

Justification for Fossil Calibrations

For nodes without a maximum justification, the maximum is constrained to be the 6% quantile of the fitted density in an ancestral node. This is done to avoid truncation artefacts between fossil calibration and fitted densities (ST and SN). Calibrations integrate geochronological updates as of September 2021.

Sort ID	Crown group	Dating step	Min (Ma)	Max (Ma)	Justification
1	Mammalia	1	164.1	252.2	<p>Node Calibrated. Divergence of monotremes, marsupials, and placentals, following Tarver et al. ¹.</p> <p>Fossil taxon and specimen. Bathonian australosphenidans such as <i>Ambondro mahabo</i> (UA 10602 University of Antananarivo, Madagascar; Flynn et al. ²).</p> <p>Phylogenetic justification. Puttick et al. ³ compared application of the Mk model in MrBayes to implied and equal-weights parsimony, and supported the interpretation of Jenkins et al. ⁴ and Luo et al. ⁵ that Triassic haramiyids fall outside of crown Mammalia.</p> <p>Minimum Age. 164.1 Ma.</p> <p>Maximum Age. 252.2 Ma.</p> <p>Age Justification. <i>Ambondro</i> comes from the upper part of the Isalo "Group" (middle Jurassic, Bathonian) of Madagascar ²), dated as generally Bathonian, so we select the top of the Bathonian as the hard minimum calibration date, 165.3 Ma \pm 1.1 Myr, or 164.1 Ma ⁶. Following Tarver et al. ¹ we revise our maximum calibration to allow for the possibility that the monotreme stem lineage really does extend into the upper Triassic ^{7,8}. Specifically, the soft maximum is set at the Permian-Triassic boundary, dated at the base of the Induan, 251.9 Ma \pm 0.3 Myr ⁹ or 252.2 Ma.</p> <p>Discussion. Our calibration for this node contrasts to suggestions (e.g., ^{7,8,10}) that Triassic <i>Thomasia</i> and <i>Haramiyavia</i> are closely related to multituberculates and monotremes, which, in turn, implies membership of these Triassic species within crown Mammalia. We follow Luo et al. ⁵, Benton et al. ¹¹, Puttick et al. ³ and Huttenlocker et al. ¹² in excluding haramiyids from crown Mammalia and in using <i>Ambondro</i> for the minimum calibration.</p>

2	Theria	1	121.56	169.4	<p>Node calibrated. Divergence of marsupial and placental mammals.</p> <p>Fossil taxon and specimen. <i>Sinodelphys szalayii</i>.</p> <p>Phylogenetic justification. Resolved on stem to Placentalia, within Theria, by Bi et al. 2018 ¹³.</p> <p>Minimum age. 121.56 Ma.</p> <p>Maximum age. 169.4 Ma.</p> <p>Age justification. Fossils from the Jehol biota of northeast China come from Barremian to Aptian-age deposits, although there is some ambiguity about their age ¹⁴. Here we take the youngest age estimate from tuffs overlying the main fossil-bearing layers, dated to 121.96 Ma \pm 0.5 Myr ¹⁵, thus 121.56 Ma. We conservatively use the age of the Barremian to define the ages of Jehol specimens, which has an upper margin of 125.0 Ma. Given the possibility that southern, tribosphenic mammals such as <i>Ambondro</i> are therian (cf. ¹⁶), we set the soft maximum age for Theria in the Bathonian, 168.2 Ma \pm 1.2 Myr so 169.4 Ma ⁶.</p> <p>Discussion. Luo et al. ¹⁷ hypothesized that <i>Juramaia sinensis</i> from the late Jurassic was the geologically oldest therian mammal, more closely related to crown placentals than to other mammals and therefore eutherian (see also Bi et al. ¹³). Some subsequent analyses have corroborated this result ^{5,8}, but others have not, placing <i>Juramaia</i> instead on the stem to Theria (e.g., ¹⁰). Other candidates for the oldest crown therians include <i>Sinodelphys</i> ¹⁸ and <i>Eomaia</i> ¹⁹ originally argued to be on the stems to Marsupialia and Placentalia, respectively. Again, <i>Eomaia</i> in more recent studies has been placed on the therian stem ^{10,20}, and <i>Sinodelphys</i> appears more consistently on the stem leading to either Placentalia ¹³ or Marsupialia ^{5,8,21}. Krause et al. ¹⁰ reconstruct <i>Sinodelphys</i> as a metatherian in at least their Bayesian topologies (their figs. S2, S4), although not with MP (their figs. S1, S3) or in Krause et al. ²². Overall, <i>Sinodelphys</i> enjoys better support as a crown therian ¹² than other taxa and we thus use it as a minimum constraint for Theria.</p>
3	Placentalia	1	61.66	162.5	<p>Node calibrated. The human-tenrec split is equivalent to the origin of the clade comprising Boreoeutheria (Laurasiatheria and Euarchontoglires) and Atlantogenata (Xenarthra and Afrotheria). Following Benton et al. ¹¹ but with the geochronology revised following ²³ and ⁶.</p>
4	Euarchontoglires	1	61.66	162.5	<p>Node calibrated. Euarchontoglires is composed of two clades, the Archonta and the Glires. Primates belong to the former, Rodentia to the latter, the common ancestor of which corresponds to the origin of Euarchontoglires. Following Benton et al. ¹¹ but with the geochronology revised following ²³ and ⁶.</p>

5	Primates	1	56	66.09	Node calibrated. Crown-group Primates, or Euprimates, encompass living forms plus the extinct adapoids and omomyoids; the latter are more closely related to extant lemuriforms than to anthropoids ²⁴⁻²⁶ . Following Benton et al. ¹¹ with the exception that the soft-maximum constraint, defined as the base of the Paleocene, is revised to 66.04 Ma \pm 0.05 Myr ²⁷ , so 66.09 Ma.
6	Anthropoidea	1	33.9	66.09	Node calibrated. Last common ancestor of platyrrhine and catarrhine primates. Following Benton et al. ¹¹ with the exception that the soft-maximum constraint, defined as the base of the Paleocene, is revised to 66.04 Ma \pm 0.05 Myr ²⁷ , so 66.09 Ma.
7	Catarrhini	1	24.44	33.9	Node calibrated. The common ancestor of Old World monkeys (Cercopithecoidea) and apes (Hominoidea), which together form crown Catarrhini. Following Benton et al. ¹¹ with the exception that the soft-maximum constraint, defined on the base of the Oligocene, is dated to 33.9 Ma ²³ .
8	Hominidae	1	11.65	33.9	Node calibrated. Last common ancestor of great apes, including human, chimp, gorilla, and orangutan. Following Benton et al. ¹¹ with the exception that the minimum age constraint is revised The Chinji Formation of Pakistan corresponds to magnetic polarity chron 5Ar, estimated to be ca. 12 Ma before present ²⁸ . This correlates to the Serravallian stage, the top of which is dated to 11.65 Ma ²⁹ .
9	Homininae	1	5.33	33.9	<p>Node calibrated. Divergence of the human-chimp lineage from that of gorillas.</p> <p>Fossil taxon and specimen. <i>Chororapithecus abyssinicus</i> CHO-BT 4 from the Beticha locality, Chorora Fm, Ethiopia.</p> <p>Phylogenetic justification. Suwa et al. ³⁰ identify shared, derived characters of their dental fossils with the lineage of <i>Gorilla</i>.</p> <p>Minimum age. 5.33 Ma.</p> <p>Maximum age. 33.9 Ma.</p> <p>Age justification. Katoh et al. ³¹ revised the geological context of this find, and concluded that it is not middle Miocene as originally reported, but upper Miocene, between 7-9 Ma in age, overlapping with the Tortonian and Messinian. The latter has an upper bound of 5.33 Ma ²⁹. The soft maximum is as for catarrhines, above.</p> <p>Discussion. The fossil lineage of habitually bipedal hominins is much better than that for great apes, and also has an oldest occurrence in the late Miocene (e.g., Brunet et al. ³²). No hominin fossils are known from deposits correlating with a marine stage older than the Messinian.</p>
10	Hominini	1	6.5	10	Node calibrated. Chimpanzee-human. Following Benton et

					al. ¹¹ .
11	Cercopithecinae	1	5.33	33.9	<p>Node calibrated. Divergence of vervet monkeys (<i>Chlorocebus</i>) from baboons and macaques (<i>Macaca</i> and <i>Papio</i>).</p> <p>Fossil taxon and specimen. <i>Macaca libyca</i>, YPM 21551 (Benefit et al. ³³: fig. 2) from Wadi Natrun, Egypt.</p> <p>Phylogenetic justification. Referred to the same genus as the living macaque by Benefit et al. ³³.</p> <p>Minimum age. 5.33 Ma.</p> <p>Maximum age. 33.9 Ma.</p> <p>Age justification. Cercopithecine fossils are known from As-Sahabi (Libya), Menacer (Algeria), Wadi Natrun (Egypt), and Toros-Menalla (Chad). All are late Miocene in age and overlap with the Messinian, with an upper bound of 5.33 Ma ²⁹. The soft maximum date is as for Catarrhini, above.</p> <p>Discussion. Cercopithecine fossils have been reported from the late Miocene of Europe ³⁴ and North Africa ³³. Following Raaijmakers et al. (³⁵: fig. 3), the record of <i>Macaca</i> is slightly older than that of baboons, but Benefit et al. ³³ summarize fossils of both lineages from North Africa. The lineage of vervet monkeys appears to be limited to the Plio-Pleistocene.</p>
12	Papionini	1	5.33	33.9	<p>Node calibrated. Divergence of baboons (e.g., <i>Papio</i>) from macaques (<i>Macaca</i>).</p> <p>Fossil taxon and specimen. <i>Macaca libyca</i>, YPM 21551 (Benefit et al. ³³: fig. 2) from Wadi Natrun, Egypt.</p> <p>Phylogenetic justification. As for cercopithecines, above.</p> <p>Minimum age. 5.33 Ma.</p> <p>Soft maximum age. 33.9 Ma.</p> <p>Age justification. As for catarrhines.</p>
13	Strepsirhini	1	33.9	66.09	<p>Node calibrated. The crown clade comprising lemurs, lorises, galagos, and other extant primates that possess a toothcomb ³⁶. Following Benton et al. ¹¹ with the exception that we use the base of the Paleocene as the soft maximum, as for Primates, above.</p>
14	Glires	1	56	162.5	<p>Node calibrated. The last common ancestor of Rodentia and Lagomorpha. Following Benton et al. ¹¹ with the exception that the soft-maximum constraint, defined as the base of the Oxfordian, is revised to 161.5 Ma \pm 1.0 Myr ⁶, so 162.5 Ma.</p>

