Rugosodon = 1

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

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

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

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

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

209. Anterior process of the coracoid:
(0) Indistinctive; (1) Distinctive; (2) Distinctive and forming a broad plate.
Rugosodon = 1
Sinobaatar = 1
Cimodontans = 1

210. Coracoid process bridging over posteriorly toward the vertebral border of scapula (or fused with the latter):
(0) Absent; (1) Present.
Rugosodon = 0

211. Size of the anterior-most element (‘manubrium’) relative to the subsequent sternebrae in the sternal apparatus:
(0) Large; (1) Small.
Rugosodon = 0

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

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

214. Medial surface of the scapula:
(0) Convex; (1) Flat.
Rugosodon = 0

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

Forelimb and Manus

216. Humeral head:
(0) Subspherical, weakly inflected; (1) Spherical, strongly inflected.
Rugosodon = 1

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

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

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

220. Ventral extension of the deltopectoral crest or the position of the deltoid tuberosity:
(0) Short and limited to the proximal part of the humeral shaft; (1) Extending ventrally (distally) at least 1/3 the length of the shaft.
Rugosodon = 0

221. Teres tuberosity on medial side of humerus.
(0) Absent; (1) Present; (2) Hypertrophied.
Rugosodon = 0

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

223. Radial articulation on the distal humerus:
(0) Distinct and rounded radial condyle in both anterior (ventral) and posterior (dorsal) aspects (that does not form a continuous synovial surface with the ulnar articulation in the ventral/anterior view of the humerus); (1) Rounded radial condyle anteriorly but cylindrical posteriorly; (2) Capitulum (forming a continuous synovial surface with the ulnar trochlea; cylindrical in both anterior and posterior aspects).
Rugosodon = 0

224. Entepicondyle and ectepicondyle of the humerus:
(0) Robust; (1) Weak.
Rugosodon = 1

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

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

227. Styloid process of the radius:
(0) Weak; (1) Strong.
Rugosodon = 1

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

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

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

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

Pelvic Girdle

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

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

234. Acetabular dorsal emargination:
(0) Open (emarginated); (1) Closed (with a complete rim).
Rugosodon = ?

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

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

237. Posterior spine of the ischium:
(0) Short and pointed; (1) expanded with oblique posterior spine; (2) expanded and truncated.
Rugosodon = 1

238. Epipubic bone:
(0) Present; (1) Absent.
Rugosodon = 0

239. Width of epipubis:
(0) Narrow; (1) Wide.
Rugosodon = 0

240. Fusion of the sacral vertebrae with the proximal caudal vertebrae:
(0) Absent; (1) Present.
Rugosodon = 0

241. Fusion of the ischium with the caudal vertebrae:
(0) Absent; (1) Present.
Rugosodon = 0

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

243. Fully encircled synovial surface inside the acetabulum:
(0) Absent; (1) Present
Rugosodon = 0

244. Lesser psoas tuberosity or process on the pubis:
(0) Absent; (1) Present.
Rugosodon = ?

Hindlimb and Pes

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

246. Fovea for the acetabular ligament on the femoral head:
(0) Absent; (1) Present.
Rugosodon = ?

247. Orientation of the greater trochanter:
(0) Directed dorsolaterally; (1) Directed dorsally.
Rugosodon = 0

248. Level of greater trochanter relative to femoral head:
(0) Mid-level of femoral head; (1) Top level of femoral head
Rugosodon = 0

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

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

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

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

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

254. Distal tibial malleolus:
(0) Weak; (1) Distinctive.
Rugosodon = 1

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

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

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

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

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

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

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

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

(0) Little or absent; (1) Weakly developed; (2) Present.
Rugosodon = 1

263. Astragalo-navicular articulation – symmetry to the neck:
(0) Articulating facet indistinctive; (1) Asymmetrical: present only on the lateral side of the "neck region", or Szalay's [1994] comment on "necklessness"); (2) Symmetrical with regard to the astragalar neck.
Rugosodon = 2

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

265. Astragalonavicular contact aspect ratio:
(0) Navicular contact transversely wider than dorsoventrally thick; (1) Navicular contact dorsoventrally thicker than transversely wide.
Rugosodon = 0

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

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

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

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

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

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

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

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

274. Peroneal groove of the calcaneus:
(0) Indistinct, on the anterolateral aspect of the lateral shelf; (1) Distinct, deep separation of the peroneal process; (2) Weakly developed, with shallow groove on the lateral side of the process; (3) Distinct, on the anterolateral corner of the peroneal process.
Rugosodon = 0

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

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

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

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

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

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

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

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

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

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

Rugosodon = 1

285. Anterior ventral (plantar) tubercle of the calcaneus:
(0) Absent; (1) Present, at the anterior edge (just lateral to the cuboid facet); (2) Present, set back from the anterior edge.
Rugosodon = 0

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

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

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

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

290. Proportion of the entocuneiform, mesocuneiform, and ectocuneiform (in ventral view):
(0) Mesocuneiform and ectocuneiform small, their combined width smaller than the width of the entocuneiform; (1) Mesocuneiform and ectocuneiform large, their combined width (in dorsal view) exceeding the width of the entocuneiform.
Rugosodon = 1

291. Saddle-shaped contact between entocuneiform and proximal end of metatarsal 1.
(0) Absent; (1) Present.
Rugosodon = 1

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

293. Prehallux:
(0) Absent; (1) Present.
Rugosodon = 0

294. End-to-end contact of metatarsal V and the peroneal process of the calcaneus:
(0) Absent; (1) Present.

Rugosodon = 0

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

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

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

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

299. Opposable hallux:
(0) Absent; (1) Present.
Rugosodon = 0

Other Postcranial Characters

300. Ossified patella:
(0) Absent; (1) Present.
Rugosodon = 0

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

302. External pedal (tarsal) spur:
(0) Absent; (1) Present.
Rugosodon = 1

303. Pes digital grouping:
(0) Didactylous; (1) Syndactylous.
Rugosodon = 0

304. Epiphyses in long bones:

(0) Absent; (1) Present.
Rugosodon = 1

Basicranium

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

306. Participation of the cranial moiety of the squamosal in the endocranial wall of the braincase:
(0) Absent; (1) Present.
Rugosodon = ?

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

308. Multiple vascular foramina (for branches of external ethmoidal artery) in the dorsal surface of the frontal:
(0) Absent; (1) Present.
Rugosodon = ?

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

310. Cross-section profile of the squamosal anterior to its zygomatic root:
(0) Rounded or triangular and tapering anteriorly; (1) Dorsoventral expanded and mediolaterally compressed, and not tapering anteriorly.
Rugosodon = ?

311. Postglenoid depression on the squamosal:
(0) Present as the post-craniomandibular joint sulcus (“external auditory meatus” on the zygoma); (1) Absent; (2) Present on the skull base.
Rugosodon = ?

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

313. Position of the craniomandibular joint:
(0) Posterior or lateral to the level of the fenestra vestibuli; (1) Anterior to the level of the fenestra vestibuli.
Rugosodon = ?

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

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

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

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

318. Medial margin of the glenoid fossa:
(0) Formed by the squamosal; (1) Formed by the alisphenoid.
Rugosodon = ?

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

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

321. Relationship of the cochlear housing to the lateral lappet of the basioccipital:
(0) Entirely covered by the basioccipital; (1) Medial aspect covered by the basioccipital; (2) Partially (~about half width on the medial side) covered by the basioccipital; (3) Fully exposed as the promontorium.

Rugosodon = ?

322. Thickened rim of the fenestra vestibuli:
(0) Present; (1) Absent.
Rugosodon = ?

323. Cochlear housing fully formed by the petrosal:
(0) Absent; (1) Present.
Rugosodon = ?

324. Ventromedial surface of the promontorium:
(0) Flat; (1) Inflated and convex.
Rugosodon = ?

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

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

327. Internal acoustic meatus - cribriform plate:
(0) Absent; (1) Present.
Rugosodon = ?

328. Internal acoustic meatus depth:
(0) Deep with thick prefacial commissure; (1) Shallow with thin prefacial commissure.
Rugosodon = ?

329. Primary bony lamina within the cochlear canal:
(0) Absent; (1) Present.
Rugosodon = ?

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

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

Rugosodon = ?

332. Post-promontorial tympanic recess:
(0) Absent; (1) Present.
Rugosodon = ?

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

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

335. Petrosal - tympanic process (Kielan-Jaworowska 1981):
(0) Absent; (1) Present.
Rugosodon = ?

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

337. Prootic canal:
(0) Absent; (1) Present, vertical; (2) Present, horizontal and reduced.
Rugosodon = ?

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

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

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

341. Enclosure of the geniculate ganglion by the bony floor of the petrosal in the cavum supracochleare:

(0) Absent; (1) Present.
Rugosodon = ?

342. Hiatus Fallopii:
(0) Present, in the petrosal roof of the middle ear; (1) Present, at the anterior end of the petrosal; (2) Absent (applicable only to those taxa with a cavum supracochleare).
Rugosodon = ?

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

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

345. Number of exit(s) for the mandibular branch of the trigeminal nerve (V_3):
(0) One; (1) Two.
Rugosodon = ?

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

347. Alisphenoid canal (for the ramus inferior and/or ramus infraorbitalis):
(0) Absent; (1) Present.
Rugosodon = ?

348. Anterior lamina exposure on the lateral braincase wall:
(0) Present; (1) Reduced or absent.
Rugosodon = ?

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

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

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

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

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

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

355. “Bifurcation of the paroccipital process” - presence vs. absence (this is modified from the character used in several previous studies):
(0) Absent; (1) Present.
Rugosodon = ?

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

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

358. Epitympanic recess lateral to the crista parotica:
(0) Absent; (1) Present.
Rugosodon = ?

359. Tympanohyal contact with the cochlear housing:
(0) Absent; (1) Present.
Rugosodon = ?

360. Relationship of the squamosal to the paroccipital process:
(0) Squamosal covers the entire paroccipital region; (1) No squamosal cover on the anterior paroccipital region; (2) Squamosal covers a part of the paroccipital region,

but not the crista parotica (the squamosal wall and the crista parotica are separated by the epitympanic recess).
Rugosodon = ?

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

362. Stapedial artery sulcus on the petrosal:
(0) Absent; (1) Present.
Rugosodon = ?

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

364. Deep groove on the anterior pole of the promontorium (Muizon 1994):
(0) Absent; (1) Present.
Rugosodon = ?

365. Perbullar canal or sulcus for the internal carotid artery.
(0) Absent; (1) Present.
Rugosodon = ?

366. Epitympanic wing medial to the promontorium:
(0) Absent; (1) Present.
Rugosodon = ?

367. Ectopterygoid process of the alisphenoid:
(0) Absent; (1) Present.
Rugosodon = ?

368. Tympanic process of the alisphenoid:
(0) Absent; (1) Present, but limited to the "piriform" region of the basicranium; (2) Intermediate; (3) Well-developed, extending to near the jugular foramen.
Rugosodon = ?

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

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

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

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

373. Relationship of the jugular foramen to the opening of the inferior petrosal sinus:
(0) Confluent; (1) Separate.
Rugosodon = ?

374. Stapedial muscle fossa size:
(0) Absent; (1) Present, small; (2) Present, large (twice the size of the fenestra vestibuli).
Rugosodon = ?

375. Alignment of the stapedial fossa relative to the crista interfenestralis:
(0) Aligned with crista interfenestralis; (1) lateral to the crista interfenestralis
Rugosodon = ?

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

377. Number of separate hypoglossal foramina:
(0) Single; (1) Double.
Rugosodon = ?

Middle Ear Ossicle Characters

378. Geometry (shape) of the incudo-mallear contact:
(0) Trochlear (convex and cylindrical) surface of the incus; (1) Trough; (2) Saddle-shaped contact on the incus; (3) Flat surface.
Rugosodon = ?

379. Alignment of the incus and the malleus:
(0) Posterior-anterior; (1) Posteromedial to anterolateral; (2) Dorsoventral.
Rugosodon = ?

380. Twisting of the dorsal plate relative to the trochlea on the quadrate:

(0) Dorsal plate aligned with the trochlea; (1) Dorsal plate twisted relative to the trochlea, (2) Dorsal plate twisted and elevated from the trochlea; (3) Dorsal plate reduced to a conical process (crus longum).
Rugosodon = ?

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

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

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

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

385. Quadratojugal:
(0) Present; (1) Absent.
Rugosodon = ?

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

387. Stapedial ratio:
(0) Less than 1.4; (1) 1.4-1.8; (2) ≥1.8.
Rugosodon = ?

388. Bullate stapedial footplate:
(0) Absent; (1) Present.
Rugosodon = ?

389. Malleolar neck:
(0) Absent; (1) Present.
Rugosodon = ?

390. Length of the malleus manubrium:
(0) Shorter than the combined width of the surangular and prearticular anterior to the incudo-malleolar joint; (1) longer than the combinted width of surangular and prearticular.
Rugosodon = ?

391. Thickness of malleolar manubrium:
(0) robust; (1) gracile.
Rugosodon = ?

392. Distinctive angle or bending of Meckel's bone (=anterior portion of postdentary rod) anterior to the level of ectotympanic (angular) bone:
(0) Absent; (1) Present.
Rugosodon = ?

393. Medio-lateral contact vs. separation of Meckel's element (either independent or as an ossified component of the "postdentary rod") from the posterior (pterygoid) region of mandible:
(0) Presence of medio-lateral contact either in adult or in embryonic stage until Meckel's cartilage re-absorption; (1) Embryonic Meckel's cartilage medio-laterally separated from the posterior part of mandible; (2) Ossified Meckel's cartilage medio-laterally separated from the posterior part of mandible:
Rugosodon = ?

394. Ectotympanic size/shape (may be ordered):
(0) Plate-like; (1) Curved and rod-like; (2) Ring-shaped; (3) Slightly expanded (fusiform); (4) Expanded; (5) Tube-like.
Rugosodon = ?

395. Ectotympanic arc:
(0) About 70 degrees: (1) ≤ 90 – 135 degrees; (2) ≥ 135 degrees.
Rugosodon = ?

396. Anterior process of the ectotympanic (angular):
(0) Present; (1) Absent.
Rugosodon = ?

397. Position/orientation of the incisura tympanica:
(0) Posteroventral; (1) Posterior; (2) Posterodorsal; (3) Dorsal.
Rugosodon = ?

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

Rugosodon = ?

399. Entotympanic and its contribution to the bullar structure:
(0) Absent; (1) Present.
Rugosodon = ?

Other Cranial Characters

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

401. Posterior median spine (or torus) on the palate:
(0) Absent; (1) Present.
Rugosodon = ?

402. Pterygopalatine ridges:
(0) Present; (1) Absent.
Rugosodon = ?

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

404. Pterygoids contact on midline on pharyngeal roof:
(0) Present; (1) Absent.
Rugosodon = ?

405. Ventral opening of the minor palatine foramen:
(0) Encircled by the pterygoid (and ectopterygoid if present) in addition to the palatine; (1) Encircled by the palatine and maxilla, separated widely from the subtemporal margin; (2) Encircled completely by the palatine (or between palatine and maxilla), large, with thin bony bridge from the subtemporal margin; (3) Large, posterior fenestration; (4) Notch.
Rugosodon = ?

406. Transverse canal foramen:
(0) Absent; (1) Present.
Rugosodon = ?

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

408. Overhanging roof of the orbit:
(0) Absent; (1) Present, formed by the frontal.
Rugosodon = ?

409. Exit(s) of the infraorbital canal:
(0) Single; (1) Multiple.
Rugosodon = ?

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

411. Size and shape of the lacrimal:
(0) Small, oblong-shaped on the facial part of the rostrum; (1) Large, triangle-shaped on the facial portion of rostrum; (2) Crescent shaped on the facial portion of the rostrum; (3) Reduced to a narrow strap; (4) Absent from the facial portion of the rostrum.
Rugosodon = ?

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

413. Number of lacrimal foramina:
(0) One; (1) Two.
Rugosodon = ?

414. Lacrimal foramen composition:
(0) Within the lacrimal; (1) Bordered by or within the maxilla.
Rugosodon = ?

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

416. Ultimate upper molar implanted in the anterior root of zygoma.
(0) Absent. (1) Present.
Rugosodon = ?

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

Rugosodon = ?

418. Frontal-maxilla facial contact:
(0) Absent; (1) Present.
Rugosodon = ?

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

420. Posterior width of the nasal bones:
(0) Narrow; (1) broader than the width at the mid-length of the nasal.
Rugosodon = ?

421. Pila antotica:
(0) Present; (1) Absent.
Rugosodon = ?

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

423. Separation of the optic foramen from the sphenorbital fissure:
(0) Absent; (1) Present.
Rugosodon = ?

424. Exit for maxillary nerve:
(0) Separate from sphenorbital fissure, behind alisphenoid; (1) Separate from sphenorbital fissure, within alisphenoid; (2) Confluent with sphenorbital fissure.
Rugosodon = ?

425. Separate anterior opening of orbitotemporal canal:
(0) Absent; (1) Present.
Rugosodon = ?

426. Orbital opening for the minor palatine nerve:
(0) Absent; (1) Present.
Rugosodon = ?

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

Rugosodon = ?

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

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

430. Orbital process of the frontal borders on the maxilla within orbit:
(0) Absent; (1) Present.
Rugosodon = ?

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

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

433. Nuchal crest:
(0) Overhanging the concave or straight supraoccipital; (1) Weakly developed with convex supraoccipital.
Rugosodon = ?

434. Sagittal crest:
(0) Prominently developed; (1) Weakly developed; (2) Absent.
Rugosodon = ?

435. Tabular bone:
(0) Present; (1) Absent.
Rugosodon = ?

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

437. Occipital artery groove on the occiput extending dorsal to the posttemporal foramen:

(0) Absent; (1) Present.
Rugosodon = ?

438. Foramina on the dorsal surface of the nasals:
(0) Absent; (1) Present.
Rugosodon = ?

439. Septomaxilla:
(0) Present, with the ventromedial shelf; (1) Present, without the ventromedial shelf;
(2) Absent.
Rugosodon = ?

440. Internarial process of the premaxilla:
(0) Present; (1) Absent.
Rugosodon = ?

441. Posterodorsal process of the premaxilla:
(0) Does not extend beyond canine ("short or absent"); (1) Extends beyond canine ("intermediate"); (2) Contacts frontal posteriorly (“long”).
Rugosodon = ?

442. Facial part of the premaxilla borders on the nasal:
(0) Absent; (1) Present.
Rugosodon = ?

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

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

445. Palatal vacuities:
(0) Absent; (1) Present, near palatomaxillary border; (2) Present, either positioned near or extended to the posterior edge of bony palate.
Rugosodon = ?

446. Major palatine foramina:
(0) Absent; (1) Present.
Rugosodon = ?

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

Rugosodon = ?

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

Cranial Vault and Brain Endocast Characters

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

450. Anterior expansion of the vermis (central lobe of the cerebellum):
(0) Absent; (1) Present.
Rugosodon = ?

451. Overall size of the vermis:
(0) Small; (1) Enlarged.
Rugosodon = ?

452. Lateral cerebellar hemisphere (excluding the paraflocculus):
(0) Absent; (1) Present.
Rugosodon = ?

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

454. Encephalization quotient
(0) Below 0.13; (1) Between 0.15-0.25, (2) Above 0.26.
Rugosodon = ?

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

Soft-tissue characters

456. Trophoblasts in the placenta:
(0) Absent; (1) Present.
Rugosodon = ?

457. Mullerian ducts (oviduct and uterus) pass in between the ureters (Renfree, 1993):
(0) Absent; (1) Present.
Rugosodon = ?

458. Placental types (Renfree 1993):
(0) Placena absent; (1) Placenta present with vascularized chorio-allantois; (2) Placenta present without vascularized chorio-allantois.
Rugosodon = ?

Part G. Matrix Table of Character Distribtution of Mammaliaform Clades

MATRIX

Polymorphic Characters:
A=0/1; B=0/2; C=2/3; D=1/2; E=3/4; F=1/3; G=0/1/2.

Thrinaxodon
0000000000 0000000000 0000000?0? 0?0?01000? ???????0?00 000?????00 ?????00??? ?000000?? 0?????????
????????00? ?????????? ?????????? ????0??000 ?????????? ???0000000 00000????0 0?0?000000 1?0??????00
0000010000 000000?0?0 0000?00000 0000000000 0000000??? ?000000??0 0000000000 0000000?0 000?000000
0000000000? 0000000011 0000000??0 0000000?0 0?????????0 000??000?? 00?0?00?00 0?00000?0? 1000000??0
????0?00?0 0??0?0?000 0000000000 0000000000 0000000000 0000000000 0000000?00 0000000000 0001000000
00000???

Massetognathus
0000010000 0000000100 0000000?0? 0?00001000? ????????20 000?????20 ?????00??? ?000000?? ??????????
????????00? ?????????? ?????????? ????0??011 ?????????? ???0000000 00000????0 0?0?000000 100?????00
??????0000 00??0?0??? ??0?????00 ????000000 0000000??? ?10????0??0 0000???0?? 0????0?00?? ??????????
?????????? ?????????? ?????????0 ????0??00?0 0????????1 000??000?? 00?0?00?00 0?00000100 1000000??0
????0?00?0 0??0?0?101 0000000000 0001000000 0000003000 0000000000 0100000?00 0000000?0 0000000000
00010???

Probainognathus
0000000000 0000000100 0000000?00 0?00001000? ????????00 000?????00 ?????00??? ?000000?? 0?????????
????????00? ?????????? ?????????? ????0??000 ?????????? ???0000000 00000????0 0?0?000000 ??0??????00
??????0100 00??0?0?0? ??0?????00 ?????????? 0????0???? ?10????0??0 00?0???0?? 0????0?00?? ??????????
?????????? ?????????? ?????????? ????0??00?0 0??????0?1 000??000?? 00?0?00?00 0?00000100 1100000??0
????0?00?0 0??0?0?001 000000?000 0001000000 0000000000 0000000000 0100000?00 0000000?0 0000000000
00101???

Tritylodontids
0000010000 0000000000 0000010?00 0?30002200? ????????20 ?00????21 ?????24???? ?000000??? ??????????
????????00? 00???????? ????1????? ?0??033023 ?????????? ???3030000 2???2??000 0?2?10??11 2010000000
00000?0100 0000000000 0000000000 000000000A 1000000??? ?200001020 0000000000 0000000?0 000?00?000
0000000000 0000000001? ?000?0?000 0000000?0 0?0????0?01 111??10000 00?0000000 0?00000100 0000100??0
00000?0000 0?0100?002 1000000000 0001000000 00A0103010 0000000000 0200100?10 0000000000 0A00000100
?0111???

Pachygenelus
0000000000 0001000000 0000000000 0?20000100 ???????1?00 000????0?00 ?????00???? ?000000?0? 00????????
????????00? ?????????? ?????????? ????0??000 ?????????? ???3030000 10000??000 0?1?200000 1?1?????00
000?0??10? ?000010020 0000?00000 0000000000 1000000100 0210001??? ?00?000000 0?????00?? ??????????
?????????? ?????????? ?????????? ???0000000 100?0?0?01 111??1?000 00?0000?00 0?00000101 1000000??0
00000?0001 0000?1?002 1001100000 0001000000 0010000010 1010100000 0100000?10 0000000000 0000000000
????????

Adelobasileus
?????????? ?????????? ?????????? ?????????? ?????????? ????????0? ?????0???? ?000000?0? 00????????
?????????? ?????????? ?????????? ????????00 ?????????? ?????????? ?????????? ?????????? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?0???????? ?????????? ??????????
?????????? ?????????? ?????????? ????00000? ????????02 21100????? 0000001?11 ??10100001 0010000???
0000000001 0000?10??? ??????0??? ????????0? ?0?0?000?? ???????00?? 0200?????? 0001100??? ????????0?
????????

Sinoconodon
0000001000 0000000000 0000001101 000000010? ?????01100 000?00?000 ??????0?20? ?0B0000010 00???0000?
??0????00? 00????0???? ????0????? ?0??000000 ?0?0?????? 0000000000 0000033112 2020000000 1???????10
00??0?01?? ??00100000 0000000000 0000000000 1000000??? ?????????? ????000?00 ?0????00??? ??????????
?????????? ?????????? ?????????? ???0000000 10000?0002 2110010000 0000001011 1010100000 0000100?00
0000000001 0001010102 1001100000 0001000001 0010100010 1000100000 0200010020 0000000100 0000000100
00102???

Morganucodon
0000101000 0000000000 0000002A01 000000010? 0000000100 000?00?000 ?0??11?20? ?200000200 00???0000?
??0????00? 40????0???? ????0????? ?0??000011 00?0?????? 000A0A0000 0000000CB0 0000000110 1????????0
00000??111 ?00??1???0 0100?00000 ?000000000 1000000??? ?2100010?? ?0000010000 010?0000?? 000?000000
0000000000 0000000??? ?0?????????0 ??00000010 100AA?0002 3111120100 0000001011 1010100011 0100111001
0000000001 0001010002 1002100000 0001000001 0010100010 1010100000 0200010020 0001100110 0000000100
00112???

Megazostrodon
0000100000 0000000000 0000002002 001000010? 0000000000 000?00?000 ?0??12?20? ?200000200 00???0000?
??0????00? 40????0???? ????0????? ?0??000011 00?0?????? 0001010000 0000000110 0000000100 1????????2?
00000?0111 00????????0 ?100000000 ?000000000 100000??0? ?2100010?0 0000010000 0?00000?0? 000?00?000
000000?00? ?0???0?0?1? 0000000000 00000?0010 100???0002 3110120100? 0000001011 1010000011 ?100110?01
0000000001 000101?002 10?21???0? ?001?00001 0?1??00010 1010100000 ??20010020 0001?00??? ????00??0?
????????

Haldanodon

0000011000 1000100010 0000002101 0010000010? 0000000100 001?10?000 ?0??11?20? ?200320000 00???0000?
??0????00? 11????0???? ?????0????? ?0??032011 00?0?????? 0000010000 0000122000 0000000110 0???????00
?????????? ?????????? ?100001000 ?00?000001 20000?0??? ?????????? ??000?0000 0?0?0?0??? ??????????
?????????? ?????????? ??????????0 ???0000010 20011?0002 3110020100 0000001?12 10100?001? ???0101001
0000000001 0001010000? ???2100??? ?00??00002 011?100010 1010100000 0200010020 1001110110 0000000000?
???2?????

Castorocauda
00?0011000 1????1?0000 0000002101 0010000010? 0???0??100 00?010?000 ?0??11?2?? ?200320000? 00????000?
??0??????? ?????????? ?????????? ??????0?011 00?0?????? 000??100?? ???01?00?? 0??0??0110 0?????????0
??????0000 00????????? ?????????? ?????00001 2000000000 0110000000 0000000000 0101000?0 000??????00
0000000000 0000??00?0 ??0?000000 1100???010 ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ????????11 0001000??? ????????0?? ????10?000 ?2?????0?2? ????1???11? 00?????????
????????

Hadrocodium
1??2?13001 0?40211000 0000002001 00200?010? 0000101000 000?0??000 ?0??12?20? ??00000000 00????0000?
??0????00? 00????0???? ?????0????? ?0??000011 00?0?????? 0000000000 0010033444 3000000110 1?????????0
?????????? ?????????? ?????????? ?????????? ?????0???? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ????100000 20101?0002 3111230100 0000001?11 1010?10011 0210101101
0000000001 00?1010??? ????21?0??? ????1????02 012?103010 1000100000 12?2?10020 1012110011 00??000?2?
?1213???

Shuotherium
0010110??0 000021??00 0?00?0???? 0?00010010? ???????1111 111??0?013 ?200120100 ?132321001 1100001100?
??0????11? 1100200000? 0??0000000 ?010012022 1100??0100 111??????? ????????3?? ????0?????? ??????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Pseudotribos
0?10011000 ?0001???00 ??????2101 0100011110? ?0????01111 1?1110?013 ?200120100 ?132321001 11000?100?
??0????11? 1100200000? 0??0000000 ?010012022 1100??0100 111?01?0?? 1001000331 0000??0110 0?????????0
?????101?0 0?00100001? ?????????? 0????0???1 2000000??? ?211???000 00?10?0000 000?00???? ??????????
?????????? ?????????? ??????????0 ????0?????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????0???? ?????????2? ??1??????? ??????????
????????

Asfaltomylos
0012112110 000021??00 2200002131 0120010??? ???????1101 1??????013 ?2??13??13 ?021000?1 1102214110
0011112??? ?????????? ?????????? ????01?022 11?1102??0 000???????? ?????????? ????0?????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Ambondro
?????1???0 0????1???? ????0????? 0???0?0??? ??????1213 1110???013 ?2??130?13 3001210?1 1102224112
0?11112??? ?????????? ?????????? ????01?022 11?1102010 000???????? ?????????? ????0?????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Ausktribosphenos
0010012010 000021??00 2200002??1 0120010010? ??????1213 111011?013 ?2??130213 3001210002 2102214122
0032123??? ?????????? ?????????? ????03?022 21?1112111 000???????? ???????3?? ??00?????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Bishops
01?1012010 0?0021??00 2200002131 0120010?0? ??????1213 1?1011?013 ?2??130213 3001210012 2102214122
0032123??? ?????????? ?????????? ????03?022 21?1112111 000???????? ??????03?? 0?00?????? ??????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Teinolophos
1100212010 013021??00 2200?2131 0120010??? ?????????? ?????????3 ?2??131111 2001201?2 2204223121
0?02?23??? ?????????? ?????????? ?????3?022 21?2113102 000???????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Steropodon

```
011001???0 ??00?1???? ?????????? ?????10??? ?????????? ???????013 ?2??131111 2001211002 2204223121
0?02?23??? ?????????? ?????????? ????03?022 21?2113102 000?????? ???????3?? 3????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????
```

Obdurodon

```
11?2?12010 0130211011 2200012131 1121110?0? ??????1013 100????013 ?2??131111 2001201002 2204223121
0?02?2320? 1????????? ?????0???? ????033022 21?2113102 0004?5???? 2???233344 3??0????1? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?21???1??? ?11??????? ?????????? ??????????
?????????? ?????????? ?????????? ???1000021 10110?0002 31111????? 0000001?11 1?11010011 1210110?11
0000000000 0?00?0???? ????1?0??? ????????03 012?10000? 40?110211? 1202011?2? 0012110011 ?0??000021
???2????
```

Ornithorhynchus

```
11?2?10010 0130211011 2200012131 112111B10? ?????????? ????????13 ?2??1?1?1? ????201002 2204223121
0??2?2320? 1????????? ?????????? ?0??0330?? ????2?1?1?2 ???4?5???? 2???233444 3??0????1? ?????????0
1110111100 0000100010 0000101000 0000000001 2000000100 1211111000 0111000000 2201100110 000?000000
0101100000 0000000110 0001101001 1A01000021 10010?0002 3111141100 0000001011 1011010011 1210111011
0000000000 0?00?0?323 1212110011 1012101003 0110100002 4001102112 1202011221 0012110011 ?0?1000021
11223000
```

Tachyglossus

```
11?2?10??0 0140211000 0000002131 11??1?010? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ???4?5???? 2???233444 3????????? ??????????
1110111100 0000100010 0000101000 0000000001 2000000100 1211111010 0111000000 2201100110 000?000000
0101100000 0000000110 0001101001 1A01000021 10010?0002 3111141100 0000001011 1011010011 1210111011
0000000001 0?00?0?323 1212110011 1012101003 0121102002 4001??2112 1202111221 0012110011 ?0?D001021
11223000
```

Fruitafossor

```
11?0014000 000021??11 0000112101 011001?10? 0000001?0? 000?0??0?? ????10???? ?0??000000? ??????????
???????00? 0????????? ?????????? ?0???44400? ?????????? ????02?0?? 1001022333 2000?00110 0????????31
??????0100 01????????0 ?000011000 ?001000001 2000100100 121??????0 000????00? 0100?100?0 ?0?????????
0000000000 00?00000?? ??????????0 1??0????10 ????1?????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????0???? ????????2?1 ?????????? ??????????
????????
```

Gobiconodon

```
11?1010??0 0010211012 2100112114 001001010? 0000001001 010000?000 ?0??12?10? ?101000?0? 00???0000?
??0????00? 10????0???? ????0????? ?0??001011 01?0?????? 0002030000 1001011120 0000000101 0????????20
????010100 000000?101 1211111110 0111000001 0100000000 ?210021000 0000000000 0100?000?0 000000?000
0000100000 0000000000? ??????????0 0100000010 20011?0002 3111130100 0000001?12 1120000011 1100111002
0000000001 1??1011??? ????1?1??? ?12?????002 0021100001 1000000001 1200111221 2101100001? 000001??0?
?0?00???
```

Repenomamus

```
11?1010??0 0110211012 2100112114 001001010? 0000001101 010000?000 ?0??12?10? ?101000?0? 00????000?
??0????00? 10????0???? ????0????? ?0??001011 01?0?????? 0002030000 1001011220 0000000101 0????????20
0000010100 0000001101 1211111110 0111000001 0100000?? ?210021000 0000000000 0100000?0 0000000000
0000100000 0000000000? 0?0??0??00 ?100000010 20011?0002 3111130100 0000001?12 1120000011 1100111002
0000?00001 1??101???? ????21?1??? ?12?????02 0021100001 1000000001 1200111221 2101100001? 000001010?
?0100???
```

Amphilestes

```
11?11?0??0 01102???12 2???0??2114 0020020l?? ??????1101 000000?000 ?0??12?10? ?101000?0? 00???0000?
??0????00? ?????????? ?????????? ????001012 01?0?????? 000???????? ???00?21?? 0000??????? 0????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ????????0?? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ??????1???? ?????????? ?????????? ??????????
????????
```

Yanoconodon

```
11?1010??0 0110211012 21001?2214 0010000l0? 0000000000 000000?000 ?0??11?10? ?020000l3?
00????000? ??0????00? 00???0???? ????0????? ?0??000011 00?0??????? 0003030000 0000033334 3000100111
0?????????0 0000010100 0000001101 1211111110 0111000001 0101000000 1210021000 0000000000 0100000?0
0000000000 0000100000 0000000000? 0?0?00??00 0000000010
20?11??00? ?????????? ?????????? ?????0???? ?????????? ?????????? ???????323 12121???11 0122101002
00?????0?? ????11???? ?2?????122? ?????????? ?0????????? ????????
```

Jeholodens

```
11?1010??0 0?10211012 ??001?2214 0010000l0? 0000000101 000000?000 ?0??11?10? ?020000l3?
??0????00? 00????0???? ????0????? ?0??000011 00?0?????? 0001010000 1001033223 2000000111 1?????????0
0000010100 0000001101 1211111110 011100??01 0101000000 1210021000 0000000000 0100000?0 0000000000
0000100000 0000000000 0000001000 0000000010 2?011?0002 3112130100 ??0????10?? 1????????? ??????????
0??0?0???? ?????????? ?21??????? ?1221????? ???????00? 10??11???0 0?????122? ??011??01? ?0???????1?
????????
```

Trioracodon

```
11?10?0??0 011021??12 2100102214 0010000l0? 00000?0101 000100?000 ?0??11?10? ?1B000031? 00???0000?
```

??0????00? 10????????? ?????1????? ?1??000011 00?0?????? 000?0300?? 0000012332 1000??0110 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ????0?????? ?????????02 311??????? ??0??0?0?? 1010???0?? ??????????
???0??0??? 1??10????? ??????0??? ?????????0? ???????0??? ?????1???? ?????????? ?0????????? ??????????
????????

Priacodon
11?1010??0 011021??12 2100102214 0010000010? 0000000001 0101000?000 ?0??11?10? ?120000031? 00???0000?
??0????00? 10????0???? ????1????? ?1??000011 00?0?????? 000??300?? 0?000012222 1000??0110 1????????10
?????????? ????0?????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ????0?????0 ????1??002 3111130l?? 0000001l?? 12100??011 1100??100?
?000??0??1 100101???? ???2??0??? ????????02 0??????000? ?????1???? ???D??122? 10???????? ??0??0??1?
????????

Haramiyavia
0100110??0 00002???00 0000002?01 0?10002l?0 ?????????2? 000??20021 ????24???? ?0??0?000? ??????????
????????0? 00????????? ????1????? ?0??033023 ?????????? ????010000 10?1?11133? 1?00??0??1 2100000?0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ??????0??? ?????????2? ?????????? ??????????
????????

Rugosodon
1112?10??0 0?302?1010 2120102224 0010002l0? ?????0???2? 0?0???2?121 ????24???? ?0??0?000? ??????????
????????0? 00????????? ????1????? ?0??033023 ?????????? ????2140000 1102?01442 2001030?111 2101010020
111110?111 1000001101 1110011110 0110010020 0001011000 121?011000 000?1?0010 0201100000 0121001000
1000120010 0011000101 1000111000 2101?0???? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ??????1???? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Kuehneodon
1112?10??0 0030211010 2120102224 0010002101 ?????0???2? 020??21121 ????24???? ?0??0?000? ??????????
????????0? 00????????? ????1????? ?0??033023 ?????????? ???2140000 1102?11443 200103?111 2101010020
1?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Sinobaatar
1112?10??0 0130211010 2120102224 0010002100 ?????0???2? 010??20121 ????24???? ?0??0?000? ??????????
????????0? 00????????? ????1????? ?0??033023 ?????????? ???2040000 2???202442 3001?0?111 2020111?20
?1?1100111 1000001101 1110011110 0110010020 0001011000 1210A11000 0000111010 0201100000 0121001000
1000120010 0011000101 1000111000 2101000010 10110?000? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ????1????? ???2???00? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Plagiaulacids
1112?10??0 0A30211010 2120102224 0010002101 ?????0???2? 020??21121 ????24???? ?0??0?000? ??????????
????????0? 00????????? ????1????? ?0??033023 ?????????? ???2140000 2???20244C 300103?111 2020111100
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ???????1?? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????2 3111130l?? 0000001012 1110110021 1???1111?1
0?00000001 0001111??? ???21?0??? ???????0?0 0020100100 200010?000 0202?11220 2000100A11 010000?21?
????????

Cimolodontans
1112?10??0 0130211010 21201022D4 0AD0002100 ?????0???2? 000???20121 ????24???? ?0??0?000? ??????????
????????0? 00????????? ????1????? ?0??033023 ?????????? ???3040000 2???21C443 300120?111 2020111120
0011100111 1000001101 1110011110 01100100D0 000A01100? ?210111000 0000111?10 0201100000 0121001000
2211120010 0111001101 1000111000 2101000010 10A10?0002 3111130100 D00A001012 1110110021 121A111A01
0AA0000001 A001110323 1212110011 1??2111000 00D0100100 2000102000 02A2111220 2001100121 0100000211
10223???

Tinodon
1??11????? 001021??12 1?00???104 ?130?00??? ???????0101 000?00?012 01??12?100 0101000l0? 1100001l0?
??00??01O? 11???00??? 0????0????0 ?000021022 11?0?????? 000??????? ????1??22?? 1??0?????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Akidolestes
1????10??0 0?20????12 2100102114 011001110? 00000?1101 000120?113 0201120100 0100000401 2200?0100?
??00??02O? 11???000?? 0??0000000 ?200022022 2100??0000 0001010??? 1001100010 0000000111 0?????????0
?????00110 0001001101 1211111110 0111011111 0111010000 1211112010 00011?0000 0210010110 0100000000
1002010010 0011000010 0001210000 21010?0010 20??1????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ????????0?? ????10?0?? ?2?????12? ????????0?? ?0?????????
????????

