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SUPPLEMENTARY ONLINE MATERIAL FOR

A new mid-Permian burnetiamorph specimen from the Main Karoo Basin of South Africa and a phylogenetic review of Burnetiamorpha

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Supplementary Online Material

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SOM 1. Figure 1. All most parsimonious trees calculated for this study. A-G, *Biarmosuchus* used as outgroup; H-L, *Hipposaurus* used as outgroup and *Biarmosuchus* excluded. See text for details.

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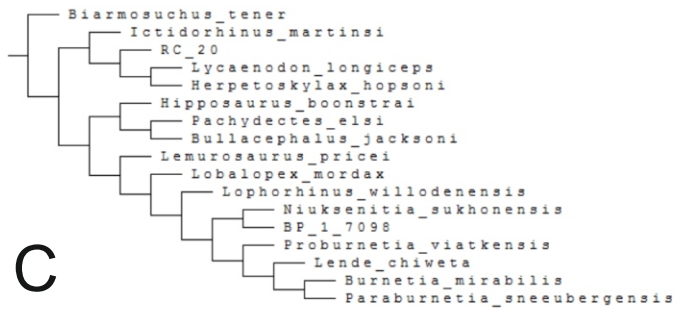
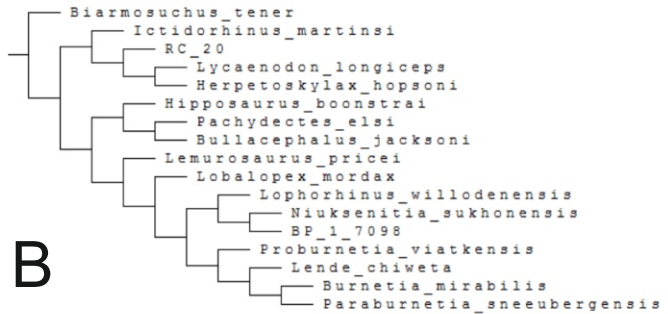
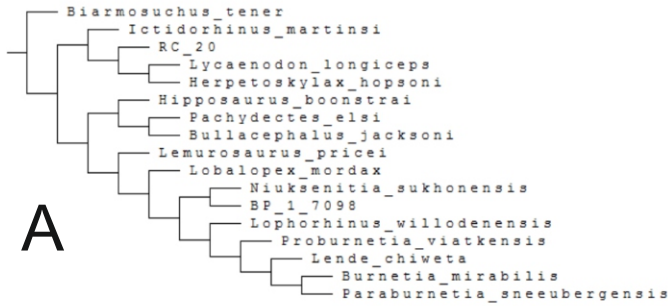
SOM 1. Table 1. Table comparing stratigraphic congruence metrics for all trees calculated in this study and those presented in Kruger et al (2015) and Kammerer (2016). OTUs were maintained for all trees by trimming BP/1/7098 and RC 20 from new trees and adding *Biarmosuchus* as a post hoc outgroup to those trees for which it had been excluded. P-values associated with individual metrics calculated from 10 000 randomly constructed trees bearing the same end taxa. Bold indicates that a stratigraphic congruence metric is significantly different from random. GER, gap excess ratio; GER*, modified GER; GERT, topological GER; MIG, minimum implied gap; MSM, manhattan stratigraphic measure; MSM, modified MSM; RCI, relative consistency index; SCI, stratigraphic consistency index; p.Wills, probability as calculated by the position of the MIG for the tree in question compared to the MIGs of random topologies (see Bell and Lloyd 2015).

Tree	Metric				Estimated p-value				Metric			
	SCI	RCI	GER	MSM*	SCI	RCI	GER	MSM*	GER*	GERT	MIG	p.Wills
Biarmosuchus outgroup												
Equal weights - MPT 1	0,461538	-268,737	0,648547	0,271196	0,083205	0,003927	0,001367	4,33E-05	0,9986	0,883646	73,01	0,0014
Equal weights - MPT 2	0,461538	-288,03	0,623316	0,257712	0,083205	0,004306	0,002978	0,000288	0,9975	0,847928	76,83	0,0025
Equal weights - MPT 3	0,461538	-282,879	0,630053	0,261179	0,083205	0,004201	0,002435	0,00018	0,9978	0,857465	75,81	0,0022
Equal weights Sconsensus	0,5	-276,439	0,638474	0,265647	0,040562	0,004075	0,001881	9,66E-05	0,9982	0,869387	74,535	0,0018
Implied weights - k=3	0,384615	-335,877	0,560743	0,229423	0,256449	0,005388	0,015673	0,008191	0,9861	0,759346	86,30357	0,0139
Implied weights - k=6	0,384615	-232,576	0,695839	0,300683	0,256449	0,003297	0,000261	3,58E-07	0,9997	0,950595	65,85	0,0003
Implied weights - k=10	0,461538	-232,576	0,695839	0,300683	0,083205	0,003297	0,000261	3,58E-07	0,9997	0,950595	65,85	0,0003
Hipposaurus outgroup												
Equal weights - MPT 1	0,461538	-228,283	0,701453	0,304615	0,083205	0,003229	0,000211	1,77E-07	0,9997	0,958542	65	0,0003
Equal weights - MPT 2	0,461538	-232,576	0,695839	0,300683	0,083205	0,003297	0,000261	3,58E-07	0,9997	0,950595	65,85	0,0003
Equal weights Sconsensus	0,5	-219,697	0,712682	0,312796	0,040562	0,003096	0,000135	3,88E-08	0,9998	0,974438	63,3	0,0002
Implied weights - k=3	0,384615	-232,576	0,695839	0,300683	0,256449	0,003297	0,000261	3,58E-07	0,9997	0,950595	65,85	0,0003
Implied weights - k=10	0,461538	-232,576	0,695839	0,300683	0,083205	0,003297	0,000261	3,58E-07	0,9997	0,950595	65,85	0,0003
Kammerer S consensus	0,285714	-510,173	0,332799	0,163888	0,628812	0,011651	0,507026	0,584651	0,6202	0,436659	120,8143	0,3798
Kruger S consensus	0,125	-575,926	0,246808	0,147945	0,986956	0,015299	0,818261	0,818212	0,3027	0,314926	133,8333	0,6973