15	Rodentia	1	56	66.09	<p>Node calibrated. The common ancestor of the three major extant rodent clades: Muroidea (mouse-related), Sciuromorpha (squirrel-related), and Ctenohystrica (guinea-pig related). Following Benton et al.¹¹ with the exception that the soft maximum constraint, defined on the base of the Paleocene, is revised to 66.04 Ma \pm 0.05 Myr²⁷, so 66.09 Ma.</p>
16	Nonsquirrel rodentia	1	48.07	59.24	<p>Node calibrated. The divergence of Myomorpha+ Ctenohystrica to the exclusion of Sciuromorpha (Fabre et al.^{37, 38}; high-level taxa defined in Asher et al.³⁸). We acknowledge that there is uncertainty regarding the initial divergence within Rodentia (cf. Myomorpha reconstructed as sister to Ctenohystrica-Sciuromorpha in Swanson et al.³⁹).</p> <p>Fossil taxon and specimen. Chapattimyidae such as <i>Birbalomys sondaari</i> (Geological Survey of Pakistan, Howard University Collection, H-GSP 92161 of Thewissen et al.⁴⁰) from the Kuldana Formation of the Ganda Kas area, Pakistan.</p> <p>Phylogenetic justification. Phylogenetic analysis by Marivaux et al.⁴¹ placed Eocene chapattimyids within the Ctenohystrica, close to hystricognaths and to the exclusion of diatomyids. They are therefore nested within the unnamed crown clade comprising Myomorpha and Ctenohystrica.</p> <p>Minimum age. 48.07 Ma.</p> <p>Maximum age. 59.24 Ma.</p> <p>Age justification. The Kuldana Formation of Pakistan has been dated as early–middle Eocene, and ages may differ in different regions of northern India, and mammals occur in different horizons. <i>Birbalomys</i> is noted as occurring at 51 Ma by Marivaux et al.^(41, p. 132), thus well within the Ypresian. Hence, we assign a minimum constraint for rodents excluding Sciuromorpha at the top of the Ypresian marine stage, hence 48.07 Ma²³. The soft maximum constraint might be taken as equivalent to the age of <i>Paramys</i> and <i>Franimys</i> from the late Paleocene (base of the Thanetian) of North America and Europe, 59.24 Ma²³.</p> <p>Discussion. Fossils associated with the mouse-related stem group are younger, including Eocene dipodids such as <i>Ulkenulastomys</i>, <i>Blentosomys</i>, and <i>Aksyiromys</i> from the Obayla Svita of the Zaysan Basin, Kazakhstan⁴². Lucas⁴³ assigned a younger, Irđinmanhan age to this site based on biostratigraphic comparisons, changing its previous stratigraphic interpretation from early Eocene to the base of the middle Eocene.</p>

17	Dipodidae-Muroidea	1	41.03	59.24	<p>Node calibrated. Divergence of dipodid from muroid(i.e., within the mouse-related clade) rodents.</p> <p>Fossil taxon and specimen. <i>Aksyiromys dalos</i>, IZ-NAS-RK 34/181 (Emry et al. ⁴⁴: fig. 3A).</p> <p>Phylogenetic justification. Following Fabre et al. ³⁷ and Asher et al. ³⁸, dipodids (jerboas, birch mice, et al.) comprise the sister taxon to Muroids. Marivaux et al. ⁴¹ reconstruct <i>Aksyiromys</i> as sister taxon to fossil dipodids (e.g., <i>Primisminthus</i>) and cricetids (e.g., <i>Pappocricetodon</i>), the latter a putative member of Muroidea.</p> <p>Minimum age. 41.03 Ma.</p> <p>Maximum age. 59.24 Ma.</p> <p>Age justification. Lucas ⁴³ and Emry ⁴⁵ note that the age of the fossils described by Shevyreva ⁴² is within the Irdinmanhan ALMA, as are their fossils from the Shinzaly fauna of eastern Kazakhstan ⁴⁴. The marine equivalent is likely the Lutetian, with an upper bound of 41.03 Ma ²³. The soft maximum is as for rodents minus the squirrel related clade, above.</p> <p>Discussion. Shevyreva ⁴² described <i>Aksyiromys</i>, <i>Ulkenulastomys</i>, and "<i>Blentosomys</i>" from middle Eocene deposits of Kazakhstan. dos Reis et al. ⁴⁶ used <i>Ulkenulastomys</i> as a minimum calibration point for this clade. Emry et al. ⁴⁴ described <i>Aksyiromys</i> as a zapodine dipodid rodent from the Shinzaly fauna of eastern Kazakhstan, equivalent in age to Obayla Svita, Zaysan Basin, Kazakhstan, where Shevyreva ⁴² first described <i>Aksyiromys</i>. Emry ⁴⁵ noted that <i>Blentosomys</i> is likely a junior synonym of <i>Aksyiromys</i>. Because their description is more accessible in the literature than that of Shevyreva ⁴², and because of their publication of good quality figures with associated specimen numbers, we base our minimum calibration on <i>Aksyiromys</i> as described by Emry et al. ⁴⁴, rather than other fossil dipodids of the same age.</p>
18	Murinae	1	7.25	15.99	<p>Node calibrated. Divergence of <i>Mus</i> from <i>Rattus</i>. Following Benton et al. ¹¹; note that their summary age constraints did not match their justification - we follow their justification and revise the age constraints following ²⁹.</p>
19	Lagomorpha	1	48.07	66.09	<p>Node calibrated. The common ancestor of leporids (rabbits and hares) and ochotonids (pikas). Following Benton et al. ¹¹ but with the geochronology revised following ²³.</p>

20	Euungulata	1	50.7	66.09	<p>Node calibrated. Common ancestor of Perissodactyla and Artiodactyla. Following calibration for crown-Artiodactyla in Benton et al. ¹¹ but with the geochronology revised following ²³.</p> <p>Discussion. dos Reis et al. ⁴⁶ took <i>Lambdaotherium</i> as the basis for a 62.5 Ma minimum date for perissodactyls, based on Benton et al. ⁴⁷. However, the 62.5 Ma date from Benton et al. ⁴⁷ derived from a topology ("Zooamata", or Carnivora-Perissodactyla) that is no longer supported by larger datasets (¹: figs S1, S3) and which was based on a carnivoran calibration: <i>Proticis</i> (Torrejonian NALMA). Instead, the 21.4 gigabase alignment of Tarver et al. (¹: fig. S1) supports an artiodactyl-perissodactyl clade, or Euungulata. Two Paleocene genera often associated with perissodactyls are worth mention: <i>Radinskya</i> and <i>Lambdaotherium</i> as possible minimum calibration points. Neither Holbrook ⁴⁸ nor Rose et al. ⁴⁹ unequivocally support <i>Radinskya</i> in a close sister-taxon relationship with perissodactyls. Rose et al. ⁴⁹ does support <i>Lambdaotherium</i> within tapiromorphs; Beard ⁵⁰ emphasizes its affinities to perissodactyls, but the description of a Gashatan ALMA (Thanetian) specimen by Meng et al. (⁵¹: 176) is more circumspect: "other than its possible perissodactyl affinities, the fragmentary material precludes definitive taxonomic placement." There are many records of slightly younger, early Eocene perissodactyls (e.g., <i>Homogalax</i>, <i>Hyracotherium</i>) and among the best material is <i>Cambaytherium</i> from the Cambay Shale, India (ca. 54.5 Ma ⁴⁹). These correlate with the Ypresian, the top of which is 47.8Ma. The record of archaeocete whales (<i>Himalayacetus</i>, described below) is likely younger in absolute terms, but is found in deposits with intercalated marine deposits (NP zones 11-12, 52.4 Ma), and thus can be correlated with the marine record at an older age than early Eocene Asian and North American records of perissodactyls.</p>
21	Artiodactyla	1	50.7	66.09	<p>Node calibrated. Common ancestor of ruminants, tylopods, and "Suiformes", including the now well-established hippo-whale clade. Following Benton et al. ¹¹ but with the geochronology revised following ²³.</p>
22	Cetruminantia	1	50.7	66.09	<p>Node calibrated. Divergence of the common ancestor of ruminants and cetaceans, excluding suids and tylopods. Following the calibration for Whippomorpha-Ruminantia in Benton et al. ¹¹ but with the geochronology revised following ²³.</p>
23	Bovidae	1	15.99	27.29	<p>Node calibrated. The branching between the cow (<i>Bos</i>) and sheep (<i>Ovis</i>) is an intrafamilial split within the Family Bovidae. <i>Bos</i> is a member of the Tribe Bovini, and <i>Ovis</i> is a member of the Tribe Caprini, which belong respectively to the subfamilies Bovinae and Antilopinae ⁵². Following the calibration for Bovinae-Antilopinae in Benton et al. ¹¹ but with the geochronology revised following ²⁹.</p>
24	Carnivora	1	37.71	66.09	<p>Node calibrated. Common ancestor of Caniformia (dogs, bears, raccoons, seals) and Feliformia (cats, mongooses, hyaenas), excluding stem carnivoramorphans sensu Wesley Hunt and Flynn ⁵³. Following Benton et al. ¹¹ but</p>

					with the geochronology revised following ²³ .
25	Caniformia	1	37.71	66.09	<p>Node calibrated. Divergence of canids (dogs) and arctoids (musteloids, ursids, pinnipeds).</p> <p>Fossil taxon and specimen. <i>Hesperocyon gregarius</i> (SMNH P1899.6; ⁵⁴) from the Cypress Hills Formation, Duchesnian NALMA, Lac Pelletier local fauna, Saskatchewan.</p> <p>Phylogenetic justification. As for Carnivora.</p> <p>Minimum age. 37.71 Ma.</p> <p>Maximum age. 66.09 Ma.</p> <p>Age justification. As for Carnivora.</p>
26	Chiroptera	1	48.07	66.09	<p>Node calibrated. Divergence of Yinpterochiroptera and Yangochiroptera.</p> <p>Fossil taxon and specimen. <i>Eppsinocyteris anglica</i> ⁵⁵, BMNH M13776 from the Lessness Shell Bed, Blackheath Beds, Abbey Wood, Ypresian.</p> <p>Phylogenetic justification. As summarized by Eiting & Gunnell ⁵⁶, the stem lineage of chiropterans extends to the basal Eocene of Europe ⁵⁷, Australia ⁵⁸. <i>Eppsinocyteris</i> from the early Eocene of the UK may be related to emballonurids ⁵⁵; <i>Honrovits</i> from the early Eocene of Wyoming may be related to natalids ⁵⁹; <i>Witwatia</i> and <i>Dizzya</i> from the early Eocene of Tunisia may be vespertilionoids ^{60,61}. We choose <i>Eppsinocyteris</i> as the minimum constraint as it is represented by a well preserved jaw ⁵⁵.</p> <p>Minimum age. 48.07 Ma.</p> <p>Maximum age. 66.09 Ma.</p> <p>Age justification. The three oldest records for modern bat groups cited above all correspond to the Ypresian in age, which has an upper bound of 48.07 Ma ²³. The absence of any chiropterans during the Paleocene may point to a soft maximum constraint at the base of the Danian, 66.04 Ma \pm 0.05 Myr ²³, so 66.09 Ma.</p> <p>Discussion. Smith et al. ⁶² estimate that the earliest records of modern families are middle Eocene, and we agree that the evidence in the above cases is uncertain. Nonetheless, the presence of multiple identifications of modern groups in the early Eocene, as noted above, implies that crown Chiroptera existed at this time.</p>
27	Lipotyphla	1	61.66	162.5	<p>Node calibrated. common ancestor of modern soricids, talpids, erinaceids, and <i>Solenodon</i>. Following the calibration for crown-Lipotyphla in Benton et al. ¹¹ but with the geochronology revised following ²³ and ⁶.</p>

28	Xenarthra	1	48.07	162.5	Node calibrated. Divergence of cingulates (armadillos) from Pilosa (i.e., sloths and anteaters). Following Benton et al. ¹¹ but with the geochronology revised following ²³ and ⁶ .
29	Afrotheria	1	56	162.5	Node calibrated. Last common ancestor of proboscideans and tenrecids (i.e., all extant afrotheres). Following Benton et al. ¹¹ but with the geochronology revised following ²³ and ⁶ .
30	Paenungulata	1	56	162.5	<p>Node calibrated. Common ancestor of <i>Loxodonta</i> and <i>Procavia</i>.</p> <p>Fossil taxon and specimen. The extinct proboscidean <i>Eritherium azzouzor</i> (MNHN PM69, Paris) from the Sidi Chennane quarries, phosphate bed IIa, lower bone-bed, Ouled Abdoun Basin of Morocco, regarded as upper Paleocene (early Thanetian ⁶³).</p> <p>Phylogenetic justification. See Afrotheria.</p> <p>Minimum age. 56 Ma.</p> <p>Soft maximum age. 162.5 Ma.</p> <p>Age justification. See Afrotheria.</p> <p>Discussion. The topology within paenungulates is less certain than most other inter-ordinal branches among mammals. Several recent studies support a proboscidean-hyrax clade to the exclusion of sirenians ^{64,65}; others support a proboscidean-sirenian clade to the exclusion of hyracoids ^{66,67}. Either way, the fossil record of Proboscidea remains the oldest, well-documented fossil lineage in Afrotheria.</p>
31	Marsupialia	1	48.07	127.2	Node calibrated. Divergence of crown marsupials. Following Benton et al. ¹¹ but with the geochronology revised following ²³ and ²⁷ .

