Mandibular and dental characteristics of Late Triassic mammaliaform *Haramiyavia* and their ramifications for basal mammal evolution

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As one of the earliest-known mammaliaforms, *Haramiyavia clemmenseni* from the Rhaetic (Late Triassic) of East Greenland has held an important place in understanding the timing of the earliest radiation of the group. Reanalysis of the type specimen using high-resolution computed tomography (CT) has revealed new details, such as the presence of the dentary condyle of the mammalian jaw hinge and the postdentary trough for mandibular attachment of the middle ear—a transitional condition of the predecessors to crown Mammalia. Our tests of competing phylogenetic hypotheses with these new data show that Late Triassic haramiyids are a separate clade from multituberculate mammals and are excluded from the Mammalia. Consequently, hypotheses of a Late Triassic diversification of the Mammalia that depend on multituberculate affinities of haramiyidans are rejected. Scanning electron microscopy study of tooth-wear facets and kinematic functional simulation of occlusion with virtual 3D models from CT scans confirm that *Haramiyavia* had a major orthal occlusion with the tallest lingual cusp of the lower molars occluding into the lingual embrasure of the upper molars, followed by a short palinal movement along the cusp rows alternating between upper and lower molars. This movement differs from the minimal orthal but extensive palinal occlusal movement of multituberculate mammals, which previously were regarded as relatives of haramiyidans. The disparity of tooth morphology and the diversity of dental functions of haramiyids and their contemporary mammaliaforms suggest that dietary diversification is a major factor in the earliest mammaliaform evolution.

mammaliaform | haramiyid | occlusion | Rhaetic

Haramiyidans are among the first mammaliaforms to appear during the Late Triassic in the evolutionary transition from premammalian cynodonts. Their fossils have a cosmopolitan distribution during the Late Triassic to the Jurassic (1–8), tentatively with the youngest record in the Late Cretaceous of India (9). Most of these occurrences are of isolated teeth. For this reason, *Haramiyavia clemmenseni* (1) holds a special place in mammaliaform phylogeny: It is the best-preserved Late Triassic haramiyid with intact molars, nearly complete mandibles, and also postcranial skeletal elements (Figs. 1 and 2 and *SI Appendix*, Figs. S1–S4) (1). By its stratigraphic provenance from the Tait Bjerg Beds of the Fleming Fjord Formation, East Greenland (Norian-Rhaetic Age) (7), *Haramiyavia* is also the oldest known haramiyid (5, 7). Haramiyids, morganucodonts, and kuehneotheriids are the three earliest mammaliaform groups that are distinctive from each other in dental morphology and masticatory functions (10–12).

Haramiyids are characterized by their complex molars with longitudinal rows of multiple cusps. The cusp rows occlude alternately between the upper and lower molars. Primarily because of similarities in molar morphology, haramiyids are considered to be related to poorly known theroteinids of the Late Triassic (5, 13) and eleutherodontids of the Middle to Late Jurassic (14–17). Collectively haramiyids and eleutherodontids are referred to as "haramiyidans" (10, 14, 15, 18, 19). Recent discoveries of diverse eleutherodontids or eleutherodontid-related forms with skeletons from the Tiaojishan Formation (Middle to Late Jurassic) of China (18–20) have greatly augmented the fossil record of haramiyidans, ranking them among the most diverse mammaliaform clades of the Late Triassic and Jurassic.

Historically, it has been a contentious issue whether haramiyidans (later expanded to include theroteinids and eleutherodontids) are closely related to the more derived multituberculates from the Middle Jurassic to Eocene (13) or represent a stem clade of mammaliaforms excluded from crown mammals (21, 22). The conflicting placement of haramiyidans was attributable in part to the uncertainties in interpreting the isolated teeth of most Late Triassic haramiyids (21, 22). More recent phylogenetic disagreements have resulted from different interpretations of mandibular characters in *Haramiyavia* (17–20, 23–25), which has not been fully described (figure 2 in ref. 1).

Here we present a detailed study of the mandibles and teeth of *Haramiyavia* from the exhaustive documentation during initial fossil preparation (Fig. 1 and *SI Appendix*, Figs. S1–S4), from scanning electron microscopy (SEM) images, and from computed tomography (CT) scans and 3D image analyses of the two fossil slabs with mandibles (MCZ7/95A and B), plus a referred

Significance

The origins and earliest evolution of mammals can be deciphered by studying Late Triassic fossil relatives of modern mammals. The computed tomography study of *Haramiyavia* from the Late Triassic has revealed new information about the skull evolution and dental function in the forerunners of mammals. *Haramiyavia* had a unique way of chewing. Its teeth of multiple cusp-rows were adapted to omnivory or herbivory and are distinctive from the teeth of other early mammal relatives that are presumed to be insectivorous. On the mammal family tree *Haramiyavia* occupies a position crucial for dating the initial appearance of the major mammalian groups. Our reanalysis affirms that the earliest diversification of mammals occurred in the Jurassic.

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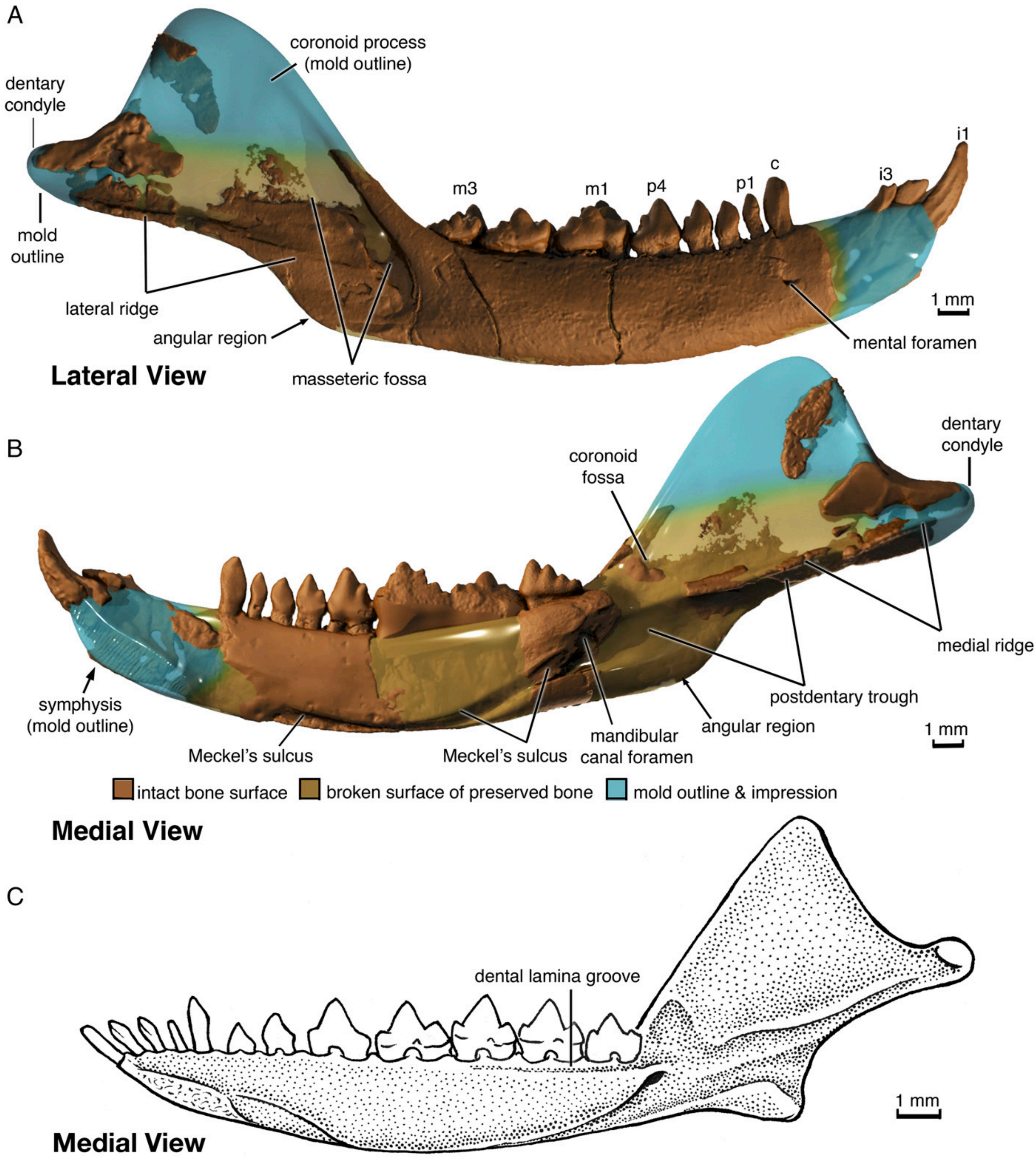

Fig. 1. (*A* and *B*) Composite reconstruction of *Haramiyavia clemmenseni* right mandible in lateral (*A*) and medial (*B*) views. Dark red: original bone with intact periosteal surface; brown: broken surface of preserved bone or remnant of bone; light blue: morphologies preserved in mold outlines or clear impression. (*C*) *Morganucodon* mandible in medial view.

specimen of upper molars in a maxilla (MCZ10/G95) (Figs. 2 and 3, *SI Appendix*, Figs. S5–S8 and Tables S2 and S3, and Movie S1). These new data are informative for testing alternative mammaliaform phylogenies (Fig. 4 and *SI Appendix*) and are useful for reconstructing evolutionary patterns of feeding function in the earliest mammaliaforms.

Mandibular Features

All mandibular characteristics of *Haramiyavia* are documented by the paired stereo photographs of the original fossil slabs and by CT scans (Fig. 1, *SI Appendix*, Figs. S1–S4, and Movie S1). The dentary condyle is relatively small, posteriorly directed, and continuous with the lateral ridge in the masseteric fossa (Fig. 1

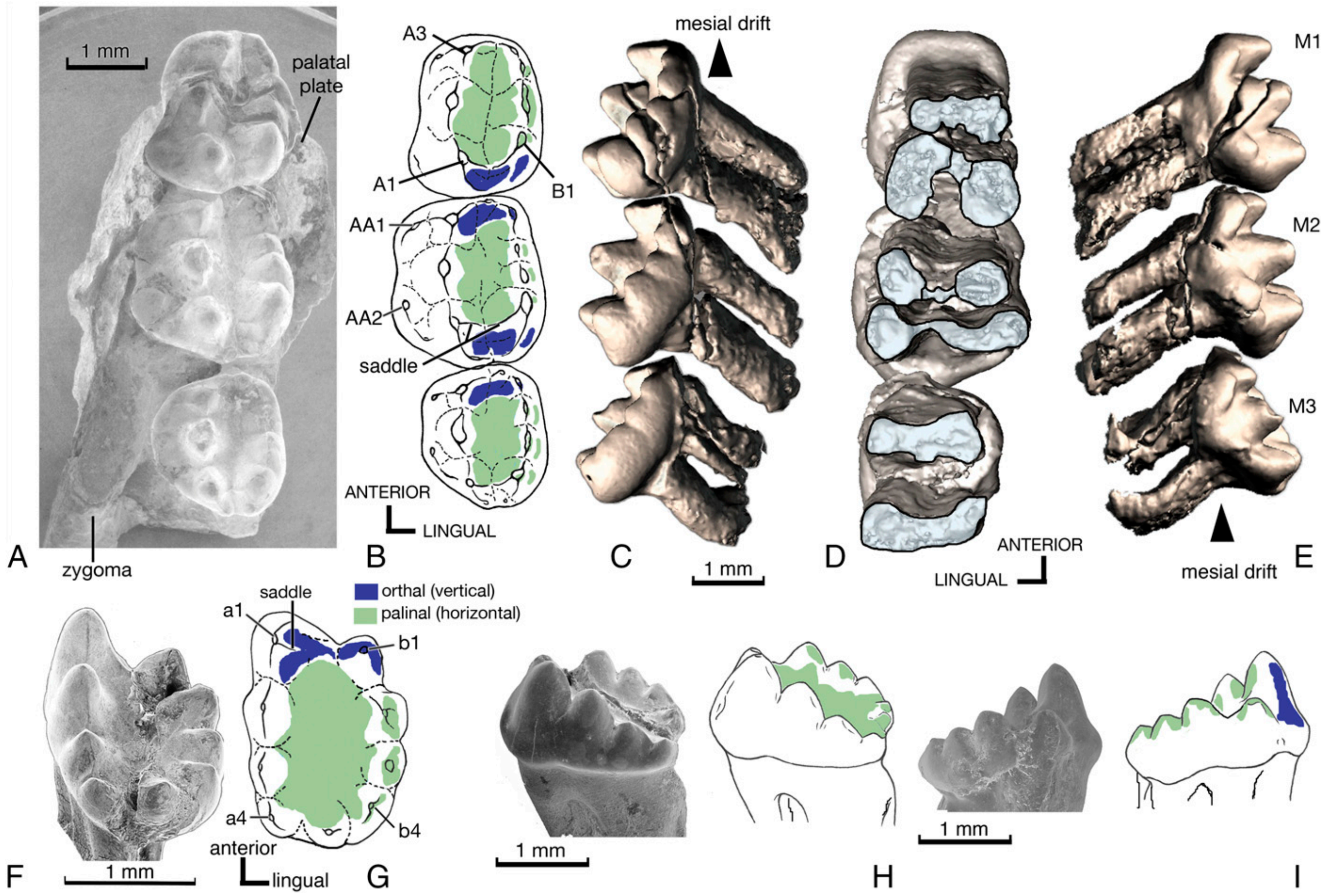

Fig. 2. Molar features of *Haramiyavia*. (*A*) Right M1–M3 in occlusal view (medio-lateral orientation by the zygomatic root and the palate). (*B*) Occlusal facets of upper molars. (*C*) Lingual view of M1–M3. (*D*) Root structures of upper molars (M1 and M2 show three partially divided anterior roots connected by dentine and two posterior roots connected by dentine; M3 has two anterior and two posterior roots connected respectively by dentine). These roots have separate root canals. (*E*) Buccal view of M1–M3. All roots are bent posteriorly, suggesting that crowns shifted mesially, relative to the roots, during the tooth eruption, also known as mesial drift of teeth (arrowhead), typical of successive eruption of multirooted postcanines. (*F*) SEM photograph of lower m3 in a posterior occlusal view. (*G*) Approximate extent of wear facets by orthal occlusion (a1 cusp in embrasure of upper molars) (blue) and palinal movement of b2–b4 cusps sliding across the median furrow of upper molars (green). (*H*) Lingual view of m3. There are no wear facets on lingual side of cusps a1–a4. (*I*) Buccal view of m3 showing wear facets on the buccal sides of cusps b1–b4 and on apices.

and *SI Appendix*, Fig. S1). The condyle and its lateral ridge are leveled to the molar alveolar line. The preserved bony parts of the condyle were extracted by CT from the two fossil slabs (*SI Appendix*, Fig. S1), and the bony parts on one slab are matched with the complementary outlines in the matrix of the opposite slab (*SI Appendix*, Figs. S2–S4 and Table S3). The masseteric fossa is bound by a low crest on its anterior and ventral margins and does not extend into the body (ramus) of the mandible (Fig. 1 and *SI Appendix*, Fig. S1). The coronoid process is typical of mammaliaforms, with its anterior margin forming a 150° angle to the molar alveolar line. There is a discernible angular region for the insertion of superficial masseter muscle, although there is no distinctive angular process. The medial side of the mandible shows a prominent postdentary trough and its medial ridge (Fig. 1 and *SI Appendix*, Figs. S2–S4). The posterior opening of the mandibular canal (alveolar foramen of ref. 1) is in the anterior part of the trough near the point where the trough continues into Meckel's sulcus (*SI Appendix*, Fig. S4). Meckel's sulcus is wider under m2 and m3 but is narrower under the premolars, maintaining a course parallel to the mandibular margin (Fig. 1). The coronoid fossa, although incomplete, is represented by a small rugose area on the left mandible. A right mandibular segment bearing m3 clearly shows the absence of the dental lamina groove on the medial side. The mandibular symphysis extends to the level of p2 and is unfused (*SI Appendix*, Figs. S2 and S4). The left mandible has a single mental foramen below the canine, but the right mandible shows two foramina. Thus, the number of foramina is variable (*SI Appendix*, Fig. S1). There is no foramen in the masseteric fossa (Fig. 1).

Haramiyavia is distinguishable from premammaliaform cynodonts by its dentary condyle (10, 25–27). *Haramiyavia* lacks the dental lamina groove (*SI Appendix*, Fig. S4) and is more derived than *Sinoconodon* and *Morganucodon* in this regard (11, 28). However, its other mandibular features are typical of mammaliaforms and are plesiomorphic for mammals. Although the middle ear bones themselves are not preserved, we infer from the postdentary trough and its related structures that *Haramiyavia* had a mandibular middle ear (*sensu* ref. 29). These structures have vis-à-vis correspondence to the middle ear in other mammaliaforms and include the medial ridge supporting the surangular, the angular concavity (also a part of the trough) accommodating the reflected lamina of the angular, and the wide sulcus hypothesized to house the Meckel's cartilage, as seen in *Sinoconodon* (25), *Morganucodon* (13), and docodonts (30). Other plesiomorphies include the absence of the pterygoid fossa defined by an

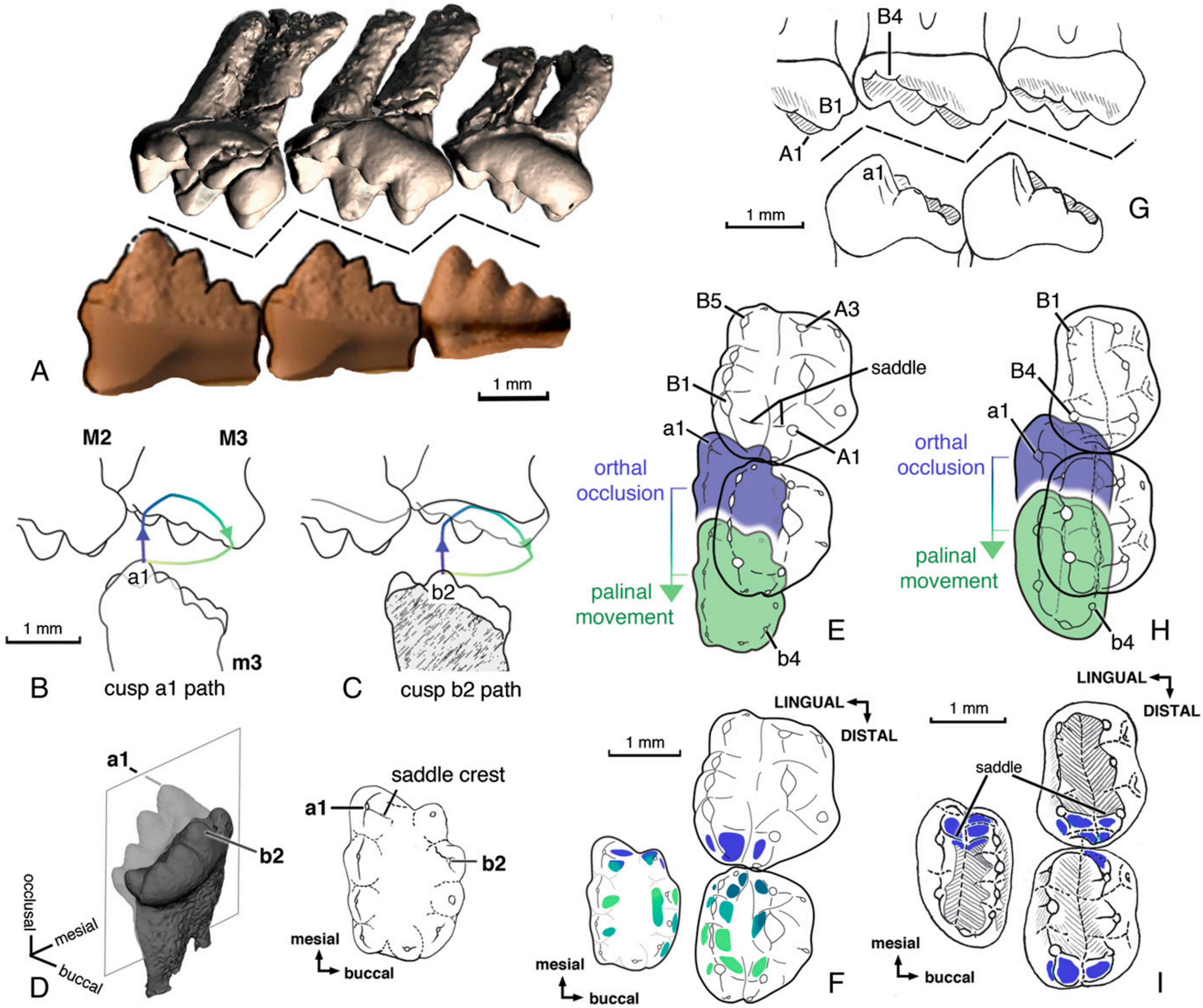

Fig. 3. Molar occlusion of haramiyids. (*A*) In *Haramiyavia* the upper and lower molars form an *en echelon* pattern, a series of parallel and step-like occlusal surfaces in lingual and buccal views (based on 3D scaled models from CT scans of MCZ7/G95 and MCZ10/G95). (*B–E*) In *Haramiyavia* are shown the occlusal paths of cusps a1–a4 of the lingual row (*B*), cusps b2–b4 of the buccal row (shown with the lingual half of the tooth cut away) (*C*), and tooth orientation and the cut-away plane (*D*). During the orthal occlusion phase, the tallest lingual cusp a1 occludes into the embrasure of the preceding and the opposing upper molars (*B* and *E*), and the tallest buccal cusp b2 occludes into the upper furrow and behind the A1–B1 saddle of the upper molar (*C*). During the palinal occlusion phase, cusps b1–b4 of the buccal row slide posteriorly in the upper furrow, and in the upper row cusps B5–B1 slide in the lower furrow (lower molars with blue and green shading, superpositioned by flipped upper molar in clear outlines) (*E*). (*F*) Extent of wear on molars during the orthal phase (blue) and the palinal movement (green) produced by OFA simulation (Movie S1). (*G–I*) In *Thomasia*, reconstruction of upper and lower molar series on the basis of wear surfaces and tooth crown morphology (revised from refs. 2, 3, and 10). (*G*) The *en echelon* occlusal surfaces in lingual view. (*H*) Orthal occlusion (blue) is followed by palinal occlusal movement (green). (*I*) Occlusal wear facets of molars. Facets worn by orthal occlusion are shown in blue, and facets worn by palinal occlusion are shown in gray hatching. Cusp and facet designations are after refs 3 and 6.

arcuate margin and an anterior location of the posterior mandibular foramen (Fig. 1).

The first report on *Haramiyavia* (1) illustrated only a small segment of the well-preserved mandibles (that under m3) in medial view (*SI Appendix*, Fig. S4). The mandibular features labeled in that figure (figure 2 in ref. 1) were questioned by Averianov et al. (17). Bi and colleagues (18) further argued that "Logically, a mandibular middle ear cannot be assumed in *Haramiyavia*" (supporting information p. 19 in ref. 18). As a result, most mandibular features of *Haramiyavia* were excluded from two recent phylogenetic estimates (18, 23). We note that Averianov et al. (17) and Bi and colleagues (18) did not examine these preserved features in the original fossil material of *Haramiyavia* before disregarding these features.

Dentition

The dentition of *Haramiyavia* is emended here as I4.C?.P?.M3/i3.c1.p4.m3. Our CT examination identified three lower incisors, not four as previously reconstructed (1). The lower p1 is present on the left mandible, but it was shed, and its alveolus was already plugged by bone on the right (*SI Appendix*, Fig. S1). The loss of anterior premolar(s) with age without replacement is typical of stem mammaliaforms (28) and also occurred in eutriconodont mammals (31).

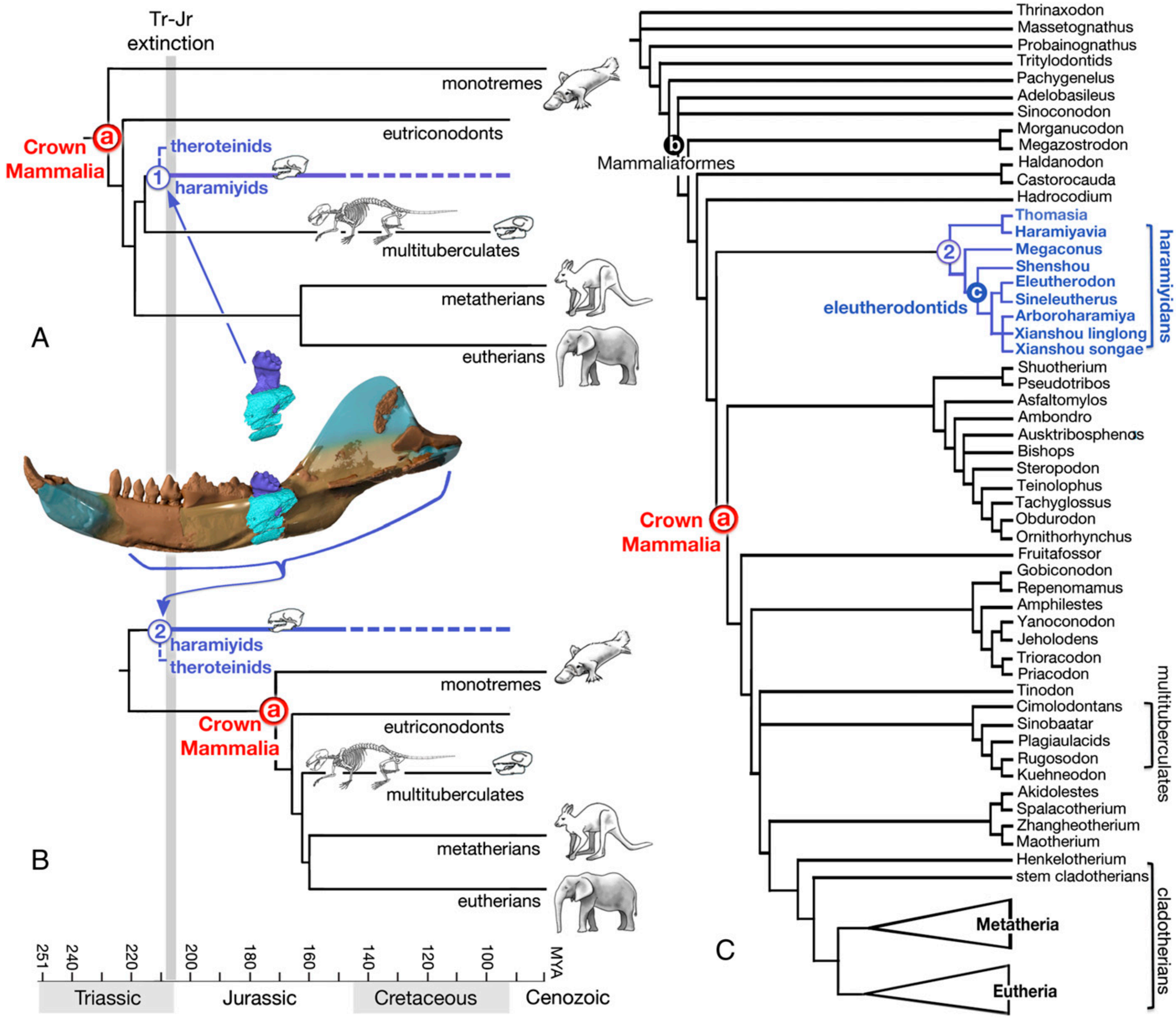

Fig. 4. Hypotheses concerning the phylogenetic relationship of *Haramiyavia* and timing estimates of the basal diversification of crown mammals. (*A*) *Haramiyavia* is a close relative of multituberculates, both nested in the crown Mammalia. This hypothesis (haramiyidan node position 1) was based on a misinterpretation of a previous illustration of a fragment of the mandible (17, 18). (*B*) *Haramiyavia* is a stem mammaliaform, as determined by incorporating the features preserved on both mandibles into phylogenetic estimates (haramiyidan node position 2). (*C*) Placement of *Haramiyavia* and other haramiyidans among mammaliaforms according to this study. Many mandibular features were treated as unknown by studies favoring a Late Triassic diversification of mammals (18, 23). A more complete sampling of informative features revealed by this study now has overturned the previous placement. Clades: crown Mammalia (node a); Mammaliaformes (node b); haramiyidans (node 1 or 2, alternative positions); Eleutherodontida (node c). The rescored datasets and analyses are presented in *SI Appendix*.

The three lower incisors are procumbent and show a size gradient from the largest, i1, to the smallest, i3, with i1 being more than twice as wide and long as i2. All lower incisors have a heel on the lingual cingulid, and their root tips are closed (Movie S1). i1 has three buccal ridges along its length and a median lingual ridge. Upper incisors are single-rooted and have a lanceolate outline, a slightly concave lingual surface, and a convex buccal surface (*SI Appendix*, Fig. S1). The upper incisors lack the heel or cingular cusp(s) of multituberculates (5). Lower premolars p2–p4 are double-rooted. Lower m3 has partially divided multiple roots (*SI Appendix*, Fig. S6). Each of the two smaller anterior roots has a separate root canal. The larger posterior root contains two root canals, which can be seen in CT serial sections. These partially divided multiple roots are similar to those of the Middle–Late Jurassic haramiyidans (18–20).

Upper molars have partially divided multiple roots in two root-rows (Fig. 2). Two to three smaller roots in the anterior root-row are connected by dentine; each root has a separate root canal. The two to three larger posterior roots are connected into the posterior root-row; each posterior root has a root canal (Fig. 2). The roots are bent posteriorly from the crown–root junction, indicating that the molar crowns shifted anteriorly relative to the anchored roots, an eruption pattern known as "mesial drift" in extant mammals (*sensu* ref. 32; also see ref. 33). The lower teeth in *Haramiyavia* show no mesial drift. More pronounced mesial drift of both upper and lower toothrows is well documented in tritylodontids, a cynodont group that also has multiple roots of postcanines (33, 34), and also evolved convergently in several marsupials and placentals (32).

Molar Occlusion

The upper molars (Fig. 2 and *SI Appendix*, Fig. S5) have two main cusp rows separated by a fusiform median furrow, which is also known as a "basin" because it is closed anteriorly by a crest (on M1) or a cusp B5 (in M2 and M3) (1, 2). The buccal shelf is absent on M1 but is present on M2 and M3. The buccal accessory cusps (AA1–AA3) are variable and have no occlusal contact with the lower molars (Fig. 2 and *SI Appendix*, Fig. S5). Adjacent upper molars are interlocked by cusp B5 of the succeeding molar fitting into a distal cingular notch of the preceding molar (Fig. 2*B*). Upper molars are in a straight alignment, without a lingual offset of the ultimate upper molar, as seen in multituberculates (1).

Upper molars are set in an *en echelon* (step-like) pattern, as first noted by Jenkins et al. (p. 171 in ref. 1). Each molar crown is much taller from the crown–root junction on the distal end than on the mesial end along both the lingual and buccal sides (Fig. 2 *C* and *D*). As the crowns are leveled to the maxillary alveolar line, cusp rows and occluding basins and furrows form a pronounced zigzag contour along the molar series (Fig. 3). Cusps B1 and A1 are the highest points, and the embrasures of adjacent molars are the lowest points of this zigzag contour.

Cusps of lingual row B show mesially (anteriorly) decreasing heights, from the tallest cusp, B1, to the lowest, B4. Cusps of buccal row A also show mesially decreasing cusp heights, with A1 being the tallest. The tallest cusps, B1 (lingual row) and A1 (buccal row), have an elevated transverse saddle (2, 6), which partially divides the distal basin from the mesial furrow. The distal basin is oriented posteroventrally, whereas the mesial furrow is oriented anteroventrally, both sloping away from the saddle. The wear surfaces are more vertically inclined in the distal basin, as seen on cusp A1 posterior to the saddle (facet 1 of ref. 3) (Fig. 2, blue). Anterior to the saddle, the striations are more vertically inclined near the bases of cusps A2 and B2 but become horizontal in most of the mesial furrow (facets 3 and 4) (Fig. 2, green).

Prominent wear of upper molars is visible on the lingual cusp in row B, on their lingual aspect (facet 6), on the apices of B2–B4, and along the furrow side of the cusp row (facet 4) (*SI Appendix*, Fig. S5). Cusps A1–A3 of the buccal row show wear in the median furrow and abrasion on the A2 apex but no sign of wear or contact on their buccal sides (*SI Appendix*, Fig. S5). The buccal shelf and its accessory cuspules have no sign of contact with the lower teeth (*SI Appendix*, Fig. S5).

On the lower molars, cusp a1 is the tallest of the lingual row and of the entire tooth. Cusp b2 is the tallest of the buccal cusp row (although still much lower than a1). Cusps a1 and b2 have an elevated oblique saddle that separates the mesial basin (Fig. 2 *G–I*, blue) from the median furrow distal to the saddle (Fig. 2 *G–I*, green). The most visible wear is on the buccal cusp row (b2–b4) with abrasion on the apices of cusps, along the furrow side (facet 4), and on the buccal side (facet 6) (Fig. 2 and *SI Appendix*, Figs. S6 and S7). On lower m3, the lingual aspect of the lingual cusp row has no wear striations or any apical wear on cusps a1–a5 (Fig. 2 and *SI Appendix*, Fig. S6).

On m3, the mesial basin anterior to the saddle shows more inclined striations [Fig. 2 *G–I*, blue, also known as "facet 1" (3)]. The furrow posterior to the saddle shows more vertically inclined wear striations at the bases of cusps a2 and b2 (and also on the posterior aspect of a1) but more horizontal striations along much of the furrow [Fig. 2 *F–I*, green; also known as "facets 3 and 4" (3)].

The associated tooth-bearing mandibles and maxillary of *Haramiyavia* offer a crucial anatomical context for orienting the isolated teeth of other haramiyids (5, 6, 10). Nonetheless there have been divergent interpretations of dental occlusion. Jenkins et al. (1) noted that the *en echelon* pattern precludes a lower molar from sliding across more than one upper molar and reconstructed only orthal occlusion without palinal movement. Subsequently, Butler (2) agreed with the interpretation that *Haramiyavia* had orthal movement and one-to-one upper–lower relationship. However, Butler (figure 3, p. 323 in ref. 2) suggested that, after the initial orthal occlusion, there was also a palinal movement about one third of the upper tooth length, similar to the palinal movement of lower teeth in cynodont group of traversodontids (35), although not to the same extent as in multituberculates (2).

Zheng et al. (20) and Meng et al. (36) offered an entirely novel interpretation of haramiyid occlusion. Based on their analysis of the isolated teeth of newly discovered *Arboroharamiya* (20) (*SI Appendix*, Fig. S8), they argued that the bucco–lingual alignment of opposing molars would be for the lingual cusp row of the lower molar to fit into the median furrow of the uppers for *Haramiyavia* and other haramiyids. This alignment of the opposing molars differs by an entire cusp row from the reconstructions for *Haramiyavia* by Jenkins et al. (1) and for all haramiyids by other studies (2, 6). These alternative interpretations can now be tested by SEM studies on wear facets, by manipulation of scaled 3D models from CT scans (*SI Appendix*, *Methods*), and by kinematic simulation using Occlusal Fingerprint Analyzer (OFA) software (*SI Appendix*, *Methods*) (37, 38).

We note that the distal basin of the upper molar and the mesial basin of the lower molar have vertically inclined striations (*SI Appendix*, Figs. S5 and S6). On m3, there also are some inclined striations at the bases of cusps a1 and a2 (*SI Appendix*, Fig. S6). However, most of the furrow of m3 shows the more horizontal striations, and both sides of b2–b4 of the buccal cusp row show a mixture of horizontal and less inclined striations.

The vertical (or strongly inclined) striations of the distal basin of the upper molar, the mesial basin of the lower molar, and those close to the lower saddle crest are evidence of orthal occlusion. As a lower molar moved vertically, the tallest lingual cusp, a1 of the lower molar, fit into the embrasure of the opposing upper molars. Concurrently, the lower cusps b2–b4 occluded vertically into the upper furrow (Fig. 2 *B–H*: orthal occlusion, blue).

The more horizontal striations in the furrow and the mixture of horizontal and less inclined striations along both sides of b2–b4 of the buccal cusp row were produced by palinal movement. Buccal cusps b2–b4 of the lower slid posteriorly along the upper furrow between the lingual row B2–B4 and the buccal row A1–A3. Concurrently, lingual cusps a1–a4 of the lower slid posteriorly past the lingual side of upper lingual cusps (Fig. 2 *B–H*: palinal movement, green). Therefore, wear patterns documented by SEM corroborate the occlusal contact reconstructed by manipulation of 3D scale models. Within a single occlusal cycle, orthal movement occurs first, followed by a subsequent palinal phase of slightly more than one third of the upper tooth length (Movie S1) (2).

We now can demonstrate that the only possible configuration of the bucco–lingual alignment of cusp rows for *Haramiyavia* (*SI Appendix*, Fig. S8) (ref. 36 vs. other studies) is for the buccal row (b2–b4) of the lower m3 to occlude the median furrow of the upper M3 and for the lingual cusp row (B1–B4) of the upper to occlude the median furrow of the lower, as originally established (1, 2). The putative alignment in which lingual cusps a1–a4 of the lower molar fit into the median furrow of the upper molar (36) would result in a mismatch of upper and lower contact surfaces for *Haramiyavia*. Meng and colleagues did not have access to the material that shows the significant height difference of cusp a1 from other lower molar cusps (*SI Appendix*, Fig. S6), the shallow depth of the occluding furrow, and the elevated saddle of the upper molars (*SI Appendix*, Fig. S8). If the lower lingual row a1–a4 were to be placed in the median furrow of the upper molar, the tallest cusp a1 would be the only possible contact point between the two teeth. If upper cusps A1–A3 were to be aligned with the median furrow of the lower molar (36), the apices of A1–A3 would not be tall enough to contact any part of the lower molar at all (*SI Appendix*, Fig. S8). The buccal aspect of the upper molar and the lingual aspect of the lower molar have no wear striations or facets, as predicted by the cusp row alignment proposed by Meng and colleagues (36).

3D Occlusal Tooth Models and OFA

Using 3D models printed from CT scans, we found that rescaling the referred and larger upper molars (MCZ10/G95) to 83% made the best match to the lower teeth (MCZ7/G95). More details are given in *SI Appendix*. Using the OFA kinematic simulation tool (37, 38), we further tested the orthal and palinal occlusal movements (2) and the alternative bucco–lingual cusp row alignments (ref. 36 vs. other studies) for the goodness of fit of the molar contact surfaces (Movie S1).

OFA analysis demonstrates that for the orthal phase of occlusion, the best fit is for the tallest cusp a1 of the lower lingual row to occlude into the lingual embrasure of the adjacent upper molars as the lower buccal cusp b1 simultaneously contacts the distal occlusal basin of the preceding upper molar (Fig. 3*B*, blue arrow and Movie S1). For the palinal phase of occlusion, the best fit is for the buccal cusps b2–b4 of the lower molar to slide through the median furrow of the upper (Fig. 3*C*, green arrow and Movie S1). These best fits of the upper–lower contacts resulted in a distribution of tooth contacts (OFA "collision") very similar to the wear facets directly observed by SEM of the teeth (Fig. 2*F*). Thus, the occlusal relationship proposed from wear facets (Fig. 2) is corroborated independently by kinematic analysis (Movie S1). On the contrary, the bucco–lingual row alignment suggested by Meng and colleagues (36) would result in minimal contact by the apex of lower cusp a1 to the entire opposing upper tooth, an obvious mismatch (*SI Appendix*, Fig. S8).

Comparison with Other Haramiyids

Tooth wear surfaces and striations of *Haramiyavia* are similar to those of *Thomasia* (2, 3, 6, 39). *Thomasia* shows an upper crown height differential similar to that in *Haramiyavia*: a taller distal end, a shorter mesial end, and a cusp row height gradient with the distal cusp B1 being the tallest (Fig. 2*G*) (3, 6). Thus, it was proposed that *Thomasia* has a similar *en echelon* arrangement for the occlusal surfaces of upper molars (2, 39). Therefore, the orthal–palinal occlusal movement (2) is likely applicable to haramiyids as a whole. For further comparisons, see Figs. 2 and 3 and *SI Appendix*, Fig. S7.

Dental Age and Body Size

We estimate by dental eruption stage that the type specimen (MCZ7/95) and the referred specimen (MCZ10/95G) of *Haramiyavia clemmenseni* are adult. The ultimate molars (m3 and M3) are fully erupted and have sustained wear from chewing (*SI Appendix*, Figs. S5 and S6). Our CT scanning detected no dental laminae or erupting teeth inside the jaws, indicating the individual was an adult. Several mammaliaforms and some premammaliaform cynodonts show a pattern of successive loss of the anterior postcanines with advancing age (28, 40). This loss creates and/or enlarges a postcanine diastema in older individuals. The lower right premolar p1 already has been shed, and its alveolus is plugged (*SI Appendix*, Fig. S1), consistent with an interpretation that aging had already started in the *Haramiyavia* type specimen, although the initiation of this pattern is different between the two mandibles.

We estimate that the body mass of *Haramiyavia* ranged from 50 to 70 g. The right mandible is 27 mm long as measured on the slabs. The reconstructed mandible is 28 mm long, based on complementary parts from the right and the left (Fig. 1 and Movie S1). Body mass of the type specimen ranges from 61 to 68 g by regression to mandibular length [Ln (body mass in grams) = 2.9677 × Ln (jaw length in millimeters) − 5.6712] from a dataset of some placental insectivores and marsupials (41). The humeral length is 17 mm (*SI Appendix*, Figs. S2 and S3). The body mass of *Haramiyavia* is estimated to be 47 g by a regression to humeral length ($\log_{10}$ body mass = 2.8626 × $\log_{10}$ humerus length − 1.8476) based on a dataset of extant mammals (42).

Phylogenetic Analyses and Implications

Since the discovery of haramiyids more than 100 years ago, their phylogenetic position has always been controversial (Fig. 4). Traditional studies assumed that haramiyidans were associated with multituberculates, and the latter were universally regarded as members of Mammalia (2, 5, 18) (Fig. 4*A*). A recent variant of this hypothesis is that haramiyids are closely related to the gondwanatherian–multituberculate clade (23). Including Late Triassic haramiyids in a clade with the geologically younger multituberculates would help extend the minimal age of their common ancestor, the basis for recent arguments in favor of a Late Triassic diversification of crown Mammalia (18, 23) (Fig. 4*A*).

However, a competing hypothesis postulates that haramiyids are a stem lineage separate from Mammalia (1, 19, 21, 22). This hypothesis is supported by the newly documented mandibular and dental characteristics of *Haramiyavia* (Fig. 4*B*). Our study revealed 37 new mandibular features of *Haramiyavia*. Most of these features were treated as unknown or inapplicable in two recent studies supporting the haramiyidan–multituberculate clade (18) or the haramiyidan–gondwanatherian–multituberculate clade (23). When these features are added into the matrices of these studies, our analyses of the improved datasets show that haramiyidans (including *Haramiyavia*) are a mammaliaform clade outside crown Mammalia, separated from multituberculates (Fig. 4*B*) and from the gondwanatherian–multituberculate clade (*SI Appendix*). The clade of gondwanatherians and multituberculates (23) is relatively robust to the character changes in haramiyidans. Removing haramiyids from the putative haramiyidan–multituberculate clade, which is the sole basis for the Late Triassic diversification of Mammalia, cancels the fossil date for the Late Triassic origin and basal diversification of Mammalia (Fig. 4 and *SI Appendix*) (21, 22, 24).

Discussion

The hypothesis of the haramiyidan–multituberculate clade, if upheld, would have another implication for vertebrate macroevolution. Fossils of *Haramiyavia*, *Thomasia*, and their putative theroteinid relatives are older than the end of Triassic extinction (7, 13), and they predate the major paleoecological transition from the Late Triassic to Early Jurassic (43, 44). A corollary of this hypothesis is that main crown mammalian clades would have split before the Triassic–Jurassic ecosystem transition, survived the mass extinction at the end of the Triassic (Fig. 4*A*), and later again survived the mass extinction at the end of the Cretaceous. On the contrary, our current analyses conclude that haramiyidans are a stem clade by its new dental and mandibular features. This conclusion is more consistent with a macroevolutionary scenario that major mammalian clades split after the end of Triassic extinction, not before it (Fig. 4*B*). The mammaliaform diversification occurred mostly during the paleoecological revolution during the Triassic–Jurassic ecosystem transition (44), not before it.

Haramiyavia of the Triassic and multituberculates of the Jurassic and Cretaceous also are different in many mandibular structures: *Haramiyavia* has a postdentary trough, indicating a plesiomorphic mandibular middle ear. It has a small, posteriorly directed dentary condyle, a larger coronoid process, and a masseteric fossa that is limited to the angular region. Also it lacks a pterygoid fossa. In contrast, multituberculates show none of these plesiomorphic features. Instead they are characterized by a rounded, dorsally directed dentary condyle (45), a masseteric fossa extending anteriorly into mandibular body, and a distinctive pterygoid fossa. These phylogenetically derived features also have significant functions in the jaws of multituberculates.

The small coronoid process of multituberculates provided less area of insertion for the temporalis muscle and likely less orthal biting force. However, their masseteric fossa has a prominent anterior extension for a larger masseter muscle and the backward power stroke of the jaw (45). Consistent with this anatomy, their molars exhibit minimal orthal occlusal wear but a greater range of wear by palinal movement (2). By comparison, *Haramiyavia* has a relatively large coronoid process (a mammaliaform plesiomorphy; see Fig. 1) with a more sizable insertion area for the temporalis muscle that is more effective in vertical biting. This characteristic is consistent with major wear by orthal occlusion as constrained by *en echelon* tooth surfaces. However, *Haramiyavia* lacks an anterior extension of the masseteric fossa and likely had a less developed masseteric muscle than can be inferred for multituberculates. We hypothesize that it has a shorter posterior power stroke powered by the masseter, as also evidenced by the limited extent of palinal wear on teeth (Fig. 2 and Movie S1).

Molariform teeth with longitudinal cusp rows in alternate upper–lower occlusion are a major feeding adaptation for a herbivorous diet or for an omnivorous diet with a major plant component (46, 47). In the cynodont–mammal phylogeny, this adaptation occurred first in traversodontids with both orthal and palinal occlusal movements (35) and then in tritylodontids with predominantly palinal movement (34, 35), according to some recent phylogenies (47, 48). It evolved again in multituberculates and rodents, two mammal clades that had spectacular radiations and evolutionary success. However, the rodent-like teeth in multituberculates occlude by a backward (palinal) power stroke of the jaw, whereas the teeth of rodents occlude by a forward power stroke of the jaw (49, 50). Thus, their dental functions are likely convergent.

We posit that teeth with multiple cusp rows evolved iteratively, each time with distinctive skeletomuscular functions of the mandible and also different occlusal structures of teeth. Molars of haramiyids represent such an iterative and convergent evolution. Moreover, haramiyids with their multirow and multicusped teeth, which are adapted to omnivorous/herbivorous feedings, are distinctive from contemporary morganucodonts and *Sinoconodon* with triconodont-like teeth (11, 28) and kuehneotheriids with a triangular cusp pattern, both of which are adapted to insectivorous feeding (12). These disparate dental patterns of the earliest mammaliaforms suggest that dietary diversification was a major factor in the earliest mammaliaform evolution through the paleoecological changes in the Late Triassic to Early Jurassic continental ecosystems (44).

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Supporting Information

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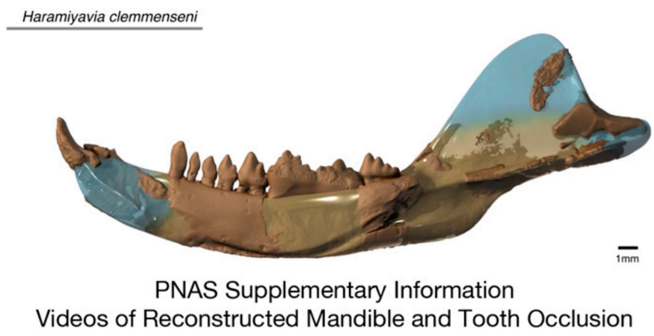

Movie S1. Composite reconstruction of the right mandible and lower dentition of *Haramiyavia clemmenseni* (Part 1) and the occlusal movement of teeth simulated by OFA virtual simulation software (Part 2). See *SI Appendix* for an extended legend and explanation. Movie courtesy of April I. Neander (University of Chicago, Chicago).