Spalacotherium
1111010??0 00202????? 2100102114 011001110? 00000?1101 000100?113 1200120100 0100000401 1200?0100?
??00??02O? 11???000?? 0??0000000 ?200022022 2100??0000 000???????? ???10?000? 0000000??1 0?????????0

```
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ????????1?? ?????0????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????0???? ?????????? ?????????? ??????????
????????

Zhangheotherium
11?0010??0 002020??12 21001?2114 0101011107 0000011101 001?00?013 1100120100 0100000401 1100?0100?
??00??020? 11???000?? 0??0000000 ?200022022 2100??0000 0002020??? 1001022000 0010000111 0???????20
?110000111 1001001101 1211111110 0111011111 0111010000 1211122000 00001?1110 0210010??0 0100000000
1302010010 0011000010 0000200000 2101????10 20111?0012 311112???? 1101001?1? 1?10???0?? 1210111102
0000000001 ?0?11?1??? ????21????? ?1???????0? ?????0???1? ????10???0 ???2????12? ?2????????? 00????????
????????

Maotherium
11?0010??0 002020??12 2100102114 0101011107 0000011101 001?00?013 1100120100 0100000401 1100?0100?
??00??020? 11???000?? 0??0000000 ?200022022 2100??0000 0002020??? 1001022000 0010000111 0????????0
?1?0000111 100?001101 1211?11110 0111011111 0111010000 1211122000 00001?1?10 021A?100?0 0100000000
1302010??? ??11000010 00002A0000 21010?0010 20111?0012 311112???? 1101001?1? ??10?100?1 1000111??2
0000000001 ???11????? ?????????? ?12?????02 01???20?0?? 22??100000 ???2????12? 02?1???0?? 00???????1?
????????

Dryolestes
11?1011100 002020??11 210?012113 0120011107 0000010000 001?00?013 0100130200 0020000001 1100002207
?000??110? 01???000?? 0??0001000 ?200022022 1100?00100 0001010??? 0000011000 0000030111 0???????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ???1?????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ????????1? ??1O?0???? ?????????? ?????????? 00??0?????
????????

Henkelotherium
11?1011100 002021??11 2101??2113 0120011107 00000?0000 0?0?00?013 0100130200 002?000001 1100002207
?000??110? 01???000?? 0??0001000 ?200022022 1100?00100 000?0????? 00?0?11000 0000??0??? 0??????????
??????0111 10??0???01 121111?110 ?111011?10 0111021000 121?022000 0000111000 0211000?1 0??????????
1????????? ?????????? ?????0???0 ?1011???10 20?11?00?2 3111?3???? ?????????? ?????????? ??????????
0????????? ?????????? ?????????? ?????????? ????1????? 20001???1? ????????20 ?????????? ??????????
????????

Amphitherium
11?1111100 002021??11 210?012103 0120011107 11?0?00000 001?00?013 0100130001 0020000000 1100002107
0000??1111 01???000?? 0??0001000 ?200021022 1111000000 000??100?? ???0??000? 0?00?????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Peramus
11?1111100 002021??11 2101012103 0120011107 1100200002 000?00?013 0100130001 0001000100 11A0002110
000A?01211 21?0?01000 0??0001002 0200011022 1111000000 000??2???? ?000000331 0?00??0??? 0??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Vincelestes
11?2?11100 0A2021??11 1101012113 0120011107 0000101000 000?00?013 0100130000 0020000000 1100002107
?00O?0120? 11?0?01000 0??0001012 0000011022 1100?00000 0001030000 0010033334 2000030??0 0??????????
0111100111 1012017101 ?211011110 0111010100 01110?0000 1210122000 0000111000 0211000?1 020?00?100
1302010110 0011010??? 0???210??0 ?001110020 20011?0012 3?11240??1 1101001011 1010010011 A211111102
0110000001 1002111??? ???21?0??? ????????01 0110100010 2010000010 1200010020 2000100111 000000??1?
????????

Nanolestes
11?1011100 002021??11 2?0??12103 0120011107 ??????0000 000?00?013 0100130001 0021000100 1100002100
0?00?0121? 11???0?000 0??1012012 0200011022 1111000000 0001?1???? ??001?02?? 0?00??0??? 0????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Kielantherium
11?1011107 002?21??11 1101?2???? 0130011?0? ??????0000 000?00?013 0110130001 1021100101 1102015110
000A00120? 120000100- 0--1002011 1?0101?022 2111001000 000???????? ???0??12?? 0??0??????? 0????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Aegialodon
?????????? ?????????? ?????????? ?????????? ?????????? ????????1? 01??130001 1021100171 1102015110
0?11001??? ?????????? ?????????? ?????1?222 21?1001000 000???????? ?????????? ?????????? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
```

```
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Montanalestes
11?2?13100 004021??11 1201032103 013001110? ??????1202 001000?013 ?2??130102 1021100120 1202115110
0111002??? ?????????? ?????????? ????0??022 21?1001110 000???????? ??????03?? 0?00?????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ????????1?
????????

Prokennalestes
11?1113100 001021??11 1201022103 012001110? 1A112?1202 000020?013 0220130201 1011100120 1202115110
0111002210 2202001001 1001011010 0200012022 2121001110 000???????? ?010100033? 0000?00?1? 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????2 3111251111 110D001102? 10?????13? 1?11101??
?11001???1 10?21????? ???2??1??? ?????????? ????????0? ?????????? 1????????? ?1???????? ????0?????
????????

Murtoilestes
?????????? ?????????? ?????????? ?????????? ?????????? ????????13 022013?202 1011100?10 1202115110
0?1100?210 2202002001 1001011000 0200012?22 2121001?10 000???????? ?0???????? ?????????? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Eomaia
11?1113100 001021??11 1201022103 012001110? 1011111201 000020?013 0220130201 1011100120 1202115110
0111??2210 2202001001 10010??000 ?200012022 2121001??? 0000010000 0000000331 0010000?10 0?????????0
11?1100111 101200?101 1221011110 0211011120 0221021000 1211122000 00001?1011 0211100?10 1221000212
2302010130 1111010000 0100210001 200111?0?1 ????2??0?? ??1??51?11 ?????????? 1????????? ??????????
?????????1 1????????? ?????????? ?????????0? ???????00? ?0??10?0?? ?2????10?20 ???????02? ?1???????1?
????????

Juramaia
1?12-?1100 0????????? 1201022?03 011001110? 1011201201 00?020?013 0230130??? ???11?012? 1???215110
01????2211 2202001001 1001011011 1201012022 2121001?10 0000010?0? 0010000331 0000000?10 0--?--???0
1111100171 ??????????1 12210??110 ?21?01???? 02210200?? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Kennalestes
11?2?13100 0040211011 1200022??? 0?20011110? 1111201002 000100?013 0220130202 1021100122 2203115110
0111002210 2201101001 1011010000 ?200012022 2121001110 000102???? 001011A332 0010000110 1????????0
01????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
???2?????? ?????????? ?????????? ????110021 2211221022 3111251l?? 210211002E 1?20010l3? ????101102
0100011001 1002110??? ???21?2??? ???3213000? 0110200000 200??0?010 1212110020 2201110021 010?00??10
11223???

Asioryctes
11?2?13100 0040211011 1200022103 013001110? 1112201102 000010?013 0220130202 1021100120 1203115110
0111002210 2201101001 1001000000 ?200012022 2121001110 0000010000 0010111332 1010000?10 1????????0
01111??111 10????????? ?????????? ????0????? 0???0?1100 0??????2?0? ?00??????? 0???1?000?0 1221000212
2302010130 1111010000 00?0200001 ?001110021 2211221022 311125?1?? 2102110?24 1?20010l3? ??111101102
0100011001 1002110??? ???21?2??? ???3213002 0110200000 200?101010 ?212110020 2201110021 010000??10
11223???

Ukhaatherium
?1????????0 0?40?????? ????022??? 0??00?110? 1112201102 000020?013 0220130202 1021100120 1203115110
0111?02210 2201101001 1001000000 ?200012022 2121001110 0000010000 0000011332 1010030?10 1????????0
?1??1?0111 10??0???0? 1221011110 ?211011120 0221021000 1210?22000 00001?1011 0211100?10 1221000212
2302010130 1111010000 0???200??1 ??01??00?1 ?2??221??? 3????????? 2???21????4 ?0?????0??? ????1?????
??0?0?1??? ???21?1??? ????????2?? ?????21??0? 0??????0??? ?????0?010 ???21??0?? ???????0??? ????0??????
????????

Zalambdalestes
11?2?1F100 0A40211011 120A022103 012001110? 1112210212 200120?013 0220131203 1021100102 2204205110
0011102202 1201201101 1000000000 ?200012022 2121001110 000C0211?0 00110DD33C 1010200?11 1????????0
??11100111 10??0???01 ?221011110 ?211011120 0221021000 1211122000 00001?1011 021112102? 1221000212
23?2010013? 0113000000 0000200001 ?001110031 2211221022 311125?1?? 2102110024 1120010l3? ??111101102
0100011001 1002111??? ????21?2??? ???3213002 0110200000 201?101010 1211110A20 2101100021 010000??10
11223???

Daulestes
11?2?13100 0140211011 1200022103 012001110? ???1?????? ????00?013 0220130202 1021100l?1 1202115110
0111002202 1202101001 1111010000 ?200012022 2121001110 000?0100?? 0001011332 00?0??0?10 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
```

```
?????????? ?????????? ?????????? ????110021 2011201022 3111251l?? ?1O??????2? ????01013? ??????11?2
011O0??001 ????????1? ???2??1??? ???3???00? 01?1??000? 100?10?000 ?212110A20 ???1??00?? ????00???2?
????????

Aspanlestes
?????1???? 0??0?????? ???1?????? 0???0?1?0? 11112?1?01 0000?0?013 0231131102 1021100l?1 1201215110
0011002202 1203211103 12100?0000 ?210012022 2121001110 000???????? ??????033? 0??0?????1? 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? 3????????? 1?0?0?1??? ?0??????1?? ??????????
??00?1???? ????1????? ???????1??? ?????????? ????????0? ?????????? ?????????? ?????????? ??????????
????????

Eoungulatum
?????1???? ?????????? ???1?????? 0???0?1??? 10110????? ???????013 0242131103 1021100l?1 1201215111
0012003202 1223211103 1210010000 ?010012022 2121001110 000???????? ??????1332 ???0????1? 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? 3????????? 1???0?1??? ?0???????? ??????????
?000?????? ????1????? ???????1??? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Cimolestes
1??2?1010? 0140211?11 1200?22103 012?01110? 10122?1101 000010?013 0231130202 1021100122 1203115110
0112002210 1211101001 1110000000 ?200012022 2121001110 000??200?? 0?00011332 1?00????1? 0????????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?0???????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Gypsonictops
1??2?10100 0140211?11 1200?22103 012?01110? 11122?1212 000110?013 0231131202 1021100122 1204115110
0112002210 1211101001 1110000000 ?200012022 2121001110 000???????? 0?00011332 0?00????1? 0????????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Protungulatum
11?2?10100 0140211?11 1200022103 0120011110? 10120?1211 000010?013 0242131102 1021100121 1201215111
0012013202 1223211103 1000000000 ?010012022 2121001110 000???????? 0?00011332 1?00????10 0????????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? 222003?212
2312?10130 1113201l?? ?????????? ?????????? ?????????2 311125?1?? 1?0?0?00?? A0?????1?? ??????????
?11001???? 1??21????? ????????2?? ?????????? ?????????? ?????????? ?????????? ?1???????? ??????????
????????

Erinaceus
11?2?13100 0141211011 1200022103 0130011110? 1011011212 200100?013 0220131103 1021100101 1202215111
0012112202 1212211102 0??0000000 ?010033022 2121111110 0002030000 1001033334 2000200111 0????????20
1111100111 101200?111 12D1011110 1211011120 0221021000 1211122l?0 0000111011 1210121?1 2220030212
2512010130 1113201100 0000200101 2001110031 2111201022 3111251111 2102110023 1130011113? ??11101102
0110011001 1002111213 1112122011 1014213002 1111300000 2001101101 121211?221 2101110021 1100201220
11223111

Leptictis
11?2?13100 0140211011 1200022103 0130011110? 1112211212 200100?013 0222131103 1021100121 1204115110
0011012202 1211111001 1110000000 ?010012022 2121111110 0002020000 0001011332 1000200?10 0????????0
??????0111 101200?101 ?22??111?0 1211011120 0221021??? ?211122l?0 0000111011 1211121?1 222003?212
2312010130 1113201100 ???0200?01 ??01110031 2111201022 3111251111 1102010023 1130011113? ??11101102
0110011001 1002110??? ????21?20?? ???3213012 1111200000 3000101101 1212111020 2101110021 0100001220
11223???

Canis
111??13101 0140211011 1100022113 0130011110? 0100010011 000010?111 0230120010 1000000000 0000010210?
0012100000? 0102021101 1000110000 ?031012121 2100?02100 0002020000 0000023323 1000000010 0????????21
1111110111 10120??101 1212011110 1211111120 0221121000 0211122l?0 0000110011 0111121?2 2212020212
2510010130 111?30110? 0?00200001 2001110030 2111311022 3111251111 11?3??0?23 1111011113? ????101102
0000100001 10?112A213 1112122011 1014213112 0111401001 3000101101 1211010220 2212100021 1111001220
01223111

Felis
111??13101 0140211011 1100022113 0130011110? 0100010011 000010?111 0230120010 1000000000 0000002l0?
0012100000? 0102021100 0?00110000 ?031012121 2100?02100 ???2020000 0000034434 30?0000010 0????????21
1111110111 10120??101 1212011110 1211111120 0221121000 0211122l?0 0000110011 0111121?2 2212020212
2510010130 111?30110? 0?00200001 2001110030 2111311022 3111251111 11?3??0?23 1111011113? ????101102
0000100001 10?1120213 1112122011 1014213112 0111401001 3000101101 1211010220 2212100021 1111001220
01223111

Rattus
1112?11100 0141211011 1120002222? 0110002l0? ?????????? ???????013 ???2131?0 0040000000? ???4204110
0013?1400? ?202221102 0?????????? ?0?0031022 ???????0l?0 ????3?41111 2???2?33334 3????1?0211 2?????????20
1111100111 101200?101 1221011100 0110100021 0221120000 1211121l?0 0101111011 1211110?1? 2210030212
2500010110 11?3101101 0100010001 2001110020 1011002012 3111251111 1101000024 1101011131 ???2?101101
```

```
0100111002 1111110213 1112122011 1014213002 0111212001 4001101100 1212011221 3212100021 21?2001211
11223111

Oryctolagus
1112?11100 0140211011 1110002222 011?11210? 0012000010 0001???013 ???0131320 0040000002 ???2104107
00?3?1300? ?201211103 0????????? ?0?0132027 ??????01?0 ???3?41111 2???233334 3??0??0211 2????????21
1111100111 101201?101 1221011100 0200101120 0221020000 1211120170 0101111011 1210111020 ?211130212
2500010130 1013101101 0100010001 2001110020 1011002027 3111251111 1101000024 1101011131 ???2101101
0000111001 1101110213 1112122011 1015213000 0111112100 30011?2111 1212011221 3212100021 21?2001211
11223111

Bradypus
111??13101 0141211011 1100022113 013?01110? ?????????? ???????0?? ????15???? ???????03? ??????????
?????????? ?????????? ?????????? ????0440?? ?????????? ???5?5???? 1??2?????0 0??????01? ????????31
1111110111 111207?101 1212011121 0211111120 0221121000 0211132171 1000110011 0110100?71 2212010212
2510010130 111?301107 0?00200001 2001110030 2111311022 3111251117 117?3??023 0211010137 ????101102
0000A00001 107?1120213 1112122011 1014213113 0111103001 01001?1102 1211011220 ?212100021 0110011220
01223111

Tamandua
111??13101 0141211?7? ????0?21?3 0???1??107 ?????????? ???????0?? ????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ???505???? 1??2?????? ???????01? ????????3?
1111110111 111207?101 1212011121 0211110120 0221121000 0211132171 1000110011 0110120072 2212010212
2510010130 ??1?301107 0?00200001 2001110031 2111311022 3111251117 117?3??023 1?11010137 ????101102
0010000001 107?1120213 1112122011 1014213113 0111103001 01002?1102 1211011220 ?212100021 0110011220
01223111

Glyptotherium
111??13101 0141211011 1100022113 0131011117 ?????????? ???????0?? ????15???? ???????03? ??????????
?????????? ?????????? ?????????? ????0330?? ?????????? ???505???? 107?????70 0??????01? ????????31
1111110111 111207?101 1212011120 0211110120 0221121000 0211132171 1000110011 0110121072 2212010212
2510010130 111?301107 0?00200001 2001111030 2111311022 3111251117 117?3??023 0?11010137 ????101102
0000?00001 107?1120??? ?11??22011 1014213113 0111103001 0100101102 1212111220 ?212101021 011?011227
???2231?

Dasypus
111??13101 0141211011 1100022113 0131011117 ?????????? ???????0?? ????15???? ???????03? ??????????
?????????? ?????????? ?????????? ????0440?? ?????????? ???505???? 107?????74 3??????01? ????????31
1111110111 111207?101 1212011120 0211110120 0221121000 0211132171 1000110011 1110121072 2212020212
2510010130 111?301107 0?00200001 2001111030 2111311022 3111251117 117?3??023 0D11010137 ????101102
0000000001 107?1120213 1112122011 1014213113 0111113001 0100201101 1212111220 ?212101021 0110011220
01223111

Chaetophractus
111??13101 0141211011 1100022113 0131011117 ?????????? ???????0?? ????15???? ???????03? ??????????
?????????? ?????????? ?????????? ????0440?? ?????????? ???505???? 107?????74 3??????01? ????????31
1111110111 111207?101 1212011120 0211110120 0221121000 0211132171 1000110011 1110121072 2212020212
2510010130 111?301107 0?00200001 2001111130 2111311022 3111251117 117?3??023 0211010137 ????101102
0000A00001 107?112A213 1112122011 1014213113 0111113001 0100201102 1212111220 ?212101021 0110011220
01223111

Euphractus
11???13101 0141211011 1100022113 0131011117 ?????????? ???????0?? ????15???? ???????03? ??????????
?????????? ?????????? ?????????? ????0440?? ?????????? ???505???? 107?????74 3??????01? ????????31
1111110111 111207?101 1212011120 0211110120 0221121000 0211132171 1000110011 1110121072 2212020212
2510010130 111?301107 0?00200001 2001111130 2111311022 3111251117 117?3??023 0211010137 ????101102
0000A00001 107?112A213 1112122011 1014213113 0111113001 0100201102 1212111220 ?212101021 0110011220
01223111

Holoclemensia
?????????? ?????????? ?????????? ????0?1??? ?????????? ????????13 0210130201 1021100111 1102115110
0?21001207 2201111000 1001001112 1210012?22 2121001000 000??????? ?????????? ???0?????? ??????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Sinodelphys
11???13101 0?4021??11 1?0???22103 0130011107 00??11?101 0?00?0?013 02??130101 1001100111 11?2115110
0121??1211 22???110?? ????011012 12100??022 21?1001000 0001010000 0000011321 1120?107107 0?????????0
?????00111 ?0120??101 1231011110 12?1111127 0221121111 021????000 00001?107? 0?10000?07 1212010??1
2422020110 21?2100011 0110210000 20011??0?? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ????????0?? ????107?0?? ?2?????0?2? 3??????0?? ?????????1?
????????

Deltatheridium
11?2?14101 0120217?11 1100042103 0130011107 0000110001 000000?013 0210130001 10B1100111 1102115110
0011001211 2201011000 1001001001 0222012022 2121001000 0001010007 0000022222 1110071210 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? 12?????????
2???????10 212???00?? ?????????? ???11100?0 20112?????2 3111251007 1101002123 12???1013? ???2?1011?2
?00001???1 101111???? ???2??1??? ?????????02 ?11?2?000? 201010?000 121???0A20 31????002? 011000????
```

????????

Atokatheridium
?????????? ?????????? ?????????? ????0????? ?????????? ????????1? 0210130001 1001100?1? 1102115110
0?0??0121? 2201011000 1001001001 0222012?22 2121001000 000??????? ?????????? ?????????? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Sulestes
11?2014101 012021??11 1100142?1? 013101110? 0000110001 000000?013 0210130002 1001100111 1112115110
0122112211 2201011000 1001001111 0222012022 2121001010 000?0?0??? ???0022222 1?10?????1? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????2 3111251O?? 1?O????12? 1????????? ??????????
?000?????? 1?1??????? ?????????? ?????????? ?????????? ?????????? ??????0?2? ?????????? ????0?????
????????

Asiatherium
11?1?14101 0140211?11 1100142?0? 013001110? 0000110001 000000?013 0220130103 1021100101 1112215110
1122112210 2202111112 11?0001001 0210012022 2121001110 000?0?0??? 0003022222 1010?????0 ?????????0
????100111 10??0????1 1231011110 ?211011120 0221121111 0210122000 00001?1011 0110010O?0 1?????????
2????????? ?????????? ?????????0 ?001110?30 2011201O?2 311125???? 1111?0??23 ??41010l3? ????10?1?2
??0?010111 1???11???? ???2?????? ????????02 011?2?00?? 21??10?0?0 ?2????0A20 ???11000?? ????10???2
????????

Kokopellia
?1?1?1410? 012??1??1? 1100?E2??? ??3?01110? ????1?0001 000000?013 0210130102 1021100100 1112215110
112210221? 2202011001 11?1001111 0210012022 2121001110 000??1???? 0?000?222? 1?10??0?10 0?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Anchistodelphys
?????????? ?????????? ?????????? ????0????? ?????????? ???????01? 0210130203 1021100l?0 1112205110
1132102211 2202212102 1010101111 0?20012022 2111001110 000??????? ?????????? ?????????? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Albertatherium
?????????? ?????????? ?????????? ????0????? ?????????? ???????0?3 022013???? ?????????? ?1????????
???????211 2202221102 1011001111 12200?2?22 2111?????? 000??????? ?????????2? ?????????? ?????????0
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
????????

Didelphodon
11?2?14101 011021??11 1100142113 01?001110? 001???0001 100000?013 0220130003 1021100121 1112205120
1?32112211 2202222102 0101002011 0221012022 2111001110 000?0????? ?0?0022222 1?00????1? 0???????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?21201?2101
2311010110 2122101l?? ?????????? ?????10?30 2011201022 31112??0?? ??1??0?1?? 11??????1?? ????1?????
0?00?1???? ?0111????? ????1?1??? ?????????0? ?????????? ?????????? ???????0?? ?1????0??? ????1?????
????????

Pediomys
????2?14101 011021??11 1100142113 01?001110? ?????????? ?????0?013 0220130103 1021100111 1112205120
1132112211 2202222102 1100001111 0210012022 2111001110 000??????? ???0022222 1100?????? 0???????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?21201?2101
2422020110 2122101l?? ?????????? ?????????? ?????????12 3111???0?? ??0??0?1?? ?1??????1?? ????1?????
??00?1???? ?0111????? ???????1??? ?????????? ????2???0? ?????????? ?????????? ?1????????? ????1?????
????????

Turgidodon
????2?14101 0110211?11 1100?4?113 01?001110? ??????0001 000000?013 0210130103 1021100111 1113215120
1132112211 2202221102 1100001111 0220012022 2111001110 000??????? ???0022222 1?00???21? 0????????20
?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ?????????? ??????????
?????????? 2????????? ?????????? ?????????? ?????????22 3111???0?? ??0??0?1?? 11??????1?? ????1?????
??00?1???? ?0?11????? ???????1??? ?????????? ?????????? ?????????? ?????????? ?1????????? ??????????
????????

Mayulestes
11?2?14101 014?211011 1100142103 0130011l0? 0000110001 000000?013 0210130103 1021100111 1112215120
1131102211 2202222002 1100001011 0221012022 2111001110 0000010000 0000022222 1100111?10 0????????0
1111100111 1012017101 1231011110 1211111120 0221121?1? ?211122000 0000111011 0111000?0 12????????
2422020110 2121101l?? ????210??0 ?001110030 2011201112 311125???? 1101002?24 1101010l3? ????101102
1001010011 1111111??? ????21????? ????????02 0110200000 2110101000 ?201010020 ??01100021 111100???2
????????

Pucadelphys
11?2?14101 0140211011 1100142103 0130011110? 0000110001 000000?013 0210131203 1021100101 1112215120
1132102210 2202222112 1110002111 1210012022 2111001110 0000010000 0000022222 1110111210 0????????0
1111100111 101201?101 1231011110 1211111121 022112???? ?211122000 0000111011 0111000?0 1213010101
2422020110 2122101171 01?0210??0 ?001110030 2011201112 3111251??? 1101002124 1101010137 ????101102
1001010011 1111111??? ????21?1??? ????????02 011?200000 2110101110 1201010020 3101100021 011100?21?
????????

Andinodelphys
11?2?14101 0140211011 1100142103 0130011110? 0000110001 000000?013 0210131203 1021100121 1112215120
1032112210 2202222112 1110002111 1210012022 2111001110 0000010000 0000022222 1110111?10 0????????0
???????0??? ????0???0? ?????????? ?????????? ?????????? ?????????? ?????????? 0????????? ??????????
2?????????? ?????????? ?????????0 ???1110037 2011201122 311125???? 1101002?24 1101010137 ????101102
1001010001 111111???? ????21?1??? ????????02 ?111?10000 21?0101100 1201?10020 3101100021 01111??21?
????????

Didelphis
11?2?14101 0141211011 1100142103 0130011110? 0000210001 000000?013 0210130203 1021100101 1112215120
1032112210 2202222112 0?00002111 1220012022 2111001110 0000010000 0000022222 1110111210 0????????20
1111100111 101201?101 1231011110 121111112A 0221121211 0211122000 0000111011 0111000000 1213010101
2422021110 2123201111 0110210010 2001110030 2011201112 3111251111 1111002123 11A1010137 ????101102
0000010111 1011111213 1112121011 1002212002 0111210000 2100101100 1201010020 3100100021 1111101210
11223002

Marmosa
11?2?14101 0141211011 1100142103 0130011110? 0000210001 000000?013 0210130203 1021100111 1112115120
1032122210 2202222112 0?00002111 1210012022 2111001110 0000010000 0001022222 1000111210 0????????0
1111100111 101201?101 1231011110 1211111120 0221121211 0211122000 0000111011 0111000000 1213010101
2422021110 2122201111 0110210010 2001110030 2011201112 3111251111 1111002123 1111010137 ????101102
0000010111 1011111213 1112121011 1002212002 0111210000 2100101101 1201010020 3112110021 1111101210
11223002

Caenolestes
11???14101 014?211011 1100142103 0130011110? ?????????? ?????0?0?3 0210130203 1021100111 1113215120
1032122210 2202222112 0?00102101 0210012022 2111001117 0001010000 0000022222 1010020210 0????0???0
1111100111 101201?101 1231011110 1211111120 0221121211 0211122000 0000111011 0111000?0 1213020?01
2422010110 2122101111 0000210100 2001110030 201120?112 3111251111 1113002?23 1101010137 ????10?102
0000000211 1011111213 1??2111011 1003212002 0111310000 21?0101170 1201010020 32??100021 11?2201217
??223002

Dasyurus
11?2?14101 0140211011 1100142103 0130011110? 00A0210001 000000?013 0210130203 1021100111 1112215120
1032122211 2202222112 0?00102101 0220012022 2111001110 0001020000 0000033223 1100011210 0????????0
1111100111 101201?101 1231011110 1211111120 0221121211 0211122000 0000111011 0111000?0 1213120101
2510010121 213?101111 0000210100 2001110030 2011201132 3111251111 1113002123 1011010137 ????101102
0000010211 1011121?13 1??2111011 1004212002 0111112000 2110101101 1201010020 3201100021 1111101210
11223002

Perameles
11???14101 0141211011 1100142103 0130011110? ?????????? ?????0?0?3 0210130202 1021100121 1113215120
0032122210 2202222112 0?00102101 0220012022 2111001117 0000020000 0000022222 1010021210 1????????0
1111100111 101201?101 1231011110 1211111120 0221121211 0211122000 0000111011 0110010?0 1213020?11
2510020121 213?101111 0100200100 2011110030 2011202112 3111251111 1113002?23 1141010137 ????101102
0000010211 1011111213 1??2111011 1004212002 0111210000 2100101101 1201010020 3212100021 1101101217
??223001

Dromiciops
1112?14101 0140211011 1100142103 0130011110? 0000210001 000000?013 0210130203 1021100110 1113205120
1032122211 2202222112 0?00000001 1210012022 2111001110 0000010000 0001022222 1010021210 0????????0
1111100111 101201?101 1231011110 1211111120 0221121211 0211122000 0000111011 0111000?0 1213020?11
2510020121 213?201111 0100210010 2001110030 2011201112 3111251111 1113002?23 1?41010137 ????101102
0000010211 1001110213 1??2122011 1003213002 0111110000 3110101100 120?010020 3212110021 0111101210
11223002

Thylacomyidae
111??14101 014?211011 1100142103 0130011110? ?????????? ?????0?0?3 0????????? ?????001?? 11132??1??
???3???4??? ?2042??112 0?00100001 ?2?0112022 2101???110 0000020000 00???22222 1??0?2?210 ??????????0
1111100111 101201?101 1231011110 1211?11120 0221121111 0211122000 0000111011 0111000?0 12130?0???
2510020121 213????11?? 0?002?0?00 2011110030 2?112?1132 3111251111 1113002?23 10?1010137 ????101102
?000010271 ???11??213 1??21??0?1 100421?002 0111?10000 21?0101170 12?101?020 ?2??1?0021 ?1???0121?
??223007

Macropus
111??14101 0140211011 1100142103 0130011110? ?????????? ?????0?0?3 ?253131303 0020000133 0113204131
0043124007 3204221112 0?00100000 ?2300122022 2101110110 ????2040000 1????33223 2?11020211 2?1?10???0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122001 0000111011 0111000?0 1213120?11
2510010121 213?101111 0100200000 2011110030 2111313032 3111251111 1113002?23 1141010137 ????101102
0000010311 1001111213 1??2122011 1005213002 0111111001 3110101100 1201010030 3212110021 01?0G01217
??223002

```
Acrobates
111??14101 0141211011 1100142103 013001110? ?????????? ??????0?0?3 ?353131302 1020000101 0113215120
0042124?0? 3204221112 0?00100001 1210012022 2101001110 ???0030000 0001022223 1000020211 0????????0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122000 0000111011 0111000?0 1213020?11
2510020121 213?2?1111 01002?0?10 2011110030 2111313032 3111251111 1113002?23 1141010?3? ????101102
0000010111 1011120213 1??212?111 1005213102 0111310000 3110101100 1201010020 3212110021 1111201?1?
??223002

Phascolarctos
111??13101 0140211011 1100142103 013001100? ?????????? ??????0?0?3 ?353131303 2020000133 0113204130
0043124?0? 3204221112 0?00100100 ?230112022 2101110110 ????2040000 10?????3223 3?20010211 1????????0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122001 0000111011 0111000?0 1213020?11
2510020121 213?101111 0100210010 2011210030 2111001032 3111251111 1113002?23 1141010?3? ????101102
0000010211 1011111213 1??2112011 1003213002 0111311001 4100101110 1201010030 3201100021 1110201?1?
??223002

Vombatus
111??14101 0140211011 1100142103 013001100? ?????????? ??????0?0?3 ?353131303 2020000133 0113204131
0043124?0? 3203221112 0?00100000 ?230112022 2101110110 ????3040101 20????3223 3?201?0211 2????????0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122001 0000111011 0110010?0 1213020?11
2510020121 213?101111 0100210010 2011210030 21110?0032 3111251111 1113002?23 0231010?3? ????101102
0000010111 1001111213 1??2112011 1005213002 0111310001 4110101100 1201010030 3202100021 1110011?1?
??223002

Phalanger
111??14101 0140211011 1100142103 013001110? ?????????? ??????0?0?3 ?353131303 2020000133 0013215120
0043124?0? 3204221112 0?00100100 ?230012022 2101110110 ????2030000 0001022222 2021020211 1????????0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122000 0000111011 0111000?0 1213020?11
2510020121 213?201111 0100210010 2011210030 2111313032 3111251111 1113002?23 1141010?3? ????101102
0000010311 1001111213 1??2122111 1005213102 0111311001 3100101100 1201010030 3202100021 1111201?1?
??223002

Pseudocheirus
111??14101 0140211011 1100142103 013001110? ?????????? ???????0?3 ?353131303 2020000133 0013204130
0042124?0? 3204221112 0?00100100 ?230112022 2101110110 ????2030000 1001033223 2000020211 1????????0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122000 0000111011 0111000?0 1213020?11
2510020121 213?201111 0100210010 2011210030 2111313032 3111251111 1113002?23 1141010?3? ????101102
0000010311 1001121213 1??2122111 1005213102 0111210000 3110101100 1201010120 3212100021 1111201?1?
??223002

Petauroides
111??14101 0140211011 1100142103 013001110? ?????????? ???????0?3 ?353131303 2020000133 0013204130
0042124?0? 3204221112 0?00100100 ?230012022 2101110110 ????2030000 0001033223 2000020211 1????????0
1111100111 101201?101 1231011110 1211111120 0221121111 0211122000 0000111011 0111000?0 1213120?11
2510020121 213?201111 0100210010 2011210030 2111313032 3111251111 1113002?23 1141010?3? ????101102
0000010311 1001121213 1??2122111 1005213102 0111210000 2110101100 1201010120 3212110021 0111201?1?
??223002
```