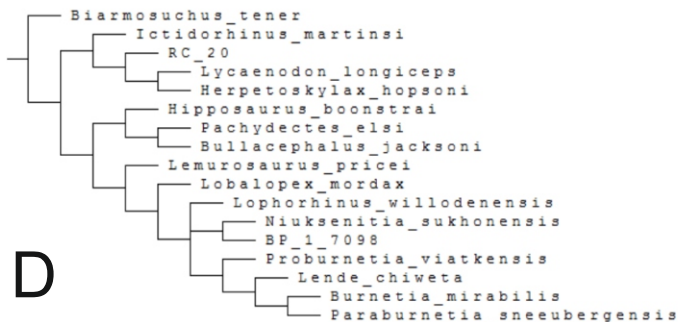
SOM 1. Figure 1. All most parsimonious trees calculated for this study. A-G, *Biarmosuchus* used as outgroup; H-L, *Hipposaurus* used as outgroup and *Biarmosuchus* excluded. See text for details.

Biarmosuchus root

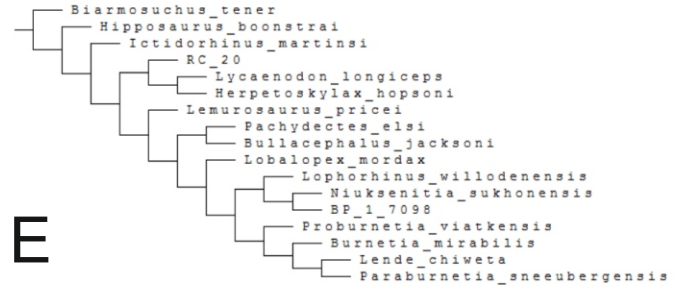
Most parsimonious trees, equal weights



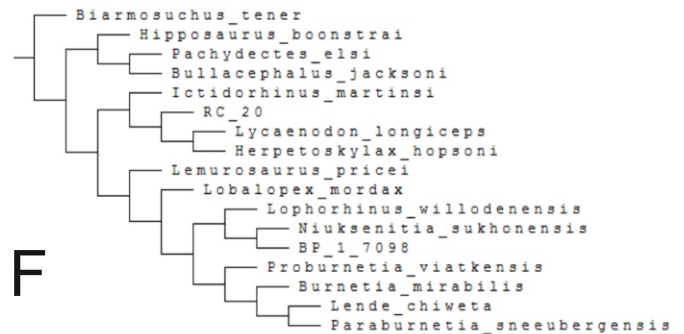
Strict consensus



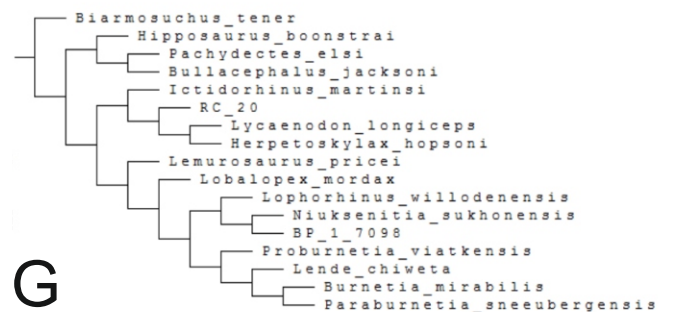
Implied weights k=3



Implied weights k=6

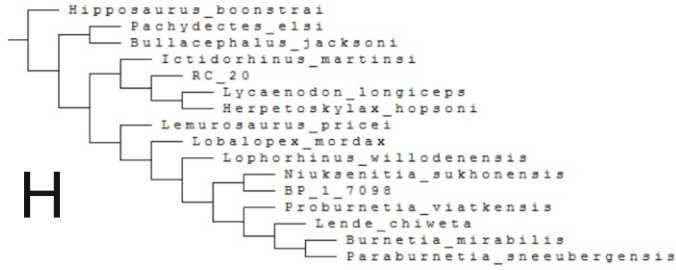


Implied weights k=10



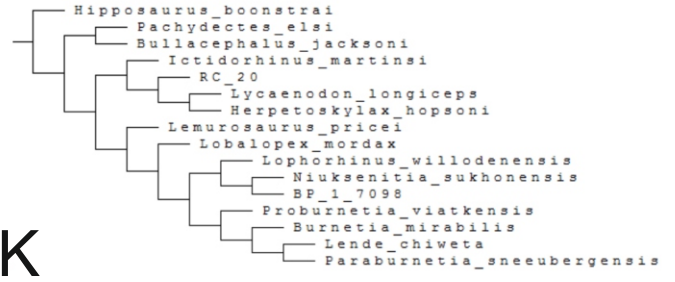
Hipposaurus root

Most parsimonious trees, equal weights

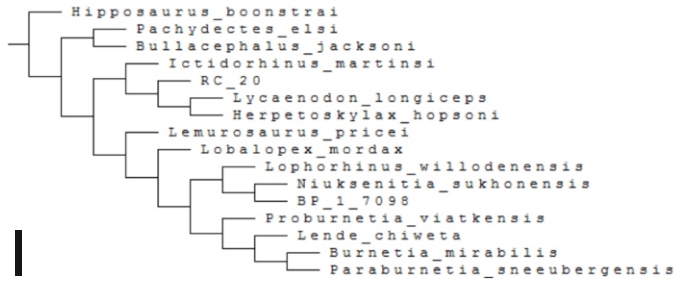


H

Implied weights k=3

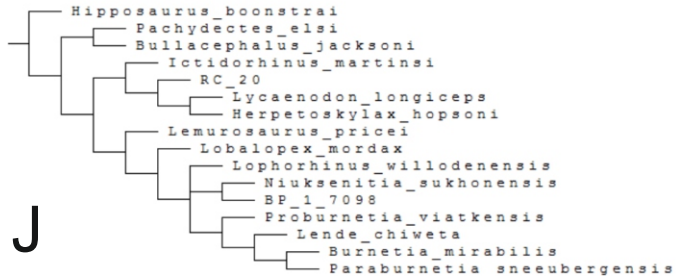


K



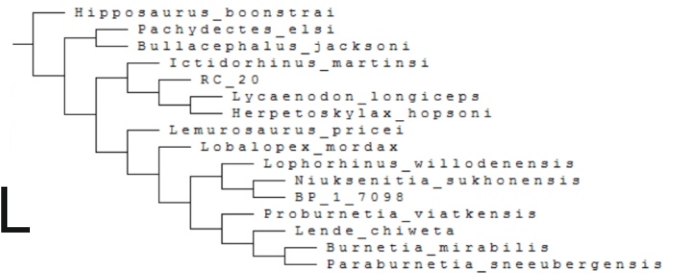
I

Strict consensus



J

Implied weights k=6



L

SOM 3. Explanation of alterations to character matrix of Kammerer (2016).

The base character matrix used at the outset of this study was the most recent in the literature, i.e., that of Kammerer (2016). Justification for our changes is provided here, where numbers in square brackets [] denote the number of the character or state in the matrix of Kammerer (2016). Numbers in round brackets () denote characters or states in the matrix used in this study, which are presented in SOM 2. As well as the addition of BP/1/7098, RC 20 (referred specimen of *Lycaenodon*) has been scored separately in accordance with Kammerer's concerns over its identification.

[1] 'Length of dorsal process of premaxilla'. Kammerer (2016) noted some changes to scoring here that we accept. *Lende* was scored as unknown for this character (?) by Kruger et al. (2015), despite being described by them as short. In fact the type specimen shows that the midline nasal crest continues anteriorly to at least the level of the anterior margin of the canine, suggesting that the dorsal processes are indeed short and terminate anterior to the canine. The premaxillae do not contribute to the midline nasal crest in any known burnetiamorph including BP/1/7098, in which the processes of the premaxillae are long. *Lende* was rescored accordingly.