Movie S1

Other Supporting Information Files

SI Appendix (PDF)

Mandibular and Dental Characteristics of Late Triassic Mammaliaform Haramiyavia and Their Ramifications for Basal Mammal Evolution

Supporting Information

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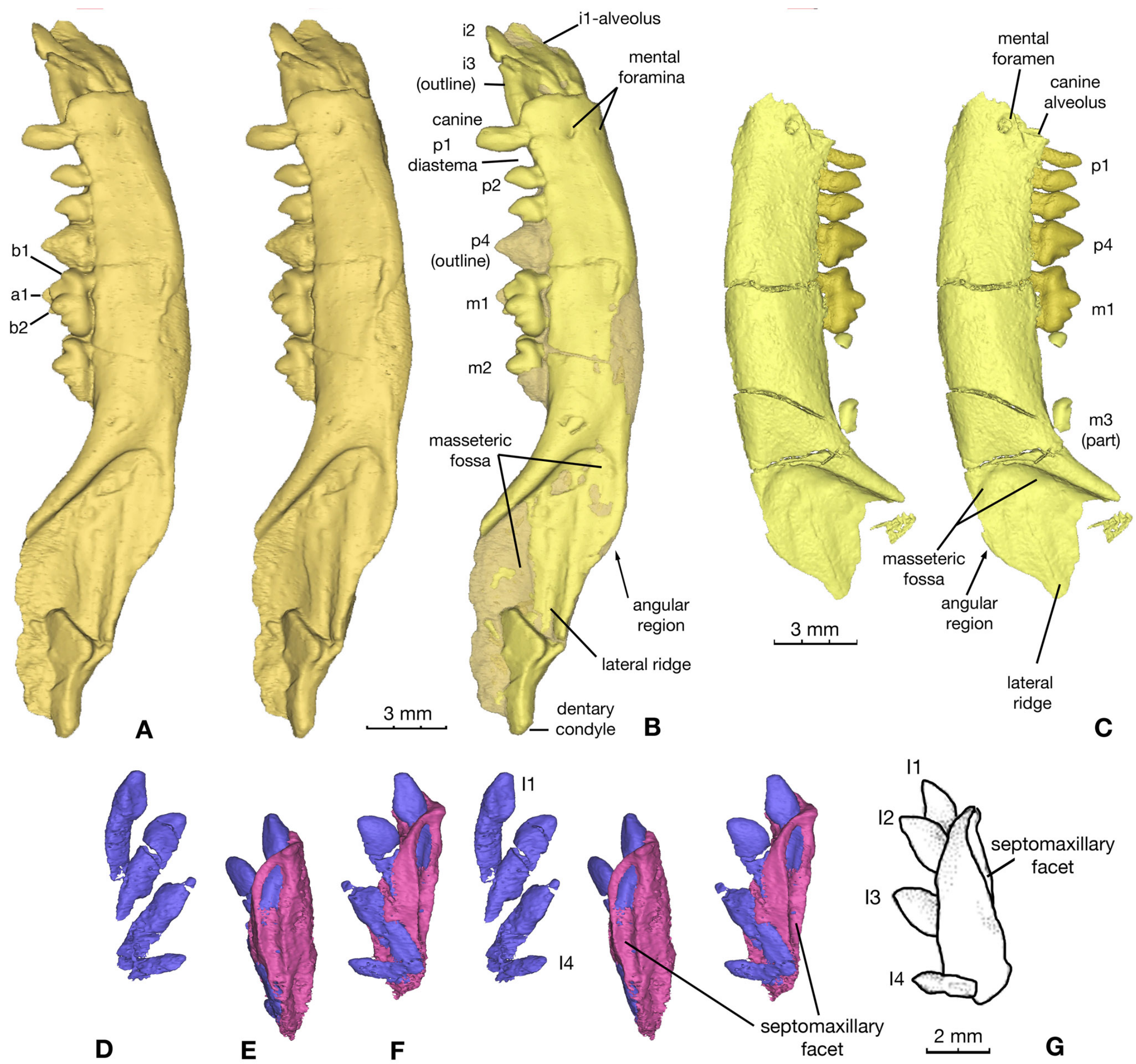
SI Appendix Table of Contents

Supporting Information Movie S1 Extended Caption and Explanation

Movie S1 – Part 1 - Composite reconstruction of the right mandible and lower dentition of Haramiyavia clemmenseni. All bony structures of the main slab and counter-slab can be matched by corresponding outlines on the opposite slab. All bone structures, and impression and outlines are documented by paired stereo photographs (Fig. S2-S4) before the excavation of right and left mandibles. The main improvement on the historical illustration of Jenkins et al. (1) (black/white) by the new CT composite restoration (color) is on the dentary condyle, a more distinctive angular region for the superficial masseter muscle insertion, and a different incisor count. The condyle was reconstructed by CT extraction of preserved bony parts from the two fossil slabs (Fig. S2-4). The bony parts on the main slab and counter-slab are matched with the complementary outlines in the matrix of the opposite slab. The CT scanning identifies only three lower incisors (color), not four as previously reconstructed (black/white). The angular region is defined as the insertion site of the superficial masseter muscle (56, 57). The new reconstruction shows, the postdentary trough, and Meckel's sulcus and other features on the medial side of the mandible, for the first time. Dark red–bone with well-preserved periosteal surface. Brown – preserved bone with broken surface or remnant of bones with impression outlines. Light blue – morphological features preserved only in clear mold outlines or impression. Movie by April I. Neander, the University of Chicago. Line drawing from Jenkins et al. (1) for comparison.

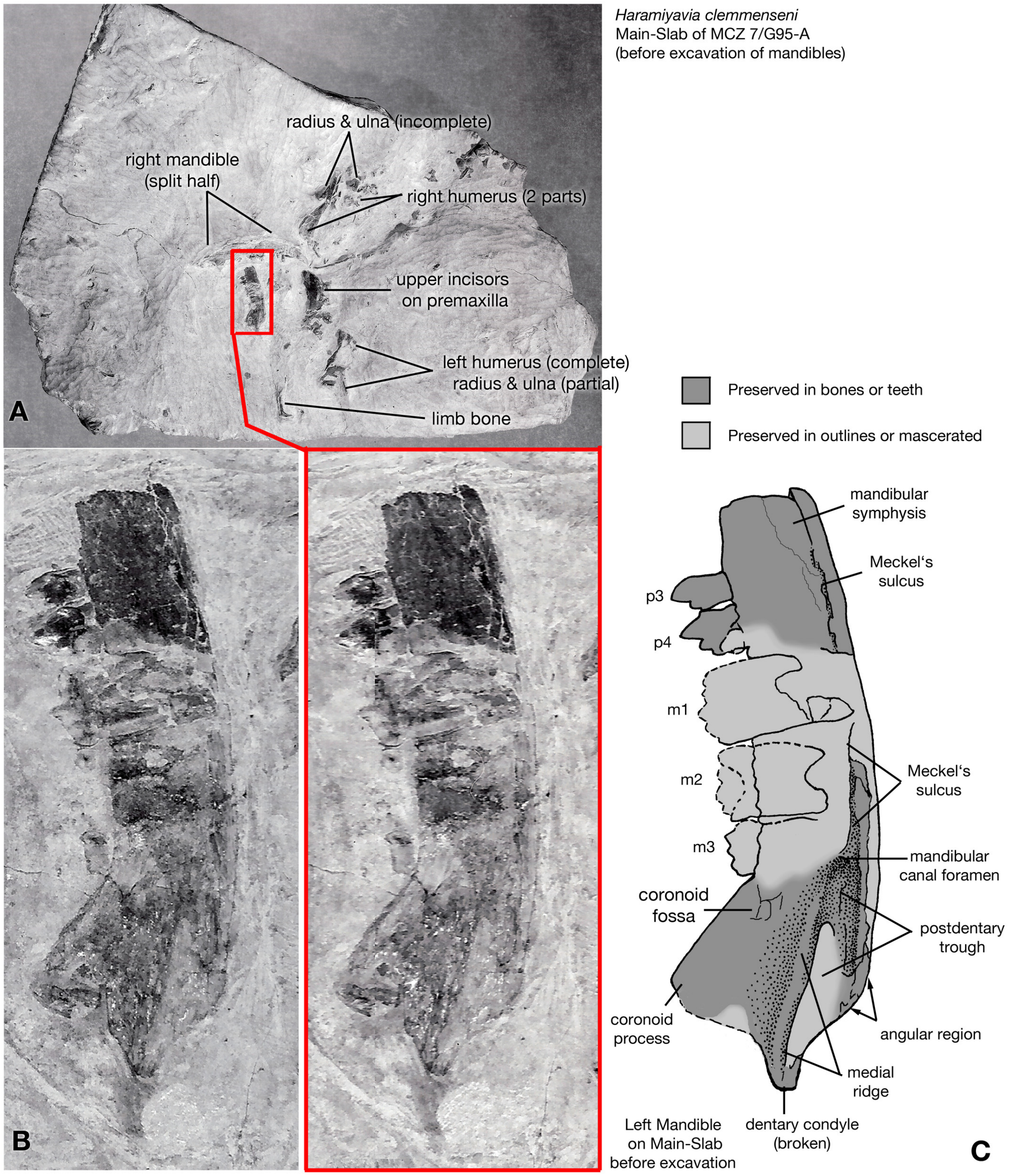
Movie S1 Part 2. Haramiyavia molar occlusal movement simulated by Occlusal Fingerprint Analyser (OFA) virtual simulation software. A. Right lower m3 occlusion cycle (orthal phase + palinal phase) in the lingual view of the upper and lower molars. Blue line envelope represents the path of lower m3 occlusal movement. B. Lower m3 occlusion cycle in buccal view. C. Slightly tilted posterior view of right m3 occluding with right upper M3. The occlusion starts from orthal movement as lower lingual cusp a1 (the tallest of lower cusps) bites into the lingual embrasure between the adjacent upper molars (*sensu* Jenkins et al. 1997 [1]), then transitioning into palinal movement (*sensu* Butler 2000 [2]). The extent of orthal-to-palinal movement is similar to that of traversodontid cynodonts (2, 35). During the orthal phase of occlusion, the lower molar also rotates slightly lingually as the mandible occludes orthally. This slight lingual rotation in transverse section may facilitated by the mobile mandibular symphysis even in the bilaterally occlusion of both mandibles (1). The lingual rotation as the lower molar approaches the upper molar during the occlusion is a plesiomorphic pattern of the mandibular movement of mammaliaforms (54, 55). By this mandibular rotation, which is not fully shown due to the limit of OFA simulation, the actual contact areas between the upper and lower molars are larger, than can be shown in this Movie. Because the chewing path is guided (and constrained) by the contact surfaces on the molars, this corroborates the occlusal movement reconstructed by manipulation of 3D print tooth models. The range of palinal movement of lower molar is about 1/3 of the tooth length. OFA source: http://www.for771.uni-bonn.de/en/ofa_info. Movie produced by April I. Neander of the University of Chicago.

Supporting Information – Appendix Figures and Captions



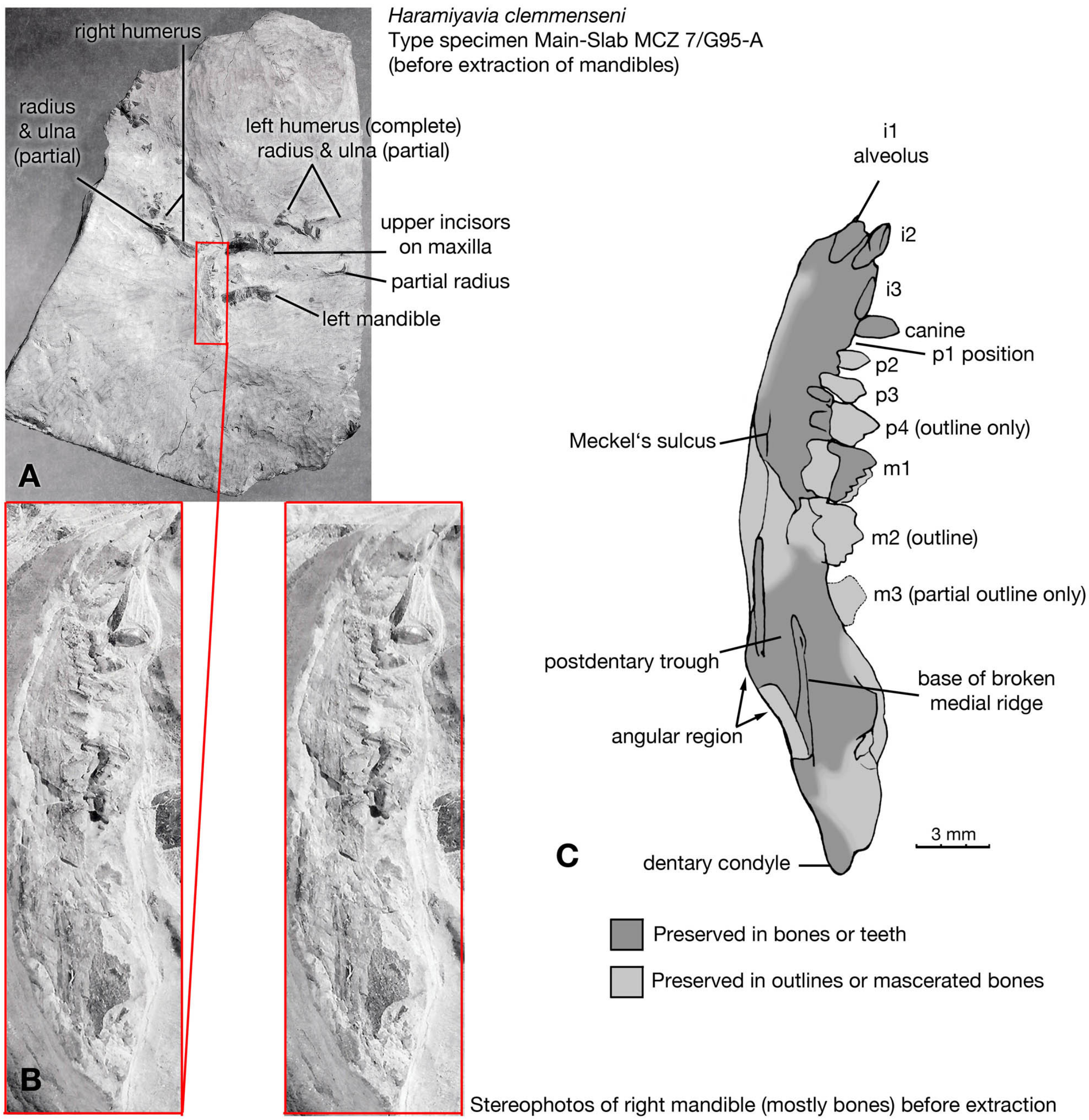
SI Appendix Fig. S1

SI – Appendix Figure S1. Haramiyavia clemmenseni mandibles and premaxilla - images rendered from CT scanning. A. Stereo images of right mandible with teeth (lateral view), after it was excavated from the holotype main slab (MCZ7/G95A), preserved in resin plastic, and then CT-scanned; presented in combined bones and molds of the original fossil. B. Lateral view, yellow – original bones and teeth; light brown- embedding resin plastic representing the original outlines and molds of the fossil. C. Left mandible with teeth from the holotype main slab (MCZ7/G95A): fossil was excavated from the main slab, preserved in resin plastic, and then CT-scanned, presented in stereo images of lateral view of mandible. D, E, F & G. Premaxilla with upper incisors. D. Ventral view (stereo-pair) of separated I1-I4. E and F. Dorsal and lateral views of premaxilla with its incisors, and premaxillary facet for the septomaxilla (stereo pairs). G. Original illustration of the same by Jenkins et al. (1997) (1).



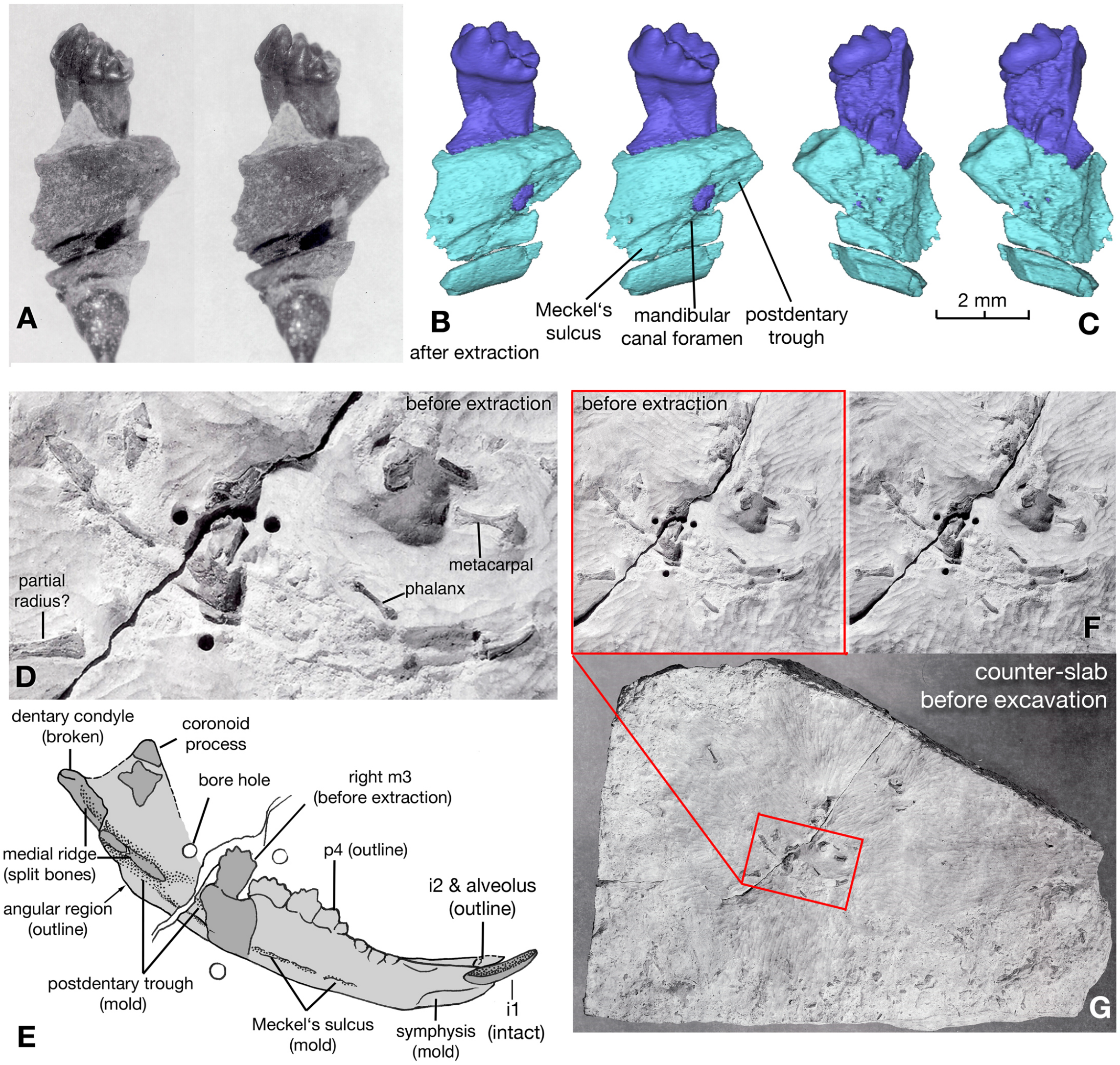
SI Appendix Fig. S2

SI – Appendix SI – Appendix Figure S2. Haramiyavia clemmenseni left mandible. A. Holotype main slab (MCZ7/G95A) - left mandible as exposed in medial view after preliminary preparation but before its excavation from the slab. B. Stereo photos of the left mandible in medial view with dental features, as preserved, taken before excavation of the mandible. C. Identification of intact p3-4, and mold outlines of m1-m3, bony part of the dentary condyle, the postdentary trough preserved in bones and mold outlines, the medial ridge mostly in bone, posterior foramen of the mandibular (alveolar) canal, remnant of the Meckel's sulcus, the incomplete coronoid fossa, the incomplete coronoid process, and the incomplete mandibular symphysis preserved in bones.



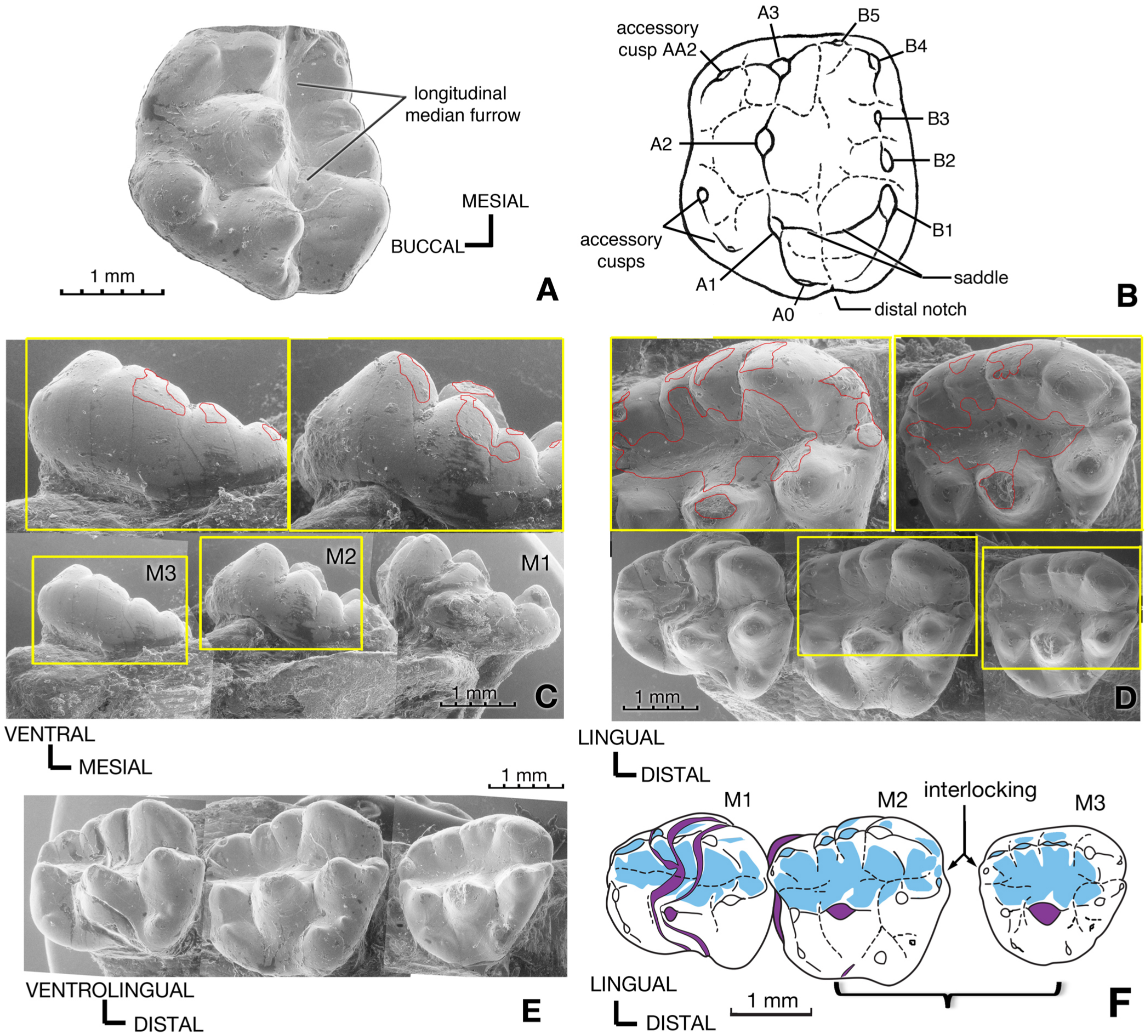
SI Appendix Fig. S3

SI – Appendix Figure S3. Haramiyavia right mandibular parts preserved on the holotype main slab (MCZ7/G95A). A. Right mandible exposed in medial view on the main slab, after preliminary preparation but before its excavation from the slab. B. Stereo photos of right mandible in medial view (after preparation but before its removal). C. Outline identification of the preserved features of teeth and the mandible. Additional intact teeth, jaw parts, and corresponding outline and mold surface features are preserved on the counter slab (MCZ7/G95B) and are matched with those on this slab.



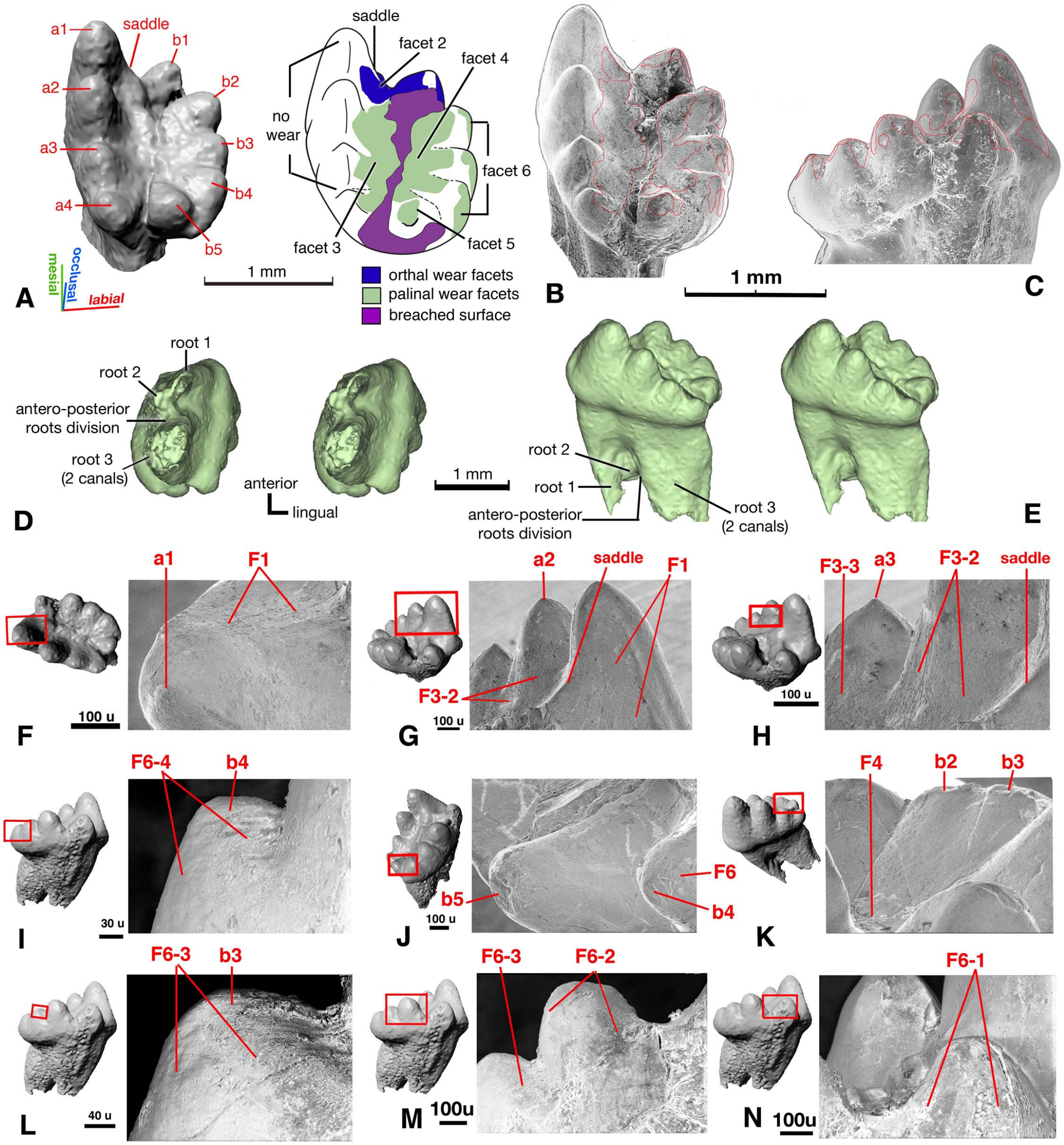
SI Appendix Fig. S4

SI – Appendix Figure S4. Haramiyavia right mandibular parts preserved on the holotype counter-slab (MCZ7/G95B). A and B. Excavated right m3 and its jaw section in medial view: paired stereo-photographs after excavation by Jenkins et al. (1997) (1) (A); stereo CT-images after excavation in medial view (B), and in lateral view (C). D. The entire right mandible with preserved teeth (i1 and m3), bony parts, and features represented by well-preserved mold outlines and surfaces. Photographed after preliminary preparation on teeth but before the excavation m3 from the slab. The three bore holes were drilled for excavation of m3 and its mandibular segment. E. The identifiable features of the right mandible and teeth on the counter-slab (MCZ7/G95B). F. Stereo photos of right mandible on counter-slab before excavation of m3 and its jaw section, showing the mandibular features on the counter-lab as found in the field. G. The location of the preserved right mandible on the entire counter-slab MCZ7/95B. Intact teeth, complementary bone parts, and corresponding mold outline and surface features on this counter-slab can be precisely matched with those preserved on the main part (MCZ7/95A).



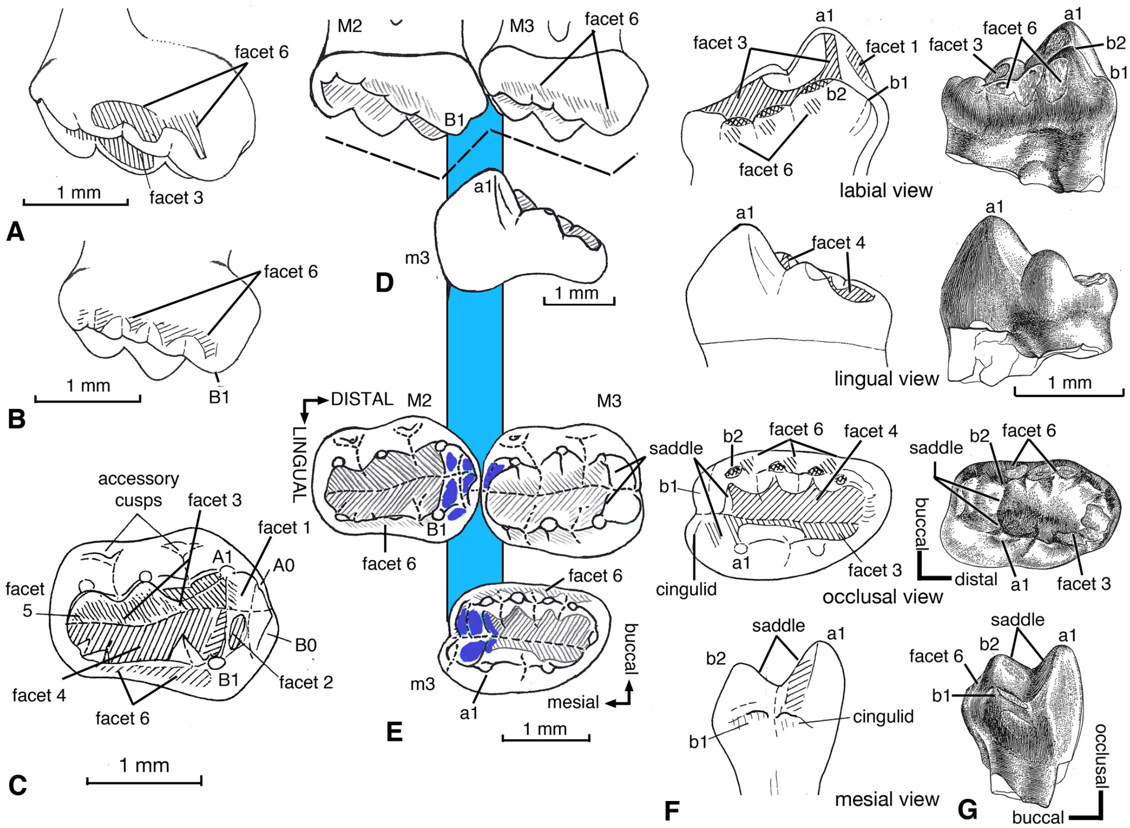
SI Appendix Fig. S5

SI – Appendix Figure S5. Haramiyavia right upper molars of the referred specimen (MCZ10/G95). A. and B. Right upper M2 SEM photo and outline for identification of molar cusps, the longitudinal furrow for occlusion and the A1-B1 saddle. C. - E. SEM photos of right M1-M3, as preserved. C. Lingual view of entire right upper M1-3, and magnified areas showing wear facets and striations on lingual aspects of M2 and M3. D. Approximately occlusal view of entire right upper M1-3, and magnified areas of wear facets and striations of M2 and M3. E. Oblique buccal view of right upper M1-3, showing no occluding furrow on the buccal aspect and absence of any striation or wear facets on the buccal side of the upper teeth. F. Outline of occlusal view of M1-M3 to illustrate the extent of wear facets (purple = damaged surfaces or fractures; blue = wear facet or striation area); M1-2 and M3 separated to show interlocking features.



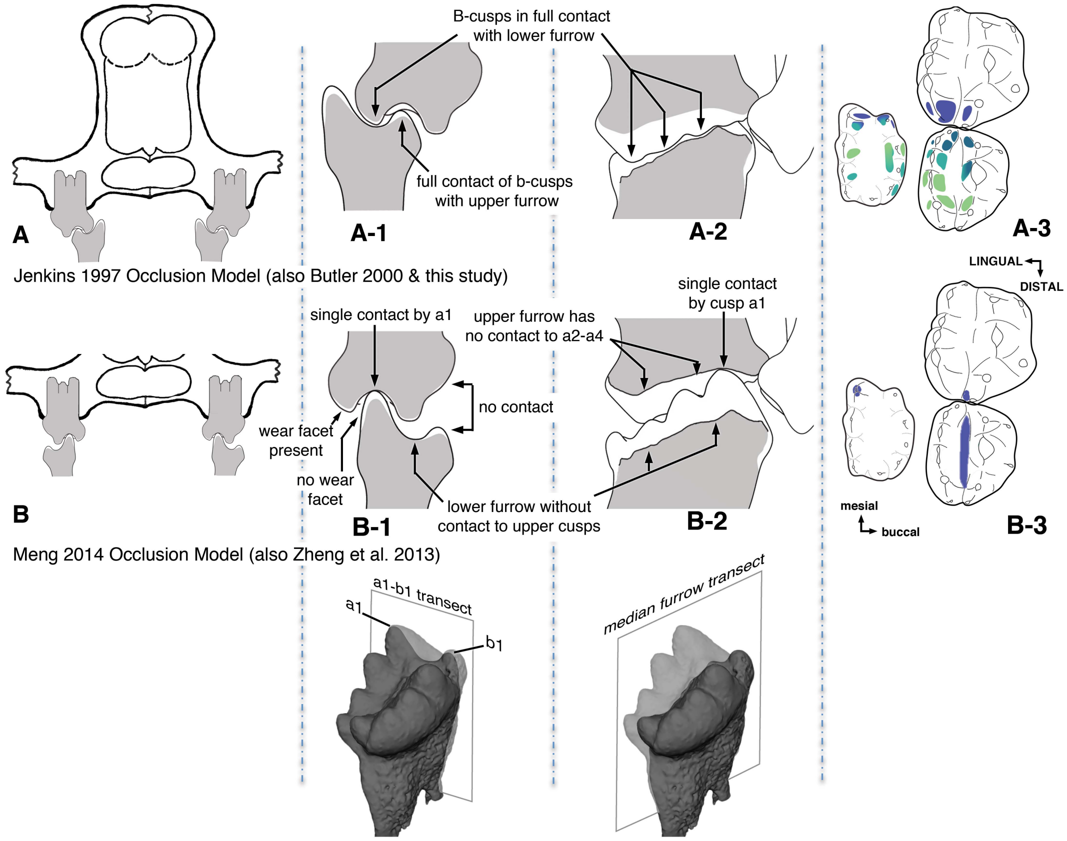
SI Appendix Fig. S6

SI – Appendix Figure S6. Haramiyavia right lower molar 3: Occlusal features and wear facets. A. CT image and outline of wear facets in posterodorsal view. B. SEM photo of m3 in posterodorsal view. C. Buccal view. Red outlines in B and C are the areas with wear facets and occlusal striations. D. Multiple roots of m3 (bottom view): anterior root 1 and root 2 are partially divided but each has a separate root canal. Roots 1 and 2 are divided from the much larger posterior root 3 that internally contains two root canals that can be seen in the flying through longitudinal sections of CT scans. E. Multiple roots of m3 (oblique lingual view): root 1 and 2 each with a root canal are confluent at their bases; larger posterior root (3) has two internal root canals. F. Facet 1 on anterolabial aspect of cusp a1 (orthal phase facet); a1 without any apical abrasion. G. Facet F3-2 on the furrow side of cusp row a2; Facet 1 on the antero-buccal side of cusp a1 and the saddle crest on the furrow side of cusp a1 separating F-1 facet from F3-2 facet. H. Facet 3-2 on cusp a2 and Facet 3-3 on cusp a3, furrow sides of cusps; the saddle crest is also visible on cusp a1. I. Facet 6-4 on buccal side of cusp b4. J. Apical wear on cusp b5 and the apical wear and buccal facet 6 on cusp b4. K. Wear facet 4 in the bottom of longitudinal furrow and on the furrow side of buccal cusps b2 and b3; apical wears on cusps b2 and b3. L. Facet 6-3 on buccal aspect of cusp b3 and apical abrasion on b3. M. Facet 6 on buccal aspects of cusps b2 and b3 and apical abrasion on b2. N. Facet 6 on buccal aspect of cusp b1 and apical abrasion on b1. Scales vary with SEM magnification.



SI Appendix Fig. S7

SI – Appendix Figure S7. Late Triassic haramiyid Thomasia: molar occlusion and wear facets (cusp and facet designation follow Clemens and Martin [6], and partly modified from Sigogneau-Russell [3]). A and B. Right upper molars in lingual view (Thomasia sp. Saint Nicholas-du-Port [SNP] collection: SNP59, SNP661, adopted with modification from ref [3]). C. Left upper molar in occlusal view (SNP661): facet designation after Sigogneau-Russell (3). D. Reconstruction of *en echelon* (step-like) occlusal pattern along tooth row, with the tallest lower cusp a1 biting into the embrasure between upper molars. E. Occlusal views of upper and lower molars. Facets 1-2 (blue facets) contact the embrasure region of upper molars during the orthal occlusion. Facets 3-6 (Grey hatch line pattern) occlude during the palinal movement of the lower tooth; facets 6 on lingual aspect of upper molars and buccal aspect of the lower. F. Right lower molar (top to bottom: labial, lingual, occlusal and anterior views of SNP665; adopted with modification from ref [3]). G. Thomasia antiqua (GIT1430/1; adopted from Hahn 1973 [4], reinterpreted as a lower tooth, flipped for comparison, from top to bottom: labial, lingual, occlusal and anterior views of a lower right tooth); well developed facet 6 on buccal side of the lower molar. Thomasia sp. (following Ref [3]) and Thomasia antiqua (4) show nearly identical molar facets as Haramiyavia clemmenseni.



SI Appendix Fig. S8

SI – Appendix Figure S8. Interpretative models of molar occlusion of <u>Haramiyavia</u>. A. The occlusal model by Jenkins et al. (1) as modified by Butler (2): Lower lingual a-cusp row occludes medial to the upper molar and the lower buccal b-cusp row occludes into the longitudinal median furrow of the upper. A-1. This model maximizes the contact between upper and lower molars by a full contact of lower b cusp-row to both sides of the longitudinal furrow of the upper. A-2. This also maximizes the upper B cusp row to the lower molar - all upper cusps B1-B4 can contact the floor of lower furrow on both sides of the lower furrow. A-3. This model generates extensive contact surfaces on both sides of upper B cusp row and also on both sides of the occlusal furrow of the upper in Occlusal Finger Print Analyser (OFA) simulation. B. Occlusal model by Zheng et al. (20) and Meng et al. (36). This posits that the lower lingual a cusp row would occlude into the upper furrow. B-1. This cannot account for the wear on the lingual sides of the upper molars. Due to the great height of cusp a1 and the height difference between a1 and a2-a4, cusps of the upper A cusp row have no possibility to contact the lower furrow. B-2. The lower cusps a2-a4 could not contact the floor of upper furrow. The entire contact of upper and lower molars would be limited to a single contact point of a1 (tallest cusp). B-3. This occlusal model shows minimal contact between cusp a1 and a single contact line in the furrow by OFA test, thus entails extensive mis-match of the known occlusal surfaces.

Appendix - Materials, Methods, Datasets and Results of Analyses

(1) SI Materials

The fossil materials of Haramiyavia clemmenseni Jenkins et al. 1997 include the holotype of H. clemmenseni Museum of Comparative Zoology MCZ7/G95, which consists of main slab MCZ7/G95A (*SI Appendix* Fig. S2) and the counter-slab MCZ7/G95B (*SI Appendix* Fig. S4), and a referred specimen MCZ10/G95 (*SI Appendix* Fig. S5). All were discovered and collected by F. A. Jenkins, S. M. Gatesy, N. H. Shubin, W. W. Amaral and collaborators in 1995 from the Tait Bjerg Beds of the Fleming Fjord Formation in East Greenland (1). The fossil site is determined to be of the Rhaetic Age of the Late Triassic and can be as old as the Norian Age (7).

Comparison to the haramiyid Thomasia (*sensu* Sigogneau-Russell [3]) is based on SEM photographs and illustrations in the literature (2-6).

(2) SI Methods

Fossil Preparation History and Documentation – The holotype of Haramiyavia is preserved in the main slab (MCZ7/G95A) and counter-slab (MCZ7/95B) that were already split but within one meter of each other when found by Stephen M. Gatesy in the field. The majority of the bones of the premaxilla and both mandible are preserved on the main slab (*SI Appendix* Fig. S2). The main slab has preserved all major features on the medial aspect of right mandible with original periosteal surface, or bone with broken surface plus mold outline (*SI Appendix* Fig. S3). The counter slab has preserved the remaining structure of the right mandible in bony features, including the medial ridge overhanging the postdentary trough, a part of the dentary condyle, the impression-mold outline of mandibular angle, outline of the postdentary trough, the incisors, m3, and the Meckel's sulcus. All features on the counter-slab MCZ7/G95B can be matched with the corresponding bony or mold outline features for the same structures of the right mandible in the main slab MCZ7/95A.

After the preliminary preparation of both slabs by William A. Amaral, all features preserved in original bones and in mold outlines were completely documented in paired stereo photographs by Farish A. Jenkins Jr., William A. Amaral, and A. H. Coleman. The left mandible, which had been naturally exposed in medial view on the main slab (*SI Appendix* Fig. S2), was reinforced and embedded in resin plastic, and then excavated to expose its buccal aspect (*SI Appendix* Fig. S1-C). The medial features on the left mandible, originally documented by stereo photographs (*SI Appendix* Fig. S2) but now under the protective resin plastic, have been extracted by CT scanning (*Supporting Information* Movie S1). The right mandible was naturally exposed in its medial view on the main slab (*SI Appendix* Fig. S3). It was also reinforced and embedded by resin plastic, and then excavated to expose the buccal side of the mandible (*SI Appendix* Fig. S1-A). The photographed medial features on the left mandible (*SI Appendix* Fig. S3) are now under the protective resin plastic, but can be detected, just as well, by CT scanning and extracted by 3D image analysis of CT data (*Supporting Information* Movie S1).

The counter-slab MCZ7/G95B has evidence of all major mandibular features. A short section of the right mandible bearing the right m3 was preserved. This bony part shows the outlines of the anterior-most part of postdentary trough, the Meckel's sulcus and the posterior opening of mandibular canal (ref [1]: fig 2). The postdentary trough and Meckel's sulcus in this in situ mandibular bone fragment (ref [1]: fig 2) are contiguous with these features on the rest of the mandible in the main slab (*SI Appendix* Fig S4). After these features of the counter slab were documented by stereophotography, the right m3 with its immediate mandibular section was extracted for SEM photography of the tooth crown (Ref [1]: fig. 2). The dentary condyle (incomplete bone) and the bones of the medial ridge overhanging the postdentary trough are left intact in the counter-slab. The latter structures have been extracted, in their entirety, by CT scanning, and documented by 3D rendering of CT data (*Supporting Information* Movie S1).

The referred specimen MCZ10/G95 of the maxilla with upper molars was found at the same fossil site. Its upper teeth are larger than the lower teeth of the type specimen (MCZ7/G95) (Ref [1]: fig. 3), but Jenkins et al. (1) considered the referred specimen to be from a larger individual of Haramiyavia clemmenseni, based on the match of occlusal features between the two (ref [1]: fig. 4).

We can now re-affirm the conspecific status of the two specimens with additional observation. The larger tooth size of MCZ10/G95 is partly from the greater width of uppers relative to lower molar width. An upper-lower width difference is now known in the larger samples of the haramiyid Thomasia and the theroteinid mammaliaforms (2, 3, 6). A greater width of the uppers is a feature of haramiyids as a group. By our SEM examination, the greater width of the uppers is formed largely by the buccal shelf, which bears non-occlusal accessory cusps (AA1-AA2). A similar, non-occlusal buccal part on wider upper molars is a plesiomorphic feature of many mammaliaforms (10). Although differences in width and length should be both corrected for wear facet analysis, the width difference is less of an issue than the length difference of MCZ10/G95.

Regarding the length of molars, the M3 to M1-2 length ratio is similar to the m3 to m1-2 length ratio (ref [1]: fig. 3) and indicates a comparable size gradient from the first to the third molar of the uppers (MCZ10/G95) and the lowers (MCZ7/G95). By 3D print models of the upper and lower molars, we determined that the intact lower m3 is 83% in length of upper M3. The reconstituted lower m1-3 series and upper M1-3 (after correction of minor deformation due to fossilization) show similar length difference.

We noted that M1, M2 and M3 are slightly separated from each other, and their tilting may be accentuated by a slight post mortem distortion (ref [1]: fig. 1). But based on 3D image rendering of the CT scan, we can confirm that the posterior bending of the multiple roots from the crown-root junction is not caused by distortion. Their corresponding root alveoli in the maxillary bone are intact. Overall, the distortion of teeth and the maxilla is limited. The *en echelon* pattern of crown occlusal surfaces and the mesial drift pattern of the roots are bona fide. In the restoration, we corrected for the minor post mortem gaps between the upper molars in Fig. 2C and 2E (buccal and lingual views of M1-M3, but not Fig. 2D of the root view).

CT-Scans of Fossil – The main slab and counter slab, the excavated mandibles and teeth were scanned in the Varian 450kv scanner in the Varian Medical Systems facility in Lincolnshire, Illinois (www.varian.com), and then the main slab was scanned again with the UChicago PaleoCT (GE Phoenix v/tome/x 240kv/180kv scanner) (http://luo-lab.uchicago.edu/paleoCT.html). The left mandible was also scanned at UChicago PaleoCT. Resolution of these datasets is listed in Table S1.

Table S1. CT scanning of Haramiyavia specimens and dataset resolution

Specimens	Resolution	Scanner
Main slab MCZ7/G95A	x and y = 46 μm z = 48 μm	Varian 450kv scanner
	voxel size 30.7 μm	UChicago v/tome/x 240/180kv scanner
Counter slab MCZ7/G95B	x and y = 29.3 μm z = 30 μm	Varian 450kv scanner
Right jaw excavated from main slab MCZ7/G95A	x and y = 9.8 μm z = 9 μm.	Varian 450kv scanner
Left jaw excavated from main slab MCZ7/G95A	voxel size = 10 μm	UChicago v/tome/x 240/180kv scanner
Upper molars MCZ10/G95A	x and y = 9.8 μm z = 9 μm	Varian 450kv scanner
Lower m3 and fragment excavated from Counter slab MCZ7/G95B	x and y = 9.8 μm z = 9 μm.	Varian 450kv scanner

3D Segmentation and Image Analysis – All image processing and segmentation analysis was carried out by April I. Neander of the Department of Organismal Biology and Anatomy of the University of Chicago, in consultation with Zhe-Xi Luo. Scan datasets were processed using Mimics software to render 3D virtual reconstructions.

A composite reconstruction of a complete mandible was reconstituted using Maya software from Mimics STereoLithography STL files of both the left mandible excavated from the main slab, and the right mandible split onto the main slab, and counter-slab. The composite mandible and full dentition (Fig. 1 and *Supporting Information* Movie S1) is rendered from the intact bone, teeth and tooth parts (dark red in Fig. 1 and SI Movie 1), and the preserved bone with broken surface (brown in

Fig 1) from both mandibles, supplemented by well-preserved outlines still on both slabs, as well as those documented by the original paired stereo photographs prior to the excavation of the mandibles and lower m3 from the slabs.

Scanning Electron Microscopy (SEM) of Tooth Features – Wear patterns were studied by SEM imaging of the extracted right lower m3 (MCZ7/G95B) and the upper M1-3 (MCZ10/G95) in 1996-97 at Museum of Comparative Zoology at Harvard, and then again in 2014 in the Field Museum Natural History SEM facility. The SEM photos of the occlusal wear patterns are presented in Fig. 2 and *SI Appendix* Figs. S5, S6.

(3) SI Analysis of Tooth Occlusion and Functional Simulation

Occlusal Modeling – Enlarged molar models were printed by 3D printer (MakerBot 2) from the STeroLithography (STL) files of 3D rendering of CT datasets of the teeth. The size difference between the referred specimen MCZ10/95 and the holotype (MCZ7/G95B) was corrected by scaling upper M1-3 by 83%, similar to morphological analyses of Jenkins et al. (Ref[1]: fig. 3) (1) and Butler (2). The occlusal contacts of the Upper M2-3 and lower m3 was re-enacted with the scale molar models according to the striation patches on the enamel surfaces and apical wears on the cusps of both the upper molars (Fig. 2 and *SI Appendix* Fig. S5) and the lower m3 (Fig. 2 and *SI Appendix* Fig. S6).