32	Eometatheria	1	23.04	56	<p>Node calibrated. Divergence of dasyuromorphs (e.g., <i>Sarcophilus</i>) and diprotodonts (e.g., <i>Macropus</i>), i.e., the origin of crown Australasian australidelphians.</p> <p>Fossil taxon and specimen. <i>Perikoala robustus</i>, SAM P26552 from Turtle Quarry, Etadunna Fm., west side of Lake Palankarinna, South Australia ⁶⁸.</p> <p>Phylogenetic justification. Black et al. ⁶⁹ reconstruct <i>Perikoala</i> closer to <i>Phascolarctos</i> than <i>Vombatus</i> (but did not test its affinities widely throughout marsupials). Combined with the identification by Wooburne et al. ⁶⁸ of features diagnostic of vombatiforms, we accept their identification of this taxon within Diprotodontia.</p> <p>Minimum age. 23.04 Ma.</p> <p>Maximum age. 56.0 Ma.</p> <p>Age justification. Woodburne et al. ⁷⁰, as summarized in Mitchell et al. ⁷¹, noted the presence of crown diprotodonts including likely pseudocheirids and phascolarctods from Zone A of the Etadunna Fm. Megirian et al. ⁷² assign an age of 24.9-25.3 Ma, equivalent to the Chattian, the top of which is 23.04 Ma ²³. Following Mitchell et al. ⁷¹, no crown australidelphian lineages are evident at Murgon (early Eocene, = Tingamarra local fauna), which samples the early Eocene at ca. 55Ma, justifying a soft maximum defined by the base of the Ypresian at 56.0 Ma ²³.</p> <p>Discussion. Other crown australidelphians from Riversleigh could also serve as the minimum, including a potorine ("<i>Kyeema mahoneyi</i>") and a pseudocheirid from the Etadunna Faunal Zone "A" ^{73,74}. The term Eometatheria dates to Simpson ⁷⁵, who used it as we do, to encapsulate Australasian marsupials. The term was subsequently used by Kirsch ⁷⁶ and Asher et al. ⁷⁷ to imply Australasian marsupials excluding peramelians, based on the now overturned idea ^{71,78,79} that peramelians are the basal-most australidelphians. Given this somewhat complicated history, Beck ⁷⁹ and Mitchell et al. ⁷¹ used the taxon "Eomarsupialia" for this clade (australidelphians excluding <i>Dromiciops</i>) instead. Arguably, however, the importance of precedent and minimizing the introduction of novel taxa would favor retaining older terms that have been used to delineate broadly similar (and in the case of Simpson ⁷⁵ identical) groups ⁸⁰. Although the content of Eometatheria has changed over time, this is also true of other high-level taxa (e.g., Primates, Dinosauria); we therefore prefer Eometatheria over alternatives to indicate the crown clade of Australasian australidelphian marsupials.</p>
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33	Cingulata	2	34.85	56.0	<p>Node calibrated. Common ancestor of dasypodids and other cingulates.</p> <p>Fossil taxon and specimen. Dasypodid petrosal (PVL 6245) from the middle Member of the Geste Formation, Antofagasta de la Sierra, Catamarca Province, Argentina Babot et al. ⁸¹.</p> <p>Phylogenetic justification. Ciancio et al. ⁸² discuss <i>Prostegotherium</i> with dermal remains from the Vacan (early Casamayoran) as a member of Dasypodinae, but this ID as a crown cingulate is I think not yet bolstered by a phylogenetic analysis. Babot et al. ⁸¹ do undertake a phylogenetic analysis and place a petrosal from the slightly younger Barrancan (late Casamayoran) Geste Fm closer to Dasypus than other cingulate genera.</p> <p>Minimum age. 34.85 Ma.</p> <p>Soft maximum. Age: 56.0 Ma.</p> <p>Age justification. The Geste Formation is conventionally interpreted as late Eocene (Barrancan subage of Casamayoran South American Land Mammal Age; SALMA ⁸¹); however, this age interpretation is not clearly established ⁸¹. Detrital zircons from Geste Formation establish a 37 Ma maximum age interpretation and a bracket of 37.3 Ma \pm 1.5 Myr to 35.4 Ma \pm 0.55 Myr ⁸³.</p> <p>The soft maximum is established on the Eocene (Itaboraian) of Itaborai, Brasil ⁸⁴ based on presence of xenarthrans but absence of any undisputed crown taxa. Also relevant is absence of any xenarthra from localities older than Itaborai (e.g., Paleocene Tiupampa; see Woodburne et al. ⁸⁴: table 1). Woodburne et al. ⁸⁴ and Speijer et al. ²³ consider the Itaboraian SALMA to be Ypresian, its base equating to 56.0 Ma ²³.</p>
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34	Chlamyphoridae	2	33.9	56.0	<p>Node calibrated. Common ancestor of tolpeutines-chlamyphorines and euphractines.</p> <p>Fossil taxon and specimen. <i>Glyptatelus</i>, e.g., scutes assigned to <i>G. fractus</i> including MACN 10949⁸⁵. Following McKenna et al. (⁸⁶: fig. 1), the jaw fragment AMNH 29483 is not <i>Glyptatelus</i> but likely the folivoran <i>Pseudoglyptodon</i> (see below).</p> <p>Phylogenetic justification. <i>Riostegotherium</i> is not convincingly a dasypodine but it is more conservatively regarded as a stem cingulate. Delsuc et al.⁸⁷ reconstruct glyptodonts within crown cingulates, closer to tolpeutines-chlamyphorines than to dasypodines or euphractines. <i>Pseudoglyptodon</i> from the Abanico Fm of Chile⁸⁶ is likely a stem folivoran (see below), but this is still younger (Tingurrician) than Mustersan fossils like <i>Glyptatelus</i>. McKenna et al.⁸⁶ assigned a jaw fragment Simpson thought was <i>Glyptatelus</i> (cingulate, AMNH 29483) to <i>Pseudoglyptodon</i> (folivoran) so affinities of that specimen remain ambiguous (although the part-skull assigned to <i>Pseudoglyptodon</i> by McKenna et al.⁸⁶ does appear to be a stem folivoran). Hence, Mustersan dermal scutes and fossil teeth are the oldest indicators of glyptodonts and therefore non-dasypodid cingulates.</p> <p>Minimum age. 33.9 Ma.</p> <p>Soft maximum age. 56.0 Ma.</p> <p>Age justification. Eocene (Mustersan SALMA), Musters Fm, Patagonia^{85,87}. The 2012 Geologic Timescale interprets the Mustersan SALMA to straddle Bartonian-Priabonian boundary, with a minimum age c. 33.9 Ma²³. The soft maximum constraint follows that of Cingulata.</p>
35	Pilosa	2	31.17	56	<p>Node calibrated. Common ancestor of folivorans (sloths) and vermilinguans (anteaters).</p> <p>Fossil taxon and specimen. <i>Pseudoglyptodon chilensis</i>, SGO PV 2995 (⁸⁶: fig. 3).</p> <p>Phylogenetic justification. Folivoran ID of <i>Pseudoglyptodon</i> from McKenna et al.⁸⁶ is supported by Slater et al.⁸⁸ and Gaudin and Croft⁸⁹.</p> <p>Minimum age. 31.17 Ma.</p> <p>Maximum age. 56.0 Ma.</p> <p>Age justification. <i>Pseudoglyptodon chilensis</i> was recovered from volcanoclastic strata within the Abanico Fm., Chile, and is considered early Oligocene in age as it forms part of the Tinguirirican fauna and its associated South American Land Mammal Age (SALMA)⁸⁶. The minimum age constraint is established based on Ar40/Ar39 dating from within the Tinguirirican SALMA stratotype, the youngest range being 31.34 Ma \pm 0.17 Myr⁹⁰, providing a minimum constraint of 31.17 Ma. The soft maximum constraint follows that of Cingulata.</p>