[2] 'Lateral surface of lacrimal bears one or more deep fossae'. This character may prove to be of little phylogenetic value but is tentatively retained here. It is difficult to score because in several biarmosuchian specimens a fossa is apparent in one side of the skull only, e.g. MAL290 (*Lende*), *Bullacephalus* (BP/1/5387) and *Hipposaurus* (CGP/1/66). In *Bullacephalus* fossae are found on the lacrimal, jugal and maxilla and are well defined on the right side of the skull but are not clear on the left side. The left side is however damaged and it is possible that this obscures the fossae on that side. In contrast, the fossae in *Lende* and *Hipposaurus* appear to be the result of damage to one side but because *Lende* exhibits more than one potential fossa at sites observed in other burnetiamorphs, it is scored conservatively as unknown (?). It is also scored as present in *Lobalopex* but in the type and only specimen of this species both lacrimal regions are badly crushed and such a fossa cannot be observed as distinct from the deformation in this area. Several burnetiamorphs also show fossae on the maxilla or jugal, or both. Kruger et al. (2015) and Kammerer (2016) scored *Pachydectes* as unknown [?] for this character; however, though it bears a small but deep fossa on its maxilla, the well preserved lacrimals show no sign of any deep fossae, as observed by Rubidge et al. (2006). It was therefore rescored as (0) 'absent'.

[4] 'Shape of dorsal surface of nasals'. This was changed to 'ridge on dorsal surface of nasals'. The reason for this is that the original character conflated the round, isolated nasal boss of *Bullacephalus* with the ridge structures found in other biarmosuchians. In particular, the nasal bosses of BP/1/7098, *Paraburnetia* and *Burnetia* are formed by the expansion of a midline ridge to varying degrees. Despite the resemblance of the round nasal knob of *Burnetia* to that of *Bullacephalus*, the lack of evidence for its genesis from a midline ridge in *Bullacephalus* suggests that the boss had a different origin. This character was ordered as was done by

Kammerer (2016) and additional states were added: ‘absent’ (0), ‘present and low’ (1), ‘present and high’ (2), ‘present and high with lateral swelling’ (3).