Occlusal Fingerprint Analyser (OFA) Simulation of Occlusal Function – Molar occlusion in <u>Haramiyavia</u> was further tested by the Occlusal Fingerprint Analyser software to quantitatively characterize the contacts ("collision") of upper and lower teeth, and to simulate the kinematic sequence of occlusion (http://www.for771.uni-bonn.de/en/ofa_info). The position and orientation of tooth wear facets are treated as the "occlusal fingerprint" of a dentition (9, 51). The OFA uses the virtual 3D upper and lower tooth models reconstructed from CT scan data to virtually simulate occlusal contacts ("collision detection") during dynamic process of chewing movement of teeth. The chewing path of the teeth is guided by topographical features, such as wear facets and contact surfaces (51). OFA is especially informative for inferring the function of fossil teeth as previously shown (38, 52). Thus, the match of wear pattern by 3D print tooth models is complemented and further tested by the OFA kinematic simulation of process of chewing (*Supporting Information* Movie S1).

In this study, we utilized the Occlusal Fingerprint Analyser simulation (*Supporting Information* Movie S1) to test the alternative hypotheses (or models) of occlusion, quantitatively, for their respective fit of the original fossil data (*SI Appendix* Fig. S8).

(4) SI New Characters of <u>Haramiyavia</u> and Phylogenetic Analyses

Background - In the first report of the discovery of <u>Haramiyavia</u>, Jenkins et al. (ref [1]: pp. 716, 718) briefly mentioned several mandibular features, including the condylar process, the inferred presence of a small dentary condyle, and a "large sulcus for postdentary bones." Jenkins et al. (1) also illustrated a masseteric fossa in the angular region of mandible (Ref [1]: fig. 1), the anterior-most part of the postdentary trough posterior to the inferior alveolar foramen, and a short section of Meckel's sulcus. Of the two relatively well preserved mandibles (Fig. 1 and *SI Appendix* Figs. S1-S3; *Supporting Information* Movie S1), only a short fragment of right mandible bearing m3 was presented by photographs in the first report (ref[1]: fig. 2; reproduced here as *SI Appendix* Fig. S4A). The majority of mandibular features have not been described in detail, although the features can be seen on the original fossil material, and have been scored into a phylogenetic matrix including Haramiyavia by Zhou et al. (19).

Averianov et al. (ref[17]: p.106) and Bi et al. (ref[18]: supplementary information, p. 20) questioned the mandibular features related to the postdentary bones of Haramiyavia as illustrated by Jenkins et al. (1). Bi et al. (18) further questioned other features of Haramiyavia (e.g. the dentary condyle, etc) and treated all mandibular features related to the coronoid process, the postdentary trough, and the dentary condyle as unknown ("?") in their phylogenetic analysis. Following the critical comment on figure 2 of Jenkins et al. (1) by Averianov et al. (17), Krause et al. (23) also treated several key mandibular features as unknown ("?") for Haramiyavia in phylogenetic analysis.

Here we provide the paired stereo photographs of Haramiyavia fossil material as originally exposed before the excavation of jaws and teeth, and by new CT scanning of the slabs and the excavated fossil parts, for a better documentation of the mandibular and skull features for Haramiyavia clemmenseni, as summarized in Table S2.

Table S2. Newly Observed Cranial and Mandibular Features of Haramiyavia

Character Name	Character State	CT and Stereo photographs
Septomaxilla facet (preserved on premaxilla)	Present	Fig S1
Dentary condyle	Present	Fig S1, S3
Dentary condyle size and shape	Small, compressed dorsoventrally	Fig 1, S2
Dentary peduncle ("condylar process")	Present	Fig 1
Dentary condyle direction	Posterior	Fig 1, S3
Coronoid process angle	Reclined	Fig 1
Alignment of last molar to coronoid	Partially medial	Movie S1
Masseteric fossa anterior and ventral crests	Low crests	Fig 1
Masseteric fossa anterior extension to mandible body	Absent	Fig 1, S1
Mandibular foramen in masseteric fossa	Absent	Fig 1, S1
Lateral ridge extending from D-condyle into	Present	Fig 1, S1

masseteric fossa		
Mandibular angle region	Present (rounded)	Fig 1, S2-S4
Inflected angle	Absent	Fig 1
Angular region A-P position	Anterior to coronoid	Fig 1
Angular region D-V position	Level with mandibular margin	Fig 1
Posterior-most mental foramina on mandible A-P position	In canine region,	Fig 1
Posterior-most mental foramina on mandible A-P position	Larger of the two foramina at mid mandibular depth	Fig. S1
Medial ridge over postdentary trough of mandible	Present	Fig 1, S2-S4
Postdentary trough behind tooth row	Present	Fig 1, S2-S4
Coronoid bone or its attachment fossa	Present	Fig 1, S2
Meckel's sulcus	Present	Fig 1, S2-S4
Curvature of Meckel's sulcus	Parallel to mandible margin	Fig 1, S2-S4
Groove for replacement dental laminae	Absent	Fig 1, Movie S1
Medial concavity (fossa) for angular reflected lamina	Present	Fig. 1
Medial pterygoid shelf on ventral border of mandible	Absent	Fig. 1
Dentary symphysis	Unfused	Fig. 1
Symphysis orientation	Anterodorsal	Fig. 1
Post-incisor diastema	Present	Fig. 1, S3

Re-Analysis of Matrix of Bi et al. (18) with new data - The new features summarized in Table S2 have certainly improved the available characters for estimating the placement of Haramiyavia and the closely related Thomasia in mammaliaform phylogenies. Bi et al. (18) treated mandibular and dental features of Haramiyavia in two significantly different ways from Jenkins et al. (1) and Zhou et al. (19):

First - All features related to the postdentary trough and the dentary condyle were treated as unknown ("?") by Bi et al. (18). Thus Bi and colleagues have excluded many informative mandibular features that can be observed on the original specimens, some of which have been also reported by Jenkins et al. (1). Differences between the Bi et al. (18) treatment of Haramiyavia and what is now documented is summarized in *SI Appendix* Table S3.

Second - Bi et al. (2014 [18]; also Zheng et al. 2013 [20]; Meng et al. 2014 [36]) proposed a novel upper-lower molar occlusion for Haramiyavia, which is different from that of Jenkins et al. (1), Butler (2), Kielan-Jaworowska et al. (10), and Clemens and Martin (6). All previous studies have the lower molar lingual cusp-row a1-a4 occlude medial (lingual) to the upper molar lingual row (*SI Appendix* Fig. S8–A). By contrast, Bi et al. (18) and Meng et al. (36) proposed that the lower molar lingual row occludes into the median furrow of the upper molar (*SI Appendix* Fig. S8-B).

In our revision of the matrix by Bi et al. (18) (as presented in extended data figure 9 of Bi et al. 2014 [18]), we have modified (or offered different interpretation for) the scoring of 38 of the 40 mandibular characters for Haramiyavia in the Bi et al. 2014 (Table S3). We further modified some of the skeletal features of the eleutherodontids recently published by Bi et al. (18) by our own re-evaluation of these fossils.

Our re-analysis by PAUP (53) of the revised matrix (*SI Appendix*) has obtained the strict consensus tree from 215equally parsimonious trees (each has Length = 2438 steps; Consistent Index [CI] = 0.341; Retention Index [RI] = 0.803), from the standard procedure of 1000 replicates of heuristic search, using the same search parameters as Bi et al. (18).

After mandibular features preserved in the fossil material of Haramiyavia are incorporated into the phylogenetic analysis, we demonstrate that Haramiyavia and Thomasia are a part of haramiyidans placed outside the crown Mammalia clade. Thus Haramiyavia is a stem taxon of the mammaliaforms, and cannot be placed in the crown Mammalia (Fig. 4: Hypothesis B).

The nexus file of the revised matrix from Bi et al. (18) is provided here in Supporting Information for others to independently verify these search results (*SI – Appendix*).

Re-Analysis of Matrix of Krause (2014) with new data - Krause et al. (23) also included both Haramiyavia and Thomasia in their phylogenetic analysis of the gondwanatherian Vintana. Krause et al. (23) followed, in part, the earlier comment on mandibular morphology of Haramiyavia by Averianov et al. (17) and further argument by Bi et al. (18) that Haramiyavia lacked certain mandibular features. Thus, Krause and colleagues (23) treated the key characters of the postdentary trough and dentary condyle to be unknown ("?"). By such treatment of morphological features of Haramiyavia, Krause and colleagues also placed Haramiyavia as a member of the allotherian clade that includes multituberculates, Vintana and other gondwanatherians, within crown Mammalia.

From our CT scanning, SEM and stereo photographs of the original fossils of Haramiyavia, as well as a reanalysis of Thomasia, we added the newly observed features of Haramiyavia into the Vintana matrix of Krause et al. (23). SI Appendix documents our modification of the character scoring on Haramiyavia and Thomasia of the Krause et al. 2014 character list and matrix (23).

Our re-analysis by PAUP of the revised Krause et al. (23) matrix (SI Appendix) has used the identical search parameters as Krause et al. (23) and we also followed Krause et al. (2014) for exclusion of taxa in their analyses. We obtained the strict consensus of 11 equally parsimonious trees (each has length = 2050 steps, CI =

0.302; RI = 0.689), from the standard procedure of 1000 replicates heuristic search by PAUP.

After introducing the newly documented morphological features of Haramiyavia into the same matrix of Krause et al. (23), we show that Haramiyavia and Thomasia are a part of haramiyidan group and that the haramiyidan clade is placed outside the crown Mammalia. Haramiyavia is a stem taxon of the mammaliaforms. This is consistent with the original hypothesis of Jenkins et al. (1) that haramiyidans are not closely related to multituberculates in the allotherian clade (Fig. 4: Hypothesis B).

We note that excluding haramiyidans from the crown Mammalia does not contradict the sistergroup relationship of gondwanatherians and multituberculates. Instead, it lends additional support for the gondwanatherian-multituberculate clade proposed by Krause et al. (23), as the clade is relatively robust to the impact from alternative interpretation of characters of haramiyids.

Nexus file of the revised matrix from Krause et al. (23) is provided as a part of this Supporting Information, for others to independently verify these search results.

(5) SI - Explanation on Revision of Bi et al. (2014) Matrix Scorings

Mandibular Features of Haramiyavia

Jenkins et al. (1) briefly mentioned and illustrated several features of the mandible. Additional mandibular features based on the Haramiyavia fossil material were coded in a phylogenetic matrix (although not fully described) for estimating the phylogenies of haramiyidans including Haramiyavia by Zhou et al. (19). However, the features identified in the published figure of the mandibular segment by Jenkins et al. (1) were questioned and misinterpreted by Averianov et al. (17). Bi et al. (18) followed the morphological opinion by Averianov et al. (17) and further disputed additional mandibular features of Haramiyavia. Bi et al. (18) treated many mandibular features of Haramiyavia as unknown and some as inapplicable. This morphological reinterpretation of the known features of Haramiyavia influenced their phylogenetic analysis to the Late Triassic haramiyids (including Haramiyavia) in the multituberculate clade.

To assess the full phylogenetic implications of the newly documented features of Haramiyavia, we are here adding these newly observed features into the same matrix on mammaliaform phylogeny by Bi et al. (18). This matrix was an expanded and partially modified version from Zhou et al. (19) (Bi et al. 2014 [18]: extended data Fig. 9). Our changes on the scorings the mandibular character for Haramiyavia from the new CT scans, SEM and stereo photographs of the original fossils of Haramiyavia are listed in Table S3.

Table S3: Revised character scoring of Bi et al. (18) according to the current new study on the two mandibles of Haramiyavia clemmenseni as preserved on the main slab (MCZ7/G95A) and counter-slab (MCZ7/G95B) (Fig. 1, and *SI Appendix* S1-S4).

Bi et al 2014 Character #	Character Name	Bi 2014 coding of Haramiyavia	Revised coding for Haramiyavia	CT rendering and stereo photo documentation
1	Postdentary (P-D) trough	?	0	Fig. 1, S2-4, Movie S1
2	Surangular-Prearticular scars	?	?	Fig. 1, S2-4
3	Medial ridge above the P-D trough	?	0	Fig. 1, S2-4, Movie S1
4	M-sulcus development	?	0	Fig. 1, S2-4, Movie S1
5	M-sulcus curvature	?	0	Fig. 1, S2-4, Movie S1
6	Crompton's dental lamina groove	?	0	Fig. 1, S4, Movie S1
7	Mandibular angle	?	0	Fig. 1, S1-S3
8	Mandibular angle-region position	?	0	Fig. 1, S1-S3
9	D-V elevation of angle & its region	?	0	Fig. 1, S1-S3
10	Flat ventral surface	?	0	Movie S1
11	Exoflection of angle	?	0	Fig. 1, S1, Movie S1
12	Coronoid or its scar	?	0	Fig. 1, S1
13	Mandibular foramen position	?	0	Fig. 1, S1
14	Mand. for. vertical elevation	?	0	Fig. 1, S1
15	Concavity for angular	?	0	Fig. 1, S1
16	Splenial scar	?	?	
17	Post-dentary reaching into CMJ	?	0	
18	Surangular to SQ	?	?	
19	Pterygoid muscle fossa	?	0	Fig. 1, S2-4
20	Med. Pteryg. ridge along mandible	?	0	Fig. 1, S2-4
21	Masseteric fossa ventral border	?	0	Fig. 1, S1
22	Masseteric fossa anterior crest	?	0	Fig. 1, S1
23	Anterior extension of	?	0	Fig. 1, S1

	mass fossa			
24	Labial man. foramen in mass. fossa	?	0	Fig. 1, S1
25	Mass fossa vertical shelf	?	0	Fig. 1, S1
26	Post mental foramen position	?	0	Fig. 1, S1
27	D/SQ articulation	?	0	Fig. 1
28	Dentary condyle shape	?	2	Fig. 1
29	Orient D-condyle & peduncle	?	0	Fig. 1, S1, S2
30	Ventral border of D-peduncle	?	0	Fig. 1, S1
31	Gracile D-peduncle	?	0	Fig. 1, S1, S2
32	D-condyle elevation to molar alveoli	?	0	Fig. 1, S1, S2
33	Post tilting of coronoid process	?	0	Fig. 1, S1
34	Gracile base of coronoid process	?	0	Fig. 1, S1-S4
35	Height of coronoid process	?	0	Fig. 1, S1-S4
36	Ultimate molar to coronoid process	?	0	Movie S1
37	Jaw occlusal movement	0	2	Fig. S5-8, Movie S2
38	Mandibular symphysis	?	1	Fig. 1
39	Rostral mandible spout	?	0	Fig. 1, Movie S1
40	Dentary depth to length	?	0	Fig. 1, S1

Summary on Revision of Dental Characters of Haramiyavia and Thomasia

We re-studied the teeth of Haramiyavia (Figs. 2, 3, and *SI Appendix* Figs. S6, S7) by SEM and CT scanning. The revised dental formula of Haramiyavia is I4.C?.P?.M3/i3.c1.p4.m3, with one fewer lower incisor than previously reconstructed by Jenkins et al. (1). We also have gather information on Thomasia from published literature (Figs. 3, S7) (2-4, 6, 39). Based on this new work, we modified the some of the scoring by Bi et al. (18) on dental characters of Haramiyavia and Thomasia.

Summary on Revision on Character Scorings for the Jurassic eleutherodontids

One co-author (Zhe-Xi Luo) of our team had the opportunities to briefly examine the type specimen of Arboroharamiya Zheng et al. (20) (courtesy of Mr. Xiaoting Zheng and Professor Shundong Bi), the Shenshou paratype 1 (courtesy of Prof. Shundong

Bi), the Shenshou lui paratype 2 (JZT-CK005A, B) and paratype 3 (JZT-D061) (courtesy of Mr. Haijun Li, Ms Zhijuan Gao, and Ms. Xianghong Ding of Jizangtang Fossil Museum of Beipiao, Liaoning), and the type specimen (IVPP 16707) of Xianshou linglong (courtesy of Profs. Yuanqing Wang and Shundong Bi). This study of the originals was complemented by information from the photographs published by Bi et al. (18). While we endorse most of the characters scored by Zheng et al. (20) and Bi et al. (18) on the new eleutherodontid taxa, we nevertheless offer our alternative interpretation on some features of these fossils. By our own assessment of fossil specimens, we propose to change the scorings by Bi et al. (18) for Arboroharamiya, Shenshou, and Xianshou, as summarized below.

Arboroharamiya's scoring has been changed on these characters (the character state after correction is in the parenthesis):

5(0); 13(2); 19(0); 23(0); 25(0); 26(0); 29(0); 30(3); 51(?); 68(?); 69(?); 70(?); 74(?); 226(0); 233(0); 235(0); 281(0); 292(0); 298(0); 307(0); 309(0); 310(0).

Shenshou's scoring has been changed on these characters (character state after correction is in the parenthesis):

5(0); 13(2); 17(0); 19(0); 21(1); 23(0); 25(0); 26(0); 29(0); 30(3); 68(?); 69(?); 70(?); 72(0); 74(?); 86(0); 156(?); 220(1); 226(0); 233(0); 235(0); 243(0); 244(0); 247(0); 248(0); 251(0); 256(0); 285(0); 286(0); 292(0); 298(0); 299(0); 307(0); 309(0); 310(0); 312(0); 314(0); 315(0); 317(0); 318(0); 320(0); 321(0); 322(0); 324(0); 325(0); 326(0); 327(0); 331(0); 346(0); 361(0); 376(1).

Xianshou's scoring has been changed on these characters (character state after correction is in the parenthesis):

5(0); 17(0); 19(0); 21(1); 23(0); 25(0); 26(0); 29(0); 30(0); 59(?); 69(?); 70(?); 74(?); 216(?); 219(?); 220(0); 226(0); 233(0); 251(0); 281(0); 285(0); 286(0); 292(0); 298(0); 307(0); 309(0); 310(0); 312(0); 314(0); 315(0); 317(0); 318(0); 320(0); 321(0); 322(0); 324(0); 325(0); 326(0); 327(0).

We provide below the revised matrix of Bi2014 and the log of PAUP searches on this revised matrix, and the revised Bi2014 matrix in nexus format is also provided.

```
P A U P *
Version 4.0b10 for Macintosh (PPC)
Thursday, September 24, 2015  11:54 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 "Xiansho(Bi14)15Sept15-ReRun.NEX" begins...

Data matrix has 114 taxa, 497 characters
Valid character-state symbols: 012345
Missing data identified by '?'
Gaps identified by '-'

*** Skipping "MacClade" block

Processing of file "Xiansho(Bi14)15Sept15-ReRun.NEX" completed.

Input data matrix:

                           111111111122222222223333333333444444444455555555556666666666777777777
Taxon/Node        123456789012345678901234567890123456789012345678901234567890123456789012345678
------------------------------------------------------------------------------------------------
Thrinaxodon       000000000000000000000000000?0?0?0?010000????????????0?0?000000000?????????00??
Massetognathus    000010000000000001000000000?0?0?0001000????????????0???200000000?????????20??
Probainognathus   00000000000000000100000000?000?00010000????????????0???000000000?????????00??
Tritylodontids    000010000000000000000000010?000?3000200????????????10??20?000000????????021??
Pachygenelus      0000000000000100000000000000000?2000100?????0??????1?1?00010000??????????00??
Adelobasileus     ??????????????????????????????????????????????????????????????????????????0???
Sinoconodon       000000100000000000000000110100000001000??00??????00?11000110000?00?0????00??
Morganucodon      0000101000000000000000000020010000000001000??00?0000001?01000110200?00?0????00?0
                                             1
Megazostrodon     00001000000000000000000002002001000010000??00?0000?01?00000110200?00?0?0??00?0
Haldanodon        00000110001000100010000000210100100001000??00?0000000?01000110201010?0?0??00?0
Castorocauda      00?00110001???1?00000000002101001000010000??00?0??0????100011020101 0?0????00?0
Megaconus         00000?10000001?000000000?220100?000210010000 0?????011??2?0112201??30000221??
Eleutherodon      ?????????????????????????????????????????1????0????????????????120????????1122????
Sineleutherus     ?????????????????????????????????????111?1????????21??2?0?120?0??301?????21??
Thomasia          ?????????????????????????????????????????00001??????0?0??0??00?000???101000 21??
Haramiyavia       0?0001000000000?0?0?00000000100000000000100????????????0??0?0000000??200100021??
Arboroharamiya    11120130000120 21?011110000220300100021011111110??????21??2?3001000?????210221??
Xianshou linglon  111201300001202100112100002203001000210111111110?????021??2?3001000?????111021??
Xianshou songae   11120130000120210011210000220300100021011111110?????021??2?3001000?????111021??
Shenshou          11120130000120210011210000220300100021011111100?????020??2?2002000?????110021??
                                                                       1
Rugosodon         1112?10??00?302?1010212010222400100021011000 1??????030??2?00001?0????1000121??
Kuehneodon        1112?10??0013021101021201022240010002101100011?????030??2?000012 0??3110000 21??
Sinobaatar        1112?10??0023021101021201022240010002101100010?????030??2?000001 0??2010001 21??
Plagiaulacids     1112?10??0013021101021201022240010002101100011?????030??2?000012 0??2110001 21??
                             2
Cimolodontans     1112?10??0023021101021201022140010002101100000?????030??2?0000000??2000001 21??
                                              2  12          1                            2
Hadrocodium       1??2?130010?4021100000000002001002 00?01000??00?0000101?10000110000?0??0????00?0
Shuotherium       0010110??0000021??000?00?0????0?00010100 0????????????0?11111000011??0?0????13?2
Pseudotribos      0?10011000?0001???00??????21010100011 1000??????0???00?1111 10000?1110?0????13?2
Asfaltomylos      00121121100000 21??0022000021310120010??00??????????????11011?0?????????0????13?2
Ambondro          ?????1???00????1?????????0?????0???0?0??00???????????????1213 1?0??110???0????13?2
Ausktribosphenos  001001201000002 1??0022000 02??101200101000??00??????????1213100001101 1?0????13?2
Bishops           01?10120100?0021??0022000021310120010?000??00??????????121310000?1011?0????13?2
Teinolophos       110021201002302 1??0022000?2131012001 0??00??00????????????????0????????????????3?2
Steropodon        011001???0??00?1?????????????????????10???????00?????????????????0??????????0????13?2
Obdurodon         11?2?120100230211011220001213111211101 0?0??00??????????101310 0??00????0????13?2
Ornithorhynchus   11?2?100100230211011220001213111211101000??00????????????????????????????????????13?2
                                                      2
Tachyglossus      11?2?10??0024021100000000002131 11??1?01000??00????????????????????????????????????????
Fruitafossor      11?0014000020021??110000112101011001?1000??00?0000000?10?0010000 0?0??0?????????
Gobiconodon       11?1010??001102110122100112114001001 01000??00?0000001?1001011001000 0?0????00?0
                             2
Repenomamus       11?1010??0021021101221001121140010010 1010??00?0000001?110101100100 00?0????00?0
Amphilestes       11?11?0??00210 2???122??0??2114002002 01?00??00??????????11010?1000000?0????00?0
Yanoconodon       11?1010??00210211012 21001?22140010000 1000??00?0000001?0000011000000 0?0????00?0
Jeholodens        11?1010??00?1021101 2??001?2214001000 01000??00?0000001?0101011000000 0?0????00?0
Trioracodon       11?10?0??0021021??12210010221400100001000??00?00000?1?010101100001 00?0????00?0
Priacodon         11?1010??0021021??12210010221400100001000??00?0000001?0001011001010 0?0????00?0
Tinodon           1??11????001021??121?00???104?130?00??00??????????????01010?00000?00?0????1201
                             1
Akidolestes       1????10??00?20????12210010211401100111000??00?00000?1?11010000000120?1????1302
Spalacotherium    1111010??001202?????21001021140110011 1000??00?00000?1?11010000000100?1????1312
Zhangheotherium   11?0010??0012020??1221001?21140101011 1000??00?0000011?11010000001?00?0????1311
Maotherium        11?0010??0012020??12210010211401010111000??00?0000011?1101000001?00?0????1311
Dryolestes        11?1011100012020??11210?0121130120011 1000??00?0000011?00000110001?00?0????1301
Henkelotherium    11?1011100012021??112101??21130120011 1000??00?00000?1?00000 1100?0?00?0????1301
Amphitherium      11?1111100012021??11210?01210301200111000?????11?0?0??00000???01?00?0????1301
Peramus           11?1111100012021??1121010121030120011 1000??00?1100201?0002011 0000?00?0????1301
Vincelestes       11?2?1110001202 1??1111010121130120011 1000??00?0000101?1000000000?00?0????1301
```

```
                             2
Nanolestes        11?1011100012021??112?0??1210301200111000?????????????00000?10000?00?0????1301
Kielantherium     11?101110?012?21??111101?2????0130011?000?????????????00000?10000?00?0????1301
Aegialodon        ??????????????????????????????????????00?????????????????????????????????1?01
Montanalestes     11?2?131000140 21??11120103210301300111000?????????????12020?1000100 0?0????13?2
Prokennalestes    11?1113100011021??11120102210301200111000??00?10112?1?12020010000020?0????1302
                                                                 1
Murtoilestes      ????????????????????????????????????????0????????????????????00????????????1302
Eomaia            11?1113100011021??11120102210301200111000??00?1011111?12010010000020?0????1302
Juramaia          1?12-?11000?????????1201022?0301100111000??00?1011201?1201001200?020?0????1302
Kennalestes       11?2?1310001402110111200022???0?200111000??00?1111201?100200120001 00?0????1302
Asioryctes        11?2?13100014021101112000221030130011100 0??00?1112201?11020012000010?0????1302
Ukhaatherium      ?1???????00?40??????????022???0??00?11000??00?1112201?11020012000020?0????1302
Zalambdalestes    11?2?111000140211011120002210301200111000??00?1112211?02122012000120?0????1302
                        3    2           1
Daulestes         11?2?131000240211011120002210301200111000?????????1??1?????0120???00?0????1302
Aspanlestes       ?????1????0??0??????????1??????0???0?1?0?0??00?11112?1?1?010?100000?0?0????1302
Eoungulatum       ?????1??????????????????1??????0???0?1???0??00?10110?1???????100??????0????1302
Cimolestes        1??2?1010?024021 1?111200?2210301 2?0111000??00?10122?1?11010012000010?0????1302
Gypsonictops      1??2?10100024021 1?111200?2210301 2?0111000??00?11122?1?12120012000110?0????1302
Protungulatum     11?2?10100024021 1?1112000221030120011100 0??00?10120?1?12110010000010?0????1302
Erinaceus         11?2?131000241211011120002210301300111000??00?1011011?12122002000100?0????1302
Leptictis         11?2?131000240211011120002210301300111000??00?1112211?12122002000100?0????1302
Canis             111??1310102402110111100022113013001110 00??00?0100011?00110100000010?1????1102
Felis             111??1310102402110111100022113013001110 10??00?0100011?00110100000010?1????1102
Rattus            1112?11100024121101111200022 2?0110002101 0???????????0??????0000??????0????13??
Oryctolagus       1112?11100024021101111100022 2?011?1121010??00?0012000?001000000001???0????13??
Bradypus          111??13101024121101111000221 13013?0111000???????????0??????0000??????0????????
Tamandua          111??131010241211 0??????0?21?30???1??10?0??????????????????????????????0????????
Glyptotherium     111??13101024121101111000221 1301310111100???????????0??????0000??????0????????
Dasypus           111??13101024121101111000221 1301310111100???????????0??????0000??????0????????
Chaetophractus    111??13101024121101111000221 1301310111100???????????0??????0000??????0????????
Euphractus        11???13101024121101111000221 1301310111100???????????0??????0000??????0????????
Holoclemensia     ???????????????????????????????????0?1???0???????????????????110?????????????1302
Sinodelphys       11???13101 0?4021??111?0??2210301300111000??00?00??111??1010110??00?0?0????1302
Deltatheridium    11?2?141010220 21??11110004210301300111000??00?0000111?0001011000000 0?0????1302
Atokatheridium    ???????????2?????????????????????0????????00?????????????????????????????1?02
Sulestes          11?20141010220 21??111100142?1?0131011100 0??00?000011??000101100000 00?0????1302
Asiatherium       11?1?1410102402 11?111100142?0?01300111000??00?0000111?000101100000 00?0????1302
Kokopellia        ?1?1?1410?022??1??1?1100?32?????3?0111000??00?????1???0001011??00000?0????1302
                                           4
Anchistodelphys   ??????????????????????????????????0????????00???????????????1????????0????1?02
Albertatherium    ??????????????????????????????????0????????00???????????????1????????0?????302
Didelphodon       11?2?141010210 21??11110014211301?00111000??00?001???1?000110100000 00?0????1302
Pediomys          ???2?141010210 21??11110014211301?00111000??00???????1???????100????0?0????1302
Turgidodon        ???2?141010210 211?111100?4?11301?00111000??00???????1?00010?1000000 0?0????1302
Mayulestes        11?2?14101024?21101111001421030130011100 0??00?0000111?000101100000 00?0????1302
Pucadelphys       11?2?141010240211011110014210301300111000??00?0000111?0001011000000 0?0????1302
Andinodelphys     11?2?141010240211011110014210301300111000??00?0000111?0001011000000 0?0????1302
Didelphis         11?2?141010241211011110014210301300111000??00?0000211?0001011000000 0?0????1302
Marmosa           11?2?141010241211011110014210301300111000??00?0000211?0001011000000 0?0????1302
Caenolestes       11???14101024?211011110014210301300111000??00???????1??????0100????0?0?????302
Dasyurus          11?2?141010240211011110014210301300111000??00?0000211?0001011000000 0?0????1302
                                                                  1
Perameles         11???141010241211011110014210301300111000??00???????????????0000????0?0?????302
Dromiciops        1112?141010240211011110014210301300111000??00?000021??000100000000 00?0????1302
Thylacomyidae     111??14101024?211011110014210301300111000??00???????1??????1000????0?0?????30?
Macropus          111??141010240211011110014210301300111000??00???????????????0000????0?0?????3?2
Acrobates         111??141010241211011110014210301300111000??00???????????????0000????0?0?????3?3
Phascolarctos     111??131010240211011110014210301300110000??00???????????????0000????0?0?????3?3
Vombatus          111??141010240211011110014210301300110000??00???????????????0000????0?0?????3?3
Phalanger         111??141010240211011110014210301300111000??00???????????????0000????0?0?????3?3
Pseudocheirus     111??141010240211011110014210301300111000??00???????????????0000??????0?????3?3
Petauroides       111??141010240211011110014210301300111000??00???????????????0?00??????0?????3?3
```