Part H. Phylogenetic Analyses for Placing *Rugosodon* among Mammaliaform Clades

```
P A U P *
Version 4.0b10 for Macintosh (PPC)
Tuesday, March 5, 2013  10:37 AM

This copy registered to: Zhe-Xi Luo
                         Carnegie Museum of Natural History
                         (serial number = B418684)

      ----------------------------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 "Rugosodon(March2013)458.nex" begins...

Data matrix has 106 taxa, 458 characters
Valid character-state symbols: 012345
Missing data identified by '?'
Gaps identified by '-'

4 trees read from TREES block
   Time used = 0.00 sec

4 trees converted from rooted to unrooted.

Warning: The following taxa were omitted from one or more trees:
            Rugosodon, Kuehneodon, Sinobaatar
         (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 "Rugosodon(March2013)458.nex" completed.

Input data matrix:

                          1111111111222222222233333333334444444444555555555566666666667777
Taxon/Node        12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
-------------------------------------------------------------------------------------------------------------
Thrinaxodon       00000000000000000000000000?0?0?0?01000???????0?00000?????00????00?????0
Massetognathus    00000100000000000100000000?0?0?0001000??????????20000?????20????00?????0
Probainognathus   00000000000000000100000000?000?0001000??????????00000?????00????00?????0
Tritylodontids    00000100000000000000000010?000?3000200??????????20?00??2??21????24?????0
Pachygenelus      00000000000001000000000000000000?20000100??????1?00000???0?00????00?????0
Adelobasileus     ?????????????????????????????????????????????????????????????????0??????0?????0
Sinoconodon       00000010000000000000000000110100000010?????70110000?00?000????00?20??0
Morganucodon      00001010000000000000000000200100000010?000000010000?00?000?0??11?20??2
                                                  1
Megazostrodon     00001000000000000000000000200200100010?000000000000?00?000?0??12?20??2
Haldanodon        00000110001000100010000002101001000010?000000010001?10?000?0??11?20??2
Castorocauda      00?00110001???1?000000000021010010000010?0???0??10000?010?000?0??11?2???2
Hadrocodium       1???2?13001O?402110000000002001002007010?000010100000?0??000?0??12?20???
Shuotherium       00101102?0000021??000?00?0?????0?0001010??????711111112?0?013?20012010O?1
Pseudotribos      0?10011000?0001???00??????210101000111O??0???011111?1110?013?20012010O?1
Asfaltomylos      00121121100000021??00220000213101200102?????????11011?????2013?2??13??13?0
Ambondro          ?????1???00?????1????????0?????0???0?0??????????12131110???013?2??130?1330
Ausktribosphenos  00100120100000021??00220000221012001010???????12131111011?013?2??13021330
Bishops           01?10120100?0021??00220000213101200102?0???????12131?1011?013?2??13021330
Teinolophos       11002120100130212?00220002?13101200102?????????????????????????3?2??13111120
Steropodon        011001???0??00?1?????????????????????10?????????????????????013?2??13111120
Obdurodon         11?2?120100130211011220001213111211101O???????1013100???013?2??13111120
Ornithorhynchus   11?2?100100130211011220001213111211101O?????????????????????13?2??1?1?1???
                                                  2
Tachyglossus      11?2?10??00140211000000002131112?1?010?????????????????????????????????
Fruitafossor      11?00140000000212?11000011210101100121O?0000001O?0000?0??0?????10??????0
Gobiconodon       11?1010??000102110122100112114001001010?000000100101000?000?0??12?10??1
Repenomamus       11?1010??00110211012210011211400100101O?000000110101000?000?0??12?10??1
Amphilestes       11?11?0??00110212???122??0??2211400200201?????????1101000000?000?0??12?10??1
Yanoconodon       11?1010??00110211012210012221400100001O?000000000000000?000?0??11?10??0
Jeholodens        11?1010??00?10211012??001?2221400100001O?000000010100000?000?0??11?10??0
Trioracodon       11?10?0??0011021??122100102214001000010?00000?0101000100?000?0??11?10??1
Priacodon         11?1010??0011021??122100102214001000010?000000000101010O?000?0??11?10??1
```

```
Haramiyavia       0100110??000002???000000002?010?100021?0?????????2?000??20021????24?????0
Rugosodon         1112?10??00?302?10102120102224001000210??????0??2?0?0??2?121????24?????0
Kuehneodon        1112?10??0003021101021201022240010002101?????0???2?020??21121????24?????0
Sinobaatar        1112?10??0013021101021201022240010002100?????0???2?010??20121????24?????0
Plagiaulacids     1112?10??0003021101021201022240010002101?????0???2?020??21121????24?????0
                             1
Cimolodontans     1112?10??0013021101021201022140010002100?????0???2?000??20121????24?????0
                                            2  12
Tinodon           1??11????001021??121?00???104?130?00?????????0101000?00?01201??12?10001
Akidolestes       1????10??00?20????122100102114011001110?00000?1101000120?113020112010001
Spalacotherium    1111010??000202?????2100102114011001110?00000?1101000100?113120012010001
Zhangheotherium   11?0010??0002020??1221001?2114010101110?0000011101001?00?013110012010001
Maotherium        11?0010??0002020??12210010211401010111O?0000011101001?00?013110012010001
Dryolestes        11?101110000202O??11210?01211301200111O?0000010000001?00?013010013020000
Henkelotherium    11?1011100002021??112101??2113012001110?00000?00000?0?00?013010013020000
Amphitherium      11?1111100002021??11210?012103012001110?11?0?00000001?00?013010013000100
Peramus           11?1111100002021??112101012103012001110?1100200002000?00?013010013000100
Vincelestes       11?2?11100002021??111101012113012001110?0000101000000?00?013010013000000
                             1
Nanolestes        11?1011100002021??112?0??12103012001110???????0000000?00?013010013000100
Kielantherium     11?101110?002?21??111101?2????0130011?0???????0000000?00?013011013000110
Aegialodon        ?????????????????????????????????????????????????????????????1?01??13000110
Montanalestes     11?2?13100004021??111201032103013001110???????1202001000?013?2??13010210
Prokennalestes    11?1113100001021??111201022103012001110?10112?1202000020?013022013020110
                                                 1
Murtoilestes      ?????????????????????????????????????????????????????????????13022013?20210
Eomaia            11?1113100001021??111201022103012001110?1011111201000020?013022013020?10
Juramaia          1?12-?11000?????????1201022?03011001110?101120120100?020?01302301302????
Kennalestes       11?2?1310000402110111200022???0?2001110?1111201002000100?013022013020210
Asioryctes        11?2?1310000402110111200022103013001110?1112201102000010?013022013020210
Ukhaatherium      ?1???????00?40??????????022???0??00?110?1112201102000020?013022013020?10
Zalambdalestes    11?2?1110000402110111200022103012001110?1112210212200120?013022013120310
                        3    1           1
Daulestes         11?2?1310001402110111200022103012001110????1??????????00?013022013020210
Aspanlestes       ?????1????0??0?????????1??????0???0?1?0?11112?1?010000?0?013023113110210
Eoungulatum       ?????1??????????????????1??????0???0?1???10110????????????013024213110310
Cimolestes        1??2?1010?0140211?111200?22103012?01110?10122?1101000010?013023113020210
Gypsonictops      1??2?101000140211?111200?22103012?01110?11122?1212000110?013023113120210
Protungulatum     11?2?101000140211?111200022103012001110?10120?1211000010?013024213110210
Erinaceus         11?2?1310001412110111200022103013001110?1011011212200100?013022013110310
Leptictis         11?2?1310001402110111200022103013001110?1112211212200100?013022213110310
Canis             111??1310101402110111100022113013001110?0100010011000010?111023012001010
Felis             111??1310101402110111100022113013001110?0100010011000010?111023012001010
Rattus            1112?111000141211011112000222?011000210??????????????????013???21313?000
Oryctolagus       1112?111000140211011111000222?011?11210?00120000100001???013???01313?000
Bradypus          111??1310101412110111100022113013?01110???????????????????0??????15??????
Tamandua          111??1310101412110??????0?21?30???1??10???????????????????0??????????????
Glyptotherium     111??1310101412110111100022113013101111???????????????????0??????15??????
Dasypus           111??1310101412110111100022113013101111???????????????????0??????15??????
Chaetophractus    111??1310101412110111100022113013101111???????????????????0??????15??????
Euphractus        11???1310101412110111100022113013101111???????????????????0??????15??????
Holoclemensia     ??????????????????????????????????0?1?????????????????????13021013020110
Sinodelphys       11???131010?4021??111?0??22103013001110?00??11?1010?00?0?01302??13010110
Deltatheridium    11?2?14101012021??111100042103013001110?0000110001000000?013021013000110
Atokatheridium    ??????????????????????????????????0???????????????????????1?021013000110
Sulestes          11?2014101012021??111100142?1?013101110?0000110001000000?013021013000210
Asiatherium       11?1?141010140211?111100142?0?013001110?0000110001000000?013022013010310
Kokopellia        ?1?1?1410?012??1??1?1100?32?????3?01110?????1?0001000000?013021013010210
                         4
Anchistodelphys   ??????????????????????????????????0??????????????????????01?021013020310
Albertatherium    ??????????????????????????????????0??????????????????????0?3022013??????
Didelphodon       11?2?14101011021??11110014211301?001110?001???0001100000?013022013000310
Pediomys          ???2?14101011021??11110014211301?001110?????????????????0?013022013010310
Turgidodon        ???2?141010110211?111100?4?11301?001110??????0001000000?013021013010310
Mayulestes        11?2?14101014?2110111100142103013001110?0000110001000000?013021013010310
Pucadelphys       11?2?1410101402110111100142103013001110?0000110001000000?013021013120310
Andinodelphys     11?2?1410101402110111100142103013001110?0000110001000000?013021013120310
Didelphis         11?2?1410101412110111100142103013001110?0000210001000000?013021013020310
Marmosa           11?2?1410101412110111100142103013001110?0000210001000000?013021013020310
Caenolestes       11???14101014?2110111100142103013001110????????????????0?0?3021013020310
Dasyurus          11?2?1410101402110111100142103013001110?0000210001000000?013021013020310
                                                  1
Perameles         11???1410101412110111100142103013001110????????????????0?0?3021013020210
Dromiciops        1112?1410101402110111100142103013001110?0000210001000000?013021013020310
Thylacomyidae     111??14101014?2110111100142103013001110????????????????0?0?30???????????
Macropus          111??1410101402110111100142103013001110????????????????0?0?3?25313130300
Acrobates         111??1410101412110111100142103013001110????????????????0?0?3?35313130210
Phascolarctos     111??1310101402110111100142103013001100????????????????0?0?3?35313130320
Vombatus          111??1410101402110111100142103013001100????????????????0?0?3?35313130320
Phalanger         111??1410101402110111100142103013001110????????????????0?0?3?35313130320
Pseudocheirus     111??1410101402110111100142103013001110??????????????????0?3?35313130320
```

```
Petauroides       111??14101014021101111001421030130011l0??????????????????0?3?35313130320

Input data matrix (continued):

                                                  1111111111111111111111111111111111111111111111111
                  7777777888888888899999999900000000001111111111222222222233333333334444444
Taxon/Node        3456789012345678901234567890123456789012345678901234567890123456789012345
------------------------------------------------------------------------------------------
Thrinaxodon       000000??0??????????????????00??????????????????????????0??000?????????????0
Massetognathus    000000??????????????????????00??????????????????????????0??011?????????????0
Probainognathus   000000??0??????????????????00??????????????????????????0??000?????????????0
Tritylodontids    000000??????????????????????00?00?????????????1??????0??033023?????????????3
Pachygenelus      000000?000??????????????????00??????????????????????????0??000?????????????3
Adelobasileus     000000?000??????????????????????????????????????????????????00?????????????
Sinoconodon       0000001000???0000???0????00?00????0????????0??????0??000000?0?0???????0000
                  2
Morganucodon      000002000???0000???0????00?40????0????????0??????0??00001100?0???????0000
                                                                                            1
Megazostrodon     000002000???0000???0????00?40????0????????0??????0??00001100?0???????0001
Haldanodon        003200000???0000???0????00?11???0????????0??????0??0320110?0???????0000
Castorocauda      003200?00????0000???0?????????????????????????????????0?0110?0???????000?
Hadrocodium       000000000???0000???0????00?00????0????????0??????0??00001100?0???????0000
Shuotherium       3232100111000010?????0????11?11002000?0??0000000?0100120221100??0100111?
Pseudotribos      323210011100?100???0????11?11002000?0??0000000?0100120221100??0100111?
Asfaltomylos      210000?111022141100011112?????????????????????????????????01?02211?1102??000?
Ambondro          012100?111022241120?11112?????????????????????????????01?02211?1102010000?
Ausktribosphenos  0121000221022141220032123?????????????????????????????03?02221?1112111000?
Bishops           012100122102214122003212 3?????????????????????????????03?02221?1112111000?
Teinolophos       012010?222042231210?02?23?????????????????????????????3?02221?2113102000?
Steropodon        012110022204223121 0?02?23?????????????????????????????03?02221?2113102000?
Obdurodon         012010022204223121 0?02?2320?1?????????????????0????????03302221?2113102000 4
Ornithorhynchus   ??2010022204223121 0??2?2320?1?????????????????????0??0330?????2?1?1?2???4
Tachyglossus      ?????????????????????????????????????????????????????????????????????????4
Fruitafossor      ??00000?????????????????????00?0?????????????????????????0???4400?????????????
Gobiconodon       0100010?00???0000???0????00?10????0????????0??????0??00101201?0???????0002
Repenomamus       0100010?00????000???0????00?10????0????????0??????0??00101101?0???????0002
Amphilestes       0100010?00???0000???0????00?????????????????????????????00?01201?0???????000?
Yanoconodon       2000031?00????000???0????00?00????0????????0??????0??00001100?0???????0003
Jeholodens        2000031?00???0000???0????00?00????0????????0??????0??00001100?0???????0001
Trioracodon       0000031?00???0000???0????00?10????????????1??????1??00001100?0???????000?
                  2
Priacodon         2000031?00???0000???0????00?10???0????????1??????1??00001100?0???????000?
Haramiyavia       ??0?000?????????????????????0?00????????????1??????0??033023?????????????
Rugosodon         ??0?000?????????????????????0?00????????????1??????0??033023?????????????2
Kuehneodon        ??0?000?????????????????????0?00????????????1??????0??033023?????????????2
Sinobaatar        ??0?000?????????????????????0?00????????????1??????0??033023?????????????2
Plagiaulacids     ??0?000?????????????????????0?00????????????1??????0??033023?????????????2
Cimolodontans     ??0?000?????????????????????0?00????????????1??????0??033023?????????????3
Tinodon           0100010?1100001 00???00??010?11???00???0???0????0?0000210221 1?0???????000?
Akidolestes       0000040122 0?0100???00??020?11???000??0??0000000?2000220222100??00000001
Spalacotherium    0000040112 00?0100???00??020?11???000??0??0000000?2000220222100??00000000?
Zhangheotherium   0000040111 00?0100???00??020?11???000??0??0000000?2000220222100??00000002
Maotherium        0000040111 00?0100???00??020?11???000??0??0000000?2000220222100??00000002
Dryolestes        2000000111 0000220??000??110?01???000??0??0001000?2000220221100?001000001
Henkelotherium    2?0000011 10000220??000??110?01???000??0??0001000?2000220221100?001000000?
Amphitherium      2000000011 0000210?0000??111101???000??0??0001000?2000210221111 0000000000?
Peramus           0100010011 0002110000 0?0121121?0?010000??0001002020001102211110000000000?
                             1         1
Vincelestes       2000000011 0000210??000?0120?11?0?010000??0001012000001102211 00?000000001
Nanolestes        2100010011 0000210 00?00?0121?11???0?0000??1012012020001102211 1 0000000001
Kielantherium     2110010111 0201511 0000000120?120000100-0--10020111?0101?0222111 0010000000?
                                     1
Aegialodon        211001?111 0201511 00?11001?????????????????????????????1??2221?10010000000?
Montanalestes     211001201 2021151 10011100 2?????????????????????????????0??0221?10011100000?
Prokennalestes    111001201 2021151 1001110 0221022020010011001011010020001202221210011100000?
Murtoilestes      111001?012 021151 100?1100?210220200?0011001011000020001 2?222121001?100000?
Eomaia            1110012??202?151 100111??2210220200100110010??000?2000120222121001 1??0000
Juramaia          ?11?012?1??2?151 1001????2211220200100110010110111201012022121001?100000
Kennalestes       2110012222031151 1001110 0221022010110100110110100002000120222121001 1100001
Asioryctes        2110012012031151 1001110 0221022011010011001000000?2000120222121001 1100000
Ukhaatherium      2110012012031151 100111?0221022011010011001000000?2000120222121001 1100000
Zalambdalestes    2110010222042051 1000111 0220?120120110110000000002000120222121001 1100002
                                                                                            3
Daulestes         211001?112021151 1001110 0220?120210100111110100002000120222121001 1100000?
Aspanlestes       211001?112012151 1000110 0220?120321110312100?0000?2100120222121001 1100000?
Eoungulatum       211001?112012151 1100120 0320?122321110312100100002010012022212100 1110000?
Cimolestes        2110012212031151 1001120 0221012111010011110000000?2000120222121001 1100000?
Gypsonictops      2110012212041151 1001120 0221012111010011110000000?2000120222121001 1100000?
Protungulatum     211001211201215 1110012 0132032?122321110310000000000?0100120222121001 1100000?
Erinaceus         2110010112022151 1100121 1220?121221110 20??0000000?0100330222121111 1100002
Leptictis         2110012112041151 1000110 1220?121111100111000000?0100120222121111 1100002
```

```
Canis             0000000000000210?00121000?0102021101100011000?0?3101212121002021000002
Felis             00000000000000210?00121000?0102021100?00110000?0?3101212121002021002???2
Rattus            4000000????42041100013?1400??2022211020??????????0?00310?????????01?0????3
Oryctolagus       400000????21041?00?3?1300??2012111030??????????0?01320?????????01?0????3
Bradypus          ?????03?????????????????????????????????????????????????0440?????????????????5
Tamandua          ????????????????????????????????????????????????????????????????????????????5
Glyptotherium     ?????03?????????????????????????????????????????????????0330?????????????????5
Dasypus           ?????03?????????????????????????????????????????????????0440?????????????????5
Chaetophractus    ?????03?????????????????????????????????????????????????0440?????????????????5
Euphractus        ?????03?????????????????????????????????????????????????0440?????????????????5
Holoclemensia     21100111110211511007210012022011110001001001112121001207222121001000000?
Sinodelphys       01100111117211511001210??12112227??110??????01101212100??02221?10010000001
Deltatheridium    011001111102115110001100121122010110001001001001022201202221210010000001
                  2
Atokatheridium    011001?111021151100?0??0121?22010110001001001001022201207222121001000000?
Sulestes          0110011111121151100122112211220101100010010011110222012022212100101000?
Asiatherium       2110010111122151101122112210220211111211?000100102100120222121001110000?
Kokopellia        2110010011122151101122102212202011001117100111021001202221210011100000?
Anchistodelphys   211001?01112205110113210221122022121021010101111?2001202221110011100000?
Albertatherium    ??????????1?????????????????2112202221102101100111112200?2?222111?????000?
Didelphodon       2110012111122051201?32112211220222210201010020111022101202221110011100000?
Pediomys          2110011111122051201132112211220222210211000011102100120222111001110000?
Turgidodon        21100111111321512011321122112202221102110000111102200120222111001110000?
Mayulestes        211001111112215120113110221122022220021100001011022101202221110011100000
Pucadelphys       2110010111122151201132102210220222211211100021111210012022211100111000000
Andinodelphys     2110012111122151201032112210220222211211100021111210012022211100111000000
Didelphis         211001011112215120103211221022022221120?000021111220012022211100111000000
Marmosa           2110011111121151201032122210220222211120?000021111210012022211100111000000
Caenolestes       211001111113215120103212221022022221120?00102101021001202221110011?0001
Dasyurus          2110011111122151201032122211220222211120?00102101022001202221110011100001
Perameles         211001211113215120003212221022022221120?00102101022001202221110011?0000
Dromiciops        2110011011132051201032122211220222211120?000000011210012022211100111000000
Thylacomyidae     ???001??111132??1????3???4????2042??1120?00100001?2?0112022210?????1100000
Macropus          2000013301132041310043124002320422111202?00100000?2300120222101110110???2
Acrobates         2000010101132151200042124202320422111202?00100001121001202221010011107??0
Phascolarctos     2000013301132041300043124202320422111202?00100100?2301120222101110110???2
Vombatus          2000013301132041310043124202320322111202?00100000?2301120222101110110???3
Phalanger         2000013300132151200043124202320422111202?00100100?2300120222101110110???2
Pseudocheirus     2000013300132041300042124202320422111202?00100100?2301120222101110110???2
Petauroides       2000013300132041300042124202320422111202?00100100?2300120222101110110???2

Input data matrix (continued):

                  1111111111111111111111111111111111111111111111111111111112222222222222222
                  4444455555555556666666666777777777788888888899999999990000000001111111
Taxon/Node        5678901234567890123456789012345678901234567890123456789012345678901234567890123456
-------------------------------------------------------------------------------------------------
Thrinaxodon       000000000000????00?0?0000001?0?????000000010000000000?0?00000?000000000000
Massetognathus    000000000000????00?0?000000100?????00?????00000??0?0?????0?????00????00
Probainognathus   000000000000????00?0?000000??0?????00?????0100002?0?0?0?0???0?????00??????
Tritylodontids    030000??2???0000?2?10??1120100000000000?0100000000000000000000000000000
Pachygenelus      0300001000??0000?1?2000001?1?????00000?0??10??0000100?00000?000000000000
Adelobasileus     ????????????????????????????????????0?????????????????????????????????????
Sinoconodon       000000000003311220200000001???????1000??0?01?????001000000000000000000000
Morganucodon      000000000000021000000001101???????0000000??111?00??1???00100?00000?00000
                   1           32
Megazostrodon     010000000000011000000001001????????2?0000?01110?????????0?10000000?00000
Haldanodon        0100000000122000000000011100???????00?????????????????????????100001000?00?00
Castorocauda      ?100?????01?00??0??0??01100?????????0??????000000?????????????????????????0
Hadrocodium       000000001003344430000001101????????0?????????????????????????????????????
Shuotherium       ?????????????3?????0?????????????????0?????????????????????????????????????
Pseudotribos      01?0??100100033100002?01100??????????0?????101?00?0010001?????????????0?????0
Asfaltomylos      ?????????????????????0?????????????????????????????????????????????????????
Ambondro          ?????????????????????0?????????????????????????????????????????????????????
Ausktribosphenos  ?????????????3????00?????????????????????????????????????????????????????
Bishops           ????????????????03??0?00?????????????????0?????????????????????????????????
Teinolophos       ?????????????????????????????????????????????????????????????????????????
Steropodon        ?????????????3??3?????????????????????????????????????????????????????????
Obdurodon         ?5?????2??2?333443??0????1??????????0?????????????????????????????????????
Ornithorhynchus   ?5?????2??2?3344430??0????1??????????0?111011110000010001000001010000000000
Tachyglossus      ?5?????2??2?3344430?????????????????????1110111100000010001000001010000000000
Fruitafossor      02?0??1001022333200?001100???????31??????010001??????0?0000110?00?00100
Gobiconodon       0300001001011120000000001010???????20????0101000000007101121111111001110?
Repenomamus       0300001001011220000000001010???????0000000101000000011011211111111001110?
Amphilestes       ?????????00?21??0000?????0?????????0?????????????????????????????????????
Yanoconodon       0300000000033334300010011107???????0000001010000000011011211111111001110?
Jeholodens        0100001001033223200000011117???????0000001010000000011011211111111001100
Trioracodon       0300??000001233210002?0110?????????0?????????????????????????????????????
Priacodon         ?300??0?000122221000??01101????????10?????????????0?????????????????????
Haramiyavia       0100001?1?1133?1?00??0??12100000?0?????????????????????????????????????
Rugosodon         1400001102?01442200103?1112101010?0?111110?1111000001101111001111001100?
```

```
Kuehneodon          1400001102?1144320010 3?1112101010 0?01?????????????????????????????????????
Sinobaatar          0400002???2024423001?0?1112020111 1?0?1?1100111100000110111100111100111001
Plagiaulacids       1400002???2024423001 03?1112020111 100?????????????????????????????????????
                                          3
Cimolodontans       0400002???2?124433001 20?1112020111 120001110011111000001101111001111001 1001
                                           3
Tinodon             ?????????1???22??1??0?????????????????????????????????????????????????????
Akidolestes         0100??100110001000000001110?????????0????2001100001001101121111111001 1101
Spalacotherium      ?????????10?000?00000000??10?????????0?????????????????????????????????????
Zhangheotherium     0200??100102200000100001110????????20?1100001111001001101121111111001 1101
Maotherium          0200??100102200000100001110????????20?1?0000111100?001101121 1?11110011101
Dryolestes          0100??000001100000000301110???????20?????????????????????????????????????
Henkelotherium      0?????00?0?1100000002??0???0?????????????????011110??0???01121111?110?111101
Amphitherium        ?100?????0??000?0?00?????????????????????????????????????????????????????
Peramus             ?2?????000000331 0?00??0???0?????????????????????????????????????????????
Vincelestes         0300000010033334200003 0??00?????????011110011111012 01?101?2110111100 1101
Nanolestes          ?1??????001?02??0?00??0???0?????????0?????????????????????????????????????
Kielantherium       ?????????0??12??0??0??????0????????0?????????????????????????????????????
Aegialodon          ?????????????????????????????????????0?????????????????????????????????????
Montanalestes       ???????????03??0?00?????????????????????????????????????????????????????
Prokennalestes      ???????01010033?0000?00?1?0????????0?????????????????????????????????????
Murtoilestes        ????????0?????????????????????????????0?????????????????????????????????
Eomaia              0100000000000331001 0000?100????????011?1100111101200?101122101111 0021101
Juramaia            010?0?0010000331 0000000?100--?--???01111100 1?1?????????112210??110?21?01
Kennalestes         02????00101103320010000110 1????????00 1?????????????????????????????????
                                            1
Asioryctes          0100000010111332101 0000?101????????001111??11110?????????????????????0?
Ukhaatherium        0100000000011332101 0030?101????????0?1??1?011110??0???0?122101111 0?21101
Zalambdalestes      0211?000110113321010200?111????????0??111001111 0??0???01?22101111 0?21101
                                          22  3
Daulestes           0100??000101133200?0??0?100????????0?????????????????????????????????????
Aspanlestes         ????????????033?0??0????1?0????????0?????????????????????????????????????
Eoungulatum         ????????????1332???0????1?0????????0?????????????????????????????????????
Cimolestes          ?200??0?000113321?00????1?0????????20?????????????????????????????????????
Gypsonictops        ??????0?000113320?00????1?0????????20?????????????????????????????????????
Protungulatum       ??????0?000113321?00????100????????20?????????????????????????????????????
Erinaceus           0300001001033334200020011 10???????201111100111101200?111121101111 0121101
                                                                                       2
Leptictis           0200000001011332100020 0?100????????0??????01111012 00?101?22??111?0121101
Canis               0200000000023323100000001 00???????211111110111101 20??101121201111 0121111
Felis               0200000000034434 30?0000100???????211111110111101 20??101121201111 0121111
Rattus              ?41111??2?3333343???1?0211 2???????201111100111012 00?101122101110 0111010
Oryctolagus         ?41111??2?3333343??0??0211 2???????211111100111101 201?101122101110 0020010
Bradypus            ?5????1??2?????00??????01?????????3111111101111120??101121201112 1021111
Tamandua            05????1??2????????????01?????????3?111111101111120??101121201112 1021111
Glyptotherium       05????10?2?????00??????01?????????3111111101111120??101121201112 0021111
Dasypus             05????10?2?????43??????01?????????3111111101111120??101121201112 0021111
Chaetophractus      05????10?2?????43??????01?????????3111111101111120??101121201112 0021111
Euphractus          05????10?2?????43??????01?????????3111111101111120??101121201112 0021111
Holoclemensia       ?????????????????????0?????????????????0?????????????????????????????????
Sinodelphys         0100000000011321112 0?10?100????????0?????00111?0120??101123101111 012?111
Deltatheridium      0100??000002222211100?1210 0???????20?????????????????????????????????????
Atokatheridium      ????????????????????????????????????0?????????????????????????????????????
Sulestes            ?????????00222221?10????1?????????0?????????????????????????????????????
Asiatherium         0?????000?022222101 0?????0?????????0????100111110??0????112310111 0?21101
Kokopellia          ?1????0?000?222?1?10??0?100????????20?????????????????????????????????????
Anchistodelphys     ????????????????????????????????????0?????????????????????????????????????
Albertatherium      ?????????????????2?????????????????????0?????????????????????????????????
Didelphodon         0??????0?00222221?00????1?0????????20?????????????????????????????????????
Pediomys            ?????????00222221100??????0????????20?????????????????????????????????????
Turgidodon          ????????00222221?00???21?0????????20?????????????????????????????????????
Mayulestes          0100000000022222110011 1?100????????0111110011110120 1?101123101111 0121111
Pucadelphys         0100000000022222110111 2100????????0111110011110120 1?101123101111 0121111
Andinodelphys       010000000002222211011 1?100????????0??????0???????0???0?????????????????
Didelphis           0100000000022222110111 2100???????201111100111012 01?101123101111 0121111
Marmosa             0100000001022222100011 2100???????0111110011110120 1?101123101111 0121111
Caenolestes         0100000000022222101002 0100????0???0111110011110120 1?101123101111 0121111
Dasyurus            0200000000033223110001 2100????????0111110011110120 1?101123101111 0121111
Perameles           0200000000022222101002 12101????????0111110011110120 1?101123101111 0121111
Dromiciops          0100000001022222101002 12100????????0111110011110120 1?101123101111 0121111
Thylacomyidae       0200000???222221??0?2?210?????????0111110011110120 1?101123101111 0121?1
Macropus            0400001????33223 2?1102021 12?1?10???0111110011110120 1?101123101111 0121111
Acrobates           0300000001022223100002021 10????????0111110011110120 1?101123101111 0121111
Phascolarctos       0400001 0???3322333?2001021 11????????0111110011110120 1?101123101111 0121111
Vombatus            0401012 0???3322333?201?021 12????????0111110011110120 1?101123101111 0121111
Phalanger           0300000001022222202102021 11????????0111110011110120 1?101123101111 0121111
Pseudocheirus       0300001001033223200002021 11????????0111110011110120 1?101123101111 0121111
Petauroides         0300000001033223200002021 11????????0111110011110120 1?101123101111 0121111

Input data matrix (continued):
```

```
                  2222222222222222222222222222222222222222222222222222222222222222222222222222222222
                  1112222222222333333333344444444455555555556666666666777777777888888888
Taxon/Node        7890123456789012345678901234567890123456789012345678901234567890123456789012345678
------------------------------------------------------------------------------------------------------
Thrinaxodon       000000000000????000000??000000000000000000?0000?000000000000000?000000000
Massetognathus    000000000000????10???0??00000???0??0???0?00?????????????????????????????????
Probainognathus   ????0????0?????10???0??000?0???0??0???0?00?????????????????????????????????
Tritylodontids    00001000000????2000010?000000000000000000?0000?00?000000000000000000000000
                     1
Pachygenelus      000010000001000210001????00?0000000?????00?????????????????????????????????
Adelobasileus     ????????????????????????????0?????????????????????????????????????????????????
Sinoconodon       000010000000?????????????????000?00?0???00?????????????????????????????????
Morganucodon      000010000000????2100010???000010000010?0000??000?000000000000000000000000000
Megazostrodon     000010000??0??2100010?000000100000?000000?0000?00?000000000?00??0??0?0?
Haldanodon        000120000?0?????????????????000?00000?0?0?0?0?????????????????????????????????
Castorocauda      000120000000000110000000000000000001010000?0000????000000000000000??00
Hadrocodium       ?????????0?????????????????????????????????????????????????????????????????????
Shuotherium       ?????????????????????????????????????????????????????????????????????????????
Pseudotribos      ???12000000????211???00000?10?0000000?00?????????????????????????????????
Asfaltomylos      ?????????????????????????????????????????????????????????????????????????????
Ambondro          ?????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ?????????????????????????????????????????????????????????????????????????????
Bishops           ?????????????????????????????????????????????????????????????????????????????
Teinolophos       ?????????????????????????????????????????????????????????????????????????????
Steropodon        ?????????????????????????????????????????????????????????????????????????????
Obdurodon         ??????????????????21???1????11?????????????????????????????????????????????
Ornithorhynchus   000120000001001211111000011100000022011001100?0000000101100000000000001
Tachyglossus      0001200000010012111110100111000000220110011000?0000000101100000000000001
Fruitafossor      000120001001001212?????0000???00??0100?100?0?0?????????000000000000?00000
Gobiconodon       000101000000002100210000000000000000100?000?0000000?000000010000000000000
Repenomamus       000101000000???2100210000000000000010000000?000000000000000010000000000000
Amphilestes       ?????????????????????????????????0?????????????????????????????????????????
Yanoconodon       000101010000001210021000000000000001000000?000000000000000010000000000000
Jeholodens        ??0101010000001210021000000000000001000000?000000000000000010000000000000
Trioracodon       ?????????????????????????????????????????????????????????????????????????????
Priacodon         ?????????????????????????????????????????????????????????????????????????????
Haramiyavia       ?????????????????????????????????????????????????????????????????????????????
Rugosodon         00?000010110001212?011000000?1?001002011000001210010001000120010001110001
Kuehneodon        ?????????????????????????????????????????????????????????????????????????????
Sinobaatar        00200001011000121001100000001110100201100000012100100010001200100011000 1
Plagiaulacids     ?????????????????????????????????1?????????????????????????????????????????
Cimolodontans     00100000011002?2101110000000111?1002011000000121001000221112001001110011
                    2    1
Tinodon           ?????????????????????????????????????????????????????????????????????????????
Akidolestes       1111011101000012111120100001 1?0000021001011001000000010020100100011000
Spalacotherium    ?????????????????????????????1??????0?????????????????????????????????????
Zhangheotherium   1111011101000012111220000000 1?11002100100?001000000001302010010001100000
Maotherium        1111011101000012111220000000 1?1?100210?100?001000000?1302010 0????110000
                                                                                  1
Dryolestes        ?????????????????????????????????????????????????????????????????????????????
Henkelotherium    1?1001110210001 21?022000000011100002110000?10?????????1?????????????????
Amphitherium      ?????????????????????????????????????????????????????????????????????????????
Peramus           ?????????????????????????????????????????????????????????????????????????????
Vincelestes       0100011 10?000012101220000000111000021100 0?1020?00?100130201011000110100
Nanolestes        ?????????????????????????????????????????????????????????????????????????????
Kielantherium     ?????????????????????????????????????????????????????????????????????????????
Aegialodon        ?????????????????????????????????????????????????????????????????????????????
Montanalestes     ?????????????????????????????????????????????????????????????????????????????
Prokennalestes    ?????????????????????????????????????????????????????????????????????????????
Murtoilestes      ?????????????????????????????????????????????????????????????????????????????
Eomaia            1120022102100012111220000000 1?1011021110 00?0122100021223020101301111 0100
Juramaia          ????022102002?????????????????????????????????????????????????????????????????
Kennalestes       ?????????????????????????????????????????????????????????????2?????????????????
Asioryctes        ????0???0?11000?????2?0??00???????0??1?000?0122100021223020101301111 0100
Ukhaatherium      1120022102100?1210?220000000 1?1011021110 00?0122100021223020101301111 0100
Zalambdalestes    112002210210001211122000000 1?1011021112 10??122100021223?201013?01130000
Daulestes         ?????????????????????????????????????????????????????????????????????????????
Aspanlestes       ?????????????????????????????????????????????????????????????????????????????
Eoungulatum       ?????????????????????????????????????????????????????????????????????????????
Cimolestes        ?????????????????????????????????????????????????????????????????????????????
Gypsonictops      ?????????????????????????????????????????????????????????????????????????????
Protungulatum     ?????????????????????????????????????????????????2220037212231 2?1013011132011
Erinaceus         1120022102100012111221?000001110111210121 0?12220030212251201013011132011
Leptictis         112022102 1????2111221?000001110111211121 0?12220037212231201013011132011
Canis             1120022112100002111221?000001100110111121 0?22212020212251001013011 1?3011
Felis             1120022112100002111221?000001100110111121 0?22212020212251001013011 1?3011
Rattus            0021022112000012111211?00101111011121111 00?12210030212250001011011?31011
Oryctolagus       1120022102000012111201?00101111011121101 10?0?21113021225000101301013 1011
Bradypus          1120022112100002111321?110001100110110100 0?12212010212251001013011 1?3011
Tamandua          0120022112100002111321?110001100110110120 0?22212010212251001013 0??1?3011
```

```
Glyptotherium     0120022112100002111321?1100011001101101210?222120102122510010130111?3011
Dasypus           0120022112100002111321?1100011001111101210?222120202122510010130111?3011
Chaetophractus    0120022112100002111321?1100011001111101210?222120202122510010130111?3011
Euphractus        0120022112100002111321?1100011001111101210?222120202122510010130111?3011
Holoclemensia     ????????????????????????????????????????????????????????????????????????????
Sinodelphys       112?022112111021???00000001?10??0?10000?01212010??124220201102l?21000
Deltatheridium    ??????????????????????????????????????????????12?????????2?????211021???00
Atokatheridium    ????????????????????????????????????????????????????????????????????????????
Sulestes          ????????????????????????????????????????????????????????????????????????????
Asiatherium       1120022112111102102122000000012101101100100?01?????????2?????????????????
Kokopellia        ????????????????????????????????????????????????????????????????????????????
Anchistodelphys   ????????????????????????????????????????????????????????????????????????????
Albertatherium    ????????????????????????????????????????????????????????????????????????????
Didelphodon       ?????????????????????????????????????????????21201?101231101011021221011
Pediomys          ?????????????????????????????????????????????21201?101242202011021221011
Turgidodon        ????????????????????????????????????????????????????????????????2???????
Mayulestes        1120022112l?1??2111220000000111011011000?012?????????2422020110212111011
Pucadelphys       1121022112?????211122000000011101101110000?012130101012422020110212211011
Andinodelphys     ????????????????????????????????????0?????????????????????2????????????????
Didelphis         1120022112121102111220000000111011011100000012130101012422021110212320l1
                     1
Marmosa           11200221121211021112200000001110110111000000121301010124220211102122201l
Caenolestes       1120022112121102111220000000111011011100?012130202012422010110212210l1
Dasyurus          11200221121211021112200000001110110111000?012131201012510010121213?1011
Perameles         11200221121211021112200000001110110111001?012130201125100201212213?1011
Dromiciops        11200221121211021112200000001110110111000?012130201125100201212213?2011
Thylacomyidae     11200221121111021112200000001110110111000?012130?0???25100201212l3???11
Macropus          11200221121111021112200100001110110111000?012131201125100101212l3?1011
Acrobates         11200221121111021112200000001110110111000?012130201125100201212l3?2?11
Phascolarctos     11200221121111021112200100001110110111000?012130201125100201212l3?1011
Vombatus          11200221121111021112200100001110110110010?012130201125100201212l3?1011
Phalanger         11200221121111021112200000001110110111000?012130201125100201212l3?2011
Pseudocheirus     11200221121111021112200000001110110111000?012130201125100201212l3?2011
Petauroides       11200221121111021112200000001110110111000?012131201125100201212l3?2011

Input data matrix (continued):

                  22222222222333333333333333333333333333333333333333333333333333333333333333
                  89999999990000000000111111111222222222233333333334444444445555555556
Taxon/Node        90123456789012345678901234567890123456789012345678901234567890123456789
------------------------------------------------------------------------------------------
Thrinaxodon       110000000??000000000?00????????0000??000??00?0?00?000?00000010?1000000??0
Massetognathus    ???????????0????0??00?00????????1000??000??00?0?00?000?00000100100000??0
Probainognathus   ???????????????0??00?00?????0??1000??000??00?0?00?000?00000100110000??0
Tritylodontids    1??000?0?000000000000?00?0????0?01111??1000000?00000000?00000100000100??0
Pachygenelus      ????????????????000000010?0?0?01111??1?00000?0000?000?00000101100000??0
Adelobasileus     ???????????????????00000?????????0221100?????0000001?11??1010000100100???
Sinoconodon       ????????????????0000000010000?000221100100000000001011101010000000000?00
Morganucodon      ????0???????0??000000101000?000231111201000000001011101010001101001110l1
                                                 11
Megazostrodon     1?000000000000000?0010100???000231101201O?000000101110100000l1?100111O?1
Haldanodon        ???????????0???000001020011?000231100201000000001?1210100?001????0101001
Castorocauda      ?0??0?000000110O???010?????????????????????????????????????????????????????
Hadrocodium       ????????????????1000002010l??000231112301000000001?111010?100110210101101
Shuotherium       ???????????????????????????????????????????????????????????????????????????
Pseudotribos      ???????????0????0?????????????????????????????????????????????????????????
Asfaltomylos      ???????????????????????????????????????????????????????????????????????????
Ambondro          ????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ???????????????????????????????????????????????????????????????????????????
Bishops           ???????????????????????????????????????????????????????????????????????????
Teinolophos       ???????????????????????????????????????????????????????????????????????????
Steropodon        ????????????????????????????????????????????????????????????????????????????
Obdurodon         ????????????????10000211011O?000231111?????0000001?111?11010011121O11O?1
Ornithorhynchus   10000110100110010000211001O?000231111411000000001011101101001112101110l1
                                 1
Tachyglossus      10000110100110010000211001O?000231111411000000001011101101001112101110l1
                                 1
Fruitafossor      ???????????01??0????10???11?????????????????????????????????????????????????
Gobiconodon       0??????????001000000102001l?000231111301000000001?121120000011110011100l
Repenomamus       0?0?0??0??00?10000001020011?000231111301000000001?121120000011110011100l
Amphilestes       ???????????????????????????????????????????????????????????????????????????
Yanoconodon       0?0?0?00??000000000001020?11??00?????????????????????????0?????????????????
Jeholodens        0000000010000000000102?011?000231l?130100??0???10??1?????????????????????
Trioracodon       ????????????????0?????????????0231l?????????0??0?0??1010???0????????????
Priacodon         ????????????????0?????0????1??00231111301??000000101?12100??0111100??100?
Haramiyavia       ???????????????????????????????????????????????????????????????????????????
Rugosodon         01100011100021O1?0?????????????????????????????????????????????????????????
Kuehneodon        ????????????????????????????????????????????????????????????????????????????
Sinobaatar        01100011100021010000101011O?000?????????????????????????????????????????????
Plagiaulacids     ???????????????????????????????231111301??000000101211101100211???1111?1
Cimolodontans     01100011100021010000101001O?000231111301001000001012111011002112101110O1
```

```
                                  1                 2  1                    1   1
Tinodon           ??????????????????????????????????????????????????????????????????????????????????????
Akidolestes       10000121000021010?001020??1????????????????????????????????????????????????????????
Spalacotherium    ??????????????????????????????????????????????????????????????????????????????????????
Zhangheotherium   10000020000021?01????1020111?00123111?2????1101001?1?1?10???0??1210111102
Maotherium        10000020000021010?00102011?00123111?2????1101001?1???10?100?11000111??2
                         1
Dryolestes        ????????????????1?????????????????????????????????????????????????????????????????????
Henkelotherium    ????????0???0?1011???1020?11?00?23111?3?????????????????????????????????????????????
Amphitherium      ????????????????????????????????????????????????????????????????????????????????????
Peramus           ????????????????????????????????????????????????????????????????????????????????????
Vincelestes       ??0???210??0?00111002020011?00123?112400?1110100101110100100110211111102
                                                                                        1
Nanolestes        ????????????????????????????????????????????????????????????????????????????????????
Kielantherium     ????????????????????????????????????????????????????????????????????????????????????
Aegialodon        ????????????????????????????????????????????????????????????????????????????????????
Montanalestes     ????????????????????????????????????????????????????????????????????????????????????
Prokennalestes    ??????????????????????????????2311125111111010010 2?10?????13?1?111011??
                                                          2
Murtoilestes      ????????????????????????????????????????????????????????????????????????????????????
Eomaia            000100210001200111?0?1?????2??0????1??51?11?????????1?????????????????????????
Juramaia          ????????????????????????????????????????????????????????????????????????????????????
Kennalestes       ??????????????????1100212211221022311125 11??2102110023 1?2001013?????101102
                                                                      4
Asioryctes        0000?0200001?001110021221122102231112 5?1??2102110?241?2001013???11101102
Ukhaatherium      000???200??1??01??00?1?2??221???3??????????2??21????4?0?????0???????1?????
Zalambdalestes    000000200001?001110031221122102231112 5?1??2102110024112001013???11101102
Daulestes         ??????????????????1100212011201022311125 11???10?????2?????01013????????1?2
Aspanlestes       ????????????????????????????????????3?????????1?0?0?1????0?????1????????????
Eoungulatum       ????????????????????????????????????3?????????1???0?1????0?????????????????
Cimolestes        ????????????????????????????????????????????????????????????????????????????????????
Gypsonictops      ????????????????????????????????????????????????????????????????????????????????????
Protungulatum     ??????????????????????????????2311125?1???1?0?0?00??00?????1????????????
                                                                      1
Erinaceus         0000002001012001110031211120102231112 5111121021100231130011 13???11101102
Leptictis         00???0200?01??0111003121112010223111 25111111020100231130011 13???11101102
Canis             0?0?0020000120011100302111311022311125111?11?3??0?2311110111 3?????101102
Felis             0?0?0020000120011100302111311022311125111?11?3??0?2311110111 3?????101102
Rattus            0101000100012001110020101100201231112 5111111010000241101011131??2?101101
Oryctolagus       0101000100012001110020101100201231112 5111111010000241101011131??2?101101
Bradypus          0?0?0020000120011100302111311022311125111?11?3??0?2302110101 3?????101102
Tamandua          0?0?0020000120011100312111311022311125111?11?3??0?231?110101 3?????101102
Glyptotherium     0?0?0020000120011110302111311022311125111?11?3??0?230?110101 3?????101102
Dasypus           0?0?0020000120011110302111311022311125111?11?3??0?2301110101 3?????101102
                                                                        2
Chaetophractus    0?0?0020000120011111302111311022311125111?11?3??0?2302110101 3?????101102
Euphractus        0?0?0020000120011111302111311022311125111?11?3??0?2302110101 3?????101102
Holoclemensia     ????????????????????????????????????????????????????????????????????????????????????
Sinodelphys       1101102100002001 1??0????????????????????????????????????????????????????????????
Deltatheridium    ??????????????????11100?02011 2????2311125 10??1101002123 12???1013????2?1011?2
Atokatheridium    ????????????????????????????????????????????????????????????????????????????????????
Sulestes          ??????????????????????????????2311125 10??1?0????12?1?????????????????????
Asiatherium       ???????????0?001110?3020112010?2311125????1111?0??23??4101013?????10?1?2
Kokopellia        ????????????????????????????????????????????????????????????????????????????????????
Anchistodelphys   ????????????????????????????????????????????????????????????????????????????????????
Albertatherium    ????????????????????????????????????????????????????????????????????????????????????
Didelphodon       ??????????????????10?3020112010223111 2??0????1??0?1??11?????1??????1?????
Pediomys          ????????????????????????????????123111???0?????0??0?1????1?????1??????1?????
Turgidodon        ??????????????????????????????223111???0????0??0?1??11?????1??????1?????
Mayulestes        ??????210??0?00111003020112011123111 25????110100??2411010101 3?????101102
Pucadelphys       ?101?0210??0?00111003020112011123111 2511??1101002124110101013?????101102
Andinodelphys     ???????????0???1110032011201122311125????1101002?2411010101 3?????101102
Didelphis         1101102100102001110030201120111231112 5111111110021231101010 13?????101102
                                                                          1
Marmosa           1101102100102001110030201120111231112 5111111110021231111010 13?????101102
Caenolestes       1100002101002001110030201120?1123111 25111111130022311010101 3?????10?102
Dasyurus          1100002101002001110030201120113231112 5111111130021231011010 13?????101102
Perameles         1101002001002011110030201120211231112 5111111130022?2311410101 3?????101102
Dromiciops        1101002100102001110030201120111231112 5111111130022?231?410101 3?????101102
Thylacomyidae     ??0?002?0?002011110030211?1323111251111111130022?2310?101013????? 101102
Macropus          1101002000002011110030211313032311125 1111111130022?2311410101 3?????101102
Acrobates         1101002?0?102011110030211313032311125 1111111130022?2311410101 3?????101102
Phascolarctos     1101002100102011210030211100103231112 5111111130022?2311410101 3?????101102
Vombatus          1101002100102011210030211107003231112 5111111130022?2302310101 3?????101102
Phalanger         1101002100102011210030211313032311125 1111111130022?2311410101 3?????101102
Pseudocheirus     1101002100102011210030211313032311125 1111111130022?2311410101 3?????101102
Petauroides       1101002100102011210030211313032311125 1111111130022?2311410101 3?????101102

Input data matrix (continued):

                  3333333333333333333333333333333333333334444444444444444444444444444444444
```

```
                 6666666667777777777888888888899999999990000000000111111111122222222223333
Taxon/Node       1234567890123456789012345678901234567890123456789012345678901234567890123456789012
-------------------------------------------------------------------------------------------------------
Thrinaxodon      ????0?00?00??0?0?0000000000000000000000000000000000000000000000000000000?0000
Massetognathus   ????0?00?00??0?0?1010000000000000010000000000030000000000000000000100000?0000
Probainognathus  ????0?00?00??0?0?0010000007000000100000000000000000000000000000100000?0000
Tritylodontids   00000?00000?0100?0021000000000000100000000001030100000000000020010?01000
                                                                                        1
Pachygenelus     00000?00010000?1?0021001100000000100000000100000101010100000010000?01000
Adelobasileus    000000000010000?10??????????0?????????????0??0?0?000????????00??0200?????00
Sinoconodon      000000000010001010102100110000000010000010010100010100010000020001002000
Morganucodon     000000000010001010002100210000000010000010010100010101010000020001002000
Megazostrodon    000000000010001010?00210?21???0??001?00001010?1??000101010100000?2?001000200
Haldanodon       000000000010001010??????1000???00??0000?011?10001010101000000200010020l0
Castorocauda     ????????????????????????????????1100010000?????????0??????10?000?2????0?2???
Hadrocodium      000000000100?1010?????????1?0???????1????02012?1030101000100000?2?21002010
Shuotherium      ????????????????????????????????????????????????????????????????????????????
Pseudotribos     ????????????????????????????????????????????????????????0?????????????2???
Asfaltomylos     ????????????????????????????????????????????????????????????????????????????
Ambondro         ????????????????????????????????????????????????????????????????????????????
Ausktribosphenos ????????????????????????????????????????????????????????????????????????????
Bishops          ????????????????????????????????????????????????????????????????????????????
Teinolophos      ????????????????????????????????????????????????????????????????????????????
Steropodon       ????????????????????????????????????????????????????????????????????????????
Obdurodon        000000000000?00?0?????????1?0?????????????03012?10000?40?110211?120201122?00
Ornithorhynchus  000000000000?00?0?3231212110011101210100301101000024001102112120201122100
Tachyglossus     000000000010?00?0?3231212110011101210100301211020024001?2112120211122100
Fruitafossor     ????????????????????????????????????????????????????????0?????????????2?1??
Gobiconodon      000000000011??1011?????????1?1????12?????002002110000110000000011200111221 21
Repenomamus      0000?000011??101?????????21?1????12?????02002110000110000000011200111221 21
Amphilestes      ????????????????????????????????????????????????????????1?????????????????
Yanoconodon      ????????????????????32312121???110122101007?00?????0??????11?????2????122???
Jeholodens       0???0?0?????????????????21?????????1221?????????????00?10??11???00?????122???
Trioracodon      ???0??0???1??10?????????????0?????????????0????????0????????1?????????????????0
Priacodon        ?000??0??1100101?????????2??0????????????020?????000??????1????????1??122?10
                                                                                          2
Haramiyavia      ????????????????????????????????????????????????????????0?????????????2???
Rugosodon        ????????????????????????????1?????????????????????????????????????????????????
Kuehneodon       ????????????????????????????????????????????????????????????????????????????
Sinobaatar       ?????????????????????????1?????????2???00?????????????????????????????????????
Plagiaulacids    0?000000010001111???????21?0???????????0?00020100100200010?00002027?1122020
Cimolodontans    000000000100011103231212110011??2111000001010010020001020000202111220 20
                  11       1                          2                1
Tinodon          ????????????????????????????????????????????????????????????????????????????
Akidolestes      ????????????????????????????????????????????0??????10?0???2?????12???
Spalacotherium   ????????????????????????????????????????????????????????0?????????????????
Zhangheotherium  000000000l?0?11?1???????21??????1??????0??????0??1?????10???0???2???12??2
Maotherium       0000000001???11?????????????????12?????0201??20?0??22??100000???2???12?02
Dryolestes       ????????????????????????????????????????????????1???10?0?????????????????
Henkelotherium   0????????????????????????????????????????????1?????20001???1?????????20??
Amphitherium     ????????????????????????????????????????????????????????????????????????????
Peramus          ????????????????????????????????????????????????????????????????????????????
Vincelestes      011000000110021l1??????21?0???????????0101101000102010000010120001002020
Nanolestes       ????????????????????????????????????????????????????????????????????????????
Kielantherium    ????????????????????????????????????????????????????????????????????????????
Aegialodon       ????????????????????????????????????????????????????????????????????????????
Montanalestes    ????????????????????????????????????????????????????????????????????????????
Prokennalestes   ?11001???110?21?????????2??1?????????????????????????0???????????1?????????1
Murtoilestes     ????????????????????????????????????????????????????????????????????????????
Eomaia           ?????????11?????????????????????????????0????????00??0??10?0???2???10?20??
Juramaia         ????????????????????????????????????????????????????????????????????????????
Kennalestes      0100011001100211?????????21?2???????321300?0110200000200??0?0101121211002022
Asioryctes       0100011001100211?????????21?2???????321300201102000000200?101010?21211002022
Ukhaatherium     ??0?0?1???????21?1?????????2????????21??0?0?????0????????0?010???21??0?????
Zalambdalestes   0100011001100211?????????21?2???????321300201102000000201?101010121111002021
                                                                                          1
Daulestes        01100??001?????????1????2??1???????3???00?01?1??000?100?10?000?21211002 0??
                                                                                          1
Aspanlestes      ??00?1?????????1???????????1?????????????????????0????????????????????
Eoungulatum      ?000?????????1?????????????1?????????????????????????????????????????????????
Cimolestes       ?0????????????????????????????????????????????????????????????????????????????
Gypsonictops     ????????????????????????????????????????????????????????????????????????????
Protungulatum    ?11001????1??21???????????2?????????????????????????????????????????????????1
Erinaceus        011001100110021112131112122011101421300211130000020011011011212 11?22121
Leptictis        01100110011002110???????21?20?????321301211112000003000101101112121 1102021
Canis            000010000110?1120213111212201110142131120111401001300010110111211010220 22
                                  1
Felis            000010000110?1120213111212201110142131120111401001300010110111211010220 22
Rattus           010011100211111102131112122011101421300201112120014001101100121201122132
Oryctolagus      000011100111011102131112122011101521300001111121003001l?2111121201122132
Bradypus         000000000110?1120213111212201110142131130111103001010l?1102121101122 0?2
```

```
                        1
Tamandua                0010000001102112021311121220111014213113011110300101002?1102121101122O?2
Glyptotherium           0000?0000110?1120????11??220111014213113011110300101001011021212111220?2
Dasypus                 0000000001102112021311121220111014213113011113001010020110112121122O?2
Chaetophractus          0000000001102112021311121220111014213113011113001010020110212121122O?2
                           1           1
Euphractus              0000000001102112021311121220111014213113011113001010020110212121122O?2
                           1           1
Holoclemensia           ????????????????????????????????????????????????????????????????????
Sinodelphys             ????????????????????????????????????????????0??????10?0????2????0?2?3?
Deltatheridium          ?00001???1101111????????2??1???????????02?11?2?000?20101?000121???002031
                                                                                              1
Atokatheridium          ????????????????????????????????????????????????????????????????????
Sulestes                ?000?????????1?1????????????????????????????????????????????????????0?2???
Asiatherium             ??0?0101111???11????????2?????????????????02011?2?00??21??10?0?0?2????0020??
                                                                                              1
Kokopellia              ????????????????????????????????????????????????????????????????????
Anchistodelphys         ????????????????????????????????????????????????????????????????????
Albertatherium          ????????????????????????????????????????????????????????????????????
Didelphodon             0?00?1?????0111?????????1?1???????????0?????????????????????????????0???1
Pediomys                ?200?1?????0111?????????????1?????????????????????2????0?????????????????????1
Turgidodon              ??00?1?????0?11???????????1?????????????????????????????????????????????1
Mayulestes              1001010011111111??????21?????????????02011020000021101010002?010100202??
Pucadelphys             100101001111111??????21?1??????2????02011?2000002110101110120101002031
Andinodelphys           1001010001111111?????????21?1???????????02?111?1000021?0101100120?1?002031
Didelphis               0000010111101111121311121210111002212002011121000021001011001201010020 31
Marmosa                 0000010111101111121311121210111002212002011121000021001011011201010020 31
Caenolestes             0000000211101111121?1??2111011100321200201113100002 1?01011?0120101002032
Dasyurus                000001021110111121?131??2111011100421200201111200021101011011201010020 32
Perameles               0000010211101111121?1??2111011100421200201111210000210010110112010100 2032
Dromiciops              0000010211100111021?1??2122011100321300201111100003110101100120?01002032
Thylacomyidae           ?0000102?1???11??2131??21??0?1100421?0020111?1000021?01011?012?101?020?2
Macropus                0000010311100111121?1??2122011100521300201111110013110101100120101003032
Acrobates               0000010111101112021?1??212?1111005213102011131000031101011001201010020 32
Phascolarctos           0000010211101111121?1??2112011100321300201113110014100101110120101003032
Vombatus                000001011110011112131??2112011100521300201113100014110101100120101003032
Phalanger               0000010311100111121?1??2122111100521310201113110013100101100120101003032
Pseudocheirus           0000010311100112121?1??2122111100521310201112100003110101100120101012032
Petauroides             0000010311100112121?1??2122111100521310201112100002110101100120101012032

Input data matrix (continued):

                        4444444444444444444444444
                        3333333444444444455555555
Taxon/Node              3456789012345678901234567 8
-----------------------------------------------------
Thrinaxodon             0000000000010000000000???
Massetognathus          000000?0000000000000010???
Probainognathus         000000?000000000000101???
Tritylodontids          00000000000000100?0111???
                              1
Pachygenelus            00000000000000000?????????
Adelobasileus           01100?????????0?????????
Sinoconodon             0000010000000001000102???
Morganucodon            0110011000000001000112???
Megazostrodon           01?00????????00??0?????????
Haldanodon              011101100000000??2?????
Castorocauda            ?1???11?00?????????????????
Hadrocodium             1211001?00??000?2??1213???
Shuotherium             ?????????????????????????
Pseudotribos            1?????????????????????????
Asfaltomylos            ?????????????????????????
Ambondro                ?????????????????????????
Ausktribosphenos        ?????????????????????????
Bishops                 ?????????????????????????
Teinolophos             ?????????????????????????
Steropodon              ?????????????????????????
Obdurodon               12110011?0??00002?????2???
Ornithorhynchus         12110011?0?100002111223000
Tachyglossus            12110011?0?100102111223000
                                2
Fruitafossor            ?????????????????????????
Gobiconodon             0110001?000001??0??0?00???
Repenomamus             0110001?00000101??0100???
Amphilestes             ?????????????????????????
Yanoconodon             ?????????0???????????????
Jeholodens              011??01??0??????1?????????
Trioracodon             ?????????????????????????
Priacodon               ??????????0??0??1?????????
Haramiyavia             ?????????????????????????
Rugosodon               ?????????????????????????
```

```
Kuehneodon          ?????????????????????????????
Sinobaatar          ?????????????????????????????
Plagiaulacids       00100011010000?21?????????
                          1
Cimolodontans       01100121010000021110223???
Tinodon             ?????????????????????????????
Akidolestes         ?????0???0???????????????????
Spalacotherium      ?????????????????????????????
Zhangheotherium     ?????????00???????????????????
Maotherium          ?1????0??00??????1?????????
Dryolestes          ?????????00??0????????????????
Henkelotherium      ?????????????????????????????
Amphitherium        ?????????????????????????????
Peramus             ?????????????????????????????
Vincelestes         00100111000000??1?????????
Nanolestes          ?????????????????????????????
Kielantherium       ?????????????????????????????
Aegialodon          ?????????????????????????????
Montanalestes       ?????????????????1?????????
Prokennalestes      ????????????0????????????????
Murtoilestes        ?????????????????????????????
Eomaia              ?????02??1??????1?????????
Juramaia            ?????????????????????????????
Kennalestes         01110021010?00??1011223???
Asioryctes          01110021010000??1011223???
Ukhaatherium        ????0??????0????????????????
Zalambdalestes      01100021010000??1011223???
Daulestes           ?1??00??????00??2?????????
Aspanlestes         ?????????????????????????????
Eoungulatum         ?????????????????????????????
Cimolestes          ?????????????????????????????
Gypsonictops        ?????????????????????????????
Protungulatum       ?????????????????????????????
Erinaceus           01110021110020122011223111
Leptictis           01110021010000122011223???
Canis               12100021111100122001223111
Felis               12100021111100122001223111
Rattus              1210002121?200121111223111
Oryctolagus         121000212l?200121111223111
Bradypus            12100021011001122001223111
Tamandua            12100021011001122001223111
Glyptotherium       1210102101l?01122??223l1?
Dasypus             12101021011001122001223111
Chaetophractus      12101021011001122001223111
Euphractus          12101021011001122001223111
Holoclemensia       ?????????????????????????????
Sinodelphys         ?????0??????????1?????????
Deltatheridium      ????002?011000????????????
Atokatheridium      ?????????????????????????????
Sulestes            ????????????0????????????????
Asiatherium         ?11000??????10??2?????????
Kokopellia          ?????????????????????????????
Anchistodelphys     ?????????????????????????????
Albertatherium      ?????????????????????????????
Didelphodon         ????0???????1????????????????
Pediomys            ????????????1????????????????
Turgidodon          ?????????????????????????????
Mayulestes          01100021111100??2?????????
Pucadelphys         01100021011100?21?????????
Andinodelphys       0110002101111??21?????????
Didelphis           00100021111110121011223002
Marmosa             12110021111110121011223002
Caenolestes         ??10002111?220121???223002
Dasyurus            01100021111110121011223002
Perameles           12100021110110121???223001
Dromiciops          12110021011110121011223002
Thylacomyidae       ??1?0021?1???0121???222300?
Macropus            12110021012000121???223002
                                1
                                2
Acrobates           121100211111201 21???223002
Phascolarctos       01100021111020121???223002
Vombatus            02100021111001121???223002
Phalanger           02100021111120121???223002
Pseudocheirus       12100021111120121???223002
Petauroides         12110021011120121???223002

Heuristic search settings:
  Optimality criterion = parsimony
    Character-status summary:
      Of 458 total characters:
```