[5] ‘Prefrontal boss’. Due to the complexity of this region, this character was changed to denote a more specific condition, that of an ‘independent, ridge-like boss on dorsal side of prefrontal’ as seen in *Bullacephalus* and *Burnetia*. The pinching and flaring of the anterior orbital margin is now covered in character (9).

[6] ‘Shape of dorsal surface of frontals’. This was changed to ‘ridge on dorsal surface of frontals’ to better clarify the posteriorly expanding frontal ridge that characterises the higher burnetiamorphs, as well as make allowance for the intermediate state of *Lemurossaurus*, where the median ridge is slightly expanded only at one point. New states were ‘flat’ (0), ‘with low and narrow median ridge’ (1), ‘with narrow boss set on median ridge’ (2), ‘with thick median ridge that is widest posteriorly’ (3). This was ordered as per Kammerer (2016).

[8 and 9] ‘Supraorbital horn’ and ‘Supraorbital horn morphology’. Kammerer (2016) provided a solution to the complexity of the morphology in this region by splitting the character of Kruger et al. (2015) ‘supraorbital margin’ into two. However, we feel that state [2] of Kammerer’s character [9], ‘two bosses, one above anterior edge of orbit and other at posterior edge/postorbital bar’ lumps two different morphologies into one, i.e. that of *Burnetia* and that of *Bullacephalus*. We propose a different solution whereby this area is broken into three characters ‘supraorbital boss above posterior margin of orbit’ (13), ‘postfrontal along orbital margin pinched anteroventrally’ (14) and ‘postorbital-postfrontal boss’ (15). This differentiates between the posterior boss in *Bullacephalus*, which is situated over the postorbital bar and where the postorbital hosts half the boss, and that of *Burnetia*, where the posterior boss is a lateral projection over the posterior margin of the orbit. It also allows *Pachydectes* to be scored for its postorbital boss despite lacking a complete supraorbital margin. A new character (14) is added to describe the development of a small, anteroventrally convex flange on the postfrontal part of the orbital margin, which is clearly visible in *Paraburnetia* and *Lende*. This is a further development of the triangular supraorbital boss but not dependent upon it so is scored as a separate character.

[10] ‘Postfrontal posterior extension along its medial contact with the frontal’. This character was requalified as ‘posterolateral constriction of the postfrontal by postorbital results in a narrow posterior process’. This is primarily to aid recognition and because in *Hipposaurus*, for which the character was scored as present, these processes border the parietals medially, not the frontals.

[11] ‘Length of posterior process of postorbital’. This was deleted as it correlates with the development of squamosal horns [20], and is thus redundant.

[12] ‘Postorbital bar scoop-shaped because temporal fenestra undercuts it’. This character was deleted as we could not replicate the scoring presented in the existing matrices and find it rather arbitrary. The temporal fenestra of the taxa concerned does vary, with most being sub-triangular with a more acute antero-ventral corner where the zygomatic arch meets the postorbital bar (e.g. *Herpetoskylax*, *Lemurosaurus*, *Lende*, *Proburnetia*). In *Biarmosuchus* and *Hipposaurus* the fenestra appears to undercut the orbit, at least in some specimens, while in *Herpetoskylax* it is at about the same level. A new character ‘temporal fenestra undercuts orbit’ was therefore created for this purpose.

[13] ‘Preparietal’. Kammerer (2016) reduces the number of states in this character to present/absent. We have reinstated the states of Kruger et al. (2016) as it is clear that there is a difference between the condition in RC 20 (‘present but is narrowly separated from pineal foramen by parietals’) and *Herpetoskylax* (‘present and forms anterior margin of pineal foramen’). Kammerer (2016) indicates that Kruger et al. (2016) only coded *Lycaenodon* and *Ictidorhinus* as having state {1} (‘present but is narrowly separated from pineal foramen by parietals’) but in fact so was *Hipposaurus*. *Bullacephalus* also has this state, so there may be some information in this distinction. In accordance with Kammerer (2016), *Lycaenodon* was scored as unknown (?) for this character and RC20 was scored separately. Despite Kammerer’s claims of its contribution to the margin of the parietal foramen in *Ictidorhinus*, we could not see the preparietal and so to err on the side of caution it was rescored as unknown.

[14] ‘Shape of dorsal surface of parietal surrounding parietal foramen’. This was maintained except that a third state was introduced to capture the condition in *Bullacephalus*, where the swelling is not as wide as in other burnetiamorphs and a rim is clearly visible round the pineal opening, rather than being flush with the surface surrounding it. This may represent an early stage in which the pineal chimney is reduced.

[15] ‘Anterior prongs on parietals that bound preparietal medially’. This character was removed as it was correlated with the presence of a preparietal (it was incorrectly scored as absent for *Hipposaurus* by Kruger et al. 2015 and Kammerer 2016).

[16] ‘Pachyostosis of zygomatic arch’. This was deleted and in its place we resurrected another, more specific character from Sidor and Smith (2007; ‘squamosal swollen to form a bulb below posteroventral end of the temporal fenestra, lateral to position of quadrate’). In some cases, such as *Burnetia*, it is hard to disentangle zygomatic pachyostosis from the growth of this bulb. An alternative to the original form of this character is the downturning of the zygomatic arch (see character 22).