Input data matrix (continued):

```
                                       111111111111111111111111111111111111111111111111111111111
                  788888888889999999999000000000011111111112222222222333333333344444444445555555
Taxon/Node        901234567890123456789012345678901234567890123456789012345678901234567890123456
------------------------------------------------------------------------------------------------
Thrinaxodon       ??0000??????????0000000???0????????????????00????????????????????????0???00???
Massetognathus    ??0400??????????0000000????????????????????00????????????????????????033300???
Probainognathus   ??0000??????????0000000???0????????????????00????????????????????????0???00???
Tritylodontids    ??24000?00??????0000000????????????????????00?00?????????????????????033300??0
Pachygenelus      ??0000??????????0000000??000???????????????00????????????????????????0???00???
Adelobasileus     ???000??????????0000000??000??????????????????????????????????????????????????
Sinoconodon       ??0000??????20??0000000?1000???0000???0????00?00???0????????0????????000000???
                                   2
Morganucodon      ??1100??????20??200000110000???0000???0????00?40???0????????0????????00000100?
Megazostrodon     ??1200??????20??200000100000???0000???0????00?40???0????????0????????00000100?
Haldanodon        ??1100??????20??2003200?0000???0000???0????00?11???0????????0????????03320100?
Castorocauda      ??1100??????2???2003200?0?00????000???0???????????????????????????????00?0?1??
Megaconus         ??240100011?????0??0?0122?????????????????????????????????????????????33401100
Eleutherodon      ??241121120?????0??0?0120?????????????????????????????????????????????443011?0
Sineleutherus     ??241120100?????0??0?0120?????????????????????????????????????????????44?011?0
                           2
Thomasia          ??240110100?????0??0?0????????????????????????????????????????????????3330???0
Haramiyavia       ??240110100?????0??0?0120?????????????????????????????????????????????333011?0
Arboroharamiya    ??241121120?????0??0?01?2?????????????????????????????????????????????33400??1
Xianshou linglon  ??241120100?????0??0?01?0?????????????????????????????????????????????43400??1
Xianshou songae   ??241120100?????0??0?01?0?????????????????????????????????????????????43400??1
Shenshou          ??241111000?????0??0?01?0?????????????????????????????????????????????33300??0
Rugosodon         ??240111000?????0??0?00?0?????????????????????????????????????????????33300??0
Kuehneodon        ??240101000?????0??0?00?0?????????????????????????????????????????????33300??0
Sinobaatar        ??240101001?????0??0?00?0?????????????????????????????????????????????33300??0
Plagiaulacids     ??240101000?????0??0?00?0?????????????????????????????????????????????33300??0
```

```
                          1   1
Cimolodontans       ??240100010?????0??0?00?0???????????????????????????????????????????33300??0
                          1  21
Hadrocodium         ??1200??????20???000000?0000???0000???0????0???????0????????0????????00000100?
Shuotherium         001200????0100?1323210?0111000010 0???0????11?110020000?0??0000000?10011200???
Pseudotribos        001200????0100?1323210?0111000?100???0????11?110020000?0??0000000?10011200???
Asfaltomylos        ??1300??????13?0210000??1110221411000111 12?????????????????????????011?0????
Ambondro            ??1300????0?1330012100??1110222411 20?11112?????????????????????????011?0????
Ausktribosphenos    ??1300????0213300121 00?0221022141220032123??????????????????????????033?0????
Bishops             ??1300????021330012100?1221022141220032123??????????????????????????033?0????
Teinolophos         ??1300????11112001201 0??2220422312 10?02?23???????????????????????????33?0????
Steropodon          ??1300????111120012110?0222042231210?02?23??????????????????????????033?0????
Obdurodon           ??1300????111120012010?0222042231210?02?2320?1???????????????0???????033300???
Ornithorhynchus     ??1?00????1?1?????2010?0222042231210??2?2320?1??????????????????????033300???
Tachyglossus        ????00???????????????????????????????????????????????????????????????????????
Fruitafossor        ??1000??????????0??0000?0???????????????????00?0????????????????????55400???
Gobiconodon         ??1200?????10??101000100?00???0000???0????00?10???0????????0????????000100???
Repenomamus         ??1200?????10??101000100?00????000???0????00?10???0????????0????????000100???
Amphilestes         ??1200?????10??101000100?00???0000???0????00??????????????????????000?0????
Yanoconodon         ??1100?????10??020000121?00????000???0????00?00???0????????0????????00000121?
Jeholodens          ??1100?????10??020000121?00???0000???0????00?00???0????????0????????00000121?
Trioracodon         ??1100?????10??100000121?00???0000???0????00?10?????????????1????????00000112?
                                 2
Priacodon           ??1100?????10??120000121?00???0000???0????00?10???0?????????1????????00000112?
Tinodon             ??1200?????100010100010 0?110000100???00??010?11???00???0???0????0?0002210????
Akidolestes         011200????01000100000130122 00?0100???00??020?11???000??0??0000000?0002220121?
Spalacotherium      001200????01000100000130112 00?0100???00??020?11???000??0??0000000?0002220121?
Zhangheotherium     001200????010001000001301110 0?0100???00??020?11???000??0??0000000?0002220121?
Maotherium          001200????0100010000013011100?0100???00??020?11???000??0??0000000?0002220121?
Dryolestes          001300????020000200000?0111000022 0??000??110?01???000??0??0001000?0002220121?
Henkelotherium      001300????020000 2?0000?011100002 20??000??110?01???000??0??0001000?0002220121?
Amphitherium        001300????00010020000 0?0011000021 0?0000??111101???000??0??0001000?0002210 1???
Peramus             001300????0001000100011001100002110000 0?0121121?0?010000??0001002000011101 21?
                                            1          1
Vincelestes         001300????000000200000100110000210??000?0120?11?0?010000??0001012000011100 01?
Nanolestes          001300????000100210001100110000210 00?00?0121?11???0?0000??10120120000111012 1?
Kielantherium       101300????000110211001101110201511000000012 0?120000100-0--100201110101 1?0121?
                                                       1
Aegialodon          ??1300????0001102110011?111020151100?11001?????????????????????????????11???21?
Montanalestes       ??1300????01021021100112012021151100111002????????????????????????????0???0?21?
Prokennalestes      201300????020110111001120120211511001110022102202001001100101101000001120121?
Murtoilestes        201300?????202101110011?0120211511 00?1100?210220200?001100101100000000112?121?
Eomaia              201300????020?1011100112??202?1511001 11??2210220200100110010??000?0001120121?
Juramaia            301300????02?????11?0112?1??2?1511001????22112202001001100101101110101120121?
Kennalestes         201300????02021021100112222031151100111002210220110100110110 10000?0001120121?
Asioryctes          201300????020210211001120120311511001110022102201101001100100000 0?0001120121?
Ukhaatherium        201300????020?1021100112012031151100111?022102201101001100100000 0?0001120121?
Zalambdalestes      201300????120310211001102222042051100011102 20?120120110110000000 0?0001120121?
Daulestes           201300????020210211001 1?1120211511001110022 0?1202101001111010000?0001120121?
Aspanlestes         311300????110210211001 1?1120121511000110022 0?120321110312100?0000?1001120121?
Eoungulatum         421300????110310211001 1?112012151110012003 20?12232111031210010000?10011200 0??
Cimolestes          311300????02021021100112212031151100112002210121110100111100000 00?0001120121?
Gypsonictops        311300????12021021100112212041151100112002210121110100111100000 00?0001120121?
Protungulatum       421300????11021021100112112012151110012013 20?12232111031000000000?1001120001?
Erinaceus           201300????110310211001101120221511100121122 0?12122111020??0000000?1003330001?
Leptictis           221300????110310211001121120411511000110122 0?12111110011110000000?1001120001?
Canis               301200????0010100000000000000010210?001210000?0102021101100011 0000?3101121001?
Felis               301200????0010100000000000000000210?001210000?01020211000?00110000?3101121001?
Rattus              ?21300????13?00040000000????42041100013?1400??2022211020??????????0033100???
Oryctolagus         ?01300????13?00040000000????210410?00?3?1300??2012111030??????????0133200???
Bradypus            ??1500?????????????003?????????????????????????????????????????????05540????
Tamandua            ????00?????????????????0???????????????????????????????????????????????????
Glyptotherium       ??1500?????????????003?????????????????????????????????????????????03330????
Dasypus             ??1500?????????????003?????????????????????????????????????????????05540????
Chaetophractus      ??1500?????????????003?????????????????????????????????????????????05540????
Euphractus          ??1500?????????????003?????????????????????????????????????????????05540????
Holoclemensia       101300????02011021100111111021151100?2100120?22011110001001001112110011 2?121?
Sinodelphys         ??1300????01011001100111111?21151100121??121122???110??????0110121100??0121?
Deltatheridium      101300????0001100110011111102115111000110012112201011000100100100102201120121?
                                 2
Atokatheridium      101300????00011001100 11?1110211511 00?0??0121?2201011000100100100102201 12?12??
Sulestes            101300????000210011001111111211511001221122112201011000100100111102201120121?
Asiatherium         201300????010310211001101111122151101122112210220211111211?0001001010011 20121?
Kokopellia          101300????01021021100110011112215110112210221?2202011001 11?1001111010011 20121?
Anchistodelphys     101300????0203102110011?01112205110113210221122022121021010101111020011 20????
Albertatherium      201300???????????????1???1???????????????21122022211021011001111120 0??2?121?
Didelphodon         201300????00031021100112111122051201?321122112202222102010100201102101120121?
Pediomys            201300????0103102110011111111220512011321122112202222102110000111101001120121?
Turgidodon          101300????010310211001111111321512011321122112202221102110000111102001120121?
Mayulestes          101300????010310211001111111221512011311022112202222002110000101102101120121?
Pucadelphys         101300????120310211001101111221512011321022102202222112111000211111001120121?
Andinodelphys       101300????120310211001121111221512010321122102202222112111000211111001120121?
Didelphis           101300????0203102110011011112215120103211221022022221120?0000211112001120121?
Marmosa             101300????0203102110011111111211512010321222102202222112 0?0000211111001120121?
Caenolestes         101300????0203102110011111113215120103212221022022221120?001021010100112012 1?
Dasyurus            101300????0203102110011111112215120103212221122022221120?001021010200112012 1?
Perameles           101300????0202102110011211113215120003212221022022221120?001021010200112012 1?
Dromiciops          101300????0203102110011011113205120103212221122022221120?000000011100112012 1?
Thylacomyidae       ????00??????????????0011??11132??1????3???4????2042??1120?00100001??011120121?
Macropus            531300????1303002000011330113204131004312400?32042211120?00100000?3001120121?
Acrobates           531300????1302102000011010113215120004212420?32042211120?0010000111001120121?
Phascolarctos       531300????1303202000011330113204130004312420?32042211120?00100100?3011120121?
Vombatus            531300????1303202000011330113204131004312420?32032211120?00100000?3011120121?
Phalanger           531300????1303202000011330013215120004312420?32042211120?00100100?3001120121?
Pseudocheirus       531300????1303202000011330013204130004212420?32042211120?00100100?3011120121?
Petauroides         531300????1303202000011330013204130004212420?32042211120?00100100?3001120121?
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Input data matrix (continued):

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                  111111111111111111111111111111111111111111122222222222222222222222222222222222
                  555666666666677777777778888888888999999999900000000001111111111222222222233333
Taxon/Node        789012345678901234567890123456789012345678901234567890123456789012345678901234
--------------------------------------------------------------------------------------------------
Thrinaxodon       ?00??????????????000000000000????00?0?0000001?????????000000000100000000000?0?
Massetognathus    ?11??????????????000000000000????00?0?000000100?????0?0000??????0000000??0?0??
Probainognathus   ?00??????????????000000000000????00?0?000000??????????0000??????0100000??0?0?0
Tritylodontids    023??????????????2?030000200????0000?0?10??11200100001000010000000?01000000000000
Pachygenelus      ?00??????????????30030000100000??0000?1?2000001?????????0000000?0??10???0000100?
Adelobasileus     ?00??????????????0??????????????????????????????????????0????????????????????
Sinoconodon       ?00?0?0??????000000000000000000331122020000001??????????100100??0?01?????0010000
Morganucodon      ?1100?0??????00000000000000000000210000000001101?????????0001000000??11?1?00??1???
                                1  1           32                        2
Megazostrodon     ?1100?0??????0001001000000000001100000000001001?????????20?200000?0110100???????
Haldanodon        ?1100?0??????000000100000000012200000000001100?????????0002????????????????????
Castorocauda      ?1100?0??????000???100?????01?00??0??0??01100??????????002??????0001000???????
Megaconus         013??????????????301400?2???2?333343000?2???12?00001101?103000?010111000000???
Eleutherodon      113??????????????1???????????????????0??????01110??01?103????????????????????
Sineleutherus     113??????????????11??????????????????????????01110??01?103????????????????????
Thomasia          013??????????????1?000??????3323????0?3???1?1?110?000??03????????????????????
Haramiyavia       013??????????????1001000010010?133?1??0000??12101100000?00????????????????????
Arboroharamiya    113??????????????411400?02???2?334443??0?3???1201110000 1?103??????01??10??????0?
Xianshou linglon  113??????????????311400002???2?334443??0?3???1201110000 1?103??11?101??100???????
Xianshou songae   113??????????????1?400?2???2?334443??0?????1201110000 1?103??11?101??1??00???1?
Shenshou          013??????????????411400002???2?334443??0?3???1201110000 1?103?????101111000000100
Rugosodon         023??????????????201400001102?01442200103?1112201010100?002111110?1121100000110
Kuehneodon        023??????????????211400001102?11443200103?1112200010100?0021??????????????????
Sinobaatar        023??????????????2104000 02???2?02442300 1?0?1112000001112?002?1?1100112110000110
Plagiaulacids     023??????????????2114000 02???2?02442300103?1112000001112000 2????????????????????
                                                  3
Cimolodontans     023??????????????300400002???2?1244330012 0?1112 0?0001112200200111001121100000110
                                   1         3
Hadrocodium       ?1100?0??????00000000000000100334443000000 1101?????????002????????????????????
Shuotherium       ?221100??0100111?????????????3?????0????????????????????????002???????????????????
Pseudotribos      ?221100??0100111??01?0??100?0003310000??01100?????????002?????101??00?0010001
Asfaltomylos      ?2211?1102??0000???????????????????????0??????????????????0?2?????????????????????
Ambondro          ?2211?11020 10000???????????????????????0??????????????????0?2?????????????????????
Ausktribosphenos  ?2221?1112111000????????????????3????00??????????????????0?2?????????????????????
Bishops           ?2221?1112111000??????????????03??0?00??????????????????002????????????????????
Teinolophos       ?2221?2113102000?????????????????????????????????????????0?2?????????????????????
Steropodon        ?2221?2113102000????????????????3??3????????????????????0?2?????????????????????
Obdurodon         ?2221?2113102000 5??5????2???2?333443??0????1?????????????002????????????????????
Ornithorhynchus   ??????2?1?1?2???5??5????2???2?334443??0????1?????????????0???1110111101000001000 1
Tachyglossus      ????????????????5??5????2???2?334443???????????????????????1110111101000001000 1
Fruitafossor      ?0????????????????02?0??1001022333 2000?001100?????????3010??????0100001???????
Gobiconodon       ?1201?0??????0002?0300001001011120000000001010?????????2002???010101000000 0?10
Repenomamus       ?1101?0??????00020030000100101122000000001010??????????002000001010100000001 10
Amphilestes       ?1201?0??????000????????????00?21??0000??????0??????????002????????????????????
Yanoconodon       ?1100?0??????00030030000000000333343000100 1110??????????0020000 1010?0000000110
Jeholodens        ?1100?0??????00010010000100103322320000001111??????????00200000 101020000000110
Trioracodon       ?1100?0??????000??0300??0000012332 1000??01100??????????002????????????????????
Priacodon         ?1100?0??????000???300??0?00012222100 0??01101?????????1002????????????????0?????
Tinodon           ?2211?0??????000????????????1???22??1??0??????????????????0?2?????????????????????
Akidolestes       ?222100??0000000100100??1001100010000000001110??????????002?????0011?0000100110
Spalacotherium    ?222100??0000000?0??????????10?000?0000000??10??????????002??????????2??????????
Zhangheotherium   ?222100??0000000200200??100102200000100001110?????????2002?110000112110010 0110
Maotherium        ?222100??0000000200200??100102200000100001110??????????002?1?000011?1100?00110
Dryolestes        ?221100?001000001001 00??000001100000000301110?????????2002????????????????????
Henkelotherium    ?221100?00100000??0?????00?0?11000000 0??0???0???????????0?2??????011?110??0???0
Amphitherium      ?2211110000000 0???100?????0??000?0?00???????????????????0?2?????????????????????
Peramus           ?2211110000000 0???2?????000000331 0?00??0???0???????????0?2?????????????????????
Vincelestes       ?221100?000000001003000000100333342000030??00???????????0?20111100 11?1101201?10
Nanolestes        ?2211110000000 010?1??????001?02??0?00??0???0???????????002????????????????????
Kielantherium     ?2221110010 00000????????????0??12??0??0??????0???????????002????????????????????
Aegialodon        ?2221?1001000000?????????????????????????????????????????002????????????????????
Montanalestes     ?2221?100111 0000??????????????03??0?00???????????????????0?2?????????????????????
Prokennalestes    ?22212100111 0000?????????01010033?0000?00?1?0???????????002????????????????????
Murtoilestes      ?22212100 1?10000?????????0??????????????????????????????002????????????????????
Eomaia            ?222121001 1??000000100000000000033100 10000?100??????????00211?11001121101200?10
Juramaia          ?22212100 1?1000000010?0?00100003310000000?100-??-?--???00211111001??1?????????
Kennalestes       ?222121001110000100 2???? 00101103320010000 1101??????????00201??????????????????
                                             1
Asioryctes        ?22212100111000000001000000101113321010000?101??????????0020 1111??11?110??????
Ukhaatherium      ?2221210011100000001000000000113321010030?101??????????002?1??1?011?110??0???0
Zalambdalestes    ?22212100111000020021 1?000110113321010200?111??????????002??1110011?110??0???0
                                3            22  3
Daulestes         ?22212100111 0000?00100??0001011332 00?0??0?100??????????002????????????????????
Aspanlestes       ?22212100111 0000??????????????033?0??0????1?0??????????002????????????????????
Eoungulatum       ?22212100111 0000??????????????1332???0????1?0??????????002????????????????????
Cimolestes        ?22212100111 0000???200??0?000113321?00????1?0?????????2002????????????????????
Gypsonictops      ?22212100111 0000????????0?00011332 0?00????1?0?????????2002????????????????????
Protungulatum     ?22212100111 0000????????0?000113321?00????100?????????2002????????????????????
Erinaceus         ?22212111111 000021030000100103333420002001110?????????200211111001121101200?11
Leptictis         ?22212111111 00002102000000010113321000200?100??????????002??????011?1101200?10
Canis             ?212100?021000002002000000000233231000000 0100?????????20121111110112110120??10
Felis             ?212100?02100???20020000000000344343 0?00000100?????????20121111110112110120??10
Rattus            ?2????????01?0???31?411112???2?333343???1?02112???????????2002111110011211012 00?10
Oryctolagus       ?2????????01?0???31?411112???2?333343??0??02112???????????21131111100112110120 1?10
Bradypus          ????????????????5??5????1??2?????00??????01????????????301?11111101121111 20??10
Tamandua          ????????????????5?05????1??2???????????????01????????????3???111111011211112 0??10
Glyptotherium     ????????????????5?05????10?2?????00??????01????????????301011111101121111 20??10
Dasypus           ????????????????5?05????10?2?????43??????01????????????301011111101121111 20??10
Chaetophractus    ????????????????5?05????10?2?????43??????01????????????301011111101121111 20??10
Euphractus        ????????????????5?05????10?2?????43??????01????????????301011111101121111 20??10
Holoclemensia     ?2221210010 00000?????????????????????0??????????????????002????????????????????
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Sinodelphys          ?2221?10010000000100100000000011321112O?10?100??????????002?????001121?0120??10
Deltatheridium       ?2222121001000000100100??000002222211100?12100?????????2002????????????????????
Atokatheridium       ?2222121001000000????????????????????????????????????????002????????????????????
Sulestes             ?222121001010000???????????0222221?10????1????????????002????????????????????
Asiatherium          ?22221210011100000??0?????000?022222101O?????0???????????002?????100112110??0????
Kokopellia           ?22221210011100000???1????0?000?2222?1?10??0?100?????????2002????????????????????
Anchistodelphys      ?222111001110000?????????????????????????????????????????002????????????????????
Albertatherium       ?222111??????000????????????????2???????????????????????????002????????????????????
Didelphodon          ?2222111001110000??0??????0?00222221?00????1?0?????????2002????????????????????
Pediomys             ?22221110011100000???????????00222221100??????0??????????2002????????????????????
Turgidodon           ?22221110011100000???????????00222221?00???21?0??????????2002????????????????????
Mayulestes           ?2222111001110000000010000000002222211001111?100?????????002111110011?1101201?10
Pucadelphys          ?222111001110000000100000000022222111011121100?????????00211111001121101201?10
Andinodelphys        ?22221110011100000001000000000222221110111?100?????????002???????0????????0???0
Didelphis            ?22221110011100000001000000000222221110111210O?????????200211111100111?1101201?10
Marmosa              ?22221110011100000000100000000102222210001112100?????????00211111001121101201?10
Caenolestes          ?22221110011100010010000000002222210100202100??????0???002111111001121101201?10
Dasyurus             ?22221110011100001002000000000332223110001121100?????????00211111001121101201?10
Perameles            ?222211100111?00000200000000022222101002121O1?????????00211111001121101201?10
Dromiciops           ?2222111001110000000100000001022222101002121O0?????????00211111001121101201?10
Thylacomyidae        ?222101???1100000000200000???222221??0?2?210???????????00211111001121101201?10
Macropus             ?2222101110110???2004000001????3322327110202112???1?10???00211111001121101201?10
Acrobates            ?222101001110???00030000000010222231000020211O?????????00211111001121101201?10
Phascolarctos        ?2222101110110???2004000010???332233?2001021111??????????00211111001121101201?10
Vombatus             ?2222101110110???30040101200???332233?201?02112??????????00211111001121101201?10
Phalanger            ?2222101110110???2003000000010222222021020211??????????00211111001121101201?10
Pseudocheirus        ?2222101110110???20030000100103332232000020211??????????00211111001121101201?10
Petauroides          ?2222101110110???2003000000010333223200002021111??????????00211111001121101201?10
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Input data matrix (continued):

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                     22222222222222222222222222222222222222222222222222222222222222222333333333333
                     33333444444444445555555555666666666677777777778888888888899999999999900000000000111
Taxon/Node           56789012345678901234567890123456789012345678901234567890123456789012345678901234567890012
--------------------------------------------------------------------------------------------------------
Thrinaxodon          00000?0000000000000000000000?????000000??000000000000000000000?0000?000000000000
Massetognathus       ???0?????00????00000000000000?????1000?0??000000???0??0???0?00??????????????????
Probainognathus      ???0?????00??????????0????0??????10???0??000?0???0??0???0?00??????????????????
Tritylodontids       000000000000000000001000000?????2000010?000000000000000000000?0000?00?000000000
                                                 1
Pachygenelus         00000?0000000000000001000000100?210001?????00?000000??????00??????????????????
Adelobasileus        ???????????????????????????????????????????0??????????????????????????????????????
Sinoconodon          000000000000000000001000000??????????????????000?00?0???00??????????????????
Morganucodon         00100?00000?00000000001000000?????2100010???00001000001O?0000???000?000000000000
Megazostrodon        0?100000000?000000000100000??0??0210001O?0000001000000?000000?0000?00?000000000
Haldanodon           ??100001000?00?00000120000?0?????21????????000?00000?0?0?0??????????????????
Castorocauda         ???????????????0000120000000000002100000000000000001010000?0000??????00000000
Megaconus            110?0??????00?00000?00001000????021?0??0000???0?00000?20021O?00?0??0000?000000
Eleutherodon         ??????????????????????????????????????????????????????????????????????????????????
Sineleutherus        ??????????????????????????????????????????????????????????????????????????????????
Thomasia             ??????????????????????????????????????????????????????????????????????????????????
Haramiyavia          ??????????????????????????????????????????????????????????????????????????????????
Arboroharamiya       01???????????????????????10????120???????0???0?000?0100?000?0??????0?????00??
                                                                 1
Xianshou linglon     ????????????????0001100001101100121002O1?0000?0?0000??00?000?00?0???000?000010
Xianshou songae      ?1??????????0???00011O000?10?1?012100201??0?000?0?00100?000?0000???000?000010
Shenshou             0100001100000000000110000110110012?00201?00?000?00000100?000?0000???000?000?10
Rugosodon            1111001111001100100?00000101100010021?0110000000?1?00100201100100012100100010012
Kuehneodon           ??????????????????????????????????????????????????????????????????????????????????
Sinobaatar           1111001111001100100200001011000102100110000000111010020110010001210010001000012
                                                                    1
Plagiaulacids        ????????????????????????????????0?????????????????1????????????????????????????
Cimolodontans        1111001111001100100100000011000??021011100000000111?1002011001000121001000221112
                                          2    1
Hadrocodium          ??????????????????????????0???????????????????????????????????????????????????????
Shuotherium          ??????????????????????????????????????????????????????????????????????????????????
Pseudotribos         ??????????0????0???12000000?????211???00000?10?0000000?00???????????????????
Asfaltomylos         ??????????????????????????????????????????????????????????????????????????????????
Ambondro             ??????????????????????????????????????????????????????????????????????????????????
Ausktribosphenos     ??????????????????????????????????????????????????????????????????????????????????
Bishops              ??????????????????????????????????????????????????????????????????????????????????
Teinolophos          ??????????????????????????????????????????????????????????????????????????????????
Steropodon           ??????????????????????????????????????????????????????????????????????????????????
Obdurodon            ??????????????????????????????????????21???1????11??????????????????????????????????
Ornithorhynchus      0000010100000000000012000000100?1?2111110000111000000220110021000O?000000010110
Tachyglossus         0000010100000000000012000000100?1?21111101001110000002201100210000?000000010110
Fruitafossor         0?000011000?001000001200010010102I??????0000???00??0100?100?0?0?????????000000
Gobiconodon          11211111110011100000101000000000??2100210000000000000100?000?0000000?000000010
Repenomamus          11211111110011100000101000000????21002100000000000001000000?00000000000000010
Amphilestes          ??????????????????????????????????????????????????????0???????????????????????????
Yanoconodon          11211111110011100000101010000000?1210021000000000000001000000?0000000000000010
Jeholodens           1121111111001100??01010100000010210021000000000000001000000?0000000000000010
Trioracodon          ??????????????????????????????????????????????????????????????????????????????????
Priacodon            ??????????????????????????????????????????????????????????????????????????????????
Tinodon              ??????????????????????????????????????????????????????????????????????????????????
Akidolestes          11211111110011101111101111010000 1?21111201000011?00000210010210010000000100201
Spalacotherium       ???????????????????????????????????????????????????????1??????0?????????????????????
Zhangheotherium      11211111110011101111101111010000102111220000001?111002100100?00100000000130201
Maotherium           11211?11110011101111101111010000102111220000001?1?100210?100?0010000000?130201
                                                                                         1
Dryolestes           ??????????????????????????????????????????????????????????????????????????????????
Henkelotherium       1121111?110?111011?100111021000 1?21?0220000000111000021100000?10?????????1?????
Amphitherium         ??????????????????????????????????????????????????????????????????????????????????
Peramus              ??????????????????????????????????????????????????????????????????????????????????
Vincelestes          1?2110111100111010100011110?00001?21012200000000111000021100000?1020?00?100130201
Nanolestes           ??????????????????????????????????????????????????????????????????????????????????
Kielantherium        ??????????????????????????????????????????????????????????????????????????????????
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Aegialodon        ??????????????????????????????????????????????????????????????????????????????
Montanalestes     ??????????????????????????????????????????????????????????????????????????????
Prokennalestes    ??????????????????????????????????????????????????????????????????????????????
Murtoilestes      ??????????????????????????????????????????????????????????????????????????????
Eomaia            112210111100211011120022102100010211122000000001?101102111000?01221000212230201
Juramaia          112210??110?21?01????02210200???0?????????????????????????????????????????????
Kennalestes       ??????????????????????????????????????????????????????????????????????????2???
Asioryctes        ???????????????0?????0???0?11000??????2?0??00???????0??1?000?01221000212230201
Ukhaatherium      ?122101111 0?21101112002210210 0?1?210?2200000001?101102111000?01221000212230201
Zalambdalestes    1?2210111110?211011120022102100010211122000000001?101102111210??1221000212 23?201
Daulestes         ??????????????????????????????????????????????????????????????????????????????
Aspanlestes       ??????????????????????????????????????????????????????????????????????????????
Eoungulatum       ??????????????????????????????????????????????????????????????????????????????
Cimolestes        ??????????????????????????????????????????????????????????????????????????????
Gypsonictops      ??????????????????????????????????????????????????????????????????????????????
Protungulatum     ??????????????????????????????????????????????????????????????222003?2122312?1
Erinaceus         1121101111012110111200221021000102111221?0000011101112101210?12220030212251201
                     2
Leptictis         1?222?111?012110111200221021????02111221?0000011101112211210?1222003?212231201
Canis             11212011110121111112002211210000211122 1?0000011001101111111 0?22212020212251001
Felis             11212011110121111112002211210000211122 1?0000011001101111111 0?22212020212251001
Rattus            1122101110001101000210221120000102111211?0010111101112111100?12210030212250001
Oryctolagus       11221011100020010112002210200001?2111201?0010111101112101110?0?211130212250001
Bradypus          11212011121021111112002211210000?2111321?1100011001101201100?12212010212251001
Tamandua          11212011121021111012002211210000?2111321?1100011001101101100?22212010212251001
Glyptotherium     11212011120021111012002211210000?2111321?1100011001101201210?22212010212251001
Dasypus           11212011120021111012002211210000?2111321?1100011001111101210?22212020212251001
Chaetophractus    11212011120021111012002211210000?2111321?1100011001111101210?22212020212251001
Euphractus        11212011120021111012002211210000?2111321?1100011001111101210?22212020212251001
Holoclemensia     ??????????????????????????????????????????????????????????????????????????????
Sinodelphys       1123101111012?111112?02211211110021????00000001?10??0?100000?01212010??1242202
Deltatheridium    ???????????????????????????????????????????????????????????????12???????2?????
Atokatheridium    ??????????????????????????????????????????????????????????????????????????????
Sulestes          ??????????????????????????????????????????????????????????????????????????????
Asiatherium       11231011110?21101112002211211110021012200000001?101101100100?01?????????2?????
Kokopellia        ????????????????????????????????0?????????????????????????????????????????????
Anchistodelphys   ??????????????????????????????????????????????????????????????????????????????
Albertatherium    ??????????????????????????????????????????????????????????????????????????????
Didelphodon       ???????????????????????????????????????????????????????????????21201?101231101
Pediomys          ???????????????????????????????????????????????????????????????21201?101242202
Turgidodon        ??????????????????????????????????????????????????????????????????????????????
Mayulestes        112310111101211111120022112 1?1???21112200000011101101110000?012????????242202
Pucadelphys       11231011110121111112102211 2??????2111220000000111011011100 00?01213010101242202
Andinodelphys     ????????????????????????????????????????????????????0???????????????????2?????
Didelphis         112310111101211111120022112121100211122000000011101101110000001213010101242202
                                      1
Marmosa           112310111101211111120022112121100211122000000011101101110000001213010101242202
Caenolestes       11231011110121111112002211212110021112200000001110110111 0000?01213020?01242201
Dasyurus          11231011110121111112002211212110021112200000001110110111 0000?01213120101251001
Perameles         11231011110121111112002211212110021112200000001110110110 0100?01213020?11251002
Dromiciops        11231011110121111112002211212110021112200000001110110111 0000?01213020?11251002
Thylacomyidae     112310111101211?1112002211211110021112200000001110110111 0000?012130?0???251002
Macropus          11231011110121111112002211211110021112200100001110110121 0010?01213120?11251001
Acrobates         1123101111012111111200221121111 0?21112200000001110110111 0000?01213020?11251002
Phascolarctos     1123101111012111111200221121111 0?21112200100001110110111 0000?01213020?11251002
Vombatus          11231011110121111112002211211110021112200100001110110110 0100?01213020?11251002
Phalanger         11231011110121111112002211211110021112200000001110110111 0000?01213020?11251002
Pseudocheirus     11231011110121111112002211211110121112200000001110110111 0000?01213020?11251002
Petauroides       11231011110121111112002211211110021112200000001110110111 0000?01213120?11251002
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Input data matrix (continued):

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                  333333333333333333333333333333333333333333333333333333333333333333333333333333
                  111111122222222223333333333444444444455555555556666666666777777777788888888889
Taxon/Node        345678901234567890123456789012345678901234567890123456789012345678901234567890
------------------------------------------------------------------------------------------------
Thrinaxodon       000?00000000110000000???000000000?00????????0000??000??00?0?00?000?0000010?100
Massetognathus    ????????????????????????0???0??00?00????????1000??000??00?0?00?000?00000100100
Probainognathus   ????????????????????????????0?200?00?????0??1000??000??00?0?00?000?00000100110
Tritylodontids    000000000001??000?0?00?000000000?00?0???0?01111??1000000?00000000?00000100000
Pachygenelus      ???????????????????????????0000000100?0?0?01111??1?00000?0000?000?00000101100
Adelobasileus     ??????????????????????????????00000?????????0221100?????0000001?11??10100001001
Sinoconodon       ??????????????????????????????00000001000?00022110010000000000010111010100000000
Morganucodon      000000000000???0????????0??0000001010000?0002311112010000000010111010100011010
                                                        11
Megazostrodon     ?00??0??0?0?1?000000000?000000?0010100???0002311012010?0000001011101000001 1?10
Haldanodon        ????????????????????????0???000001020011?000231100201000000001?1210100?001????
Castorocauda      00000000??00?0??0?00000?01100???010???????????????????????????????????????????
Megaconus         00???00???0???00?0??????00100????1????????????????????????????????????????????
Eleutherodon      ??????????????????????????????????????????????????????????????????????????????
Sineleutherus     ??????????????????????????????????????????????????????????????????????????????
Thomasia          ??????????????????????????????????????????????????????????????????????????????
Haramiyavia       ??????????????????????????????????????????????????????????????????????????????
Arboroharamiya    ????????????????0????001?0?01?????????????????????????????????????????????????
Xianshou linglon  000?00000000000000100100?01???????????????????????????????????????????????????
Xianshou songae   000?00000000000000100100101???????????????????????????????????????????????????
Shenshou          000?000000000000001001001011??0001?110??0??31?01??????????????????????????????
Rugosodon         00100011000101100011100002101?0???????????????????????????????????????????????
Kuehneodon        ??????????????????????????????????????????????????????????????????????????????
Sinobaatar        0010001100010110001110000210100001010110?000??????????????????????????????????
Plagiaulacids     ????????????????????????0???????????????????231111301??000000101211101100211??
Cimolodontans     001001110011011000111000021010000101001 0?000231111301001000001012111011 0021121
                                                       1                 2  1
Hadrocodium       ?????????????????????????????10000020101?00023111230100000000 1?111010?10011021
Shuotherium       ??????????????????????????????????????????????????????????????????????????????
Pseudotribos      ???????????????????????0???0??????????????????????????????????????????????????
Asfaltomylos      ??????????????????????????????????????????????????????????????????????????????
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Ambondro          ????????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ????????????????????????????????????????????????????????????????????????????????
Bishops           ????????????????????????????????????????????????????????????????????????????????
Teinolophos       ????????????????????????????????????????????????????????????????????????????????
Steropodon        ????????????????????????????????????????????????????????????????????????????????
Obdurodon         ?????????????????????????????100002110110?0002311111?????0000001?111?11010011121
Ornithorhynchus   00000000000110000110100?11001000021100l0?0002311114110000000010111011010011121
                                             1
Tachyglossus      00000000000110000110100?11001000021100l0?0002311114110000000010111011010011121
                                             1
Fruitafossor      000000?00000???????????001??0????10???11????????????????????????????????????????
Gobiconodon       000000000000???????????0010000001020011?0002311113010000000001?121120000011110
Repenomamus       000000000000?0?0??0??0?0?1000000102011?0002311113010000000001?121120000011110
Amphilestes       ????????????????????????????????????????????????????????????????????????????????
Yanoconodon       000000000000?0?0?00??0?000000000102O?11??00?????????????????????????0???????
Jeholodens        000000000000000000001000000000000102?011?0002311?130100??0???10??1?????????????
Trioracodon       ??????????????????????????0???????????????02311?????????0??0?0??1010???0?????
Priacodon         ?????????????????????????0?????0????1??0023111301??000000101?12100??011110
Tinodon           ????????????????????????????????????????????????????????????????????????????????
Akidolestes       001000110000100001210000?021010?001020??1???????????????????????????????????????
Spalacotherium    ????????????????????????????????????????????????????????????????????????????????
Zhangheotherium   0010001100001000002000000002101????1020111?001231111 2????1101001?1?1?10???0??121
Maotherium        00????11000010000020000000021010?001020111?0012311112????1101001?1???10?100?1100
                                      1
Dryolestes        ???????????????????????????1????????????????????????????????????????????????????
Henkelotherium    ???????????????????0????0?1011???1020?11?00?23111?3???????????????????????????
Amphitherium      ????????????????????????????????????????????????????????????????????????????????
Peramus           ????????????????????????????????????????????????????????????????????????????????
Vincelestes       01100011010O??0???210???0?0011100202001 1?00123?112400?1110100101110100100 11021
                                                                                             1
Nanolestes        ????????????????????????????????????????????????????????????????????????????????
Kielantherium     ????????????????????????????????????????????????????????????????????????????????
Aegialodon        ????????????????????????????????????????????????????????????????????????????????
Montanalestes     ????????????????????????????????????????????????????????????????????????????????
Prokennalestes    ?????????????????????????????????????????????????2311125111111010010 2?10?????13?1?1
                                                                              2
Murtoilestes      ????????????????????????????????????????????????????????????????????????????????
Eomaia            013011110100000100210000120011 1?0?1????2??0????1??51?11??????????1????????????
Juramaia          ?????????????????????????0??????????????????????????????????????????????????????
Kennalestes       ????????????????????????????11002122112210223111251 1??2102110023 1?2001013????
                                                                                    4
Asioryctes        0130111101000000?020000?1?001110021221122102231 1125?1??2102110?241?2001013???1
Ukhaatherium      0130111101000000???200???1??01??00?1?2??221???3??????????2??21????4?0????0??????
Zalambdalestes    013?0113000000000002000001?001110031221122102231 1125?1??21021100241120010 13???1
Daulestes         ?????????????????????????????11002120112010223111251 1???10?????2?????01013????
Aspanlestes       ?????????????????????????????????????????????3?????????1?0?0?1????0?????1?????
Eoungulatum       ?????????????????????????????????????????????3?????????1???0?1????0???????????
Cimolestes        ????????????????????????????????????????????????????????????????????????????????
Gypsonictops      ????????????????????????????????????????????????????????????????????????????????
Protungulatum     01301113201 1??????????????????????????????????2311125?1??1?0?0?00??00?????1?????
                                                                                     1
Erinaceus         0130111320110000000200100120011100312111201022311125111121021100231130011 13???1
Leptictis         01301113201100???0200?001??01110031211120102231112511111102010023113001113???1
Canis             0130111?30110?0?002000001200111003021113110223111251 11?11?3??0?23111101113????
Felis             0130111?30110?0?002000001200111003021113110223111251 11?11?3??0?23111101113????
Rattus            011011?310110101000100001200111002010110020123111251111110100002411010 11131??2
Oryctolagus       0130101310110101000100 0?120011100201011002 0?2311125111111010000241101011131??2
Bradypus          0130111?30110?0?0020000?1200111003021113110223111251 11?11?3??0?23021101013????
Tamandua          0130??1?30110?0?0020000?1200111003121113110223111251 11?11?3??0?231?1101013????
Glyptotherium     0130111?30110?0?0020000?1200111103021113110223111251 11?11?3??0?230?1101013????
Dasypus           0130111?30110?0?0020000?1200111103021113110223111251 11?11?3??0?2301110101 3????
                                                                                      2
Chaetophractus    0130111?30110?0?0020000?1200111113021113110223111251 11?11?3??0?23021101013????
Euphractus        0130111?30110?0?0020000?1200111113021113110223111251 11?11?3??0?23021101013????
Holoclemensia     ????????????????????????????????????????????????????????????????????????????????
Sinodelphys       011021?2100011011021000002001 1??0??????????????????????????????????????????????
Deltatheridium    ?110212???00?????????????????11100?020112????2311125 10??11010021 2312???1013???2
Atokatheridium    ????????????????????????????????????????????????????????????????????????????????
Sulestes          ?????????????????????????????????????????????2311125 10??1?0????12?1????????????
Asiatherium       ???????????????????????00?001110?30201120 10?2311125????1111?0??23??4101013????
Kokopellia        ????????????????????????0???????????????????????????????????????????????????????
Anchistodelphys   ????????????????????????????????????????????????????????????????????????????????
Albertatherium    ????????????????????????????????????????????????????????????????????????????????
Didelphodon       01102122101 1??????????????????10?302011201022311 12??0????1??0?1??11?????1?????
Pediomys          01102122101 1?????????????????????????????????123111???0????0??0?1???1?????1?????
Turgidodon        ????2??????????????????????????????????????223111???0????0??0?1??11?????1?????
Mayulestes        0110212110 11??????210???0?0011100302011201 1123111 25???110100??2411010101 3????
Pucadelphys       011021221011?101?0210???0?0011100302011201112311125 11??1101002124110101 013????
Andinodelphys     ????????????????????????0???111003?20112011223111 25???110100 2?241101 01013????
Didelphis         11102123201111011021001002001110030201120111231112511111111002123110101013????
                                                                                       1
Marmosa           11102122201111011021001002001110030201120111231112511111111002123111101013????
Caenolestes       0110212210111100002101000200111003020112 0?112311125111111130 02?231101010 13????
Dasyurus          0121213?1011110000210100020011100302011201132311125111111130021231011 01013????
Perameles         0121213?10111101002001000201111003020112021123111251111111 3002?2311 4101013????
Dromiciops        0121213?20111101002100100200111003020112011123111251111111 3002?231?4101013????
Thylacomyidae     0121213???11??0?002?0?00020111100302?112?1132311125111111130 02?2310?101013????
Macropus          0121213?101111010020000002011110030211131303231112511111111 3002?23114101013????
Acrobates         0121213?2?11110100 2?0?1?020111100302111313032311125111111130 02?23114101013????
Phascolarctos     0121213?1011110100 21001?02011210030211100103231112511111113002?23114101013????
Vombatus          0121213?101111010021001002011210030211 10?003231112511111113002?23023101013????
Phalanger         0121213?20111101002100100201121003021113130323111251111111 3002?23114101013????
Pseudocheirus     0121213?2011110100210010020112100302111313032311125111111130 02?23114101013????
Petauroides       0121213?2011110100210010020112100302111313032311125111111130 02?23114101013????
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Input data matrix (continued):

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                  333333333444444444444444444444444444444444444444444444444444444444444444444444
                  999999999000000000011111111112222222222333333333344444444445555555555666666666
Taxon/Node        123456789012345678901234567890123456789012345678901234567890123456789012345678
------------------------------------------------------------------------------------------------
Thrinaxodon       0000??0????0?00?00??0?0?00000000000000000000000000000000000000000000000000?000
Massetognathus    0000??0????0?00?00??0?0?10100000000000001000000000000300000000000000100000?000
Probainognathus   0000??0????0?00?00??0?0?001000000?000000100000000000000000000000000001 00000?000
Tritylodontids    0100??000000?00000?0100?0021000000000000100000000010301000000000000020 0100?100
                                                                   1
Pachygenelus      0000??000000?00010000?1?00210011000000001000000001000001010101000000100000?100
Adelobasileus     0000???000000000100000?10?????????0???????????0??0?0?000????????00??0200??????0
Sinoconodon       0100?00000000000100010101021001100000000100000100101000101000100000020 00100200
Morganucodon      011100100000000010001010002100210000000010000010010100010101010000002000100200
Megazostrodon     01110?10000000001000101?00210?21???0??001?00001 0?1??0001010101 00000?2?00100200
Haldanodon        01010010000000001000101000???21000???00??00002011?1000101010100000002000100201
Castorocauda      ???????????????????????????????????1100010000???????0??????10?000?2?????0?2???
Megaconus         ????????????????????????00?????1???011??10000?????????????????????????????????
Eleutherodon      ??????????????????????????????????????????????????????????????????????????????
Sineleutherus     ??????????????????????????????????????????????????????????????????????????????
Thomasia          ??????????????????????????????????????????????????????????????????????????????
Haramiyavia       ??????????????????????????????????????????????????????????????0????????????2??
Arboroharamiya    ??????????????????????????????????????????????????????????????????????????????
Xianshou linglon  ???????????????????????????????1?????????????????????????????10???????????????
Xianshou songae   ???????????????????????????????1??????????????????????????????????????????????
Shenshou          ????????????????1?0????????????1??????????????20?????????????10?000???????????
Rugosodon         ???????????????????????????????1??????????????????????????????????????????????
Kuehneodon        ??????????????????????????????????????????????????????????????????????????????
Sinobaatar        ???????????????????????????????1????????2???00????????????????????????????????
Plagiaulacids     ?1111?10?00000001000111 1??????21?0??????????0?00020100100200010?0000202?112202
Cimolodontans     011100100000000010001110323121211001 11??211100000101001002000102000020211122 02
                  1   1   11       1                               2                   1
Hadrocodium       01011010000000001 00?1010??????21?0??????1????02012?1030101000100000 12?2?100201
Shuotherium       ??????????????????????????????????????????????????????????????????????????????
Pseudotribos      ??????????????????????????????????????????????????????????????0????????????2??
Asfaltomylos      ??????????????????????????????????????????????????????????????????????????????
Ambondro          ??????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ??????????????????????????????????????????????????????????????????????????????
Bishops           ??????????????????????????????????????????????????????????????????????????????
Teinolophos       ??????????????????????????????????????????????????????????????????????????????
Steropodon        ??????????????????????????????????????????????????????????????????????????????
Obdurodon         01110?100000000000?00?0????????1?0???????????03012?10000?40?110211?120201122?0
Ornithorhynchus   0111011000000000000?00?0?32312121100111012101003011010000240011021121202011 2210
Tachyglossus      0111011000000000 10?00?0?3231212110011101210100301121102002401 1?211212021112210
Fruitafossor      ??????????????????????????????????????????????????????????????0???????????2?1?
Gobiconodon       011100200000000001 1?1011????????1?1????12????0020021100001100000000112001112212
Repenomamus       01110020000?000011??101???????21?1????12????0200211000011000000000112001112212
Amphilestes       ??????????????????????????????????????????????????????????????1???????????????
Yanoconodon       ????????????????????????32312121???11012210100?00?????0??????11??????????12???
Jeholodens        ??????0??0?0??????????????????21????????1221??????????00?10??11???00?????122??
Trioracodon       ?????????0??0???1??10?????????????0???????????0????????0????????1?????????????
Priacodon         0??100??000??0??1100101???????2??0???????????020?????000??????1???????1??122?1
                                                                        2
Tinodon           ??????????????????????????????????????????????????????????????????????????????
Akidolestes       ?????????????????????????????????????????????????????0??????10?0???2??????1???
Spalacotherium    ??????????????????????????????????????????????????????????????0???????????????
Zhangheotherium   01111020000000001?0?11?1??????21??????????1?????0????0??1?????10??0???2???12??
Maotherium        0111??20000000001???11????????????????12?????0201??20?0??22??100000???2???12?0
Dryolestes        ???????????????????????????????????????????????????????1???10?0???????????????
Henkelotherium    ???????0???????????????????????????????????????????1?????20001???1?????????20?
Amphitherium      ??????????????????????????????????????????????????????????????????????????????
Peramus           ??????????????????????????????????????????????????????????????????????????????
Vincelestes       111110201100000011002111??????21?0??????????0101101000102010000010120000100202
Nanolestes        ??????????????????????????????????????????????????????????????????????????????
Kielantherium     ??????????????????????????????????????????????????????????????????????????????
Aegialodon        ??????????????????????????????????????????????????????????????????????????????
Montanalestes     ??????????????????????????????????????????????????????????????????????????????
Prokennalestes    11011???11001???110?21????????2??1????????????????????0????????????1??????????
Murtoilestes      ??????????????????????????????????????????????????????????????????????????????
Eomaia            ????????????????11??????????????????????????0?????????00??0??10?0??2????10?20?
Juramaia          ??????????????????????????????????????????????????????????????????????????????
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Asioryctes        110110201000110011002110??????21?2???????3213002011020000002 00?101010?2121100202
Ukhaatherium      ?1???????0?0?1??????21?1?????????2???????21??0?0?????0????????0?010???21??0???
Zalambdalestes    110110201000110011002111??????21?2???????32130020110200000020 1?10101012111100202
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Daulestes         ???11?201100??001????????1????2??1??????3???00?01?1??000?100?10?000?212110020?
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Aspanlestes       ??????????00?1???????1???????????1?????????????????????0??????????????????????
Eoungulatum       ????????000??????????1???????????1????????????????????????????????????????????
Cimolestes        ????????0?????????????????????????????????????????????????????????????????????
Gypsonictops      ??????????????????????????????????????????????????????????????????????????????
Protungulatum     ????????1001????1??21????????????2????????????????????????????????????????????
Erinaceus         110110201100110011002111213111212201110142130021111300000200110110112121 1?2212
Leptictis         110110201100110011002110??????21?20?????32130121111200000300010110112121110202
Canis             ?101102000010000110?1120213111212201110142131120111401001300010110112110102202
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Felis             ?101102000010000110?1120213111212201110142131120111401001300010110112110102202
Rattus            ?101101010011100211111102131112122011101421300201112120014001101100121201 12213
Oryctolagus       ?1011010000111001110111021311121220111015213000011111210030011?211112120112213
Bradypus          ?101102000000000110?112021311121220111014213113011110300101001?11021211011220?
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Tamandua          ?101102001000000110?112021311121220111014213113011110300101002?11021211011220?
Glyptotherium     ?1011020000?0000110?1120????11??22011101421311301111030010100101102121211 1220?
Dasypus           ?101102000000000110?112021311121220111014213113011111300101002011011212111220?
Chaetophractus    ?101102000000000110?112021311121220111014213113011111300101002011021212111220?
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Euphractus        ?101102000000000110?112021311121220111014213113011111300101002011021212111220?
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Deltatheridium    ?1011?2?00001???1101111???????2??1???????????02?11?2?000?201010?000121???00203
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Atokatheridium    ??????????????????????????????????????????????????????????????????????????????
Sulestes          ????????000??????1?1?????????????????????????????????????????????????????0?2??
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Kokopellia        ??????????????????????????????????????????????????????????????????????????????
Anchistodelphys   ??????????????????????????????????????????????????????????????????????????????
Albertatherium    ??????????????????????????????????????????????????????????????????????????????
Didelphodon       ?1?????0?00?1?????0111?????????1?1???????????0????????????????????????????0???
Pediomys          ?1???????00?1?????0111???????????1?????????????????2???0??????????????????????
Turgidodon        ?1???????00?1?????0?11???????????1????????????????????????????????????????????
Mayulestes        ?10110210010100111111111??????21?????????????0201102000002110101000?201010020?
Pucadelphys       ?10110210010100111111111??????21?1??????2????02011?200000211010111012010100203
Andinodelphys     ?1011021001010001111111???????21?1???????????02?111?1000021?01011001201?100203
Didelphis         ?10110200000101111011111213111212101110022120020111210000210010110012010100203
Marmosa           ?10110200000101111011111213111212101110022120020111210000210010110112010100203
Caenolestes       ?10?102000000021110111112131??21110111003212002011131000021?01011?012010100203
Dasyurus          ?10110200000102111011121?131??211101110042120020111112000211010110112010100203
Perameles         ?101102000001021110111112131??211101110042120020111210000210010110112010100203
Dromiciops        ?101102000001021110011102131??2122011100321300201111100003110101100120?0100203
Thylacomyidae     ?101102?0000102?1???11??2131??21??0?1100421?0020111?1000021?01011?012?101?020?
Macropus          ?101102000001031110011112131??212201110052130020111111001311010110012010100303
Acrobates         ?101102000001011110111202131??212?11110052131020111310000311010110012010100203
Phascolarctos     ?101102000001021110111112131??211201110032130020111311001410010111012010100303
Vombatus          ?101102000001011110011112131??211201110052130020111310001411010110012010100303
Phalanger         ?101102000001031110011112131??212211110052131020111311001310010110012010100303
Pseudocheirus     ?101102000001031110011212131??212211110052131020111210000311010110012010101203
Petauroides       ?101102000001031110011212131??212211110052131020111210000211010110012010101203
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Input data matrix (continued):

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Massetognathus    0000000?0000000000000010???01
Probainognathus   0000000?0000000000000101?????
Tritylodontids    0000000000000000100?0111???00
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Pachygenelus      0000000000000000000??????????
Adelobasileus     001100???????????0???????????
Sinoconodon       000000100000000010000102?????
Morganucodon      001100110000000010000112?????
Megazostrodon     001?00?????????00??0?????????
Haldanodon        001110110000000000???2???????
Castorocauda      ??1??11?00???????????????????
Megaconus         ???????????????????????????00
Eleutherodon      ???????????????????????????00
Sineleutherus     ???????????????????????????00
Thomasia          ???????????????????????????11
Haramiyavia       ???????1???????????????????11
Arboroharamiya    ???????????????????????????00
Xianshou linglon  ???????????????????????????00
Xianshou songae   ???????????????????????????00
Shenshou          ?02?0??11?1??????1?1???????00
Rugosodon         ???????????????????????????00
Kuehneodon        ???????????????????????????00
Sinobaatar        ???????????????????????????00
Plagiaulacids     0001000110100000?21????????00
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Cimolodontans     001100121010000021110223???00
Hadrocodium       01211001?00??000?2??1213?????
Shuotherium       ?????????????????????????????
Pseudotribos      ?1???????????????????????????
Asfaltomylos      ?????????????????????????????
Ambondro          ?????????????????????????????
Ausktribosphenos  ?????????????????????????????
Bishops           ?????????????????????????????
Teinolophos       ?????????????????????????????
Steropodon        ?????????????????????????????
Obdurodon         012110011?0??00002????2??????
Ornithorhynchus   012110011?0?10000211122 3000??
Tachyglossus      012110011?0?100102111223000??
                              2
Fruitafossor      ?????????????????????????????
Gobiconodon       10110001?000001??0??0?00?????
Repenomamus       10110001?000001010??0100?????
Amphilestes       ?????????????????????????????
Yanoconodon       ??????????0??????????????????
Jeholodens        ?011??01??0??????1???????????
Trioracodon       0????????????????????????????
Priacodon         0??????????0??0??1???????????
Tinodon           ?????????????????????????????
Akidolestes       ??????0???0??????????????????
Spalacotherium    ?????????????????????????????
Zhangheotherium   2?????????00?????????????????
Maotherium        2?1???0??00??????1???????????
Dryolestes        ?????????00??0???????????????
Henkelotherium    ?????????????????????????????
Amphitherium      ?????????????????????????????
Peramus           ?????????????????????????????
Vincelestes       000100111000000??1???????????
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Nanolestes        ?????????????????????????????
Kielantherium     ?????????????????????????????
Aegialodon        ?????????????????????????????
Montanalestes     ?????????????????1???????????
Prokennalestes    1????????????0???????????????
Murtoilestes      ?????????????????????????????
Eomaia            ??????02??1??????1???????????
Juramaia          ?????????????????????????????
Kennalestes       201110021010?00??1011223?????
Asioryctes        2011100210100000??1011223?????
Ukhaatherium      ?????0??????0????????????????
Zalambdalestes    101100021010000??1011223?????
Daulestes         ??1??00??????00??2???????????
Aspanlestes       ?????????????????????????????
Eoungulatum       ?????????????????????????????
Cimolestes        ?????????????????????????????
Gypsonictops      ?????????????????????????????
Protungulatum     1????????????????????????????
Erinaceus         101110021110020122011223111??
Leptictis         10111002101000012201122 3?????
Canis             212100021111100122001223111??
Felis             212100021111100122001223111??
Rattus            21210002121?2001211112231 11??
Oryctolagus       21210002121?200121111223111??
Bradypus          212100021011001122001223111??
Tamandua          212100021011001122001223111??
Glyptotherium     212101021011?01122???22311???
Dasypus           212101021011001122001223111??
Chaetophractus    212101021011001122001223111??
Euphractus        212101021011001122001223111??
Holoclemensia     ?????????????????????????????
Sinodelphys       ??????0??????????1???????????
Deltatheridium    1????002?011000??????????????
Atokatheridium    ?????????????????????????????
Sulestes          ?????????????0???????????????
Asiatherium       ??11000??????10??2???????????
Kokopellia        ?????????????????????????????
Anchistodelphys   ?????????????????????????????
Albertatherium    ?????????????????????????????
Didelphodon       1????0???????1???????????????
Pediomys          1????????????1???????????????
Turgidodon        1????????????????????????????
Mayulestes        ?01100021111100??2???????????
Pucadelphys       101100021011100?21???????????
Andinodelphys     10110002101111??21???????????
Didelphis         100100021111110121011223002??
Marmosa           112110021111110121011223002??
Caenolestes       2??1000211 1?220121???223002??
Dasyurus          201100021111110121011223002??
Perameles         212100021110110121???223001??
Dromiciops        212110021011110121011223002??
Thylacomyidae     2??1?0021?1???0121???22300???
Macropus          21211002101?000121???223002??
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                               2
Acrobates         212110021111120121???223002??
Phascolarctos     201100021111020121???223002??
Vombatus          202100021111001121???223002??
Phalanger         202100021111120121???223002??
Pseudocheirus     212100021111120121???223002??
Petauroides       212110021011120121???223002??


Heuristic search settings:
  Optimality criterion = parsimony
    Character-status summary:
      Of 497 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 = 894606526
  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 = 8.3605e+09
   Score of best tree(s) found = 2437
   Number of trees retained = 220
   Time used = 01:29:57.9

Tree-island profile:
                     First      Last                     First   Times
Island      Size*     tree      tree         Score   replicate     hit
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     2          1        2         2          2437           4       1
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222	1	-	-	2439	3	147**
223	1	-	-	2440	2	150**
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226	1	-	-	2443	8	20**
227	1	-	-	2444	187	10**
228	1	-	-	2445	71	16**
229	1	-	-	2446	76	10**
230	1	-	-	2447	240	3**
231	1	-	-	2448	68	6**
232	1	-	-	2449	72	14**
233	1	-	-	2450	90	8**
234	1	-	-	2451	191	3**
235	1	-	-	2452	18	2**
236	1	-	-	2453	259	4**
237	1	-	-	2454	81	3**
238	1	-	-	2455	351	1
239	1	-	-	2456	16	1
240	1	-	-	2459	292	3**
241	1	-	-	2460	131	7**
242	1	-	-	2461	120	8**
243	1	-	-	2462	586	4**
244	1	-	-	2463	931	1
245	1	-	-	2464	622	2**
246	1	-	-	2466	616	1
247	1	-	-	2467	174	6**
248	1	-	-	2468	654	2**
249	1	-	-	2469	574	2**
250	1	-	-	2470	639	2**
251	1	-	-	2471	186	1
252	1	-	-	2477	682	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 220 trees:

```
/------------------------------------------------------------------------------ Thrinaxodon
+------------------------------------------------------------------------------ Massetognathus
| /---------------------------------------------------------------------------- Probainognathus
| | /-------------------------------------------------------------------------- Tritylodontids
\-+ | /------------------------------------------------------------------------ Pachygenelus
  \-+ |  /--------------------------------------------------------------------- Adelobasileus
    \-+  +--------------------------------------------------------------------- Sinoconodon
      |  |                                                                  /-- Morganucodon
      \--+ /----------------------------------------------------------------+-- Megazostrodon
         | |                                                                /-- Haldanodon
         | | /--------------------------------------------------------------+-- Castorocauda
         \-+ | /--------------------------------------------------------------- Hadrocodium
           | | |                                                            /-- Thomasia
           | | |                                                   /--------+-- Haramiyavia
           \-+ |                                                   | /--------- Megaconus
             | | /-------------------------------------------------+ |  /------ Shenshou
             | | |                                                 \-+  |   /-- Eleutherodon
             \-+ |                                                   \--+ /-+-- Sineleutherus
               | |                                                      \-+ /-- Arboroharamiya
               | |                                                        \-+-- Xianshou linglon
               | |                                                          \-- Xianshou songae
               | |                                                          /-- Shuotherium
               | |                                             /------------+-- Pseudotribos
               \-+                                             | /------------- Asfaltomylos
                 |  /------------------------------------------+ | /----------- Ambondro
                 |  |                                          \-+ | /--------- Ausktribosphenos
                 |  |                                            \-+ +--------- Bishops
                 |  |                                              \-+  /------ Steropodon
                 |  |                                                \--+ /---- Teinolophos
                 |  |                                                   \-+ /-- Obdurodon
                 |  |                                                     \-+-- Ornithorhynchus
                 \--+                                                       \-- Tachyglossus
                    | /-------------------------------------------------------- Fruitafossor
                    | |                                                 /------ Amphilestes
```

```
| |                                                 |   /-- Gobiconodon
| |                                                 +---+-- Repenomamus
| | /-----------------------------------------------+   /-- Yanoconodon
\-+ |                                               | /-+-- Jeholodens
  | |                                               \-+ /-- Trioracodon
  | |                                                 \-+-- Priacodon
  | | /---------------------------------------------------- Tinodon
  \-+ |                                          /--------- Cimolodontans
    | +------------------------------------------+  /------ Sinobaatar
    | |                                          \--+ /---- Plagiaulacids
    | |                                             \-+ /-- Rugosodon
    \-+                                               \-+-- Kuehneodon
      |                                                 /-- Akidolestes
      |                                               /-+-- Spalacotherium
      | /---------------------------------------------+ /-- Zhangheotherium
      | |                                             \-+-- Maotherium
      \-+ /------------------------------------------------ Henkelotherium
        | | /---------------------------------------------- Dryolestes
        \-+ |  /------------------------------------------- Amphitherium
          \-+  | /----------------------------------------- Peramus
            |  | +----------------------------------------- Vincelestes
            \--+ +----------------------------------------- Nanolestes
               | | /--------------------------------------- Kielantherium
               | | | /------------------------------------- Aegialodon
               \-+ | |                /-------------------- Montanalestes
                 | | |                +-------------------- Prokennalestes
                 | | |                +-------------------- Murtoilestes
                 | | |                +-------------------- Eomaia
                 \-+ |                +-------------------- Juramaia
                   | |                |  /----------------- Zalambdalestes
                   | | /--------------+  +----------------- Daulestes
                   | | |              |  |              /-- Cimolestes
                   | | |              |  +--------------+-- Gypsonictops
                   \-+ |              |  |            /---- Ukhaatherium
                     | |              |  +------------+ /-- Kennalestes
                     | |              \--+            \-+-- Asioryctes
                     | |                 | /--------------- Aspanlestes
                     | |                 | +--------------- Eoungulatum
                     | |                 | +--------------- Protungulatum
                     | |                 | +--------------- Erinaceus
                     | |                 \-+--------------- Leptictis
                     | |                   |            /-- Rattus
                     \-+                   | /----------+-- Oryctolagus
                       |                   | |          /-- Canis
                       |                   \-+ /--------+-- Felis
                       |                     | | /--------- Bradypus
                       |                     \-+ +--------- Tamandua
                       |                       \-+  /------ Glyptotherium
                       |                         \--+ /---- Dasypus
                       |                            \-+ /-- Chaetophractus
                       |                              \-+-- Euphractus
                       |  /-------------------------------- Holoclemensia
                       |  +-------------------------------- Sinodelphys
                       |  |                             /-- 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
```

```
Lengths and fit measures of trees in memory:
  Character-status summary:
    Of 497 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