36	Folivora	2	15.99	56	<p>Node calibrated. Common ancestor of megalonychid sloths (including <i>Choloepus</i>) and <i>Bradypus</i>.</p> <p>Fossil taxon and specimen. <i>Imagocnus zazaе</i>, holotype MNHNH P 3014 (MacPhee & Iturralde-Vinent ⁹¹: fig. 1).</p> <p>Phylogenetic justification. <i>Octodontotherium</i> and <i>Desadognathus</i> from Salla (Bolivia) may be stem folivorans rather than <i>Choloepus</i> sister taxa (following discussion in Slater et al. ⁸⁸). Pujos et al. (⁹²: fig. 5) show a consensus tree with <i>Octodontotherium</i> closer to <i>Choloepus</i> than <i>Bradypus</i>, but this was not an original phylogenetic analysis (and neither <i>Octodontotherium</i> nor <i>Desadognathus</i> are mentioned by Gaudin and Croft ⁸⁹). Thus, we interpret <i>Imagocnus</i> as the oldest definitive crown folivoran.</p> <p>Minimum age. 15.99 Ma.</p> <p>Maximum age. 56.0 Ma.</p> <p>Age justification. The holotype of <i>Imagocnus zazaе</i> was recovered from the Lagunitas Fm., Domo de Zaza, Cuba ⁹¹. As a majority of the remains recovered were found in float that cannot be constrained stratigraphically, the minimum constraint is based on the age of the Formation, believed to be Burdigalian (Miocene) based on foraminifera indicative of the Miogypsina-Soritiidae zone (<i>Miopypsinia antillea</i>, <i>Heterostegina antillea</i>, and <i>Sorites marginalis</i>) ⁹³. MacPhee et al. ⁹³ also attempted to date 4 shelly horizons using Sr87/Sr86 analysis but decided the results were inconsistent as stratigraphically older horizons produced younger dates than the youngest horizons. The minimum age is thus the Upper Burdigalian-Lower Langhian boundary, dated at 15.97 Ma ²⁹.</p> <p>The soft maximum constraint follows that of Cingulata.</p>
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37	Vermilingua	2	17.36	56	<p>Node calibrated. Common ancestor of <i>Cyclopes</i> and myrmecophagines (<i>Myrmecophaga-Tamandua</i>).</p> <p>Fossil taxon and specimen. <i>Protamandua rothi</i> from the Santacrucian of Argentina, represented by a partial skull (YPM-VPPU 15267) and postcrania (e.g., astragalus MACN-A 10901b and calcaneus MACN-A 11530; see Bargo et al. ⁹⁴; fig. 13.2).</p> <p>Phylogenetic justification. Following Gaudin & Bramhan (⁹⁵; fig. 1) and Bargo et al. (⁹⁴; fig. 13.1), <i>Protamandua</i> comprises the sister taxon of myrmecophagines (extant <i>Myrmecophaga</i> and <i>Tamandua</i>) to the exclusion of <i>Cyclopes</i>. Skeletal elements now recognized as <i>Protamandua</i> were first assigned by Ameghino ⁹⁶ to multiple species but later recognized as a single species (and perhaps individual) by Hirschfeld ⁹⁷.</p> <p>Minimum age. 17.36 Ma.</p> <p>Maximum age. 56.0 Ma.</p> <p>Age justification. These remains of <i>Protamandua rothi</i> were collected south of the Río Coyle correlated to the lower fossiliferous levels (FL 1-7) of the Estancia La Costa Member of the Santa Cruz Formation, which is generally considered to be of Miocene age ⁹⁸. Tephra analysis using Ar40/Ar39 methods suggest FL 1-7 are part of a conformable sequence and that there is no temporal distinction between FL 3 and 7 ⁹⁹. Ar40/Ar39 dating of tephra sample CO from above FL 1-7, correlated across the Estancia La Costa Member fossil localities (Puesto Estancia La Costa, Cañadón Silva, and Estancia La Costa) was dated as 17.41 Ma \pm 0.05 Myr ¹⁰⁰, thus making the minimum age 17.36 Ma.</p> <p>The soft maximum constraint floors that of Cingulata.</p>
38	<i>Chrysochloris asiatica</i> - other chrysochlorids	2	3.6	33.9	<p>Node calibrated. Divergence of <i>Chrysochloris asiatica</i> from other chrysochlorids.</p> <p>Oldest crown fossil. Following Asher & Avery ¹⁰¹, two Pliocene chrysochlorids from Langebaanweg, South Africa (<i>Chrysochloris bronneri</i> and <i>C. arenosa</i>) are more closely related to the extant <i>C. asiatica</i> than to other extant chrysochlorids. Other extinct chrysochlorids such as <i>Chlorotalpa spelea</i> from Sterkfontein and <i>Amblysomus hamiltoni</i> from Makapansgat, South Africa ¹⁰¹⁻¹⁰³ may also be crown taxa, but likely post-date the Pliocene.</p> <p>Minimum age. 3.6 Ma.</p> <p>Maximum age. 33.9 Ma.</p> <p>Age justification. <i>Chrysochloris arenosa</i> and <i>C. bronneri</i> are from early Pliocene deposits at Langebaanweg, South Africa. Most fossils from this locality were not recovered in-situ and represent at least some time-averaging. Nonetheless, they are generally regarded as early Pliocene and thus older than fossils recovered from South African hominid sites. Hence the minimum constraint for crown chrysochlorids would be the Langebaanweg fossils, correlating to Zanclean with a top of 3.6Ma. We propose a soft maximum in the late Eocene given the abundance of African mammal fossils during that time but absence of uncontroversial crown chrysochlorids elsewhere ^{101,104}.</p>

39	Macroscelidea	2	23.04	56	<p>Node calibrated. Divergence of <i>Rhynchocyon</i> from other macroscelidids.</p> <p>Oldest crown fossil. <i>Oligorhynchocyon songwensis</i>, RRBP 08086 (left p4) from the Songwe Member of Nsungwe Formation.</p> <p>Minimum age. 23.04 Ma.</p> <p>Maximum age. 56.0 Ma.</p> <p>Age justification. Stevens et al. ¹⁰⁵ describe an isolated lower premolar from Tanzania, 25.2 Ma in age and diagnostic to Rhynchocyoninae. This falls within the Chattian marine stage the upper margin of which is 23.04 Ma ²³. As the soft maximum, we propose the base of the Eocene (Ypresian) dated to 56.0 Ma ²³. Various localities near and above the Paleocene-Eocene boundary have yielded numerous remains of afrotherians ^{63,106} without evidence for crown macroscelideans.</p>
40	Proboscidea	2	5.33	23.04	<p>Node calibrated. Common ancestor of <i>Elephas</i> and <i>Loxodonta</i>, following Benton et al. ¹¹ but with the geochronology revised following ²⁹ and ²³.</p>
41	Sirenia	2	41.03	66.09	<p>Node calibrated. Common ancestor of <i>Dugong</i> and <i>Trichechus</i>. Following ¹¹ excepting (i) that we use the top rather than base of the Lutetian to define the minimum age constraint, (ii) we include the dating errors in defining the soft maximum constraint, and (iii) with the geochronology revised following ²³.</p>
42	Hyracoidea	2	5.33	33.9	<p>Node calibrated. Divergence of <i>Dendrohyrax</i> from other hyracoid genera.</p> <p>Oldest crown fossil. <i>Dendrohyrax validus</i> ¹⁰⁷. Pickford & Hlusko ¹⁰⁷ describe many specimens of <i>Dendrohyrax cf. validus</i> from Lemudong'o, Narok, Kenya., one of which is KNM-NK 36534 (left mandible with p4-m2)).</p> <p>Minimum age. 5.33 Ma.</p> <p>Maximum age. 33.9 Ma.</p> <p>Age justification. According to Pickford & Hlusko ¹⁰⁷, fossils from Lemudong'o Locality 1, including <i>Dendrohyrax</i>, are ca. 6.1 Ma old. This is within the Messinian marine stage with an upper bound of 5.33 Ma ²⁹. <i>Heterohyrax auricampensis</i> from Berg Aukas, Namibia is presumably contemporaneous (see Rasmussen et al. ¹⁰⁸). Max bound would be better constrained by lack of crown hyracoid spp. in north African localities. As the soft maximum, we propose the base of the Oligocene, corresponding to the Rupelian ²³. Numerous localities from near this age show no evidence of the divergence of extant hyracoid genera.</p>
43	Paucituberculata (Caenolestidae)	2	0	15.97	<p>Node calibrated. Divergence of <i>Caenolestes</i>, <i>Rhyncholestes</i> and <i>Lestoros</i>.. Following Emerling et al. ¹⁰⁹.</p>

44	Didelphidae	2	11.608	28.1	Node calibrated. Divergence of didelphine and caluromyine marsupials. Following Emerling et al. ¹⁰⁹ .
45	Dasyuromorphia	2	15.97	-	Node calibrated. Divergence of <i>Thylacinus</i> from other dasyuromorphs. Following Emerling et al. ¹⁰⁹ .
46	Peramelidae	2	4.36	23.8	Node calibrated. Divergence of <i>Peroryctes</i> from other peramelids. Following Emerling et al. ¹⁰⁹ .
47	Vombatiformes	2	25.5	-	Node calibrated. Divergence of phascolarctids from other vombatiformes. Following Emerling et al. ¹⁰⁹ .
48	Phalangeridae-Burramyidae	2	25	-	Node calibrated. Divergence of <i>Phalanger</i> from <i>Burramys</i> . Following Emerling et al. ¹⁰⁹ .
49	Petauridae - Pseudocheiridae	2	25.5	-	Node calibrated. Divergence of <i>Petaurus</i> from <i>Pseudocheirus</i> . Following Emerling et al. ¹⁰⁹ .
50	Macropodoidea (=Macropodidae + Potoroidae)	2	24.7	-	Node calibrated. Divergence of <i>Macropus</i> from <i>Potorous</i> . Following Emerling et al. ¹⁰⁹ .
51	Platyrrhini	2	20.45	37.7	<p>Node calibrated. Divergence of cebids from other South American monkeys (Platyrrhini).</p> <p>Fossil taxon and specimen. <i>Panamacebus transitus</i>, left upper M1 (UF 280128) from Lirio Norte, Panama Canal area, Panama ¹¹⁰.</p> <p>Phylogenetic justification. Bloch et al. ¹¹⁰ resolved <i>Panamacebus transitus</i> as a member of crown-Cebinae based on parsimony analysis of a morphological dataset.</p> <p>Minimum age. 20.45 Ma.</p> <p>Maximum age. 37.7 Ma.</p> <p>Age justification. Bloch et al. (2016) report a "a precisely dated 20.9-Ma layer in the Las Cascadas Formation in the Panama Canal Basin, Panama" as the source of <i>Panamacebus</i>. This is just within the Aquitanian marine stage with an upper bound of 20.45 Ma. As a soft maximum we suggest the late Eocene, a time by which a number of localities globally have yielded abundant primate remains, but as yet without evidence for crown platyrrhines.</p>

52	Primates	2	64.645	-	<p>Node calibrated. Divergence of dermopterans from primates.</p> <p>Fossil taxon and specimen. <i>Purgatorius</i> UCMP 197509 isolated astragalus attributed to <i>Purgatorius</i> by Chester et al. ¹¹¹ from the late Puercan Garbani Channel fauna, northeastern Montana, USA.</p> <p>Phylogenetic justification. Chester et al. (2015: fig. 2) place <i>Purgatorius</i> within a dermopteran-scandentian-primate clade.</p> <p>Minimum age. 64.645 Ma.</p> <p>Age justification. The late Puercan Garbani Channel fauna <i>Purgatorius</i> occurs within Puercan 2-3 ¹¹², the top of which falls within Chron C28r ²³, the top of which is dated to 64.645 Ma ²³.</p>
53	Scandentia	2	38	66.0	<p>Node calibrated. Divergence of <i>Tupaia</i> from <i>Ptilocercus</i>, following Emerling et al. ¹⁰⁹.</p>
54	Suina	2	34.7	-	<p>Node calibrated. Divergence of <i>Tayassu</i> from <i>Sus</i>.</p> <p>Fossil taxon and specimen(s). <i>Perchoerus probus</i>; UMPE 0031: mandible fragment with m2-m3 and UMPE: upper canine from the Municipality of Santiago Yolomécatl, Tlaxiaco basin, northwestern Oaxaca, southern Mexico ¹¹³.</p> <p>Phylogenetic justification. <i>Perchoerus probus</i> has been classified as either a crown tayassuid, suid or stem suoid in whole-scale analyses of Cetartiodactyla ^{114,115}, however in suoid-level analyses ^{114,116,117} <i>Perchoerus</i> is nested within Tayassuidae due to a suite of cranial characters ¹¹⁸.</p> <p>Minimum age. 34.7 Ma.</p> <p>Age justification. The minimum age constraint is based on the age of the Santiago Yolomécatl fauna. K-Ar dating of overlying volcanic rocks and the presence of <i>Miohippus assinoboimensis</i> suggest the fauna is late Miocene in age, equivalent to the Chadronian North American Land Mammal Age ¹¹³. K-Ar dating of the Cañada María Andesite overlying the mudstone outcrops from which the remains of the Santiago Yolomécatl fauna were recovered produced dates of 35.7 Ma ±1.0 Myr at the base and 32.9 Ma ±0.9 Myr further up the volcanic sequence ¹¹³. The minimum age constraint therefore is 34.7 Ma.</p>