[17] ‘Ventral surface of zygomatic arch and suborbital bar’. This was changed in accordance with the recognition of twin bosses in this area being common to most burnetiamorphs. The anterior boss extends slightly onto the suborbital bar and the posterior boss just underlies the anteroventral end of the lateral temporal fenestra. In some cases, i.e., *Lobalopex* and

Bullacephalus, only one boss is present in this area, and this is reflected in the available states ('absent', 'one boss', 'two bosses'). One specimen of *Lemurosaurus* (NMQR 1702) has a ventral flange posterior to these two bosses, but this is unique to this specimen.

[18] 'Boss on anterior margin of squamosal'. This appears to overlap with character [16] and/or character [17] so was removed.

[19] 'Zygomatic arch elevated in lateral view'. This character was created by Kruger et al. (2015) and tentatively retained by Kammerer (2016), though the latter conceded that is not well defined. We decided to delete it here as we were uncertain of its scoring; the zygomatic arch in *Herpetoskylax* still descends posteriorly. Instead, we introduced a new character (22) 'Zygomatic steeply downturned in posteroventral direction'. This captures the distinct downturn of the zygomatic arch in taxa like *Bullacephalus* and *Paraburnetia*, independent of the squamosal swelling lateral to the quadrate. *Hipposaurus* also possesses a steeply descending zygomatic arch and is scored accordingly.

[20] 'Squamosal horns'. This character was listed as ordered by Kammerer (2016) but as it only has two states it is implicitly unordered.

[21] 'Paired ridges lateral to nuchal crest'. This character was proposed by Kammerer (2016) and acknowledges an interesting feature of burnetiamorphs. These ridges manifest in most cases as small spurs of bone descending from the parietals onto the postparietal, or perhaps between the postparietal and tabular (e.g., *Bullacephalus*). However, in *Proburnetia* the state is rather different in that two ridges clearly delimit the postparietal, which is posteriorly raised above the occipital surface, and descend all the way to the supraoccipital. In this case the ridges are formed of the postparietal itself. To recognize this difference, a third state was added and a present condition qualified in states (1), 'present as ventral spurs of parietals', and (2), 'present as long ridges reaching supraoccipital'. Kammerer (2016) scored *Ictidorhinus* as 'absent' for this character but we are uncertain of this, as a small spur may be present on the right side. We rescored *Ictidorhinus* as unknown (?) for this character to reflect this uncertainty.

[22] 'Squamosal thickened along its posterior margin with tabular'. This character, conceived by Sidor and Smith (2007) but removed by Kruger et al. (2015), was resurrected by Kammerer (2016). This was used to differentiate the slight swelling of the squamosal margin in *Lobalopex* from the greater thickening in more derived burnetiamorphs and burnetiids. However, this coding does not properly encompass the fact that the whole post-temporal portion of the squamosal in *Bullacephalus* is pachyostosed; in other burnetiamorphs it is the posterior rim of squamosal that is particularly thickened to a greater degree. This is even noticeable in *Burnetia*, where the post-temporal part of the squamosal is expanded. In order to avoid the creation of a new character, a new state is proposed for *Bullacephalus* 'present between tabular and temporal fenestra'. In addition, because the states no longer necessarily

reflect a simple scale of development within one trait the two states of the thickened rim, both moderately and greatly, are collapsed into one ‘present along posterior rim’.

[24] ‘Palatine dentition’. The states of this character were changed to better reflect the trends in dental distribution. Kammerer (2016) retains the score of ‘spread over palatine’ for this character in *Biarmosuchus* and *Hipposaurus* but this is not the case in *Hipposaurus*, where the tooth row, despite containing a high number of teeth, is in fact restricted to the periphery of the boss. Personal inspection of specimens attributed to *Biarmosuchus tener* (though excluding the holotype of “*Eotitanosuchus olsoni*”) did not provide a definite observation of the condition in this taxon but it does appear that a number of teeth are present across the middle of the palatine boss in the holotype. Alternatively, Sigogneau and Chudinov (1972) and Ivakhnenko (1999, 2003) figure *B. tener* as having the palatine teeth limited to the periphery of the boss, though the peripheral dentigerous area is shown to be several teeth deep in places. The state ‘spread over palatine’ is tentatively retained for *Biarmosuchus* but further preparation would be required to confirm this. Kammerer (2016) also maintained the state ‘anterior, lateral and medial edges’ for *Burnetia*, *Proburnetia* and *Paraburnetia*. *Proburnetia* and *Paraburnetia* show a clustering of teeth at the anterior end of the palatine boss (Rubidge and Sidor 2002; Smith et al. 2006) in a way not just limited to a marginal row, so scoring them the same as the clearly defined single peripheral row seen in *Lemurosaurus* obscures a noticeable difference in distribution. Rubidge and Sidor (2002: fig. 3) show that *Burnetia* has a cluster of teeth on the palatine boss, resembling the condition in RC20. While in both cases this may be related to the smaller size of the boss, and in *Burnetia* compounded by potential overpreparation, the available evidence is that the arrangement in these three taxa is different to the peripheral tooth rows seen in other biarmosuchians.

In order to improve this character we introduced a new set of states, ‘multiple rows, limited to margin of boss’ (0), ‘single row, limited to margin of boss’ (1), and ‘small cluster’ (2). State (0) reflects the condition in some of the earliest biarmosuchians: *Hipposaurus*, *Bullacephalus* and *Pachydictes*. In the latter genus, the anterior portion of the palatine boss is not preserved but two teeth are observed on the posterior of the right boss, one medial to the other, suggesting this condition. The presence of multiple rows gave the appearance of more widespread palatine dentition in these genera in the past, although Kammerer (2016) noticed the more peripheral nature of the tooth row in *Bullacephalus* and *Pachydictes*. State (1) reflects the single peripheral tooth row best exemplified by *Lemurosaurus* but also present in *Herpetoskylax*, *Lobalopex*, *Lophorhinus*, *Niuksenitia* and BP/1/7098.

