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SUPPLEMENTARY ONLINE MATERIAL FOR

A new centrosaurine from the Late Cretaceous of Alberta, Canada, and the evolution of parietal ornamentation in horned dinosaurs

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SOM 1. A sample of the matrix surrounding NHMUK R16306 was collected and processed for palynological analysis. Recovery from the sample was poor, but yielded the following species:
Aquilapollenites attenuatus Funkhouser, 1961
Aquilapollenites cf. *A. quadrilobus* Rouse emend. Srivastava and Rouse, 1970
Aquilapollenites trialatus Rouse, 1957
Aquilapollenites turbidus Tschudy and Leopold, 1971
Cibotiumspora juncta (Kara-Murza) Singh, 1983
Circumflexipollis tilioides Chlonova, 1961
Cyathidites minor Couper, 1953
Droseridites cf. *D. spinulosus* Manum, 1962
Heliosporites kemensis (Chlonova) Srivastava, 1972
Integricorpus clarireticulatus Samoilovitch, 1965
Laevigatosporites haardti (Potonié and Venitz) Thomson and Pflug, 1953
Mancicorpus anchoriforme Mtchedlishvili *in* Samoilovitch and Mtchedlishvili 1961
Retitriletes mediocris (Bolkhovitina) Krutzsch, 1963
Siberiapollis montanensis Tschudy, 1971
Scabrastephanocolpites lepidus Srivastava, 1969
Taxodiaceaepollenites hiatus (Potonié) Kremp, 1949
Translucentipollis plicatilis Chlonova, 1961
Tricolpites reticulatus Cookson, 1947

A previous study at Dinosaur Provincial Park (Braman and Koppelhus 2005) demonstrated that most of the palynological species in this assemblage have long ranges that span all of the exposed section at Dinosaur Provincial Park (including the Oldman, Dinosaur Park, and Bearpaw formations). An exception to this generalization is *Translucentipollis plicatilis*, which has a restricted range from the uppermost few metres of the Oldman Formation through the Dinosaur Park Formation into the Bearpaw Formation. This would therefore indicate that the ceratopsian specimen came from the uppermost few metres of the Oldman Formation or from the Dinosaur Park Formation. Previous work in the area has shown that the exposed section from where the specimen was taken spans the uppermost Oldman and lower Dinosaur Park formations. Until the quarry site can be located and more accurately placed in a stratigraphic context, the stratigraphic position of the specimen cannot be determined more accurately.