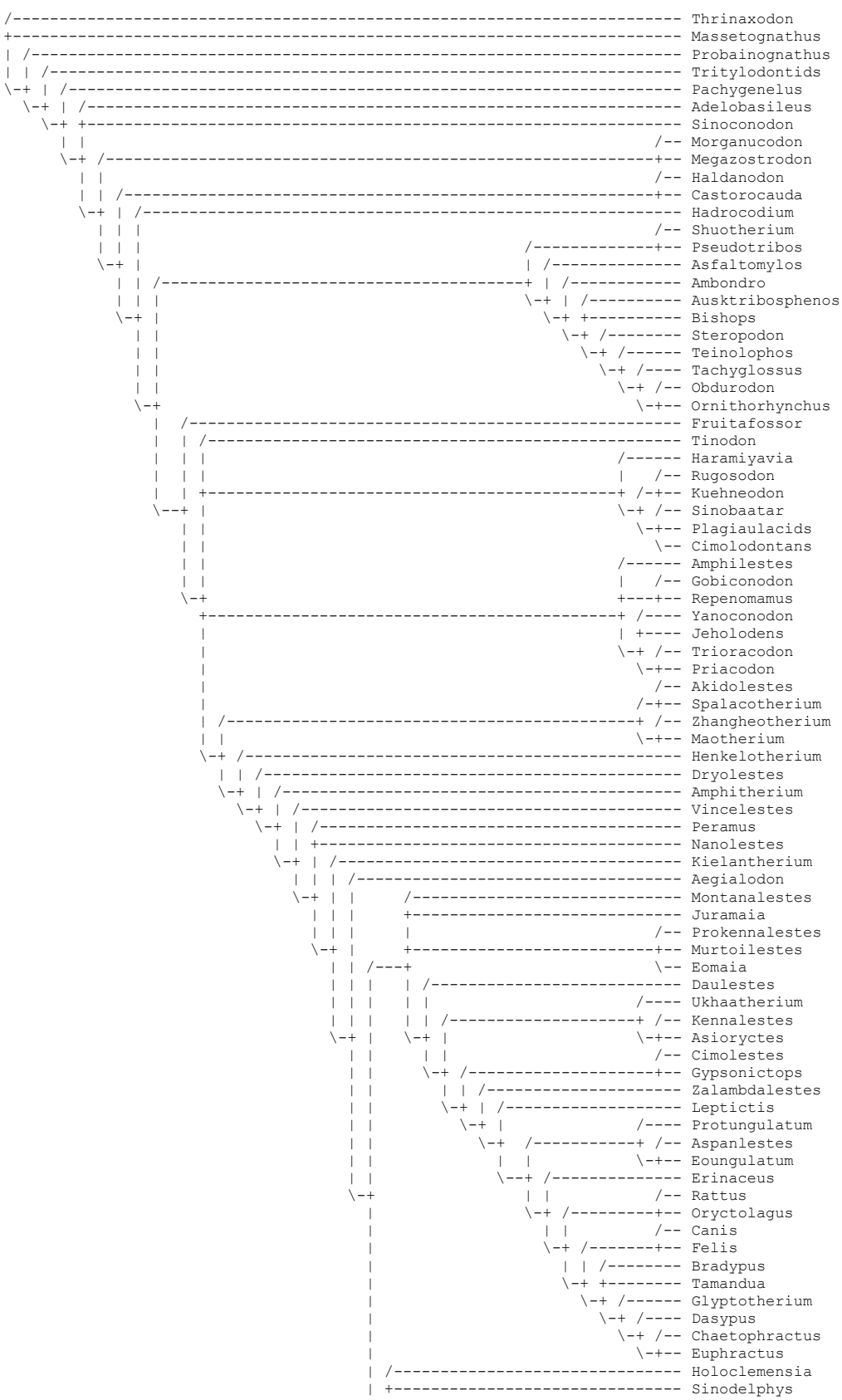
```
        All characters are of type 'unord'
        All characters have equal weight
        All characters are parsimony-informative
    Gaps are treated as "missing"
    Multistate taxa interpreted as uncertainty
  Starting tree(s) obtained via stepwise addition
  Addition sequence: random
    Number of replicates = 1000
    Starting seed = 338401823
  Number of trees held at each step during stepwise addition = 1
  Branch-swapping algorithm: tree-bisection-reconnection (TBR)
  Steepest descent option in effect
  Initial 'MaxTrees' setting = 200 (will be auto-increased by 100)
  Branches collapsed (creating polytomies) if maximum branch length is zero
  'MulTrees' option not in effect; only 1 tree will be saved per replicate
  Topological constraints not enforced
  Trees are unrooted

Heuristic search completed
   Total number of rearrangements tried = 6.4065e+09
   Score of best tree(s) found = 2200
   Number of trees retained = 175
   Time used = 01:28:22.4

Tree-island profile:
                  First      Last                    First   Times
Island      Size*     tree      tree        Score    replicate     hit
-------------------------------------------------------------------
     1         1         1         1         2200            3       1
     2         1         2         2         2200           10       1
     3         1         3         3         2200           17       1
     4         1         4         4         2200           24       1
     5         1         5         5         2200           26       1
     6         1         6         6         2200           28       1
     7         1         7         7         2200           39       1
     8         1         8         8         2200           51       1
     9         1         9         9         2200           62       1
    10         1        10        10         2200           65       1
    11         1        11        11         2200           84       1
    12         1        12        12         2200           87       1
    13         1        13        13         2200           97       1
    14         1        14        14         2200          100       1
    15         1        15        15         2200          101       1
    16         1        16        16         2200          103       1
    17         1        17        17         2200          124       1
    18         1        18        18         2200          131       1
    19         1        19        19         2200          137       1
    20         1        20        20         2200          144       1
    21         1        21        21         2200          150       1
    22         1        22        22         2200          154       1
    23         1        23        23         2200          160       1
    24         1        24        24         2200          164       1
    25         1        25        25         2200          173       1
    26         1        26        26         2200          175       1
    27         1        27        27         2200          181       1
    28         1        28        28         2200          194       1
    29         1        29        29         2200          202       1
    30         1        30        30         2200          207       1
    31         1        31        31         2200          208       1
    32         1        32        32         2200          214       1
    33         1        33        33         2200          216       1
    34         1        34        34         2200          244       1
    35         1        35        35         2200          249       1
    36         1        36        36         2200          252       1
    37         1        37        37         2200          256       1
    38         1        38        38         2200          259       1
    39         1        39        39         2200          271       1
    40         1        40        40         2200          274       1
    41         1        41        41         2200          277       1
    42         1        42        42         2200          283       1
    43         1        43        43         2200          284       1
    44         1        44        44         2200          286       1
    45         1        45        45         2200          293       1
    46         1        46        46         2200          300       1
    47         1        47        47         2200          309       1
    48         1        48        48         2200          324       1
    49         1        49        49         2200          339       1
    50         1        50        50         2200          340       1
    51         1        51        51         2200          341       1
    52         1        52        52         2200          345       1
    53         1        53        53         2200          355       1
```

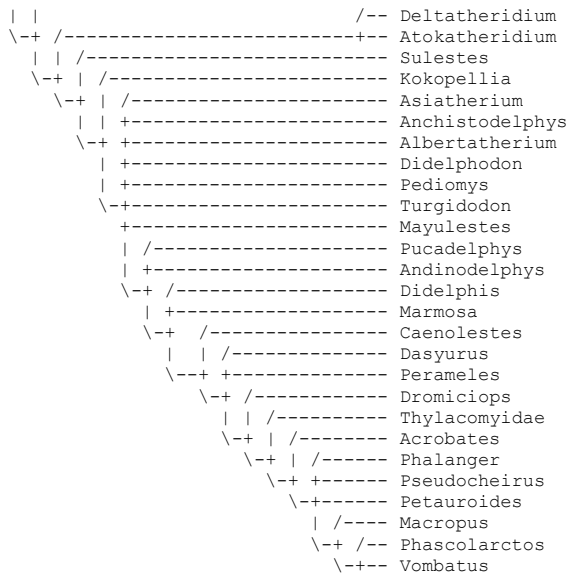
54	1	54	54	2200	364	1
55	1	55	55	2200	368	1
56	1	56	56	2200	369	1
57	1	57	57	2200	371	1
58	1	58	58	2200	372	1
59	1	59	59	2200	374	1
60	1	60	60	2200	383	1
61	1	61	61	2200	393	1
62	1	62	62	2200	399	1
63	1	63	63	2200	400	1
64	1	64	64	2200	401	1
65	1	65	65	2200	411	1
66	1	66	66	2200	413	1
67	1	67	67	2200	416	1
68	1	68	68	2200	424	1
69	1	69	69	2200	433	1
70	1	70	70	2200	437	1
71	1	71	71	2200	438	1
72	1	72	72	2200	441	1
73	1	73	73	2200	451	1
74	1	74	74	2200	453	1
75	1	75	75	2200	465	1
76	1	76	76	2200	467	1
77	1	77	77	2200	469	1
78	1	78	78	2200	473	1
79	1	79	79	2200	474	1
80	1	80	80	2200	480	1
81	1	81	81	2200	481	1
82	1	82	82	2200	485	1
83	1	83	83	2200	486	1
84	1	84	84	2200	493	1
85	1	85	85	2200	501	1
86	1	86	86	2200	511	1
87	1	87	87	2200	512	1
88	1	88	88	2200	519	1
89	1	89	89	2200	521	1
90	1	90	90	2200	522	1
91	1	91	91	2200	531	1
92	1	92	92	2200	549	1
93	1	93	93	2200	556	1
94	1	94	94	2200	557	1
95	1	95	95	2200	562	1
96	1	96	96	2200	563	1
97	1	97	97	2200	570	1
98	1	98	98	2200	578	1
99	1	99	99	2200	596	1
100	1	100	100	2200	597	1
101	1	101	101	2200	606	1
102	1	102	102	2200	607	1
103	1	103	103	2200	609	1
104	1	104	104	2200	610	1
105	1	105	105	2200	612	1
106	1	106	106	2200	622	1
107	1	107	107	2200	623	1
108	1	108	108	2200	637	1
109	1	109	109	2200	638	1
110	1	110	110	2200	647	1
111	1	111	111	2200	670	1
112	1	112	112	2200	679	1
113	1	113	113	2200	688	1
114	1	114	114	2200	689	1
115	1	115	115	2200	692	1
116	1	116	116	2200	697	1
117	1	117	117	2200	698	1
118	1	118	118	2200	699	1
119	1	119	119	2200	703	1
120	1	120	120	2200	710	1
121	1	121	121	2200	719	1
122	1	122	122	2200	730	1
123	1	123	123	2200	738	1
124	1	124	124	2200	742	1
125	1	125	125	2200	753	1
126	1	126	126	2200	754	1
127	1	127	127	2200	755	1
128	1	128	128	2200	769	1
129	1	129	129	2200	774	1
130	1	130	130	2200	785	1
131	1	131	131	2200	787	1
132	1	132	132	2200	797	1
133	1	133	133	2200	807	1
134	1	134	134	2200	809	1

135	1	135	135	2200	813	1
136	1	136	136	2200	815	1
137	1	137	137	2200	827	1
138	1	138	138	2200	832	1
139	1	139	139	2200	834	1
140	1	140	140	2200	835	1
141	1	141	141	2200	840	1
142	1	142	142	2200	854	1
143	1	143	143	2200	857	1
144	1	144	144	2200	871	1
145	1	145	145	2200	872	1
146	1	146	146	2200	875	1
147	1	147	147	2200	878	1
148	1	148	148	2200	879	1
149	1	149	149	2200	883	1
150	1	150	150	2200	909	1
151	1	151	151	2200	910	1
152	1	152	152	2200	911	1
153	1	153	153	2200	914	1
154	1	154	154	2200	915	1
155	1	155	155	2200	918	1
156	1	156	156	2200	920	1
157	1	157	157	2200	927	1
158	1	158	158	2200	929	1
159	1	159	159	2200	930	1
160	1	160	160	2200	933	1
161	1	161	161	2200	935	1
162	1	162	162	2200	938	1
163	1	163	163	2200	941	1
164	1	164	164	2200	942	1
165	1	165	165	2200	943	1
166	1	166	166	2200	949	1
167	1	167	167	2200	952	1
168	1	168	168	2200	957	1
169	1	169	169	2200	963	1
170	1	170	170	2200	966	1
171	1	171	171	2200	970	1
172	1	172	172	2200	982	1
173	1	173	173	2200	989	1
174	1	174	174	2200	992	1
175	1	175	175	2200	998	1
176	1	-	-	2201	2	269**
177	1	-	-	2202	4	238**
178	1	-	-	2203	30	136**
179	1	-	-	2204	1	82**
180	1	-	-	2205	31	46**
181	1	-	-	2206	70	14**
182	1	-	-	2207	155	7**
183	1	-	-	2208	889	1
184	1	-	-	2209	27	1
185	1	-	-	2211	116	6**
186	1	-	-	2212	50	4**
187	1	-	-	2213	46	2**
188	1	-	-	2215	113	4**
189	1	-	-	2216	463	2**
190	1	-	-	2219	235	5**
191	1	-	-	2220	78	2**
192	1	-	-	2223	48	4**
193	1	-	-	2224	111	1
194	1	-	-	2231	232	1

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

Strict consensus of 175 trees:




Deltatheridium
Atokatheridium
Sulestes
Kokopellia
Asiatherium
Anchistodelphys
Albertatherium
Didelphodon
Pediomys
Turgidodon
Mayulestes
Pucadelphys
Andinodelphys
Didelphis
Marmosa
Caenolestes
Dasyurus
Perameles
Dromiciops
Thylacomyidae
Acrobates
Phalanger
Pseudocheirus
Petauroides
Macropus
Phascolarctos
Vombatus

Part I. Systematic characters for in-group phylogenetic placement of *Rugosodon* (BMNH1142) among major Cretaceous and Cenozoic multituberculates and their mammaliaform outgroups.

To test the hypotheses on phylogenetic relationship of the new taxon Rugosodon eurasiaticus among the known multituberculate mammals, their putative "allotherian" relatives and more basal mammaliaforms, a dataset of cranial and dental characters has been gathered from the following major references on multituberculate systematic characters (in chronological order): Simmons (1993) (32), Rougier et al. (1997) (15), Weil (1998) (33), Hahn and Hahn (1998; 2000) (3, 17), Kielan-Jaworowska and Hurum (2000 [16]; also Kielan-Jaworowska et al. 2004 [1]), Butler (2000) (4); Butler and Hooker (2005) (5); Cifelli et al. (2013) (18). Additional characters known to be informative for relationships of mammaliaforms, such as *Sinoconodon* and *Morganucodon*, are also incorporated from Luo et al. (2002; 2011) (13, 59).

All characters by the previous publications have been re-evaluated before the adoption, and the scoring of these characters in the taxon-character matrix have verified, re-checked and all quantitive characters have been re-assessed from the original taxonomic literature of multituberculates.

Abbreviations

KJ-H ## - characters discussed by Kielan-Jaworowska and Hurum (2000) in their formal character list.

Luo## - characters from Luo et al. mammaliaform character list

R## - characters discussed by Rougier, Novacek and Dashzeveg (1997) in their formal character list.

W## - characters discussed by Weil (1998) in her character list.

C## - characters discussed by Cifelli et al. (2013) on M2.

Mandibular Features

1. (Luo1) Postdentary trough:
(0) Present:
(1) Absent:
Rugosodon = 1

2. (Luo2) Meckel's sulcus presence:
(0) Present;
(1) Vestigial or absent.
Rugosodon =1,

3. (Luo et al. 2002: 20) Anterio-ventral extension of masseteric fossa to mandibular body below m1:
(0) Absent;
(1) Present and extending to below m1;
(2) Present and extending more anteriorly than the p4-m1 junction.

Rugosodon =1

4. Coronoid or coronoid scar on mandible:
(0) Present;
(1) Absent.
Rugosodon = ? (Unknown)

5. (Luo33, ZJK-H57 states are switched, distribution same) Angle of the coronoid anterior margin to the molar alveolar line on the mandibular body:
(0) > 45 degrees (Luo33 states 1-2; Note: more steep in plesiomorphic taxa than in cimolodontans);
(1) Low < 45 degrees (Luo33 states 2-3).
Rugosodon = 1.

6. (ZJK-H 58) Coronoid process orientation in parasaggital plane:
(0) Parallel to the rest of the outer wall of the dentary;
(1) Flared laterally.
Rugosodon = ? (not preserved).

7. (R67; ZJK-H 35) Angle between the lower margin of the dentary and alveolar line of the lower p4 and molars:
(0) 11-17 degrees;
(1) 18 degrees or above.
Rugosodon = 0.

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

9. (ZJK-H60) Mandibular condyle height to the m1-m2 alveolar line:
(0) Opposite or below the level of the molar alveoli;
(1) Above the level of the molars.
Rugosodon = 0.

10. Mandibular angle: presence vs. absence:
(0) Present;
(1) Absent.
Rugosodon = 1.

Incisor and Canine Features

11. (Luo142) Number of lower incisors:
(0) Four or More:
(1) One.
Rugosodon =1.

12. (Luo166) Procumbency and enlargement of the lower anterior-most incisors:
(0) Absent;
(1) Present (at least 50% longer than the adjacent incisor).
Rugosodon=1.

13. (R2) Lower incisor 1 root posterior extension:
(0) Not extending below p3;
(1) Extending posteriorly beyond p3-p4 junction.
Rugosodon=1.

14. (Luo167) Enlarged diastema in lower incisor-canine region (More developed in older individuals):
(0) Present and behind the canine;
(1) Present and behind the posterior incisor.
Rugosodon=1.

15. **(**ZJK-H21) Lower incisor robustness:
(0) Robust:
(1) Gracile.
Rugosodon=0.

16. (R3; ZJK-H 20) Enamel covering of lower incisor
(0) Of uniform thickness:
(1) Thicker or restricted to the ventro-labial surface.
Rugosodon=0.

17. (R18; Luo143) Number of upper incisors (Ordered):
(0) Four or more;
(1) Three;
(2) Two.
Rugosodon=1.

18. (New) Diastema between Upper Incisor 2 and Incisor 3:
(0) No large diastema between the second incisor and third upper incisors;
(1) I2-I3 diastema.
Rugosodon = 0.

19. (R19; ZJK-H3: states and distribution revised) Upper Incisor 2 (or penultimate incisor) morphology:
(0) Peg-like or single cusp;
(1) Two-cusped, or more.
Rugosodon = 1,

20. (R21; Modified from ZJK-H4) Upper Incisor 3 (or ultimate upper incisor) morphology:
(0) Single cusped or peg-like;
(1) 2-cusped;

(2) 3-4-cusped.
Rugosodon = 1.

21. (R22; ZJK-H 13) Placement of posterior upper incisor (I3):
(0) On the margin of premaxilla;
(1) Medial to the margin-crest of facio-palatal faces of premaxilla;
(2) More internal on the palatal part (close to the first premolar).
Rugosodon = 0.

22. (R23; ZJK-H5-Luo148) Upper canine - presence vs. absence, and size:
(0) Present and enlarged;
(1) Present and small;
(2) Absent.
Rugosodon = 1.

23. (R24) Upper canine – number of cusps:
(0) Peg-like with single cusp;
(1) Two or more cusps.
Rugosodon = 1.

24. (Luo150) Lower canine - presence vs. absence:
(0) Present;
(1) Absent.
Rugosodon = 1

Premolar Features

25. (ZJK-H15) Ratio between I3 & first maxillary tooth vs. length of upper premolars and molars (Ordered):
(0) Below 0.09;
(1) Between 0.1-0.19;
(2) 0.2 or above.
Rugosodon = 0

26. (ZJK-H6; Luo152) Number of upper premolars (only applicable to taxa with premolar vs. molar differentiation) (Ordered):
(0) Five;
(1) Four;
(2) Three;
(3) Two or one.
Rugosodon = 0.

27. (R31, R34; ZJK-H14) Root(s) of posterior upper premolar(s):
(0) Double-rooted;
(1) Single-rooted (1).
Rugosodon = 0.

28. (ZJK-H7) Labial cuspules on posterior upper premolars:
(0) Absent;
(1) Present.
Rugosodon = ? (ultimate premolar labial aspect broken).

29. (ZJK-H8) Upper premolars/upper molars length ratio (re-measured and revised) (Ordered):
(0) 1.5 or more;
(1) 1.5-0.8;
(2) 0.8 or less.
Rugosodon = 0 (>1.5).

30. (ZJK-H9) Last upper premolar: number and length of cusp rows:
(0) Two main and equal rows of cusps;
(1) Two equal rows of cusps and a continuous row of labial cingular cuspules or cingulum:
(2) One main row and a shorter buccal row (anterior or posterior);
(3) One main row only on P4.
Rugodoson = 0

31. P4 (or penultimate Upper Premolar) - the main labial cusp row (excluding the labial cingular cuspules) (ZJK-H18, modified; herein the multituberculate labial row is considered the same row as the main row of upper premolar of Morganucodon) (ordered):
(0) 1-4;
(1) 5-8;
(2) 9-10.
Rugosodon = ? (Unknown: labial aspect of P4 is broken),

32. (ZJK-H19) Width ratio of ultimate upper premolar vs M1 (Ordered):
(0) More than 0.9;
(1) 0.9-.07;
(2) 0.69-0.4;
(3) 0.39-0.2.
Rugosodon = ? (P4 broken).

33. (R5; ZJK-H22, distribution revised) Lower p1:
(0) Present;
(1) Absent.
Rugosodon = 0.

34. (R6; ZJK-H23) Lower p2:
(0) Present;
(1) Absent.
Rugosodon = 0.

35. (R7; ZJK-H24, modified) Lower p3 (or penultimate premolar) presence vs. absence:
(0) Present;

(1) Absent.
Rugosodon = 0.

36. (Luo160) p3 (or penultimate lower premolar) laterally compressed to be blade-like:
(0) No (including taxa with peg-like p3);
(1) Yes.
Rugosodon = 1.

37. (R8; ZJK-H24, modified) Lower p3 (or penultimate premolar) cusp/serration count:
(0) Present, with 3-5 cusps;
(1) Present, with 1-2 cusps.
Rugosodon = ? (Not preserved well enough to score).

38. (ZJK-H25) Shape of p3:
(0) Single row of cusps;
(1) Blade-like rectangular;
(2) Blade-like triangular;
(3) Peg-like.
Rugosodon =1 (impression outline).

39. (ZJK-H 26) Labial basal cuspules on p3 (applicable to bladed lower premolars):
(0) Present;
(1) Absent.
Rugosodon = ? (unknown because the labial cuspule row position is not exposed).

40. Contact of penultimate and ultimate lower premolars:
(0) Juxtaposition;
(1) Staged: p4 overhanging p3.
Rugosodon = 0.

41. (Luo160) Lower p4 (or ultimate lower premolar) laterally compressed to be blade-like:
(0) No;
(1) Yes.
Rugosodon = 1.

42. (R11; ZJK-H27) Lower p4 (or ultimate premolar) profile in lateral view:
(0) Tricuspate;
(1) Rectangular;
(2) Arcuate;
(3) Triangular.
Rugosodon = ?

43. (R9; ZJK-H28) Order: Blade-like p4 serration count (character state modified):
(0) 7 or less;

(1) 8-10;
(2) More than 10.
Rugosodon = 0

44. (New) Lower p4 anterior root - Exoedaenodont at crown-root junction (Krause 1977, synonymous as the "triangular premolar lobe" of Kielan-Jaworowska et al. 2004):
(0) Absent;
(1) Present.
Rugosodon = 0

45. (ZJK-H34) Dorsal margin of p4 to m1:
(0) On the level of molars;
(1) Protruding dorsally over molars.
Rugosodon = 1.

46. (ZJK-H29) p3/p4 maximum length ratio (ordered):
(0) Above 0.7;
(1) 0.7 – 0.4;
(2) 0.39-0.11;
(3) 0.10 or less.
Rugosodon = ? (cannot be estimated reliably).

47. (ZJK-H30) Labial basal cuspules on p4 (ordered):
(0) Absent;
(1) Single cusp or a simple cingulid;
(2) Several-single row;
(3) Several-double rows;
Rugosodon = ?

48. (W14; ZJK-H31) Ratio of p4:m1 length (ordered):
(0) Less than 0.99;
(1) 1-1.49;
(2) 1.5-1.99;
(3) 2 or greater.
Rugosodon = 1 (p4:m1 ration =1.3).

49. (Luo154) Number of lower molars or molariform postcanines (ordered):
(0) Three or more;
(1) Two molars.
Rugosodon = 1.

50. (Luo155) Number of upper molars or molariform postcanines:
(0) Three or more;
(1) Two.
Rugosodon =1.

51. (Luo156) Total number of upper postcanine loci (order):

(0) More than 8 (including the loci plus the alveoli of shed anterior postcanines):
(1) Seven loci;
(2) Six;
(3) Five or fewer.
Rugosodon = 1.

52. (Luo157) Number of lower postcanine loci (ordered):
(0) Eight or more;
(1) Six;
(2) Five or less.
Rugosodon = 1.

53. (Luo168 originally from Butler 2000) U-shaped transverse ridge(s) between b1-l1, or b2-l2 cusps in lower molars:
(0) Absent;
(1) Present.
Rugosodon = 1.

54. (Luo169 originally from Butler 2000) Lower molar 1 longtitudinal cusp row(s) (the buccal row in case of multi-rows) – relative cusp height:
(0) Second mesial cusp (b2 of Butler 2000) highest;
(1) All cusps are of equal height.
Rugosodon = 0.

55. Order: M1 lingual row cusp count (applicable only to teeth with multi-row of multi-cusps):
(0) 4 or fewer;
(1) 5;
(2) 7-9 ore more.
Rugosodon = 0.

56. (Luo170 originally from Butler 2000) Penultimate Upper molar 1 (M1) of multi-rowed upper molar (or postcanines) - cusp height ratio in the lingual row:
(0) Distal cusp or second distal cusp highest, with a gradient of anteriorly decreasing height;
(1) Cusps in same row of equal height.
Rugosodon, = 1.

57. (ZJK-H 12) M1 posterolingual wing (applicable to molars with multi-rows of multiple cusps):
(0) Absent;
(1) Present.
Rugosodon = 0.

58. (W18, ZJK-H11) M1 posterolingual wing to M1 length (applicable to M1with multi-rows) (ordered):

(0) Present and below 0.2;
(1) Present and between 0.2 and 0.5;
(2) Present and more than 0.5.
Rugosodon = ? (not applicable).

59. (ZJK-H12) M1 posterolingual wing morphology (applicable only to M1s with posterolingual wing) (ordered):
(0) Wing smooth;
(1) Wing is crested;
(2) Wing cuspate with 3-4 cuspules;
(3) Wing cuspate with 5 or more cuspules.
Rugosodon = ? (Not applicable because the wing is absent).

60. (Luo171) Off-set alignment of main cusp-row(s) of the first and second upper molars:
(0) Absent;
(1) Present.
Rugosodon =1.

61. (C2) Upper M2 (or ultimate upper Molar) Middle row cusp count (ordered):
(0) Two cusps;
(1) Three cusps;
(2) Four cusps.
Rugosodon = 0.

62. (C9-modified) Anterior end of middle valley of Upper M2 (or ultimate upper molar):
(0) Middle valley absent:
(1) Present as a uniform groove along most length but anterior end closed by a crescentic rim;
(2) Uniform valley posteriorly open.
Rugosodon = 1.

63. (New) Middle valley of Upper M1 (or penultimate molar):
(0) Middle valley absent;
(1) Valley present along the tooth length but its posterior end closed by a rim or rim with tiny cuspules;
(2) Valley present along most of the tooth length but posterior end closed by a single enlarged cusp in mid position;
(3) Uniform valley posteriorly open.
Rugosodon = 1.

64. (C12-modified) Curvature of lingual cusp row (applicable to multi-rowed M2):
(0) Straight;
(1) Curved posterolabially.
Rugosodon = 1.

65. (New) M2 middle valley posterior end (applicable to multi-rowed M2):
(0) Valley posteriorly open;
(1) Valley closed by a posterior cusp;
Rugosodon = 1.

66. M2 anterobuccal ridge (sensu Butler and Hooker 2005 = crista anterobuccalis of Hahn and Hahn 1998a) (State 2 adopted from Cifelli et al. 2012 character 8):
(0) Absent;
(1) Present;
(2) Present and expanded to mesial margin of main labial cusp row.
Rugosodon = 2.

67. (ZJK-H36) m1 main lingual row cusp count (distribution revised):
(0) 4 or fewer;
(1) 5;
(2) 6 or higher.
Rugosodon = 0.

68. Lower m1 middle valley:
(0) Middle valley absent;
(1) Present and posteriorly open and completely separating distal cusps of lingual vs. labial rows;
(2) Middle valley present, but rimmed posteriorly.
Rugosodon = 2.

69. (ZJK-H33, modified) m2 middle longitudinal valley:
(0) Middle valley absent;
(1) Present and completely separating two rows of cusps;
(2) Middle valley present, incomplete and rimmed anteriorly and/or posteriorly.
Rugosodon= 2.

70. Coalescence of m2 labial row cusps (applicable only to teeth with multi-rows of multiple cusps):
(0) Absent;
(1) Present.
Rugosodon = 1.

71. (R17) Complete rim of m2 basin (applicable only to teeth with multi-rows of multiple cusps):
(0) Absent;
(1) Present.
Rugosodon = 2.