55	Whippomorpha	2	52.4	-	<p>Node calibrated. Clade containing Cetacea and Hippopotamidae according to ¹¹⁹.</p> <p>Fossil taxon and specimen. <i>Himalayacetus subathensis</i>; Holotype: specimen 2003, left dentary with molar teeth M2-3, Roorkee University Vertebrate Paleontology Laboratory (RUSB); from oyster-rich limestone near the base of the Subathu Formation, type section in Kuthar Nala, Simla Hills, Lesser Himalaya Range, Himachal Pradesh, India ¹²⁰.</p> <p>Phylogenetic justification. <i>Himalayacetus subathensis</i> is a representative of the extinct cetacean suborder Archaeoceti based on the absence of auditory specialisations within a small mandibular canal present in the type dentary and its possession of Pakicetus-like teeth ¹²⁰.</p> <p>Minimum age. 52.4 Ma.</p> <p>Age justification. <i>Himalayacetus subathensis</i> was found in zone IIIc from (Mathur 1978), associated with <i>Nummulites atacicus</i> from shallow benthic zone SB8 (zones II-IV) ¹²⁰. The minimum age constraint therefore is correlated to the top of nanoplankton zone NP11-12, which gives a minimum age constraint of 52.4 Ma (Benton, et al. 2015).</p>
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56	Cetacea	2	36.13	56	<p>Node calibrated. The crown cetacean clade consisting of the suborders Odontoceti and Mysticeti to the exclusion of the extinct Archaeoceti ¹²¹.</p> <p>Fossil taxon and specimen. <i>Mystacodon selenensis</i>; Holotype: MUSM 1917, partial skeleton including cranium, mandibles, teeth, cervical, thoracic, lumbar and caudal vertebrae, ribs, partial right and left forelimbs, and left innominate from the Yumaque Formation, Playa Media Luna, southern part of Pisco Basin, southern coast of Peru ¹²².</p> <p>Phylogenetic justification. <i>Mystacodon</i> possesses derived mysticete characters including: a dorsoventrally thin lateral edge of maxilla on the rostrum, the presence of an antorbital process of the maxilla, the presence of a maxillary infraorbital plate, and triangular supraoccipital shield ¹²². As a result <i>Mystacodon</i> is considered the oldest mysticete, part of the basal-most mysticete family Llanocetidae ¹²³. This group is characterised by large cheek teeth with two separate roots, and strong labial and lingual enamel ornament (uncertain in <i>Mystacodon</i>) ¹²³.</p> <p>Minimum age. 36.13 Ma.</p> <p>Maximum age. 56 Ma.</p> <p>Age justification. The <i>Mystacodon selenensis</i> holotype was discovered 77 metres above the base of the Yumaque Formation, correlated to calcareous nanofossil zone NP19/20 of ¹²⁴ in ¹²². This corresponds to the <i>Isthmolithus recurvus</i> Partial Range Zone CNE18, with an estimated age range of 37.46-36.13 Ma ¹²⁵. The availability of this marine correlation for this fossil enables us to forego use of the corresponding marine stage (Ypresian). This gives a minimum age constraint of 36.13 Ma. We follow Benton et al. ¹¹ in establishing the soft maximum constraint on the presence of a diverse, early Eocene artiodactyl record, including archaeocetes but no crown cetaceans during the Ypresian. Thus, the base of the Eocene serves as a soft maximum for the odontocete-mysticete divergence, dated at 56.0 Ma ²³.</p>
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57	Mysticeti	2	15.99	-	<p>Node calibrated. Clade consisting of the most recent common ancestor of the living baleen whale families Balaenidae, Balaenopteridae, Cetotheriidae, and Eschrichtiidae ¹²⁶.</p> <p>Fossil taxon and specimen. <i>Morenocetus parvus</i>; Holotype: MLP 5-11, incomplete cranium including the left periotic and incomplete right periotic in articulation with the basicranium but lacking the rostrum from El Castillo locality, Gaiman Formation, southern margin of the Lower Valley of the Chubut River, Chubut Province, central Patagonia, Argentina ^{127,128}.</p> <p>Phylogenetic justification. An unnamed stem balaenid from New Zealand dated to approximately 28 Ma was previously thought to be the oldest balaenid ¹²⁹, however recent analyses have reported it outside Balaenidae ¹²⁸. Instead <i>Morenocetus parvus</i> is now considered the oldest representative of Balaenidae, the oldest lineage of crown Mysticeti ¹²⁸. Identified as a balaenid due to the posterior margin of the zygomatic process of the squamosal and the lateral edge of the occipital forming a continuous lateral skull border, an anterolaterally directed zygomatic process of the squamosal, a squamosal that is higher dorsoventrally than long anteroposteriorly, and the body of the periotic lateral to the pars cochlearis is laterally and ventrally hypertrophied ¹²⁸.</p> <p>Minimum age. 15.99 Ma.</p> <p>Age justification. The lower Cerro Castillo beds of the lower part of the Gaiman Formation are considered Aquitanian-Burdigalian in age ¹²⁸. An Early Miocene age is supported by the Colhuehuapian mammal fauna from the underlying Trelew member of the Sarmiento Formation since it is dated to 21.0-20.5 Ma in age at Gran Barranca, Chubut Province, central Patagonia, Argentina ^{128,130}. The overlying Gaiman Formation shouldn't be older than this estimate, and the presence of marine vertebrates (fishes and penguins) indicate an early Miocene (Burdigalian) age ¹²⁸. The minimum constraint is then defined on the Burdigalian-Langhian boundary and the base of the Burdigalian, dated at 15.99 Ma ²⁹.</p>
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58	Odontoceti	2	23.04	-	<p>Node calibrated. Clade consisting of the most recent common ancestor of the living toothed whale families Delphinidae, Monodontidae, Phocoenidae, Iniidae, Pontoporiidae, Platanistidae, Lipotidae, Kogiidae, Physteridae, and Zhiphidae.</p> <p>Fossil taxon and specimen. <i>Arktocara yakataga</i>; type specimen: USNM 214830, incomplete skull lacking the rostrum anterior of the antorbital notches, tympanoperiotics, dentition and mandibles from Poul Creek Formation, Yakutat City and Borough, Alaska, United States of America ¹³¹.</p> <p>Phylogenetic justification. <i>Arktocara yakataga</i> belongs in Platanistoidea since the width of its maxilla is exceeds 50% of the width of the rostrum at the antorbital notch and it possesses affinities with members of Allodelphinidae that possess unequivocal synapomorphies of Platanistoidea ¹³¹. Phylogenetic analysis supports this by placing <i>Arktocara</i> as the sister taxon to Allodelphis, meaning <i>Arktocara yakataga</i> is the oldest allodelphinid and oldest crown odontocete ¹³¹.</p> <p>Minimum age. 23.04 Ma.</p> <p>Age justification. The <i>Arktocara yakataga</i> holotype (USNM 214830) was recovered from an unknown locality 400-500 metres below the top of the Poul Creek Formation ¹³¹. The Poul Creek Formation is constrained to approximately 40-20 Ma in age, so, using a broadcast time of ~20 Ma and a thickness of ~2 km for the Poul Creek Formation, a constant rate of sedimentation gives an approximate age of 25 Ma to USNM 214830 (Late Eocene-Early Miocene) ¹³¹. USNM 214830 is therefore Chattian in age (but with a possible species range extending into the Rupelian ¹³¹). The minimum age constraint is therefore 23.04 Ma ²³.</p>
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59	Delphinida	2	15.99	-	<p>Node calibrated. Clade consisting of the most recent common ancestor of the living delphinoid odontocete families Lipotidae, Iniidae, Phocoenidae, Monodontidae and Delphinidae ¹³².</p> <p>Fossil taxon and specimen. <i>Kentriodon pernix</i>; Type specimen: USNM 8060, fairly complete skeleton with skull, mandibles, tympanic bullae, periotics, right thyrohyal of the hyoids, and cervical and dorsal vertebrae in their natural positions; the left side displays 10 mostly incomplete ribs, an incomplete vertebral column with 7 cervicals, 10 dorsals, 4 lumbers with 3 transverse processes of others, 10 caudals with 1 epiphysis of another, and 4 chevrons; the right side displays 6 articulated and 4 disarticulated ribs; forelimbs are missing ; from greenish sandy clay of Shattuck's zone 5, Calvert formation, Chesapeake bay, Chesapeake Beach, Calvert County, Maryland, Virginia, United States of America ¹³³.</p> <p>Phylogenetic justification. <i>Kentriodon pernix</i> shares various anatomical similarities with the living porpoise genus <i>Sotalia</i> as described by ¹³³.</p> <p>Minimum age. 15.99 Ma.</p> <p>Age justification. Referred materials USNM 10670 (skull) and USNM 11400 (atlas) suggest that the stratigraphic range of <i>Kentriodon pernix</i> extends between zones 3 to 10 of the Calvert Formation ¹³³. The minimum age constraint is therefore based on the minimum age of zone C3 since it is the earliest stratigraphic occurrence of the <i>Kentriodon pernix</i>. Zone C3 has Sr87/Sr86 ages of 19.2-18.6 Ma with the best estimated range being 18.8-18.4 Ma ¹³⁴. This makes the minimum age constraint 18.4 Ma.</p>
60	Phocoenidae-Monodontidae	2	7.6	-	<p>Node calibrated. Divergence between porpoises (Phocoenidae) and narwhals (Monodontidae).</p> <p>Fossil taxon and specimen. <i>Salumiphocaena stocktoni</i>; Type specimen: UCMP 34576, a skull from Dacelite Quarry, Valmonte Diatomite Member, Monterey Formation, Palos Verdes Peninsula, California, United States of America ^{135,136}.</p> <p>Phylogenetic justification. <i>Salumiphocaena stocktoni</i> is considered the most basal phocoenid ¹³⁷.</p> <p>Minimum age. 7.6 Ma.</p> <p>Age justification. The minimum age constraint is based on the earliest recorded appearance of <i>Salumiphocaena stocktoni</i> in the Late Miocene Monterey Formation ¹³⁷. Barnes ¹³⁶ described the age of the holotype to be between 11-10 Ma, while Xiong et al. ¹³⁸ suggested 11.2-10 Ma, Chen et al. ¹³⁹ suggested 11.2-10 Ma \pm 1.138 Myr, and Galatius et al. ¹⁴⁰ suggested 11.2-7.246 Ma. However, the upper bound on the Valmonte Diatomite is constrained by the <i>Thalassiosira antiqua</i> Zone ¹⁴¹, the upper bound on which is 7.2 Ma ²⁹.</p>