[25] ‘Row of teeth on the transverse flange of the pterygoid’. Kammerer (2016) maintained the score of ‘present’ for *Niuksenitia* and a score of ‘absent’ for *Proburnetia* and *Lycaenodon*. Our inspection of the holotype of *Niuksenitia* found that the ventral margins of the transverse processes are so weathered it is not possible to tell if teeth were present, so it was rescored as unknown (?). *Proburnetia* is figured to have a row of teeth on the transverse process of its pterygoids by Tatarinov (1977) and Ivakhnenko (2003) but teeth are not visible in the latex casts available to the authors or to Rubidge and Sidor (2002); Sigogneau-Russell (1989)

merely indicates the possibility of teeth but does not figure them. However, Kammerer (pers comm. 2016) has observed no teeth in the original natural mould so we have rescored *Proburnetia* as absent for this character (1). *Lycaenodon* was rescored as unknown (?) as this area is not preserved in the holotype and RC20 is scored separately.

[26] 'Basicranial rami of pterygoids'. The state [2] 'broadly contacting anterior to basicranium' was changed to (2) 'separated by ventral rostrum of parabasisphenoid' to clarify this condition in *Biarmosuchus*.

[27] 'Medial edge of pterygoid basicranial ramus forms parasagittal ridge on ventral surface'. This character was given two 'present' states to reflect the state in *Biarmosuchus*, i.e., (1) 'present to basicranium' and (2) 'present anteriorly'. In *Biarmosuchus* this ridge is visible as it curves posteriorly from the transverse processes but seems to disappear posteriorly as it meets the ventral rostrum of the parasphenoid. Along with character (32) this is rather different to the situation in other biarmosuchians.

[28] 'Deep depression in basicranium'. This character was omitted as this depression seems to be related to the size of specimens and is rather arbitrarily scored. Where it appears to be shallower, such as in *Lende*, there is also the possibility that weathering of the adjacent tubera makes the depression appear shallower than it was.

[29] 'Ratio of dentary height in canine versus anterior postcanine regions'. This character was omitted from our analysis. The reasons for this were that 1) the scoring for this character did not seem consistent, i.e. *Herpetoskylax* was scored [1] 'show pronounced difference' though in both specimens it appears more gradual an incline, 2) this area of the dentary is not clearly visible in *Proburnetia*, *Paraburnetia* or *Lende* due to close contact with the skull, 3) the rami of the mandible are possibly distorted posterior to the canine in *Lobalopex*, accentuating the difference between in height between these areas and 4) we could never score the same taxa twice the same, confirming to us that this character is too subjective. All biarmosuchians have an increase in height between the canine and postcanine regions to varying degrees with associated upturn in the anterior end of the snout. In *Lemurosaurus* this is particularly pronounced and in *Paraburnetia* less so, but this would perhaps need to be reconsidered as a ratio before it could be applied to phylogenetic reconstruction.

[30] 'Dentary-angular suture'. This character was deleted because it was parsimony uninformative. Despite being the only biarmosuchian scored as having the condition [0] 'runs diagonally across lateral surface of mandible', in larger specimens of *Biarmosuchus tener* this character appears as state [1] 'posterior margin of dentary deeply incised'. In the holotype it is ambiguous, as sutures have been drawn in that suggest a more diagonal contact. Closer inspection suggests that weathering has possibly removed the posterior spur of the dentary. If the referred specimens of *Biarmosuchus* are indeed conspecific with the holotype, which we accept here, then *Biarmosuchus* had the derived state (1) for this character.

Characters added

- (5) 'Median nasal ridge extends to level of external nares'.
- (7) 'Lateral projection of prefrontal above lacrimal'.
- (14) 'Temporal fenestra undercuts orbit'.
- (17) 'Squamosal swollen to form a bulb below posteroventral end of temporal fenestra, lateral to position of quadrate'.
- (19) 'Zygomatic steeply downturned in in posteroventral direction'.
- (25) 'Combined palatal boss length relative to choana'.
- (27) 'Pterygoid dentition excluding transverse process'.
- (30) 'Dorsal skull angulation above the orbital region'. This character was deleted by Kammerer (2016) on the basis that it either scored incorrectly or was redundant with respect to his character [26] ('squamosal horns'). While it is true that all biarmosuchians, except perhaps *Bullacephalus*, display some angulation of the skull at this point, it is not to an equivalent degree in all taxa: most biarmosuchians have a moderate angulation of the skull at this point, but a few burnetiids have developed a steeper angulation in this region. We reinstate this character but propose a different set of available states, namely 'slight to moderate' and 'steep', with latter referring to the highly angled skulls of *Lende* and *Paraburnetia*. While Kammerer (2016) expressed concerns that the flatter skull roof in burnetiids was the result of pachyostosis resulting from the formation of squamosal horns, the fact that *Lende* and *Paraburnetia* have the steepest skull angulation and yet possess squamosal horns indicates that these characters are not equivalent.
- (31) 'Fossa on ventral surface of pterygoid portion of palatal boss bounded by peripheral row of teeth'.
- (32) 'Contact of frontals and nasals'.
- (33) 'Anterior end of quadrate ramus of the pterygoid bears a triangular shelf ventrally offset from the basicranial ramus'.
- (34) 'Jugal contribution to lateral temporal fenestra'.