72. (ZJK-H 37, modified to restrict to lingual row, switched states 1 vs. 2) m2 lingual row cusp count (ordered):

(0) One trenchant anterior cusp;
(1) 2-3;
(2) 4-5.
Rugosodon = 0.

73. (Luo 171) Ultimate lower molar (or m2) with multi-rows – ratio of row length:
(0) Labial cusp row about equal as lingual cusp row;
(1) Labial row is longer (by at least half-cusp length) than lingual row;
Rugosodon = 0.

74. (ZJK-H38) Cusp shape on lower molars:
(0) Conical;
(1) Crescentic.
Rugosodon = 0.

75. (Hahn and Hahn 1998) Enlarged trenchant second cusp of lingual row enclosed into the basin on lower m1 (applicable only to molars with multi-rows of multiple cusps)
(0) Absent;
(1) b2 cusp enlarged;
(2) b2 cusp enlarged and encircled into the basin.
Rugosodon = 1

76. (ZJK-H 39; C1) Molar enamel surface:
(0) Not ornamented;
(1) Covered with grooves, pits and ridges.
Rugosodon = 1.

77. (ZJK-H1) Enamel microstructure:
(0) prismless (preprismatic of Simmons 1993):
(1) Gigantoprismatic;
(2) Small prismatic.
Rugosodon = ? Unknown.

78. Differentiation of premolars vs. molars:
(0) Absent;
(1) Present.
Rugosodon = 1.

79. Diphyodont dental replacement:
(0) Absent;
(1) Present.
Rugosodon = 1.

Cranial Features (from R 1997 and ZJK-H 2001)

80. (R43; ZJK-H16) Infraorbital foramen:

(0) Double;
(1) Single.
Rugosodon = ? Unknown.

81. (ZJK-H17) Palatal vacuities:
(0) Absent;
(1) Present and single;
(2) Present and double.
Rugosodon = ? Unknown.

82. (ZJK-H40) Sharp ridge between the palate and lateral walls of premaxilla
(0) Absent;
(1) Present.
Rugosodon = ? Unknown.

83. Curvature of anterior zygomatic root (best viewed in dorsal view) (R48; Modified from ZJK-H41):
(0) Zygomatic root aligned with (or lightly incurved into) facial part of rostrum:
(1) Zygomatic root is more transverse and deeply incurved with facial part of rostrum.
Rugosodon = ? Unknown.

84. (ZJK-H42) Number of pairs of vascular foramina on nasal:
(0) Absent: Morganucodon
(1) One;
(2) Two;
(3) Three or more.
Rugosodon = ? Unknown.

85. (R44; ZJK-H43) Posterior-most infraorbital foramen positions (ordered):
(0) Dorsal to P3 or P4, or more posterior:
(1) Dorsal to P2;
(2) Dorsal to P1.
Rugosodon = ? Unknown.

86. (R49; ZJK-H44) Base of zygomatic arch as marked by posterior edge:
(0) Dorsal to P4 or more anterior;
(1) Dorsal or posterior to P5/M1 or P4/M1 embrasure, or further posterior.
Rugosodon = ? Unknown.

87. (R47) Bony roof over anterior orbital space:
(0) Absent;
(1) Present.
Rugosodon = ? Unknown.

88. (R50, ZJK-H45) Postorbital process:
(0) Absent:

(1) Present and short;
(2) Present and long.
Rugosodon = ? Unknown.

89. (R52, ZJK-H46) Snout length:
(0) < 49 percent of total skull length;
(1) > 50 percent of skull length.
Rugosodon = ? Unknown.

90. (ZJK-H47, modified) Frontal/nasal suture pattern:
(0) With subtransverse anterior margins or zigzag line;
(1) Pointed anteriorly and not deeply inserted between the nasals;
(2) Frontal deeply inserted between the nasals.
Rugosodon = ? Unknown.

91. (R53, ZJK-H48) Frontal-parietal suture:
(0) Roughly V-shaped parietal lappet into frontal;
(1) U-shaped.
Rugosodon = ?

92. (R54; ZJK-H 49) Contacts between nasals and parietals:
(0) Absent;
(1) Present.
Rugosodon = ?

93. (ZJK-H50) Facial exposure of lacrimal:
(0) Very small and arcuate;
(1) Large, roughly rectangular.
Rugosodon = ?

94. (R56; ZJK-H51) Thickening in palatal process of premaxilla:
(0) Absent;
(1) Present.
Rugosodon = ?

95. (ZJK-H52) Incisive foramen positioned:
(0) Within premaxilla;
(1) Limited posteriorly by maxilla.
Rugosodon = ?

96. (R61; ZJK-H53) Foramen ovale inferium placement:
(0) Medial to foramen masticatorium:
(1) Posterior to foramen masticatorium:
Rugosodon = ?

97. (R62; ZJK-H54) Jugular fossa:
(0) Small and shallow:

(1) Large and deep.
Rugosodon = ?

98. (ZJK-H55) Anterior part of promontorium (sensu Hurum et al. 1996):
(0) Oval;
(1) Irregular within curvatures on both sides.
Rugosodon = ?

99. (ZJK-H56) Glenoid fossa length-width ratio (length as measured as maximum dimension from anterolateral to posteromedial end of glenoid for multituberculates) (re-measured and distribution modified):
(0) 1.5 or more;
(1) Below 1.49.
Rugosodon = ?

100. (ZJK-H59) Post-temporal fossa:
(0) Large: Ptilodus;
(1) Reduced to a small foramen.
Rugosodon = ?

101. (ZJK-H61) Width of the snout: skull length ratio (change of character state partition:
(0) Above 0.4;
(1) Below 0.39.
Rugosodon = ?

102. (ZJK-H62) Skull width:length ratio:
(0) 0.79 and below;
(1) Above 0.8.
Rugosodon = ?

Part J. Matrix Table for Character Distribution of Multituberculates and Outgroups

Polymorphic Characters
A=0/1; B = 0/2; C=2/3; D=1/2; E=3/4; F=1/3

Ancestor
00000 00000 00000 00000 00000 00000 0000? 0000? ?0-00 0-000 0000? 0???0 ?00?? 0000? ?0?0?
00000 00000 00000 00000 00000 00

Sinoconodon
00000 00000 00000 00000 00000 0002? 00000 000?0 00?00 100?? 0000? 0???0 100??
0000? ????? 00000 00010 00010 00000 ?0000 00

Morganucodon
00000 00000 00000 00000 00000 0002? 00000 000?0 00?00 10000 0000? 0???0 100?? 0000? ?????
00110 00000 00010 00000 ?0000 00

Thomasia
????? ????? 01??0 00?00 ????? 30020 01??0 000?0 01?00 10000 ??100 00??0 11300 00?20 02000
0?1?? ????? ????? ????? ????? ??

Haramiyavia
000?1 00000 01000 00100 0100? ????? ??000 000?0 00?00 ?0000 00100 00??0 11300 10120 02000
011?? ????? ?0??? ????? ????? ??

Meketichoffatia
????? ????? ????? ????? ?11?0 00100 00??? ????? ????? ????1 1???0 00??1 ?11?? ????? ?????
1?1?0 000?? 00?00 ????1 1000? 10

Henkelodon
????? ????? ????? ?1012 02??0 00100 00??? ????? ????? ????1 1???0 10??1 ?12?? ????? ?????
1?110 ????? ????? ????? ????? ??

Rugosodon
111?1 ?0101 11110 01011 01110 00?00 ??000 1?1?0 11001 ??111 11100 10??1 01111 20221 10001
11110 ????0 ???0? ??11? ????? ??

Paulchoffatia
111?1 00101 11010 0???? ???1? ????? ??000 10100 11001 0211? ?110? ????? ????? ?0221 10002
111?? ????? ????? ????? ????? ??

Meketibolodon
11111 00101 11010 0???? ???1? ????? ??000 10100 11001 03??? ????? ????? ????? ??2?? ?0??2
1?1?? ????? ????? ????? ????? ??

Guimarotodon
11111 00101 11010 0???? ???1? ????? ??000 10100 11001 0311? ?110? ????? ????? ?0221 10002
111?? ????? ????? ????? ????? ??

Kuehneodon
11101 00101 11110 01012 01110 10100 00000 10100 11001 02111 21100 10??1 01211 20221 1100D
11110 ????? ?0??? ????? ????? ??

Ctenacodon
11110 ?1111 11110 01011 01?10 00101 00000 10110 11001 12111 11010 11001 02300 10110 01100
001?0 ??0?? 0???? ????? ????? ??

Glirodon
11110 01111 11110 11011 01010 00101 00000 ?0110 11001 12111 11010 10??1 02300 10110 01100
001?0 01011 00??0 ?0??1 ????? ??

Bolodon
11111 ?11?? 111?0 0???? ?1?1? 00101 00000 10210 11001 12?11 11010 11001 02300 10?1? ?1100
101?0 0???1 ????? ????? ????? ??

Plagiaulax
11110 01111 11110 0???? ???1? ????? ??100 10210 1110? 12?1? ?101? ????? ????? 10110 011?0
001?? ????? ????? ????? ????? ??

Zofiabaatar

11110 01111 11?10 ????? ????? ????? ??000 10110 11001 1231? ?101? ????? ????? 10?10 01100
001?? ????? ????? ????? ????? ??

Sinobaatar
11110 ?1101 11110 02101 ?2?10 00002 01100 11210 12111 21211 12011 11101 12300 10111 01100
10111 01?10 10??? ??1?? ????? ??

Eobaatar
11?1? ??1?1 11110 1???? ???1? 00000 01100 10210 1211? 21?11 12011 11101 12300 10111 01100
111?? ????? ????? ????? ????? ??

Arginbaatar
?1210 ??1?? 11110 0???? ???1? 00000 01100 01211 12211 20311 1201? 11001 02300 10110 01100
011?0 ????? ????? ????? ????? ??

Cimexomys
1121? ????1 11110 0???? ???1? 10012 12100 01311 12110 30211 22011 11221 12300 11110 01100
111?1 ???10 1???? ????? ????? ??

Boffius
????? ????? ????0 12??? ????? ????? 11??? ????? ????? ???1? ????? ?1231 ?23?? 1???? ??1?0
011?? ????? ????? ????? ????? ??

Meniscoessus
11211 ?01?1 11110 02111 12?12 10022 02110 01311 12110 30011 22011 11231 22300 11?10 02110
111?0 210?0 1???? ???01 ????? ??

Buginbaatar
11111 001?? 11?10 0???? ????? ??0?2 13111 ????? 12000 ?0011 ?2011 11131 32300 12?10 01100
0?1?? ????? ????? ????? ????? ??

Cimolodon
11210 ?01?1 1111? 0???? ?2?1? 10012 11110 01311 12211 20111 22011 11221 22300 12110 02100
1111? ????? ????? ????? ????? ??

Ectypodus
11210 ?0111 11111 02101 12?10 10012 21110 01311 12211 30311 22011 11131 12310 12110 02100
12111 1?2?0 10?0? ?0??1 1001? 10

Mesodma
11211 ?01?1 11111 02?11 12?1? 100?2 11110 01311 12211 30111 22011 11131 12300 12110 01100
12111 ????? ????? ????? ????? ??

Ptilodus
11210 00101 11111 02101 12?10 10002 21110 01311 12211 30211 22011 11131 12310 12110 02100
12111 11020 00?00 00001 00010 10

Neoliotomus
11211 ?01?1 11110 1??0? ???1? 10012 21110 01311 12211 30311 22011 11231 12300 12110 02110
121?? ????? ????? ????? ????? ??

Pentacosmodon
112?0 01111 11110 1???? ???1? ????? ??111 0???1 12010 ?1011 ?201? ????? ????? ?0110 01100
011?? ?2??? ????? ????? ????? ??

Catopsbaatar
11210 01111 11110 12101 22?10 20022 12110 01311 11000 30211 32011 11231 02300 10110 01100
011?1 02220 11111 10110 ?1100 01

Kamptobaatar
11211 10111 11110 12101 22?10 10012 12110 01311 12110 30111 22011 11011 12300 10110 01100
011?1 02032 01001 10111 01000 10

Chulsanbaatar
11211 01101 11110 12101 22?10 10012 12110 01311 12110 30111 22011 11011 12300 10110 01100
01111 02022 01001 10111 11000 10

Kryptobaatar
11211 00101 11110 12101 22?10 10012 12110 01311 12110 30111 22011 11021 22300 10110 01100
01111 02221 01111 10111 11100 01

Nemegtbaatar
11211 00101 11110 12101 22?11 10012 12110 01311 12110 30111 22011 11221 22300 10110 01100
01111 22031 01001 10111 01000 10

Eucosmodon
11211 ?1101 11110 12?11 ?2?1? 200?2 ??111 ????? 12210 ?0111 22011 11??1 ?23?? 11110 02100
011?1 ????? ????? ????? ????? ??

Stygimys
11111 00101 11110 12111 12?11 10012 21111 ????? 12210 ?1111 22011 111C1 12300 12110 01100
011?1 210?2 0???? ???11 ????? ??

Microcosmodon
112?0 ?0111 11110 12111 12?10 10012 12110 01211 12010 ?1211 22011 11131 12300 12110 01100
0?11? ?1??? ?0??? ????? ????? ??

Lambdopsalis
11210 11011 11110 12101 12?12 31023 03111 ????? 13000 ?0011 32011 11231 12300 11110 02110
01111 01130 10?02 01001 ?1111 11

Taeniolabis
11210 00111 11110 12101 12?12 31023 03111 ????? 13000 ?0011 32011 11231 22300 12110 02100
01111 01130 ?0?02 0100? ????1 11

Kogaionon
????? ????? ????? ?2101 12??1 10003 01??? ????? ????? ????1 2???1 11221 02300 1???? ?????
0?1?1 01130 00000 00??1 ?1?1? 10

Part K. PAUP Analysis of Multituberculate Genera

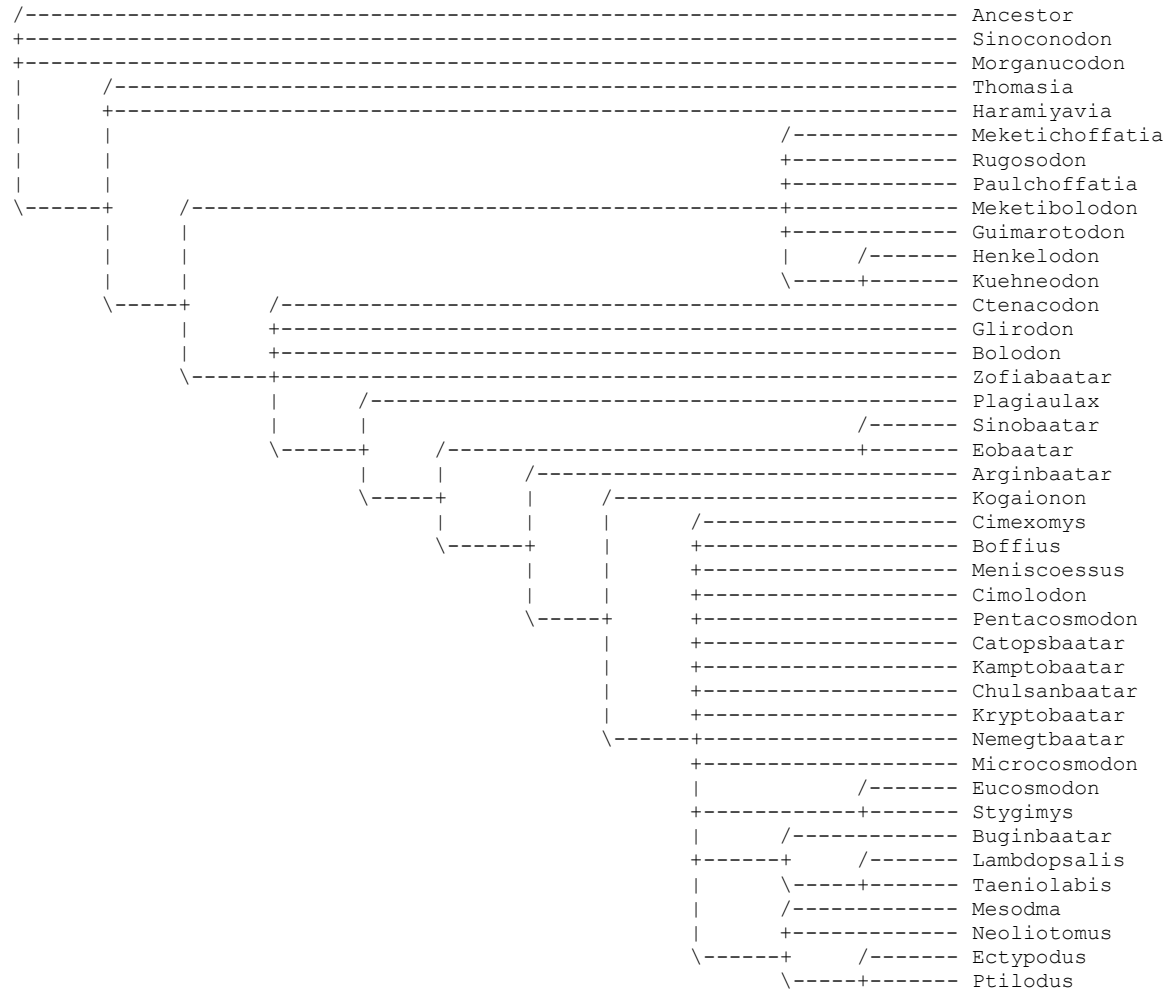
```
P A U P *
Version 4.0b10 for Macintosh (PPC)
Saturday, February 16, 2013  2:20 PM

This copy registered to: Zhe-Xi Luo
                         Carnegie Museum of Natural History
                         (serial number = B418684)

      -----------------------------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 "Rugosodon(InGroup)Mtx.doc" begins...

Data matrix has 41 taxa, 102 characters
Valid character-state symbols: 0123
Missing data identified by '?'
Gaps identified by '-'

*** Skipping "MacClade" block

Processing of file "Rugosodon(InGroup)Mtx.doc" completed.

Outgroup status changed:
  3 taxa transferred to outgroup
  Total number of taxa now in outgroup = 3
  Number of ingroup taxa = 38

Heuristic search settings:
  Optimality criterion = parsimony
    Character-status summary:
      Of 102 total characters:
        18 characters are of type 'ord' (Wagner)
        84 characters are of type 'unord'
        All characters have equal weight
        All characters are parsimony-informative
    Gaps are treated as "missing"
    Multistate taxa interpreted as uncertainty
  Starting tree(s) obtained via stepwise addition
  Addition sequence: random
    Number of replicates = 1000
    Starting seed = 338401823
  Number of trees held at each step during stepwise addition = 1
  Branch-swapping algorithm: tree-bisection-reconnection (TBR)
  Steepest descent option in effect
  Initial 'MaxTrees' setting = 200 (will be auto-increased by 100)
  Branches collapsed (creating polytomies) if maximum branch length is zero
  'MulTrees' option not in effect; only 1 tree will be saved per replicate
  Topological constraints not enforced
  Trees are unrooted

Heuristic search completed
   Total number of rearrangements tried = 167669364
   Score of best tree(s) found = 317
   Number of trees retained = 82
   Time used = 00:01:20.2

Tree-island profile:
                   First      Last                     First   Times
Island      Size*   tree      tree        Score    replicate     hit
-------------------------------------------------------------------
     1         1         1         1          317           1       1
     2         1         2         2          317          15       1
```

3	1	3	3	317	24	1
4	1	4	4	317	26	1
5	1	5	5	317	47	1
6	1	6	6	317	91	1
7	1	7	7	317	95	1
8	1	8	8	317	120	1
9	1	9	9	317	131	1
10	1	10	10	317	163	1
11	1	11	11	317	183	1
12	1	12	12	317	191	1
13	1	13	13	317	199	1
14	1	14	14	317	202	1
15	1	15	15	317	203	1
16	1	16	16	317	211	1
17	1	17	17	317	213	1
18	1	18	18	317	214	1
19	1	19	19	317	218	1
20	1	20	20	317	219	1
21	1	21	21	317	236	1
22	1	22	22	317	245	1
23	1	23	23	317	250	1
24	1	24	24	317	277	1
25	1	25	25	317	310	1
26	1	26	26	317	313	1
27	1	27	27	317	314	1
28	1	28	28	317	317	1
29	1	29	29	317	320	1
30	1	30	30	317	334	1
31	1	31	31	317	347	1
32	1	32	32	317	348	1
33	1	33	33	317	350	1
34	1	34	34	317	367	1
35	1	35	35	317	406	1
36	1	36	36	317	415	1
37	1	37	37	317	434	1
38	1	38	38	317	459	1
39	1	39	39	317	460	1
40	1	40	40	317	479	1
41	1	41	41	317	486	1
42	1	42	42	317	499	1
43	1	43	43	317	508	1
44	1	44	44	317	517	1
45	1	45	45	317	537	1
46	1	46	46	317	538	1
47	1	47	47	317	569	1
48	1	48	48	317	581	1
49	1	49	49	317	584	1
50	1	50	50	317	608	1
51	1	51	51	317	616	1
52	1	52	52	317	628	1
53	1	53	53	317	637	1
54	1	54	54	317	642	1
55	1	55	55	317	659	1
56	1	56	56	317	664	1
57	1	57	57	317	671	1
58	1	58	58	317	674	1
59	1	59	59	317	687	1
60	1	60	60	317	703	1
61	1	61	61	317	710	1
62	1	62	62	317	712	1
63	1	63	63	317	731	1
64	1	64	64	317	733	1
65	1	65	65	317	737	1
66	1	66	66	317	746	1
67	1	67	67	317	751	1
68	1	68	68	317	810	1
69	1	69	69	317	814	1
70	1	70	70	317	824	1
71	1	71	71	317	829	1
72	1	72	72	317	840	1
73	1	73	73	317	859	1

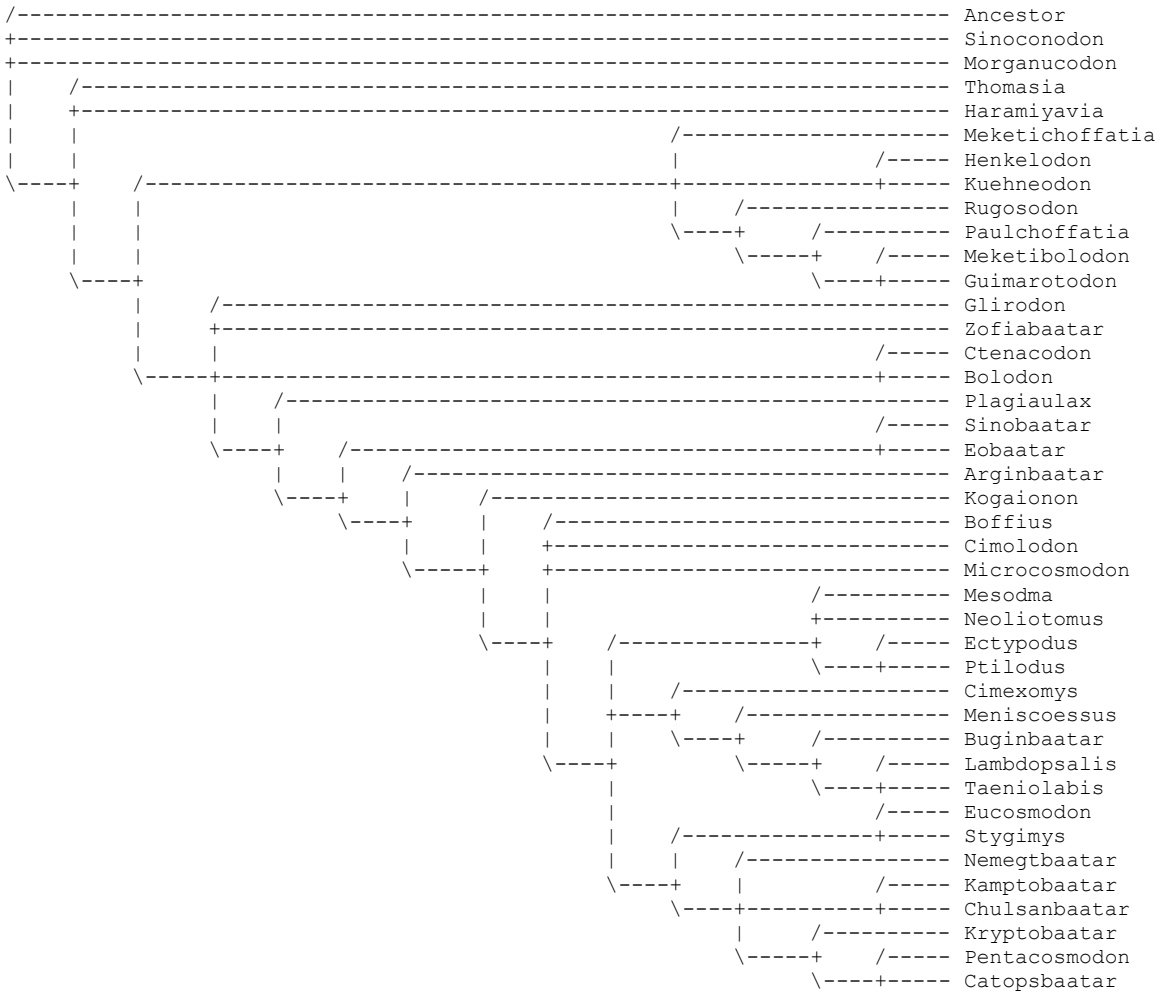
74	1	74	74	317	868	1
75	1	75	75	317	875	1
76	1	76	76	317	886	1
77	1	77	77	317	896	1
78	1	78	78	317	897	1
79	1	79	79	317	912	1
80	1	80	80	317	914	1
81	1	81	81	317	920	1
82	1	82	82	317	995	1
83	1	-	-	318	3	172**
84	1	-	-	319	11	296**
85	1	-	-	320	5	216**
86	1	-	-	321	2	117**
87	1	-	-	322	7	55**
88	1	-	-	323	19	26**
89	1	-	-	324	75	18**
90	1	-	-	325	101	11**
91	1	-	-	326	80	5**
92	1	-	-	327	625	2**

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

Strict consensus of 82 trees:



Adams consensus of 82 trees:



Part L. References Cited

References in Supplementary Information are cited by sequential number follow the last number in the main paper.

32 - Simmons, N. B. 1993. Phylogeny of Multituberculata. *In* F. S. Szalay, M. J. Novacek, and M. C. McKenna (eds.), *Mammal Phylogeny: Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials*, 146–164. Springer-Verlag, New York.

33 - Weil, A. 1998. A new species of *Microcosmodon* (Mammalia: Multituberculata) from the Paleocene Tullock Formation of Montana, and an argument for the Microcosmodontinae. *PaleoBios* 18 (2&3):1-15.

34 - Chang, S.-C., Zhang, H.-C., Renne, P. R. & Fang, F. 2009. High-precision 40Ar/39Ar age constraints on the basal Lanqi Formation and its implications for the origin of angiosperm plants. *Earth and Planetary Science Letters* 279, 212–221.

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

36 - Kielan-Jaworowska, Z., Dashzeveg, D., and Trofimov, B. A.. 1987. Early Cretaceous multituberculates from Mongolia and comparison with Late Jurassic forms. *Acta Palaeontologica Polonica* 32: 3-47.

37 - Kusuhashi, N. 2008. Early Cretaceous multituberculate mammals from the Kuwajima Formation (Tetori Group), central Japan. *Acta Palaeontologica Polonica* 53 (3): 379–390.

38 - Hu, Y.-M., and Wang, Y. 2002b. *Sinobataar* gen. nov.: first multituberculate from Jehol Biota of Liaoning, Northern China. *Chinese Science Bulletin* 47: 933–938.

39 - Hahn, G. and R. Hahn. 1999b. Pinheirodontidae, n. fam. (Multituberculata, Mammalia) aus der tiefen Under-Krede Portugals. *Palaeontographica, Abteilung A* 253:7-222.

40 - Badiola, A., Canudo, J. I. and G. Cuenca-Bescós. 2008. New multituberculate mammals from the Heuterivian/Barremian transition of Europe (Iberian Pennisula). *Palaeontology* 51:1455-1469.

41 - Hahn, G., and R. Hahn. 1999. Nomemklatorische Notiz: Namens-Änderung bei Multituberculata (Mammalia). *Geologica et Palaeontologica* 33:156.

42 - Liu, Y.-Q. Liu, Y.-X. Ji, S.-A., and Yang, Z.-Q. 2006. U-Pb zircon age for the Daohugou Biota at Ningcheng of Inner Mongolia and comments on related issues. *Chinese Science Bulletin* 51, 2634—2644 (DOI: 10.1007/s11434-006-2165-2) (2006).

43 - Ren, D., Gao, K.-Q., Guo, Z. et al. 2002. Stratigraphic division of the Jurassic in the Daohugou area, Ningcheng, Inner Mongolia, *Geological Bulletin of China 21*, 584-588. (in Chinese)

44 - Hu, D.-Y., Hou, L.-H., Zhang, L.-J., and Xu, X. 2009. A pre-*Archaeopteryx* troodontid theropod from China with long feathers on the metatarsus. *Nature* 461: 640-643. (doi:10.1038/nature08322)

45 - Zhang, H., Wang M.-X., and Liu, X.-M. 2008. Constraints on the upper boundary age of the Tiaojishan Formation volcanic rocks in West Liaoning-North Hebei by LA-ICP-MS dating. *Chinese Science Bulletin* 53(22): 3574-3584.

46 - Gradstein, F., Ogg, J., and Smith, A. 2004. *A geologic time scale.* Cambridge University Press, Cambridge.

47 - Lü, J-C., Unwin, D. M., Jin, X-S., Liu, Y.-Q., and Ji, Q. 2009. Evidence for modular evolution in a long-tailed pterosaur with a pterodactyloid skull. *Proceedings of Royal Society B. (Biological Sciences),* 277(1680): 383-389 *(*doi:10.1098/rspb.2009.1603).

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

49 - Meng J, Y.-M. Hu, Y.-Q. Wang, X.-L. Wang, and Li ,C.-K. 2006. A Mesozoic gliding mammal from northeastern China. *Nature* **444**, 889.

50 - Gingerich, P. D., and B. H. Smith. 1984. Allometric scaling in the dentition of primates and insectivores. Pp. 257-272. In W. L. Jungers (Editor), *Size and Scaling in Primate Biology* (Plenum Press, New York, 1984).

51 - Luo, Z.-X., Crompton, A. W., and Sun, A.-L.. 2001. A new mammaliaform from the Early Jurassic of China and evolution of mammalian characteristics. *Science* 292: 1535-1540.

52 - Foster, J. R. 2009. Preliminary mass estimates for mammalian genera of the Morrison Formation (Upper Jurassic; North America). *PaleoBios* 28:114-122.

53 - Krause, D. W. 1982a. Jaw movement, dental function, and diet in the Paleocene multituberculate *Ptilodus*. *Paleobiology* 8: 265–281.

54 - Lazzari, V., Schultz, J. A., Tafforeau, P. and T. Martin. 2010. Occlusal pattern in Paulchoffatiid multituberculates and the evolution of cusp morphology in mammaliamorphs with rodent-like dentitions. *Journal of Mammalian Evolution* 17:177-192.

55 - Weisbecker, V. and S. Schmid. 2007. Autopodial skeletal diversity in hystricognath rodents: functional and phylogenetic aspects. *Mammalian Biology.* 72(1): 27–44.

56 - Ji, Q., Z.-X. Luo, and S.-A. Ji. 1999. A Chinese triconodont mammal and mosaic evolution of mammalian skeleton. *Nature* 398: 326-330.

57 - Hu, Y.-M. 2006. *Postcranial morphology of Repenomamus (Eutriconodonta, Mammalia): implications for the higher-level phylogeny of mammals*. Ph.D. dissertation, the City University of New York. Pp. 1-405.

58 - Luo, Z.-X., P.-J. Chen, G. Li, and M. Chen. 2007. A new eutriconodont mammal and evolutionary development of early mammals. *Nature* 446: 288-293.

59. Luo, Z.-X., Kielan-Jaworowska, Z., and Cifelli, R. L. 2002. In quest for a phylogeny of Mesozoic mammals. *Acta Palaeontologica Polonica* 47: 1–78.