61	Hippopotamidae	2	7.74	-	<p>Node calibrated. Divergence of <i>Hippopotamus</i> from <i>Hexaprotodon</i>.</p> <p>Fossil taxon and specimen. <i>Cororatherium roobii</i>; Holotype: CHO-BT 68, partial right upper unerupted molar from Beticha locality, 3 km south of Chorora type locality, Chorora Formation, southern Afar Depression, Ethiopia ¹⁴².</p> <p>Phylogenetic justification. <i>Cororatherium roobii</i> displays a hippopotamine trigonid defined by lacking a developed metacristid, an enlarged endometacristid and a postprotocristid reduced compared to the postparacristid, supporting a placement within the subfamily Hippopotaminae ¹⁴². Phylogenetic analysis utilising the ¹⁴³ data matrix recovers <i>Cororatherium roobii</i> as the basal-most hippopotamine based on various other dental characters.</p> <p>Minimum age. 7.74 Ma.</p> <p>Age justification. The minimum age constraint is based on the age of the Beticha locality. This was dated to between 8.02 Ma and 7.74 Ma through single crystal step-heating Ar40-Ar39 analysis undertaken by ³¹, though the remains are stated to be closer to 8.0 Ma in age ^{31,142}.</p>
62	Giraffidae	2	14	-	<p>Node calibrated. Divergence of <i>Okapia</i> from <i>Giraffa</i> ^{144,145}.</p> <p>Fossil taxon and specimen. <i>Giraffokeryx punjabiensis</i>; PC-GCUF 163/19 (Pakistan Palaeontology Research Center, Faisalabad, Pakistan), partial skull roof with horn cores and incomplete upper dentition ¹⁴⁶.</p> <p>Phylogenetic justification. Danowitz et al. ¹⁴⁵ follow Hamilton ¹⁴⁷ and Solounias ¹⁴⁸ in identifying <i>Giraffokeryx punjabiensis</i> as an ingroup member of the <i>Giraffa-Okapia</i> clade based on the presence of ossicones ¹⁴⁹, among other characters (shortened back of skull, posteriorly positioned orbits, flexed skull, brachycephalic skulls, cheek teeth with high crowns).</p> <p>Minimum age: 14 Ma.</p> <p>Age justification. Samiullah et al. ¹⁴⁶ describe cranial fossils of <i>G. punjabiensis</i> from the Chinji Fm. of Pakistan, dated to the middle Miocene, between 11.2 and 14.2 Ma. This would indicate a marine equivalent of either (from oldest to youngest) the Langhian, Serravallian, or Tortonian marine stages. The top of the youngest (Tortonian) is 7.25 Ma in age. However, Barry et al. ¹⁵⁰ suggest that <i>G. punjabiensis</i> from the Chinji Fm. has a first appearance of 14 Ma, which we accept.</p>

63	Bovini	2	10.2	-	<p>Node calibrated. Bovini is the clade consisting of all extant and extinct species that share a common ancestor more closely related to Bovini than <i>Pseudoryx nghetinhensis</i> ¹⁵¹. This node is equivalent to the Bovini + <i>Pseudoryx</i> clade when only considering extant taxa ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Selenoportax vexillarius</i>; Holotype: AMNH 19748, cranium with right and left horn cores from Hasnot, Jhelum district, Punjab province, Nagri Formation, Siwalik Group, northern Pakistan ¹⁵².</p> <p>Phylogenetic justification. <i>Selenoportax vexillarius</i> is the oldest bovid species to display derived morphological characters associated with the early evolution of Bovini according to Bibi ¹⁵¹. These bovine synapomorphies include a great basal divergence of the horns, a low and wide cranium with an enlarged mastoid region, and the absence of a textured dorsal cranial depression present in fossil and living Boselaphini ¹⁵³. The consideration of this taxon as a representative of stem Bovini however is due to poorly developed bovine dental synapomorphies such as the complication of occlusal enamel surfaces, tall and wide entostyles and ectostylids involved in occlusion, and increased crown height ¹⁵¹.</p> <p>Minimum age. 10.2 Ma.</p> <p>Age justification. The minimum age constraint is based on the species range of <i>Selenoportax vexillarius</i>, dated to be 10.2-9.8 Ma in age based on magnetostratigraphic dating of localities associated with the first and last occurrences of <i>Selenoportax vexillarius</i> ¹⁵⁴. The minimum age constraint is therefore set as 10.2 Ma since it is the earliest recorded appearance of <i>Selenoportax vexillarius</i> ¹⁵⁴.</p>
64	Tragelaphini	2	5.49	-	<p>Node calibrated. The clade is defined by the most recent common ancestor of <i>Tragelaphus scriptus</i> and all living bovids more closely related to it than to <i>Boselaphus tragocamelus</i> or <i>Bos primigenius</i> ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Tragelaphus moroitu</i>; Holotype: ALA-VP-2/2, frontlet with almost complete left horn core, proximal half of right horn core, and occipital fragment from the Asa Koma Member, Adu-Asa Formation, Middle Awash, Ethiopia ¹⁵⁵.</p> <p>Phylogenetic justification. <i>Tragelaphus moroitu</i> possesses all the synapomorphies of Tragelaphini: horn cores rising upright, spiralling 270°, with three keels and a triangular cross-section throughout the core, with weak anteroposterior compression basally if at all, and simple mesodont teeth with relatively long premolar rows ¹⁵¹. <i>Tragelaphus moroitu</i> however lacks any autapomorphies or apomorphies that ally it with any of the living lineages of tragelaphins, therefore it is considered ancestral to all tragelaphin lineages ¹⁵¹.</p> <p>Minimum age. 5.49 Ma.</p> <p>Age justification. Bibi ¹⁵¹ suggested deriving the minimum age constraint from the age of the Asa Koma Member. The Wittl Mixed Magmatic Tuff (WMMT, MA96-30) near the top of the Asa Koma Member was dated using Ar40/Ar39 dating methods, yielding an age of 5.57 Ma ±0.08 Myr ¹⁵⁶, resulting in a minimum age constraint of 5.49 Ma.</p>

65	Reduncini	2	5.111	-	<p>Node calibrated. The clade is defined by the most recent common ancestor of <i>Redunca redunca</i> and <i>Kobus kob</i> ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Redunca ambae</i>; Holotype: AME-VP-1/42, cranium from the Kuseralee Member, Sagantole Formation, Middle Awash, Ethiopia ¹⁵⁵.</p> <p>Phylogenetic justification. <i>Redunca ambae</i> is the first appearance of <i>Redunca</i> in the fossil record and thus the first crown reduncin ¹⁵¹.</p> <p>Minimum age. 5.111 Ma.</p> <p>Age justification. The minimum age constraint is based on the minimum age of the Kuseralee Member. Basalt sample MA92-15 from the Gawto Member basalts overlying the Kuseralee Member was dated to 5.177 Ma \pm 0.066 Myr in age using Ar40/Ar39 step heating methods ¹⁵⁷. The minimum age constraint therefore is set at 5.111 Ma.</p>
66	Hippotragini-Alcelaphini	2	6.48	-	<p>Node calibrated. Divergence of Hippotragini and Alcelaphini ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Tchadotragus sudrei</i>; Holotype: TM12-97-23, near complete skull lacking premaxillae, right nasal, zygomatic arches, and most of auditory region from the anthracotheriid unit of Toros-Menalla, Djurab region, northern Chad ¹⁵⁸.</p> <p>Phylogenetic justification. <i>Tchadotragus sudrei</i> possesses typical hippotragine features including long slender, curved horn cores, weak cranial flexure, large frontal sinuses, and hippotragine-like dentition ¹⁵⁸. It is thus considered a basal member of the tribe predating the <i>Oryx-Praedamalis</i> split ¹⁵⁸.</p> <p>Minimum age. 6.48 Ma.</p> <p>Age justification. The minimum age constraint is based on the minimum age constraint of the anthracotheriid unit. Be¹⁰/Be⁹ atmospheric cosmogenic nuclide dating of the anthracotheriid unit resulted in a mean authigenic age of 6.88 Ma \pm 0.40 Myr above the ash tuff layer at TM 254 ¹⁵⁹. The minimum age constraint is based on the Be¹⁰/Be⁹ authigenic mean above TM 254 and so is set as 6.48 Ma.</p>

67	Alcelaphini	2	5.05	-	<p>Node calibrated. This clade is defined by the most recent common ancestor of <i>Alcelaphus buselaphus</i>, <i>Connochaetes gnou</i>, <i>Damaliscus pygargus</i>, and <i>Beatragus hunteri</i> ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Damalacra neanica</i>; Holotype: L7257, complete skull with horn cores and upper dentitions comprising P3-M3 on the right and broken M1-M3 on the left from bed 3aS, 'E' Quarry, Pelletal Phosphorite Member (PPM), Varswater Formation, Langebaanweg, South Africa ¹⁶⁰.</p> <p>Phylogenetic justification. <i>Damalacra neanica</i> is recognised as an alcelaphine based on a suite of cranial and dental characters as highlighted by Gentry ¹⁶⁰. This placement in crown Alcelaphini has been supported by morphological and molecular analyses done by Vrba ¹⁶¹ and Faith et al. ¹⁶².</p> <p>Minimum age. 5.05 Ma.</p> <p>Age justification. The minimum age constraint is based on the minimum age of the Muishond Fontein Pelletal Phosphorite Members (MPPM). The fossils from the MPPM are considered slightly younger than sea level cycle T7 since they occur within a small interval between 26-30 metres above sea level (asl) within the Varswater Formation, which starts approximately 15 metres asl ¹⁶³. This gives an age estimate of 5.15 Ma \pm0.1 Myr ¹⁶³, establishing the minimum age constraint at 5.05 Ma.</p>
68	Caprinae	2	8.9	-	<p>Node calibrated. Clade that consists of all extant and extinct species that share a more recent common ancestor (MRCA) with <i>Capra ibex</i> than <i>Pantholops hodgsonii</i> ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Aragoral mudejar</i>; Holotype: RO-2268, MPZ 96/54, frontal fragment with two horn cores from La Roma 2, Alfambra, Teruel, Aragón, Spain ^{164,165}.</p> <p>Phylogenetic justification. <i>Aragoral mudejar</i> is considered a member of Caprini due to the presence of hystodonty, reduced premolar rows, horn cores with well-developed pedicular sinuses, and short and robust metacarpals ¹⁶⁶. The greatly shortened and wide metacarpals is synapomorphy of Caprini ¹⁶⁷, however the simple frontal sinuses in the pedicel and horn core base are a synapomorphy of the Caprini + Alcelaphini + Hippotragini clade justifying the consideration of <i>Aragoral Mudejar</i> as a stem caprine ¹⁵¹.</p> <p>Minimum age. 8.9 Ma.</p> <p>Age justification. The minimum age constraint is based on the minimum age of the La Roma 2 locality, which is upper Vallesian in age ¹⁶⁶. This locality is correlated to Mammal Neogene zone MN10 and dated to 8.9 Ma using bio- and magnetostratigraphy ^{168,169}.</p>