   Sum of min. possible lengths = 832
   Sum of max. possible lengths = 8980

Tree #      1
Length   2437
CI      0.341
RI      0.803
```

```
#NEXUS

Begin data;
          Dimensions ntax=114 nchar=497;
          Format datatype=standard interleave symbols="012345" gap=-;
          Matrix
Thrinaxodon       000000000000000000000000000?0?0?0?010000????????????0?0?0000
Massetognathus    0000010000000000001000000000?0?0?00010000???????????0???2000
Probainognathus   000000000000000001000000000?000?00010000???????????0???0000
Tritylodontids    0000010000000000000000000010?000?30002000???????????10??20?0
Pachygenelus      0000000000001000000000000000000?20000100?????0??????1?1?0001
Adelobasileus     ????????????????????????????????????????????????????????????
Sinoconodon       0000001000000000000000000110100000001000??00??????00?110001
Morganucodon      00001010000000000000000002{01}010000001000??00?0000001?010001
Megazostrodon     000010000000000000000000002002001000010000??00?0000?01?000001
Haldanodon        00000110001000100010000000210100100001000??00?0000000?010001
Castorocauda      00?00110001???1?00000000002101001000001000??00?0???0????10001
Megaconus         00000?100000001?000000000?220100?0002100100000?????011??2?01
Eleutherodon      ?????????????????????????????????????????1????0???????????????
Sineleutherus     ?????????????????????????????????????????111?1???????21???0?
Thomasia          ?????????????????????????????????????????00001?????0?0??0??0
Haramiyavia       0?0001000000000?0?0?0000000100000000100?????????????0??0?00
Arboroharamiya    11120130000120 21?01111000022030010002101111110??????21???2?30
Xianshou_linglong 111201300001202100112100002203001000210111111 0?????021??2?30
Xianshou_songae   1112013000012021001121000022030010002101111110?????021??2?30
Shenshou          1112013000012021001121000022030010002101111100?????02{01}??2?20
Rugosodon         1112?10??00?302?1010212010222400100021011000 1??????030??2?00
Kuehneodon        1112?10??0013021101021201022240010002101100011?????030??2?00
Sinobaatar        1112?10??0023021101021201022240010002101100010?????030??2?00
Plagiaulacids     1112?10??00{12}3021101021201022240010002101100011?????030??2?00
Cimolodontans     1112?10??0023021101021201022{12}40{01}{12}00021011000{01}0?????030??2?00
Hadrocodium       1???2130010?40211000000000200100200?01000??00?0000101?100001
Shuotherium       0010110??0000021??000?00?0????0?000101000???????????0?111110
Pseudotribos      0?10011000?0001???00??????21010100011 1000??????0???00?111110
Asfaltomylos      001211211000002 1??00220000213101200 10??00??????????????11011?
Ambondro          ?????1???00????1?????????0?????0???0?0??00??????????????12131?
Ausktribosphenos  0010012010000021??00220000 2??101200101000??00??????????121310
Bishops           01?10120100?0021??002200002131012001 0?000??00??????????121310
Teinolophos       11002120100230 21??0022000?2131012001 0??00??00????????????????
Steropodon        011001???0??00?1??????????????????????10???????00????????????????
Obdurodon         11??2120100230211011220001213111211 1010?0??00??????????101310
Ornithorhynchus   11??21001002302110112200012131112111{02}1000??00????????????????
Tachyglossus      11??210??00240211000000000213111??1?01000??00????????????????
Fruitafossor      11?0014000020021??11000011210101 1001?1000??00?0000000?10?001
Gobiconodon       11?1010??00{12}1021101221001121140010010 1000??00?0000001?100101
Repenomamus       11?1010??0021021101221001121140010010 1010??00?0000001?110101
Amphilestes       11?11?0??002102???122??0??21140020020 1?00??00???????????11010?
Yanoconodon       11?1010??002102110122100 1?2214001000 01000??00?0000001?000001
Jeholodens        11?1010??00?1021101 2??001?22140010000 1000??00?0000001?010101
Trioracodon       11?10?0??0021021??1221001022140010000 1000??00?00000?1?010101
Priacodon         11?1010??0021021??1221001022140010000 1000??00?0000001?000101
Tinodon           1??11?????0{01}1021??121?00???104?130?00??00?????????????01010?
Akidolestes       1????10??00?20???1221001021140110011 1000??00?00000?1?110100
Spalacotherium    1111010??00120 2?????21001021140110011 1000??00?00000?1?110100
Zhangheotherium   11?0010??0012020??1221001?21140101011 1000??00?0000011?110100
Maotherium        11?0010??0012020??12210010211401010111000??00?0000011?110100
Dryolestes        11?10111000120 20??11210?0121130120011 1000??00?0000011?000001
Henkelotherium    11?1011100012021??112101??211301200111000??00?00000?1?000001
Amphitherium      11?1111100012021??11210?01210301200111000?????11?0?0??00000?
Peramus           11?11111000120 21??1121010121030120011 1000??00?1100201?000201
Vincelestes       11?2?111000{12}2021??11110101211301200111000??00?0000101?100000
Nanolestes        11?1011100012021??112?0??1210301200111000?????????????00000?
Kielantherium     11?101110?012?21??111101?2????0130011?000?????????????00000?
Aegialodon        ????????????????????????????????????????00??????????????????
Montanalestes     11?2?13100014021??111201032103013001 11000?????????????12020?
Prokennalestes    11?111310001102 1??11120102210301200111000??00?1{01}112?1?120200
Murtoilestes      ????????????????????????????????????????0??????????????????
Eomaia            11?111310001102 1??11120102210301200111000??00?1011111?120100
Juramaia          1?12-?11000?????????1201022?0301100111000??00?1011201?120100
Kennalestes       11?2?1310001402110111200022???0?200111000??00?1111201?100200
Asioryctes        11?2?131000140211011120002210301300111000??00?1112201?110200
Ukhaatherium      ?1???????00?40??????????022???0??00?11000??00?1112201?110200
Zalambdalestes    11?2?1{13}1000{12}40211011120{01}02210301200111000??00?1112211?021220
Daulestes         11?2?131000240211011120002210301200111000????????1??1??????0
Aspanlestes       ?????1????0??0??????????1??????0???0?1?0?0??00?11112?1?1?010?
Eoungulatum       ?????1????????????????????1??????0???0?1???0??00?10110?1???????
Cimolestes        1???21010?0240211?111200?2210301 2?0111000??00?10122?1?110100
Gypsonictops      1???21010002402 11?111200?221030 12?0111000??00?11122?1?121200
Protungulatum     11?2?1010002402 11?111200022103012001 11000??00?10120?1?121100
Erinaceus         11?2?131000241211011120002210301300111000??00?1011011?121220
Leptictis         11?2?131000240211011120002210301300111000??00?1112211?121220
Canis             111??131010240211011110002211301300111000??00?0100011?001101
Felis             111??131010240211011110002211301300111010??00?0100011?001101
Rattus            1112?1110002412110111120002 22?01100021010???????????0??????0
Oryctolagus       1112?11100024021101111100022 2?011?1121010??00?0012000?001000
Bradypus          111??131010241211011110002211301 3?0111000???????????0??????0
Tamandua          111??13101024121 10??????0?21?30???1??10?0??????????????????
Glyptotherium     111??131010241211011110002211301310111100???????????0??????0
Dasypus           111??131010241211011110002211301310111100???????????0??????0
Chaetophractus    111??131010241211011110002211301310111100???????????0??????0
Euphractus        11???131010241211011110002211301310111100???????????0??????0
Holoclemensia     ???????????????????????????????????0?1???0??????????????????1
Sinodelphys       11???131010?4021??111?0??2210301300111000??00?00??111??10101
Deltatheridium    11?2?14101022021??11110004210301300111000??00?0000111?000101
```

Atokatheridium	???????????2??????????????????????0????????00???????????????
Sulestes	11?2014101022021??111100142?1?01310111000??00?000011??000101
Asiatherium	11?1?14101024021 1?111100142?0?01300111000??00?0000111?000101
Kokopellia	?1?1?1410?022??1??1?1100?{34}2?????3?0111000??00?????1???000101
Anchistodelphys	??????????????????????????????????0????????00???????????????
Albertatherium	??????????????????????????????????0????????00???????????????
Didelphodon	11?2?14101021021??11110014211301?00111000??00?001???1?000110
Pediomys	???2?14101021021??11110014211301?00111000??00???????1???????
Turgidodon	???2?14101021021 1?111100?4?11301?00111000??00???????1?00010?
Mayulestes	11?2?141010224?211011110014210301300111000??00?0000111?000101
Pucadelphys	11?2?1410102402110111100142103013001110 00??00?0000111?000101
Andinodelphys	11?2?14101024021101111001421030130011100 0??00?0000111?000101
Didelphis	11?2?14101024121101111001421030130011100 0??00?0000211?000101
Marmosa	11?2?14101024121101111001421030130011100 0??00?0000211?000101
Caenolestes	11???141010224?2110111100142103013001110 00??00???????1??????0
Dasyurus	11?2?14101024021101111001421030130011100 0??00?00{01}0211?000101
Perameles	11???14101024121101111001421030130011100 0??00??????????????0
Dromiciops	1112?14101024021101111001421030130011100 0??00?000021??000100
Thylacomyidae	111??141010224?2110111100142103013001110 00??00???????1??????1
Macropus	111??14101024021101111001421030130011100 0??00??????????????0
Acrobates	111??14101024121101111001421030130011100 0??00??????????????0
Phascolarctos	111??13101024021101111001421030130011000 0??00??????????????0
Vombatus	111??14101024021101111001421030130011000 0??00??????????????0
Phalanger	111??14101024021101111001421030130011100 0??00??????????????0
Pseudocheirus	111??14101024021101111001421030130011100 0??00??????????????0
Petauroides	111??14101024021101111001421030130011100 0??00??????????????0
Thrinaxodon	00000?????????00????0000??????????0000000??0????????????????
Massetognathus	00000?????????20????0400??????????0000000???????????????????
Probainognathus	00000?????????00????0000??????????0000000??0????????????????
Tritylodontids	00000????????021????24000?00??????0000000???????????????????
Pachygenelus	00000?????????00????0000??????????0000000??000??????????????
Adelobasileus	??????????????0??????000??????????0000000??000??????????????
Sinoconodon	10000?00?0????00????0000??????20??0{02}00000?1000???0000???0???
Morganucodon	10200?00?0????00?0??1100??????20??200000110000???0000???0???
Megazostrodon	10200?00?0?0??00?0??1200??????20??200000100000???0000???0???
Haldanodon	10201010?0?0??00?0??1100??????20??2003200?0000???0000???0???
Castorocauda	10201010?0????00?0??1100??????2???2003200?0?00????000???0???
Megaconus	12201??300000221????240100011?????0??0?0122?????????????????
Eleutherodon	120???????11122?????241121120?????0??0?0120?????????????????
Sineleutherus	120?0??301????21????2411201{02}0?????0??0?0120?????????????????
Thomasia	0?000???10100021????240110100?????0??0?0????????????????????
Haramiyavia	00000??200100021????240110100?????0??0?0120?????????????????
Arboroharamiya	01000?????210221????241121120?????0??0?01?2?????????????????
Xianshou_linglong	01000?????111021????241120100?????0??0?01?0?????????????????
Xianshou_songae	01000?????111021????241120100?????0??0?01?0?????????????????
Shenshou	02000?????110021????241111000?????0??0?01?0?????????????????
Rugosodon	001?0????1000121????240111000?????0??0?00?0?????????????????
Kuehneodon	00120??311000021????240101000?????0??0?00?0?????????????????
Sinobaatar	00010??201000121????240101001?????0??0?00?0?????????????????
Plagiaulacids	00120??211000121????2401{01}100{01}?????0??0?00?0?????????????????
Cimolodontans	00000??200000{12}21????2401{01}00{12}{01}?????0??0?00?0?????????????????
Hadrocodium	10000?0??0????00?0??1200??????20???000000?0000???0000???0???
Shuotherium	00011??0?0????13?2001200?????0100?1323210?01110000100???0???
Pseudotribos	000?1110?0????13?2001200?????0100?1323210?0111000?100???0???
Asfaltomylos	0????????0????13?2??1300???????13?0210000??11102214110001111
Ambondro	0??110???0????13?2??1300?????0?1330012100??111022241120?1111
Ausktribosphenos	00011011?0????13?2??1300?????021330012100?022102214122003212
Bishops	000?1011?0????13?2??1300?????021330012100?122102214122003212
Teinolophos	0??????????????3?2??1300?????111120012010??222042231210?02?2
Steropodon	0????????0????13?2??1300?????111120012110?0222042231210?02?2
Obdurodon	0??00????0????13?2??1300?????111120012010?0222042231210?02?2
Ornithorhynchus	??????????????13?2??1?00?????1?1?????2010?0222042231210??2?2
Tachyglossus	??????????????????????00????????????????????????????????????
Fruitafossor	00000?0??0??????????1000??????????0??0000?0?????????????????
Gobiconodon	10010000?0????00?0??1200??????10??101000100?00???0000???0???
Repenomamus	10010000?0????00?0??1200??????10??101000100?00????000???0???
Amphilestes	10000000?0????00?0??1200??????10??101000100?00???0000???0???
Yanoconodon	10000000?0????00?0??1100??????10??020000121?00????000???0???
Jeholodens	10000000?0????00?0??1100??????10??020000121?00???0000???0???
Trioracodon	10000100?0????00?0??1100??????10??1{02}0000121?00???0000???0???
Priacodon	10010100?0????00?0??1100??????10??120000121?00???0000???0???
Tinodon	00000?00?0????1201??1200??????1000101000100?110000100???00??
Akidolestes	00000120?1????1302011200?????0100010000013012200?0100???00??
Spalacotherium	00000100?1????1312001200?????0100010000013011200?0100???00??
Zhangheotherium	00001?00?0????1311001200?????0100010000013011100?0100???00??
Maotherium	00001?00?0????1311001200?????0100010000013011100?0100???00??
Dryolestes	10001?00?0????1301001300?????020000200000?01110000220??000??
Henkelotherium	100?0?00?0????1301001300?????0200002?0000?01110000220??000??
Amphitherium	???01?00?0????1301001300?????000100200000?00110000210?0000??
Peramus	10000?00?0????1301001300?????00010001000110011{01}0002110000{01}?0
Vincelestes	00000?00?0????1301001300?????000000200000100110000210??000?0
Nanolestes	10000?00?0????1301001300?????00010021000110011000021000?00?0
Kielantherium	10000?00?0????1301101300?????0001102110011011102015110000{01}00
Aegialodon	??????????????1?01??1300?????00011021100 11?111020151100?1100
Montanalestes	10001000?0????13?2??1300?????0102102110011201202115110011100
Prokennalestes	10000020?0????1302201300?????0201101110011201202115110011100
Murtoilestes	?00???????????1302201300??????202101110011?012021151100?1100
Eomaia	10000020?0????1302201300?????020?1011100112??202?151100111??
Juramaia	1200?020?0????1302301300?????02?????11?0112?1??2?1511001????
Kennalestes	12000100?0????1302201300?????0202102110011222203115110011100
Asioryctes	12000010?0????1302201300?????0202102110011201203115110011100
Ukhaatherium	12000020?0????1302201300?????020?1021100112012031151100111?0
Zalambdalestes	12000120?0????1302201300?????1203102110011022204205110001110
Daulestes	120???00?0????1302201300?????0202102110011?11202115110011100
Aspanlestes	100000?0?0????1302311300?????1102102110011?11201215110001100
Eoungulatum	100??????0????1302421300?????1103102110011?11201215111001200

```
Cimolestes        12000010?0????1302311300????0202102110011221203115110011200
Gypsonictops      12000110?0????1302311300????1202102110011221204115110011200
Protungulatum     10000010?0????1302421300????1102102110011211201215111001201
Erinaceus         02000100?0????1302201300????1103102110011011202215111001211
Leptictis         02000100?0????1302221300????1103102110011211204115110001101
Canis             00000010?1????1102301200????00101000000000000000010210?001210
Felis             00000010?1????1102301200????00101000000000000000000210?001210
Rattus            000??????0????13???21300????13?0004000000????4204110001 3?1
Oryctolagus       000001???0????13???01300????13?0004000000????210410?00?3?1
Bradypus          000??????0?????????1500????????????????003?????????????????
Tamandua          ?????????0?????????????00?????????????????0?????????????????
Glyptotherium     000??????0?????????1500????????????????003?????????????????
Dasypus           000??????0?????????1500????????????????003?????????????????
Chaetophractus    000??????0?????????1500????????????????003?????????????????
Euphractus        000??????0?????????1500????????????????003?????????????????
Holoclemensia     10????????????1302101300????0201102110011111102115110?2100
Sinodelphys       10??00?0?0????1302??1300????010110011001111?2115110012 1??
Deltatheridium    10000000?0????1302101300????000110{02}110011111102115110001100
Atokatheridium    ??????????????1?02101300????00011001100 11?11102115110 0?0??0
Sulestes          10000000?0????1302101300????00021001100111111121151100 12211
Asiatherium       10000000?0????1302201300????01031021100110111122151100 12211
Kokopellia        1??00000?0????1302101300????01021021100110011122151100 12210
Anchistodelphys   1????????0????1?02101300????02031021100 11?01112205110113210
Albertatherium    1????????0????30220130 0??????????????????1???1??????????????
Didelphodon       10000000?0????1302201300????00031021100112111122051201?3211
Pediomys          100????0?0????1302201300????01031021100111111122051201 13211
Turgidodon        10000000?0????1302101300????01031021100111111132151201 13211
Mayulestes        10000000?0????1302101300????01031021100111111122151201 13110
Pucadelphys       10000000?0????1302101300????12031021100110111122151201 13210
Andinodelphys     10000000?0????1302101300????12031021100112111122151201 03211
Didelphis         10000000?0????1302101300????02031021100110111122151201 03211
Marmosa           10000000?0????1302101300????02031021100111111121151201 03212
Caenolestes       100????0?0????302101300????02031021100111111132151201 03212
Dasyurus          10000000?0????1302101300????02031021100111111122151201 03212
Perameles         000????0?0????302101300????02021021100112111132151200 03212
Dromiciops        00000000?0????1302101300????02031021100111011132051201 03212
Thylacomyidae     000????0?0????30????00??????????????0011??11132??1????3???
Macropus          000????0?0????3?2531300????1303002000011330113204131004312
Acrobates         000????0?0????3?3531300????1302102000011010113215120004212
Phascolarctos     000????0?0????3?3531300????1303202000011330113204130004312
Vombatus          000????0?0????3?3531300????1303202000011330113204131004312
Phalanger         000????0?0????3?3531300????1303202000011330013215120004312
Pseudocheirus     000??????0????3?3531300????1303202000011330013204130004212
Petauroides       ?00??????0????3?3531300????1303202000011330013204130004212

Thrinaxodon       ?00????????????????????????0???00????00?????????????00000000
Massetognathus    ?00????????????????????????033300????11?????????????00000000
Probainognathus   ?00????????????????????????0???00????00?????????????00000000
Tritylodontids    ?00?00?????????????????????033300??0023?????????????2?030000
Pachygenelus      ?00????????????????????????0???00????00?????????????30030000
Adelobasileus     ?????????????????????????????????????00??????????????0??????
Sinoconodon       ?00?00???0????????0????????000000????00?0?0??????00000000000
Morganucodon      ?00?40???0????????0????????00000100??1100?0??????000{01}00{01}0000
Megazostrodon     ?00?40???0????????0????????00000100??1100?0??????00010010000
Haldanodon        ?00?11???0????????0????????03320100??1100?0??????00000010000
Castorocauda      ???????????????????????????00?0?1????1100?0??????000???100??
Megaconus         ????????????????????????????33401100013?????????????301400??
Eleutherodon      ????????????????????????????443011?0113??????????????1??????
Sineleutherus     ????????????????????????????44?011?0113??????????????11?????
Thomasia          ????????????????????????????3330???0013???????????????1?000?
Haramiyavia       ????????????????????????????333011?0013?????????????10010000
Arboroharamiya    ????????????????????????????33400??1113??????????????41140?0
Xianshou_linglong ????????????????????????????43400??1113?????????????31140000
Xianshou_songae   ????????????????????????????43400??1113??????????????1?400??
Shenshou          ????????????????????????????33300??0013?????????????41140000
Rugosodon         ????????????????????????????33300??0023?????????????20140000
Kuehneodon        ????????????????????????????33300??0023?????????????21140000
Sinobaatar        ????????????????????????????33300??0023?????????????21040000
Plagiaulacids     ????????????????????????????33300??0023?????????????21140000
Cimolodontans     ????????????????????????????33300??0023?????????????3004{01}000
Hadrocodium       ?0???????0????????0????????00000100??1100?0??????00000000000
Shuotherium       ?11?11002000?0??0000000?10011200???221100??0100111???????
Pseudotribos      ?11?11002000?0??0000000?10011200???221100??0100111??01?0??
Asfaltomylos      2??????????????????????????011?0?????2211?1102??0000????????
Ambondro          2??????????????????????????011?0?????2211?11020 10000????????
Ausktribosphenos  3??????????????????????????033?0?????2221?111211000????????
Bishops           3??????????????????????????033?0?????2221?111211000????????
Teinolophos       3???????????????????????????33?0?????2221?2113102000????????
Steropodon        3??????????????????????????033?0?????2221?2113102000????????
Obdurodon         320?1??????????????0???????033300????2221?21131020005??5????
Ornithorhynchus   320?1??????????????????????033300?????????2?1?1?2???5??5????
Tachyglossus      ????????????????????????????????????????????????????5??5????
Fruitafossor      ?00?0??????????????????????55400?????0????????????????02?0??
Gobiconodon       ?00?10???0????????0????????000100????1201?0??????0002?030000
Repenomamus       ?00?10???0????????0????????000100????1101?0??????00020030000
Amphilestes       ?00????????????????????????000?0?????1201?0??????000????????
Yanoconodon       ?00?00???0????????0????????00000121??1100?0??????00030030000
Jeholodens        ?00?00???0????????0????????00000121??1100?0??????00010010000
Trioracodon       ?00?10????????????1????????00000112??1100?0??????000??0300??
Priacodon         ?00?10???0????????1????????00000112??1100?0??????000???300??
Tinodon           010?11???00???0???0????0?0002210?????2211?0??????000????????
Akidolestes       020?11???000??0??0000000?000220121??222100??0000000100100??
Spalacotherium    020?11???000??0??0000000?000220121??222100??0000000?0??????
Zhangheotherium   020?11???000??0??0000000?000220121??222100??0000000200200??
Maotherium        020?11???000??0??0000000?000220121??222100??0000000200200??
Dryolestes        110?01???000??0??0001000?000220121??221100?0010000010 0100??
Henkelotherium    110?01???000??0??0001000?000220121??221100?00100000??0?????
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Amphitherium       111101???000??0??0001000?00022101????2211110000000000???100??
Peramus            121121?0?010000??000100200001110121??2211110000000000???2????
Vincelestes        120?11?0?010000??00010120000111000 1??221100?00000000010030000
Nanolestes         121?11???0?0000??101201200001110121??2211110000000000010?1????
Kielantherium      120?120000100-0--100201110101 1?0121??22211100100000 0???????
Aegialodon         1????????????????????????????11????21??2221?1001000000???????
Montanalestes      2??????????????????????????0???0?21??2221?100111000 0???????
Prokennalestes     2210220200100110010110100000112012 1??22212100111000 0???????
Murtoilestes       ?210220200?0011001011000000011 2?121??22212100 1?10000???????
Eomaia             2210220200100110010??000?0001120121??222121001 1??00000010000
Juramaia           2211220200100110010110111010112 0121??22212100 1?100000010?0?
Kennalestes        2210220110100110110100000?0001120121??222121001110000 1002????
Asioryctes         22102201101001100100000 00?0001120121??2221210011100000 0010000
Ukhaatherium       22102201101001100100000 00?0001120121??2221210011100000 0010000
Zalambdalestes     220?120120110110000000000?0001120121??222121001110000{23}00211?0
Daulestes          220?120210100111110100 00?0001120121??222121001110000?00100??
Aspanlestes        220?120321110312100?0000?1001120121??222121001110000???????
Eoungulatum        320?122321110312100100 00?10011200 0???222121001110000???????
Cimolestes         2210121110100111100000 00?0001120121??222121001110000???200??
Gypsonictops       2210121110100111100000 00?0001120121??222121001110000???????
Protungulatum      320?1223211103100000000 0?100112000 1??222121001110000???????
Erinaceus          220?121221110 20??000000 0?10033000 1??22212111111000021030000
Leptictis          220?12111110011110000000 ?10011200 01??22212111111000021020000
Canis              000?010202110110001100 00?3101121001??212100?0210000020020000
Felis              000?0102021100 0?0011000 0?3101121001??212100?02100???20020000
Rattus             400??202221102 0???????????003310 0????2????????01?0???31?41111
Oryctolagus        300??20121110 30???????????0133200 0???2????????01?0???31?41111
Bradypus           ????????????????????????????05540?????????????????????5??5????
Tamandua           ??????????????????????????????????????????????????????5?05????
Glyptotherium      ????????????????????????????03330?????????????????????5?05????
Dasypus            ????????????????????????????05540?????????????????????5?05????
Chaetophractus     ????????????????????????????05540?????????????????????5?05????
Euphractus         ????????????????????????????05540?????????????????????5?05????
Holoclemensia      120?2201111000100100111211001 12?121??222121001000000???????
Sinodelphys        121122???110??????0110121100???0121??2221?100100000 0010010000
Deltatheridium     121122010110001001001001022011201 21??222121001000000 0100100??
Atokatheridium     121?220101100010010010010220112?12???222121001000000???????
Sulestes           221122010110001001001111022011201 21??222121001010000???????
Asiatherium        221022021111121 1?0001001010100112012 1??222121001110000??0?????
Kokopellia         221?22020110011 1?1001111010011201 21??222121001110000???1????
Anchistodelphys    22112202212102101010111102001120?????22211100111000 0???????
Albertatherium     ?2112202221102101100111112 00???121??222111??????000???????
Didelphodon        2211220222210201010020110210112 0121??2221110011100 00??0?????
Pediomys           2211220222210211000011110100112012 1??22211100111000 0???????
Turgidodon         221122022211021100001111020011201 21??2221110011100 00???????
Mayulestes         22112202222002110000101102101120121??22211100111000000010000
Pucadelphys        22102202222112111000211111001120121??22211100111000000010000
Andinodelphys      22102202222112111000211111001120121??22211100111000000010000
Didelphis          2210220222211 20?000021111200 1120121??22211100111000000010000
Marmosa            221022022221120?000021111100 1120121??22211100111000000010000
Caenolestes        221022022221120?001021010100 1120121??222111001 11?00010010000
Dasyurus           221122022221120?001021010200 1120121??22211100111000010020000
Perameles          221022022221120?001021010200 1120121??222111001 11?00000020000
Dromiciops         221122022221120?000000011100 1120121??22211100111000000010000
Thylacomyidae      4????2042??1120?0010000 1??011120121??222101???11000000020000
Macropus           400?3204221112 0?0010000 0?30011201 21??222101110110???20040000
Acrobates          420?32042211120?00100001110011201 21??222101001110???00030000
Phascolarctos      420?32042211120?00100100?30111201 21??222101110110???20040000
Vombatus           420?32032211120?00100000?30111201 21??222101110110???30040101
Phalanger          420?32042211120?00100100?30011201 21??222101110110???20030000
Pseudocheirus      420?32042211120?00100100?30111201 21??222101110110???20030000
Petauroides        420?32042211120?00100100?30011201 21??222101110110???20030000

Thrinaxodon        00000???00?0?0000001?????????00000000010000000000?0?00000?
Massetognathus     00000???00?0?000000100?????0?0000??????0000000??0?0?????0??
Probainognathus    00000???00?0?000000??????????0000??????0100000??0?0?0???0??
Tritylodontids     2??2???0000?0?10??11200100001000010 0000?010000000000000000000
Pachygenelus       10000??0000?1?200000 1?????????000000 0?0??10???0000100?00000?
Adelobasileus      ????????????????????????????????0?????????????????????????????
Sinoconodon        00000331122020000000 1?????????100100??0?01?????0010000000000
Morganucodon       0000000{23}{12}00000000 1101??????????000{12}00000??11?1?00??1???00100?
Megazostrodon      000000011000000001001?????????20?200000?0110100???????0?1000
Haldanodon         000012200000000001100?????????0002?????????????????????????1000
Castorocauda       ???01?00??0??0??01100???????????002??????0001000?????????????
Megaconus          2???2?333343000?2???12?00001101?103000?0101110000000???110?0?
Eleutherodon       ??????????????0???????01110??01?103?????????????????????????????
Sineleutherus      ?????????????????????? 01110??01?103????????????????????????????
Thomasia           ?????3323????0?3???1?1?110?000??03?????????????????????????????
Haramiyavia        10010?133?1??0000??12101100000?00?????????????????????????????
Arboroharamiya     2???2?334443??0?3???12011100001?103??????01??10??????0?01????
Xianshou_linglong  2???2?334443??0?3???12011100001?103??11?101??100?????????????
Xianshou_songae    2???2?334443??0?????12011100001?103??11?101??1??00???1??1????
Shenshou           2???2?334443??0?3???12011100001?103?????1011110000001 00010000
Rugosodon          1102?01442200103?1112201010100?0021111 10?11211000001 10111100
Kuehneodon         1102?11443200103?11122000101 00?0021???????????????????????????
Sinobaatar         2???2?02442 3001?0?1112000001112?002?1?110011211000001 10111100
Plagiaulacids      2???2?0244{23}300103?1112000001112 0002???????????????????????????
Cimolodontans      2???2?1{23}443300120?11120?000111220020011100112110000011 0111100
Hadrocodium        0010033444300000001101???????????002?????????????????????????????
Shuotherium        ???????3?????0???????????????????002?????????????????????????????
Pseudotribos       100?0003310000??01100???????????002??????101??00?0010001??????
Asfaltomylos       ??????????????0???????????????????0?2????????????????????????????
Ambondro           ??????????????0???????????????????0?2????????????????????????????
Ausktribosphenos   ???????3????00????????????????????0?2????????????????????????????
Bishops            ??????03??0?00????????????????????002????????????????????????????
Teinolophos        ??????????????????????????????????0?2????????????????????????????
Steropodon         ???????3??3???????????????????????0?2????????????????????????????
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Obdurodon          2??2?333443??0????1?????????????002??????????????????????????
Ornithorhynchus    2??2?334443??0????1????????????0???11101111010000010001000001
Tachyglossus       2??2?334443????????????????????????11101111010000010001000001
Fruitafossor       10010223332000?001100??????????3010??????0100001???????0?0000
Gobiconodon        100101112000000001010??????????2002????0101010000000?10112111
Repenomamus        100101122000000001010???????????00200000101010000000110112111
Amphilestes        ???00?21??0000??????0???????????002??????????????????????????
Yanoconodon        000003333430001001110???????????002000001010?0000000110112111
Jeholodens         100103322320000001111???????????00200000101020000000110112111
Trioracodon        00000123321000??01100???????????002??????????????????????????
Priacodon          0?000122221000??01101??????????1002??????????????0???????????
Tinodon            ???1??22??1??0??????????????????0?2??????????????????????????
Akidolestes        100110001000000001110???????????002?????0011?0000100110112111
Spalacotherium     ???10?000?0000000??10???????????002?????????2????????????????
Zhangheotherium    100102200000100001110??????????2002?1100001121100100110112111
Maotherium         100102200000100001110???????????002?1?000011?1100?0011011211?
Dryolestes         000001100000000301110??????????2002??????????????????????????
Henkelotherium     00?0?110000000??0???0???????????0?2??????011?110??0???0112111
Amphitherium       ???0??000?0?00??????????????????0?2??????????????????????????
Peramus            ?0000003310?00??0???0???????????0?2??????????????????????????
Vincelestes        00100333342000030??00???????????0?2011110011?1101201?101?2110
Nanolestes         ??001?02??0?00??0???0???????????002??????????????????????????
Kielantherium      ???0??12??0??0??????0???????????002??????????????????????????
Aegialodon         ????????????????????????????????002??????????????????????????
Montanalestes      ??????03??0?00??????????????????0?2??????????????????????????
Prokennalestes     ?01010033?0000?00?1?0???????????002??????????????????????????
Murtoilestes       ?0??????????????????????????????002??????????????????????????
Eomaia             00000003310010000?100???????????00211?11001121101200?10112210
Juramaia           00100003310000000?100-??-?--???00211111001??1??????????112210
Kennalestes        001011{01}33200100001101???????????00201????????????????????????
Asioryctes         00101113321010000?101???????????00201111??11?110?????????????
Ukhaatherium       00000113321010030?101???????????002?1??1?011?110??0???0?12210
Zalambdalestes     00110{12}{12}33{23}1010200?111???????????002??1110011?110??0???01?2210
Daulestes          000101133200?0??0?100???????????002??????????????????????????
Aspanlestes        ??????033?0??0????1?0???????????002??????????????????????????
Eoungulatum        ??????1332???0????1?0???????????002??????????????????????????
Cimolestes         0?000113321?00????1?0??????????2002??????????????????????????
Gypsonictops       0?000113320?00????1?0??????????2002??????????????????????????
Protungulatum      0?000113321?00????100??????????2002??????????????????????????
Erinaceus          100103333420002001110??????????200211111001121101200?11112{12}10
Leptictis          00010113321000200?100???????????002??????011?1101200?101?22??
Canis              000002332310000000100??????????20121111110112110120??10112120
Felis              000003443430?00000100??????????20121111110112110120??10112120
Rattus             2??2?333343???1?02112??????????200211111001121101200?10112210
Oryctolagus        2??2?333343??0??02112??????????211311111001121101201?10112210
Bradypus           1??2??????00??????01???????????301?1111110112111120??10112120
Tamandua           1??2??????????????01???????????3???1111110112111120??10112120
Glyptotherium      10?2??????00??????01???????????30101111110112111120??10112120
Dasypus            10?2??????43??????01???????????30101111110112111120??10112120
Chaetophractus     10?2??????43??????01???????????30101111110112111120??10112120
Euphractus         10?2??????43??????01???????????30101111110112111120??10112120
Holoclemensia      ?????????????0??????????????????002??????????????????????????
Sinodelphys        00000113211120?10?100???????????002?????001121?0120??10112310
Deltatheridium     000002222211100?12100??????????2002??????????????????????????
Atokatheridium     ????????????????????????????????002??????????????????????????
Sulestes           ????0222221?10????1?????????????002??????????????????????????
Asiatherium        000?0222221010?????0????????????002????100112110??0????112310
Kokopellia         0?000?222?1?10??0?100??????????2002??????????????????????????
Anchistodelphys    ????????????????????????????????002??????????????????????????
Albertatherium     ????????2???????????????????????002??????????????????????????
Didelphodon        ?0?00222221?00????1?0??????????2002??????????????????????????
Pediomys           ???00222221100??????0??????????2002??????????????????????????
Turgidodon         ???00222221?00???21?0??????????2002??????????????????????????
Mayulestes         00000222221100111?100???????????002111110011?1101201?10112310
Pucadelphys        000002222211101112100???????????00211111001121101201?10112310
Andinodelphys      00000222221110111?100???????????002??????0????????0???0??????
Didelphis          000002222211101112100??????????2002111110011?1101201?10112310
Marmosa            000102222210001112100???????????00211111001121101201?10112310
Caenolestes        000002222210100202100???????0???00211111001121101201?10112310
Dasyurus           000003322311000112100???????????00211111001121101201?10112310
Perameles          000002222210100212101???????????00211111001121101201?10112310
Dromiciops         000102222210100212100???????????00211111001121101201?10112310
Thylacomyidae      00???222221??0?2??210???????????00211111001121101201?10112310
Macropus           1????332232?110202112????1?10???00211111001121101201?10112310
Acrobates          000102222310000202110???????????00211111001121101201?10112310
Phascolarctos      10???332233?200102111???????????00211111001121101201?10112310
Vombatus           20???332233?201?02112???????????00211111001121101201?10112310
Phalanger          000102222220210202111???????????00211111001121101201?10112310
Pseudocheirus      100103322320000202111???????????00211111001121101201?10112310
Petauroides        000103322320000202111???????????00211111001121101201?10112310

Thrinaxodon        00000000000000000000000?????000000??0000000000000000000?0000?
Massetognathus     ???00????00000000000000?????1000?0??00000???0??0???0?00??????
Probainognathus    ???00???????????0????0??????10???0??000?0???0??0???0?00??????
Tritylodontids     000000000000000{01}1000000?????2000010?0000000000000000000?0000?
Pachygenelus       00000000000000001000000010000?21000 1???00?0000000????00???????
Adelobasileus      ??????????????????????????????????????0??????????????????????
Sinoconodon        00000000000000001000000????????????????????000?00?0??00??????
Morganucodon       00000?00000000001000000?????2100010???000010000010?0000??000?
Megazostrodon      00000?000000000010000 0??0??02100010?000000100000?000000?0000?
Haldanodon         01000?00?00000120000?0??????21?????????000?00000?0?0?0???????
Castorocauda       ??????????0000120000000000002100000000000000000001010000?0000?
Megaconus          ?????00?00000?000001000????021?0??0000???0?00000?200210?00?0?
Eleutherodon       ?????????????????????????????????????????????????????????????
Sineleutherus      ?????????????????????????????????????????????????????????????
Thomasia           ?????????????????????????????????????????????????????????????
Haramiyavia        ?????????????????????????????????????????????????????????????
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Arboroharamiya      ????????????????????10????12{01}???????0???0?000?0100?000?0????
Xianshou_linglong   ??????????0001100001101100121002 01?0000?0?0000??00?000?00?0?
Xianshou_songae     ??????0???000110000?10?1?012100201??0?000??0?00100?000?0000?
Shenshou            1100000000000110000110110012?00201?00?000?00000100?000?0000?
Rugosodon           1111001100100?000010110001021?011000000?1?001002011001000121
Kuehneodon          ????????????????????????????????????????????????????????????
Sinobaatar          111100110010020000101100010210{01}110000000111010020110010001 21
Plagiaulacids       ??????????????????????????0????????????????1????????????????
Cimolodontans       1111001100100{12}0000{01}01100??02101110000000111?1002011001000121
Hadrocodium         ????????????????????0???????????????????????????????????????
Shuotherium         ????????????????????????????????????????????????????????????
Pseudotribos        ?????0????0???12000000?????211???00000?10?0000000?00????????
Asfaltomylos        ????????????????????????????????????????????????????????????
Ambondro            ????????????????????????????????????????????????????????????
Ausktribosphenos    ????????????????????????????????????????????????????????????
Bishops             ????????????????????????????????????????????????????????????
Teinolophos         ????????????????????????????????????????????????????????????
Steropodon          ????????????????????????????????????????????????????????????
Obdurodon           ???????????????????????????21???1????11?????????????????????
Ornithorhynchus     010000000000000120000001001?21111100001110000002201100210000?
Tachyglossus        010000000000000120000001001?21111101001110000002201100210000?
Fruitafossor        11000?00100000120001001001021??????0000???00??0100?100?0?0??
Gobiconodon         111100111000000101000000 0??21002000000000000000100?000?00000
Repenomamus         111100111000000101000000???21002000000000000000 1000000?00000
Amphilestes         ???????????????????????????????????????????0????????????????
Yanoconodon         11110011100000010101000001?210020000000000000001000000?00000
Jeholodens          1111001110 0??0101010000010210020000000000000001000000?00000
Trioracodon         ????????????????????????????????????????????????????????????
Priacodon           ????????????????????????????????????????????????????????????
Tinodon             ????????????????????????????????????????????????????????????
Akidolestes         11110011101111101110100001?21111201000011?000002100102100100
Spalacotherium      ???????????????????????????????????????????1??????0?????????
Zhangheotherium     11110011101111101110100001021112200000001?111002100100?00100
Maotherium          11110011101111101110100001021112200000001?1?10021{01}?100?00100
Dryolestes          ????????????????????????????????????????????????????????????
Henkelotherium      1?110?111011?1001110210001?21?02200000001110000211 0000?10???
Amphitherium        ????????????????????????????????????????????????????????????
Peramus             ????????????????????????????????????????????????????????????
Vincelestes         11110011101010001110?00001?210122000000011100002110000?1020?
Nanolestes          ????????????????????????????????????????????????????????????
Kielantherium       ????????????????????????????????????????????????????????????
Aegialodon          ????????????????????????????????????????????????????????????
Montanalestes       ????????????????????????????????????????????????????????????
Prokennalestes      ????????????????????????????????????????????????????????????
Murtoilestes        ????????????????????????????????????????????????????????????
Eomaia              111100211011120022102100010211122000000 01?101102111000?01221
Juramaia            ??110?21?01????02210200???0?????????????????????????????????
Kennalestes         ????????????????????????????????????????????????????????????
Asioryctes          ?????????0?????0???0?11000??????2?0??00???????0??1?000?01221
Ukhaatherium        11110?211011120022102100?1?210?2200000001?101102111000?01221
Zalambdalestes      11110?211011120022102100010211122000000 01?10110211121 0??1221
Daulestes           ????????????????????????????????????????????????????????????
Aspanlestes         ????????????????????????????????????????????????????????????
Eoungulatum         ????????????????????????????????????????????????????????????
Cimolestes          ????????????????????????????????????????????????????????????
Gypsonictops        ????????????????????????????????????????????????????????????
Protungulatum       ????????????????????????????????????????????????????????2220
Erinaceus           111101211011120022102100010211122 1?00000111011121012 10?12220
Leptictis           111?01211011120022102 1????02111221?00000111011122112 10?12220
Canis               1111012111111200221121000002111221?000001100110111111 10?22212
Felis               1111012111111200221121000002111221?000001100110111111 10?22212
Rattus              1110001101000210221120000102111211?001011110111211111 00?12210
Oryctolagus         11100020010112002210200001?2111201?00101111011121011 10?0?211
Bradypus            11121021111112002211210000?2111321?11000110011012011 00?12212
Tamandua            11121021111012002211210000?2111321?11000110011011011 00?22212
Glyptotherium       11120021111012002211210000?2111321?11000110011012012 10?22212
Dasypus             11120021111012002211210000?2111321?11000110011111012 10?22212
Chaetophractus      11120021111012002211210000?2111321?11000110011111012 10?22212
Euphractus          11120021111012002211210000?2111321?11000110011111012 10?22212
Holoclemensia       ????????????????????????????????????????????????????????????
Sinodelphys         1111012?111112?02211211110021????00000001?10??0?100000?01212
Deltatheridium      ????????????????????????????????????????????????????????12??
Atokatheridium      ????????????????????????????????????????????????????????????
Sulestes            ????????????????????????????????????????????????????????????
Asiatherium         11110?211011120022112111100210122000000001?10110100100?01???
Kokopellia          ??????????????????????????0?????????????????????????????????
Anchistodelphys     ????????????????????????????????????????????????????????????
Albertatherium      ????????????????????????????????????????????????????????????
Didelphodon         ?????????????????????????????????????????????????????????212
Pediomys            ?????????????????????????????????????????????????????????212
Turgidodon          ????????????????????????????????????????????????????????????
Mayulestes          1111012111111200221121?1???211122000000011101101110000?012??
Pucadelphys         1111012111112102211 2??????211122000000001110110111 0000?01213
Andinodelphys       ??????????????????????????????????????????????0?????????????
Didelphis           11110121111112{01}02211212110021112200000001110110111 0000001213
Marmosa             111101211111120022112121100211122000000011101101110000001213
Caenolestes         11110121111112002211212110021112200000001110110111 0000?01213
Dasyurus            11110121111112002211212110021112200000001110110111 0000?01213
Perameles           111101211111120022112121100211122000000001110110100100?01213
Dromiciops          11110121111112002211212110021112200000001110110111 0000?01213
Thylacomyidae       11110121?11120022112111100211122000000001110110111 0000?01213
Macropus            11110121111112002211211110021112200100001110110121 0010?01213
Acrobates           111101211111120022112111110?2111220000000111011011 10000?01213
Phascolarctos       111101211111120022112111110?2111220010000111011011 10000?01213
Vombatus            11110121111112002211211110021112200100001110110100100?01213
Phalanger           11110121111112002211211110021112200000001110110111 0000?01213
Pseudocheirus       11110121111112002211211110121112200000001110110111 0000?01213
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Petauroides       111101211111120022112111100211122000000001110110111000?01213

Thrinaxodon       000000000000000?00000000110000000???000000000?00????????0000
Massetognathus    ????????????????????????????????????0???0??00?00????????1000
Probainognathus   ????????????????????????????????????????0??00?00?????0??1000
Tritylodontids    00?0000000000000000000001??000?0?00?000000000?00?0???0?01111
Pachygenelus      ????????????????????????????????????????0000000100?0?0?01111
Adelobasileus     ?????????????????????????????????????????00000?????????02211
Sinoconodon       ???????????????????????????????????????0000000010000?0002211
Morganucodon      000000000000000000000000???0????????0??00000010100{01}{01}?0002311
Megazostrodon     00?000000000?00??0??0?0?1?000000000?000000?0010100???0002311
Haldanodon        ????????????????????????????????????0???000001020011?0002311
Castorocauda      ????0000000000000000??00?0??0?00000?01100???010?????????????
Megaconus         ?0000?00000000???00???0???00?0????00100??????1??????????????
Eleutherodon      ????????????????????????????????????????????????????????????
Sineleutherus     ????????????????????????????????????????????????????????????
Thomasia          ????????????????????????????????????????????????????????????
Haramiyavia       ????????????????????????????????????????????????????????????
Arboroharamiya    ??0?????00?????????????????0????001?0?01????????????????????
Xianshou_linglong ??000?000010000?0000000000000000100100?01???????????????????
Xianshou_songae   ??000?000010000?0000000000000000100100101???????????????????
Shenshou          ??000?000?10000?00000000000000001001001011??0001?110??0??31?
Rugosodon         00100010001200100011000101100011100002101?0?????????????????
Kuehneodon        ????????????????????????????????????????????????????????????
Sinobaatar        0010001000120010001100010110001110000210100001010110?000????
Plagiaulacids     ???????????????????????????????????0????????????????????2311
Cimolodontans     0010002211120010011100110110001110000210100001010{01}10?0002311
Hadrocodium       ?????????????????????????????????????????10000020101?0002311
Shuotherium       ????????????????????????????????????????????????????????????
Pseudotribos      ????????????????????????????????????0???0???????????????????
Asfaltomylos      ????????????????????????????????????????????????????????????
Ambondro          ????????????????????????????????????????????????????????????
Ausktribosphenos  ????????????????????????????????????????????????????????????
Bishops           ????????????????????????????????????????????????????????????
Teinolophos       ????????????????????????????????????????????????????????????
Steropodon        ????????????????????????????????????????????????????????????
Obdurodon         ????????????????????????????????????????100002110110?0002311
Ornithorhynchus   00000001011000000000000110000110100?11{01}0100002110010?0002311
Tachyglossus      00000001011000000000000110000110100?11{01}0100002110010?0002311
Fruitafossor      ?????0000000000000?00000???????????001??0????10???11????????
Gobiconodon       00?000000010000000000000000??????????00100000001020011?0002311
Repenomamus       0000000000100000000000000?0?0??0??0?0?10000001020011?0002311
Amphilestes       ????????????????????????????????????????????????????????????
Yanoconodon       0000000000100000000000000?0?0?00??0?0000000001020?11??00????
Jeholodens        000000000010000000000000000000001000000000000102?011?0002311
Trioracodon       ????????????????????????????????????????0??????????????02311
Priacodon         ????????????????????????????????????????0?????0????1??002311
Tinodon           ????????????????????????????????????????????????????????????
Akidolestes       000000100201001000110000100001210000?021010?001020??1???????
Spalacotherium    ????????????????????????????????????????????????????????????
Zhangheotherium   00000013020100100011000010000020000002101????1020111?0012311
Maotherium        00000?13020100????11000010000002{01}0000021010?001020111?0012311
Dryolestes        ??????????????????????????????????????????1?????????????????
Henkelotherium    ??????1????????????????????????0????0?1011???1020?11?00?2311
Amphitherium      ????????????????????????????????????????????????????????????
Peramus           ????????????????????????????????????????????????????????????
Vincelestes       00?100130201011000110100??0???210???0?00111002020011?00123?1
Nanolestes        ????????????????????????????????????????????????????????????
Kielantherium     ????????????????????????????????????????????????????????????
Aegialodon        ????????????????????????????????????????????????????????????
Montanalestes     ????????????????????????????????????????????????????????????
Prokennalestes    ????????????????????????????????????????????????????????2311
Murtoilestes      ????????????????????????????????????????????????????????????
Eomaia            00021223020101301111101000001002100001200111?0?1????2??0???1
Juramaia          ???????????????????????????????????0????????????????????????
Kennalestes       ?????????2???????????????????????????????1100212211221022311
Asioryctes        0002122302010130111110100000?020000?1?0011100212211221022311
Ukhaatherium      000212230201013011111010000???200???1??01??00?1?2??221???3??
Zalambdalestes    00021223?201013?011300000000002000001?0011100312211221022311
Daulestes         ?????????????????????????????????????????1100212011201022311
Aspanlestes       ?????????????????????????????????????????????????????????3??
Eoungulatum       ?????????????????????????????????????????????????????????3??
Cimolestes        ????????????????????????????????????????????????????????????
Gypsonictops      ????????????????????????????????????????????????????????????
Protungulatum     03?2122312?1013011132011????????????????????????????????2311
Erinaceus         030212251201013011132011000000200100120011100312111201022311
Leptictis         03?21223120101301113201100???0200?001??011100312111201022311
Canis             0202122510010130111?30110?0?00200000120011100302111311022311
Felis             0202122510010130111?30110?0?00200000120011100302111311022311
Rattus            030212250001011011?31011010100010000120011100201011002012311
Oryctolagus       130212250001013010131011010100010000?12001110020101100 20?2311
Bradypus          0102122510010130111?30110?0?0020000?120011100302111311022311
Tamandua          0102122510010130??1?30110?0?0020000?120011100312111311022311
Glyptotherium     0102122510010130111?30110?0?0020000?120011110302111311022311
Dasypus           0202122510010130111?30110?0?0020000?120011110302111311022311
Chaetophractus    0202122510010130111?30110?0?0020000?120011111302111311022311
Euphractus        0202122510010130111?30110?0?0020000?120011111302111311022311
Holoclemensia     ????????????????????????????????????????????????????????????
Sinodelphys       010??1242202011021?21000110110210000020011??0???????????????
Deltatheridium    ??????2??????110212???00????????????????11100?020112????2311
Atokatheridium    ????????????????????????????????????????????????????????????
Sulestes          ????????????????????????????????????????????????????????2311
Asiatherium       ??????2????????????????????????????00?001110?3020112010?2311
Kokopellia        ???????????????????????????????????0????????????????????????
Anchistodelphys   ????????????????????????????????????????????????????????????
Albertatherium    ????????????????????????????????????????????????????????????
Didelphodon       01?101231101011021221011??????????????????10?302011201022311
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Pediomys          01?101242202011021221011????????????????????????????????12311
Turgidodon        ??????????????????2??????????????????????????????????????22311
Mayulestes        ??????24220201102121101l??????210???0?00111003020112011l12311
Pucadelphys       010101242202011021221011?101?0210???0?00111003020112011l12311
Andinodelphys     ??????2???????????????????????????????0???111003?2011201122311
Didelphis         010101242202111021232011110110210010020011100302011201112311
Marmosa           010101242202111021222011110110210010020011100302011201112311
Caenolestes       020?01242201011021221011110000210100020011100302011202112311
Dasyurus          120101251001012121 3?101111000021010002001110030201120113231l
Perameles         020?11251002012121 3?101111010020010002011110030201120211231l
Dromiciops        020?112510020121213?201111010021001002001110030201120111231l
Thylacomyidae     0?0???25100201212 13???11??0?002?0?00020111100302?112?113231l
Macropus          120?112510010121213?1011110100200000020111100302111313032311
Acrobates         020?112510020121213?2?111101002?0?1?020111100302111313032311
Phascolarctos     020?112510020121213?101111010021001?020112100302111001032311
Vombatus          020?112510020121213?10111101002100100201121003021110?0032311
Phalanger         020?112510020121213?201111010021001002011210030211131303231l
Pseudocheirus     020?112510020121213?2011110100210010020112100302111313032311
Petauroides       120?112510020121213?2011110100210010020112100302111313032311

Thrinaxodon       ??000??00?0?00?000?0000010?1000000??0????0?00?00??0?0?000000
Massetognathus    ??000??00?0?00?000?00000100100000??0????0?00?00??0?0?101000
Probainognathus   ??000??00?0?00?000?00000100110000??0????0?00?00??0?0?001000
Tritylodontids    ??1000000?00000000?00000100000010??000000?00000?0100?002100
Pachygenelus      ??1?00000?0000?000?00000101100000??000000?0001000 0?1?002100
Adelobasileus     00?????000001?11??1010000100100 00???000000000010000?10??????
Sinoconodon       001000000000010111010100000000000100?00000000000010001010102100
Morganucodon      1120100000000010111010100011010011100100000000010001010002100
Megazostrodon     012010?0000001011101000001 1?1001110?1000000000100010 1?00210?
Haldanodon        00201000000001?1210100?001????01010010000000001000101000????
Castorocauda      ????????????????????????????????????????????????????????????
Megaconus         ??????????????????????????????????????????????????????00????
Eleutherodon      ????????????????????????????????????????????????????????????
Sineleutherus     ????????????????????????????????????????????????????????????
Thomasia          ????????????????????????????????????????????????????????????
Haramiyavia       ????????????????????????????????????????????????????????????
Arboroharamiya    ????????????????????????????????????????????????????????????
Xianshou_linglong ????????????????????????????????????????????????????????????
Xianshou_songae   ????????????????????????????????????????????????????????????
Shenshou          01????????????????????????????????????????????1?0???????????
Rugosodon         ????????????????????????????????????????????????????????????
Kuehneodon        ????????????????????????????????????????????????????????????
Sinobaatar        ????????????????????????????????????????????????????????????
Plagiaulacids     11301??000000101211101100211???1111?10?0000000100011 11??????
Cimolodontans     1130100{12}00{01}001012111011002 1121{01}111{01}010{01}{01}0000001{01}001110323121
Hadrocodium       12301000000001?111010?10011021010110100000000 0100?1010??????
Shuotherium       ????????????????????????????????????????????????????????????
Pseudotribos      ????????????????????????????????????????????????????????????
Asfaltomylos      ????????????????????????????????????????????????????????????
Ambondro          ????????????????????????????????????????????????????????????
Ausktribosphenos  ????????????????????????????????????????????????????????????
Bishops           ????????????????????????????????????????????????????????????
Teinolophos       ????????????????????????????????????????????????????????????
Steropodon        ????????????????????????????????????????????????????????????
Obdurodon         11?????0000001?111?110100111210111 0?100000000000?00?0???????
Ornithorhynchus   114110000000010111011010011121011101100000000000?00?0?323121
Tachyglossus      11411000000001011101101001112101110110000000000 10?00?0?323121
Fruitafossor      ????????????????????????????????????????????????????????????
Gobiconodon       11301000000001?12112000001111001110020000000000011??1011??????
Repenomamus       11301000000001?1211200000111100111002 0000?000011??101???????
Amphilestes       ????????????????????????????????????????????????????????????
Yanoconodon       ??????????????????????0???????????????????????????????323121
Jeholodens        ?130100??0???10??1????????????????????0??0????????????????21
Trioracodon       ?????????0??0?0??1010???0??????????????0??0???1??10????????
Priacodon         11301??000000101?12100??0111100??100??000??0??1100101???????
Tinodon           ????????????????????????????????????????????????????????????
Akidolestes       ????????????????????????????????????????????????????????????
Spalacotherium    ????????????????????????????????????????????????????????????
Zhangheotherium   112????1101001?1?1?10???0??1210111102000000001?0?11?1??????
Maotherium        112????1101001?1???10?100?11000111??20000000001???11????????
Dryolestes        ????????????????????????????????????????????????????????????
Henkelotherium    1?3??????????????????????????????????0??????????????????????
Amphitherium      ????????????????????????????????????????????????????????????
Peramus           ????????????????????????????????????????????????????????????
Vincelestes       12400?11101001011101001001 1{01}2111111020110000001100211 1??????
Nanolestes        ????????????????????????????????????????????????????????????
Kielantherium     ????????????????????????????????????????????????????????????
Aegialodon        ????????????????????????????????????????????????????????????
Montanalestes     ????????????????????????????????????????????????????????????
Prokennalestes    12511111 10{12}00102?10?????13?1?111011???11001???110?21????????
Murtoilestes      ????????????????????????????????????????????????????????????
Eomaia            ??51?11???????????1??????????????????????????11?????????????
Juramaia          ????????????????????????????????????????????????????????????
Kennalestes       12511??210211002{34}1?2001013?????1011020100011001100211 0??????
Asioryctes        125?1??2102110?241?2001013???111011020100011001100211 0??????
Ukhaatherium      ???????2??21????4?0????0???????1???????0?0?1??????21?1??????
Zalambdalestes    125?1??21021100241120010 13???111011020100011001100211 1??????
Daulestes         12511???10?????2?????01013????????11?201100??001????????1????
Aspanlestes       ???????1?0?0?1????0?????1????????????????00?1????????1???????
Eoungulatum       ???????1???0?1????0????????????????????000??????????1???????
Cimolestes        ??????????????????????????????????????0?????????????????????
Gypsonictops      ????????????????????????????????????????????????????????????
Protungulatum     125?1??1?0?0?00??{01}0?????1??????????????11001????1??21????????
Erinaceus         125111121021100231130011 13???111011020110011001100211 1213111
Leptictis         1251111110201002311300111 3???11101102011001100110021 10??????
Canis             125111?11?3??0?231111011 13?????10110200001000011 0?112{01}213111
Felis             125111?11?3??0?23111101113?????101102000010000110?1120213111
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Rattus             125111111010000241101011131??2?101101010011100211111110213111
Oryctolagus        125111111010000241101011131??2?101101000011100111011110213111
Bradypus           125111?11?3??0?2302110101 3?????1011020000{01}0000110?1120213111
Tamandua           125111?11?3??0?231?1101013?????101102001000000110?1120213111
Glyptotherium      125111?11?3??0?230?1101013?????1011020000?0000110?1120???11
Dasypus            125111?11?3??0?230{12}1101013?????101102000000000110?1120213111
Chaetophractus     125111?11?3??0?2302110101 3?????1011020000{01}0000110?112{01}213111
Euphractus         125111?11?3??0?2302110101 3?????1011020000{01}0000110?112{01}213111
Holoclemensia      ????????????????????????????????????????????????????????????
Sinodelphys        ????????????????????????????????????????????????????????????
Deltatheridium     12510??110100212312???1013???2?1011?2?00001???1101111???????
Atokatheridium     ????????????????????????????????????????????????????????????
Sulestes           12510??1?0????12?1???????????????????????000??????1?1??????????
Asiatherium        125????1111?0??23??4101013?????10?1?2??0?0101111???11???????
Kokopellia         ????????????????????????????????????????????????????????????
Anchistodelphys    ????????????????????????????????????????????????????????????
Albertatherium     ????????????????????????????????????????????????????????????
Didelphodon        12??0????1??0?1??11?????1??????1?????0?00?1?????0111????????
Pediomys           1???0????0??0?1???1?????1??????1???????00?1?????0111????????
Turgidodon         1???0????0??0?1??11?????1??????1???????00?1?????0?11????????
Mayulestes         125????110100??24110101013?????10110210010100111111111??????
Pucadelphys        12511??1101002124110101013?????10110210010100111111111??????
Andinodelphys      125????1101002?24110101013?????1011021001010001111111???????
Didelphis          1251111111100212311{01}101013?????10110200000101111011111213111
Marmosa            125111111110021231111101013?????10110200000101111011111213111
Caenolestes        1251111111113002?2311010101 3?????10?1020000000211101111121 31??
Dasyurus           1251111111300212310110101 3?????101102000001021110111121?131??
Perameles          12511111113002?2311410101 3?????10110200000102111011111213 1??
Dromiciops         12511111113002?231?410101 3?????10110200000102111001110213 1??
Thylacomyidae      12511111113002?2310?101013?????101102?000010 2?1???11??2131??
Macropus           12511111113002?2311410101 3?????1011020000010311100111121 31??
Acrobates          12511111113002?2311410101 3?????10110200000101111011120213 1??
Phascolarctos      12511111113002?2311410101 3?????10110200000102111011111213 1??
Vombatus           12511111113002?2302310101 3?????10110200000101111001111213 1??
Phalanger          12511111113002?2311410101 3?????10110200000103111001111213 1??
Pseudocheirus      12511111113002?2311410101 3?????10110200000103111001121213 1??
Petauroides        12511111113002?2311410101 3?????10110200000103111001121213 1??