SOM 4. Taxon biostratigraphic range or occurrence assignments.

Biarmosuchus: 268.8–267 Ma, Lower Wordian age for Ocher subassemblage (Golubev 2005)

Bullacephalus: 265.1–265.1 Ma, Base of *Tapinocephalus* AZ (Rubidge and Kitching 2003).

Burnetia: 255.2–251.9 Ma, *Daptocephalus* AZ, formerly the *Dicynodon* AZ (Rubidge and Sidor 2002; Viglietti et al. 2016).

BP/1/7098: 259.2–259.2 Ma, Middle *Pristerognathus* AZ (this study).

Herpetoskylax: 256.8–255.2 Ma, *Cistecephalus* AZ (Sidor and Rubidge 2006). The specimen comes from the Nuweveld escarpment close to the border of the Northern and Western Cape provinces, about 6 km southeast of Teekloof Pass. The farm plot is referred to variously as 235 or 404 in the Beaufort West district (or Matjiesfontein 235 in Sidor and Rubidge 2006). The locality indicated by the coordinates provided by Sidor and Rubidge (2006) suggest that the specimen occurs in or very close to the lower Steenkampsvlakte Member. Such an origin would suggest that it occurs high in the *Cistecephalus* AZ or perhaps in the lowest *Daptocephalus* AZ, though Sidor and Rubidge (2006) preferred the former on the basis of associated fossils. Referred specimen BP/1/3924 comes from the farm Bultfontein (Bult en Rietfontein 96) in the Richmond district, where it occurs in association with the *Cistecephalus* AZ taxa *Aulacephalodon* and *Cistecephalus*. Because the holotype specimen occurs quite high in the *Cistecephalus* AZ and the referred specimen likely rather low, we consider it to have a range equivalent to the whole zone.

Hipposaurus: 263–260 Ma, Upper *Tapinocephalus* AZ (Day 2013).

Ictidorhinus: 253–251.9 Ma, Upper *Daptocephalus* AZ, formerly the *Dicynodon* AZ (Broom 1913; Sigogneau-Russell 1989; Viglietti et al. 2016). Broom (1913: 560) suggests that it occurs about 1000 feet above Nieu Bethesda and not far below ‘the thick bed of sandstone which probably divides the *Cistecephalus* zone from the *Lystrosaurus*.’ Using his height estimate this would put the origin of the *Ictidorhinus* holotype about 400 ft (122 m) below the base of the Katberg Formation. According to Viglietti et al. (2016) this corresponds to the upper *Daptocephalus* AZ and thus can constrain the occurrence of *Ictidorhinus* to the latest Permian. An age estimate of 253 Ma for the base of the Upper *Daptocephalus* AZ is derived from a simple extrapolation in that the Upper *Daptocephalus* AZ represents around the upper third of the *Daptocephalus* AZ as a whole. This is not inconsistent with an age of 253.48 Ma for a horizon in the *Daptocephalus* AZ at Old Lootsberg Pass (Gastaldo et al. 2015) as *Dicynodon lacerticeps*, which is typical of the lower *Daptocephalus* AZ, occurs above this dated horizon.

Lende: 256.8–255.2 Ma, Lower Bone Bed (B1) of the Chiweta Beds, Malawi, which are correlated with the *Cistecephalus* AZ (Kruger et al. 2015).

Lemurosaurus: 256.8–255.2 Ma, *Cistecephalus* AZ (Sidor and Welman 2003).

Lobalopex: 258.8–258.8 Ma, Base of *Tropidostoma* AZ and Hoedemaker Member (Sidor et al. 2004) or potentially the top of the *Pristerognathus* AZ, as its coordinates suggest it comes from the upper Poortjie Member. In either case it occurs close to the boundary of the two biozones.

Lophorhinus: 257.8–257.8 Ma, Middle *Tropidostoma* AZ (Sidor and Smith 2007).

Lycaenodon: 257.3–256 Ma, upper *Tropidostoma* AZ–lower *Cistecephalus* AZ. This specimen was retrieved near Biesiespoort Station south of Victoria West (Broom 1925; Sidor 2003), probably on the farm Nobelsfontein 248 but perhaps further north on the farm Matjiesfontein 220. Broom (1925: 325) describes the holotype as coming from “a horizon about 100 feet above the level of Biesjespoort [*sic*] Station, and thus well within the *Cistecephalus* AZ.” Geological mapping has shown the rocks exposed in the vicinity of Biesiespoort to be of the upper Poortjie Member with some Hoedemaker Member exposed not far to the north (Geological map sheet 3122: Victoria West, Council for Geoscience, Pretoria, 1989) and ~100 ft above Biesiespoort could be in either of these members. This would suggest upper *Pristerognathus* AZ or lower *Tropidostoma* AZ rather than *Cistecephalus* AZ but fossil material collected in the immediate area contains no clear representatives of the *Pristerognathus* or *Tropidostoma* AZs and includes *Oudenodon*. As *Oudenodon* does occur in the upper *Tropidostoma* AZ and, if the *Cistecephalus* AZ is present in the vicinity, it can only be the lower part, we consider the possible provenance of NHMUK R5700 to include the upper *Tropidostoma* AZ and lower *Cistecephalus* AZ; however, we acknowledge that this area needs to be reconsidered biostratigraphically.