Part M. Nexus files of PAUP analyses of mammaliaforms and multituberculates

```
#NEXUS
[MacClade 4.06 registered to Zhe-Xi Luo, Carnegie Museum of Natural
History Carnegie Museum of Natural Hi]


BEGIN DATA;
      DIMENSIONS  NTAX=106 NCHAR=458;
      FORMAT SYMBOLS= " 0 1 2 3 4 5" MISSING=? GAP=- ;
      CHARSTATELABELS
            1  'P-D trough' / present absent,
  2  'SA/PRA scars' / present absent,
  3  Dent_medial_ridge / present absent,
  4  'M-groove width' / Well_developed Present_but_weakly_developed
Absent,
  5  'M-groove curvature' / parellel_to_mandibular_ventral_border
tangential_and_intersecting_with_mandibular_ventral_border,
  6  Dent_lamina_groove / present absent,
  7  Dent_angl_presence / absent_or_weakly_developed
'Present,_distinctive_but_not_inflected_or_efflected'
Present_and_transversely_flaring Present_and_slightly_inflected
Present_and_strongly_inflected_with_an_anterior_shelf,
  8  Dent_angle_position / 'anterior_-_below_coronoid_process'
'posterior_-
_between_the_posterior_level_of_coronoid_and_dentary_condyle',
  9  Vertical_elevation_of_mandibular_angle / 'low_-
_leveled_with_mandibular_ventral_border' 'high_-
_at_or_near_the_level_of_alveolar_line',
  10  Ang_ventral_surface / absent present,
  11  Ectoflex_Man_Angle / absent present,
  12  Coronoid_fossa / present absent,
  13  Mandibular_foramen_position /
'in_postdentary_trough_of_its_connected_Meckel''s_sulcus'
'in_pterygoid_fossa_and_off-set_from_Meckel''s_sulcus'
'in_pterygoid_fossa_and_in_alignment_with_Meckel''s_sulcus',
  14  Elevation_of_mand_foramen / below_the_alveolar_level
near_or_above_alveolar_level,
  15  'Fossa for reflected lamina (angular)' /
Present_on_medial_side_of_mandibular_angular_process
Present_on_posterior_side Fossa_absent,
  16  Splenial_scar / present absent,
  17  'Post-dents CMJ' / participating_in_CMJ excluded_from_CMJ,
  18  'SQ-Surangular contact' / absent present,
  19  Pterygoid_fossa / present absent,
  20  Pterygoid_shelf / absent present
pterygoid_crest_continuing_to_dentary_condyle,
  21  Masseter_fossa_ventral_border / absent present_as_low_ridge
present_as_distinctive_border,
  22  Anterior_border_of_masseter / absent_or_weakly_developed
present_and_distinctive 'present_as_well-developed_crest',
  23  Anterior_extension_of_masseter_fossa / absent
present_on_the_ramus_of_mandible
present_and_anteriorly_extedned_to_below_the_last_premolar,
  24  Labial_mand_foramen_in_masseter_fossa / absent present,
  25  Posterior_masseter_shelf / absent
present_as_a_thin_crest_of_the_arcuate_angular_margin
present_as_a_vertical_ridge,
```

```
  26  'Posterior-most mental foramen' / 'in_canine_-
_anterior_premolar_region' below_penultimate_premolar
below_ultimate_premolar below_first_molar,
  27  'D-condyle & Sq-glenoid' / absent 'present_but_without_condyle-
glenoid' present_with_condyle_and_glenoid,
  28  Size_of_Dentary_contact / condyle_small_or_absent
'condyle_massive,_bulbous_and_transversely_broad'
condyle_mediolaterally_compressed_and_vertically_deep,
  29  Dentary_peduncle_orient_and_condyle / posteriorly_directed
semicircular_margin_continuous_with_dorsally_directed_condyle
peduncle_indistinctive_and_dentary_extends_the_vertical_depth_of_horizon
tal_ramus vertically_directed_peduncle_and_condyle,
  30  Dent_peduncle_border / posteriorly_tapering
columnar_with_a_lateral_ridge ventrally_flaring robust_and_short
condyle_continuous_with_ventral_margin_of_peduncle_and_mandibular_ramus,
  31  Gracile_and_elongate_dentary_peduncle / absent present,
  32  Condyle_elevation_to_alveoli / below_or_about_the_same_level
above_alveolar_level,
  33  Angle_of_coronoid_process / 'strongly_reclined_(≥150_degrees)'
'less_reclined_(145_to_135_degrees)'
'less_vertical_(125_to_110_degrees)'
'nearly_vertical_(105_to_95_degrees)',
  34  Gracile_base_of_coronoid_process / absent present,
  35  dentary_coronoid_height / not_reduced reduced,
  36  'Erupt molar-PC coronoid' / 'molar/pc_medial_to_coronoid'
'molar/pc_anterior_to_coronoid',
  37  Jaw_move_direction / dorsal_movement dorsal_and_medial_movement
dorsoposterior_movement,
  38  Fused_Dentary_symphysis / fused unfused,
  39  Mandibular_rostral_spout / absent present,
  40  'UltiPremo-labial cingulid',
  41  U_ulti_Pm_metastyle / absent_or_vestigial 'enlarged_and_wing-
like',
  42  U_ulti_Pm_metacone / absent present,
  43  U_Ulti_Pm_protocone / absent protoconal_swelling_or_protocone,
  44  Penultim_U_Pm_protocone / lingual_swelling_absent
lingual_swelling_present distinctive_protocone,
  45  Trenchant_U_premol / no_premolar_standing_out
trenchant_ultimate_premolar trenchant_penultimate_premolar,
  46  'Up P1-P2 diastema' / absent present,
  47  Symmetry_of_last_low_premolar / asymmetrical symmetrical,
  48  Ultimate_l_pm_pacd / absent_or_indistinctive
present_and_distinctive enlarged,
  49  Ult_Pm_cusp_triangle / straight_alignment
distinctive_triangulation 'multi-cusps_in_longitudinal_row',
  50  Last_Pm_dist_cingulid_or_cuspule_d / Absent_or_indistinctive
A_small_cusp_present 'Present_as_cuspule_d_(in_addition_to_cusp_c)'
Presence_of_continuous_cingulid,
  51  Last_pm_outline / mediolaterally_compressed
mediolaterally_wide_by_trigonid mediolaterally_wide_by_talonid,
  52  Last_pm_labial_cingulid / Absent_or_vestigial
'Present_(along_more_than_half_of_crown_length)',
  53  Last_pm_lingual_cingulid / absent_or_vestigial
'present_(along_more_than_half_tooth_length)',
  54  'U lw pm cusps a-c height ratio' / indistinctive_c
cusp_c_distinctive_but_less_than_30% cusp_c_more_than_40%_of_cusp_a,
  55  penult_low_pm_pacd_b / absent present present_and_enlarged,
  56  Penultimate_pm_triangle / cusps_in_straight_line
cusps_in_triangulation multicuspe_in_longitudinal_row,
  57  'Penulti-Premo-labial cingulid',
  58  Elongate_post_lw_premolars / absent present,
```

```
  59  'lw m-1 triangle' / straight_alignment 'reverse-triangular'
multicusps_in_multiple_rows,
  60  Post_molar_triangle / Absent multicusps_in_multiple_rows
'posterior_m_with_obtuse_triangle_(about_120_degrees)'
'posterior_m_with_acute_triangle_(around_90_degrees)',
  61  B1_cusp_of_upper_molar_with_triangulation / Absent Presetn,
  62  'angle postvlm/prevallid□□□□□' / Absent
'Present_but_weak,_slightly_oblique'
'Present,_strong,_long_and_transverse'
'Present,_strong,_short_and_oblique',
  63  Rank_of_postvallum / '1st_rank:_present_at_postmetacrista'
'2nd_rank:_present_at_postprotocrista_in_addition_to_postmetacrista'
Metacingulum_present_in_addition_to_postprotocrista
Metacingulum_elongates_and_extends_beyond_metacone
Metacingulum_extends_to_metastylar_lobe
Second_rank_postvallum_forming_a_broad_shelf,
  64  Postcingulum / Absent_or_vestigial Present
Present_and_extending_beyond_metaconule
Hypoconal_shelf_raised_near_postprotocrista,
  65  'Up-low opposition' / lacking 'Present_as_one-to-one_contact'
'Present,_one_lower_tooth_contacting_more_than_one_uppers',
  66  Cusp_occlusion / absent
'present,_lower_a_occluding_between_upper_A,_B'
'present,_lower_a_occluding_in_front_of_upper_B_and_into_embrassure',
  67  Molar_Prtd_a_to_mecd_c_ratio / cusp_a_distinctively_higher_than_c
cusps_a_and_c_nearly_equal,
  68  Molar_Pacd_b_to_mecd_c_ratio /
cusp_b_distinctively_higher_than_cusp_c cusps_b_and_c_nearly_equal
cusp_b_present_but_lower_than_cusp_c cusp_b_vestigial_or_absent,
  69  Elevation_of_paraconid_base / absent present,
  70  Cristid_obliqua / absent 'present_and_contacting_mid-
posterior_of_metaconid' 'present_and_contacting_mid-
point_of_protocristid' 'present_and_contacting_mid-
posterior_of_protoconid',
  71  'Molar Pre-entocristid or longitudinal crest' /
no_medial_or_longitudinal_crest 'medial-
most_cristid_connected_to_entoconid_(pre-entocristid)' 'medial-
most_cristid_connected_to_hypoconulid_(pre-hypoconucristid),_v-
notch_with_postmetacristid' 'mediol-
most_cristid_connected_to_entoconid_(pre-entocristid)_and_off-
set_from_metaconid_base',
  72  'Molar posterior-lingual cingulid' / absent_or_weak distinctive
strongly_and_crenulated_with_distinctivfe_cuspules,
  73  'Ant-Ling cusp e' / present_as_cuspule_but_below_cingulid_level
present_at_the_cingulid_level present_and_above_cingulid_level
'present,_hypertrophied_and_forming_pseudohypoconulid' absent,
  74  'Ant-labial cusp f' / absent present,
  75  Mesial_cingulid_above_gum / absent
present_but_without_occlusal_contact_to_upper
present_with_occlusal_contact_to_upper,
  76  Wrapping_cingulid_at_anteromedial_base_of_trigonid / Absent
Present_but_without_occlusal_contact_to_upper
Present_and_with_occlusal_contact_to_upper
Absent_but_with_occlusal_contact_to_upper,
  77  Postcingulid / Absent Present_as_horizontal_cingulid_crest,
  78  lw_molar_interlock / Absent 'Present_-
_distal_cuspule_d_fitting_between_e_and_f_of_succeeding_molar'
'Present_-_distal_cuspule_d_fitting_between_e_and_b_of_succeeding_molar'
'Present_-
_distal_cuspule_d_fitting_the_anterior_embayment_of_succeeding_molar'
'Present_-
```

```
_anterior_corner_of_succeeding_molar_overlapping_posterior_corner_of_pre
ceding_molar',
  79  Lower_molar_size_ratio /
'Last_three_in_posteriorly_decreasing_gradient_(m1≥_m2_≥_m3)'
'Penultimate_is_the_largest_of_last_three_molars_(e.g.,_m1≤_m2_≥_m3)'
'Last_three__in_anteriorly_decreasing_gradient_(e.g.,_m1_≤_m2_≤_m3)',
  80  trigonid_pattern / 'paraconid_in_antero-lingual_position'
paraconid_in_lingual_most_position
paraconid_in_lingual_most_position_and_appressed_to_metaconid
paraconid_reduced_in_selenodonty_or_lophodonty,
  81  'Paracristid (a-b)' / nearly_longitudinal_orientation oblique
nearly_transverse_orientation,
  82  'Paracristid-protocristid angle m2-3' / '>_90_degrees'
90_to_50_degrees '<_35_degrees',
  83  'Paraconid mes-lin vertical keel' / 'absent_(rounded)'
present_and_forming_a_keel,
  84  Trigonid_shortening / 'trigonid_long_(3/4_tooth_length)'
swelling_on_trigonid_sidewall 'no_shortening_(trigonid_50-
65%_of_tooth_length)' 'shortening_(trigonid_≤_50%_of_tooth_length)'
'trigonid_compression_(40-50%_of_tooth_length)',
  85  'm2 trg-ta width ratio' /
'talonid_narrow_(≤40%_of_trigonid_width)' 'talonid_wide_(40-
70%_of_trigonid_width)' 'talonid_equal_(90_-_110%_of_trigonid_width)',
  86  Hypoflexid / absent_or_shallow 'present_and_40-
50%_deep_of_talonid_width' deep_and_≥_60%_of_talonid_width,
  87  Talonid_morphology / absent
'present_as_an_incipient_heel,_cuspule_d,_or_cingulid'
'present_as_accute_v-basin_with_2_functioning_cusps'
'present_as_obtuse_v-basin_with_2_cusps' presnet_as_basin_with_3_cusps,
  88  Hypoconid / present_but_not_elevated_above_cingulid
present_and_elevated_above_cingulid
'present,_labially_positioned_and_with_occlusal_contact',
  89  Hypoconulid / absent present_in_median_position
'present_within_lingual_1/3_of_talonid_width'
'present_but_incorporated_into_transverse_crest_(lophodont_or_selenodont
)',
  90  Hypoconulid_orient /
cusp_reclined_and_posterior_wall_slant_and_overhang_root
cusp_apex_procumbent_but_posterior_wall_vertical
cusp_apex_procumbent_and_posterior_wall_gibbous,
  91  Hypoconulid_labial_shelf / absent
'present_(as_a_line_descending_from_hypoconulid_apex_to_base_of_hypoconi
d',
  92  'Ultimate-l-m hpcld' / short_and_erect tall_and_recurved,
  93  Entoconid / absent 'present,_entoconid-
hypoconulid_distance_equals_to_hypoconid-hypoconulid_distance'
'present,_entoconid-hypoconulid_approximation_(65_-
75%_of_hypoconulid_to_hypoconid_distance)' 'present,_entoconid-
hypconulid_twinned_(≤60%_of_hypoconulid_-_hypoconid_distance)',
  94  'hypo-ento height ratio' / entoconid_absent_on_talonid
entoconid_lower_than_hypoconid entoconid_equal_to_hypoconid
entoconid_equal_to_hypoconid_and_linked_by_crest,
  95  'paraconid - metaconid - entoconid alignment' / no_alignment
straight_alignment,
  96  'Talonid L-W ratio' / longer_than_wide length_equals_width
wider_than_long,
  97  'Talonid elevation (hypoconid-protoconid height ratio)' /
'Hypoconid-protoconid_ratio_≤20%' 25%_t0_35% 40%_to_60% 60%_to_80%
equal_height,
  98  Lab_Stylar_Shelf_width / absent present_and_narrow
'present_and_broad_(≤_40%_of_crown_width)',
```

```
  99  'Ectoflexus: present-absent' / absent_or_weakly_developed present,
  100  Gradient_ectoflexus / only_present_on_penultimate_molar
present_on_penultimate_and_preceding_molars_in_a_gradient,
  101  stylar_shelf_morphology / indistinctive_shelf
'distinctive_cingulum,_withour_crenulation'
distinctive_cingulum_with_individualized_cuspules 'W-pattern_shelf'
cingulum_with_even_crenulation,
  102  Upper_protocone / absent lingual_cingular_swelling_but_not_cusp
functional_cusp_present,
  103  Protocone_labial_shift /
'no_labial_shift_(in_lingual_20%_of_crown_width)'
'moderate_shift_(in_lingual_25-30%_of_crown_width)'
'substantial_labial_shift_(≥40%_of_crown_width)',
  104  Protocone_compress / protoconoal_region_present_but_no_protocone
'protocone_present_and_antero-posteriorly_compressed'
protocone_apical_region_expanded
protocone_apical_region_and_side_wall_expanded
protocone_strongly_expanded_so_preprotocrista_and_postprotocrista_formin
g_obtuse_triangle,
  105  Protocone_height /
less_than_70%_of_the_lower_of_the_paracone_and_metacone '70-
80%_eight_of_the_lower_cusp_of_paracone_and_metacone'
within_80%_of_the_lower_cusp_of_paracone_metacone,
  106  'Up Paracone-metacone height-size' /
paracone_higher_and_larger_at_base_than_metacone
paracone_larger_at_the_base_than_metacone 'paracone_-
_metacone_of_equal_size' paracone_lower_than_metacone,
  107  Mtn_pacn_labial_placement / metacone_more_labial_than_paracone
metacone_same_as_paracone_in_labial_placement
paracone_more_labial_than_metacone,
  108  'Paracone-metacone base' / merged separated,
  109  Centrocrista / straight 'v-
shaped_with_labially_oriented_postparacrista_and_premetacrista',
  110  Conular_width / 'narrow_-
_conular_width_30%_of_total_tooth_width' 'moderate_-_conular_width_31%_-
_50%_of_total_tooth_width' 'wide_-_conular_width_51%-
70%_of_total_tooth_width' 'expanded_-
_conular_width_over_70%_of_total_tooth_width',
  111  Para_or_meta_conule / absent present,
  112  Conule_distance /
conules_closer_to_protocone_than_paracone_and_metacone 'conules_mid-
distance_between_protocone_and_metacone' 'conules_closer_to_paracone_-
_metacone_than_protocone',
  113  Conule_wing / indistinctive distinctive,
  114  Parastylar_groove / weak_or_absent well_developed,
  115  Up_Mo_parastyle_A / cuspule_A_or_swelling_present absent,
  116  Preparastyle / absent present,
  117  'Stylar cuspule "B"' / vestigial_or_absent
distinctive_although_small subequal_to_parastyle 'large,_with_extra_B-
1_cusp',
  118  Stylar_cuspule_C / absent present,
  119  Stylar_cuspule_D / absent present,
  120  Size_of_Stylar_E / absent_or_vestigial
'present,_subequal_to_cusp_D' 'present,_larger_than_cusp_D',
  121  Position_of_stylar_E / 'stylar_cusp_E_more_lingual_to_D_or_D-
position' 'E_distal_to_or_leveled_with_D_or_D-position',
  122  Up_Molar_interlock / absent 'tongue-in-grooe_interlock'
parastylar_region_lumbricate_with_metastylar_region_of_preceding_tooth,
  123  Metastylar_lobe_size / smaller_than_parastylar_lobe
similar_to_parastylar_lobe_in_size_and_extent
larger_than_parastylar_lobe parastylar_lobe_absent,
```

```
  124  Salient_metacrista / absent_or_weakly_developed
'developed,_but_shorter_than_metacone-protocone_distance'
'hypertrophied_and_longer_than_metacone-protocone_distance',
  125  Selenodont_upper_molar / absent present,
  126  outline_of_lower_m1□□□ / mediolaterally_compressed
oblong_with_labial_bulging 'triangular_or_tear-drop_shaped'
rectangular_to_rhomboidal circular,
  127  outline_of_upper_M1 / mediolaterally_compressed
'longer_than_wide_(oval_or_spindle_shaped)'
'wider_than_long_(triangular_outline)' rectangular_to_rhomboidal
circular,
  128  'P4-m1 carnasial' / absent present,
  129  Wear_facet_development / absent
absent_at_eruption_but_later_development_by_crown_wear
wear_facets_match_upon_eruption,
  130  facet_to_cusp_relationships / wear_pattern_across_entire_crown
'lower_cusps_a,_c_support_different_facets_1_and_4'
'lower_cusps_a,_c_support_a_single_facet_(4)'
'multicusps_series,_each_supporting_two_wear_facets',
  131  'Prevallum-postvalid shear' / absent present_and_obtusely_angled
'present,_hypertrophied_and_transverse',
  132  Molar_Facets_1_&_2 / absent present,
  133  Preprotocrista /
'facet_1_(prevallum)_short,_not_extening_to_stylocone_area'
facet_1_extending_into_stylocone_area
'distinctive_preprotocrista_present,_extending_beyond_paracone',
  134  Molar_facets_3_&_4 / absent present
facets_3_and_4_hypertrophied_on_flanks_of_hypconid,
  135  Orient_facet_4 /
present_and_obliquely_oriented_to_long_axis_of_tooth
present_and_more_transversely_oriented_to_long_axis_of_tooth,
  136  'post-lateral aspect of talonid' / gently_rounded angular,
  137  wear_in_talonid_basin / absent present
present_apically_on_crests_of_talonid
apical_wear_on_crest_on_selenodont_and_lophodont,
  138  Distal_metacristid / present absent,
  139  Separate_facets_5_vs._6 / absent present,
  140  Surface_in_talonid / 'smooth_surface_on_talonid_heel_(or_basin)'
'multi-ridges_within_talonid_basins'
wear_not_in_talonid_but_on_cristid_obliqa_and_hypoconid_cristid,
  141  facets_pseudo3_pseudo4 / Absent Present,
  142  facets_pseudo5_pseudo6 / Absent Present,
  143  Pseudo_cusp_e_f_hypertrophied / Absent Present,
  144  #_upper_incisors / five four three two_to_one none,
  145  Up_Inc_cusp_numbers,
  146  #_of_lower_incisors / five_or_more four three two one absent,
  147  lower_incisor_enamel / covering_whole_incisor
restricted_anteriorly,
  148  lower_incisor_root / closed open,
  149  upper_incisor_enamel / entire_crown restricted_anteriorly,
  150  upper_incisor_root / closed open,
  151  'Upper canine presence (size)' / present_and_enlarged
present_and_small absent,
  152  Up_Canine_Cusp_Numbers,
  153  #_up_canine_roots / single double,
  154  Lower_canine_size / five_or_more four three two_or_fewer,
  155  #_lw_canine_roots / single double,
  156  #_upper_premolar / five_or_more four three two_or_fewer,
  157  #_of_lower_premolars / five_or_more four three two_or_fewer,
  158  #_lower_molar / six_or_more five four three two_or_fewer,
  159  #_Upper_Molars / six_or_more five four three two_or_fewer,
```

```
  160  #_total_Upper_PC_Loci / more_than_8 eight seven six
five_or_fewer,
  161  #_total_lower_pc_loci / eight_or_more seven six five_or_fewer,
  162  Procumbent_P1&_C / not_procumbent_and_without_diastema
procumbent_and_with_diastema,
  163  'p1-p2 diastema' / 'absent_(gap_less_than_one_tooth-root)'
'present_(subequal_to_one_tooth-root_or_more)'
present_and_more_than_one_tooth_length,
  164  bladed_ulti_P_&_p / absent present,
  165  'I-1 projec-diastema' /
'subequal_to_other_incisors,_no_diastema_from_i2'
anteriorly_project_with_diastema_from_i2,
  166  Spoon_posterior_upper_incisor / absent 'present_and_spoon-
_or_rhomboid-shaped' present_and_spatular_shaped
bicuspate_or_tricuspate,
  167  i2_staggered / absent present,
  168  'Multi-replace incis canine' / more_than_one_replacements
one_replacement no_replacement,
  169  Molariform_replaced / present absent,
  170  enlargement_anterior_lower_incisor / absent
'present_(≥50%_of_the_next_incisor)',
  171  Anter._dent._diastema / absent present_and_behind_canine
present_and_behind_posterior_incisor,
  172  'U-ridge multi-teeth' / absent present,
  173  b1_&_b2_ratio_multi / second_mesial_cusp_b2_highest
mesial_cusp_b1_highest,
  174  Central_labial_cusp_on_m1,
  175  Upper_row_ratio / distal_cusp_highest_and_lowering_anteriorly
all_cusps_of_equal_height,
  176  Upper_lingual_offset /
lingual_row_of_lower_m2_occluding_lingual_side_of_upper_M2
lower_m2_labial_row_occluding_labial_side_of_upper_M2,
  177  Lwr_m2_middle_valley,  178  Lwr_m2_labial_row_longer,
  179  Enamel_structures / 'synapsid_columnar_(prismless)'
'transitional_(sheath_indistinctive)'
'full_enamel_prism_(sheat_distinctive)' enamel_absent,
  180  'Open-rooted PC''s' / absent present,
  181  Atlas_intercentrum / unfused fused,
  182  Atlas_rib / unfused fused,
  183  Dens_of_axis / unfused fused,
  184  Axis_rib_trans_proc / present_and_unfused
fused_to_form_transverse_process,
  185  Cervical_ribs / unfused fused_to_form_transverse_process,
  186  Thoracic_# / 13_or_fewer 15_or_more,
  187  'overlap ven-costal  plates' / Absent Present,
  188  'Overlap thora-lumb plates',
  189  Anticlinal_vertebra / absent present,
  190  Mobile_lumbar_ribs / present absent,
  191  'Orient l-ribs trans proc' / posterolaterally_directed
laterally_or_anterior_laterally_directed,
  192  Xenarthrous_zygapophyses / absent present,
  193  Interclavicle / present absent,
  194  Interclv_&_manubrium / abutting_relationship
overlapping_relationship 'complete_co-ossification',
  195  Interclavicle_distal_expansion / Absent Present,
  196  Front_interclavicle_or_manubrium / emarginated_or_flat
with_a_median_process,
  197  'Interclav-manub leng ratio' /
interclavicle_twice_the_length_of_manubrium
interclavicle_about_equal_to_manubrium,
  198  'Clv-sternal joint' / immobile mobile,
```

```
  199  manubrial_craniolateral_expansion / absent present,
  200  Acromioclav_joint / extensive_articulation limited_articulation,
  201  Clavicle_curve / boomerang slightly_curved,
  202  Supraspin_fossa_of_scapula /
on_cranial_margin_and_limited_to_acromion_region
weakly_developed_and_only_near_the_glenoid_region
fully_developed_along_the_scapular_length,
  203  'width ratio s-sp to i-sp' /
supraspinous_on_cranial_aspect_and_much_narrower_than_infraspinous_fossa
'supraspinous_fossa_is_50-80%_of_infraspinous_fossa'
supra_and_infraspinous_subequal supraspinous_150%_of_infraspinous_fossa,
  204  Acromion / 'short_stump,_leveled_to_glenoid' 'hook-
like_and_extending_below_glenoid',
  205  Teres_m_fossa / absent present,
  206  Procoracoid / present_as_separate_element absent,
  207  Procoracoid_foramen / present absent,
  208  Coracoid / large_with_a_posterior_process
'small_fused_to_scapula,_without_posterior_process',
  209  Ant_coracoid_process / indistinctive distinctive
distinctive_and_forming__a_broad_plate,
  210  Corac_post_process_fusion / absent
'present_(coracoid_process_bridging_over_to_scapular_border)',
  211  Manubrium_size_to_subsequent_sternabrae / large small,
  212  Glenoid_orientation / parallel_and_facing_posterolaterally
oblique_and_facing_more_posteriorly
perpendicular_to_long_axis_of_scapula,
  213  Glenoid_shape / saddle_shaped uniformly_concave,
  214  Scap_medial_face / convex flat,
  215  Suprascap_incisure / absent present,
  216  Humeral_head / 'spindle-shaped,_no_inflection'
spherical_shape_with_inflection,
  217  'Inter-tubercular groove' / shallow_and_broad narrow_and_deep,
  218  Lesser_tubercle_relative_to_greater_tubercle /
wider_than_greater_tubercle narrower_than_greater_tubercle,
  219  Humeral_torsion / strong_≥_30_degrees 'moderate_30_-_15_degrees'
weak_≤_15_degrees,
  220  Deltopectoral_crest / limited_to_proximal_part_of_humerus
'extending_distally_for_at_least_1/3_of_humeral_length',
  221  Teres_tuberosity / absent present 'hypertrophied_and_shelf-like',
  222  Hu_ulnar_condyle / bulbous_condyle
trochlear_in_posterior_aspect_but_condylar_in_anterior_aspect
trochlear_in_both_anterior_and_posterior_aspects,
  223  Hu_radial_condyle / rounded_radial_condyle
trochlear_posteriorly_but_condylar_anteriorly
'capitulum_(trochlear_both_anteriorly_and_posteriorly)',
  224  Hu_Epicondyles / robust weak,
  225  'S-shape supinat shelf' / absent present,
  226  Coronoid_process_ulna / absent
present_and_leveled_to_olecranon_process
present_and_higher_than_olecranon_process,
  227  Radius_distal_styloid / weak_or_absent present,
  228  scaphoid_size_&_shape /
'not_enlarged_(scaphoid_≤_150%_of_lunate)'
'enlarged_(scaphoid_≥_200%_of_lunate)'
enlarged_with_a_distolateral_process,
  229  'Hamate (unciform)' /
equal_to_triquetrum_and_anteroposteriorly_compressed
'hypertrophied_(larger_than_triquetrum)_and_mediolaterally_compressed',
  230  Trapezium_proportion /
'larger_or_subequal_to_trapezoic_(elongate_ro_cuboidal)'
'smaller_than_trapezoid_(bean_shaped)',
```

```
  231  'Triq-lunate ratio' / triquetrum_twice_the_size_of_lunate
triquetrum_subequal_to_lunate,
  232  Anterior_orient_ilium / 'short_(less_than_acetabular_diameter)'
'long_(1_to_1.5_times_the_acetabular_diameter)'
'elongate_(≥1.5_times_the_acetabular_diameter)',
  233  'Ilium-post process' / present absent,
  234  Acebatular_dorsal_emargination / open
'closed_(with_complete_rim)',
  235  Pelvic_fusion / unfused fused,
  236  Ischium_margine_and_tuberosity / ischial_margin_concave
ischial_margin_concave_with_hypertrophied_tuberosity
ischial_margin_straight_and_tuberosity_small,
  237  Ischium_posterior_spine / short_and_pointed
spine_expanded_with_oblique_posterior_margin
spine_expanded_and_truncated,
  238  Epipubic_bone / present absent,
  239  Epipubis_width / narrow wide,
  240  'Fusion sacral+caudal' / separated_from_proximal_caudals
fused_with_proximal_caudals,
  241  'Fusion ischium+caudal' / ischium_separated_from_caudals
ischium_fused_with_caudals,
  242  Preacetabular_process / absent present,
  243  Acetabulum_synovial_surface_encircled / absent present,
  244  Lesser_psoas_tuberosity / absent present,
  245  Femoral_head / neck_absent_and_head_oriented_dorsally
neck_present_and_head_inflected_medially,
  246  Femor_head_fovea / absent present,
  247  Great_trochanter / directed_dorsolaterally directed_dorsally,
  248  Femur_Grt_Trochant_height,
  249  Less_trochanter_position / medial_side_of_shaft
ventromedial_side_of_shaft,
  250  Less_trochanter_size / large small_to_absent,
  251  3rd_Trochanter_of_Femur / absent present
present_with_a_shelf_continuing_to_greater_trochanter,
  252  Fe_patellar_groove / absent
present_but_shallow_without_defining_margin
well_developed_with_defining_margin,
  253  'P-Lt Tibia Tuberosity' / 'large_and_hook-like' indistinct,
  254  Tibial_malleolus / weak_or_absent distinctive,
  255  Tibial_mtc_ltc_differentiation,
  256  'Fibula-femur contact' / present absent
indistinctive_due_to_fusion_of_fibula_and_tibia,
  257  'T-F distal fusion' / absent present,
  258  Parafibular_enlargment / absent_or_not_fused_to_fibula
fused_to_fibula_and_enlarged,
  259  Parafibula_types,
  260  Fibular_styloid / weak_or_absent distinctive,
  261  'Fibo-calcaneus' / extensive_contact reduced_contact absent,
  262  'Ast+cal overlap' / absent weakly_developed_by_partial_overlap
present_as_superposition,
  263  'Astra-navic articulation' / articulating_facet_indistinctive
facet_developed_but_asymmetrical,
  264  'As-neck width ratio' / neck_narrower_than_head
neck_with_same_width_as_head 'widest_point_of_neck_at_mid-length'
neck_widest_at_its_base,
  265  Navicular_facet_aspect_ratio /
transversely_wider_than_vertically_deep vertically_deeper_than_wide,
  266  Navi_facet_spread / restricted_anteriorly
'asymmetrical_spread_to_medial_side_of_head-neck'
navicular_facet_shifted_ventrally
symmetrical_spread_both_medially_and_laterally,
```

```
  267  'Astrag-navicul shape',
  268  Astragalar_trochlea / absent 'present_but_lacking_medio-
lateral_tibial_crest'
present_with_crest_separating_medial_and_lateral_tibial_facets,
  269  'Astra M-D crest parallel to lateral fibular crest' / absent
present,
  270  Astragalus_AMPT / absent present
present_and_ventrally_flaring_or_protruding,
  271  Calcaneal_tuber / 'short,_dorsoventrally_compressed'
dorsoventrally_compressed_with_terminal_swelling
'elongate,_laterally_compressed_with_terminal_swelling',
  272  'Pero-Proc-Morph' / laterally_expanded_and_continuous_shelf
distinctive_lateral_peroneal_process
long_peroneal_process_with_a_deep_peroneal_groove_at_base
anterolateral_directed_and_hypertrophied_peroneal_shelf
peroneal_structure_reduced_and_truncated,
  273  Peron_base_extension / posterior_to_level_of_cuboid_facet
to_the_same_level_of_cuboid_facet
hypertrophied_peroneal_structure_extending_anterior_beyond_cuboid_facet,
  274  Peroneal_groove / indistinctive
'distinctive,_deep_separation_from_peroneal_process'
shallow_groove_on_lateral_aspect_of_peroneal_process
'distinctive,_on_anteriolateral_cornor_of_peroneal_process',
  275  'Cal-cub bone alignment' / aligned_with_long_axis_of_calcaneus
'on_anteromedial_aspect_of_calcaneus_(oblique_to_long_axis_of_calcaneus)
',
  276  'Cal-Cu joint orient' / 'C-C_facet_facing_ventrally' 'C-
C_facet_facing_anteriorly' 'C-C_facet_facint_medially_and_obliquely',
  277  'Shape of cal-cub joint' / flat_or_slightly_concave 'saddle-
shaped',
  278  Sustent._facet_orient / nearly_vertical
'oblique_(≤70_degree_from_horizontal)_to_horizontal',
  279  Calcaneal__sustentacular_facet_placement /
anterior_to_astraglar_facet_and_vertical_orientation
on_dorsal_aspect_of_calcaneus_and_anteromedial_to_astragalar_facet
medial_to_astragalar_facet_and_horizontally_orient
on_dorsal_aspect_of_astragalus_and_anterior_to_astraglar_facet,
  280  'Sust-astra facet fusion' / absent present,
  281  'Sust-vent-outline' / indistinctive
medially_directed_shelf_with_round_outline
posteromedially_protruding_process_with_triangular_outline,
  282  _Pos._Sust._position / 'near_mid-length_of_calcaneus'
'near_anterior_1-3_of_calcaneus',
  283  Post_CAF_structure /
confluent_with_fibular_contact_and_indistinctive oblong_to_ellipsoidal
spherical_and_bulbous transversely_confluent_with_sustentacular_facet,
  284  CA_facet_Medial / on_medial_side_of_calcaneus
on_dorsal_side_of_calcaneus
'on_dorsal_side_of_calcaneus_and_protruding_beyond_the_body''s_medial_ma
rgin'
'withdrawn_and_separated_from_the_medial_margin,_and_placed_on_the_later
al_margin_of_calcaneus',
  285  'Ant-plant tuber' / absent present_at_the_naterior_endge
present_but_set_back_from_the_anterior_edge,
  286  'A-V grv calcaneus' / absent present,
  287  Cal_body_compress / dorsoventrally_compressed
mediolaterally_compressed,
  288  'Cal-tuber curvature' / present absent,
  289  'Nav-Cuboid ratio' /
navicular_narrower_than_or_subequal_to_cuboid
navicular_wider_than_cuboid,
```

```
  290  Cuneiform_ratios /
meso_and_ecto_combined_width_narrower_than_entocuneiform
meso_and_ecto_combined_width_wider_than_entocuneiform,
  291  'Entocunei-MT5 joint shape',
  292  Cuboid_notch / absent present,
  293  'Pre-hallux' / absent present,
  294  'Cal-Pero-MT 5' / absent present,
  295  'Mt V off-set' / Mt5_contacting_lateral_side_of_cuboid
'Mt5_is_far_off-set_from_cuboid_to_contact_calcaneus' 'Mt5_is_off-
set_from_cuboid_but_leveled_with_anterior_end_of_cuboid',
  296  'Protub on Mt-V' / absent
present_but_not_reaching_the_level_of_calcaneus
present_and_extending_to_anterior_part_of_calcaneus,
  297  MT_III_orientation / aligned_with_long_axis_of_calcaneus
oblique_to_long_axis_of_calcaneus,
  298  MT_II_&_III_levels / Mt2_Mt3_even_or_Mt2_more_proximal_than_Mt3
Mt3_more_proximal_than_Mt2,
  299  Hullax_opposable / absent present,
  300  Ossified_patella / absent present,
  301  Flexor_Sesamoid / absent 'present_but_un-paired'
present_and_paired,
  302  Extarsal_spur / absent present,
  303  'Pes didact-syndact' / didactylous syndactylous,
  304  Long_bone_epiphysis / absent present,
  305  SQ_cranial_moiety_size / narrow_strap broad_plate
expanded_posteriorly_to_form_skull_roof_table,
  306  SQ_in_cranial_wall / absent present,
  307  'Multi vasc fora in SQ+PA' / absent present,
  308  Multi_vasc_fora_in_FR / absent present,
  309  'SQ/glenoid relationship' / on_the_insid_of_zygomatic_root
'on_zygoma,_but_lateral_to_zyogoma-cranial_moiety_constriction'
contact_on_cranial_moiety_of_squamosal
'on_zygoma_without_a_constriction_of_zygoma-
cranial_moiety_of_squamosal',
  310  'SQ zygo-profile' / rounded_or_triangular_in_cross_section
dorsoventrally_deep_and_mediolaterally_compressed,
  311  SQ_PG_depression / 'present_as_post-
CMJ_joint_sulcus_(EAM)_on_zygoma' absent present_on_skull_base,
  312  SQ_Entoglenoid_process / absent_or_vestigial
present_but_separated_from_postglenoid_process
'present,_enlarged_and_connected_to_postglenoid_process',
  313  SQ_CMJ_position_to_FV /
CMJ_posterior_or_leveled_to_fenestra_vestibuli
CMJ_anterior_to_the_level_of_fenestra_vestibuli,
  314  SQ_glenoid_orient / on_the_inside_of_zygoma_facing_ventromedially
on_a_platform_facing_ventrally,
  315  SQ_Postglenoid_process / absent present_as_a_raised_crest
present_as_a_distinctive_process
present_as_process_and_buttressed_to_ectotympanic,
  316  PG_foramen_position / posterior_to_glenoid
medial_to_postglenoid_process anterior_to_postglenoid_process,
  317  PG_for_composition / absent present_in_squamosal
present_at_junction_of_squamosal_and_petrosal
present_at_junction_of_squamosal_and_ectotympanic,
  318  Media_marg_TMJ_fossa / by_squamosal by_alisphenoid,
  319  SQ_epitym_recess_portion /
no_contribution_to_epit_recess_which_is_formed_by_petrosal
small_contribution_to_posterolateral_wall_of_epitympanic_recess
large_contribution_to_lateral_wall_of_epitympanic_recess
large_SQ_wall_to_enlarged_epitympanic_sinus,
```

```
  320  'BWS-in-FV' / BSW_reaching_the_rim_of_fenestra_vestibuli
BSW_reduced_and_withdrawn_from_fenestra_vestibuli
BSW_absent_from_cochlear_bony_housing,
  321  BO_on_pars_cochlearis / Basioccipital_forming_cochlear_housing
medial_aspect_of_petrosal_cochlear_housing_covered_by_basioccipital
'half-width_of_petrosal_cochlear_housing_covered_by_basioccipital'
petrosal_cochlear_housing_is_not_covered_by_basioccipital,
  322  Rim_of_FV,
  323  Pars_cochleari_completed_by_petrosal / absent present,
  324  flat_facet_prom / flat_ventromedial_surface inflated_and_convex,
  325  Promon_outline / triangular_with_steep_lateral_wall
elongate_and_cylindrical_with_steep_lateral_wall
bulbous_and_oval_shaped,
  326  Cochlear_recess_or_canal / recess_but_not_a_canal
'short_canal_(without_reaching_the_full_extent_of_promontorium)'
elongate_canal_to_reach_full_length_of_promontorium canal_curved
canal_coiled_upto_270_degrees canal_coiled_over_360_degrees,
  327  IAM_cribriform_plt / absent present,
  328  IAM_depth / deep_with_thick_prefacial_commissure
shallow_with_thin_prefacial_commissure,
  329  Primary_coch_lamina / absent present,
  330  2nd_coch_lamina / absent present,
  331  'Crista int-fenest' /
'horizontal,_broad,_extending_to_base_of_paroccipital_process'
'vertical,_delimiting_the_back_of_promontorium'
horizontal_and_connecting_to_caudal_tympanic_process,
  332  Post_Tymp_Recess / absent present,
  333  Rost_tymp_process / absent_or_present_only_as_a_low_ridge
Tall_ridge_in_anterior_half_of_promontorium 'well-
developed_ridge_reachin_anterior_pole_of_promontorium',
  334  Caud_tymp_process / absent present present_and_notched
'present,_hypertrophied_and_butressed_to_exoccipital_paroccipital_proces
s',
  335  'ZJK-Tympanic process' / absent present,
  336  flat_margin_aud_reg / marked_by_steep_wall
extended_onto_flat_surface,
  337  Prootic_canal / absent present_and_vertical
reduced_to_a_thin_canal_and_horizontal,
  338  trans_sinus_SA / anterolateral_to_subarcuate_fossa
posterolateral_to_subarcuate_fossa,
  339  Lateral_trough / open_lateral_trough_without_bony_floor
bony_floor_present lateral_trough_absent,
  340  Vent_Open_Cavum_Epipt / present present_but_reduced_in_size
partial_enclosure_by_petrosal enclosure_by_alisphenoid_and_petrosal
present_as_large_piriform_fenestra,
  341  'Cavum sup-coch VII' / absent present,
  342  Hiatus_fallop_position / present_in_petrosal_roof_of_middle_ear
present_in_anterior_end_of_petrosal absent,
  343  FO_composition /
primary_foremen_ovale_between_petrosal_and_basioccipital
secondary_forament_ovale_by_alisphenoid_in_addition_to_the_primary
in_anterior_lamina_of_petrosal between_alisphenoid_and_squamosal
within_alisphenoid,
  344  FO_position / on_lateral_wall_of_braincase
on_ventral_surface_of_basicranium,
  345  #_of_V3_exits / one two,
  346  'Q-ramus on lt flg' / think_rod_underlying_the_quadrate_ramus
absent,
  347  Alisphenoid_canal / absent present,
  348  Anterior_lamina_PE / present reduced_or_absent,
```

```
  349  Lateral_flange_PE / horizontal_shelf ventrally_directed
medially_directed_and_contacting_promontorium vestigial_or_absent,
  350  'L-shape lat flange' / Present Absent,
  351  Lf_vascul_foramina / present absent,
  352  Pe_LF_&_CP_connection / widely_separated narrowly_separated
continuous,
  353  PPF_Morph_composition / open_notch
foramen_enclosed_by_petrosal_and_squamosal foramen_absent,
  354  Position_of_PPF_to_Fenestra_Vestibuli / posterior_or_lateral
anterior,
  355  PP_bifurcation / absent present,
  356  Ventral_Proj_PPP / absent present,
  357  APP_differentiation / anterior_pp_bulbous_and_spherical
anterior_pp_has_distinctive_crista_parotica,
  358  Epitym_Recess / absent present,
  359  Tympanohyal_contacting_cochlear_housing / absent present,
  360  SQ_PP_differentiation / SQ_covering_entire_paroccipital
No_SQ_cover_for_paroccipital
SQ_covering_part_of_paroccipital_but_not_crista_parotica,
  361  'SQ-Medial expansion' / Absent
'Present_(near_or_bording_on_foramen_ovale)',
  362  Stapedial_sulcus / absent present,
  363  Transprom_sulcus / absent present,
  364  Deep_groove_on_ant_promon / absent present,
  365  Perbullar_canal / absent present,
  366  Prom_epitymp_wing / absent present,
  367  'Al-ecto process' / absent present,
  368  'Al-tympanic proc' / absent present,
  369  Hypotympanic_recess / absent present,
  370  'JF-FC separation' / absent separated_within_the_same_depression
separated_in_different_depressions,
  371  Perilym_channel / open_channel_and_sulculs
at_least_partially_enclosed_by_bone,
  372  Large_jug_foramen_to_fenestra_cochleae /
subequal_to_fenestra_cochleae larger_than_fenestra_cochleae,
  373  inf_pe_si_jugular / confluent separated,
  374  Stapedial_fossa_size / absent present_and_small
'present_and_large_(twice_the_size_of_fenestra_cochleae)',
  375  Stapedial_fossa_position / aligned_with_crista_interfenestralis
lateral_to_crista_interfenestralis,
  376  XII_foramen_location / indistinct separated_from_jugular_foramen
separated_from_jugular_foramen_by_elevated_rim_of_the_latter,
  377  #_XII_foramen / single doulbe,
  378  Incus_troch_saddle / trochlear trough 'saddle-shaped' flat,
  379  'Incus-Malleus alignment' / 'postero-anterior'
posteromedial_to_anterolateral dorsoventral,
  380  'Q-twist of dorsal plat' / dorsal_plate_aligned_with_trochlea
dorsal_plate_twisted_relative_to_trochlea
dorsal_plate_twisted_and_elevated_from_trochlea
dorsal_plate_reduced_to_a_conical_process,
  381  'Q-neck' / absent present,
  382  'D-plate & crus brevis' / broad_plate pointed_triangle reduced,
  383  Angle_of_proce_brev_long / alignment_with_stapedial_process
'perpendicular_(or_acute-angled)_to_stapedial_process',
  384  'Q-suspension' /
at_least_one_cranial_bone_in_addition_to_quadratojugal by_squamosal_only
by_petrosal_only,
  385  Quadratojugal / present absent,
  386  Stapedial_morph / 'columnelliform-macroperforate'
'columnelliform-impreforate' 'bicrurate-performate',
  387  Stapedial_ratio / less_than_1.4 1.4_to_1.8 '>1.8',
```

```
  388  Bullate_Stapes / absent present,
  389  Malleolar_neck / absent present,
  390  'Mal-manubrium length' /
'short_(shorter_than_width_of_prearticular-gonial)'
'long_(equal_to_or_longer_than_width_of_prearticular-gonial)',
  391  'Mal-manub thickness' / robust gracile,
  392  Midlength_angle_of_Meckel_bone / absent present,
  393  'M-L separate of MC' / absent
embryonic_cartilage_separated_from_posterior_part_of_mandible
ossified_MC_separated_from_posterior_part_of_mandible,
  394  Ectotymp_size_&_shape / 'plate-like' 'curved_and_rod-like' 'ring-
shaped' 'ring-shaped_and_fusiform' expanded
elongate_lateral_expansion_and_tubular,
  395  Ectotypm_arc_degree / about_70_degrees ≤90_to_135_degrees
≥135_degrees,
  396  Ectotym_anterior_process / present absent,
  397  Incisura_tymp_posit / posteroventral posterior posterodorsal
dorsal,
  398  'Fusion ectotym ring to basicranial bone(s)' / absent
'fused_to_other_bone(s)',
  399  Entotympanic / absent present,
  400  2nd_palate_posterior_extension / 'anterior_to_tooth-
row_posterior_end' 'leveled_with_tooth-row_posterior_end'
'posterior_to_the_tooth-row_posterior_end' 'extending_to_basisphenoid-
basioccipital',
  401  'Post-spine on palate' / absent present,
  402  'Pt-Pl ridges' / present absent,
  403  Pt_flg_&_hamulus / Present_as_full_flange
reduced_to_small_hamulus vestigial_or_absent,
  404  Pterygoid_midline_contact / present absent,
  405  Minor_pal_f_on_palate / encircled_by_pterygoid
encircled_by_palatine_and_maxilla_but_separated_widely_from_subtemporal_
margin
encircled_by_palatine_and_narrowly_separated_from_subtemporal_margin
large_posterior_fenestration open_notch,
  406  Trans_canal / absent present,
  407  IntCarotid_entry / in_basisphenoid 'at_basipshenoid-
basioccipital_suture' through_open_cavum_epiptericum,
  408  Orbital_overhanging_roof / absent present_and_formed_by_frontal,
  409  infraorbit_canal_exits / single multiple,
  410  'IOF composition (posterior)' /
'at_junction_of_lacrimal,_palatine,_and_maxilla' encircled_by_maxilla
'at_junction_maxilla,_palatine_and_frontal',
  411  facial_part_of_lacrimal / small_and_oblong large_and_triangular
crescent reduced_to_narrow_strap absent,
  412  Lacrimal_canal_location / inside_orbit
on_facial_side_of_lacrimal,
  413  #_lacrimal_foramina / one two,
  414  'Lacr fo composition (orbit)' / encircled_by_lacrimal
bordered_on_or_within_maxilla,
  415  Zygoma_Depth_relative_to_skull_length / '10_-_20%' '5_-_7%'
zygoma_incomplete,
  416  Last_U_Molar_on_zygoma / absent present,
  417  'Frnt-Alisph contact' / alisphenoid_contacting_frontal_by_corner
alisphenoid_contacting_frontal_by_50%_of_alipshenoid_margin absent,
  418  'Frontal-max contact' / absent present,
  419  Frotnal_midian_process_wedging_nasals / absent present,
  420  post_width_nasals / narrow broader_than_nasal_width_at_midlength,
  421  Pila_antotica / present absent,
```

```
  422  Orbitosph_ossification / absent
present_but_only_forming_braincase_ventral_floor
present_and_forming_both_braincase_ventral_floor_and_orbital_wall,
  423  Optical_foramen / absent present,
  424  Maxillary_nerve_exit /
separated_from_sphenoorbital_fissure_and_behind_alisphenoid
separated_from_sphenoorbital_fissure_but_within_alisphenoid
confluent_with_sphenoorbital_fissure,
  425  Orbitotemp_foramen / absent present,
  426  Lesser_Pal_in_orbit / absent present,
  427  'Ant Jugal-Mx' /
jugal_extending_onto_maxilla_and_forming_orbital_border
jugal_not_reaching_maxilla_and_excluded_from_orbital_border,
  428  'Post Jugal-Glenoid' / participating_in_squamosal_glenoid
bordering_on_glenoid_but_not_a_part_of_glenoid
terminated_anterior_to_glenoid,
  429  Mx_margin_in_orbit / absent present present_and_extensive,
  430  'Frontal-Mx in orbit' / absent present,
  431  Ascending_channel / open_groove partially_enclosed_in_canal
completely_enclosed_in_canal_or_endocranial absent,
  432  PTC_size / present_and_large present_and_small absent,
  433  Lambdoidal_crest / 'overhaning_the_concave_-
_straight_supraoccipital' weakly_developed_with_convex_supraoccipital,
  434  Sagittal_crest / prominently_developed weakly_developed absent,
  435  Tabular / present absent,
  436  Occiput_sloping / sloping_posterodorsally_or_oriented_vertically
sloping_anterodorsally_from_occipital_condyles,
  437  Occipital_artery_groove / absent present,
  438  Nasal_foramina / absent present,
  439  Septomaxilla / present_with_ventromedial_shelf
present_without_ventromedial_shelf absent,
  440  Pmx_internarial / present absent,
  441  'Pmx P-D process' / short_and_not_extending_beyond_canine
extending_to_the_canine extending_past_canine_to_contact_frontal,
  442  'Pmx facial-nasal' / absent present,
  443  Pmx_palate_extension /
terminated_anterior_to_level_of_canine_alveolus
reaching_the_level_of_canine_alveolus,
  444  Incisive_foramen_size / 'small_(size_of_one_or_two_incisors)'
'intermediate_(size_of_3_or_4_incisors)'
'large_(more_than_half_palatal_length)',
  445  Palatal_vacuities / absent present_near_palatomaxillary_border
present_near_or_extended_to_the_posterior_palatal_edge,
  446  Major_palatal_foramina / absent present,
  447  Ossified_cribriform / absent present,
  448  Nasal_post_extension_into_sphenoid / absent present,
  449  Parietal_vault / absent present
present_and_expanded_to_lambdoidal_region,
  450  Vermis_anterior / absent present,
  451  Vermis_size / small enlarged,
  452  Cerebellar_Hemisphere / absent present,
  453  Olfactory_lobe /
absence_of_external_division_from_cerebral_hemisphere
olfactory_lobes_differentiated_from_cerebral_hemisphere
olfactory_lobes_clearly_defined_by_transverse_sulcus,
  454  Encephalization_Quotient / below_0.13 'between_0.15_-_0.25'
above_0.26,
  455  Cerebr_Hemisph_divergence / absent present,
  456  Trophoblast / absent present,
  457  'Ureter-Mullerian Tube' / absent present,
  458  Placenta_types
```

```
          ;

MATRIX
[                              10        20        30        40        50
60        70        80        90        100       110       120
130       140       150       160       170       180       190
200       210       220       230       240       250       260
270       280       290       300       310       320       330
340       350       360       370       380       390       400
410       420       430       440       450      ]
[                             .         .         .         .         .
       .         .         .         .         .         .         .
     .         .         .         .         .         .         .
   .         .         .         .         .         .         .
  .         .         .         .         .         .         .         .
        .         .         .         .         .         .         .
       .         .         .         .        ]

Thrinaxodon
0000000000000000000000000000?0?0?0?01000???????0?00000?????00?????00?????0
000000??0??????????????????00?????????????????????????0??000?????????????0
000000000000????00?0?0000001?0?????000000010000000000?0?00000?00000000000
000000000000????000000??000000000000000000000?0000?0000000000000000?00000000
110000000??000000000?00?????????0000??000??00?0?00?000?00000?0?1000000??0
????0?00?00???0?0?000000000000000000000000000000000000000000000000000?0000
0000000000010000000000???
Massetognathus
0000010000000000010000000?0?0?0001000?????????20000?????20?????00?????0
000000?????????????????????00?????????????????????????0??011?????????????0
000000000000????00?0?0000001000?????00?????000000??0?0?????0?????00????00
000000000000????10???0??00000???0??0???0?00?????????????????????????????
???????????0???0??00?00????????1000??000??00?0?00?000?00000100100000??0
????0?00?00???0?0?101000000000000010000000000030000000000000010000?0000
000000?000000000000010???
Probainognathus
0000000000000000010000000?000?0001000?????????00000?????00?????00?????0
000000??0??????????????????00?????????????????????????0??000?????????????0
000000000000????00?0?000000??0?????00??????010000??0?0?0???0?????00??????
????0????0?????10???0??000?0???0??0???0?00?????????????????????????????
??????????????0??00?00?????0??1000??000??00?0?00?000?00000100110000??0
????0?00?00???0?0?001000000?000000100000000000000000000000000100000?0000
000000?00000000000000101???
Tritylodontids
0000010000000000000000000010?000?3000200?????????20?00??2??21????24?????0
000000?????????????????????00?00?????????????1???????0??33023?????????????3
0300002??2???0000?2?10??1120100000000000?0100000000000000000000000000000
000{01}1000000????2000010?000000000000000000?0000?00?000000000000000000
0001??000?0?000000000000?00?0????0?01111??1000000?00000000?000001000000100
??000000?00000?0100?00210000000000001000000000{01}0103010000000000020010
0?1000000000000{01}00000100?0111???
Pachygenelus
0000000000000100000000000000000?2000010000?????1?00000???0?00????00?????0
000000?000?????????????????00?????????????????????????0??000?????????????3
0300001000??0000?1?2000001?1?????00000?0??10??0000100?00000?00000000000
000010000001000210001????00?0000000?????00?????????????????????????????
??????????????000000010?0?0?01111??1?00000?0000?000?000001011000000??0
00000?00010000?1?00210011000000001000000001000001010101000000100000?1000
0000000000000000000????????
Adelobasileus       ??????????????????????????????????????????????????????
??????0??????0????0000000?000?????????????????????????????????????????????
????00?????????????????????????????????????????????????0??????????????????
```

```
????????????????????????????????????????????????0????????????????????????
????????????????????????????????????????00000?????????022110?????0000001?11
??10100001001000??????000000000100002?10?????????0???????????0??0?0?000????
????00??0200??????0001100???????????0?????????
Sinoconodon
000000100000000000000000001101000000010??????011000002?00?000????00?20??0
{02}000001000???0000???0????00?00???0?????????0??????0??000000?0?0???????0
000000000000033112202000000017???????1000??0?01????001000000000000000000
00000010000007?????????????????????000?00?0???00?????????????????????????
??????????????????000000010000?000221100100000000001011101010000000000100
?000000000001000101010210011000000001000001001010001010001000000200010002
000000001000000000100001027??
Morganucodon
000010100000000000000000002{01}0100000010?000000010000?00?000?0??11?20
??2000002000???0000???0????00?40???0????????0??????0??0000110?0???????0
00{01}0{01}00000000000{23}{12}000000001101??????70000000??111?00??1???00
100?00000?000000000100000?????2100010???0000100000010?0000??000?000000000
000000000000000???0????????0??00000010100{01}{01}?000231111201000000000101
110101000110100111001000000000100010100021002100000000100000100101000101
010100000020001002000011001100000000100001127??
Megazostrodon
000010000000000000000000002002001000010?000000000000?00?000?0??12?20??2
000002000???0000???0??????00?40????0????????0??????0??0000110?0???????0001
010000000000011000000001001???????2?00000?011100????????0?100000000?00000
000010000??0??2100010?000000100000?000000?0000?00?000000000?00??0??0?0?
1?000000000000000?0010100???000231101201?000000101110100000117?100111?1
000000000100010?00210?21???0??001?000010?1??000101010100000?2?001002000
01?00???????00??0?????????
Haldanodon
000001100010001000100000002101001000010?000000010000?10?000?0??11?20??2
003200000???0000???0??????00?11???0????????0??????0??032011007?0???????0000
010000000012200000000001100???????00?????????????????????100001000?00?00
000120000?0?????????????????000?00000?0?0?0?????????????????????????????
???????????0???000001020011?000231100201000000001?121010007?001????0101001
000000000100010100???721000???00??00002011?100010101010000002000100201 0
011101100000000007??2?????
Castorocauda
00?00110001???1?000000000210100100001 0?0???0??10000?010?000?0??11?2????2
003200?00????000???0?????????????????????????????????0?01100?0???????000?
?100?????01?00??0??0??011007????????0??????000000?????????????????????0
000120000000000110000000000000000001010000?0000?????000000000000000??00
?0??0?00000011007??010?????????????????????????????????????????????????
??????????????????????????1100010000?????????0???????10?000?2????0?2???
?1????11?00???????????????
Hadrocodium
1??2?130010?402110000000002001002007010?000010100000?0??000?0??12?20???
000000000???0000???0??????00?00???0????????0??????0??0000110?0???????0000
000000010033444300000011017????????0????????????????????????????????????
??????????0????????????????????????????????????????????????????????????
??????????????????1000002010?000231112301000000001?111010?100110210101101
000000000100?1010??????21?0???????1????02012?1030101000100000127?21002010
1211001?00??000?2??1213???
Shuotherium
0010110??0000021??000?00?0????0?0001010??????1111111??0?013?2001201007?1
3232100111000010007??0????11?1100200007?0??0000000?0100120221100??0100111?
????????????3?????0??????????????0????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
??????????????????????????
```