Thrinaxodon        000000000000000000000000000000000000000000000?000000000000000
Massetognathus     000000000010000000000000300000000000000001000 00?000000000?0000
Probainognathus    000?000000100000000000000000000000000000100000?000000000?0000
Tritylodontids     000000000010000000{01}01030100000000000000200100?1000000000000{01}0
Pachygenelus       110000000010000000010000010101010000000100000?100000000000000
Adelobasileus      ???0????????????0??0?0?000?????????00??0200??????000110 0??????
Sinoconodon        110000000010000010010100010100010000000200010020000000010 0000
Morganucodon       210000000010000010010100010101010000000200010020000110011 0000
Megazostrodon      21???0??001?000010?1??0001010101 00000?2?00100200001?00??????
Haldanodon         21000???00??00002011?100010101010000000200010020100111011 0000
Castorocauda       ?????1100010000?????????0??????10?000?2????0?2????1???11?00?
Megaconus          ?1???011??10000?????????????????????????????????????????????
Eleutherodon       ????????????????????????????????????????????????????????????
Sineleutherus      ????????????????????????????????????????????????????????????
Thomasia           ????????????????????????????????????????????????????????????
Haramiyavia        ????????????????????????????????0?????????????2?????????1????
Arboroharamiya     ????????????????????????????????????????????????????????????
Xianshou_linglong  ?1??????????????????????????????10????????????????????????????
Xianshou_songae    ?1??????????????????????????????????????????????????????????
Shenshou           ?1??????????????20?????????????10?000????????????02?0??11?1?
Rugosodon          ??1?????????????????????????????????????????????????????????
Kuehneodon         ????????????????????????????????????????????????????????????
Sinobaatar         ?1????????2???00????????????????????????????????????????????
Plagiaulacids      21?0???????????0?000201001002000 10?0000202?112202000100{01}11010
Cimolodontans      21100111??211100000{12}0100100200010200002{01}2111220200110 0121010
Hadrocodium        21?0??????1????02012?103010100010000012??2?10020101211001?00?
Shuotherium        ????????????????????????????????????????????????????????????
Pseudotribos       ????????????????????????????????0?????????????2???1??????????
Asfaltomylos       ????????????????????????????????????????????????????????????
Ambondro           ????????????????????????????????????????????????????????????
Ausktribosphenos   ????????????????????????????????????????????????????????????
Bishops            ????????????????????????????????????????????????????????????
Teinolophos        ????????????????????????????????????????????????????????????
Steropodon         ????????????????????????????????????????????????????????????
Obdurodon          ?1?0????????????03012?10000?40?110211?120201122?0012110011?0?
Ornithorhynchus    211001110121010030110100002400110211212020112210012110011?0?
Tachyglossus       21100111012101003012110200240011?21121202111221001211001 1?0?
Fruitafossor       ????????????????????????????????0?????????????2?1?????????????
Gobiconodon        ?1?1????12????002002110000110000000011200111221210110001?000
Repenomamus        21?1????12?????020021100001100000000112001112212101100 01?000
Amphilestes        ????????????????????????????????1???????????????????????????
Yanoconodon        21???1101221 0100?00?????0??????11??????2????122?????????????0?
Jeholodens         ????????1221?????????????00?10??11???00?????122???011??01??0?
Trioracodon        ???0????????????0????????0?????????1?????????????????0???????????
Priacodon          2??0??????????020?????000??????1????????{12}??122?10??????????0
Tinodon            ????????????????????????????????????????????????????????????
Akidolestes        ????????????????????????0???????10?0???2??????12?????????0???0?
Spalacotherium     ????????????????????????????????0???????????????????????????
Zhangheotherium    21??????1??????0??????0??1?????10???0???2???12??2?????????00?
Maotherium         ????????12??????0201??20?0??22??100000???2???12?02?1???0??00?
Dryolestes         ?????????????????????????1???10?0???????????????????????????00?
Henkelotherium     ?????????????????????1?????20001???1??????????20?????????????
Amphitherium       ????????????????????????????????????????????????????????????
Peramus            ????????????????????????????????????????????????????????????
Vincelestes        21?0????????????01011010001020100000101200010020200010011 1000
Nanolestes         ????????????????????????????????????????????????????????????
Kielantherium      ????????????????????????????????????????????????????????????
Aegialodon         ????????????????????????????????????????????????????????????
Montanalestes      ????????????????????????????????????????????????????????????
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Prokennalestes	2??1?????????????????????0???????????1??????????1???????????
Murtoilestes	??
Eomaia	???????????????0????????00??0??10?0???2???10?20??????02???1?
Juramaia	??
Kennalestes	21?2??????321300?0110200000200??0?01012121100202201110021010
Asioryctes	21?2??????32130020110200000200?101010?2121100202201110021010
Ukhaatherium	???2???????21??0?0?????0????????0?010???21??0????????0??????
Zalambdalestes	21?2??????32130020110200000201?1010101211110{01}202101100021010
Daulestes	2??1??????3???00?01?1??000?100?10?000?212110{01}20???1??00?????
Aspanlestes	???1?????????????????????0??????????????????????????????????
Eoungulatum	???1??
Cimolestes	??
Gypsonictops	??
Protungulatum	???2??1???????????
Erinaceus	2122011101421300211113000002001101101121211?2212101110021110
Leptictis	21?20?????32130121111200000300010110112121110202101110021010
Canis	212201110142131120111401001300010110112110102202212100021111
Felis	212201110142131120111401001300010110112110102202212100021111
Rattus	21220111014213002011121200140011011001212011221321210002121?
Oryctolagus	21220111015213000011111210030011?211112120112213212100002121?
Bradypus	2122011101421311301111030010100 1?1102121101122 0?212100021011
Tamandua	212201110142131130111103001010 02?11021211011220?212100021011
Glyptotherium	??2201110142131130111103001010010110212121112 20?212101021011
Dasypus	2122011101421311301111130010100201101121211122 0?212101021011
Chaetophractus	21220111014213113011111300101002011021212111220?212101021011
Euphractus	21220111014213113011111300101002011021212111220?212101021011
Holoclemensia	??
Sinodelphys	????????????????????????0??????10?0???2????0?2?3??????0?????
Deltatheridium	2??1???????????02?11?2?000?201010?000121???0{01}2031????002?011
Atokatheridium	??
Sulestes	???0?2??????????????
Asiatherium	2??????????????02011?2?00??21??10?0?0?2????0{01}20???11000?????
Kokopellia	??
Anchistodelphys	??
Albertatherium	??
Didelphodon	?1?1???????????0????????????????????????????0???1????0??????
Pediomys	???1?????????????????2???0??????????????????????1???????????
Turgidodon	???1??1???????????
Mayulestes	21?????????????0201102000002110101000?201010020??01100021111
Pucadelphys	21?1??????2????02011?200000211010111012010100203101100021011
Andinodelphys	21?1???????????02?111?1000021?01011001201?100203101100021011
Didelphis	212101110022120020111210000210010110012010100203100100021111
Marmosa	212101110022120020111210000210010110112010100203112110021111
Caenolestes	2111011100321200201113100002 1?01011?0120101002032??10002111?
Dasyurus	211101110042120020111112000211010110112010100203201100021111
Perameles	211101110042120020111210000210010110112010100203212100021110
Dromiciops	212201110032130020111110000311010110012 0?010020321211002101 1
Thylacomyidae	21??0?110042 1?0020111?1000021?01011?012?101?020?2??1?0021?1?
Macropus	21220111005213002011111100131101011001201010030321211002101?
Acrobates	212?11110052131020111310000311010110012010100203212110021111
Phascolarctos	211201110032130020111311001410010111012010100303201100021111
Vombatus	211201110052130020111310001411010110012010100303202100021111
Phalanger	212211110052131020111311001310010110012010100303202100021111
Pseudocheirus	212211110052131020111210000311010110012010101203212100021111
Petauroides	212211110052131020111210000211010110012010101203212110021011

Thrinaxodon	100000000000?????
Massetognathus	000000000010???01
Probainognathus	000000000101?????
Tritylodontids	0000100?0111???00
Pachygenelus	0000000??????????
Adelobasileus	?????0???????????
Sinoconodon	000010000102?????
Morganucodon	000010000112?????
Megazostrodon	?00??0???????????
Haldanodon	000000???2???????
Castorocauda	?????????????????
Megaconus	???????????????00
Eleutherodon	???????????????00
Sineleutherus	???????????????00
Thomasia	???????????????11
Haramiyavia	???????????????11
Arboroharamiya	???????????????00
Xianshou_linglong	???????????????00
Xianshou_songae	???????????????00
Shenshou	?????1?1???????00
Rugosodon	???????????????00
Kuehneodon	???????????????00
Sinobaatar	???????????????00
Plagiaulacids	000?21?????????00
Cimolodontans	000021110223???00
Hadrocodium	?000?2??1213?????
Shuotherium	?????????????????
Pseudotribos	?????????????????
Asfaltomylos	?????????????????
Ambondro	?????????????????
Ausktribosphenos	?????????????????
Bishops	?????????????????
Teinolophos	?????????????????
Steropodon	?????????????????
Obdurodon	?00002????2??????
Ornithorhynchus	100002111223000??
Tachyglossus	{12}00102111223000??
Fruitafossor	?????????????????
Gobiconodon	001??0??0?00?????
Repenomamus	001010??0100?????
Amphilestes	?????????????????

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Yanoconodon       ?????????????????
Jeholodens        ?????1???????????
Trioracodon       ?????????????????
Priacodon         ??0??1???????????
Tinodon           ?????????????????
Akidolestes       ?????????????????
Spalacotherium    ?????????????????
Zhangheotherium   ?????????????????
Maotherium        ?????1???????????
Dryolestes        ?0???????????????
Henkelotherium    ?????????????????
Amphitherium      ?????????????????
Peramus           ?????????????????
Vincelestes       000??1???????????
Nanolestes        ?????????????????
Kielantherium     ?????????????????
Aegialodon        ?????????????????
Montanalestes     ?????1???????????
Prokennalestes    ?0???????????????
Murtoilestes      ?????????????????
Eomaia            ?????1???????????
Juramaia          ?????????????????
Kennalestes       ?00??1011223?????
Asioryctes        000??1011223?????
Ukhaatherium      0????????????????
Zalambdalestes    000??1011223?????
Daulestes         ?00??2???????????
Aspanlestes       ?????????????????
Eoungulatum       ?????????????????
Cimolestes        ?????????????????
Gypsonictops      ?????????????????
Protungulatum     ?????????????????
Erinaceus         020122011223111??
Leptictis         000122011223?????
Canis             100122001223111??
Felis             100122001223111??
Rattus            200121111223111??
Oryctolagus       200121111223111??
Bradypus          001122001223111??
Tamandua          001122001223111??
Glyptotherium     ?01122???22311???
Dasypus           001122001223111??
Chaetophractus    001122001223111??
Euphractus        001122001223111??
Holoclemensia     ?????????????????
Sinodelphys       ?????1???????????
Deltatheridium    000??????????????
Atokatheridium    ?????????????????
Sulestes          ?0???????????????
Asiatherium       ?10??2???????????
Kokopellia        ?????????????????
Anchistodelphys   ?????????????????
Albertatherium    ?????????????????
Didelphodon       ?1???????????????
Pediomys          ?1???????????????
Turgidodon        ?????????????????
Mayulestes        100??2???????????
Pucadelphys       100?21???????????
Andinodelphys     11??21???????????
Didelphis         110121011223002??
Marmosa           110121011223002??
Caenolestes       220121???223002??
Dasyurus          110121011223002??
Perameles         110121???223001??
Dromiciops        110121011223002??
Thylacomyidae     ??0121???22300???
Macropus          0{012}0121???223002??
Acrobates         120121???223002??
Phascolarctos     020121???223002??
Vombatus          001121???223002??
Phalanger         120121???223002??
Pseudocheirus     120121???223002??
Petauroides       120121???223002??
          ;
End;
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(8) SI-Explanation on revision of Krause et al. (2014) Matrix

To assess the impact of the newly documented features of Haramiyavia on its placement in mammaliaform phylogeny, we tested it with an independent phylogenetic matrix developed by Krause et al. (23) for their estimate of the phylogenetic position of the gondwanatherian Vintana.

Krause et al. (23) partially followed the earlier morphological interpretation of Haramiyavia of Averianov et al. (17) and treated many mandibular features of Haramiyavia as unknown or not preserved. Our newly documented features from CT scanning, SEM and stereo photograph, and our own reanalysis of Thomasia can provide a test how the new character information can influence the overall mammaliaform phylogeny within the framework of the Krause et al. (23) dataset.

Listed below are the characters on the list of Krause et al. (23) that have been changed, as part of this test.

Cranium

70. Septomaxilla: 0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

Mandible

257. Mental foramina, number (only applicable in taxa with well-developed foramina):
0) one 1) two 2) three 3) four 4) five or more

	Krause 2014	Revised Scoring
Haramiyavia	0	**0/1**

Note: the number of mental foramina in the incisor-canine region appears to be bilaterally asymmetrical: left mandible has only one, but right mandible appears to have two.

258. Anterior-most mental foramen, vertical position:
0) at ventral margin of mandible 1) at midline of mandible 2) at dorsal margin of mandible, close to tooth row

	Krause 2014	Revised Scoring
Haramiyavia	1	**0/1**

259. Anterior-most mental foramen, anteroposterior position:
0) below incisors or canine 1) below mesial premolars (p1, p2) or diastema 2) more posterior

	Krause 2014	Revised Scoring
Haramiyavia	1	**0**

260. Postdentary trough, behind tooth row:
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

264. Angular process (or region):
0) absent 1) present

	Krause 2014	Revised Scoring and note of explanation
Haramiyavia	?	**1**
Megazostrodon	1	0

Note: The definition of character is slightly modified here. The angular region of the dentary (also knonw as the mandibular angle) serves as insertion site for the superficial masseter laterally, and for the medial pterygoid medially (57). In stem mammaliaforms and premammalian cynodonts, the angular region of the dentary has been interpreted to be the insertion site of the superficial masseter, the same as in extant mammals (refs [55, 56], literature cited therein). However, the angular region as the attachment site of the superficial masseter shows a range of variation, in stem mammaliaforms as in extant mammals. This region can possess a pointed angle, or a recognizable angular region that corresponds, by its position, to the angular process, but lacks a pointed angle, or a shallow, curved border that precludes the identification of an "angular region" (as exemplified by <u>Megazostrodon</u> and <u>Kuehneotherium</u>) (56). Thus we modified this character definition to account for this range of morphological difference and still make the character amenable for scoring. We consider that <u>Haramiyavia</u> as have a recognizable angular region (Fig. 1 and S1), and that <u>Kuehneotherium</u> as an exemplar of lacking an angular region.

265. Angular process orientation:
0) not posteriorly projecting, possibly slightly inflected 1) straight, posteriorly directed 2) transversely flaring 3) strongly medially inflected

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**
Megazostrodon	0	**-**

266. Anteroposterior position of angular process (or its region) relative to dentary condyle:
0) anterior position, angular process below main body of coronoid process 1) posterior position, angular process placed at same level as posterior border of coronoid process

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

Note: definition of character is slightly modified.

267. Vertical position of angular process (or region):
0) low, at or near level of ventral border of mandibular horizontal ramus 1) high, at or near level of molar alveolar line

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**
Megazostrodon	0	-

268. Medial concavity (fossa for reflected lamina) on dentary angular process:
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

269. Coronoid bone, or its attachment scar, in adults:
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

270. Medial pterygoid ridge or shelf along ventral border of body of mandible:
0) absent 1) present

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**
Rugosodon	0	1
Sinobaatar	0	1

272. Medial pterygoid ridge or shelf posterior direction:
0) directed to angular process 1) reaching dentary condyle via low crest

	Krause 2014	Revised Scoring
Haramiyavia	?	-
Arboroharamiya	?	0
Sinobaatar	?	1
Rugosodon	?	1
Nemegtbaatar	?	1
Other multituberc	?	**1**

273. Position of mandibular foramen:
0) below or near base of anterior border of coronoid process 1) posterior to anterior border of coronoid process

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

274. Ventral border of masseteric fossa:
0) absent (or indistinctive) 1) present

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

275. Ventral border of masseteric fossa, extent:
0) low crest 1) well-defined crest

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

279. Dentary peduncle:
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

280. Dentary condyle direction:
0) posteriorly directed, forms angle of ≤35º to alveolar margin 1) vertically directed, forms angle of >35º to alveolar margin

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

281. Shape and relative size of dentary articulation:
0) small, dorsoventrally compressed 1) condyle massive, bulbous, transversely broad in dorsal view 2) condyle mediolaterally narrow, vertically deep, forming broad arc in lateral outline, either ovoid or triangular in posterior view

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

282. Position of dentary condyle relative to vertical level of postcanine alveoli:
0) below or about same level as postcanine alveoli 1) above level of postcanine alveoli

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

Dentition

287. Replacement of at least some distal postcanines:
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

288. Distal migration of postcanines, loss of mesial and addition of distal postcanines:
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

293. Diastema distal to ultimate lower incisor:
0) absent 1) present

	Krause 2014	Revised Scoring
Haramiyavia	?	**1**

294. Diastema distal to lower canine (only applicable if canine present):
0) absent 1) present

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

296. Number of upper incisors in each quadrant:
0) five 1) four 2) three 3) two 4) one 5) none

	Krause 2014	Revised Scoring
Haramiyavia	2	**1**

298. I2 gliriform:
0) absent 1) present

	Krause 2014	Revised Scoring
Haramiyavia	0	0
Thomasia	1	0
Yunnanodon	?	0

Bienotherium	?	0
Bocatherium	?	0
Guimarota multis	1	0
Sinobaatar	1	0

307. Position of distal end of root of lower mesial incisor relative to cheek teeth:
0) mesial to level of premolars 1) opposite level of premolars 2) opposite level of molars

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**

315. Total number of lower postcanine teeth in each quadrant:
0) ten or more 1) nine 2) eight 3) seven 4) six 5) five 6) four 7) three or fewer

	Krause 2014	Revised Scoring & notes
Haramiyavia	?	**3** (Haramiyavia has 7 postcanines)

318. Number of lower premolars in each quadrant:
0) five or more 1) four 2) three 3) two 4) one 5) none

	Krause 2014	Revised Scoring
Haramiyavia	0	**1**

322. Ultimate upper premolar (P5)/first upper molar (M1) length ratio:
0) >1.5 1) 1.5–0.8 2) <0.8

	Krause 2014	Revised Scoring & notes
Thomasia	2	?

Note: character state scoring for Thomasia is modified here because the upper ultimate premolar size ratio to the first upper molar is unreliable, given that all teeth are isolated.

328. Penultimate lower premolar (p4), roots:
0) three or more 1) two (or incipiently divided into two) 2) single

	Krause 2014	Revised Scoring
Haramiyavia	2	**1**

329. Penultimate lower premolar (p4),
buccal basal cuspules (applicable to bladed lower premolars):
0) present 1) absent

	Krause 2014	Revised Scoring
Haramiyavia	?	**1**

332. Ultimate lower premolar (p5) cusp alignment:
0) principal cusps mesiodistally aligned 1) principal cusps arranged in triangle

	Krause 2014	Revised Scoring
Thomasia	0	?

334. Ultimate lower premolar (p5), symmetry of protoconid (cusp a):
0) asymmetrical, mesial edge of protoconid more convex in outline than distal edge 1) symmetrical, mesial and distal cutting edges equal or subequal in length

	Krause 2014	Revised Scoring
Haramiyavia	-	**0**

335. Ultimate lower premolar (p5), paraconid (cusp b):
0) absent or indistinct 1) present as distinct or well-developed cusp

	Krause 2014	Revised Scoring
Haramiyavia	-	**0**

336. Ulitmate lower premolar (p5), relative height of protoconid (cusp a) to metaconid (cusp c); measured as height ratio of a and c from bottom of valley between two adjacent cusps:
0) metaconid absent or very small 1) metaconid distinctive but <30% of protoconid 2) metaconid and protoconid equal or subequal in height (40–100% of protoconid)

	Krause 2014	Revised Scoring
Haramiyavia	-	**1**

337. Ultimate lower premolar tooth (p5), hypoconid (= cusp d, following Davis, 2011):
0) absent 1) present

	Krause 2014	Revised Scoring
Haramiyavia	-	**0**

341. Ultimate lower premolar tooth (p5), buccal cingulid cuspules:
0) absent 1) present

	Krause 2014	Revised Scoring
Haramiyavia	-	**0**

342. Ultimate lower premolar tooth (p5), lingual cingulid:
0) absent or vestigial 1) present

	Krause 2014	Revised Scoring
Haramiyavia	-	**0**

344. Ultimate lower premolar (P5), organization of multiple cusps and rows (only applicable to taxa with multi-rowed cheek teeth): 0) two rows 1) one row

	Krause 2014	Revised Scoring
Haramiyavia	?	**1**

349. Transverse widening of upper relative to lower molars (or distal cheek teeth): 0) upper teeth not wider 1) upper teeth wider, up to 1/3 wider than lowers 2) upper teeth much wider than lowers (>1/3)

	Krause 2014	Revised Scoring & Note
Haramiyavia	2	2
Thomasia	1	1
Probainognathus	?	0
Yunnanodon	?	2
Bocatherium	?	2
Tritheledontids	?	0
Hadrocodium	?	0

Nemegbaatar	?	1 (applicable to upper M2)
Guimarota multis	?	1 (applicable to upper M2)
Rugosodon	?	1 (applicable to upper M2)
Sinobaatar	?	1 (applicable to upper M2)

390. m1-2 orientation of postcingulid:
0) oblique, connected to hypoconid 1) horizontal above gum level

	Krause 2014	Revised Scoring
Thomasia	0	-

392. Number of roots on each m1 and m2:
0) one 1) two 2) three or more

	Krause 2014	Revised Scoring
Thomasia	?	**1**

393. m1-2, root length
0) > three times crown height 1) ≤ three times crown height

	Krause 2014	Revised Scoring
Haramiyavia	?	**1**
Thomasia	?	1
Sinobaatar	?	1

394. m1-2, root orientation
0) straight 1) apical ends inclined or bent posteriorly

	Krause 2014	Revised Scoring
Haramiyavia	?	**0**
Thomasia	?	0

395. m1 cusp formula in taxa with multi-rowed cheek teeth:
0) 2:2–3 1) 3–4:2–3 2) 4:4 3) 5:4 4) 6:4 or higher

	Krause 2014	Revised Scoring
Thomasia	1	**2**

427. M1-2, buccal cingulum:
0) absent or weak 1) present

	Krause 2014	Revised Scoring
Haramiyavia	0	**1**
Thomasia	0	**1**

432. Number of roots on each M1 and M2:
0) one 1) two 2) three 3) more than three

	Krause 2014	Revised Scoring
Haramiyavia	?	**3**
Thomasia	1/2	2
Sinobaatar	?	1 (two-rooted)
Rugosodon	?	1 (two-rooted)

435. M1 cusp formula in taxa with multi-rowed cheek teeth (only applicable to buccal and middle rows – i.e., cusps and cuspules on distolingual wing not included):
0) 2-3:2-4 1) 4-7:4-6 2) 6-11:7-11

	Krause 2014	Revised Scoring
Thomasia	?	0
Oligokyphus	0	1

436. M2 cusp formula in taxa with multi-rowed cheek teeth (only applicable to buccal and middle rows – i.e., cusps and cuspules on distolingual wing not included):
0) 2-3:2-4 1) 2-3:5 2) 4-5:4-6

	Krause 2014	Revised Scoring
Thomasia	?	**1**

437. M1, distolingual wing (only applicable to taxa with multi-rowed cheek teeth): 0) absent 1) present

	Krause 2014	Revised Scoring
Thomasia	-	0

440. M1-2, third row in taxa with multi-rowed cheek teeth:
0) present, equal in length to or more than ½ tooth length (modified character state definition); 1) absent or third row shorter than ½ length of buccal rows (modified definition).

	Krause 2014	Revised Scoring
Ptilodus	1	0
Taeniolabis	1	0
Lambdopsalis	1	0

Note: For the state "0" of this character, we modified the definition of this character state "third row equal in length to buccal rows" to "equal in length to or more than ½ tooth length".

New Characters from This Study

New characters have been added from our re-study on Haramiyavia. These characters are informative, in our view, for estimating the position of Haramiyavia in the mammaliaform phylogeny.

454. (New character) Lateral ridge of dentary in masseteric fossa
0) Absent: All premammaliaform cynodonts (except tritylodontids and tritheledontids); all crown mammals for which this feature has been assessed.

1) Present: all tritylodontids, tritheledontids, Sinoconodon, Morganucodon, Megazostrodon, Hadrocodium, Haldanodon, Haramiyavia.

?) Scored for those taxa for which the mandible is not preserved or the labial view of the mandible is not exposed.

455. (New character) Anterior extension of masseteric fossa onto the body (horizontal ramus) of mandible.

0) Absent: all premammaliaform cynodonts, all premammalian mammaliaforms, Haramiyavia, all eutriconodonts, all ausktribosphenids, all monotremes, all spalacotheroids, all dryolestoids, all cladotherians including metatherians and eutherians.

1) Present: In all multituberculates: Guimarota Paulchoffattiids, Plagaiulacidae, Ptilodus, Taeniolabis, Lambdopsalis, Kryptobaatar, Catopsabaatar, Nemegtbaatar, Rugosodon, Sinobaatar. Arboroharamiyia is tentatively scored as having this feature (until further study).

?) Scored for those taxa for which the mandible is not preserved or labial aspect of the jaw is not exposesd.

456. (New character) Occlusal relationship of the tallest cusp of cusp row - tallest cusp of lower occludes the lingual embrasure of adjacent upper molars (Only score for those taxa with multi-cuspate multi-row molars, not applicable to other tooth types).
0) Absent: Exaeretodon, Diademodon, Oligokyphus, Bienotherium, Kayentatherium, Yunnanodon, Bocatherium, paulchoffattiids, plagiaulacids, Ptilodus, Taeniolabis, Lambdopsalis, Kryptobaatar, Chulsanbaatar, Nemegtbaatar;

1) Present: Haramiyavia, Thomasia

?) Not applicable: Thinaxodon, Cynognathus, tritheledontids, all mammaliaforms with "triconodont" molars, all eutriconodonts, all spalacotherioids, all cladotherians including metatherians and eutherians.

Note: cusp occlusion of Exaeretodon and Diademodon following Crompton (35).

457. (New character) Saddle-shaped crest between the cusp A1 (the tallest of A-row) and B2 (the tallest of B-row) (Only score for those taxa with multi-cuspate multi-row molars, not applicable to other tooth types).

0) Absent: Oligokyphus, Bienotherium, Kayentatherium, Yunnanodon, Bocatherium, paulchoffattiids, plagiaulacids, Ptilodus, Taeniolabis, Lambdopsalis, Kryptobaatar, Chulsanbaatar, Nemegtbaatar;

1) Present: Exaeretodon, Diademodon, Haramiyavia, Thomasia.

?) Not applicable: Thinaxodon, Cynognathus, tritheledontids, all mammaliaforms with "triconodont" molars, all eutriconodonts, all spalacotherioids, all cladotherians including metatherians and eutherians.

Note: cusp occlusion of upper and lower postcanines for Exaeretodon and Diademodon following Crompton (35).

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P A U P *
Version 4.0b10 for Macintosh (PPC)
Thursday, June 25, 2015  1:36 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 "Vintana(Krause2014)Re-run3.nex" begins...

Data matrix has 91 taxa, 457 characters
Valid character-state symbols: 01234567
Missing data identified by '?'
Gaps identified by '-'

1 tree read from TREES block
   Time used = 0.02 sec

1 tree converted from rooted to unrooted.

*** Skipping "MacClade" block

Processing of file "Vintana(Krause2014)Re-run3.nex" completed.

Input data matrix:

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Taxon/Node        123456789012345678901234567890123456789012345678901234567890123456789012345678
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Thrinaxodon       00000?00?1000000000?00000001000000?00000000?000000000000?????001000000000101-0
Probainognathus   00?00?0????0?000000?00000000000000?0???000000?00000???010???0-?1000000000101-0
Exaeretodon       0?000?00?1??0?0?000?00?0000100000??00??000000001000000000??????100100000?100-0
Diademodon        0?000?0???0?0000000?0000000100000??00?00000000?000???00???????1000000000101-0
Cynognathus       0?000?0???0?0000000?0000000100000??00?00000000?00?????????????010000000?101-0
Oligokyphus       0?1?0?0????010000000000000000100000??000?0010000000000?000100????010??0????????0
Bienotherium      ????????????????????????0000?00000?????0000000??????????????????0?0000???001-0
Kayentatherium    0?000?00?0?10101000100000001000000?00??00000000????????????????1000000010101-0
Yunnanodon        ?????????????????????????????????????????????????????????????????0??010???10???
Bocatherium       ???????????????????????????????????????????????????????????????00??110???11???
Bienotheroides    0?000?0001?0110?000000000001000000??0??000000??????????????????101?110???111?0
Tritheledontids   ?0??0?00?110100000?000000000000000?0???0?000???0????????????????0000000??101-0
                                                                                 1   1  1
Adelobasileus     ??????????????????????????????????????????????????????????????????????????????
Sinoconodon       000?00?0000000000000000000000000????000000??0???????????????000000000110?-0
Morganucodon      00000?10?1?0010?000?000000000000000?000?010001 0?0?000000100????010100011?10110
Megazostrodon     ?0000?1????0?100000?000000000000?00000?01000?00000000010?000-0010??????????1?
Haldanodon        ?????????????100????00?00?0100000??????0?000?0???????????????????010100011011010
Hadrocodium       ????????????????????????????????????????????????????????????????000?00011?10?1?
Pseudotribos      ?????0000000000101000000000001000????0?110?000?????????????????????????????????
Ambondro          ??????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ??????????????????????????????????????????????????????????????????????????????
Henosferus        ??????????????????????????????????????????????????????????????????????????????
Asfaltomylos      ??????????????????????????????????????????????????????????????????????????????
Bishops           ??????????????????????????????????????????????????????????????????????????????
Steropodon        ??????????????????????????????????????????????????????????????????????????????
Teinolophos       ??????????????????????????????????????????????????????????????????????????????
Obdurodon         ????????????????????????????????????????????????????????????????0102000011?00101
Ornithorhynchus   ?11011100000000010100000000001000000?111100000201000000000101111010102000011?00101
Gobiconodon       ?????00????1?21?1-1?111000011000 0??000?00000100100?????????????1010?0001?????11
Repenomamus       ?1??0100??1??21?1-??11100011100?0??0001???0?1?0?001000010???10001010001 10?0110
Yanoconodon       000010000111 2111-10111000011010000000?00000100000 0??00101?00-0???????????????
Jeholodens        ??0??10???112111-?01110??0110100000?0100000100000 1?000101100-0000?10011???01
Amphilestes       ??????????????????????????????????????????????????????????????????????????????
Priacodon         ????????????????????????????110100?????????????????????????????????????????????
Trioracodon       ??????????????????????????????????????????????????????????????????????????????
Tinodon           ??????????????????????????????????????????????????????????????????????????????
Akidolestes       ?????00010111 2111-1011111111 1?100000 1111?000210 1001??0110002111?10???????????
Spalacotherium    ??????????????????????????????????????????????????????????????????????????????
Maotherium        ?1?0001????121?1-1?11111111111100001 1011?110210?001??0110002111010 2000??11110
Zhangheotherium   ?11000101011 12111-10111101011110000000 111110110000110011 11?1111?10?0??????????
                                            1
Amphitherium      ??????????????????????????????????????????????????????????????????????????????
Cronopio          ????????????????????????????????????????????????????????????????010 2000?1?11??0
Henkelotherium    0????01????112011-1??1110?00111000??0011111011 10101??11??????1???????????????
Dryolestes        ???????????????????????????111100???????????????????????????????0??????????????
Peramus           ??????????????????????????????????????????????????????????????????????????????
Vincelestes       01111?11--1112111-10111101001111000010111100111010110011 01??0-?000200011?11110
Kielantherium     ??????????????????????????????????????????????????????????????????????????????
Sinodelphys       ?????011--1112101-112?11112?2211111???11?1???1000121??11000?110???????????????
Pappotherium      ??????????????????????????????????????????????????????????????????????????????
Deltatheridium    ???????????????????????????????????????????????1211?110??????00?2101-----??0
Asiatherium       ????101????112101-1?21111120221111?01011?11111111 01??????????110000??0????????0
Kokopellia        ??????????????????????????????????????????????????????????????????????????????
Pucadelphys       11111011--1112101-11211101202211111?11011111111111 01211111 0002??00002101-----100
Didelphis         11111011--1112101-11211101202211111?11011111111111 01211111 0002??00002101-----100
Juramaia          111101????11210??1?21?1????22100??????????????????????????????0????????????
Eomaia            11?11011--1112001-102111012022101001 1011?1112110011?21111002??0?0??101-----???
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Prokennalestes    ??????????????????????????????????????????????????????????????????????????????
Asioryctes        01111?????????????????????????0101????????????10122?21111002??00002101-----???
Zalambdalestes    ??11111??????2?01-1??111112022101001111??1112111?1212110-002??00102101-----010
Ukhaatherium      ?1??1?1?????12001-1?21111?2022101000?011?1112110??2121110002???0002101-----???
Gomphos           11111?11-?1?12?01?1021110?10???????0100111?12?1?1?1?2100-1?????0002101?????110
Tribosphenomys    ??????????????????????????????????????0???????11?11?210111????????????????????
Erinaceus         11111011--1112101-1011111120221010111001111121101221211110021100?02101-----101
                       1
Dasypus           11111011-?1112101-102111112022111001110110111101222?211100021102102101-----101
Ferugliotherium    ??????????????????????????????????????????????????????????????????????????????
Ferugliotherium   ??????????????????????????????????????????????????????????????????????????????
Trapalcotherium   ??????????????????????????????????????????????????????????????????????????????
Bharattherium     ??????????????????????????????????????????????????????????????????????????????
Gondwanatherium   ??????????????????????????????????????????????????????????????????????????????
Lavanify          ??????????????????????????????????????????????????????????????????????????????
Sudamerica A      ??????????????????????????????????????????????????????????????????????????????
Sudamerica B      ??????????????????????????????????????????????????????????????????????????????
Tanzanian taxon   ??????????????????????????????????????????????????????????????????????????????
Tanzanian taxon   ??????????????????????????????????????????????????????????????????????????????
Greniodon         ??????????????????????????????????????????????????????????????????????????????
Vintana A         ???????????????????????????????????????????????????????????????000101001101111
Vintana B         ???????????????????????????????????????????????????????????????000101001101111
Guimarota Paulch  ??????????????????????????????????????????????????????????????????2101-----010
Plagiaulacidae    ??????????????????????????????????????????????????????????????????????????????
Ptilodus          ?????01???????????0????10?00000?????1?1111112011101100110?02???0002101-----111
Taeniolabis       ??10?????????10?????2?0100??00?????????????????????????????????101?101-----??1
Lambdopsalis      ????010001??11?1-?021110001000??????1??????????????????????????1012101-----111
Kryptobaatar      ?0?00010?011111?1-1?21?10000000?1??01111?1102011101000110?021102112101-----010
Catopsbaatar      ?????1???????????????????????000?????0??1?111?1????1?111101???02112101-----010
Chulsanbaatar     ???0001???????????1????100?????????0???1?110??????1?001101?????0002101-----?10
Nemegtbaatar      ???00?1???????????1??1?110?0????1?101??11110?0?????????????????0002101-----?10
Thomasia          ??????????????????????????????????????????????????????????????????????????????
Haramiyavia       ??????????????????????????????????????????????????????????????????????????????
Arboroharamiya    ??????1?????1?????????????????????????0????0?1?0??100000??????0-??????????????
Rugosodon         11111010001111001-10110100?0?010100?0111?010201?001??0110111111???????????????
Sinobaatar        11?11010001111001-1011010020?010100?01?11110201?001??0110111111???????????????
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Input data matrix (continued):