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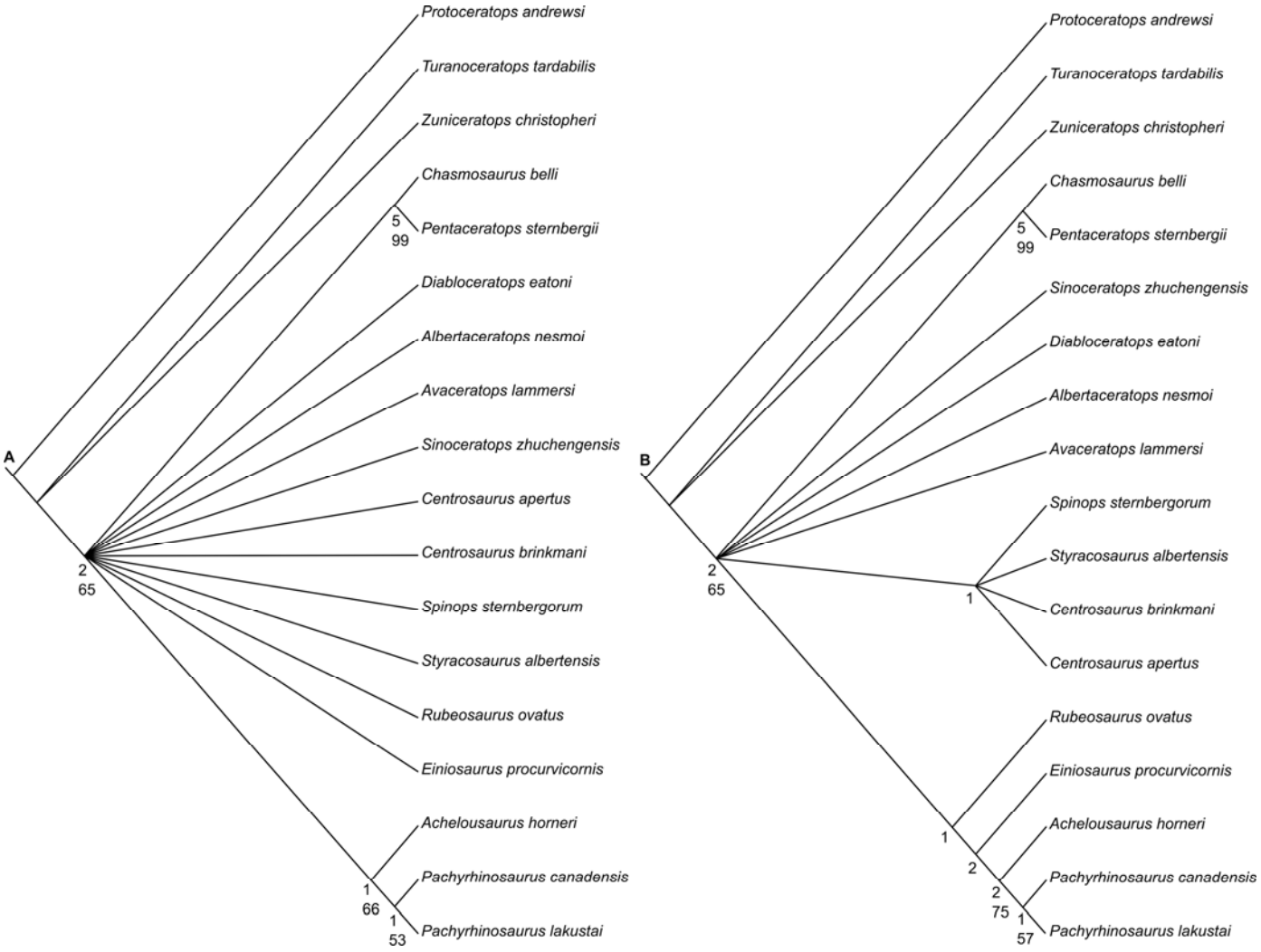
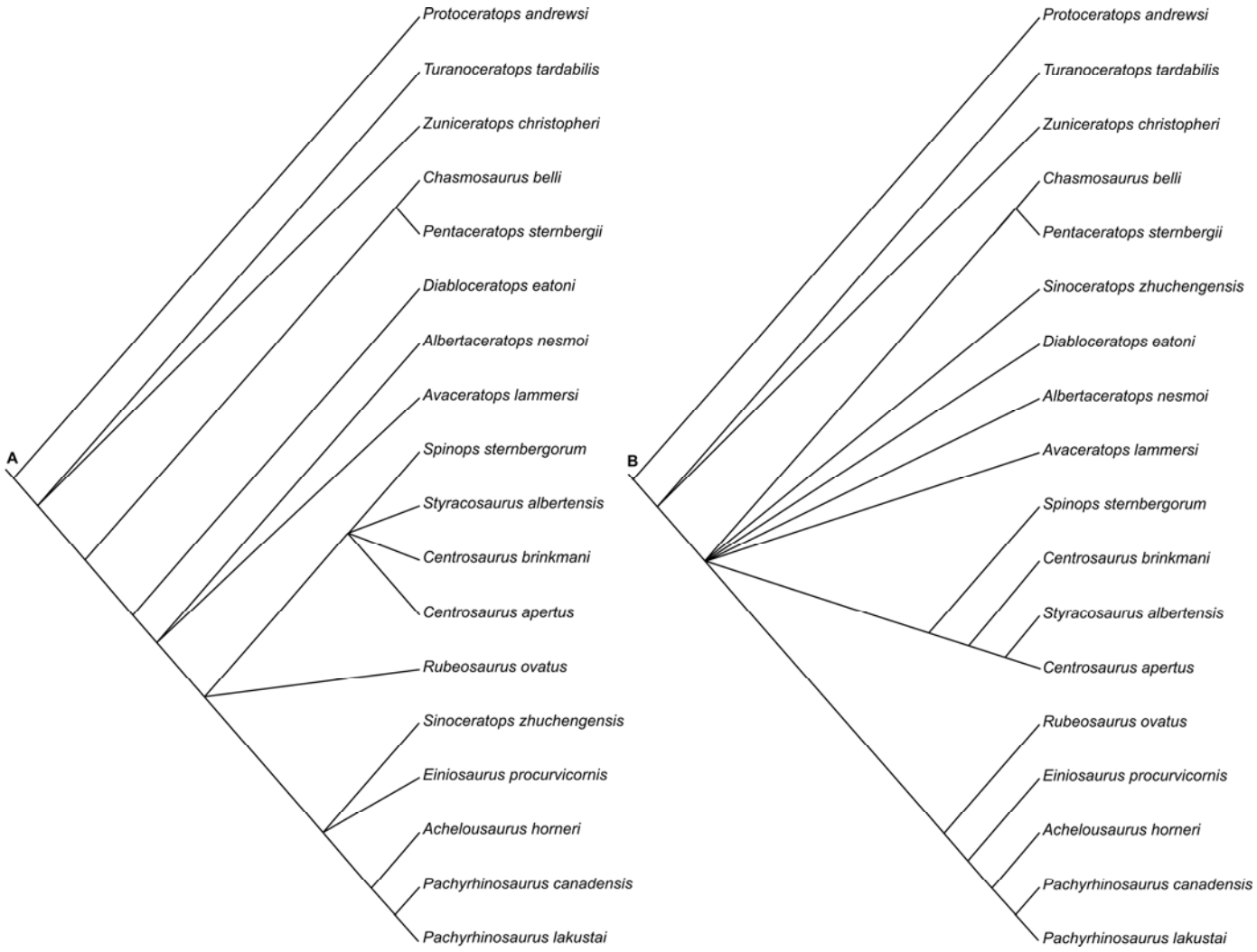
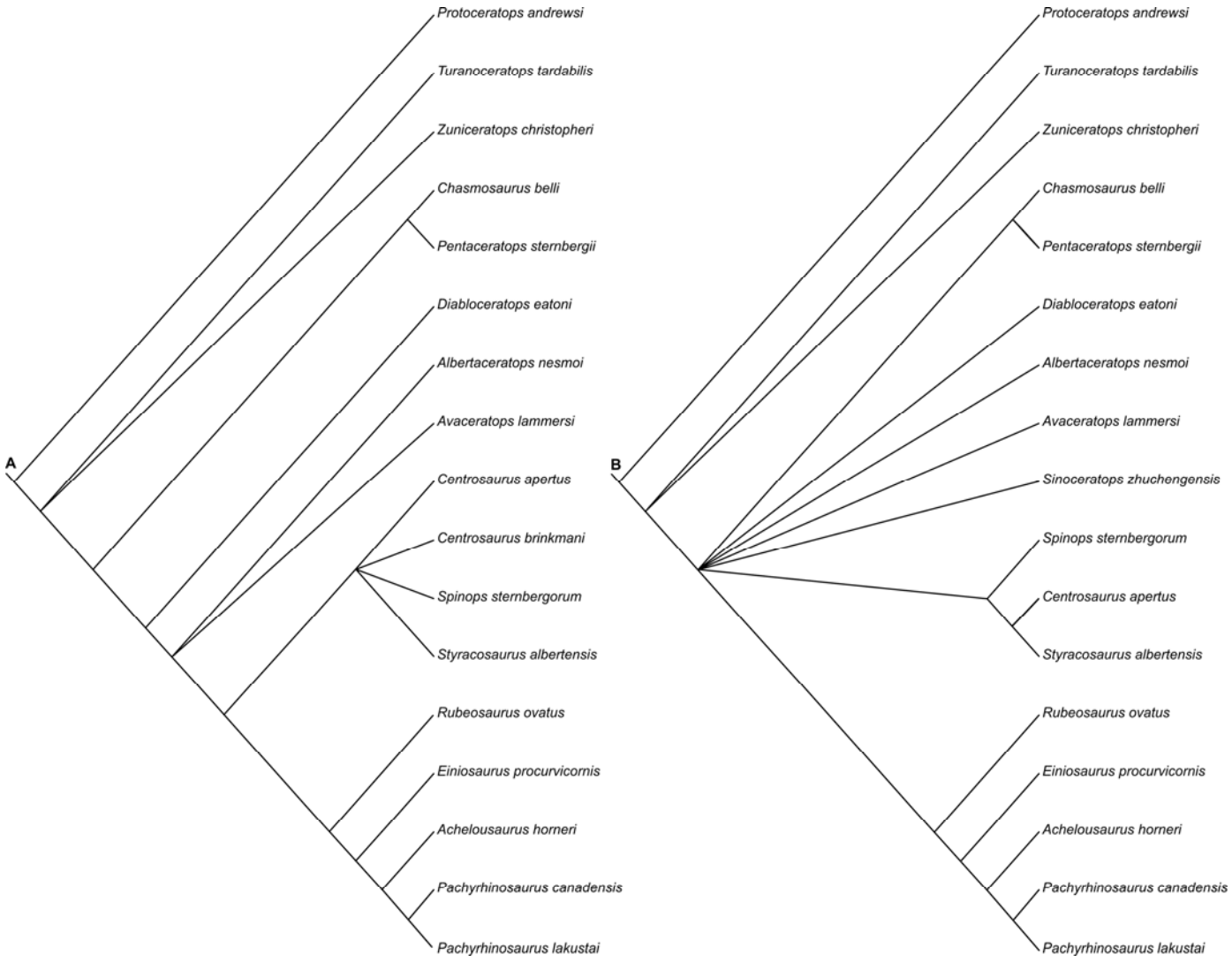
SOM 2. Phylogenetic hypotheses for relationships within Ceratopsidae, focusing on Centrosaurinae. **A**. Strict consensus tree using "traditional" codings for the epiparietal homologies in selected centrosaurines. **B**. Strict consensus tree using "new" codings for epiparietal homologies. At selected nodes, the top number indicates Bremer support and the bottom number indicates bootstrap support values above 50 percent.