Pseudotribos
0?10011000?0001???00??????210101000111O??0???01111?1110?013?20012010O?1
32321001110O0?100???0????11?11002000O?0??OOOOOOO?01001202211OO??0100111?
01?0??100100033100OO??01100?????????0?????101?00?0010001?????????????0????0
???12000000????211???OOOOO?10?OOOOOOO?00??????????????????????????????????
???????????0???0???
??0????????????2???
1?????????????????????????
Asfaltomylos
00121121100000021??00220000213101200l0??????????11011?????013?2??13??13?0
210000?11102214110001111?2??????????????????????????????01?02211?1102??0000?
?????????????????????0??
???
???
???
?????????????????????????
Ambondro   ?????1???00????1????????0?????0???0?0??????????121311
10???013?2??130?133001210O?11102224112O?1111?????????????????????????????
01?02211?1102010000?????????????????????0????????????????????????????????
??
??
??
??
Ausktribosphenos
00100120100000021??00220000O??10120010l0???????12131110l1?013?2??13021330
012100022102214122003212З?????????????????????????????03?02221?1112111000?
????????????3????00??
??
??
??
????????????????????????
Bishops
01?10120100?0021??00220000213101200l0?0???????12131?1011?013?2??13021330
012100122102214122003212З?????????????????????????????03?02221?1112111000?
???????????03??0?00??????????????0??
??
??
??
????????????????????????
Teinolophos
11002120100130210??00220002131012001O?????????????????????3?2??13111120
012010?22204223121O?02?23?????????????????????????????3?02221?2113102000?
??
??
??
??
????????????????????????
Steropodon
011001???0??00?1?????????????????????10?????????????????????013?2??13111120
012110022204223121O?02?23?????????????????????????????03?02221?2113102000?
????????????????3??3??
??
??
??
????????????????????????
Obdurodon
11?2?120100130211011220001213111211010???????1013100????013?2??13111120
012010022204223121O?02?2320?1?????????????0????????033022212211310200O4
?5?????2??2333443??0?????1?????????0??
????????????????21???1????11??
??????????????????10002110110?0002311115????0000001?111?11010011121011O?1

```
000000000000?00?0????????1?0???????????03012?10000?40?110211?12020122?00
12110011?0??00002????2????
Ornithorhynchus
11?2?1001001302110112200012131112111{02}10??????????????????????13?2??1?1?1
?????201002220422312102?2?2320?1?????????????????????0??0330?????2?1?1?2?
??4?5?????2??2?334443??0????1?????????0?111011110000001000100000101000000
000000120000001001211111000011100000022011001100007000000010110000000000
00110000110100116{01}0100002110010?0002311114110000000010111011010011121O
11101100000000000?00?0?32312121100111012101003011010000240011021121202O1
12210012110011?0?100002111223000
Tachyglossus
11?2?10??00140211000000000213111??1?010??????????????????????????????????
????????????????????????????????????????????????????????????????????????4
?5?????2??2?334443?????????????????????1110111100000010001000001010000000000
000120000001001211111010011100000022011001100007000000010110000000000000001
1000011010011{01}0100002110010?0002311114110000000010111011010011121011101
01100000000010?00?0?32312121100111012101003012110200240011?2112120211122
100121100011?0?{12}00102111223000
Fruitafossor
11?00140000000021??110000112101011001?10?00000010?0000?0??0??????10?????0
??00000?????????????????????00?0?????????????????????0???44007?????????????
02?0??100102233320007001100???????31??????010001????????0?00001100?00100
000120001001001217?????0000???00??0100?100?0?0?????????000000000000?00000
???????????01??0????10???11?????????????????????????????????????????????
????????????????????????????????????????????????????0????????????2?1??
??????????????????????????
Gobiconodon
11?1010??000102110122100112114001001010?000000100101000?000?0??12?10??1
0100010?00???0000???0?????00?10????0????????0??????0??001012017?0??????0002
0300001001011120000000010107???????20????010100000000?10112111111100111OO
000101000000007?1002100000000000000001007?000?0000000?000000010000000000000
0?????????001000000102001107?0002311113010000000017?12112000001111001110O2
000000000117??1011????????1?1????12????002002110000110000000011200111221210
0110001?000001??0??0?00???
Repenomamus
11?1010??001102110122100112114001001010?000000110101000?000?0??12?10??1
0100010?00????000???0?????00?10????0????????0??????0??001011017?0??????0002
0300001001011220000000010107???????0000001010000000011011211111100111OO
000101000000???2100210000000000000001000000?000000000000000010000000000000
0?0?0??0??00?1000000102001107?0002311113010000000017?12112000001111001110O2
0000?000011??101????????21?1????12?????020021100001100000000112001112212O1
0110001?000001010??0100???
Amphilestes
11?11?0??001102???122??0??211400200201????????110100000?000?0??12?10??1
0100010?00???0000???0?????00?????????????????????????00?01201?0??????000?
??????????00?21??0000??????0????????0????????????????????????????????????
????????????????????????????0????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????1?????????????????
??????????????????????????
Yanoconodon
11?1010??001102110122100?2214001000010?000000000000000?000?0??11?10??0
2000031?00????000???0?????00?00???0????????0??????0??0000110007?0??????0003
0300000000033334300010011107???????000000101000000001101121111111001110OO
000101010000001210021000000000000001000000?000000000000000010000000000000
0?0?0?00??000000000010207117??00?????????????????????????0?????????????
??????????????????32312121???1101221010007?00?????0??????11?????2????122???
??????????0???????????????
Jeholodens
11?1010??00?10211012??001?2214001000010?000000010100000?000?0??11?10??0
2000031?00???0000???0?????00?00???0????????0??????0??0000110007?0??????0001
```

0100001001033223200000011111????????0000001010000000011011211111110011100
??0101010000001210021000000000000001000000?000000000000000010000000000000
000000001000000000000102?011?0002311?130100??0???10??1?????????????????????
0??0?0?????????????????21????????1221?????????????00?10??11???00?????122???
011??01??0??????1?????????
Trioracodon
11?10?0??0011021??122100102214001000010?00000?0101000100?000?0??11?10??1
{02}000031?00???0000???0????00?10?????????????1??????1??0000110?0???????0
00?0300??000001233210000??01100????????0?????????????????????????????????
??
????????????????????0?????????????????02311?????????0??0?0??1010???0?????????
??????0??0???1??10?????????????0?????????????0???????0????????1????????????
??0??????????????????????????
Priacodon
11?1010??0011021??122100102214001000010?000000000101010100?000?0??11?10??1
2000031?00???0000???0?????00?10????0????????1???????1??0000110?0???????000?
?300??0?000122221000??01101???????10?????????????0????????????????????????
??
????????????????0?????0????1??00231111301??000000101?12100??0111100??100?
?000??0??1100101???????2??0???????????020?????000??????1???????{12}??122
?10??????????0??0??1?????????
Haramiyavia
0100110??000002???000000002?010?100021?0????????2?000??20021????24?????0
??0?000?????????????????????0?00????????????1???????0??033023?????????????
01000010?1?1133?1?00??0??121000000?0????????????????????????????????????
??
??
??0????????????2???
????????????????????????
Rugosodon
1112?10??00?302?10102120102224001000210??????0??2?0?0??2?121????24?????0
??0?000?????????????????????0?00????????????1???????0??033023?????????????2
140000110?0144220010 3?1112101010 0?0111110?1111000001101111001111001 1001
00?000010110001 21?01100000 0?1?001002011000000121001000100012001000110001
011000111000210 1?0??
????????????????????????1??
????????????????????????
Kuehneodon
1112?10??000302110102120102224001000210 1?????0??2?020??21121????24?????0
??0?000?????????????????????0?00????????????1???????0??033023?????????????2
140000110 2?1144320010 3?1112101010 0?01????????????????????????????????????
??
??
??
????????????????????????
Sinobaatar
1112?10??00130211010212010222400100021 00?????0??2?010??20121????24?????0
??0?000?????????????????????0?00????????????1???????0??033023?????????????2
0400002??2?02442300 1?0?1112020111 1?0?1?1100111100000110111100111100110 01
00200001011000121 0{01}1100000001110100201100000012100100010001200100011 0
00101100011100021010000101011 0?000??
????????????????????????????1????????2???00????????????????????????????????
????????????????????????????
Plagiaulacidans
1112?10??00{01}3021101021201022400100021 01?????0??2?020??21121????24???
??0??0?000?????????????????????0?00????????????1??????0??033023??????????
??2140000 2??2?0244{23}300103?111202011 1100????????????????????????????
????????????????????????????????????1????????????????????????????????????
????????????????????????????????????2311 1301??000000101211101100211???
1111?10?000000010001111??????21?0??????????0?000201001002000 10?000020?1
12202000100{01}11010000?21?????????

Cimolodontans
1112?10??00130211010212010 22{12}40{01}{12}0002100?????0??2?000??20121???
?24?????0??0?000?????????????????????0?00???????????1??????0??033023?????
????????3040000 2??2?1{23}44330012 0?11120201111200011100111100000110111 10
01111001100100{12}0000{01}01100??2101110000000111?100201100000012100 1000
22111200100111001101100011100021010000 1010{01}10?00023111130100{12}00{01
}00101211101100211 21{01}111{01}010{01}{01}0000001{01}0011103231212110011
1??211100000{12}0100100200010200002{01}21112202001100121010000021110223?
??
Tinodon
1??11?????001021??121?00???104?130?00??????????0101000?00?01201??12?10001
0100010?1100001 00???00??010?11???00???0???0????0?0000210221 1?0??????000?
?????????1??22??1??0??
??
??
??
????????????????????????
Akidolestes
1????10??00?20????122100102114011001110?00000?1101000120?113020112010001
0000040122 00?0100???00??020?11???000??0??0000000?2000220222100??00000001
0100??100110001000000001110?????????0?????001100001001101121111111001110 1
1111011101000012111120100001 1?0000021001011001000000001002010010001100 00
1000012100002101 0?001020??1???
??0??????10?0???2?????12???
?????0???0?????????????????
Spalacotherium
1111010??000202?????2100102114011001110?00000?1101000100?113120012010001
0000040112 00?0100???00??020?11???000??0??0000000?2000220222100??00000000?
?????????10?000?0000000??10?????????0????????????????????????????????????
????????????????????????????1??????0????????????????????????????????????
??
??0??????????????????
????????????????????????
Zhangheotherium
11?0010??0002020??122100 1?2114010101110?00000111010 01?00?013110012010001
0000040111 00?0100???00??020?11???000??0??0000000?2000220222100??00000002
0200??100102200000100001110???????20?1100001111001001101121111111001110 1
1111011101000012111220000000 1?1110021001 00?0010000000130201001000110000
1000002000002101????1020111?0012311112????1101001?1?1?10???0??1210111102
0000000001?0?11?1??????21??????1??????0??????0??1?????10???0???2???12??2
????????00?????????????????
Maotherium
11?0010??0002020??122100102114010101110?00000111010 01?00?013110012010001
0000040111 00?0100???00??020?11???000??0??0000000?2000220222100??00000002
0200??100102200000100001110????????0?1?00001111 00?0011011211?11110011101
1111011101000012111220000000 1?1?10021{01}?100?0010000000?13020100????110
0001000002{01}00002101 0?0010201 11?0012311112????1101001?1???10?100?11000
111??2000000000 1???11?????????????????12?????0201??20?0??222??100000???2??
?12?02?1???0??00??????1?????????
Dryolestes
11?1011100002020??11210?0121130120011 10?0000010000001?00?013010013020000
2000000111000022 0??000??110?01???000??0??0001000?2000220221100?001000001
0100??000001100000000301110???????20?????????????????????????????????????
??
????????????????1???
??1???10?0?????????????????
????????00??0????????????
Henkelotherium
11?1011100002021??112101??2113012001110?00000?00000?0?00?013010013020000
2?0000011100002 20??000??110?01???000??0??0001000?2000220221100?00100000?
0?????00?0?1100000000??0???0?????????????????011110??0???0112111?110?11101

1?10011102100012l?022000000011100002110000?10?????????1????????????????
???????0???0?1011???1020?11?00?23111?3????????????????????????????????
0??1?????20001???1?????????20??
??????????????????????????
Amphitherium
11?111110002021??11210?012103012001110?11?0?00000001?00?013010013000100
200000011000210?0000??111101???000??0??0001000?2000210221111000000000?
?100?????0??000?0?00???
??
??
??
??????????????????????????
Peramus
11?111110002021??112101012103012001110?1100200002000?00?013010013000100
0100010011{01}0002110000{01}?0121121?0?010000??000100202000110221111000O
00000??2?????0000003310?00??0???0??
??
??
??
????????????????????????????????
Vincelestes
11?2?111000{01}2021??111101012113012001110?000010100000?00?013010013000
000200000001100002l0??000?0120?11?0?010000??000101200000110221100?000000
001030000001003333420000030??00?????????011110011110120l?101?211011110011
101010001110?000012101220000000111000021100007?1020?00?100130201011000110
100??0???210??0?00111002020011?00123?112400?11101001011101001000l1{01}211
111102011000000110021l1??????21?0???????????010110100010201000001012000l
00202000100111000000??1?????????
Nanolestes
11?101110002021??112?0??121030120011l0??????0000000?00?013010013000100
210001001100002100O?00?0121?11???0?0000??10120120200011022111100000000001
?1??????001?02??0?00??0???0????????0????????????????????????????????????
??
??
??
??????????????????????????
Kielantherium
11?10111O?002?21??111101?2????0130011?0???????0000000?00?013011013000110
211001011102015110000{01}00120?120000100-0--
10020111?0101?022211100100000???????????0??12??0??0??????0?????????0?????
??
??
??
??
Aegialodon   ??
???????1?01??13000110211001?11102015110O?11001?????????????????????????????
?1??2221?10010000O???0?????????????????
??
??
??
??
Montanalestes
11?2?131000040?1??11120103210301300111O???????120200100O?013?2??13010210
211001201202115110011100?????????????????????????????0??02221?1001110000?
???????????03??0?00??
??
??
??
????????????????1?????????
Prokennalestes
11?111310000102l??11120102210301200111O?1{01}112?120200002O?013022013020

```
1101110012012021151100111002210220200100110010110100200012022212100111000
00?????????01010033?0000?00?1?0????????0?????????????????????????????????
??????????????????????????????????????????????????????????????????????
??????????????????????????????????23111251111110{12}00102?10?????13?1?11
1011???11001???110?21?????????2??1?????????????????????0???????????1?????
?????1???????????0????????????
Murtoilestes        ??????????????????????????????????????????????????
??????13022013?202101110012012021151100?1100?210220200?001100101100002000
012?22212100l?10000????????0????????????????????????????0??????????????
??????????????????????????????????????????????????????????????????????
??????????????????????????????????????????????????????????????????????
??????????????????????????????????????????????????????????????????????
??????????????????????????????????????????????????
Eomaia
11?111310000102l??11120102210301200111O?10111112010000?0?013022013020?10
1110012??202?151100111??221022020010011001O??000?200012022212100l??0000
0100000000000331001000?100????????011?110011110120O?101122101111002110l
1120022102100012111220000000l?101102111000?012210002122302010130111101000
000100210001200111?0?1????2??0?????1??51?11??????????1????????????????
?????????11?????????????????????????????0????????00??0??10?0???2???10?20??
?????02??1??????1?????????
Juramaia            1?12-
?11000?????????1201022?0301100111O?10112012010O?020?013023013O2?????11?0
12?1???2?151100l????2211220200100110010111011120101202221210011?10000001O?0
?00100003310000000?100--?--
???011111001?1?????????112210??110?21?01????022102O0?????????????????
??????????????????????????????????????????????????????????????????????
??????????????????????????????????????????????????????????????????????
??????????????????????????????????????????????????
Kennalestes
11?2?131000040211011120002???0?2001110?111120100200010O?013022013020210
2110012222031151100111002210220111010011011010000?200012022212100111000l1
02????001011{01}33200100001101????????001?????????????????????????????
??????????????????????????????????????????????????????????????2??????????
??????????????????1100212211221022311125l1??210211002{34}1?2001013?????
10110201000110011002110??????21?2??????321300?01102000002OO??0?010121211
00202201110021010?00??1011223???
Asioryctes
11?2?131000040211011120002210301300111O?111220110200001O?013022013020210
2110012012031151100111002210220111010011001000000?200012022212100111000001
0100000010111332101000O?101????????001111??11110?????????????????????0?
????0???0?11000??????2?0??00????????0??1?000?012210002122302010130111101000
0000?0200001?00111002122112210223111125?1??2102110?241?2001013???11101102
0100011001100211O??????21?2??????321300201102000002OO?10101O?21211002022
0111002101000O??1011223???
Ukhaatherium        ?1????????00?40??????????022???0??00?110?111220110200
0020?013022013020?102110012012031151100111?022102201101001100100000O?200
012022212100111000000100000000011332101003O?101?????????0?1??1?011110??0?
??0?122101111O?211011120022102100?1210?220000000l?101102111000?012210002
122302010130111101000O???200??1??01??00?1?2???221???3?????????2??21????4
?0?????0???????1???????0?0?1??????21?1?????????2????????21??0?0?????0?????
???0?010???21??0?????????0??????0?????????????
Zalambdalestes
11?2?1{13}1000{01}40211011120{01}022103012001110?111221021220012O?013022
013120310211001022204205110001110220?120120110110000000000?20001202221210
01110000{23}0211?000110{12}{12}33{23}1010200?111?????????0??111001111O??0
???01?22101111O?211011120022102100012111220000000l?101102111210??1221000
21223?201013?011300000000002000O1?001110031221122102231112S?1??210211002
411200101З???11101102010001100110021l1??????21?2??????321300201102000002
01?10101012111l0{01}2021011000210100O0??1011223???
```

Daulestes
11?2?131000140211011120002210301200111O????1??????????00?013022013020210
211001?11202115110011100220?120210100111110100O0?200012022212100111O000?
0100??0001011332O0?0??0?100????????0????????????????????????????????????
??
????????????????1100212011201022311125111???10?????2?????01013???????1?2
01100??001????????1????2??1??????3???00?01?1??000?100?10?000?212110{01}2
0???1??00??????00??2?????????
Aspanlestes ?????1????0??0?????????1??????0???0?1?0?11112?1?0100
00?0?013023113110210211001?11201215110001100220?120321110312100?0000?210
012022212100111000O????????????033?0??0?????1?0????????0???????????????
??
??3?????????1?0?0?1???
?0?????1????????????????00?1????????1???????????1?????????????????????0???
??
Eoungulatum ?????1?????????????????1??????0???0?1???10110???????
?????013024213110310211001?11201215111001200320?122321110312100100O0?010
012022212100111000O????????????1332???0?????1?0????????0???????????????
??
??3?????????1???0?1???
?0?????????????????????000?????????1???????????1?????????????????????????
??
Cimolestes
1???2?1010?0140211?111200?2210301 2?01110?10122?110100001 0?013023113020210
211001221203115110011200221012111010011110000000?200012022212100111O000?
?200??0?0001133 21?00?????1?0????????20????????????????????????????????????
??
??
?0??
????????????????????????????
Gypsonictops
1???2?10100014021 1?111200?2210301 2?01110?11122?121200011 0?013023113120210
211001221204115110011200221012111010011110000000?200012022212100111O000?
??????0?0001133 20?00?????1?0????????20????????????????????????????????????
??
??
??
????????????????????????????
Protungulatum
11?2?1010001402 11?111200022103012001110?10120?121100001 0?013024213110210
211001211201215111001201320?122321110310000000000?010012022212100111O000?
??????0?0001133 21?00????100????????20????????????????????????????????????
??2220 03?212231 2?1013011132011
????????????????????????????????2311125?1??1?0?0?00??{01}0?????1?????????
????11001????1??21?????????????2??
??1????????????????????????????
Erinaceus
11?2?131000141211011120002210301300111O?10110112122001 00?013022013110310
211001011202215111001211220?121221110 20??0000000?010033022212111111100002
030000100103333420002001110???????2011111001111012 00?11112{12}1011110121
101112002210210001211122 1?000001110111210121O?122200302122512010130111 32
011000000200101200111003121112010223111251111210211002311300111 3???11101
102011001100110021112131112122011101421300211113000002001101101121211?22
121011100211100201220112231 11
Leptictis
11?2?131000140211011120002210301300111O?111221121220010 0?013022213110310
211001211204115110001101220?121111100111100000000?010012022212111111100002
020000000101133210002 00?100????????0??????011110120 0?101?22??111?0121101
112002210 21????2111221?000001110111211121O?122200 3?212231201013011132011
00???0200?01??011100312111201022311125111111020100231130011 13???11101102

```
01100110011002110??????21?20?????32130121111200000300010110112121110202102111002101000012201122 3???
Canis
111??131010140211011110002211301300111 0?0100010011000010?111023012001010
000000000000010210?001210000?010202110110001100 00?031012121210 0?021000002
020000000002332310000000100???????211111110111101 20??101121201111012111 1
112002211210000211122 1?000001100110111210?222120202122510010130111?3011
0?0?00200001200111003021113110223111251 11?11?3??0?2311110111 3?????101102
000010000110?112{01}213111212201110142131120111401001300010110112110102 2
022121000211111001220012231 11
Felis
111??131010140211011110002211301300111 0?0100010011000010?111023012001010
000000000000000210?001210000?010202110 00?00110000?031012121210 0?02100???2
020000000003443430?00000100???????211111110111101 20??101121201111012111 1
112002211210000211122 1?000001100110111210?222120202122510010130111?3011
0?0?00200001200111003021113110223111251 11?11?3??0?2311110111 3?????101102
000010000110?112021311121220111014213112011140100130001011011211010222022
121000211111001220012231 11
Rattus
1112?111000141211011112000222?0110002 10??????????????????013???21313?000
4000000????42041100013?1400??20222110 20??????????0?003102???????01?0???3
?411112???2333343????1?02112???????201111100111101200?101122101110001 1010
002102211200001211121 1?001011110111211110 0?122100302122500010110 11?31011
010100010001200111002010110020123111251111110100002411010111 31???2101101
010011100211111102131112122011101421300201112120014001101100121201122132
121000212 1?200121111223111
Oryctolagus
1112?111000140211011111000222?011?11210?00120000100001???013???01313?000
4000000????210410?00?3?1300??20121110 30??????????0?013202???????01?0???3
?411112???2333343??0??02112???????211111100111101201?101122101110002 0010
112002210200001211120 1?001011110111210110?0?211130212250001013010131011
010100010001200111002010110020?231112511111101000024110101113 1???2101101
000011100111011102131112122011101521300001111121003001 1?2111121201122132
121000212 1?200121111223111
Bradypus
111??131010141211011110002211301 3?01110??????????????????0??????15??????
?????03????????????????????????????????????????????????0440??????????????5
?5????1??2??????00??????01?????????3111111101111120??101121201112102 1111
112002211210000211132 1?100011001101101000?122120102122510010130111?3011
0?0?00200001200111003021113110223111251 11?3??0?23021101013?????101102
0000{01}0000110?112021311121220111014213113011110300101001?1102121101122
0?212100021011001122001223111
Tamandua
111??131010141211 0??????0?21?30???1??10????????????????????0????????????
?????????????????????????????????????????????????????????????????????????5
05????1??2?????????????????01?????????3?111111101111120??101121201112102 1111
012002211210000211132 1?100011001101101200?222120102122510010130??1?3011
0?0?00200001200111003121113110223111251 11?3??0?231?1101013?????101102
001000000110?112021311121220111014213113011110300101002?1102121101122 0?2
121000210110011220012231 11
Glyptotherium
111??131010141211011110002211301310111 1??????????????????0??????15??????
?????03????????????????????????????????????????????????0330??????????????5
05????10?2??????00??????01?????????3111111101111120??101121201112002 1111
012002211210000211132 1?100011001101101210?222120102122510010130111?3011
0?0?00200001200111103021113110223111251 11?3??0?230?1101013?????101102
0000?0000110?1120????11??220111014213113011110300101001011021212111220?2
121010210 11?01122???223 11?
Dasypus
111??131010141211011110002211301310111 1??????????????????0??????15??????
?????03????????????????????????????????????????????????0440??????????????5
```

```
05????10?2?????43??????01?????????3111111101111120??101121201112002111
0120022112100002111321?1100011001111101210?222120202122510010130111?3011
0?0?00200001200111103021113110223111251l1?11?3??0?230{12}1101013?????101
1020000000001l0?1120213111212201110142131130111113001010020110112121112 2
0?21210102101100122001223111
Chaetophractus
111??131010141211011110002211301310111?????????????????0??????15??????
?????03?????????????????????????????????????????????0440??????????????5
05????10?2?????43??????01?????????3111111101111120??101121201112002111
0120022112100002111321?1100011001111101210?222120202122510010130111?3011
0?0?00200001200111113021113110223111251l1?11?3??0?230211010l3?????101102
0000{01}0000110?112{01}213111212201110142131130111113001010020110212121l
1220?212101021011001122001223111
Euphractus
11???131010141211011110002211301310111?????????????????0??????15??????
?????03?????????????????????????????????????????????0440??????????????5
05????10?2?????43??????01?????????3111111101111120??101121201112002111
0120022112100002111321?1100011001111101210?222120202122510010130111?3011
0?0?00200001200111113021113110223111251l1?11?3??0?230211010l3?????101102
0000{01}0000110?112{01}213111212201110142131130111113001010020110212121l
1220?212101021011001122001223111
Holoclemensia       ??????????????????????????????????0?1?????????????
??????13021013020110211001111102115110O?2100120?220111100010010011121210
012?222121001000000?????????????????????0?????????????0?????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????
Sinodelphys
11???131010?4021??111?0??2210301300111O?00??11?1010?00?0?0130??13010110
011001111l?2115110012l??12112???110??????0110121210O??0222l?10010000001
0100000000011321112O?10?100????????0?????00111?0120??101123101111012?111
112?02211211110?1????00000001?10??0?100000?0121201O??124220201102l?21000
1101102100020011??0??????????????????????????????????????????????????????
??????????????????????????????????????????0??????10?0???2????0?2?3?
?????0??????????1?????????
Deltatheridium
11?2?14101012021??111100042103013001110?000011000100000?013021013000110
{02}1100111110211511000110012112201011000100100100102220120222121001000O
0010100??000002222211100?1210O???????20????????????????????????????????
??????????????????????????????????????????????12????????2??????11021??
?00?????????????????11100?02011?????2311125l0??1101002123l2???1013???2?101
1?2?00001???1101111????????2??1???????????02?11?2?000?20101O?000121???0{0
1}2031????002?011000???????????
Atokatheridium      ??????????????????????????????????0????????????????
??????1?02101300011001100l?1110211511O0?0??0121?220101100010010010010222
012?222121001000000?????????????????????????????????????0????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????
Sulestes
11?20141010120?1??111100142?1?013101110?000011000100000?013021013000210
011001111112115110012211221122010110001001001111022012022212100l010000?
?????????00222221?10????1??????????0????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
?000???????1?1?????????????????????????????????????????????????????????0?2???
???????????0????????????
Asiatherium
11?1?141010140211?111100142?0?013001110?000011000100000?013022013010310
```

```
2110010111122151101122112210220211111211?000100102100120222121001110000?
0?????000?022222101?????0?????????0????100111102?0????1123101111?21101
1120022112111102101220000001?101101100100?01??????????2???????????????
???????????0?001110?302011201?2311125????1111?0???23??4101013?????10?1?2
??0?0101111???11???????2?????????????02011?2?00??21??10?0?0?2????0{01}2
0???11000??????10??2?????????
Kokopellia          ?1?1?1410?012??1??1?1100?{34}2??????3?01110?????1?000
1000000?013021013010210211001001112215110112210221?22020110011?10011110
2100120222121001110000??1????0?000?222?1?10??0?100???????20?????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????
Anchistodelphys     ?????????????????????????????????????0???????????????
?????01?021013020310211001?011122051101132102211220221210210101011110?20
0120222111001110000?????????????????????????????????????????0???????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????
Albertatherium      ?????????????????????????????????????0???????????????
?????0?3022013?????????????????1?????????????211220222110210110011111220
0?2?222111??????000?????????????????2?????????????????????0???????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????????????????????????
????????????????????????????????????????????????????
Didelphodon
11?2?14101011021??111100142113O1?001110?001???000110000?013022013000310
2110012111122051201?321122112202222102010100201102210120222111001110000?
0??????0?00222221?00?????1?0????????20?????????????????????????????????
?????????????????????????????????????????????????21201?101231101011021221011
??????????????????10?3020112010223111212?0?????1??0?1??11?????1??????1?????
0?00?1?????0111?????????1?1?????????????0????????????????????????????0????1
????0???????1????????????
Pediomys            ????2?14101011021??111100142113O1?001110????????????
???0?013022013010310211001111112205120113211221122022221021100001111021O
0120222111001110000?????????00222221100??????0???????20?????????????????
????????????????????????????????????????????????????????????????????21201?1
012422020110212210111?????????????????????????????????123111???0????0??0?1??
?1?????1??????1???????00?1?????0111???????????1?????????????????2???0???
????????????????????1????????????1????????????
Turgidodon          ????2?14101011021?111100?4?11301?001110??????000100
0000?013021013010310211001111113215120113211221122022211021100001111022O
0120222111001110000?????????00222221?00???21?0???????20?????????????????
????????????????????????????????????????????????????????????????????????
????????????2????????????????????????????????????223111???0????0??0?1??
11?????1??????1???????00?1?????0?11???????????1?????????????????????????
?????????????????????1?????????????????????????
Mayulestes
11?2?14101014?2110111100142103013001110?000011000100000?013021013010310
2110011111122151201131102211220222200211000010110221012022211100111000O0
0100000000022222110011?100?????????011111001111012O1?101231011110121111
1120022112?1?1??2111220000000111011011100O0?012?????????24220201102121101l
??????210??0?001110030201120111231112S????110100??2411010101?????101102
1001010011111111??????21?????????????020110200000211010100O?2010100?0??
0110002111110O??2?????????
Pucadelphys
11?2?14101014021101111100142103013001110?000011000100000?013021013120310
2110010111122151201132102210220222211211100021111210012022211100111000O0
0100000000022222111011121O0?????????011111001111012O1?101231011110121111
```

```
112102211?????211122000000011101101110000?012130101012422020110212210 11
?101?0210??0?00111003020112011123111251 1??1101002124110101013?????101102
100101001111111111??????21?1??????2????02011?200000211010111012010100203 1
01100021011100?21?????????
Andinodelphys
11?2?141010140211011110014210301300111 0?0000110001000000?013021013120310
211001211112215120103211221022022221121110002111121001202221110011100000
010000000002222211101117100????????0??????0???????0???0??????????????????
??????????????????????????????????????0??????????????????2???????????????
???????????0???111003?201120112231112 5????1101002?24110101013?????101102
100101000111111?????????21?1???????????02?111?1000021?0101100120 1?1002031
01100021011111??21?????????
Didelphis
11?2?141010141211011110014210301300111 0?0002100010000000?013021013020310
211001011112215120103211221022022221120?0000211112200120222111001110000 0
010000000002222211101112100???????201111100111101201?101123101111012111 1
112{01}022112121102111220000000111011011100000012130101012422021110212 32
011110110210010200111003020112011123111251111111100212311{01}101013????? 
101102000001011110111112131112121011100221200201112100002100101100120101
002031001000211111110121011223002
Marmosa
11?2?141010141211011110014210301300111 0?0002100010000000?013021013020310
211001111112115120103212221022022221120?0000211112100120222111001110000 0
010000000102222210001112100????????011111001111012 01?101123101111012111 1
112002211212110211122000000011101101110000001213010101242202111021222011
110110210010200111003020112011123111251111111100212311110101 3?????101102
000001011110111112131112121011100221200201112100002100101101120101002031
121100211111110121011223002
Caenolestes
11???141010142110111100142103013001110?????????????????0?0?3021013020310
211001111113215120103212221022022221120?001021010210012022211100111?0001
010000000002222210100202100????0???011111001111012 01?101123101111012111 1
112002211212110211122000000011101101110000?01213020?012422010110212210 11
110002101002001110030201120?112311125111111130 02?2311010101 3?????10?102
000000021110111112131??211101110032120020111310000 21?01011?0120101002032
??10002111?220121???223002
Dasyurus
11?2?141010140211011110014210301300111 0?00{01}021000100000?013021013020
310211001111112215120103212221122022221120?001021010220012022211100111 00
001020000000003322311000112100????????011111001111012 01?101123101111012 1
111120022112121102111220000000111011011100 00?012131201012510010121213?1
011110000210100200111003020112011323111251111111300212310110101 3?????101
102000001021110111121?131??211101110042120020111112000211010110112010100 2
032011000211111101210112230 02
Perameles
11???141010141211011110014210301300111 0?????????????????0?0?3021013020210
211001211113215120003212221022022221120?001021010220012022211100111?0000
020000000002222210100212101????????011111001111012 01?101123101111012111 1
112002211212110211122000000011101101100100?01213020?112510020121213?1011
110100200100201111003020112021123111251111111300 2?2311410101 3?????101102
000001021110111112131??211101110042120020111120000210010110112010100 2032
121000211101101 21???223001
Dromiciops
1112?141010140211011110014210301300111 0?0002100010000000?013021013020310
211001101113205120103212221122022221120?000000011210012022211100111000 00
010000000102222210100212100????????011111001111012 01?101123101111012111 1
112002211212110211122000000011101101110000?01213020?112510020121213?2011
110100210010200111003020112011123111251111111300 2?231?4101013?????101102
000001021110011102131??212201110032130020111110000311010110012 0?01002032
121100210111101210112230 02
```