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Thrinaxodon       201200??00--200100000000100-0000-0-030-0012000000000-0------?-0000000?000??0?0
Probainognathus   200--00-00--2001?000000000100000-0-03110012000000000-0------0-00001100000??00?
Exaeretodon       000--???011-?0001000000000100000-0-02110012011-00000-0------0-0000110000?00???
                                     1
Diademodon        200--00-00--?1011000000000100000-0-23100012011-01000-0------0-000010000200???
Cynognathus       200--???00--?0011000000000???000-0-2310?0120?1-0000?-0------0-0?00100?00200???
Oligokyphus       200--???11102101010100000120000-1-0211010-0???20?00-0------0-0?10?10?01?00??0
Bienotherium      200--???0110?10??101000000??0000-?-?211?1000?0?00000-0------0-000110?01?00???
Kayentatherium    100--???00--10011101000000120000-0-0211010002000100?-?------?-000011?01000???
Yunnanodon        200--????0--?01??1???000?????0?0-0-0211010002000?00?-0------0-?00?1?1?011000??
Bocatherium       ?0120???00--?00??101100010??0000-0-?2???1000???????-?------?-0001110?1?00???
Bienotheroides    20110???0101?0010101100010??0000-0-221?0100020101 00?-0------0-0100110001?00???
Tritheledontids   100--?0-10--2001010100010010 0100-0-0211010-010000000-0------0-000001000000001??
                                          1                      11
Adelobasileus     ???????????????????????????????????????????0?0011?00???????????0??0?1101111???
Sinoconodon       2010001010--2001110000?100120100-001311010-0200111000002 00000?001011101110010?
Morganucodon      1012001010--1001010000010012 0100-001311010-02001110010120000000010101011211100
Megazostrodon     ?0??????1???20010???0??1?0????????0?13??01??02000010???????000??1???1?1120010?
Haldanodon        2011110-110020010100000200120000-000210010-0200000001010000000012?1?1111200100
Hadrocodium       ?00--???1100200??1??0002?0???0?0-0013??010-0200???000100010000?12?1?1111212???
Pseudotribos      ??????????????????????????????????????????????????????????????????????????????
Ambondro          ??????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ??????????????????????????????????????????????????????????????????????????????
Henosferus        ??????????????????????????????????????????????????????????????????????????????
Asfaltomylos      ??????????????????????????????????????????????????????????????????????????????
Bishops           ??????????????????????????????????????????????????????????????????????????????
Steropodon        ??????????????????????????????????????????????????????????????????????????????
Teinolophos       ??????????????????????????????????????????????????????????????????????????????
Obdurodon         011111??111022?111?00002?00-00012121?1??100021-?0100011100?0000120101111212???
Ornithorhynchus   0110100-111?22?0111?0002?00-00012121?111100021-2010000110000000120101111212110
Gobiconodon       ?00--???12?1000011??0??2?01101???120?1?110?02??10100101200?000?0101???11211???
Repenomamus       200--???12?10000?10000?2?01101?0-12021?110?0200101?01012000000?010????11211???
Yanoconodon       ???????????????????????????????0-121??????????????1?120000?0?0????????????????
Jeholodens        110--????2???0?????????????????0-121????1??0??????0010??00?00?????????????0???
                                                                                            1
Amphilestes       ??????????????????????????????????????????????????????????????????????????????
Priacodon         ?1??????11?0????????0??0?10-0???????2??????????20?????????????????????11211100
Trioracodon       ??????????????????????????????????????????????????????????????????????11211?00
Tinodon           ??????????????????????????????????????????????????????????????????????????????
Akidolestes       ??????????????????????????????????11????????????????1???000???????????????????
Spalacotherium    ??????????????????????????????????????????????????????????????????????????????
Maotherium        200--???11?1010??1?????2?0?????0-011?1??10-?200???00111??00?00????????11211???
Zhangheotherium   ???????11?????????????????????1?0-011???10-??????????111200000???0????1?211???
Amphitherium      ??????????????????????????????????????????????????????????????????????????????
Cronopio          00??????11100100111?000000??0?00-0??3???10002???????111001????????110?1121????
Henkelotherium    ?????????????1?011?????????1????0-0?1???0?????????1?1?11000000????????11212210
Dryolestes        ?????????????????????????0????????????????????????????????????????????11212210
Peramus           ??????????????????????????????????????????????????????????????????????????????
Vincelestes       201111??110021000100000100110000-0003100100020020100011000000000?0111111212201
                                                     1
Kielantherium     ??????????????????????????????????????????????????????????????????????????????
Sinodelphys       ?00--???1??????????????????????0-0?1???????02?????1???????????????????????????
Pappotherium      ??????????????????????????????????????????????????????????????????????????????
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Deltatheridium    200--????20001-10100000200??0?00-0012??010-02?????11?112010?1??11???1011212?1?
                                                    1
Asiatherium       100--???12?001???1???002?1???000-0013??010-02???0?11011201001 0?11?1?1011212???
Kokopellia        ??????????????????????????????????????????????????????????????????????????????
Pucadelphys       110--111120001-1011000020?120100-0?12110100020130211011201001101 1?111011212310
Didelphis         110--111120021-11110000201110000-0?1211010-020130211011201001101110110 11212310
Juramaia          ??????????????????????????????????????????????????????????????????????????????
Eomaia            ?00--????2?0??-1?1??????????????0-0?1???010-?2??????11?????1??10????????????????
Prokennalestes    ????????????????????????????????????????????????????????????????????????11212?10
Asioryctes        ?00--1??120?21-?110????200120100-00131?010-1201302110102010110011011111 1212???
Zalambdalestes    000--???120011-10100001100110100-011111111002003011101010101110110111111 2123?0
                  2
Ukhaatherium      10????????2???-10101000 2?0??0100-10131?010-12??30????1020101 1?0????1111212 3?0
Gomphos           010?????1210?1?1?1110002100-0000-01001?111002??3011?0101110010011 10?1111212???
Tribosphenomys    ??????????????????????????????????????????????????????????????????????????????
Erinaceus         110--111120?21-11100000201121100-02120-110002013021101010101100110111011212 31?
Dasypus           010--110121100-011010002000-1000-021-0-0100020130111010011011001211111111212310
Ferugliotherium   ??????????????????????????????????????????????????????????????????????????????
Ferugliotherium   ??????????????????????????????????????????????????????????????????????????????
Trapalcotherium   ??????????????????????????????????????????????????????????????????????????????
Bharattherium     ??????????????????????????????????????????????????????????????????????????????
Gondwanatherium   ??????????????????????????????????????????????????????????????????????????????
Lavanify          ??????????????????????????????????????????????????????????????????????????????
Sudamerica A      ??????????????????????????????????????????????????????????????????????????????
Sudamerica B      ??????????????????????????????????????????????????????????????????????????????
Tanzanian taxon   ??????????????????????????????????????????????????????????????????????????????
Tanzanian taxon   ??????????????????????????????????????????????????????????????????????????????
Greniodon         ??????????????????????????????????????????????????????????????????????????????
Vintana A         001011101110001111011000000-1000-01221101000200001001111101000200?110011111111
Vintana B         001011101110001111011000000-1000-01221101000200001001111101000200?110011111111
Guimarota Paulch  00000110?100?1-11000000??0?????1112?0???100?2???21??001?1????1??0??1?1?11211???
                    1                                 1
Plagiaulacidae    ?????????1?0????????????????????????2?????????0???????????????????????????????
Ptilodus          21111???12000?-1112001?0010-00?1112110-110002??111001111100000102111111 1211??0
Taeniolabis       0?0--???1200?2-??11?0000?0?????111202??010102??1????0?10?000?0?????????1??????
Lambdopsalis      0?120???120?02-111100000000-0111112120-0100021-?11000110100000012111111 12?1100
Kryptobaatar      20110110121001-11100011000120111112110-1111121-111001111?000001021111111 2011?0
Catopsbaatar      20110????110?1-111010110000-01111?2010-111112??111001111100000102111111 1211???
                           2
Chulsanbaatar     00110110121001-??10001110012011111211??0101121-111001111000?01021111111 121110?
Nemegtbaatar      00121110121001-01100011001120111112111001 01121-11100111110001 0?021111111211100
Thomasia          ??????????????????????????????????????????????????????????????????????????????
Haramiyavia       ??????????????????????????????????????????????????????????????????????????????
Arboroharamiya    ??????????????????????????????????????????????????????????????????????????????
Rugosodon         ?????????1?????????????1??????????????????????????????????????????????????????
Sinobaatar        ??1?0????2?1???????????1??0?????1?1??1??????0??????00111210?000????????????????
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Input data matrix (continued):

```
                  111111111111111111111111111111111111111111111222222222222222222222222222222222
                  555666666666677777777778888888888999999999990000000000111111111122222222223333 3
Taxon/Node        789012345678901234567890123456789012345678901234567890123456789012345678901234
------------------------------------------------------------------------------------------------
Thrinaxodon       ?0000-10-00??0000010000--000000001000-0?01??0-01??30?00-000000000000000030004000
Probainognathus   ?0000-01000??0????11000--00?000001000-0000????01??30000-0000?00010000130000000
Exaeretodon       ??000-01000?00000010010--00000??00100-2000??0-0?????????00??100000000100000100
Diademodon        ??000-0??00?00000010010--000001-00100-2000??0-0????0000-00100000000000000003000
                                                                                            4
Cynognathus       ??000-0??00?00000010010--000001-00100-2000??0-0????0000-00??000000001000000000
Oligokyphus       ??000-00?00?10000000010--1010?1-0001002011100-011-?0011021??1000????1120003000
Bienotherium      ??000-00?00??0000000010--101001-001?0??0?1??0-011-?0011021??????????0??0000010
Kayentatherium    ??000-0??00??00000?0010--101001-???????01???0-?????0010021??1000000000130000??0
Yunnanodon        00000-0??00?00000000010--101001-000100201 11?0-??????001-21??????????01300??010
Bocatherium       ???00-0??00???00????????????????????????????????????????????????????????0??????
Bienotheroides    ??000-0??00??0000000010--10100??00110020?11?0-?????0010021??1000????013000?010
Tritheledontids   00000-00000?00000010000--000000000000000001?0-01???0000-1100????????0100000000
                                             1                                        1 3
Adelobasileus     ??000-0?011??0??0101000--00?00000101?000011???01??????????????????????????0102100
Sinoconodon       00000-01011100000000010--0010000000100001 1000-01???0000-11001000 1?000130001000
Morganucodon      00000-01011100000101120--10100000001000111000-01000011 0?21001000100011 30101000
Megazostrodon     0?000-0?0111?00001?1120--1010000000100011110???????01?0?21??????1?00????1??000
Haldanodon        00000-0101?10000010 2020--1010000010100001 1000-010000????2?001????0000110101100
Hadrocodium       ??000-0?0111?10?0102020--101001?0101000?1100??1??????????2????????1??????0201101
Pseudotribos      ??????????????????????????????????????????????????????????????????????????????
Ambondro          ??????????????????????????????????????????????????????????????????????????????
Ausktribosphenos  ??????????????????????????????????????????????????????????????????????????????
Henosferus        ??????????????????????????????????????????????????????????????????????????????
Asfaltomylos      ??????????????????????????????????????????????????????????????????????????????
Bishops           ??????????????????????????????????????????????????????????????????????????????
Steropodon        ??????????????????????????????????????????????????????????????????????????????
Teinolophos       ??????????????????????????????????????????????????????????????????????????????
Obdurodon         ??000-0?11010100011212 0--1010000010001000 0?0??1?????????2?????????????1?0201001
Ornithorhynchus   00000-0111010100011212 0--1010000010001000 0?0111?0122012?2111111122010110201001
Gobiconodon       ??000-0?0111?10001?1120--20100000???????11?0-???????????1????????????1?01010?0
Repenomamus       ?0000-0?0111?100???1120--2010000000 10?1?11??0-??????????21??????????010000?0?0
                                                                                          1
Yanoconodon       ??????????????????????????????????????????????????????21?2221???110200 1??????????
Jeholodens        ??????0?0?????????????????????????????????????????????122?????????2??????01?????
Amphilestes       ??????????????????????????????????????????????????????????????????????????????
Priacodon         ??000-0101?11??00111?20--??10000000 1?00111?20-????0?????2??????????????????0111?
Trioracodon       ??000-0101111??00111120--1?100000001?0011??00-0?000?????2??????????????????0111?
Tinodon           ??????????????????????????????????????????????????????????????????????????????
Akidolestes       ??????????????????????????????????????????????????????????????????????????????
Spalacotherium    ??????????????????????????????????????????????????????????????????????????????
Maotherium        ??11100??1???20001101 11??20?00??????0???1????????????????2????????????1?1011-0??
Zhangheotherium   ??11100?0??1??0001121210020100??0101???1111?0-???????????21????????????????????
Amphitherium      ??????????????????????????????????????????????????????????????????????????????
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Cronopio          ??11100?011???????01021?02?111??01010?111???????????????210????????1?30??????
                          1                                                 3
Henkelotherium    11?11001?1?1????011?02????0111?????1??10???0?????????????????????????????????
Dryolestes        111110010??1????01??1210????11??0?01??101??0??01????????????????????????01???
Peramus           ?????????????????????????????????????????????????????????????????????????????
Vincelestes       ?111100?0111110001021210020111000111001011100-01000?????21?????????0130001110
Kielantherium     ?????????????????????????????????????????????????????????????????????????????
Sinodelphys       ?????????????????????????????????????????????????????????????????????????????
Pappotherium      ?????????????????????????????????????????????????????????????????????????????
Deltatheridium    ??11100?0221?21?1-1?0210?2?100?????1?01011??0-????1?????21?????????????1012??
Asiatherium       ??1110???2???2101-??0????211??00???10?1??1??????????????21??????????1?01?????
Kokopellia        ?????????????????????????????????????????????????????????????????????????????
Pucadelphys       ??11100?-211?2?01-1?0210121100001--1011011110-??001?????21?????2???11301??3-0
                                                                    2
Didelphis         ??111001-22112101-1?0211120100001--1001011110-1-01?1????2120111120121100101 3-0
Juramaia          ?????????????????????????????????????????????????????????????????????????????
Eomaia            ?????????????????????????????????????????????????????????????????????????????
Prokennalestes    11111011??11???1-110210 1??111??0111??101??0??1-??0?????2????????????????0?1??
Asioryctes        ??11111?-21112011-1?021??20110000111?010110?0-1-??1????21??????3013??3011-201
Zalambdalestes    11111110-21112011-1-021002111?000111001111110-1-??1????21??????30121100101200
                                                                    2
Ukhaatherium      111?1110-21112011-?-0?10020110001--10?101100?????1??????????????01??0?01????1
                                                            1
Gomphos           1101??????2?1201????0????10???0?????1???110?1?????????????1??????4??221001????1
Tribosphenomys    ?????????????????????????????????????????????????????????????????????????????
Erinaceus         11111110-22112011-1-0210120111000111001011110-1-002111112120111141131100201200
Dasypus           11111010-210?2001-1-021011010?011--1011?11010-1-0021112221201?11311221302013-0
                             1
Ferugliotherium   ?????????????????????????????????????????????????????????????????????????????
Ferugliotherium   ?????????????????????????????????????????????????????????????????????????????
Trapalcotherium   ?????????????????????????????????????????????????????????????????????????????
Bharattherium     ?????????????????????????????????????????????????????????????????????????????
Gondwanatherium   ?????????????????????????????????????????????????????????????????????????????
Lavanify          ?????????????????????????????????????????????????????????????????????????????
Sudamerica A      ?????????????????????????????????????????????????????????????????????????????
Sudamerica B      ?????????????????????????????????????????????????????????????????????????????
Tanzanian taxon   ?????????????????????????????????????????????????????????????????????????????
Tanzanian taxon   ?????????????????????????????????????????????????????????????????????????????
Greniodon         ?????????????????????????????????????????????????????????????????????????????
Vintana A         11111011-12111010112121??1010001011100001112 10????3?????21?????1????1120002110
Vintana B         11111011-12111010112121??1010001011100001112 10????3?????21?????1????1120002110
Guimarota Paulch  ?0000-0101210?????1?1?????011000???10?00??1???00?????????????????1?????1?01???
                                                        1
Plagiaulacidae    ?????????????????????????????????????????????????????????????????????????????
Ptilodus          ????100??121020?021212100?01110101110001?11???????0??????????????????2100102210
Taeniolabis       ???????????????????????????????????????????????????????????????????01011????0
Lambdopsalis      00000-0?01210200021112100101000101?110?1?11???000022112?21??1???2????101202210
Kryptobaatar      ??0010011121020002121210010111010101102111120-00012?????21211???2???2110202210
Catopsbaatar      ??????0??121?2000212121001 0???010110???1?0???????????????????????????2110202 2?1
Chulsanbaatar     00??10010121020002121210010?110101?110?1?0????00012?11???1??????????2110202211
Nemegtbaatar      00??1001?12102000212121001 0?1101011110?1?0????00012??????????????????1110201211
Thomasia          ?????????????????????????????????????????????????????????????????????????????
Haramiyavia       ?????????????????????????????????????????????????????????????????????????????
Arboroharamiya    ?????????????????????????????????????????????????????????????????????????????
Rugosodon         ?????????????????????????????????????????????????????????1???????????????????
Sinobaatar        ?????????????????????????????????????????????????????????????????1????0??????

Input data matrix (continued):

                  22222222222222222222222222222222222222222222222222222222222222223333333333333
                  33333444444444455555555556666666666777777777788888888889999999999000000000111
Taxon/Node        56789012345678901234567890123456789012345678901234567890123456789012345678901 2
-----------------------------------------------------------------------------------------------
Thrinaxodon       0000?0?0???0??001?-00101100000---000--00-000----101000000-00210000011000000000
Probainognathus   00011?00??000?00??-00031100001010000--00-000----000?0?010-00210000011000000000
Exaeretodon       00111000??000?01??-00101200011?0000???00??00----1001?0001-0122000111001000?00
Diademodon        00111000??000?001?-000311000?1000000--?0?100----100?00011-0121000??1100?000?00
Cynognathus       ??11?000?????????-00101?00001000000--00?100----100???011-0021000??1100?000?00
Oligokyphus       10010010????0?001?-01101100011010?10--110100----30011001--1-22000001000001---1
Bienotherium      ?00?0010????0?001?-011012001 1?????????110?00----30011001--1-43-00?01?-???1---1
Kayentatherium    ?00????0?????????-00101200011010?00--011100----??0110-1--1-44-00-01--0101---1
                                                            1
Yunnanodon        ??0??000?????????-?????????????????????????----3001??01--???3-00????????1---?
Bocatherium       ?????0????????????-?01022?????????????11110----3001?001--1-42000????-??21---1
Bienotheroides    ??1??000?????????-00101200011010000--?11100----30011001--1-32000????0???1---1
Tritheledontids   1000??00??0000001?-111011000000?0000--00-100----100?00?11-?122000??1?00?000?00
                                        1      1                              33
                                                                               4
Adelobasileus     111???00?????????????????????????????????????????????????????????????????????
Sinoconodon       100??000??0?00???011????0001000000--00-0000010100100001?01000000?110?0000000
Morganucodon      1?001001101000000??11111000101000000--00-0000000200110000001010000011000000000
                                                                1
Megazostrodon     1?1???0?????????????11????00100???000--00-00000101001??000?000100000110000??000
Haldanodon        0111111????00?000?011101100011000000--00-000001020111100000010000???0000000100
Hadrocodium       111???111000??001001?????????1010??0--?0-00000002??1?000100110000001?000000?00
Pseudotribos      ??????????????????0??????0???1000???????????00102011?????1???????????0???????
Ambondro          ????????????????????????????1??????????????????????1?????????????????????????
Ausktribosphenos  ??????????????????0??????10111211?0100010100????2111?????????????????????????
Henosferus        ??????????????????01112100011120000100011100000121111?????011????????00?0????0
Asfaltomylos      ??????????????????0??10110??11210??10001110001?13111??????????????????????????
Bishops           ??????????????????0??1?1?11-112111110001010001113111???????????????????????????
Steropodon        ????????????????????????????1??????????????????????1?????????????????????????
Teinolophos       ?????????????????????????11-112111?10001110101112111?????????????????????????
Obdurodon         111?1?1212?11?00000111???110113101?100011111011112111????????55-----------1---1
Ornithorhynchus   111111121211110000011121-11-10010111000111110111??1111-????55-----------1---1
                                               1
Gobiconodon       11???001?????????01113?210010----11010111001010111101-0000043000001--00001000
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```
                                                            1
Repenomamus       1????0?1??????????011121010010----110101110010101111??100000320000011000001000
Yanoconodon       ??????????????????011????10010----11010?????1010200l??-?000033000???-00?000000
Jeholodens        ?1?????1??????????011????10010----????0?????1010?0?1??????0011???????0000?????
Amphilestes       ??????????????????011????10110----110101l?0?????2111??????????????????0???????
Priacodon         ??0???????????000?01111111 0010----1101011110102021011l??10013???????-00?000??0
Trioracodon       ??????????101100??011????10010----11010111101020200l????10002??????????????00100
Tinodon           ??????????????????011????10110----010101 0??01111311l???????0??????????????????0
Akidolestes       ??????????????????????????????0----??????????1??????1??????0011000????0000?????
Spalacotherium    ??????????????????0??????10010----?1010111001111211l??????????????????????????
Maotherium        ??1???????????????01113101 0010----?10101110011110111??0?100122000?10000001000
Zhangheotherium   ??????????????????01111?010010----?10101110011110111l1????0022000????0000????0
Amphitherium      ??????????????????011????101111010100011100011121 11??????001????????0000????0
Cronopio          ??????????????????011101111-11?10?1???0111000111111l??-111???3000001-????0000?
Henkelotherium    ??????????????????01111?010011110101000111 00???13011?????0????????????????0010?
Dryolestes        ??????????????00??01110111011111010100011100011130 1111?00000110000???000000100
Peramus           ??????????????????01110101001111011100110100001121 11??????001?????????00???????
                                        1 1
                                        2
Vincelestes       11??11111110010010011111111-11110101001101000111211l1??01000131000000000000000100
Kielantherium     ?????????????????????????1001?????????????110?????111???????????????????????????
Sinodelphys       ???????1??????????0111310 1??113101?100010???1011311l???0110011??000??000000000
Pappotherium      ??????????????????????????????????????????????????1???????????????????????????
Deltatheridium    ??????01??????00??011111111-11310111001101001?113011??0?00002100 0????10??00000
Asiatherium       ?1???102???????????0?????11??113101110011010011113111????00??????????????????000??
Kokopellia        ??????????????????0111111101 1?????1????????10????3111??????0?1?????????00??????0
Pucadelphys       0100110111101100110111111111-11310110--110100111131111101000010000????100000000
Didelphis         01101101111 1??00100111111111-11311110--110100101130111101010110000000111 00000000
                                                                 1
Juramaia          ??????????????????01?1111???????????????10?1?????111111101000110 00?0?11000000100
Eomaia            ???????1??????????01110121011111 0100--11010?00112111??0101111000000110 0?000000
Prokennalestes    ??????????????000?01111111001 1?1010100110110001121 11??????????????????????????
                                                  1
Asioryctes        ?1001?12111?01????011121?11-111101010011-100101131 11??01000010000001 1000?001?0
                                        3         1
                                        4
Zalambdalestes    11101002 1111??????011111111-111101110011110011111111111101012200 0??11011100100
                                                                               3          2
Ukhaatherium      ?100?012??????000?011111111-?1110??1--?10???10113111??11000110000001?000000000
Gomphos           ?100011 2??????00??0110---11-11210?11001100001121301111-1-01-33110111-01121---1
Tribosphenomys    ??????????????????011101211-11110?1100110000???0301111-1-?1-441--1----1121---1
Erinaceus         11111112111101001?011111111-11110110--1101000111311111000000320000011000001100
Dasypus           11111?021011111-1?011111?11-11110110--00-0001111101111??--??-?55-----------?????
                                        2                         1
                                        3
Ferugliotherium   ??????????????????????????????????????????????????????1????????????????????????????
Ferugliotherium   ????????????????????????????????????????????????????1??????1?4?1??1???-112?????
Trapalcotherium   ??????????????????????????????????????????????????????????????????????????????
Bharattherium     ????????????????????????????????????????????????????1??????????????????1???????
Gondwanatherium   ????????????????????????????????????????????????????1??????????1??1???-11??????
Lavanify          ????????????????????????????????????????????????????1??????????????????????????
Sudamerica A      ??????????????????1010211??1??????????????????????1??????1-4????????-112????1
Sudamerica B      ??????????????????1010211??1??????????????????????1??????1-4????????-112????1
Tanzanian taxon   ????????????????????101112-1??????????1110?????1001??????1-4????????-1?2????1
Tanzanian taxon   ????????????????????101112-1??????????1110?????1001??????1-4????????-1?1????1
Greniodon         ????????????????????????????????????????????????????1??????????????????????????
Vintana A         001100010010110100??????????????????????????????????1??-1--???3110???-????1---?
Vintana B         001100010010110100??????????????????????????????????1??-1-0???3110???-????1---?
Guimarota Paulch  ?1????????????000?011101111-10----0111110100102011011?00001-420000000?10201011
                                                    1   111
Plagiaulacidae    ?????????????????110101011-10----111111110010201001???1?01-42000-000-10?1-??1
Ptilodus          11???001111101100??110101111-10----1111111100112010011?1-01-43-10-01?-10?1---1
Taeniolabis       01???00???????????110101011-10----11111111000110200111111-01-43-10-110-1121---1
                                                 1
Lambdopsalis      11??100???????01??110101111-10----1111111100011120011111-01-43-10-?11-1121---1
Kryptobaatar      1110100112101100001101011111-10----1111111100112010011111-01-43-11-110-1121---1
Catopsbaatar      11???00???????????110102111-10----111111110011201001??11-01-43-11-110-1121---1
Chulsanbaatar     1111?0011?1011000?111002111-10----1111111100112010011111-01-43-11-?10-11?1---1
Nemegtbaatar      111110011?1011000?111101111-10----1111111100112010011111-01-43-11-110-11?1---1
Thomasia          ????????????????????????????????????????????????????1?????????200?000??10??????
Haramiyavia       ?????????????????011000000011000000-00000000000000110 1?0110210000011010?????0
                                       11
Arboroharamiya    ?????????????????1101???11-11010111?011000010201001????-?1-43???????-1021---1
                                                                               4
Rugosodon         ?????????????????010????1??10----?1?11111?0112010011100001-420000000-10101011
Sinobaatar        ?????????????????010101111-10----11?1111100112010011111-01-42?00-000-1011---1
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Input data matrix (continued):

```
                  333333333333333333333333333333333333333333333333333333333333333333333333333333
                  111111122222222223333333333444444444455555555556666666666777777777788888888889
Taxon/Node        345678901234567890123456789012345678901234567890123456789012345678901234567890
------------------------------------------------------------------------------------------------
Thrinaxodon       00100-------------------------------000-0-0-0---------------------------------
                    21
                    32
                    43
                     4
Probainognathus   00320-------------------------------000-0-0-0---------------------------------
Exaeretodon       0?000-------------------------------000-0-0-0---------------------------------
                    11
                    22
                    33
Diademodon        0?000-------------------------------000-0-0-0---------------------------------
Cynognathus       0?000-------------------------------000-0-0-0---------------------------------
Oligokyphus       --320-----------------------------00200-0-0-0??---------------------------0-0-
                                                                                            1
```

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Bienotherium      --320-----------------------------00200-0-0-00----------------------------0-0-
Kayentatherium    --320-----------------------------00200-0-0-00----------------------------0-0-
Yunnanodon        ???40-----------------------------?1200-0-0-0??---------------------------????
Bocatherium       --?40-----------------------------?1200-0-0-0??---------------------------????
Bienotheroides    --210-----------------------------00200-0-0-00----------------------------0-0-
Tritheledontids   0?210-------------------------------000-0-??0---------------------------------
                    32
Adelobasileus     ????????????-??????????????????---????????????????????????????????????????????
Sinoconodon       003203301??1-0??-0000110000--01---11000-0-0-00-0000000?010??0---0--?0?--000-0-
                                                                                          1
Morganucodon      002000001101-001-0000011000--01---12000-0-0-0110000000?010??0---0--?0?--00110-
                                                    23
                                                    3
Megazostrodon     000000001??1-001-0000001000--01---11000-0-0-0110000000?010??0---0--?0?--00100-
Haldanodon        011102200121-011-00000100010011---01100-0-0-0120000001?110?????-0--?0?--00100-
                    2                               1
Hadrocodium       0?550330?101-0?1-0100100000-??1---44000-0-0-00-0000000?010??0---0--?0?--000-0-
Pseudotribos      ??21?00?????-0??-00101111?11?1?---33100-0-0-00-001111111000?0---0--?0?2?00110-
Ambondro          ????????????-???-?0000?1110--1?---???00-0-0-00-000?11101011010001011121101110-
                                                                                        2
Ausktribosphenos  ????????????-??1-?0111111111011---3??00-0-0-00-000021111011210101111122300110-
Henosferus        0?2??0??????-00?-0000??01?0--0?---3??00-0-0-0??0002111010110100010011221110-0-
                                                                                   1
Asfaltomylos      ????????????-??1-????????????11---3??00-0-0-00-000?111?101121000101?1221110-0-
Bishops           ??0??0??????-011-0011111110--11---3??00-0-0-00-000011111011210101111122300110-
                    1
Steropodon        ????????????-???-??????????????---???00-0-0-00-001121201011110110--?0223101011
Teinolophos       ????????????-???-??????????????---???00-0-??00-001121201011110110--?0223001011
                                                                   2
Obdurodon         --55?3300110-???-00001001111?1?---34000-0-??00-100121211011110110--?0223101011
Ornithorhynchus   --76?4400??0----------------------44000-0-0-?0-1----?21-011-0---0--?0-23??0-11
Gobiconodon       101001101131-202-0000101?00??01---11100-0-0-0100?01000?010??0---0--?0---010-0-
                    21 2                        2   22
                    3
Repenomamus       103303301101-002-000110?000--02---12100-0-0-0100?01000?0?0??0---0--?0---01????
Yanoconodon       005403300???-???-?000?000????01---33000-0-0-012000100??010??0---0--?0---100-0-
Jeholodens        ??44033?????-???-?00011100???0?---23000-0-0-0120001000?010??0---0--?0---100-0-
Amphilestes       ??1?01??????-001-000011100???0?---1??00-0-0-0100?01000?010??0---0--?0---010-0-
Priacodon         003202201101-001-010000210???01---22000-0-0-0120001000?010??0---0--?0---100-0-
Trioracodon       0032011011?1-10?-010001110???0?---33000-0-0-0120001000?010??0---0--?0---000-0-
                                                                                          1
Tinodon           114?02??????-01?-0000111100--0?---3??00-0-0-010000111102000-0---0--00---01110-
Akidolestes       ??0000??????-11?-010011110???0?---0??00-0-0-013000?211?1000-0---0--00---000-0-
Spalacotherium    ??0??2?????1-001-00001111????0?---00000-0-0-0130001111?1000-0---0--00---000-0-
Maotherium        1013?230010?-??1-?0001111?0?011---00000-0-0-0130001111?1000-0---0--00---000-0-
                    2  44
Zhangheotherium   101?03??????-???-?100???100--01---01000-0-0-0130001111?2000-0---0--000--00110-
Amphitherium      010?00??????-00?-?0000001????11---0??00-0-0-00-000011101011011?00--00001100-0-
Cronopio          ???20?1??111-?11-0111??2100--01---33000?0-0-00-001021211000-0---0--00000100-0-
Henkelotherium    ??0001101111-001-00000011????11---00100-0-0-013000011211000-0---0--00000100-0-
Dryolestes        0100014?1001-001-01000011?0--11---00100-0-0-00-000011211000-0---0--00000100-0-
Peramus           ??21011??111-001-0110001100--01---22?00-0-0-0100002111010110110 00--00001010-0-
                                                                  1
Vincelestes       015403300101-002-0100000100--11---33000-0-0-00-000111102011000?-0--01101100-0-
Kielantherium     ??1?0???????-???-??????????????---2??00-0-0-0100002112010110100 00--11101010-0-
                    2                                                                     1
Sinodelphys       00?1?00?????-1??-??????????????---?3?00-0-0-0100?011?201?110110010?111?1010-0-
Pappotherium      ????????????-???-??????????????---?3?00-0-0-0??0000111010?12????????????110-?-
Deltatheridium    0032011?????-101-??????????????---33200-0-0-00-0002112010110110010011101100-0-
Asiatherium       ??32011?????-001-??????????????---33200-0-0-00-0100112110112110011111213101-10
Kokopellia        003?01??????-10?-??????????????---3?200-0-0-00-0101111110112110011111203100-10
Pucadelphys       0032011?????-101-??????????????---33200-0-0-0100100112110112111011111121?010-10
                                                                                        2
Didelphis         0032022------001------------------33200-0-0-00-0100112110112111011111223110-0-
Juramaia          0021?001011?-011-0?00100100???1---33?00-0-0-0??0?001?1???1??110?1???1???10-0-
Eomaia            002100010??1-111-0000110100--01---33?00-0-0-010000???1?10110110?11?11?13010-0-
Prokennalestes    ??2100010110-01?-0000110100??0?---33200-0-0-0100000111010110110011111103010-0-
                           2
Asioryctes        1132011?1110-10?-0000110100??0?---33200-0-0-00-0010212110110110011011112110-0-
Zalambdalestes    103201111100-111-01100121?0--0?---33200-0-0-0120010212110112110?11111223110-0-
                            1                                                   1
Ukhaatherium      003201100100-111-0000100100--??---33200-0-0-00-0?0?????1?11?1???????1??3?10-0-
Gomphos           --5303210101-?01-0111102100--01---33200-0-0-00-1---2121-0110100011-11223100-0-
Tribosphenomys    --6404310211------0100021?0--01---33200-0-0000-0-1021211011010001110122?100-0-
                                                                 1
Erinaceus         104402310110-00?-0011110000--01---33200-0-0-00-00011121101121--011111223110-0-
Dasypus           ????0????101-0??-???1???00--0?---??010-0-0-00-?????????????????????--????0-0-
Ferugliotherium   ???????--?????????????????????????????00-10100??--------------------------?-?-
Ferugliotherium   ??7?4??--???------202----00--011104??00-10100??---------------------------?-?-
Trapalcotherium   ???????--?????????????????????????????00-10100??--------------------------????
Bharattherium     ???????--?????????????????????????????1111?101??--------------------------????
Gondwanatherium   ?????5?--????------------?-??-----???11110100??---------------------------0-0-
Lavanify          ???????--?????????????????????????????11111101??--------------------------????
Sudamerica A      --6?15?--????---------------------2??110111000----------------------------0-0-
                                                             1
Sudamerica B      --6?13?--????2-2101?1----00--02---4??11011100??---------------------------0-0-
                                                             1
Tanzanian taxon   --6?1??--????-----?????--?-??-????2??1?????????---------------------------????
Tanzanian taxon   --6????--?????-??0???----?-??-2???2??1?????????---------------------------????
Greniodon         ???????--?????????????????????????????11110110??--------------------------????
Vintana A         ???4??4--231????????????????????????2?11110100??--------------------------????
Vintana B         ???4??2--100????????????????????????4?11110100??--------------------------????
Guimarota Paulch  --42010--10101-100102----01110100044100-0-0-00----------------------------0-0-
                    3121
Plagiaulacidae    --42?10--00101-110202----01110100144100-0-0-00----------------------------0-0-
                    5  2
Ptilodus          --63131--00131-211202----01000112144100-0-0-00----------------------------0-0-
```

```
Taeniolabis       --76144--2211-----002----00--0110044100-0-0-00----------------------------0-0-
Lambdopsalis      --76144--2322-----0-2----00--0210044100-0-0-00----------------------------0-0-
Kryptobaatar      --63131--11111-211102----0???0011144100-0-0-00----------------------------0-0-
Catopsbaatar      --64132--23111-211002----01010110044100-0-0-00----------------------------0-0-
Chulsanbaatar     --63131--22111-211002----01010110144100-0-0-00----------------------------0-0-
                                                      2
Nemegtbaatar      --63131--22111-211?02----01010110144100-0-0-00----------------------------0-0-
Thomasia          ?-?????--???0?-?????0----?0--0?0-0??100-0-0-00----------------------------0-0-
Haramiyavia       003?01?--????10110000001000-0011-033200-0-0-00----------------------------0-0-
Arboroharamiya    --75143--100?---?-100----0101010-044?00-0-0-00----------------------------0-0-
Rugosodon         --42?10--0?1?1-1?0?02----0???0?00044100-0-0-00----------------------------0-0-
Sinobaatar        --52120--10101-110202----01000?11144100-0-0-00----------------------------0-0-
                            1

Input data matrix (continued):

                  3333333334444444444444444444444444444444444444444444444444444444444
                  9999999990000000000111111111122222222223333333333444444444455555555
Taxon/Node        1234567890123456789012345678901234567890123456789012345678901234567
-------------------------------------------------------------------------------------
Thrinaxodon       --------------------------------------------------0????0-------00??
Probainognathus   --------------------------------------------------0??000-------00??
Exaeretodon       --------------------------------------------------0????4-------00?1
Diademodon        --------------------------------------------------0????4-------00?1
Cynognathus       --------------------------------------------------?????4-------00??
Oligokyphus       010101?-----------------------------00---3--01---00??044-------0100
Bienotherium      010101?-----------------------------00---3--00---0????44-------0100
Kayentatherium    01??01?-----------------------------00---3--00---0????44-------0100
Yunnanodon        ?10101?-----------------------------00---3--00---0????44-------0100
Bocatherium       ???????-----------------------------00---?--00---0????44-------0100
Bienotheroides    010101?-----------------------------00---3--00---0????44-------0100
Tritheledontids   --------------------------------------------------100100-------01??
Adelobasileus     ???????????????????????????????????????????????????????????????????
Sinoconodon       011?--00----000??00000-0-----00--0??01-??10?------110000000?-?-01??
                                1
Morganucodon      2110--00----000??00000-0-----00--0??100??10?------110010000?-?-010?
Megazostrodon     2110--00----000??00000-0-----00--0??100??10?------100120000?-?-011?
Haldanodon        21??--00----000??00000-0-----00--0??11-00211------0??010000?0?-010?
Hadrocodium       ?11?--00----??0??0??00-0-----????0??0????10?------????200?0?-?-011?
Pseudotribos      1?1?--00????000??00001010100000--01111-00?11------????21110?00-000?
Ambondro          01??--??????????????????????????????????????------????311?11?0???0?
Ausktribosphenos  011?--??????????????????????????????????????------????3111??01?000?
Henosferus        011?--??????????????????????????????????????------0??1311?1000?000?
Asfaltomylos      011?--??????????????????????????????????????------????311??000?000?
Bishops           011?--??????????????????????????????????????------????311???01?000?
Steropodon        011?--??????????????????????????????????????------????301?2100?000?
Teinolophos       011?--??????????????????????????????????????------????301?2100?000?
Obdurodon         021?--0?????000??001???10100?00--000100??3??------221?301?2100-000?
                                                         2
Ornithorhynchus   ?21?--0?????0001200120-10100?00--000100??310------0????0??????-00??
                                                         2
Gobiconodon       1110--00----002??00000-0-----00--0??101??10?------110020010?-?-001?
Repenomamus       01??--?0----00???00000-0-----00--000101??10?------??????01??-?-001?
Yanoconodon       0110--00----?????????0-0-----00--?0001-?????------????100?0?-?-001?
Jeholodens        011?--00----??0??0000??0-----00--000001??10?------????200?0?-?-001?
                                2
Amphilestes       1110--0????????????????0-----????????????10?------????20010?-?-??1?
Priacodon         1110--10----000??0002??0-----00--000101??10?------110010000?-?-000?
Trioracodon       11??--10----000??0002??0-----00--000101??10?------????10000?-?-000?
Tinodon           111?--00----0001201000-111000011?000100??10?------????20110?-?-001?
Akidolestes       1???--10----00???01000-100---00--???1???????------????211?0?-0-001?
Spalacotherium    111?--10----0011201000-100---00--1111????10?------????21110?-0-001?
Maotherium        1???--10----0001201000-100---00--011?00?????------????211?0?-0-001?
Zhangheotherium   1110--??-???????????????????????????????????------????21110?-?-001?
Amphitherium      0110--??-???????????????????????????????????------????3111100??0?1?
Cronopio          00?0--00----001121---??101102011100001-??00-------??????1?????-001?
Henkelotherium    01??--00----00112010010101000010100001-??210------100?21110?0?-001?
Dryolestes        0110--00----00112010010101111010100001-??210------100021110?0?-001?
Peramus           0110--00----000120000101010000111111100??110------????3111100?-001?
                                1
Vincelestes       01??--0100?0000??0000??10100000--00011-??211------100031111000-001?
Kielantherium     01?0--?100?0000110000101010000111111?1-00211------????31111010-000?
Sinodelphys       011?--?1???1?????0001??1010???1???111???????------????31111010-000?
Pappotherium      ????--0100201101200101010100001111?1?1-00211------????311?1010-??0?
Deltatheridium    0110--0100101100-000010101000001011011-00211------100031112010-000?
                           1
Asiatherium       01??--01111111010001010101000011010111-11211------????31111010-000?
Kokopellia        01?0--0101211101200101010100100--1?111-00211------????31111010-000?
Pucadelphys       011?--01021011012001111101100110010111-00211------????31112010-000?
                                              1  1
Didelphis         0110--01121011012001111101101111010111-0?211------221131111110-000?
Juramaia          ??1?--?101211001200001010100001?0?1111-00211------????311?2010-000?
Eomaia            011?--01?1001101200?01?1000??00--?0111-001?1------????3?1120??-000?
                            1              1
Prokennalestes    011?--01111110012000010101000011110111-00211------100031111010-000?
Asioryctes        011?--0111111000-000010101001011111111-00211------????31111010-000?
Zalambdalestes    011?--01111011002001210100---00--11111-00211------????3?112010-000?
                                 1
Ukhaatherium      ?11?--0111211100-000010101001011011111-00211------????31111010-000?
Gomphos           01??--011?1011?0-01121-0-0---10--00001-01211------????311121100000?
Tribosphenomys    0110--?110101100100120-0-0---00--00011-00211------????3?112010??00?
                           1     12
Erinaceus         0110--01011101011001010110---00--00011-11211------221131111110-000?
Dasypus           0110--0????-????????????????????????01-0010-------????51?-----0000?
Ferugliotherium   ????--?-----------------------------??---?--------?02?44-------????
Ferugliotherium   ????--?-----------------------------???--?--------?02?44-------????
Trapalcotherium   ????--?-----------------------------???--?--------????5?------?????
```

```
Bharattherium     ????--?------------------------------???--?--------?2115?------?????
Gondwanatherium   0010--?------------------------------01---0--------100154------0????
Lavanify          ????--?------------------------------???--?--------?2115?------?????
Sudamerica A      0010--?------------------------------01---0--------100154------0????
Sudamerica B      0010--?------------------------------01---0--------100154------0????
Tanzanian taxon   ?0??--?------------------------------???--?--------????5?------?????
Tanzanian taxon   ?0??--?------------------------------???--?--------????5?------?????
Greniodon         ????--?------------------------------???--0--------102154------0????
                                                                     2
Vintana A         ????--0------------------------------01-??3----0---221155------1????
Vintana B         ????--0------------------------------01-??3----0---221155------1????
Guimarota Paulch  01?0100------------------------------01---1--0?0--10???44-------1000
Plagiaulacidae    01??0?0------------------------------01---1--0010110???44-------1000
Ptilodus          0110420------------------------------01---1--201110210?44-------1000
Taeniolabis       011?420------------------------------01---3--221210110?44-------1000
Lambdopsalis      01??320------------------------------01---?--2012101???44-------1000
Kryptobaatar      0???110------------------------------01---1--101111110?44-------1000
                       2
Catopsbaatar      01?0210------------------------------01---1--101211????44-------1000
Chulsanbaatar     0???110------------------------------01---1--1011011???44-------1000
Nemegtbaatar      0???310------------------------------01---1--201211????44-------1000
Thomasia          0110220------------------------------11---2--?10--1????43-------??11
Haramiyavia       0110220------------------------------11---3--010--1????43-------0111
Arboroharamiya    0010420------------------------------?1---3--010--1????43-------0100
Rugosodon         0110200------------------------------01---1--110--1????44-------1000
Sinobaatar        011?110------------------------------01---1--001101????44-------1000
                                                               1

All trees cleared from memory.

Taxon-deletion status changed:
  4 taxa deleted
  Total number of taxa now deleted = 4
  Number of nondeleted taxa = 87

Heuristic search settings:
  Optimality criterion = parsimony
    Character-status summary:
      Of 457 total characters:
        All characters are of type 'unord'
        All characters have equal weight
        1 character is constant
        13 variable characters are parsimony-uninformative
        Number of parsimony-informative characters = 443
    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 = 894606526
  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 = 3.3234e+09
   Score of best tree(s) found = 2050
   Number of trees retained = 11
   Time used = 00:38:56.7

Tree-island profile:
                     First      Last                      First   Times
Island      Size*     tree      tree        Score     replicate     hit
----------------------------------------------------------------------
     1          1        1         1         2050           122       1
     2          1        2         2         2050           337       1
     3          1        3         3         2050           452       1
     4          1        4         4         2050           467       1
     5          1        5         5         2050           475       1
     6          1        6         6         2050           534       1
     7          1        7         7         2050           672       1
     8          1        8         8         2050           749       1
     9          1        9         9         2050           796       1
    10          1       10        10         2050           799       1
    11          1       11        11         2050           928       1
    12          1        -         -         2051            19      16**
    13          1        -         -         2052            61      27**
    14          1        -         -         2053             2      64**
    15          1        -         -         2054             5     115**
    16          1        -         -         2055            13     129**
    17          1        -         -         2056            23     115**
    18          1        -         -         2057             1      83**
    19          1        -         -         2058            12      90**
    20          1        -         -         2059            10      73**
    21          1        -         -         2060            18      66**
    22          1        -         -         2061             3      46**
    23          1        -         -         2062            15      45**
    24          1        -         -         2063            69      33**
    25          1        -         -         2064            59      19**
    26          1        -         -         2065            28      11**
    27          1        -         -         2066           101      17**
    28          1        -         -         2068            36       2**
```