SOM 3. Phylogenetic hypotheses for relationships within Ceratopsidae, focusing on Centrosaurinae. **A**. 50 percent majority rule consensus tree using "traditional" codings for the epiparietal homologies in selected centrosaurines. **B**. 50 percent majority rule consensus tree using "new" codings for epiparietal homologies.



SOM 4. Phylogenetic hypotheses for relationships within Ceratopsidae, focusing on Centrosaurinae. **A**. Strict reduced consensus tree using "new" codings for the epiparietal homologies in selected centrosaurines, with *Sinoceratops zhuchengensis* removed. **B**. Strict reduced consensus tree using "new" codings for the epiparietal homologies in selected centrosaurines, with *Centrosaurus brinkmani* removed.



SOM 5. List of characters and character states used in the phylogenetic analysis of Centrosaurinae. The characters are listed by general anatomical category, with citations indicating first use within a cladistic context. Original uses within a non-cladistic context (e.g., within a taxonomic diagnosis) are not considered.

Dermal skull roof

1. Rostral, extent of dorsal and ventral processes: (0) triangular in lateral view, with short dorsal and ventral processes; (1) elongate, with deeply concave caudal margin and hypertrophied dorsal and ventral processes; (Dodson et al. 2004, character 1).
2. Premaxillary septum, shape: (0) rostrally elongate; (1) semicircular; (Dodson et al. 2004, character 4).
3. Premaxillary septum, nasal contribution: (0) septum formed by premaxilla only; (1) septum formed by premaxilla and nasal; (Sampson et al. 2010, character 5).
4. Premaxilla, narial strut: (0) absent; (1) present; (Holmes et al. 2001, character 1).
5. Premaxilla, septal fossa: (0) absent; (1) present; (Holmes et al. 2001, character 4).
6. Premaxilla, triangular process: (0) absent; (1) present; (Forster 1990, character 21).
7. Premaxilla, recess along ventral portion of septum: (0) absent; (1) present; (Dodson et al. 2004, character 9).
8. Premaxilla, caudoventral expansion of oral margin: (0) absent; (1) present; (Forster 1990, character 6).
9. Premaxilla, ventral extent of caudoventral oral margin: (0) at or above level of alveolar margin of maxilla; (1) well below alveolar margin of maxilla; (Makovicky and Norell 2006, character 12, modified).
10. Caudoventral oral margin, composition of ventral angle: (0) premaxilla and maxilla; (1) premaxilla only; (Makovicky and Norell 2006, character 12, modified).
11. Premaxilla, position of caudal tip of caudoventral process: (0) inserts into an embayment in the nasal; (1) intervenes between nasal and maxilla; (Forster et al. 1993, character 7).
12. Premaxilla, distal end of caudoventral process forked: (0) absent; (1) present; (Forster 1990, character 14).
13. Premaxilla-nasal contact in dorsal view: (0) premaxillae insert between nasal; (1) nasals insert between premaxillae; (Sampson et al. 2010, character 20).
14. Accessory antorbital fenestra: (0) present; (1) absent; (Forster 1990, character 15).
15. Accessory antorbital fenestra size: (0) pronounced, penetration of nasal cavity visible in lateral view; (1) slight penetration, nasal cavity not visible in lateral view; (Sampson et al. 2010, character 22).
16. External antorbital fossa, size: (0) large, 20% or more length of body of maxilla; (1) greatly reduced or absent, less than 10% length of body of maxilla; (Forster 1990, character 44).
17. Maxillary tooth row, position: (0) ventrally displaced from rostral edentulous portion of maxilla; (1) at same level as rostral edentulous portion of maxilla; (Sampson et al. 2010, character 24).
18. Maxilla, maxillary cavity: (0) absent; (1) present; (Sampson et al. 2010, character 26).
19. Ectopterygoid/pterygoid complex: (0) covers entire dorsal surface and laps onto lateral surface of caudal ramus of maxilla; (1) ectopterygoid vestigial; (new character).
20. Nasal, ornamentation type in adult (ORDERED): (0) non-pronounced; (1) distinct horncore; (2) pachyostotic boss; (Forster 1990, character 26, 27, 28, 126, modified).
21. Epinasal ossification on nasal: (0) absent; (1) present; (new character).
22. Nasal, narial spine: (0) absent; (1) present; (Forster 1990, character 22).
23. Postorbital, extent of cornual sinuses in base of supraorbital ornamentation: (0) sinus invades frontal and parietal; (1) sinus enters postorbital; (Forster 1990, character 123, modified).
24. Postorbital, type of supraorbital ornamentation in subadult: (0) pointed apex, horncore at least as tall as rostrocaudally long; (1) rounded apex, horncore rostrocaudally longer than tall; (Sampson 1995, character 10, modified).
25. Postorbital, type of supraorbital ornamentation in adult: (0) horncore; (1) rugose boss; (Sampson 1995, character 9, modified).
26. Postorbital, position of supraorbital horncore: (0) centered rostrodorsal or dorsal to orbit, narrow base with caudal margin of supraorbital horncore extending to or only slightly behind caudal margin of orbit; (1) centered caudodorsal to orbit, broad base with caudal margin of supraorbital horncore extending well behind caudal orbit (Lehman 1996, character 9).
27. Postorbital, orientation of supraorbital horncore base: (0) dorsally directed; (1) dorsolaterally directed; (Sampson et al. 2010, character 38).
28. Postorbital, length of supraorbital horncore: (0) short, less than 15% basal skull length; (1) present, elongate, greater than 35% basal skull length; (Forster 1990, character 58, modified).
29. Postorbital, curvature of supraorbital horncore in lateral view: (0) caudally recurved; (1) rostrally curved; (2) straight; (Forster et al. 1993, character 2, modified).
30. Postorbital, curvature of supraorbital horncore in rostral view: (0) medially recurved; (1) laterally curved; (2) straight; (Sampson et al. 2010, character 41).
31. Prefrontal-prefrontal contact: (0) absent; (1) present; (Forster 1990, character 30, modified).
32. Palpebral, shape: (0) rod-like, articulates with prefrontal only at its base and projects across dorsal orbit, ligamentous attachment; (1) blocky, fully fused into dorsal orbital margin, sutural articulation with prefrontal and frontal; (Forster 1990, character 31, modified).