Thylacomyidae
111??14101014?2110111100142103013001110?????????????????0?0?30??????????
???001??11132??1????3???4????2042??1120?00100001?2?01120222101???1100000
02000000???222221??0?2?210??????????011111001111012O1?10112310111101211?1
11200221121111021112200000001110110111000?012130?0????2510020121213???11
??0?002?0?00201111003O2?112?113231112511111113002?2310?101013?????101102
?0000102?1???11??2131??21??0?1100421?0020111?1000021?01011?012?101?020?2
??1?0021?1???0121???22300?
Macropus
111??14101014021101111001421030130011l0?????????????????0?0?3?25313130300
20000133011320413100431240O?32042211120?00100000?2300120222101110110???2
0400001????33223 2?1102021 12?1?10???0111110011110120 1?10123101111012 1111
11200221121111021112200100001110110111000?0121312O?1125100101212 13?1011
11010020000020111100302111313032311125111111300 2?2311410101 3?????101102
00000103111001111213 1??2122011100521300201111110013110101100120101003032
121100210 1?0{012}0121???223002
Acrobates
111??14101014121101111001421030130011l0?????????????????0?0?3?35313130210
20000101011321512000421242O?32042211120?00100001121001202221010011 10???0
03000000010222231000020211 0????????0111110011110120 1?10123101111012 1111
11200221121111021112200000001110110111000?01213020?1125100201212 13?2?11
1101002?0?10201111003021113130323111251111111300 2?2311410101 3?????101102
00000101111011120213 1??212?1111005213102011131000031110101100120101002032
12110021111120121???223002
Phascolarctos
111??13101014021101111001421030130011 00?????????????????0?0?3?35313130320
20000133011320413000431242O?32042211120?00100100?2301120222101110110???2
04000010???33223 3?20010211 1????????0111110011110120 1?10123101111012 1111
11200221121111021112200100001110110111000?01213020?1125100201212 13?1011
11010021001020112100302111001032311125111111300 2?2311410101 3?????101102
00000102111011111213 1??2112011100321300201113110014100101110120101003032
01100021111020121???223002
Vombatus
111??14101014021101111001421030130011 00?????????????????0?0?3?35313130320
20000133011320413100431242O?32032211120?00100000?2301120222101110110???3
04010120???33223 3?201?02112????????0111110011110120 1?10123101111012 1111
11200221121111021112200100001110110110010 0?01213020?1125100201212 13?1011
11010021001020112100302111 0?003231112511111113002?2302310101 3?????101102
00000101111001111213 1??2112011100521300201113100014110101100120101003032
02100021111001121???223002
Phalanger
111??14101014021101111001421030130011l0?????????????????0?0?3?35313130320
20000133001321512000431242O?32042211120?00100100?2300120222101110110???2
03000000010222222021020211 1????????0111110011110120 1?10123101111012 1111
11200221121111021112200000001110110111000?01213020?1125100201212 13?2011
11010021001020112100302111313032311125111111300 2?2311410101 3?????101102
00000103111001111213 1??2122111100521310201113110013100101100120101003032
02100021111120121???223002
Pseudocheirus
111??14101014021101111001421030130011l0?????????????????0?0?3?35313130320
20000133001320413000421242O?32042211120?00100100?2301120222101110110???2
03000010010332232000020211 1????????0111110011110120 1?10123101111012 1111
11200221121111021112200000001110110111000?01213020?1125100201212 13?2011
11010021001020112100302111313032311125111111300 2?2311410101 3?????101102
00000103111001121213 1??2122111100521310201112100003110101100120101012032
12100021111120121???223002
Petauroides
111??14101014021101111001421030130011l0?????????????????0?0?3?35313130320
20000133001320413000421242O?32042211120?00100100?2300120222101110110???2
03000000010332232000020211 1????????0111110011110120 1?10123101111012 1111
11200221121111021112200000001110110111000?01213120?1125100201212 13?2011

```
1101002100102011210030211131303231112511111113002?23114101013?????101102
0000010311100112121 31??212211110052131020111210000211010110012010101203 2
12110021011120121???223002
;
END;


BEGIN ASSUMPTIONS;
     OPTIONS  DEFTYPE=unord PolyTcount=MAXSTEPS ;
END;


BEGIN TREES;

     TRANSLATE
          1     Thrinaxodon,
          2     Massetognathus,
          3     Probainognathus,
          4     Tritylodontids,
          5     Pachygenelus,
          6     Adelobasileus,
          7     Sinoconodon,
          8     Morganucodon,
          9     Megazostrodon,
          10    Haldanodon,
          11    Castorocauda,
          12    Hadrocodium,
          13    Shuotherium,
          14    Pseudotribos,
          15    Asfaltomylos,
          16    Ambondro,
          17    Ausktribosphenos,
          18    Bishops,
          19    Teinolophos,
          20    Steropodon,
          21    Obdurodon,
          22    Ornithorhynchus,
          23    Tachyglossus,
          24    Fruitafossor,
          25    Gobiconodon,
          26    Repenomamus,
          27    Amphilestes,
          28    Yanoconodon,
          29    Jeholodens,
          30    Trioracodon,
          31    Priacodon,
          32    Haramiyavia,
          33    Rugosodon,
          34    Kuehneodon,
          35    Sinobaatar,
          36    Plagiaulacidans,
          37    Cimolodontans,
          38    Tinodon,
          39    Akidolestes,
          40    Spalacotherium,
          41    Zhangheotherium,
          42    Maotherium,
          43    Dryolestes,
          44    Henkelotherium,
          45    Amphitherium,
          46    Peramus,
```

```
      47    Vincelestes,
      48    Nanolestes,
      49    Kielantherium,
      50    Aegialodon,
      51    Montanalestes,
      52    Prokennalestes,
      53    Murtoilestes,
      54    Eomaia,
      55    Juramaia,
      56    Kennalestes,
      57    Asioryctes,
      58    Ukhaatherium,
      59    Zalambdalestes,
      60    Daulestes,
      61    Aspanlestes,
      62    Eoungulatum,
      63    Cimolestes,
      64    Gypsonictops,
      65    Protungulatum,
      66    Erinaceus,
      67    Lepticti s,
      68    Canis,
      69    Felis,
      70    Rattus,
      71    Oryctolagus,
      72    Bradypus,
      73    Tamandua,
      74    Glyptotherium,
      75    Dasypus,
      76    Chaetophractus,
      77    Euphractus,
      78    Holoclemensia,
      79    Sinodelphys,
      80    Deltatheridium,
      81    Atokatheridium,
      82    Sulestes,
      83    Asiatherium,
      84    Kokopellia,
      85    Anchistodelphys,
      86    Albertatherium,
      87    Didelphodon,
      88    Pediomys,
      89    Turgidodon,
      90    Mayulestes,
      91    Pucadelphys,
      92    Andinodelphys,
      93    Didelphis,
      94    Marmosa,
      95    Caenolestes,
      96    Dasyurus,
      97    Perameles,
      98    Dromiciops,
      99    Thylacomyidae,
     100    Macropus,
     101    Acrobates,
     102    Phascolarctos,
     103    Vombatus,
     104    Phalanger,
     105    Pseudocheirus,
     106    Petauroides
;
```

```
      TREE 'Jura-Eutherians' =  [&R]
(1,(2,(3,(4,(5,(6,(7,((8,9),((10,11),(12,(((((((((22,21),23),19),20),18,
17),16),15),(13,14)),(24,(38,((((28,29),(30,31)),27),(25,26)),((37,36),3
2),(((40,39),(41,42)),(43,44,(45,47,(46,48,((49,50),((51,55,(52,(53,54))
,(60,((58,(57,56)),((63,64),(59,(67,((65,(61,62)),(66,((71,70),((69,68),
(72,73,(74,(75,(76,77)))))))))))))),(79,78,((80,81),(82,(84,(83,(86,87,8
8,89,85,90,(91,92,(94,93,(95,(96,97,(98,(99,(101,(104,106,105,(100,(102,
103))))))))))))))))))))))))))))))));
      TREE 'Jura-Boreo' =  [&R]
(1,(2,(3,(4,(5,(6,(7,((8,9),((10,11),(12,(((((((((22,21),23),19),20),18,
17),16),15),(13,14)),(24,(38,((((28,29),(30,31)),27),(25,26)),((37,36),3
2),(((40,39),(41,42)),(43,44,(45,47,(46,48,((49,50,55),((51,(52,(53,54))
,(60,((58,(57,56)),((63,64),(59,(67,((65,(61,62)),(66,((71,70),((69,68),
(72,73,(74,(75,(76,77)))))))))))))),(79,78,((80,81),(82,(84,(83,(86,87,8
8,89,85,90,(91,92,(94,93,(95,(96,97,(98,(99,(101,(104,106,105,(100,(102,
103))))))))))))))))))))))))))))))));
      TREE 'Jura-boreo-poly' =  [&R]
(1,(2,(3,(4,(5,(6,(7,((8,9),((10,11),(12,(((((((((22,21),23),19),20),18,
17),16),15),(13,14)),(24,(38,((((28,29),(30,31)),27),(25,26)),((37,36),3
2),(((40,39),(41,42)),(43,44,(45,47,(46,48,(55,49,50,((51,(52,(53,54)),(
60,((58,(57,56)),((63,64),(59,(67,((65,(61,62)),(66,((71,70),((69,68),(7
2,73,(74,(75,(76,77)))))))))))))),(79,78,((80,81),(82,(84,(83,(86,87,88,
89,85,90,(91,92,(94,93,(95,(96,97,(98,(99,(101,(104,106,105,(100,(102,10
3))))))))))))))))))))))))))))))));
      TREE  * 'Jura-Metatherian' =  [&R]
(1,(2,(3,(4,(5,(6,(7,((8,9),((10,11),(12,(((((((((22,21),23),19),20),18,
17),16),15),(13,14)),(24,(38,((((28,29),(30,31)),27),(25,26)),((37,36),3
2),(((40,39),(41,42)),(43,44,(45,47,(46,48,((49,50),((51,(52,(53,54)),(6
0,((58,(57,56)),((63,64),(59,(67,((65,(61,62)),(66,((71,70),((69,68),(72
,73,(74,(75,(76,77)))))))))))))),(79,78,55,((80,81),(82,(84,(83,(86,87,8
8,89,85,90,(91,92,(94,93,(95,(96,97,(98,(99,(101,(104,106,105,(100,(102,
103))))))))))))))))))))))))))))))));

END;


BEGIN MacClade;
      Version 4.0  84;
      LastModified -849625102;
      FileSettings editor  '0' '0' '1' '1';
      Singles 100;
      Editor 000110011111111100100010001 '0' '24' Geneva '9' '124' '1'
all;
      EditorPosition  '58' '49' '339' '1371';
      TreeWindowPosition  '46' '6' '835' '1390';
      ListWindow Characters closed Geneva '9' '50' '10' '257' '497' 000;
      ListWindow Taxa closed Geneva '9' '101' '73' '273' '285' 100000;
      ListWindow Trees closed Geneva '9' '48' '173' '129' '379' ;
      ListWindow TypeSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow WtSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow ExSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow CharSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow TaxSets closed Geneva '9' '50' '10' '129' '177' ;
      ListWindow CharPartitions closed Geneva '9' '50' '10' '276'
'490' ;
      ListWindow CharPartNames closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow WtSets closed Geneva '9' '50' '10' '276' '490' ;
      ChartWindowPosition  '52' '30' '686' '964';
      StateNamesSymbols closed Geneva '9' '10' '504' '376' '192' '580';
      WindowOrder  Data;
      OtherSymbols &/ 00 ?-;
```

```
      Correlation  '0' '0' '1000' '0' '0' 10011010;
      Salmo 00000001;
      EditorFile  '2';
      ExportHTML _ MOSS  '100' 110000;
      PrettyPrint 10;
      EditorToolsPosition  '443' '84' '115' '192';
      TreeToolsPosition  '724' '9' '126' '138';
      TreeWindowProgram 10;
      TreeWindow 0000;
      Continuous  '0' '3' 1;
      Calculations 0000001;
      SummaryMode  '0' '0' 0;
      Charts  Geneva '9' (normal) 0010;
      NexusOptions  '0' '0' '50' 001011001;
      TipLabel  '1';
      TreeFont  Geneva '9' (normal);
      TreeShape  1.0 1.0 0100;
      TraceLabels 0101;
      ChartColors  '0' '0' '65535' '9' '0' 1;
      ChartBiggestSpot 1;
      ChartPercent 10;
      ChartBarWidth  '10' 1;
      ChartVerticalAxis 10101;
      ChartMinMax  '0';
      TraceAllChangesDisplay  '1' 1;
      BarsOnBranchesDisplay  '0' '0' '60000' '10000' '10000' '10000'
'10000' '60000' '65000' '65000' '65000' '6' '1' 0000101;
      ContinuousBranchLabels 0;
      AllStatesBranchLabels 1;
      IndexNotation  '2' 1;
      PrintTree  10.00 '2' '2' '2' '2' '2' '2' '2' '2' '2' '2' '2'
Geneva '9' (normal) Geneva '10' (normal) Geneva '9' (normal) Geneva '9'
(normal) Geneva '9' (bold ) Geneva '9' (normal) Geneva '9' (normal) '0'
'0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'
'0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '1' '1' '1' '1' '30' '243'
'-39' '4' '-40' '0' '1' '2' '1' '8' '0' '0' '0' '2'
1000111000000000000100000111000;
      MatchChar 00 .;
      EntryInterpretation 01;
      ColorOptions 00;
      TreeTools  '0' '5' '4' '0' '10' '4' '0' 00100111111101110;
      EditorTools  '0' '0' '0' '1000' '0' '0' '7' '3' '0'
100000101110001;
      PairAlign  '2' '2' '3' '2' '1' '1' '2' '1' '3' 1010;
      BothTools  '1';
END;
```

```
#NEXUS
[MacClade 4.06 registered to Zhe-Xi Luo, Carnegie Museum of Natural
History
Carnegie Museum of Natural Hi]


BEGIN TAXA;
      DIMENSIONS  NTAX=41;
      TAXLABELS
      Ancestor
      Sinoconodon
      Morganucodon
      Thomasia
      Haramiyavia
      Meketichoffatia
      Henkelodon
      Rugosodon
      Paulchoffatia
      Meketibolodon
      Guimarotodon
      Kuehneodon
      Ctenacodon
      Glirodon
      Bolodon
      Plagiaulax
      Zofiabaatar
      Sinobaatar
      Eobaatar
      Arginbaatar
      Cimexomys
      Boffius
      Meniscoessus
      Buginbaatar
      Cimolodon
      Ectypodus
      Mesodma
      Ptilodus
      Neoliotomus
      Pentacosmodon
      Catopsbaatar
      Kamptobaatar
      Chulsanbaatar
      Kryptobaatar
      Nemegtbaatar
      Eucosmodon
      Stygimys
      Microcosmodon
      Lambdopsalis
      Taeniolabis
      Kogaionon;
END;


BEGIN CHARACTERS;
      DIMENSIONS  NCHAR=102;
      FORMAT SYMBOLS= " 0 1 2 3" MISSING=? GAP=- ;
      CHARSTATELABELS
           1  Postdent_trough,  2  'Meckel''s sulcus',  3
Masset_extension,  4  'Corod-Co-scar',  5  CoroProAngle,  6  CorodFlare,
  7  'De-Mgn-molar alveoli',  8  'D-Peduncle',  9  'D-Condyle level',
10  Mandibular_angle,  11  LwIncisor#,
```

```
  12  lwInc1_procumbe,  13  incis1_root,  14  'Inc-Ca diastema',  15
LwrIncis1_thickness,  16  Incis1_enamel,
  17  UpIncisor_#,  18  'NewI2-3 distama',  19  Incis2_cusp#,  20
Incis3_cusp#,  21  Incis3_position,
  22  'UpCanine P-A',  23  UpCanine_cusp#,  24  'LwCanine P/A',  25
'I3-P diastema ratio',  26  UpPremol#,
  27  AntUpPrmRoots,  28  LabCusplUpPrem,  29  'UpPm/M ratio',  30
LastUP_row_#,  31  P4_CuspFormula,
  32  P4M1_width,  33  'lwp1 Prs/Absen',  34  'lwp2 Prs/Absen',  35
'lrp3 Prs/Abs',  36  p3_bladelike,
  37  'lwp3 CuspP/A',  38  'lw-p3 shape',  39  lwp3_basalcusps,  40
'Staged p3/p4',  41  'lrp4 blade-like',
  42  lwp4_shape,  43  lrp4Serrat#,  44  p3_rt_exodeanodont,  45
top_of_p4_to_m1,  46  'lwp3/p4 ratio',
  47  lwp4_basal_cusps,  48  'p4/m1 length ratio',  49  #Lmolars,  50
#Up_molars,  51  #UpPC_loci,
  52  #LwPC_loci,  53  'U-ridge',  54  lm1_Cusheight_ratio,  55  'UpM
cusp h-ratio',  56  M1_cusp_formula,
  57  'M1PLwin P-A',  58  M1PLwin_length,  59  M1PLwin_shape,  60  'M2
off-set',  61  UM2Cusp#,
  62  'M1 midvaly-anterior',  63  'M1MidVal-Posterior',  64  'M2
LingRow-Curv',  65  'M2-MidVal-cusp',  66  M2_AB_ridge,
  67  'lm1-cusp#',  68  open_m1,  69  m2_mid_valley,  70  'lm -labial
coalescences',  71  LwM2_basin_rim,
  72  'lm2-cusp#',  73  lm2_row_ratio,  74  mol_cusp_shapes,  75
m1_trenchant_cusp,  76  Molar_ornament,
  77  Enamel_Structure,  78  'Premo-Mo diff',  79  Diphyodont_teeth,  80
Infraorb_foramen,  81  PalatVacuities,
  82  Pmx_ridge,  83  'Snout-Zygoma',  84  Nasal_foramina,  85
IfOrbF_position,  86  ZygoPostRidge,
  87  'Orbit-Roof',  88  PostOrb_Process,  89  Snout_length,  90
'Nasal-Frt suture',  91  'Frt-Par suture',
  92  'Nasal-Parietal',  93  Lacrml_facial,  94  ThickPmx,  95
IncisFor,  96  Fovale_position,
  97  Jugul_fossa,  98  Promontorium,  99  Glenoidlength,  100
PTC_size,  101  'Snout w/l ratio',
  102  'Skull-W-L ratio'
          ;

MATRIX
[                          10        20        30        40        50
60        70        80        90        100]
[                         .         .         .         .         .
     .         .         .         .         .  ]

Ancestor           0000000000000000000000000000000?0000??0-000-
0000000?0???0?00??0000??0?0?0000000000000000000000000000
Sinoconodon
0000000000000000000000000002?00000000?000?00100??0000?0???0100??0000???
???000000001000010000007000000
Morganucodon
0000000000000000000000000002?00000000?000?001000000007?0???0100??0000???
???00110000000001000000?000000
Thomasia           ??????????01??000?00?????3002001??0000?001?0010000??1
0000??0113000?2002000?1?????????????????????
Haramiyavia
000?10000001000001000100????????000000?000?00?000000100007?0113001012002
000011????????0?????????????
Meketichoffatia    ??????????????????????11?00010000?????????????????11??
?000??1?11?????????????1?1?0000??00?00????11000?10
```

```
Henkelodon         ?????????????????01202??00010000?????????????????1??
?010??1?12?????????????1?110?????????????????????
Rugosodon
111?1?0101111100101101111000?00??0001?1?011001??1111110010??1011112022110
00111110????0???0???11????????
Paulchoffatia
111?100101110100???????1????????00010100110010211??110?????????????022110
002111?????????????????????????
Meketibolodon
1111100101110100???????1????????00010100110010 3?????????????????????2???0
??21?1?????????????????????????
Guimarotodon
1111100101110100???????1????????00010100110010311??110?????????????022110
002111?????????????????????????
Kuehneodon
1110100101111100101201110101000000010100110010211121100 10??1012112022111
00{12}11110??????0?????????????????
Ctenacodon
11110?1111111100101101?100010100000101101100112111110101100102300101100 1
100001?0??0??0???????????????????
Glirodon
1111001111111101101101010001010000?0110110011211111010 10??1023001011001
100001?00101100??0?0??1???????
Bolodon
11111?11??111?00?????1?1?00101000001021011001 12?1111010110010230010?1??1
100101?00???1?????????????????
Plagiaulax
1111001111111100???????1????????10010210111 0?12?1??101????????????1011001
1?0001?????????????????????????
Zofiabaatar
111100111111?10?????????????????00010110110011231??101????????????10?1001
100001?????????????????????????
Sinobaatar
11110?1101111100210 1?2?10000020110011210121112121112011111011230010111 01
100101110 1?1010?????1????????
Eobaatar
11?1???1?1111101???????1?0000001100102101211?21?1112011111011230010111 01
100111?????????????????????????
Arginbaatar        ?1210??1??111100???????1?0000001100012111221120311120
1?1100102300101100110001 1?0?????????????????????
Cimexomys
1121?????1111100???????1?10012121000131112110302112201111221123001111001
100111?1???101?????????????????
Boffius            ?????????????012?????????????11?????????????????1????
???1231?23??1??????1?0011?????????????????????????
Meniscoessus
11211?01?1111100211112?1210022021100131112110300112201111231223001 1?1002
110111?0210?01???????01???????
Buginbaatar
1111100 1??11?100???????????0?213111?????12000?0011?2011111313230012?1001
1000?1?????????????????????????
Cimolodon
11210?01?11111?0??????2?1?10012111100131112211201112201111221223001211002
1001111?????????????????????????
Ectypodus
11210?0111111110210112?10100122111001311122113031122011111311231012110 02
100121111?2?010?0??0??11001?10
Mesodma
11211?01?1111110 2?1112?1?100?2111100131112211301112201111131123001211001
100121111?????????????????????????
```

```
Ptilodus
112100010111111021011 2?10100022111001311122113021122011111311231012110021
10012111110200 0?00000010001010
Neoliotomus
11211?01?1111101??0????1?10012211100131112211303112201111231123001211002
110121?????????????????????????
Pentacosmodon
112?00111111110 1???????1????????1110???11201 0?1011?201?????????????011001
100011???2?????????????????????
Catopsbaatar
11210011111111012101 22?10200221211001311110003021132011112310230010110 01
100011?10222011111101 10?110001
Kamptobaatar
11211101111111012101 22?10100121211001311121103011122011110111230010110 01
100011?10203201001101110100010
Chulsanbaatar
11211011011111012101 22?10100121211001311121103011122011110111230010110 01
10001111020220100110111 1100010
Kryptobaatar
11211001011111012101 22?10100121211001311121103011122011110212230010110 01
10001111022210111110111 1110001
Nemegtbaatar
11211001011111012101 22?11100121211001311121103011122011111221230010110 01
10001111220310100110111 0100010
Eucosmodon
11211?11011111012?11?2?1?200?2??111?????12210?01112201111??1?23??1111002
100011?1?????????????????????
Stygimys
11111001011111012111 12?11001221111?????12210?11112201111 1{23}1123001211
00110011?1210?20????????11???????
Microcosmodon
112?0?01111111012111 12?10100121211001211120 10?12112201111131123001211001
1000?11??1????0?????????????????
Lambdopsalis
11210110111111012101 12?12310230311 1?????13000?00113201111231123001111002
11001111011301 0?0201001?111111
Taeniolabis
11210001111111012101 12?12310230311 1?????13000?00113201111231223001211002
10001111011 30?0?020100?????111
Kogaionon          ??????????????????210112??1100030 1?????????????????12??
?111221023001?????????0?1?101130000000??1?1?1?10
;
END;


BEGIN ASSUMPTIONS;
      OPTIONS  DEFTYPE=unord PolyTcount=MINSTEPS ;
      TYPESET * UNTITLED  = unord: 1-16 18-28 30 33-42 44-45 50 53-54
56-57 60 62-71 73-74 76-84 86-102, ord: 17 29 31-32 43 46-49 51-52 55
58-59 61 72 75 85;
END;


BEGIN MacClade;
      Version 4.0  84;
      LastModified -848836092;
      FileSettings editor  '0' '0' '77' '1';
      Singles 000;
      Editor 000110011111111 10010001001 '1' '12' Geneva '9' '86' '1' all;
      EditorPosition  '100' '120' '755' '925';
      TreeWindowPosition  '46' '6' '835' '1390';
```

```
      ListWindow Characters closed Geneva '9' '50' '10' '129' '449' 100;
      ListWindow Taxa closed Geneva '9' '50' '10' '129' '490' 100000;
      ListWindow Trees closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow TypeSets closed Geneva '9' '50' '10' '129' '277' ;
      ListWindow WtSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow ExSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow CharSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow TaxSets closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow CharPartitions closed Geneva '9' '50' '10' '276'
'490' ;
      ListWindow CharPartNames closed Geneva '9' '50' '10' '276' '490' ;
      ListWindow WtSets closed Geneva '9' '50' '10' '276' '490' ;
      ChartWindowPosition  '52' '30' '772' '1220';
      StateNamesSymbols closed Geneva '9' '10' '50' '30' '192' '220';
      WindowOrder  Data;
      OtherSymbols &/ 00 ?-;
      Correlation  '0' '0' '1000' '0' '0' 10011010;
      Salmo 00000001;
      EditorFile  '2';
      ExportHTML _ MOSS  '100' 110000;
      PrettyPrint 10;
      EditorToolsPosition  '90' '1264' '115' '165';
      TreeWindowProgram 10;
      TreeWindow 0000;
      Continuous  '0' '3' 1;
      Calculations 0000001;
      SummaryMode  '0' '0' 0;
      Charts  Geneva '9' (normal) 0010;
      NexusOptions  '0' '0' '50' 001011011;
      TipLabel  '1';
      TreeFont  Geneva '9' (normal);
      TreeShape  1.0 1.0 0100;
      TraceLabels 0101;
      ChartColors  '0' '0' '65535' '9' '0' 1;
      ChartBiggestSpot 1;
      ChartPercent 10;
      ChartBarWidth  '10' 1;
      ChartVerticalAxis 10101;
      ChartMinMax  '0';
      TraceAllChangesDisplay  '1' 1;
      BarsOnBranchesDisplay  '0' '0' '60000' '10000' '10000' '10000'
'10000' '60000' '65000' '65000' '65000' '6' '1' 0000101;
      ContinuousBranchLabels 0;
      AllStatesBranchLabels 1;
      IndexNotation  '2' 1;
      PrintTree  10.00 '2' '2' '2' '2' '2' '2' '2' '2' '2' '2' '2'
Geneva '9' (normal) Geneva '10' (normal) Geneva '9' (normal) Geneva '9'
(normal) Geneva '9' (bold ) Geneva '9' (normal) Geneva '9' (normal) '0'
'0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0'
'0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '0' '1' '1' '1' '1' '-24143' '-
15917' '-39' '4' '-40' '0' '1' '2' '1' '8' '0' '0' '0' '2'
1000111000000000000100000111000;
      MatchChar 00 .;
      EntryInterpretation 01;
      ColorOptions 00;
      TreeTools  '0' '5' '4' '0' '10' '4' '0' 00100111111101110;
      EditorTools  '0' '0' '0' '1000' '0' '0' '6' '3' '0'
100000101110001;
      PairAlign  '2' '2' '3' '2' '1' '1' '2' '1' '3' 1010;
      BothTools  '1';
END;
```

Full Reference List

1. Z. Kielan-Jaworowska *et al*., *Mammals from the Age of Dinosaurs; Origins, Evolution, and Structure* (Columbia Univ Press, New York, 2004).

2. G. P. Wilson, A. R. Evans, I. J. Corfe, P. D. Smits, M. Fortelius, J. Jernvall, Adaptive radiation of multituberculate mammals before the extinction of dinosaurs. *Nature* **483**, 457–460 (2012). doi:10.1038/nature10880 Medline

3. G. Hahn, R. Hahn, in *Guimarota: A Jurassic Ecosystem*, T. Martin, B. Krebs, Eds. (Verlag Dr. Friedrich Pfeil, München, 2000), pp. 97–108.

4. P. M. Butler, Review of the early allotherian mammals. *Acta Palaeontol. Pol.* **45**, 317–342 (2000).

5. P. M. Butler, J. J. Hooker, New teeth of allotherian mammals from the English Bathonian, including the earliest multituberculates. *Acta Palaeontol. Pol.* **50**, 185–207 (2005).

6. K. D. Rose, *The Beginning of the Age of Mammals* (Johns Hopkins Univ. Press, Baltimore, 2006).

7. F. A. Jenkins, Jr., D. W. Krause, Adaptations for climbing in North American multituberculates (Mammalia). *Science* **220**, 712–715 (1983). doi:10.1126/science.220.4598.712 Medline

8. D. W. Krause, F. A. Jenkins, The postcranial skeleton of North American multituberculates. *Bull. Mus. Compar. Zool.* **150**, 199–246 (1983).

9. Z. Kielan-Jaworowska, P. P. Gambaryan, *Postcranial Anatomy and Habits of Asian Multituberculate Mammals: Fossils and Strata no. 36* (Scandinavian Univ. Press, Oslo, Copenhagen, Stockholm, 1994).

10. F. S. Szalay, *Evolutionary History of the Marsupials and an Analysis of Osteological Characters* (Cambridge Univ. Press, Cambridge, 1994).

11. Materials and methods are available as supplementary materials on *Science* Online.

12. Y.-Q. Liu *et al*., Timing of the earliest known feathered dinosaurs and transitional pterosaurs older than the Jehol Biota. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **323–325**, 1–12 (2012); doi:dx.doi.org/10.1016/j.palaeo.2012.01.017

13. Z.-X. Luo, C. X. Yuan, Q. J. Meng, Q. Ji, A Jurassic eutherian mammal and divergence of marsupials and placentals. *Nature* **476**, 442–445 (2011). doi:10.1038/nature10291 Medline

14. Z.-X. Luo, Q. Ji, C. X. Yuan, Convergent dental adaptations in pseudo-tribosphenic and tribosphenic mammals. *Nature* **450**, 93–97 (2007). doi:10.1038/nature06221 Medline

15. G. W. Rougier *et al*., *Am. Mus. Novit.* **3193**, 1–12 (1997).

16. Z. Kielan-Jaworowska, J. H. Hurum, Phylogeny and systematics of multituberculate mammals. *Palaeontology* **44**, 389–429 (2001). doi:10.1111/1475-4983.00185

17. G. Hahn, R. Hahn, New observations on Plagiaulacoidea (Multituberculata) of the Upper Jurassic. 3. The construction of the molars of Paulchoffatiidae. *Berliner Geowissen. Abhand. E* **28**, 39–84 (1998).

18. R. L. Cifelli, C. L. Gordon, T. R. Lipka, C. S. Scott, New multituberculate mammal from the Early Cretaceous of eastern North America. *Can. J. Earth Sci.* **50**, 315–323 (2013). doi:10.1139/e2012-051

19. A. Badiola, J. I. Canudo, G. Cuenca-Bescós, A systematic reassessment of Early Cretaceous multituberculates from Galve (Teruel, Spain). *Cretac. Res.* **32**, 45–57 (2011). doi:10.1016/j.cretres.2010.10.003

20. N. Kusuhashi, Y. Hu, Y. Wang, T. Setoguchi, H. Matsuoka, Two Eobaatarid (Multituberculata; Mammalia) genera from the Lower Cretaceous Shahai and Fuxin Formations, northeastern Chinau. *J. Vertebr. Paleontol.* **29**, 1264–1288 (2009). doi:10.1671/039.029.0433

21. T. Martin, A. O. Averianov, H.-U. Pfretzschner, Mammals from the Late Jurassic Qigu Formation in the Southern Junggar Basin, Xinjiang, Northwest China. *Palaeodiversity Palaeoenvironment* **90**, 295–319 (2010). doi:10.1007/s12549-010-0030-4

22. N. S. Greenwald, Patterns of tooth eruption and replacement in multituberculate mammals. *J. Vertebr. Paleontol.* **8**, 265–277 (1988). doi:10.1080/02724634.1988.10011709

23. R. M. Nowak, *Walker's Mammals of the World: Vol. II (6th Edition)* (Johns Hopkins Univ. Press, Baltimore, 1999).

24. N. MacLeod, K. D. Rose, Inferring locomotor behavior in Paleogene mammals via eigenshape analysis. *Am. J. Sci.* **293**, (A), 300–355 (1993). doi:10.2475/ajs.293.A.300

25. F. S. Szalay, E. J. Sargis, Model-based analysis of postcranial osteology of marsupials from the Palaeocene of Itaboraí (Brazil) and the phylogenetics and biogeography of Metatheria**.** *Geodiversitas* **23**, 139–302 (2001).

26. E. C. Kirk, P. Lemelin, M. W. Hamrick, D. M. Boyer, J. I. Bloch, Intrinsic hand proportions of euarchontans and other mammals: implications for the locomotor behavior of plesiadapiforms. *J. Hum. Evol.* **55**, 278–299 (2008). doi:10.1016/j.jhevol.2008.02.008 Medline

27. V. Weisbecker, D. I. Warton, Evidence at hand: Diversity, functional implications, and locomotor prediction in intrinsic hand proportions of diprotodontian marsupials. *J. Morphol.* **267**, 1469–1485 (2006). doi:10.1002/jmor.10495 Medline

28. Q. Ji, Z. X. Luo, X. Zhang, C. X. Yuan, L. Xu, Evolutionary development of the middle ear in Mesozoic therian mammals. *Science* **326**, 278–281 (2009). doi:10.1126/science.1178501 Medline

29. P. C. Sereno, in *Amniote Paleobiology: Perspectives on the Evolution of Mammals, Birds, and Reptiles*, M. T. Carrano *et al.* , Eds. (Univ. Chicago Press, Chicago, 2006) 315–370.

30. Z.-X. Luo, J. R. Wible, A Late Jurassic digging mammal and early mammalian diversification. *Science* **308**, 103–107 (2005). doi:10.1126/science.1108875 Medline

31. M. Chen, Z.-X. Luo, Postcranial skeleton of the Cretaceous mammal *Akidolestes cifellii* and its locomotor adaptations. *J. Mamm. Evol.* **20**, 159–189 (2013). doi:10.1007/s10914-012-9199-9

32. N. B. Simmons, Phylogeny of multituberculata, in F. S. Szalay, M. J. Novacek, M. C. McKenna, Eds., *Mammal Phylogeny: Mesozoic Differentiation, Multituberculates, Monotremes, Early Therians, and Marsupials* (Springer-Verlag, New York, 1993), pp. 146–164.

33. A. Weil, A new species of *Microcosmodon* (Mammalia: Multituberculata) from the Paleocene Tullock Formation of Montana, and an argument for the Microcosmodontinae. *PaleoBios* **18**, 1–15 (1998).

34. S.- Chang, H. Zhang, P. R. Renne, Y. Fang, High-precision 40Ar/39Ar age constraints on the basal Lanqi Formation and its implications for the origin of angiosperm plants. *Earth Planet. Sci. Lett.* **279**, 212–221 (2009). doi:10.1016/j.epsl.2008.12.045

35. F. A. Jenkins, Jr., S. M. Gatesy, N. H. Shubin, W. W. Amaral, Haramiyids and Triassic mammalian evolution. *Nature* **385**, 715–718 (1997). doi:10.1038/385715a0 Medline

36. Z. Kielan-Jaworowska, D. Dashzeveg, B. A. Trofimov, Early Cretaceous multituberculates from Mongolia and comparison with Late Jurassic forms. *Acta Palaeontol. Pol.* **32**, 3–47 (1987).

37. N. Kusuhashi, Early Cretaceous multituberculate mammals from the Kuwajima Formation (Tetori Group), central Japan. *Acta Palaeontol. Pol.* **53**, 379–390 (2008). doi:10.4202/app.2008.0302

38. Y. Hu, *Sinobataar* gen. nov.: First multituberculate from Jehol Biota of Liaoning, Northeast China. *Chin. Sci. Bull.* **47**, 933–938 (2002). doi:10.1360/02tb9209

39. G. Hahn, R. Hahn, Pinheirodontidae, n. fam. (Multituberculata, Mammalia) aus der tiefen Under-Krede Portugals. *Palaeont. Abteilung A* **253**, 7–222 (1999).

40. A. Badiola, J. I. Canudo, G. Cuenca-Bescós, New multituberculate mammals from the Heuterivian/Barremian transition of Europe (Iberian Pennisula). *Palaeontology* **51**, 1455–1469 (2008). doi:10.1111/j.1475-4983.2008.00822.x

41. G. Hahn, R. Hahn, Nomenklatorische Notiz: Namens-Änderung bei Multituberculata (Mammalia). *Geologica et Palaeontologica* **33**, 156 (1999).

42. Y.-Q. Liu, Y.-X. Liu, S. Ji, Z. Yang, U-Pb zircon age for the Daohugou Biota at Ningcheng of Inner Mongolia and comments on related issues. *Chin. Sci. Bull.* **51**, 2634–2644 (2006). doi:10.1007/s11434-006-2165-2

43. D. Ren, K. Gao, Z. Guo, S. Ji, J. Tan, Z. Song, Stratigraphic division of the Jurassic in the Daohugou area, Ningcheng, Inner Mongolia. *Geol. Bull. China* **21**, 584–588 (2002).

44. D. Hu, L. Hou, L. Zhang, X. Xu, A pre-*Archaeopteryx* troodontid theropod from China with long feathers on the metatarsus. *Nature* **461**, 640–643 (2009). doi:10.1038/nature08322 Medline

45. H. Zhang, M. X. Wang, X. M. Liu, Constraints on the upper boundary age of the Tiaojishan Formation volcanic rocks in West Liaoning-North Hebei by LA-ICP-MS dating. *Chin. Sci. Bull.* **53**, 3574–3584 (2008). doi:10.1007/s11434-008-0287-4

46. F. Gradstein, J. Ogg, A. Smith, *A Teologic Time Scale* (Cambridge Univ. Press, Cambridge, 2004).

47. J.-C. Lü, D. M. Unwin, X.-S. Jin, Y.-Q. Liu, Q. Ji, Evidence for modular evolution in a long-tailed pterosaur with a pterodactyloid skull. *Proc. Biol. Sci.* **277**, 383–389 (2010). doi:10.1098/rspb.2009.1603 Medline

48. Q. Ji, Z. X. Luo, C. X. Yuan, A. R. Tabrum, A swimming mammaliaform from the Middle Jurassic and ecomorphological diversification of early mammals. *Science* **311**, 1123–1127 (2006). doi:10.1126/science.1123026 Medline

49. J. Meng, Y. Hu, Y. Wang, X. Wang, C. Li, A Mesozoic gliding mammal from northeastern China. *Nature* **444**, 889–893 (2006). doi:10.1038/nature05234 Medline

50. P. D. Gingerich, B. H. Smith, Allometric scaling in the dentition of primates and insectivores, in W. L. Jungers, Ed., *Size and Scaling in Primate Biology* (Plenum Press, New York, 1984), pp. 257–272.

51. Z. X. Luo, A. W. Crompton, A. L. Sun, A new mammaliaform from the Early Jurassic and evolution of mammalian characteristics. *Science* **292**, 1535–1540 (2001). doi:10.1126/science.1058476 Medline

52. J. R. Foster, Preliminary mass estimates for mammalian genera of the Morrison Formation (Upper Jurassic; North America). *PaleoBios* **28**, 114–122 (2009).

53. D. W. Krause, Jaw movement, dental function, and diet in the Paleocene multituberculate Ptilodus. *Paleobiology* **8**, 265–281 (1982).

54. V. Lazzari, J. A. Schultz, P. Tafforeau, T. Martin, Occlusal pattern in Paulchoffatiid multituberculates and the evolution of cusp morphology in mammaliamorphs with rodent-like dentitions. *J. Mamm. Evol.* **17**, 177–192 (2010). doi:10.1007/s10914-010-9139-5

55. V. Weisbecker, S. Schmid, Autopodial skeletal diversity in hystricognath rodents: functional and phylogenetic aspects. *Mamm. Biol.* **72**, 27–44 (2007). doi:10.1016/j.mambio.2006.03.005

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

57. Y.-M. Hu, Postcranial morphology of Repenomamus (Eutriconodonta, Mammalia): Implications for the higher-level phylogeny of mammals. Ph.D. dissertation, City University of New York, 2006, pp. 1–405.

58. Z. X. Luo, P. Chen, G. Li, M. Chen, A new eutriconodont mammal and evolutionary development in early mammals. *Nature* **446**, 288–293 (2007). doi:10.1038/nature05627 Medline

59. Z.-X. Luo, Z. Kielan-Jaworowska, R. L. Cifelli, In quest for a phylogeny of Mesozoic mammals. *Acta Palaeontol. Pol.* **47**, 1–78 (2002).