69	Cervidae	2	17.235	28.4	<p>Node calibrated. Clade consisting of all extant and extinct species that share a more recent common ancestor with Cervidae than any other living ruminant ¹⁵¹.</p> <p>Fossil taxon and specimen. <i>Procervulus praelucidus</i>; Specimens: BSPG 1937 II 16841, BSPG 1937 II 16803, BSPG 1937 II 16794, BSPG 1937 II 16852, antlers from Wintershof-West, Germany ^{170,171}.</p> <p>Phylogenetic justification. <i>Procervulus praelucidus</i> is classified as a cervid as it possesses antlers with a proximal permanent pedicel and an upper deciduous antler ¹⁵¹. <i>Procervulus praelucidus</i> is however considered a stem taxon as it retains the conserved character of antler burrs, suggesting a different method of antler development to the crown clade ¹⁵¹.</p> <p>Minimum age. 17.235 Ma.</p> <p>Maximum age. 28.4 Ma.</p> <p>Age justification. The minimum age constraint is based on the minimum age of the type locality of Wintershof-West. This locality is the type locality for the Mammal Neogene zone MN3 ¹⁶⁹, the top of which is dated to 17.235 Ma ¹⁷². Due to a lack of phylogenetic resolution between late Oligocene ruminants and their living relatives Bibi ¹⁵¹ suggests utilising a soft maximum age constraint of 28.4 Ma.</p>
70	stem-Moschidae	2	19.5	-	<p>Node calibrated. Divergence of moschids from other pecoran artiodactyls.</p> <p>Fossil taxon and specimen. <i>Dremotherium feignouxii</i>; MNHN SG. 4304 (Museum national d'Histoire naturelle, Paris, France) and StG. 548 (Centre de Conservation et d'Etudes des Collections Lyon), from early Miocene deposits, Saint-Gérard-le-Puy, France ¹⁷³.</p> <p>Phylogenetic justification. <i>Dremotherium feignouxii</i> was identified as a stem-Moschidae based on a morphological (skeletal) phylogenetic analysis by Janis and Scott ¹⁷⁴ and this interpretation has been followed to justify calibrations for stem-Moschidae in Bibi ¹⁵¹ and Zusano et al. ¹⁴⁴.</p> <p>Minimum age. 19.5 Ma.</p> <p>Age justification. Saint-Gérard-le-Puy is a suite of localities, the stratigraphy of which is not very well constrained. However. Costeur ¹⁷³ asserts an early Miocene age, Aquitanian, European Land Mammal Zone MN2. The MN2-3 boundary has been dated to 19.3 Ma ¹⁶⁹.</p>

71	Neobalaeninae	2	23.04	33.9	<p>Node calibrated. Divergence of <i>Caperea</i> (pygmy right whale) from Balaenopteridae ¹⁷⁵.</p> <p>Fossil taxon and specimen. <i>Mauicetus parki</i>; OU 22545 (Otago University), from the Otekaike Limestone at Hakataramea Valley, South Canterbury, New Zealand ¹⁷⁶.</p> <p>Phylogenetic justification. Both Marx and Fordyce ¹⁷⁷ and Lloyd and Slater ¹⁷⁸ resolved <i>Mauicetus parki</i> as the oldest representative of Balaenopteridae and, therefore, Neobalaeninae, based on total evidence and supertree methods.</p> <p>Minimum age. 23.04 Ma.</p> <p>Maximum age. 33.9 Ma.</p> <p>Age justification. Integrated biostratigraphy and isotope stratigraphy has established that the top of the Otekaike Limestone falls fully within the Chattian ¹⁷⁹, the top of which is dated to 23.04 ²³.</p>
72	Balaenopteridae	2	7.3	-	<p>Node calibrated. Divergence of crown Balaenopteridae (<i>Balaenoptera</i>, <i>Eschrichtius</i>, <i>Megaptera</i>).</p> <p>Fossil taxon and specimen. <i>Incakujira anillodefuego</i> GNMH Fs-098-1 (Gamagori Natural History Museum, Gamagori, Japan) from <i>Cosmopolitodus</i>-bearing horizons of the Pisco Formation, Aguada de Lomas, near Puerto de Lomas, approximately 80 km south of Nazca, Peru.</p> <p>Phylogenetic justification. Resolved as the oldest member of crown-Balaenopteridae by Marx and Kohno ¹⁸⁰ based on a total evidence analysis.</p> <p>Minimum age. 7.3 Ma.</p> <p>Age justification. Marx and Kohno ¹⁸⁰ quote a 7.3 Ma minimum constraint based on Sr isotope dating.</p>
73	Physeteroidea	2	13.82	-	<p>Node calibrated. Divergence of <i>Kogia</i> and <i>Physeter</i> ¹⁷⁸.</p> <p>Oldest crown fossil. <i>Idiophyseter merriami</i>; UCMP V75114 (University of California Museum of Paleontology, Berkeley, California) at Locality Templeton 2, San Luis Obispo County, California ¹⁸¹.</p> <p>Phylogenetic justification. Collareta et al. ¹⁸² identified <i>Idiophyseter merriami</i> as the oldest member of the crown-clade defined by extant <i>Kogia</i> and <i>Physeter</i> based on a morphological phylogenetic analysis.</p> <p>Minimum age. 13.82 Ma.</p> <p>Age justification. The Palaeobiology Database asserts a Langhian age for <i>Idiophyseter merriami</i>, the top of which is dated to 13.82 Ma ²⁹.</p>

74	Perissodactyla	2	55.5	66.09	Node calibrated. The clade comprised of Equidae, Tapiridae and Rhinocerotidae. Following Emerling et al. ¹⁰⁹ with the exception that the soft-maximum constraint, defined as the base of the Paleocene, is revised to 66.04 Ma \pm 0.05 Myr ²⁷ , so 66.09 Ma.
75	Ceratomorpha	2	48.078	66.09	<p>Node calibrated. Divergence of tapirids from rhinocerotids.</p> <p>Fossil taxon and specimen: <i>Cambaylophus</i>. IITR/SB/VLM 760, right maxilla fragment from the Cambay Shale, Vastan Lignite Mine, western India ¹⁸³.</p> <p>Phylogenetic justification. Kapur & Bajpai ¹⁸³ reconstruct <i>Cambaylophus</i> as a tapiroid. Its relation to modern tapirids to the exclusion of rhinocerotids is also reflected in the analysis of Bai et al. ¹⁸⁴.</p> <p>Minimum age. 48.078 Ma.</p> <p>Age justification. Kapur & Bajpai ¹⁸³ cite data from isotope stratigraphy and dinoflagellate biostratigraphy supporting the interpretation that Vastan fossils are between 54.5 (PETM) and 53.7 Ma (9 ETM2) in age. This provides for a minimum constraint defined on the Ypresian-Lutetian boundary which is dated at 48.07 Ma. The soft maximum, defined as the base of the Paleocene, is revised to 66.04 Ma \pm 0.05 Myr ²⁷, so 66.09 Ma.</p>
76	Prionodontidae-Felidae	2	28.1	66.09	Node calibrated. Divergence of Prionodontidae from Felidae. Following Emerling et al. ¹⁰⁹ with the exception that the soft-maximum constraint, defined as the base of the Paleocene, is revised to 66.04 Ma \pm 0.05 Myr ²⁷ , so 66.09 Ma.
77	Herpestidae-Eupleridae	2	15.97	33.9	Node calibrated. The clade comprised of mongooses and Malagasy mongooses ⁶⁴ . Following Emerling et al. ¹⁰⁹ .

78	Mustelidae-Procyonidae	2	26.42	-	<p>Node calibrated. The split between mustelids (weasels) and procyonids (raccoons) ¹⁸⁵.</p> <p>Fossil taxon and specimen. <i>Pseudobassaris riggsi</i>; Holotype: YPM-PU 11455, skull from the Phosphorites du Quercy, France ¹⁸⁶.</p> <p>Phylogenetic justification. <i>Pseudobassaris riggsi</i> is considered the oldest known procyonid since it possesses procyonid suprameatal fossae and epitympanic recesses of the middle-ear ^{186,187}. <i>Pseudobassaris riggsi</i> is also stratigraphically older than the oldest known mustelid, <i>Plesictis plesictis</i> ¹⁸⁵.</p> <p>Minimum age. 26.42 Ma.</p> <p>Age justification. <i>Pseudobassaris riggsi</i> is from French localities Belgarrie 1 and Belgarrie 4A and so the minimum age constraint is based on the minimum age of these localities ¹⁸⁷. These localities are correlated with European Paleogene reference levels MP 24 and MP 25 ¹⁸⁵ the upper range of which is constrained with Chron C25r ¹⁸⁸; the upper bound of Chron C25r is dated to 26.42 Ma, providing the minimum age constraint.</p>
79	Feliformia	2	19.535	-	<p>Node calibrated. Most recent common ancestor of Felidae (cats), Prionodontidae (Asiatic lisangs), Herpestidae (mongooses), Eupleridae (Malagasy mongooses), Hyaenidae (Hyaenas) and Viverridae (civets and genets).</p> <p>Fossil taxon and specimen. <i>Proailurus lemanensis</i>; Holotype: MNHN SG 3509, skull from Saint-Gérard-le-Puy, France ¹⁸⁹.</p> <p>Phylogenetic justification. <i>Proailurus lemanensis</i> is placed within Feliformia based on its possession of an anteriorly positioned middle lacerate foramen (extreme in its case) ¹⁹⁰, and was further identified as a felid based on a derived petrosal morphology that incorporates a uniquely bony flange on the medial border of the promontorium (a feature that is suppressed and/or reoriented in living felids) ^{191,192}. However, under more recent analysis <i>Proailurus lemanensis</i> falls outside Felidae and nests within Eupleridae, though it is still considered a feliform ¹⁹³.</p> <p>Minimum age. 19.535 Ma.</p> <p>Age justification. The minimum age constraint is based on the age of the early Miocene Saint-Gérard-le-Puy locality ¹⁹⁴, correlated to Mammal Neogene zone MN2 ¹⁸⁹. The top of this zone is correlated to chron C6r ¹⁷², dated to 19.535 Ma ²³.</p>

80	Viverrinae- Genettinae	2	20.44	-	<p>Node calibrated. Most recent common ancestor of <i>Genetta</i> and <i>Viverra</i> ¹⁹⁵.</p> <p>Fossil taxon and specimen. <i>Herpestides antiquus</i>; Specimen: MGL SG 3066, cranium and associated lower jaw from unknown locality, Sant Gérard, Allier basin, France ¹⁹⁶.</p> <p>Phylogenetic justification. Basicranial morphology of the auditory region has patterns similar to those found in living viverrids ¹⁹⁶, however based on the differences in peculiarities of the dental morphotypes of Hemigalinae and Paradoxurinae ¹⁹⁷ hypothesize <i>Herpestides</i> is a representative of a viverrine and genettine fossil lineage.</p> <p>Minimum age. 20.44 Ma.</p> <p>Age justification. Though the specific locality from which the 12 basicrania analysed by Hunt Jr ¹⁹⁶ is unknown the regional geology is considered of Aquitanian age. The minimum age constraint is therefore based on the minimum age of the Aquitanian, dated to 20.45 Ma ²⁹.</p>
81	Lobodontini	2	5.05	-	<p>Node calibrated. Common ancestor of <i>Ommatophoca</i>, <i>Lobodon</i>, <i>Leptonychotes</i> and <i>Hydruga</i> ¹⁹⁸.</p> <p>Fossil taxon and specimen. <i>Homiphoca capensis</i>; Holotype: SAM-PQI-15695, rostral segment of partial skull from the Muishond Fontein Pelletal Phosphorite Members (MPPM), Varswater Formation, Langebaanweg, republic of South Africa ¹⁹⁹.</p> <p>Phylogenetic justification. A phylogenetic analysis utilising 6 skulls attributed to <i>Homiphoca capensis</i> from the Varswater Formation resulted in the taxon nesting within Lobodontini ¹⁹⁹.</p> <p>Minimum age. 5.05 Ma.</p> <p>Age justification. The minimum age constraint is based on the minimum age of the Muishond Fontein Pelletal Phosphorite Members (MPPM). The MPPM is considered to be of early Pliocene Zanclean age ²⁰⁰, as the member overlies sea level cycle T7 within the Varswater Formation ²⁰¹. This gives a central age estimate of 5.15 Ma \pm0.1 Myr for the MPPM ²⁰¹, setting the minimum age constraint at 5.05 Ma.</p>