33. Palpebral, antorbital buttress: (0) absent; (1) present; (Sampson 1995, character 7, modified).
34. Palpebral, extent of antorbital buttress: (0) present along only rostrorodorsal portion of orbit; (1) present along entire rostral portion of orbit; (Currie et al. 2008, modified).
35. Jugal, size and orientation of jugal body: (0) projects strongly caudoventrally, does not extend below the level of the maxillary tooth row; (1) projects nearly ventrally, elongated to extend below the level of the maxillary tooth row; (Makovicky 2001, character 22).
36. Jugal infratemporal process: (0) absent; (1) present, contacts or nearly contacts infratemporal process of squamosal; (Forster 1990, character 62, modified).
37. Epijugal attachment scar: (0) large blade like triangle with obtuse angle oriented towards quadratojugal; (1) scar roughly equilateral in shape; (Sereno 1999, character 113, modified).
38. Frontal fontanelle leading into supracranial cavity complex (ORDERED): (0) absent; (1) present; (Forster et al. 1996, character 3, modified).
39. Frontal fontanelle, shape: (0) transversely narrow, slit-like; (1) key-hole shaped, circular or elongate oval; (Forster 1990, characters 49 and 50, modified).
40. Parietal, rostral extent on dorsum of skull relative to occipital condyle: (0) rostral end of parietal located well in front of occipital condyle; (1) rostral end of parietal lies directly over occipital condyle; (Sampson et al. 2010, character 57).
41. Squamosal, shape of expanded blade: (0) sub-rectangular in outline; (1) triangular in outline, caudally narrowed; (Sampson et al. 2010, character 59).
42. Squamosal, rostromedial lamina forming the caudolateral floor of dorsotemporal fenestra: (0) absent; (1) present; (Penkalski and Dodson 1999, character 9).
43. Squamosal-quadrate contact: (0) socket-like cotylus on ventrolateral squamosal for ball-like quadrate head; (1) elongate groove on medial surface of squamosal to receive lamina of quadrate; (Forster 1990, character 64, modified).
44. Squamosal, thickened, rounded swelling along medial margin: (0) absent, lateral surface of squamosal flat to slightly convex; (1) present, lateral surface of squamosal slightly concave; (Forster 1990, character 90).
45. Parietosquamosal contact, shape in lateral view: (0) straight; (1) curved, medially concave; (Forster 1990, character 119).
46. Parietal, concave median embayment on caudal margin: (0) absent; (1) present; (Sampson et al. 2010, character 66).
47. Parietal, shape of concave median embayment: (0) shallow, restricted to center of margin; (1) shallow, entire transverse bar is a V-shaped embayment; (Forster 1990, character 83, modified).
48. Parietal, rim on medial margin of dorsotemporal fenestra: (0) absent; (1) present, well-defined, laterally projecting rim defines medial margin of fenestra; (Forster 1990, character 86).
49. Parietal, sharp median crest: (0) present; (1) absent; (Sampson et al. 2010, character 75).
50. Parietal, rostrocaudal thickness of transverse bar at narrowest point: (0) narrow and straplike, less than 10% total parietal length; (1) broad, 20% or more of total parietal length; (Holmes et al. 2001, character 22).
51. Parietal, median bar, transverse width: (0) narrow and straplike, transverse width less than 10% total parietal length; (1) relatively wide, transverse width 15% or more of total parietal length; (Holmes et al. 2001, character 23).
52. Parietosquamosal frill, imbrication of marginal undulations: (0) absent; (1) present; (Dodson et al. 2004, character 34).