29	1	–	–	2069	418	2**
30	1	–	–	2070	343	2**
31	1	–	–	2071	321	1
32	1	–	–	2073	203	3**
33	1	–	–	2074	665	1
34	1	–	–	2075	264	3**
35	1	–	–	2076	38	7**
36	1	–	–	2077	169	4**
37	1	–	–	2078	844	2**
38	1	–	–	2079	658	2**
39	1	–	–	2080	135	2**
40	1	–	–	2082	674	1
41	1	–	–	2083	310	1
42	1	–	–	2084	401	3**
43	1	–	–	2085	366	1
44	1	–	–	2086	977	1
45	1	–	–	2087	641	1
46	1	–	–	2088	513	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 11 trees:

```
/-------------------------------------------------------------------------------- Thrinaxodon
+-------------------------------------------------------------------------------- Probainognathus
|                                                                          /----- Exaeretodon
| /------------------------------------------------------------------------+  /-- Diademodon
| |                                                                        \--+-- Cynognathus
| |  /--------------------------------------------------------------------------- Tritheledontids
\-+  |                                                                     /----- Oligokyphus
  |  |                                                                     +----- Bienotherium
  |  |                                                                     +----- Kayentatherium
  \--+ /-------------------------------------------------------------------+----- Yunnanodon
     | |                                                                   |  /-- Bocatherium
     | |                                                                   \--+-- Bienotheroides
     \-+ /----------------------------------------------------------------------- Sinoconodon
       | | /--------------------------------------------------------------------- Adelobasileus
       \-+ |  /------------------------------------------------------------------ Hadrocodium
         \-+  |                                                               /-- Morganucodon
           |  | /-------------------------------------------------------------+-- Megazostrodon
           \--+ | /-------------------------------------------------------------- Haldanodon
              | | |                                                           /-- Thomasia
              \-+ |  /--------------------------------------------------------+-- Haramiyavia
                | |  |                                                     /----- Yanoconodon
                \-+  |                                                     +----- Jeholodens
                  |  | /---------------------------------------------------+  /-- Priacodon
                  |  | |                                                   \--+-- Trioracodon
                  \--+ |                                                   /----- Amphilestes
                     | | /-------------------------------------------------+  /-- Gobiconodon
                     | | |                                                 \--+-- Repenomamus
                     | | |                                             /--------- Pseudotribos
                     | | |                                             |      /-- Ausktribosphenos
                     \-+ |                                    /--------+ /----+-- Bishops
                       | |                                    |        | |    /-- Steropodon
                       | |                                    |        \-+ /--+-- Teinolophos
                       | |                                    |          \-+  /-- Obdurodon
                       | |                                    |            \--+-- Ornithorhynchus
                       | |  /---------------------------------+ /---------------- Arboroharamiya
                       | |  |                                 | |             /-- Guimarota Paulch
                       \-+  |                                 | |             +-- Plagiaulacidae
                         |  |                                 | | /-----------+-- Rugosodon
                         |  |                                 \-+ |           \-- Sinobaatar
                         |  |                                   | |           /-- Taeniolabis
                         |  |                                   | |    /------+-- Lambdopsalis
                         |  |                                   \-+    | /------- Ptilodus
                         |  |                                     |  /-+ | /----- Chulsanbaatar
                         |  |                                     |  | \-+ +----- Nemegtbaatar
                         |  |                                     |  |   \-+  /-- Kryptobaatar
                         |  |                                     \--+     \--+-- Catopsbaatar
                         |  |                                        |   /------- Ferugliotherium
                         \--+                                        |   | /----- Trapalcotherium
                            |                                        \---+ |  /-- Bharattherium
                            |                                            \-+  +-- Gondwanatherium
                            |                                              |  +-- Lavanify
                            |                                              \--+-- Sudamerica A
                            |                                                 +-- Tanzanian taxon
                            |                                                 +-- Greniodon
                            |                                                 \-- Vintana A
                            |                                                 /-- Akidolestes
                            |                                                 +-- Spalacotherium
                            | /-----------------------------------------------+-- Maotherium
                            | |                                               \-- Zhangheotherium
                            \-+ /------------------------------------------------ Tinodon
                              | | /---------------------------------------------- Cronopio
                              \-+ |                                           /-- Henkelotherium
                                \-+  /----------------------------------------+-- Dryolestes
                                  |  | /----------------------------------------- Amphitherium
                                  \--+ |                                      /-- Ambondro
                                     \-+ /------------------------------------+-- Henosferus
                                       | |                                    \-- Asfaltomylos
                                       \-+  /------------------------------------ Vincelestes
                                         |  | /---------------------------------- Peramus
                                         \--+ | /-------------------------------- Kielantherium
                                            \-+ | /------------------------------ Pappotherium
                                              \-+ |  /--------------------------- Juramaia
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                                                \-+  | /------------------------ Prokennalestes
                                                  \--+ | /---------------------- Eomaia
                                                     \-+ |  /------------------- Sinodelphys
                                                       \-+  | /----------------- Deltatheridium
                                                         \--+ |            /-- Asiatherium
                                                            | |         /--+-- Kokopellia
                                                            \-+ /--------+  /-- Pucadelphys
                                                              | |        \--+-- Didelphis
                                                              \-+  /------------ Ukhaatherium
                                                                |  | /---------- Asioryctes
                                                                \--+ | /-------- Zalambdalestes
                                                                   \-+ +-------- Erinaceus
                                                                     \-+ /------ Dasypus
                                                                       \-+  /-- Gomphos
                                                                         \--+-- Tribosphenomys

Lengths and fit measures of trees in memory:
  Character-status summary:
    Of 457 total characters:
      All characters are of type 'unord'
      All characters have equal weight
      1 character is constant
      13 variable characters are parsimony-uninformative
      Number of parsimony-informative characters = 443
  Gaps are treated as "missing"
  Multistate taxa interpreted as uncertainty

   Sum of min. possible lengths = 620
   Sum of max. possible lengths = 5216

Tree #      1
Length   2050
CI      0.302
RI      0.689
```

```
#NEXUS

Begin data;
        Dimensions ntax=91 nchar=457;
        Format datatype=standard interleave symbols="01234567" gap=-;
        Matrix
Thrinaxodon                00000?00?1000000000?00000001000000?00000000?000000000000????
Probainognathus            00?00?0????0?000000?00000000000000?0???000000?00000???010???
Exaeretodon                0?000?00?1??0?0?000?00?0000100000??00??00000000100000000????
Diademodon                 0?000?0???0?0000000?00000001000000??00?00000000?000??00????
Cynognathus                0?000?0???0?0000000?00000001000000??00?00000000?00??????????
Oligokyphus                0?1?0?0???01000000000000000100000??000?001000000000?000100??
Bienotherium               ???????????????????????0000?00000??????0000000??????????????
Kayentatherium             0?000?00?0?1010100010000000100000 0?00??00000000?????????????
Yunnanodon                 ????????????????????????????????????????????????????????????
Bocatherium                ????????????????????????????????????????????????????????????
Bienotheroides             0?000?0001?0110?000000000001000000??0??000000???????????????
Tritheledontids            ?0??0?00?1101000000?00000000000000?0???0?000???0????????????
Adelobasileus              ????????????????????????????????????????????????????????????
Sinoconodon                000?00?000000000000000000000000000????000000??0?????????????
Morganucodon               00000?10?1?0010?000?00000000000000?000?0100010?0?000000100??
Megazostrodon              ?0000?1????0?100000?000000000000?00000?01000?000000000010?00
Haldanodon                 ?????????????100????00?00?0100000??????0?000?0??????????????
Hadrocodium                ????????????????????????????????????????????????????????????
Pseudotribos               ?????00000000001010000000001000????0?110?000????????????????
Ambondro                   ????????????????????????????????????????????????????????????
Ausktribosphenos           ????????????????????????????????????????????????????????????
Henosferus                 ????????????????????????????????????????????????????????????
Asfaltomylos               ????????????????????????????????????????????????????????????
Bishops                    ????????????????????????????????????????????????????????????
Steropodon                 ????????????????????????????????????????????????????????????
Teinolophos                ????????????????????????????????????????????????????????????
Obdurodon                  ????????????????????????????????????????????????????????????
Ornithorhynchus            ?11011100000000101000000000010000000?11110000201000000000010111
Gobiconodon                ?????00????1?21?1-1?1110000110000??000?00000100100??????????
Repenomamus                ?1??0100??1??21?1-??1110001110 0?0??0001???0?1?0?001000010???
Yanoconodon                00000100001112111-10111000011010000000?000001000000??00101?0
Jeholodens                 ??0??10????112111-?01110??0110100000?01000001000001?00010110
Amphilestes                ????????????????????????????????????????????????????????????
Priacodon                  ???????????????????????????110100???????????????????????????
Trioracodon                ????????????????????????????????????????????????????????????
Tinodon                    ????????????????????????????????????????????????????????????
Akidolestes                ?????000101112111-10111111111?1000001111?0002101001??0110002
Spalacotherium             ????????????????????????????????????????????????????????????
Maotherium                 ?1?0001?????121?1-1?11111111111000011011?110210?001??0110002
Zhangheotherium            ?110001010111 2111-10111101{01}111100000001111101100001100111 1?1
Amphitherium               ????????????????????????????????????????????????????????????
Cronopio                   ????????????????????????????????????????????????????????????
Henkelotherium             0????01????112011-1??1110?00111000??001111101110101???11????
Dryolestes                 ???????????????????????????111100???????????????????????????
Peramus                    ????????????????????????????????????????????????????????????
Vincelestes                01111?11--1112111-101111010011110000101111001110101100 1101??
Kielantherium              ????????????????????????????????????????????????????????????
Sinodelphys                ?????011--1112101-112?11112?2211111???11?1???1000121??11000?
Pappotherium               ????????????????????????????????????????????????????????????
Deltatheridium             ?????????????????????????????????????????????????1211?110???
Asiatherium                ????101????112101-1?21111120221111?01011?11111101???????????
Kokopellia                 ????????????????????????????????????????????????????????????
Pucadelphys                11111011--1112101-1121110120221111?1101111111111012111110002
Didelphis                  11111011--1112101-1121110120221111?1101111111111012111110002
Juramaia                   111101????11210??1?21?1????22100???????????????????????????
Eomaia                     11?11011--1112001-1021110120221010011011?1112110011?21111002
Prokennalestes             ????????????????????????????????????????????????????????????
Asioryctes                 01111?????????????????????????0101????????????10122?21111002
Zalambdalestes             ??11111??????2?01-1??111112022101001111??1112111?1212110-002
Ukhaatherium               ?1??1?1?????12001-1?21111?2022101000?011?1112110??2121110002
Gomphos                    11111?11-?1?12?01?1021110?10???????0100111?12?1?1?1?2100-1??
Tribosphenomys             ???????????????????????????????????????0???????11?11?21011??
Erinaceus                  11111{01}11--1112101-101111112022101011100111112110122121111002
Dasypus                    11111011-?1112101-102111112022111001110110111101222?21110002
Fergliotherium_A           ????????????????????????????????????????????????????????????
Ferugliotherium_B          ????????????????????????????????????????????????????????????
Trapalcotherium            ????????????????????????????????????????????????????????????
Bharattherium              ????????????????????????????????????????????????????????????
Gondwanatherium            ????????????????????????????????????????????????????????????
Lavanify                   ????????????????????????????????????????????????????????????
Sudamerica_A               ????????????????????????????????????????????????????????????
Sudamerica_B               ????????????????????????????????????????????????????????????
Tanzanian_taxon_A          ????????????????????????????????????????????????????????????
Tanzanian_taxon_B          ????????????????????????????????????????????????????????????
Greniodon                  ????????????????????????????????????????????????????????????
Vintana_A                  ????????????????????????????????????????????????????????????
Vintana_B                  ????????????????????????????????????????????????????????????
Guimarota_Paulchoffatiidae ????????????????????????????????????????????????????????????
Plagiaulacidae             ????????????????????????????????????????????????????????????
Ptilodus                   ?????01???????????0????10?00000?????1?1111112011101100110?02
Taeniolabis                ??10?????????10?????2?0100??00??????????????????????????????
Lambdopsalis               ?????010001??11?1-?021110001000??????1??????????????????????
Kryptobaatar               ?0?00010?011111?1-1?21?10000000?1??01111?1102011101000110?02
Catopsbaatar               ??????1?????????????????????000?????0??1?111?1????1?111101??
Chulsanbaatar              ???0001???????????1????100?????????0???1?110??????1?001101??
Nemegtbaatar               ???00?1???????????1??1?110?0????1?101??11110?0??????????????
Thomasia                   ????????????????????????????????????????????????????????????
Haramiyavia                ????????????????????????????????????????????????????????????
Arboroharamiya             ??????1?????1???????????????????0????0?1?0??100000??????????
Rugosodon                  11111010001111001-10110100?0?010100?0111?010201?001??0110111
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```
Sinobaatar                 11?11010001111001-1011010020?010100?{01}1?11110201?001??0110111

Thrinaxodon                ??00100000000101-0201200??00--200100000000100-0000-0-030-001
Probainognathus            0-?1000000000101-0200--00-00--2001?000000000100000-0-0311001
Exaeretodon                ???100100000?100-0000--???011-?000100{01}000000100000-0-0211001
Diademodon                 ???1000000000101-0200--00-00--?1011000000000100000-0-2310001
Cynognathus                ???010000000?101-0200--???00--?0011000000000???000-0-2310?01
Oligokyphus                ???010??0????????0200--???1110210101010000000120000-1-0211010
Bienotherium               ????0?0000???001-0200--???0110?10??101000000??0000-?-?211?10
Kayentatherium             ???1000000010101-0100--???00--1001110100000120000-0-0211010
Yunnanodon                 ????0??010???10???200--????0--?01??1????000????0?0-0-0211010
Bocatherium                ???00??110???11????0120???00--?00??101100010??0000-0-?2???10
Bienotheroides             ???101?110???111?020110???0101?00101011000 10??0000-0-221?010
Tritheledontids            ???{01}000{01}00{01}??101-0100--?0-10--200101010001{01}0100100-0-0211010
Adelobasileus              ????????????????????????????????????????????????????????????
Sinoconodon                ???000000000110?-02010001010--200111000 0?100120100-001311010
Morganucodon               ???01010001 1?101101012001010--10010100000100120100-001311010
Megazostrodon              0-0010??????????1??0??????1???20010???0??1?0???????0?13??01?
Haldanodon                 ???010100011011010201 1110-110020010100000200120000-000210010
Hadrocodium                ???000?00011?10?1??00--???1100200??1??0002?0???0?0-0013??010
Pseudotribos               ????????????????????????????????????????????????????????????
Ambondro                   ????????????????????????????????????????????????????????????
Ausktribosphenos           ????????????????????????????????????????????????????????????
Henosferus                 ????????????????????????????????????????????????????????????
Asfaltomylos               ????????????????????????????????????????????????????????????
Bishops                    ????????????????????????????????????????????????????????????
Steropodon                 ????????????????????????????????????????????????????????????
Teinolophos                ????????????????????????????????????????????????????????????
Obdurodon                  ???010200011?001010111 11??111022?111?00002?00-00012121?1??10
Ornithorhynchus            101010200011?001010110100-111?22?0111?0002?00-00012121?11110
Gobiconodon                ??1010?0001????11?00--???12?1000011??0??2?01101???120?1?110
Repenomamus                1000101000110?0110200--???12?10000?10000?2?01101?0-12021?110
Yanoconodon                0-0??????????????????????????????????????????????0-121??????
Jeholodens                 0-0000?10011???01110--????2???0??????????????????0-121????1?
Amphilestes                ????????????????????????????????????????????????????????????
Priacodon                  ???????????????????1??????11?0????????0??0?10-0???????2?????
Trioracodon                ????????????????????????????????????????????????????????????
Tinodon                    ????????????????????????????????????????????????????????????
Akidolestes                111?10??????????????????????????????????????????????11??????
Spalacotherium             ????????????????????????????????????????????????????????????
Maotherium                 1110102000???11110200--???11?1010??1?????2?0?????0-011?1??10
Zhangheotherium            111?10?0??????????????????11???????????????????1?0-011????10
Amphitherium               ????????????????????????????????????????????????????????????
Cronopio                   ???0102000?1?11??000??????1110010011 1?000000??0?00-0??3???10
Henkelotherium             ??1????????????????????????????1?011????????1????0-0?1???0??
Dryolestes                 ???0???????????????????????????????????????0????????????????
Peramus                    ????????????????????????????????????????????????????????????
Vincelestes                0-?00020001 1?11110201111??110021000100000100110000-00{01}310010
Kielantherium              ????????????????????????????????????????????????????????????
Sinodelphys                110????????????????00--???1??????????????????????0-0?1??????
Pappotherium               ????????????????????????????????????????????????????????????
Deltatheridium             ???00?2101-----??0200--????20001-10100000200??0?00-0{01}12??010
Asiatherium                110000??0????????0100--???12?001???1???002?1???000-0013??010
Kokopellia                 ????????????????????????????????????????????????????????????
Pucadelphys                ??00002101-----100110--111120001-1011000020?120100-0?1211010
Didelphis                  ??00002101-----100110--111120021-1111000020111 0000-0?1211010
Juramaia                   ?????0??????????????????????????????????????????????????????
Eomaia                     ??0?0??101-----???00--????2?0??-1?1??????????????0-0?1???010
Prokennalestes             ????????????????????????????????????????????????????????????
Asioryctes                 ??00002101-----???00--1??120?21-?110????200120100-00131?010
Zalambdalestes             ??00102101-----010{02}00--???120011-10100001100110100-011111111
Ukhaatherium               ???0002101-----???10????????2??2?-10101000 2?0??0100-10131?010
Gomphos                    ???0002101?????110010?????1210?1?1?1110002100-0000-01001?111
Tribosphenomys             ????????????????????????????????????????????????????????????
Erinaceus                  1100?02101-----101110--111120?21-11100000201121100-02120-110
Dasypus                    1102102101-----101010--110121100-011010002000-1000-021-0-010
Feruglio therium_A         ????????????????????????????????????????????????????????????
Feruglio therium_B         ????????????????????????????????????????????????????????????
Trapalcotherium            ????????????????????????????????????????????????????????????
Bharattherium              ????????????????????????????????????????????????????????????
Gondwanatherium            ????????????????????????????????????????????????????????????
Lavanify                   ????????????????????????????????????????????????????????????
Sudamerica_A               ????????????????????????????????????????????????????????????
Sudamerica_B               ????????????????????????????????????????????????????????????
Tanzanian_taxon_A          ????????????????????????????????????????????????????????????
Tanzanian_taxon_B          ????????????????????????????????????????????????????????????
Greniodon                  ????????????????????????????????????????????????????????????
Vintana_A                  ???0001010011011110010111011100011110110000000-1000-012211010
Vintana_B                  ???0001010011011110010111011100011110110000000-1000-012211010
Guimarota_Paulchoffatiidae ??????2101-----01000{01}00110?100?1-11000000??0?????1112?{01}???10
Plagiaulacidae             ????????????????????????????1?0???????????????????????2?????
Ptilodus                   ???0002101-----11121111???12000?-1112001?0010-00?1112110-110
Taeniolabis                ???101?101-----??10?0--???1200?2-??11?0000?0?????111202??010
Lambdopsalis               ???1012101-----1110?120???120?02-111100000000-0111112120-010
Kryptobaatar               1102112101-----01020110110121001-11100011000120111112110-111
Catopsbaatar               ??02112101-----01020110????{12}10?1-111010110000-01111?2010-111
Chulsanbaatar              ???0002101-----?100011011012 1001-??10001110012011111211??010
Nemegtbaatar               ???0002101-----?100012111012 1001-01100011001120111112 1110010
Thomasia                   ????????????????????????????????????????????????????????????
Haramiyavia                ????????????????????????????????????????????????????????????
Arboroharamiya             0-??????????????????????????????????????????????????????????
Rugosodon                  111???????????????????????1????????????1????????????????????
Sinobaatar                 111????????????????1?0????2?1???????????1??0?????1?1??1?????

Thrinaxodon                2000000000-0------?-0000000?000??0?0?0000-10-00??0000010000-
Probainognathus            2000000000-0------0-0001100000??00??0000-01000??0????11000-
Exaeretodon                2011-00000-0------0-0000110000?00?????000-01000?00000010010-
```

Diademodon 2011-01000-0-------0-0000100000200????000-0??00?00000010010-
Cynognathus 20?1-0000?-0-------0-0?00100?00200????000-0??00?00000010010-
Oligokyphus -0???20?00-0-------0-0?10?10?01?00??0??000-00?00?1000000010-
Bienotherium 00?0?00000-0-------0-0000110?01?00????000-00?00??000000010-
Kayentatherium 002000100?-?-------?-0000011?01000????000-0??00??00000?0010-
Yunnanodon 002000?00?-0-------0-?00?1?1?011000??00000-0??00?0000000010-
Bocatherium 00?????????-?-------?-00001110?1?00??????00-0??00??00????????
Bienotheroides 002010100?-0-------0-0100110001?00????000-0??00??000000010-
Tritheledontids -0100{01}{01}000-0-------0-00000100000001??00000-00000?00000010000-
Adelobasileus ?0?0011?00????????????0??0?1101111?????000-0?011??0??0101000-
Sinoconodon -0200111000002000000?0010111011110010?00000-01011100000000010-
Morganucodon -02001110010120000000001010101121110000000-0101110000010112 0-
Megazostrodon ?02000010????????000??1???1?1120010?0?000-0?0111?00001?1120-
Haldanodon -0200000001010000000012?1?1111200100000000-0101?100000102020-
Hadrocodium -0200???0001000100000?12?1?1111212?????000-0?0111?10?0102020-
Pseudotribos ??
Ambondro ??
Ausktribosphenos ??
Henosferus ??
Asfaltomylos ??
Bishops ??
Steropodon ??
Teinolophos ??
Obdurodon 0021-?0100011100?0000120101111212?????000-0?110101000112120-
Ornithorhynchus 0021-2010000110000000120101111212110000000-0111010100011 2120-
Gobiconodon ?02??10100101200?000?0101???11211?????000-0?0111?10001?1120-
Repenomamus ?0200101?0101200000 0?010????11211????0000-0?0111?100???1120-
Yanoconodon ??????????1?120000?0?0??????????????????????????????????????
Jeholodens ?0??????0010???00?00????????????{01}?????????0?0???????????????
Amphilestes ??
Priacodon ?????20??????????????????????11211100??000-0101?11??00111?20-
Trioracodon ????????????????????????????11211?00??000-0101111??00111120-
Tinodon ??
Akidolestes ??????????1????000??
Spalacotherium ??
Maotherium -?200???00111??00?00????????11211?????11100??1???2000110111?
Zhangheotherium -?????????1112000000???0????1?211?????11100?0??1??0001121210
Amphitherium ??
Cronopio 002???????111001????????110?1121??????11100?{01}11???????01021?
Henkelotherium ????????1?1?11000000????????1121221011?11001?1?1????011?02??
Dryolestes ????????????????????????????1121221011111 0010??1????01??1210
Peramus ??
Vincelestes 0020020100011000000000?0111111212201?111100?0111110001021210
Kielantherium ??
Sinodelphys ?02?????1???
Pappotherium ??
Deltatheridium -02?????11?112010?1??11???101121 2?1???11100?0221?21?1-1?0210
Asiatherium -02???0?110112010010?11?1?101121 2??????1110????2????2101-??0???
Kokopellia ??
Pucadelphys 0020130211011201001101 1?111011212310??11100?-211?2?01-1?0210
Didelphis -0201302110112010011011101101121231 0??111001-22112101-1?0211
Juramaia ??
Eomaia -2?????11?????1??10??
Prokennalestes ????????????????????????????11212?10111111011??11???1-110210
Asioryctes -1201302110102010110011011111212?????11111?-21112011-1?021?
Zalambdalestes 002003011101010101110110111111212 3?011111110-21112011-1-0210
Ukhaatherium -12??30????10201011?0????11111212 3?0111?1110-21112011-?-0?10
Gomphos 002??3011?010111001001110?1111212???1101??????2?1201????0???
Tribosphenomys ??
Erinaceus 00201302110101010110011011101121231?11111110-22112011-1-0210
Dasypus 0020130111010011011001211111111212310111110 10-21{01}?2001-1-0210
Fergliotherium_A ??
Ferugliotherium_B ??
Trapalcotherium ??
Bharattherium ??
Gondwanatherium ??
Lavanify ??
Sudamerica_A ??
Sudamerica_B ??
Tanzanian_taxon_A ??
Tanzanian_taxon_B ??
Greniodon ??
Vintana_A 0020000100111110100020 0?110011111111111111011-12111010112121?
Vintana_B 0020000100111110100020 0?110011111111111111011-12111010112121?
Guimarota_Paulchoffatiidae 0?2??21??001?1????1??0??1?1?11211????0000-010121 0?????1?1???
Plagiaulacidae ?0??
Ptilodus 002??11100111110000010211111112 11??0????100??121020?02121210
Taeniolabis 102??1????0?10?000?0?????????1??????????????????????????????
Lambdopsalis 0021-?1100011010000001211111112?110000000-0?0121020002111210
Kryptobaatar 1121-111001111?0000010211111112011?0??0010011121020002121210
Catopsbaatar 112??1110011111000000102111111 1211?????????0??121?20002121210
Chulsanbaatar 1121-1110011111000?010211111112 1110?00??10010121020002121210
Nemegtbaatar 1121-11100111110001 0?02111111121 110000??1001?121020002121210
Thomasia ??
Haramiyavia ??
Arboroharamiya ??
Rugosodon ??
Sinobaatar ?0??????00111210?000??

Thrinaxodon -000000001000-0?01??0-01??30?00-000000000000003000400000000?0
Probainognathus -00?000001000-0000????01??30000-0000?00010000130000000000 11?
Exaeretodon -00000??00100-2000??0-0?????????00??100000000100000100001110
Diademodon -000001-00100-2000??0-0????0000-001000000000000000{34}000001110
Cynognathus -000001-00100-2000??0-0????0000-00??00000000100000000??11?0
Oligokyphus -1010?1-0001002011100-011-?0011021??1000????1120003000100100
Bienotherium -101001-001?0??0?1??0-011-?0011021??????????0??0000010?00?00
Kayentatherium -101001-???????01???0-?????0010021??100000000130000??0?00???

Yunnanodon	-101001-0001002011 1?0-??????001-21??????????01300??010??0??0
Bocatherium	???0???????????0
Bienotheroides	-10100??00110020?11?0-?????0010021??1000????013000?010??1??0
Tritheledontids	-00{01}0000000000000001?0-01???0000-1100????????{01}1{03}000000001000??
Adelobasileus	-00?00000101?000011???01???????????????????????010210011 1???
Sinoconodon	-00100000001000011000-01???0000-11001000 1?00013000100010 0??0
Morganucodon	-101000000010001110 00-01000011 0?21001000100011301010001?0010
Megazostrodon	-1010000000100011110??????01?0?21??????1?00????1??0001?1???
Haldanodon	-101000001010000110 00-010000????2?001????00001101011000 11111
Hadrocodium	-101001?0101000?1100??1??????????2????????1??????020110 1111???
Pseudotribos	??
Ambondro	??
Ausktribosphenos	??
Henosferus	??
Asfaltomylos	??
Bishops	??
Steropodon	??
Teinolophos	??
Obdurodon	-1010000010001000 0?0??1??????????2?????????????1?020100111 1?1?
Ornithorhynchus	-10100000100010000?0111?0122012?211111112201011020100111 1111
Gobiconodon	-20100000???????11?0-????????????1????????????1?01010?011???0
Repenomamus	-2010000000 10?1?11??0-???????????21???????????0100{01}0?0?01????0
Yanoconodon	????????????????????????????21?2221???110200 1???????????????
Jeholodens	??????????????????????????????122?????????2???????01??????1????
Amphilestes	??
Priacodon	-??10000000 1?00111?20-????0?????2??????????????????0111???0???
Trioracodon	-1?10000000 1?0011??00-0?000?????2??????????????????0111??????
Tinodon	??
Akidolestes	??
Spalacotherium	??
Maotherium	?20?00??????0???1????????????????2????????????1?1011-0????1???
Zhangheotherium	020100??0101???1111?0-???????????21????????????????????????????
Amphitherium	??
Cronopio	02?111??01010?111????????????????21{03}??????????1?30????????????
Henkelotherium	??0111?????1??10???0??
Dryolestes	????11??0?01??101??0??01???????????????????????????01?????????
Peramus	??
Vincelestes	020111000111001011100-01000?????21??????????01300011101 1??11
Kielantherium	??
Sinodelphys	??
Pappotherium	??
Deltatheridium	??100?????1?01011??0-????1?????21???????????????1012????????
Asiatherium	?211??00???10?1??1???????????????21????????????1?01???????1???1
Kokopellia	??
Pucadelphys	121100001--1011011110-??00{12}?????21??????2???11301??3-0010011
Didelphis	120100001--1001011110-1-01?1????2120111120121100101 3-0011011
Juramaia	??
Eomaia	??
Prokennalestes	1??111??0111??101??0??1-??0?????2???????????????????0?1????????
Asioryctes	?20110000111?010110?0-1-??1?????21??????3013??3011-201?1001?
Zalambdalestes	02111?000111001111110-1-??{12}?????21??????3012110010120 0111010
Ukhaatherium	020110001--10?1011{01}0??????1???????????????01??0?01????1?100?0
Gomphos	?10???0?????1???110?1??????????????1??????4??221001????1?10001
Tribosphenomys	??
Erinaceus	120111000111001011110-1-00211111212011114113110020120 0111111
Dasypus	11010?011--1011?11010-1-0021112221201?1131122130 2013-011111?
Feruglio therium_A	??
Feruglio therium_B	??
Trapalcotherium	??
Bharattherium	??
Gondwanatherium	??
Lavanify	??
Sudamerica_A	??
Sudamerica_B	??
Tanzanian_taxon_A	??
Tanzanian_taxon_B	??
Greniodon	??
Vintana_A	?101000101110000111210????3?????21?????1????1120002110001100
Vintana_B	?101000101110000111210????3?????21?????1????1120002110001100
Guimarota_Paulchoffatiidae	??011000???10?{01}0??1???00??????????????????1?????1?01????1????
Plagiaulacidae	??
Ptilodus	0?01110101110001?11??????0?????????????????210010221011???0
Taeniolabis	??01011????001???0
Lambdopsalis	0101000101?110?1?11???000022112?21??1???2????10120221011??10
Kryptobaatar	010111010101102111120-00012?????21211???2????2110202210111010
Catopsbaatar	010??010110???1?0??????????????????????????2110202??111??0
Chulsanbaatar	010?110101?110?1?0????00012?11???1??????????2110202211111?0
Nemegtbaatar	010?1101011110?1?0????00012?????????????????1110201211111110
Thomasia	??
Haramiyavia	??
Arboroharamiya	??
Rugosodon	??????????????????????????????????1?????????????????????????
Sinobaatar	???1????0???????????

Thrinaxodon	?0???0??001?-00101100000---000--00-000----101000000-00210000
Probainognathus	00??000?00??-00031100001010000--00-000----000?0?010-00210000
Exaeretodon	00??000?01??-00101200011?0000???00??00----1001?0001-01220001
Diademodon	00??000?001?-000311000?1000000--?0?100----100?00011-0121000?
Cynognathus	00??????????-00101?00001000000--00?100----100???011-0021000?
Oligokyphus	10????0?001?-01101100011010?10--110100----30011001--1-220000
Bienotherium	10????0?001?-01101200 11????????110?00----30011001--1-43-00?
Kayentatherium	?0??????????-00101200011010?00--0111{01}0----??0110-1--1-44-00-
Yunnanodon	00??????????-?????????????????????????----3001??01--???3-00?
Bocatherium	???????????-?01022????????????????11110----3001?001--1-42000?
Bienotheroides	00??????????-00101200011010000--?11100----30011001--1-32000?
Tritheledontids	00??0000001?-111{01}110000{01}0?0000--00-100----100?00?11-?1{23}{234}000?
Adelobasileus	00??

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Sinoconodon                 00??0?00????011????00001000000--00-000001010010000l?01000000
Morganucodon                01101000000??11111000101000000--00-00000{01}0200110000001010000
Megazostrodon               0????????????11????00100???000--00-000001010O1??000?00010000
Haldanodon                  1????00?000?011101100011000000--00-00000102011110000000100000?
Hadrocodium                 111000??001001?????????1010??0--?0-00000002??1?0001001100000
Pseudotribos                ????????????0??????0???1000???????????00102011?????1???????
Ambondro                    ??????????????????????1??????????????????????1??????????????
Ausktribosphenos            ????????????0??????10111211?01000101OO????2111??????????????
Henosferus                  ????????????01112100011120000100011100000121111??????011?????
Asfaltomylos                ????????????0??10110??11210??10001110001?13111??????????????
Bishops                     ????????????0??1?1?11-1121111100010100011131111??????????????
Steropodon                  ??????????????????????1??????????????????????1??????????????
Teinolophos                 ??????????????????11-112111?1000111010111211??????????????
Obdurodon                   1212?11?00000111???110113101?10001111011121111???????55----
Ornithorhynchus             121211110000011121-11-1{01}010111000111110111??1111-????55----
Gobiconodon                 01?????????01113?210010----11010111{01}01010111101-00000430000
Repenomamus                 ?1?????????011121010010----1101011100101011111??100000320000
Yanoconodon                 ????????????011????10010----11010?????1010200l??-?000033000?
Jeholodens                  ?1??????????011????10010----????0?????1010?0?1??????0011????
Amphilestes                 ????????????011????10110----1101011?0?????2111??????????????
Priacodon                   ????????000?011111110010----1101011110102021011??10013?????
Trioracodon                 ????101100??011????10010----1101011110102020O1????10002?????
Tinodon                     ????????????011????10110----0101010??011113111???????0??????
Akidolestes                 ????????????????????????0----???????????1??????1??????00110000?
Spalacotherium              ????????????0??????10010----?1010111001111121111??????????????
Maotherium                  ????????????01113101O010----?101011100111101111??0?1001220000
Zhangheotherium             ????????????01111?010010----?1010111001111011111????00220000?
Amphitherium                ????????????011????10111110101000111000111121111??????001?????
Cronopio                    ????????????011101111-11?10?1???01110001111111??-111???30000
Henkelotherium              ????????????01111?0100111101010001110O???13011??????0????????
Dryolestes                  ????????00??01110111011111010100011100011130111l?00000110000
Peramus                     ????????????0111{012}1{01}100111101110011010000112111??????001?????
Vincelestes                 1111100100100111111111-1111010100110100011121111??010001310000
Kielantherium               ???????????????????1001?????????????110?????111??????????????
Sinodelphys                 ?1?????????01113101??113101?100010???10113111???0110011??00
Pappotherium                ???????????????????????????????????????????????1??????????????
Deltatheridium              01??????00??011111111-1131011100110100l?113011??0?000021000?
Asiatherium                 02??????????0?????11??11310111001101001111131111????00????????
Kokopellia                  ????????????01111111011?????1???????10????3111??????0?1?????
Pucadelphys                 0111101100110111111111-11310110--1101001111311111010000100000?
Didelphis                   011111??00100111111111-11311110--11010010113{01}1111010101100000
Juramaia                    ????????????01?1111??????????????10?1????1111111010001100?0
Eomaia                      ?1??????????0111012101111101O0--11010?0011211l??010111100000
Prokennalestes              ????????000?0111111100111?1{01}101001101100011211l??????????????
Asioryctes                  12111?01????0111{234}1?11-1111{01}1010011-10010113111??010000100000
Zalambdalestes              021111?????011111111-11110111001111001111111111101012{23}000?
Ukhaatherium                12??????000?011111111-?1110??1--?10???1011311l??110001100000
Gomphos                     12???????00??0110---11-11210?11001100001121301111-1-01-331101
Tribosphenomys              ????????????011101211-11110?1100110000???0301111-1-?1-441--1
Erinaceus                   1211110100l?011111111-11110110--110100011131111100000320000
Dasypus                     021011111-1?0111{123}1?11-11110110--00-0001111{01}111??--??-?55----
Feruglíotherium_A           ?????????????????????????????????????????????????1?????????????
Feruglíotherium_B           ?????????????????????????????????????????????????1??????1?4?1??1
Trapalcotherium             ???????????????????????????????????????????????????????????????
Bharattherium               ?????????????????????????????????????????????????1?????????????
Gondwanatherium             ?????????????????????????????????????????????????1??????????1??1
Lavanify                    ?????????????????????????????????????????????????1?????????????
Sudamerica_A                ?????????????1010211??1????????????????????????1??????1-4?????
Sudamerica_B                ?????????????1010211??1????????????????????????1??????1-4?????
Tanzanian_taxon_A           ???????????????101112-1???????????1110?????1001??????1-4?????
Tanzanian_taxon_B           ???????????????101112-1???????????1110?????1001??????1-4?????
Greniodon                   ?????????????????????????????????????????????????1?????????????
Vintana_A                   010010110100????????????????????????????????????1??-1--???3110?
Vintana_B                   010010110100????????????????????????????????????1??-1-0???3110?
Guimarota_Paulchoffatiidae ???????000?011101111-10----011111010010201 1{01}11?{01}{01}{01}01-420000
Plagiaulacidae              ????????????110101011-10----111111110010201001???1?01-42000-
Ptilodus                    0111101100??110101111-10----111111110011201001 11?1-01-43-10-
Taeniolabis                 0???????????110101011-10----1111111100011{01}20011111-01-43-10-
Lambdopsalis                0???????01??110101111-10----111111110001112001 1111-01-43-10-
Kryptobaatar                01121011000011010111 1-10----1111111100112010011111-01-43-11-
Catopsbaatar                0???????????110102111-10----111111110011201001??11-01-43-11-
Chulsanbaatar               011?1011000?111102111-10----1111111100112010011111-01-43-11-
Nemegtbaatar                011?1011000?111101111-10----1111111100112010011111-01-43-11-
Thomasia                    ?????????????????????????????????????????????????1?????????200?0
Haramiyavia                 ????????????011{01}{01}00000110000000-000000000000001101?0110210000
Arboroharamiya              ????????????1101??11-11010111?011000010201001????-?1-4{34}????
Rugosodon                   ????????????010????1??10----?1?11111?0112010011100001-420000
Sinobaatar                  ????????????010101111-10----11?11111001120100111 11-01-42?00-

Thrinaxodon                 01100000000000{1234}{01234}0-------------------------------000-0-0-0---
Probainognathus             01100000000000320-------------------------------000-0-0-0---
Exaeretodon                 111001000?000?{0123}{0123}0-------------------------------000-0-0-0---
Diademodon                  ?1100?000?000?000-------------------------------000-0-0-0---
Cynognathus                 ?1100?000?000?000-------------------------------000-0-0-0---
Oligokyphus                 01000001---1--320-----------------------------00200-0-0-0??-
Bienotherium                01?-???1---1--320-----------------------------00200-0-0-00--
Kayentatherium              01--0101---1--320-----------------------------00200-0-0-00--
Yunnanodon                  ???????1---????40-----------------------------?1200-0-0-0??-
Bocatherium                 ???-??21---1--?40-----------------------------?1200-0-0-0??-
Bienotheroides              ???0???1---1--210-----------------------------00200-0-0-00--
Tritheledontids             ?1?00?000?000?{23}{12}0-------------------------------000-0-??0---
Adelobasileus               ????????????????????????-??????????????????---??????????????
Sinoconodon                 ?110?0000000003203301??1-0??-0000110000--01---11000-0-0-00-0
Morganucodon                011000000000002000001101-001-0000011000--01---{123}{23}000-0-0-0110
Megazostrodon               0110000??000000000001??1-001-0000001000--01---11000-0-0-0110
Haldanodon                  ??000000010001{12}102200121-011-00000100010011---{01}1100-0-0-0120
Hadrocodium                 01?000000?000?550330?101-0?1-0100100000-??1---44000-0-0-00-0
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Pseudotribos                ???0?????????21?00?????-0??-00101111?11?1?---33100-0-0-00-0
Ambondro                    ???????????????????????-???-?0000?1110--1?---??00-0-0-00-0
Ausktribosphenos            ???????????????????????-??1-?0111111111011---3??00-0-0-00-0
Henosferus                  ???00?0????00?2??0??????-00?-0000??01?0--0?---3??00-0-0-0??0
Asfaltomylos                ???????????????????????-??1-????????????11---3??00-0-0-00-0
Bishops                     ?????????????{01}??0??????-011-0011111110--11---3??00-0-0-00-0
Steropodon                  ???????????????????????-???-??????????????---??00-0-0-00-0
Teinolophos                 ???????????????????????-???-??????????????---??00-0-??00-0
Obdurodon                   -------1---1--55?3300110-???-0000100111?1?---34000-0-??00-1
Ornithorhynchus             -------1---1--76?4400??0---------------------44000-0-0-?0-1
Gobiconodon                 01--0000100010{123}{01}0{12}101131-202-0000101?00??0{12}---{12}{12}100-0-0-0100
Repenomamus                 01100000100010330330110l-002-000110?000--02---12100-0-0-0100
Yanoconodon                 ??-00?00000000540330???-???-?000?000???01---33000-0-0-0120
Jeholodens                  ???0000??????44033?????-???-?00011100???0?---23000-0-0-0120
Amphilestes                 ???0??????????1?01??????-001-000011100???0?---1??00-0-0-0100
Priacodon                   ??-00?000??000320220l101-001-010000210??01---22000-0-0-0120
Trioracodon                 ??????001000032011011?1-10?-010001110???0?---33000-0-0-0120
Tinodon                     ??????????0114?02??????-01?-0000111100--0?---3??00-0-0-0100
Akidolestes                 ???0000???????0000??????-11?-010011110???0?---0??00-0-0-0130
Spalacotherium              ??????????????0??2?????1-001-00001111????0?---00000-0-0-0130
Maotherium                  ?1000000100010{12}3?{24}{34}0010?-??1-?0001111?0?011---00000-0-0-0130
Zhangheotherium             ???0000????0101?03??????-???-?100???100--01---01000-0-0-0130
Amphitherium                ???0000????0010?00??????-00?-?0000001????11---0??00-0-0-00-0
Cronopio                    01-????0000????20?1??111-?11-0111??2100--01---33000?0-0-00-0
Henkelotherium              ??????0010???0001101111-001-00000011????11---00100-0-0-0130
Dryolestes                  ???00000010001000l4?1001-001-0100001l?0--11---00100-0-0-00-0
Peramus                     ???00?????????21011??111-001-0110001100--01---22?00-0-0-0100
Vincelestes                 000000000100015403300101-002-0100000100--11---33000-0-0-00-0
Kielantherium               ?????????????{12}?0???????-???-??????????????---2??00-0-0-0100
Sinodelphys                 0??000000000000?1?00?????-1??-??????????????---?3?00-0-0-0100
Pappotherium                ???????????????????????-???-??????????????---?3?00-0-0-0??0
Deltatheridium              ???10??000000032011?????-101-??????????????---33200-0-0-00-0
Asiatherium                 ???????000????32011?????-001-??????????????---33200-0-0-00-0
Kokopellia                  ???00??????0003?01??????-10?-??????????????---3?200-0-0-00-0
Pucadelphys                 ???10000000000032011?????-101-??????????????---33200-0-0-0100
Didelphis                   011100000000032022------001------------------33200-0-0-00-0
Juramaia                    ?11000000100002l?001011?-011-0?00100100???1---33?00-0-0-0??0
Eomaia                      01100?000000002100010??1-111-0000110100--01---33?00-0-0-0100
Prokennalestes              ??????????????2100010{12}10-01?-0000110100??0?---33200-0-0-0100
Asioryctes                  011000?001?01132011?1110-10?-0000110100??0?---33200-0-0-00-0
Zalambdalestes              ?11011{12}00100103201111l{01}0-111-0110012l?0--0?---33200-0-0-0120
Ukhaatherium                01?000000000003201100100-111-0000100100--??---33200-0-0-00-0
Gomphos                     11-01121---1--5303210101-?01-0111102100--01---33200-0-0-00-1
Tribosphenomys              ----1121---1--6404310211------0100021?0--01---33200-0-0000-{01}
Erinaceus                   011000001100104402310110-00?-0011110000--01---33200-0-0-00-0
Dasypus                     -------?????????0????101-0??-???1???00--0?---??010-0-0-00-?
Ferugliotherium_A           ???????????????????--????????????????????????????00-10100??-
Ferugliotherium_B           ???-112????????7?4??--???------202----00--011104??00-10100??-
Trapalcotherium             ???????????????????--????????????????????????????00-10100??-
Bharattherium               ????1??????????????--?????????????????????????????1111?101??-
Gondwanatherium             ???-11???????????5?--????-----------?-??-----???1111010 0??-
Lavanify                    ???????????????????--?????????????????????????????1111101??-
Sudamerica_A                ???-112????1--6?15?--????---------------------2??110111{01}00--
Sudamerica_B                ???-112????1--6?13?--????2-2101?1----00--02---4??110111{01}0??-
Tanzanian_taxon_A           ???-1?2????1--6?1??--????-----?????--?-??-????2??1?????????-
Tanzanian_taxon_B           ???-1?1????1--6????--?????-??0???----?-??-2???2??1?????????-
Greniodon                   ???????????????????--?????????????????????????????1110110??-
Vintana_A                   ??-????1---????4??4--231????????????????????????2?11110100??-
Vintana_B                   ??-????1---????4??2--100????????????????????????4?11110100??-
Guimarota_Paulchoffatiidae  000?10201011--4{23}{01}{12}{01}--10101-100102----01110100044100-0-0-00--
Plagiaulacidae              000-10?1-??1--{45}2?{12}0--00101-110202----01110100144100-0-0-00--
Ptilodus                    01?-10?1---1--63131--00131-211202----01000112144100-0-0-00--
Taeniolabis                 110-1121---1--76144--2211-----002----00--0110044100-0-0-00--
Lambdopsalis                ?11-1121---1--76144--2322-----0-2----00--0210044100-0-0-00--
Kryptobaatar                110-1121---1--63131--11111-211102----0???0011144100-0-0-00--
Catopsbaatar                110-1121---1--64132--23111-211002----01010110044100-0-0-00--
Chulsanbaatar               ?10-11?1---1--63131--22111-211002----01010110144{12}00-0-0-00--
Nemegtbaatar                110-11?1---1--63131--22111-211?02----01010110144100-0-0-00--
Thomasia                    00??10???????-?????--???0?-?????0----?0--0?0-0??100-0-0-00--
Haramiyavia                 011010????0003?01?--????10110000001000-0011-033200-0-0-00--
Arboroharamiya              ???-1021---1--75143--100?---?-100----0101010-044?00-0-0-00--
Rugosodon                   000-10101011--42?10--0?1?1-1?0?02----0???0?00044100-0-0-00--
Sinobaatar                  000-1011---1--52120--1{01}101-110202----01000?11144100-0-0-00--

Thrinaxodon                 ------------------------------------------------------------
Probainognathus             ------------------------------------------------------------
Exaeretodon                 ------------------------------------------------------------
Diademodon                  ------------------------------------------------------------
Cynognathus                 ------------------------------------------------------------
Oligokyphus                 --------------------------{01}-0-010101?-----------------------
Bienotherium                --------------------------0-0-010101?-----------------------
Kayentatherium              --------------------------0-0-01??01?-----------------------
Yunnanodon                  --------------------------????10101?-----------------------
Bocatherium                 --------------------------???????????-----------------------
Bienotheroides              --------------------------0-0-010101?-----------------------
Tritheledontids             ------------------------------------------------------------
Adelobasileus               ????????????????????????????????????????????????????????????
Sinoconodon                 000000?010??0---0--?0?--{01}00-0-011?--00----00{01}??00000-0-----0
Morganucodon                000000?010??0---0--?0?--00110-2110--00----000??00000-0-----0
Megazostrodon               000000?010??0---0--?0?--00100-2110--00----000??00000-0-----0
Haldanodon                  000001?110?????-0--?0?--00100-21??--00----000??00000-0-----0
Hadrocodium                 000000?010??0---0--?0?--000-0-?11?--00----??0??0??00-0-----?
Pseudotribos                011111111000?0---0--?0?2?00110-1?1?--00????000??0000101010000
Ambondro                    00?1110101101000101112{12}101110-01??--????????????????????????
Ausktribosphenos            000211110112101011111223001l0-011?--????????????????????????
Henosferus                  002111010110100001{01}011221110-0-011?--????????????????????????
Asfaltomylos                00?111?101121000101?1221110-0-011?--????????????????????????
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Bishops                     00011111011210101111122300110-011?--????????????????????????
Steropodon                  01121201011110110--?0223101011011?--????????????????????????
Teinolophos                 0{12}121201011110110--?0223001011011?--????????????????????????
Obdurodon                   00121211011110110--?0223101011021?--0?????000??001???10100?0
Ornithorhynchus             ----?21-011-0---0--?0-23??0-11?21?--0?????0001200120-10100?0
Gobiconodon                 ?01000?010??0---0--?0---010-0-1110--00----002??00000-0-----0
Repenomamus                 ?01000?0?0??0---0--?0---01????01??--?0----00???00000-0-----0
Yanoconodon                 00100??010??0---0--?0---100-0-0110--00----?????????0-0-----0
Jeholodens                  001000?010??0---0--?0---100-0-011?--00----??{02}??0000??0-----0
Amphilestes                 ?01000?010??0---0--?0---010-0-1110--0????????????????0-----?
Priacodon                   001000?010??0---0--?0---100-0-1110--10----000??0002??0-----0
Trioracodon                 001000?010??0---0--?0---{01}00-0-11??--10----000??0002??0-----0
Tinodon                     00111102000-0---0--00---01110-111?--00----0001201000-1110000
Akidolestes                 00?211?1000-0---0--00---000-0-1???--10----00???01000-100---0
Spalacotherium              001111?1000-0---0--00---000-0-111?--10----0011201000-100---0
Maotherium                  001111?1000-0---0--00---000-0-1???--10----0001201000-100---0
Zhangheotherium             001111?2000-0---0--000--00110-1110--??-?????????????????????
Amphitherium                00011101011011?00--00001100-0-0110--??-?????????????????????
Cronopio                    01021211000-0---0--00000100-0-00?0--00----001121---??1011020
Henkelotherium              00011211000-0---0--00000100-0-01??--00----001120100101010000
Dryolestes                  00011211000-0---0--00000100-0-0110--00----001120100101011110
Peramus                     {01}0211101011011000--00001010-0-0110--00----00{01}120000101010000
Vincelestes                 00111102011000?-0--01101100-0-01??--0100?0000??0000??1010000
Kielantherium               00211201011010000--11101{01}10-0-01?0--?100?0000110000101010000
Sinodelphys                 ?011?201?110110010?111?1010-0-011?--?1???1?????0001??1010???
Pappotherium                000111010?12????????????110-?-????--010020110120010101010000
Deltatheridium              002112010110110010011101100-0-0110--010{01}101100-0000101010000
Asiatherium                 100112110112110011111213101-1001??--011111110100010101010000
Kokopellia                  101111110112110011111203100-1001?0--010121110120010101010010
Pucadelphys                 1001121101121110111112{12}?010-10011?--0102101101200111110110{01}1
Didelphis                   100112110112111011111223110-0-0110--011210110120011111011011
Juramaia                    ?001?1???1??110?1???1???10-0-??1?--?10121100120000101010000
Eomaia                      00???1?10110110?11?11?13010-0-011?--01?1{01}01101200?01?10{01}0??0
Prokennalestes              000111010110110011111103010-0-011?--011111100120000101010000
Asioryctes                  010212110110110011011112110-0-011?--0111111000-0000101010010
Zalambdalestes              0102121101121 1{01}?11111223110-0-011?--011110110{01}2001210100---0
Ukhaatherium                ?0?????1?11?1???????1??3?10-0-?11?--0111211100-0000101010010
Gomphos                     ---2121-0110100011-11223100-0-01??--011?1011?0-01121-0-0---1
Tribosphenomys              -102121101101000111 0122?100-0-0110--?11{01}10110{01}{12}00120-0-0---0
Erinaceus                   0011121101121--011111223110-0-0110--01011101011001010110---0
Dasypus                     ????????????????????--????0-0-0110--0????-??????????????????
Ferugliotherium_A           --------------------------?-?-????--?-----------------------
Ferugliotherium_B           --------------------------?-?-????--?-----------------------
Trapalcotherium             --------------------------????????--?-----------------------
Bharattherium               --------------------------????????--?-----------------------
Gondwanatherium             --------------------------0-0-0010--?-----------------------
Lavanify                    --------------------------????????--?-----------------------
Sudamerica_A                --------------------------0-0-0010--?-----------------------
Sudamerica_B                --------------------------0-0-0010--?-----------------------
Tanzanian_taxon_A           --------------------------?????0??--?-----------------------
Tanzanian_taxon_B           --------------------------?????0??--?-----------------------
Greniodon                   --------------------------????????--?-----------------------
Vintana_A                   --------------------------????????--0-----------------------
Vintana_B                   --------------------------????????--0-----------------------
Guimarota_Paulchoffatiidae  --------------------------0-0-01?0100-----------------------
Plagiaulacidae              --------------------------0-0-01??0?0-----------------------
Ptilodus                    --------------------------0-0-0110420-----------------------
Taeniolabis                 --------------------------0-0-011?420-----------------------
Lambdopsalis                --------------------------0-0-01??320-----------------------
Kryptobaatar                --------------------------0-0-0??1{12}0-----------------------
Catopsbaatar                --------------------------0-0-01?0210-----------------------
Chulsanbaatar               --------------------------0-0-0???110-----------------------
Nemegtbaatar                --------------------------0-0-0???310-----------------------
Thomasia                    --------------------------0-0-0110220-----------------------
Haramiyavia                 --------------------------0-0-0110220-----------------------
Arboroharamiya              --------------------------0-0-0010420-----------------------
Rugosodon                   --------------------------0-0-0110200-----------------------
Sinobaatar                  --------------------------0-0-011?110-----------------------

Thrinaxodon                 --------------------0????0-------00??
Probainognathus             --------------------0??000-------00??
Exaeretodon                 --------------------0????4-------00?1
Diademodon                  --------------------0????4-------00?1
Cynognathus                 --------------------?????4-------00??
Oligokyphus                 ------00---3--01---00??044-------0100
Bienotherium                ------00---3--00---0????44-------0100
Kayentatherium              ------00---3--00---0????44-------0100
Yunnanodon                  ------00---3--00---0????44-------0100
Bocatherium                 ------00---?--00---0????44-------0100
Bienotheroides              ------00---3--00---0????44-------0100
Tritheledontids             --------------------100100-------01??
Adelobasileus               ?????????????????????????????????????
Sinoconodon                 0--0??01-??10?------110000000?-?-01??
Morganucodon                0--0??100??10?------110010000?-?-010?
Megazostrodon               0--0??100??10?------100120000?-?-011?
Haldanodon                  0--0??11-00211------0??010000?0?-010?
Hadrocodium                 ???0??0????10?------????200?0?-?-011?
Pseudotribos                0--01111-00?11------????21110?00-000?
Ambondro                    ??????????????------????311?11?0???0?
Ausktribosphenos            ??????????????------????3111??01?000?
Henosferus                  ??????????????------0??1311?1000?000?
Asfaltomylos                ??????????????------????311??000?000?
Bishops                     ??????????????------????311???01?000?
Steropodon                  ??????????????------????301?2100?000?
Teinolophos                 ??????????????------????301?2100?000?
Obdurodon                   0--000100??3??------221?3{02}1?2100-000?
Ornithorhynchus             0--000100??310------0????{02}??????-00??
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Gobiconodon                0--0??101??10?------110020010?-?-001?
Repenomamus                0--000101??10?------??????01??-?-001?
Yanoconodon                0--?0001-?????------????100?0?-?-001?
Jeholodens                 0--000001??10?------????200?0?-?-001?
Amphilestes                ???????????10?------????20010?-?-??1?
Priacodon                  0--000101??10?------110010000?-?-000?
Trioracodon                0--000101??10?------????10000?-?-000?
Tinodon                    11?000100??10?------????20110?-?-001?
Akidolestes                0--???1???????------????211?0?-0-001?
Spalacotherium             0--1111????10?------????21110?-0-001?
Maotherium                 0--011?00?????------????211?0?-0-001?
Zhangheotherium            ??????????????------????21110?-?-001?
Amphitherium               ??????????????------????3111100??0?1?
Cronopio                   11100001-??00-------??????1?????-001?
Henkelotherium             10100001-??210------100?21110?0?-001?
Dryolestes                 10100001-??210------100021110?0?-001?
Peramus                    111111100??110------????3111100?-001?
Vincelestes                0--00011-??211------100031111000-001?
Kielantherium              111111?1-00211------????31111010-000?
Sinodelphys                1???111???????------????31111010-000?
Pappotherium               1111?1?1-00211------????311?1010-??0?
Deltatheridium             01011011-00211------100031112010-000?
Asiatherium                11010111-11211------????31111010-000?
Kokopellia                 0--1?111-00211------????31111010-000?
Pucadelphys                1{01}010111-00211------????31112010-000?
Didelphis                  11010111-0?211------221131111110-000?
Juramaia                   1?0?1111-00211------????311?2010-000?
Eomaia                     0--?0111-001?1------????3?1120??-000?
Prokennalestes             11110111-00211------100031111010-000?
Asioryctes                 11111111-00211------????31111010-000?
Zalambdalestes             0--11111-00211------????3?112010-000?
Ukhaatherium               11011111-00211------????31111010-000?
Gomphos                    0--00001-01211------????311121100000?
Tribosphenomys             0--00011-00211------????3?112010??00?
Erinaceus                  0--00011-11211------221131111110-000?
Dasypus                    ??????01-0010-------????51?-----0000?
Ferugliotherium_A          ------??---?--------?02?44-------????
Ferugliotherium_B          ------???--?--------?02?44-------????
Trapalcotherium            ------???--?--------????5?------?????
Bharattherium              ------???--?--------?2115?------?????
Gondwanatherium            ------01---0--------100154------0????
Lavanify                   ------???--?--------?2115?------?????
Sudamerica_A               ------01---0--------100154------0????
Sudamerica_B               ------01---0--------100154------0????
Tanzanian_taxon_A          ------???--?--------????5?------?????
Tanzanian_taxon_B          ------???--?--------????5?------?????
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Vintana_A                  ------01-??3----0---221155------1????
Vintana_B                  ------01-??3----0---221155------1????
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Plagiaulacidae             ------01---1--0010110???44-------1000
Ptilodus                   ------01---1--201110210?44-------1000
Taeniolabis                ------01---3--221210110?44-------1000
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Chulsanbaatar              ------01---1--1011011???44-------1000
Nemegtbaatar               ------01---1--201211????44-------1000
Thomasia                   ------11---2--?10--1????43-------??11
Haramiyavia                ------11---3--010--1????43-------0111
Arboroharamiya             ------?1---3--010--1????43-------0100
Rugosodon                  ------01---1--110--1????44-------1000
Sinobaatar                 ------01---1--{01}01101????44-------1000
              ;
End;
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