Niuksenitia: 260–258 Ma, Lower *Pristerognathus* AZ (260–259.5 Ma). This is taken from its occurrence in the *Chroniosaurus dongusensis* subassemblage of the *Proelginia* AZ (Ilyinskoe subassemblage; Ivakhnenko, 2008), which is estimated to be latest Capitanian in age (Arefiev et al. 2015). Its faunal assemblage, however, is closer to the *Tropidostoma* AZ than to the *Pristerognathus* AZ and so an earliest Wuchiapingian age is possible (Rubidge 2005).

Pachydictes: 265.1–265.1 Ma, Base of *Tapinocephalus* zone. The specimen comes from the Eastern Cape where biozonation is uncertain but it occurs very low in the Abrahamskraal Formation (Day 2013; Rubidge et al. 2006). Because the *Eodicynodon* AZ has not yet been recognized from the Eastern Cape we err on the side of caution and suggest a basal *Tapinocephalus* AZ age for *Pachydictes*.

Paraburnetia: 256.8–256.8 Ma, Base of the *Cistecephalus* AZ (Smith et al. 2006).

Proburnetia: 259.5–257 Ma, Upper *Pristerognathus* or *Tropidostoma* AZ. This is taken from its occurrence in the Sokol'ya Gora Member at the eponymous locality near Kotel'nich. The Sokol'ya Gora Member is a channel sandstone that cuts into older fluvio/lacustrine and aeolian strata of the Kotel'nich sequence, including the Vanyushonki and Shestakovy members that have yielded most of the classic Kotel'nich fauna. Importantly, the Sokol'ya Gora channel cuts into the Shestakovy Member, in which good fossils of the dicynodont genus *Australobarbarus* have been found (Kurkin 2000; Benton et al. 2012); this genus is closely allied to the South African taxon *Tropidostoma*. The Sokol'ya Gora Member itself has produced several taxa typical of the *Chroniosaurus levis* subassemblage of the *Proelginia* AZ (Ilyinskoe subassemblage; Ivakhnenko, 2008), which is estimated to be latest Capitanian to early Wuchiapingian in age (Arefiev et al. 2015) or just early Wuchiapingian (Benton et al. 2012). Because the Sokol'ya Gora Member is the youngest fossil-bearing unit at Kotel'nich, overlies strata bearing a *Tropidostoma*-like dicynodont, and has produced osteoderms of *Chroniosaurus levis* (being the index taxon for the younger of the *Proelginia permiana* Assemblage Zone subzones), we believe an early Wuchiapingian age is most likely for *Proburnetia*.

RC20 (referred specimen of *Lycaenodon*): 256.8–255.2 Ma, *Cistecephalus* AZ (Sidor 2003).

SOM 5. Beaufort Assemblage Zone age assignments.

268.8–265.1 Ma, *Eodicynodon* Assemblage Zone (AZ)—The upper boundary of this AZ is not well constrained and the lower boundary is unknown as it is (possibly) truncated by the base of the Beaufort Group. Its duration is considered to be equivalent to the Wordian, after Rubidge (2005) and International Commission on Stratigraphy – Subcommission on Permian Stratigraphy [ICS-SPS], (2016).

265.1–260 Ma, *Tapinocephalus* AZ—This is based on the age of 260.2 Ma for the base of the Poortjie Member (which only slightly predates the top of the *Tapinocephalus* AZ; Day *et al.*, 2015) and an age of 265.1 Ma for the base of the Capitanian (ICS-SPS, 2016).

260–258.8 Ma, *Pristerognathus* AZ—Based on an age of 260.2 Ma from base of Poortjie Member and an estimated age for the *Pristerognathus-Tropidostoma* AZ boundary of 258.8 Ma, derived from relative biozone thicknesses and an age of 256.25 Ma for the lower *Cistecephalus* AZ (Day *et al.*, 2015; Rubidge *et al.*, 2013).

258.8–256.8 Ma, *Tropidostoma* AZ—Based on an age of 260.2 Ma from base of Poortjie Member and an estimated age for the *Pristerognathus-Tropidostoma* AZ boundary of 258.8 Ma, derived from relative biozone thicknesses and an age of 256.25 Ma for the lower *Cistecephalus* AZ (Day *et al.*, 2015; Rubidge *et al.*, 2013).

256.8–255.2 Ma, *Cistecephalus* AZ—Estimated from dates published by Rubidge *et al.* (2013).

255.2–251.9 Ma, *Daptocephalus* AZ—Estimated from date of 255.2 Ma for the base of the *Dicynodon* AZ (Rubidge *et al.* 2013) and an age of 251.9 Ma for the Permo-Triassic boundary (Burgess *et al.* 2014; ICS-SPS, 2016). Very recently it has been proposed to supplant the name *Dicynodon* AZ with the *Daptocephalus* AZ (Viglietti *et al.* 2015). The exact litho-stratigraphic limits of this zone are not yet completely understood and it may be more extensive than reported for the *Dicynodon* AZ so one could argue it would be prudent to follow the former regime for the time being. However, the newly-proposed biozone has essentially the same composition as the former *Dicynodon* AZ, so the age of specimens reported from that zone in historical collections is likely to be mostly unaffected. We therefore adopt the new system.

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