82	Phocidae	2	13.82	-	<p>Node calibrated. Divergence between the subfamilies Monachinae and Phocinae ¹⁹⁸.</p> <p>Fossil taxon and specimen. <i>Monotherium? wymani</i>; Holotype: MCZ 8741, left and right temporal bones from Shockoe creek ravine near the base of Church Hill, Calvert Formation, Richmond, Virginia, United States of America ²⁰².</p> <p>Phylogenetic justification. <i>Monotherium? wymani</i> is considered the oldest known monachine phocid according to ²⁰³⁻²⁰⁶.</p> <p>Minimum age. 13.82 Ma.</p> <p>Age justification. The Calvert Formation spans an interval of time from the early to middle Miocene (Aquitania-Langhian) ²⁰², however Deméré et al. ²⁰⁵ cite <i>Monotherium? wymani</i> as exclusively Langhian in age, and phocid remains from zone 10 of the Calvert Formation outcropping at the Calvert Cliffs in Maryland are cited as early middle Miocene age ²⁰². The minimum age constraint is therefore defined by the upper bound of the Langhian, dated at 13.82 Ma ²⁹.</p>
83	Otarioidea	2	15.97	-	<p>Node calibrated. Divergence between the families Otariidae (fur seals and sea lions) and Odobenidae (walruses) ¹⁹⁸.</p> <p>Fossil taxon and specimen. <i>Proneotherium repenningi</i>; Holotype: USNM 205334, nearly complete skull with all teeth except left I1, right P1, left P4, and right and left M1-2; missing part of right zygomatic arch from the "Iron Mountain bed", Astoria Formation, Lincoln County, Oregon, United States of America ²⁰⁷.</p> <p>Phylogenetic justification. A phylogenetic analysis utilising 24 cranial, dental and postcranial characters done by ²⁰⁷ supports the monophyly of Odobenidae with the genera <i>Proneotherium</i> and <i>Prototaria</i> as sister taxa and basal members of the group. Because of this <i>Proneotherium repenningi</i> can be considered the oldest odobenid taxon to date ^{205,208}.</p> <p>Minimum age. 15.99 Ma.</p> <p>Age justification. <i>Proneotherium repenningi</i> is of Burdigalian age ²⁰⁵, the top of which is dated to 15.99 Ma ²⁹.</p>

84	Pinnipedia	2	20.45	27.29	<p>Node calibrated. Divergence between the super families Otarioidea (Otariidae+Odobenidae) and Phocoidea (Desmatophocidae+Phocidae).</p> <p>Fossil taxon and specimen. <i>Desmatophoca brachycephala</i>; Holotype: LACM 120199, incomplete cranium with crowns of left I1-3, parts of both canines, lacking other teeth and parts of the rostrum, and the right dorsolateral part of the braincase from locality LACM 4584, Astoria Formation, east of Knappton, Pacific County, Washington State, United States of America ²⁰⁹.</p> <p>Phylogenetic justification. <i>Desmatophoca brachycephala</i> is the oldest records of crown-Pinnipedia ²⁰⁶.</p> <p>Minimum age. 20.45 Ma.</p> <p>Maximum age. 27.29 Ma.</p> <p>Age justification. <i>Desmatophoca brachycephala</i> is of Aquitanian age ²⁰⁵, the top of which is dated to 20.45 Ma ²⁹. The presence of stem pinnipeds such as <i>Enaliarctos tedfordi</i> extends no further than the late Oligocene Chattian age ^{64,206,210}. The soft maximum age constraint is thus set to the base of the Chattian age, dated at 27.29 Ma ²³.</p>
85	Hipposideridae-Rhinolophidae	2	38	0.56	<p>Node calibrated. Divergence of Hipposideridae-Rhinolophidae. Following Emerling et al. ¹⁰⁹.</p>
86	Megadermatidae-Craseonycteridae	2	33.9	47.8	<p>Node calibrated. Divergence of megadermatids from craseonycterids. Following Emerling et al. ¹⁰⁹.</p>
87	Molossidae - Vespertilionidae + Miniopteridae	2	38	56	<p>Node calibrated. Divergence of Molossidae from Vespertilionidae + Miniopteridae. Following Emerling et al. ¹⁰⁹.</p>
88	Natalidae - Vespertilionidae + Miniopteridae + Molossidae	2	38	56	<p>Node calibrated. Divergence of Natalidae from Molossidae plus Vespertilionidae plus Miniopteridae. Following Emerling et al. ¹⁰⁹.</p>

89	Sciuromorpha	2	41.03	59.24	<p>Node calibrated. Common ancestor of the glirid-<i>Aplodontia</i>-sciurid clade within Sciuromorpha.</p> <p>Fossil taxon and specimen. <i>Eogliravus wildi</i>; Specimen: WDC-C-MG202, articulated skeleton from Messel, Germany (Storch and Seiffert 2007).</p> <p>Phylogenetic justification: <i>Eogliravus wildi</i> is thought to be the earliest appearance of the suborder Gliridae²¹¹, since It possesses occlusal tooth morphology that links Eocene/Oligocene Glirid genera with Eocene ischyromyids²¹².</p> <p>Minimum age. 41.03 Ma.</p> <p>Maximum age. 59.24 Ma.</p> <p>Age justification. The minimum age constraint is based on the age of the Messel Formation. The Messel Formation is early-middle Eocene in age, correlated with Mammal Paleogene (MP) zone 11²¹². This suggests that the Messel Formation is Lutetian in age and therefore the minimum age is set by the age of the Lutetian-Bartonian boundary²¹². This is dated to 41.03 Ma²³, giving a minimum age constraint of 40.7 Ma. The soft maximum age is based on the presence of <i>Paramys</i> in Thanetian age deposits. The base of the Thanetian is dated to 59.24 Ma²³ and serves as the soft maximum constraint.</p>
90	Abrocomidae	2	1.778	13.82	<p>Node calibrated. Most recent common ancestor of Abrocomidae (<i>Abrocoma</i>+<i>Cuscomys</i>).</p> <p>Fossil taxon and specimen. <i>Abrocoma</i> sp.; MMP 1059-M: fragment of left maxillary with DP4-M1 from Punta San Andrés, San Andrés Formation²¹³; and MACN 19722: right mandible with incisor and dp4-m2 from Santa Isabel, San Andrés Formation, between S2 and S3²¹⁴.</p> <p>Phylogenetic justification. <i>Abrocoma</i> is the oldest crown member of Abrocomidae (<i>Abrocoma</i>+<i>Cuscomys</i>)²¹⁵.</p> <p>Minimum age. 1.778 Ma.</p> <p>Maximum age. 9.112 Ma.</p> <p>Age justification. The fossiliferous unit from which the San Andrés Formation rodents are recovered from is part of the Sanandresian substage of the upper Marplatan South American Land Mammal Age (SALMA)²¹³. West²¹⁶ suggests that the Marplatan extends up until the end of chron C2, dated to 1.775 Ma by²⁹. Verzi et al.²¹⁷ noted paleontological evidence for divergence within abrocomids through the middle and late Miocene, prior to the divergence of <i>Abrocoma</i> from <i>Cuscomys</i> (Verzi et al.²¹⁷: fig. 10). We therefore define the soft maximum on the middle Miocene (base Serravallian), dated to 13.82 Ma²⁹.</p>

91	Monotremata	2	24.459	133.2	<p>Node calibrated. Divergence of <i>Platypus</i> from echidnas.</p> <p>Fossil taxon and specimen. <i>Obdurodon insignis</i> SAM P18087 and AMNH 97228, (right upper molars) from University of California, Riverside Loc. RV-7247, SAM Quarry North, Unit 2 of Etadunna Formation, west side of Lake Palankarinna, South Australia ²¹⁸.</p> <p>Minimum age. 24.459 Ma.</p> <p>Soft maximum age. 133.2 Ma.</p> <p>Age justification. Woodburne et al. ⁷³ identify Unit 2 of Etadunna Formation as falling within magnetozone C7r which is age constrained by the base of the succeeding C7n.2n, dated to 24.459 Ma ²³. Given the possibility that Cretaceous fossils such as <i>Teinolophos</i> from Flat Rocks, Australia, might be crown monotremes, more closely related to the extant <i>Ornithorhynchus</i> than to <i>Tachyglossus</i>, we use the maximum age of the Flat Rocks site to establish the soft maximum constraint. The age of the Flat Rocks site (Strzelecki Group) is usually considered Barremian-Aptian (e.g. ²¹⁹). However, the age of the Flat Rocks site has been subject to detailed palynological characterization finding that it falls fully within the range of the spore <i>Pilosiporites notensis</i> ²²⁰, the FAD of which coincides with the base of the <i>Foraminisporis wonhaggiensis</i> Zone, <i>Dictyosporites speciosus</i> Zone and its <i>Cyclosporites hughesii</i> subzone ²²⁰. The <i>Foraminisporis wonhaggiensis</i> Zone is interpreted to have a Hauterivian to Barremian age (Partridge (2011) in Holdgate, et al. ²²¹). A soft maximum can therefore be established on the base of the Hauterivian 132.6 Ma \pm 0.6 Myr ²⁷, thus 133.2 Ma.</p>
92	Tachyglossidae	2	2.58	133.2	<p>Node calibrated. Common ancestor of <i>Tachyglossus</i> and <i>Zaglossus</i>.</p> <p>Fossil taxon and specimen. Postcranial elements of tachyglossids from Chinchilla Sands ²²², no specimen numbers given.</p> <p>Phylogenetic Justification. "<i>Zaglossus</i>" (<i>Megalibgwilia</i>) <i>robustus</i> from the Miocene of Gulgong, NSW may constrain age of crown echidnas, but this taxon is now referred to <i>Megalibgwilia robustus</i> and is not clearly demonstrated to be closer to <i>Zaglossus</i> than <i>Tachyglossus</i>. Following Pian et al. ²²³ there are no unequivocal pre-Pliocene echidnas and, following Musser ²²², the oldest are <i>Tachyglossus</i> sp. from Pliocene of Chinchilla Sands.</p> <p>Minimum age. 2.58 Ma.</p> <p>Maximum age. 133.2 Ma.</p> <p>Age justification. The Chinchilla Sand fluvial deposits near the town of Chinchilla, on the Darling Downs, Queensland. No direct dates have been obtained for this deposit but Tedford et al. ²²⁴ and Mackness et al. ²²⁵ in Dawson ²²⁶ argue for an early to middle Pliocene age interpretation based on correlation. Hence, we use the date of the Pliocene-Pleistocene boundary to inform the minimum age interpretation of this fossil, dated to 2.58 Ma ²²⁷. The soft maximum follows that of Monotremata.</p>

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