Epiossifications

53. Marginal dermal ossifications on parietal and squamosal: (0) absent; (1) present; (Forster 1990, characters 91 and 92, modified).
54. Episquamosal, midlateral, shape: (0) crescentic or ellipsoidal; (1) triangular or elongate; (Dodson et al. 2004, character 45, modified).
55. Episquamosals, number per side: (0) three to five; (1) six or more; (new character).
56. Marginal ossification crossing squamosal-parietal contact: (0) absent; (1) present; (Dodson et al. 2004, character 43).
57. Epiparietals, number per side: (0) three; (1) five or more; (Holmes et al. 2001, character 28).
58. Epiparietal locus P1: (0) absent; (1) present; (Sampson 1995, character 14, modified).
59. Epiparietal, shape of locus P2: (0) low D-shaped process, wider than long; (1) elongate flattened process or spike, longer than wide; (Sampson 1995, character 15, modified).
60. Epiparietal, curvature of locus P2: (0) straight; (1) laterally curved; (2) medially curved; (3) dorsally curved; (Sampson 1995, character 15, modified).
61. Epiparietal, shape of locus P3: (0) low D-shaped or triangular process; (1) elongate flattened process or spike; (Sampson 1995, character 16, modified).
62. Epiparietal, curvature of locus P3: (0) uncurved or slightly medially curved; (1) laterally curved; (2) dorsally curved (new character).

63. Epiparietal, locus P4 shape: (0) low raised D-shaped process; (1) elongate spike; (Sampson et al. 2010, character 102, modified).
64. Epiparietal, locus P5: (0) absent; (1) present; (new character).
65. Epiparietal, locus P5 shape: (0) low D-shaped or triangular process; (1) elongate spike; (new character).
66. Epiparietal, locus P6: (0) absent; (1) present; (new character).
67. Epiparietal, locus P6 shape: (0) low D-shaped or triangular process; (1) elongate spike; (new character).
68. Epiparietal, locus P7: (0) absent; (1) present; (new character).

Braincase

69. Supraoccipital, contribution to foramen magnum: (0) forms dorsal margin of foramen magnum; (1) eliminated from margin by exoccipital-exoccipital contact on midline; (Forster 1990, character 63).

Lower jaw

70. Predentary, dentary processes: (0) ventral processes much longer than abbreviated dorsal processes; (1) dorsal and ventral processes elongate and subequal in length; (Sampson et al. 2010, character 114).
71. Predentary, orientation of triturating surface: (0) nearly horizontal; (1) inclined steeply laterally; (Dodson et al. 2004, character 57).
72. Dentary lateral ridge confluent with cutting surface of predentary: (0) present; (1) absent; (Sampson et al. 2010, character 116).
73. Dentary, caudal extent of tooth row: (0) terminates at the center of the coronoid process; (1) terminates caudal to the coronoid process; (Chinnery and Weishampel 1998, character 18).

Dentition

74. Teeth, number of roots: (0) one; (1) two; (Forster 1990, character 34).
75. Teeth, number of alveoli in dentary: (0) fewer than 20; (1) more than 20; (Makovicky and Norell 2006, character 104).
76. Teeth, number of replacements per alveolus: (0) one or two replacement teeth; (1) three or more replacement teeth; (Sereno 1999, character 137).

Axial skeleton

77. Cervical vertebrae, formation of syncervical: (0) C1-3 fused or tightly articulated, atlantal hypocentrum present as a ventrally placed, wedge-like bone; (1) C1-3 firmly fused, atlantal hypocentrum forms a complete ring; (Forster 1990, character 122)
78. Axis, neural spine shape and orientation: (0) blade-like and nearly vertical, overhangs only rostralmost portion of C3; (1) blade-like morphology lost, spine steeply angled to reach caudal margin of C3; (Sereno 1999, character 141)
79. Atlantal rib: (0) present; (1) absent; (Sampson et al. 2010, character 129).
80. Dorsal vertebrae, shape of centra: (0) relatively axially elongate; (1) axially shortened; (Sampson et al. 2010, character 130).
81. Sacrum, longitudinal sulcus on ventral surface: (0) absent; (1) present (Sereno 1999, character 144).

Pectoral girdle and forelimb

82. Scapula, relative contribution to glenoid fossa: (0) scapula and coracoid contribute equally; (1) scapula contributes well over half of the glenoid; (Sereno 1999, character 145).
83. Olecranon process: (0) relatively small; (1) enlarged (>one-third of ulnar length); (Forster 1990, character 104, modified).
84. Clavicle: (0) present; (1) absent; (Sereno 1999, character 147).
85. Manual and pedal unguals, shape: (0) taper to distal tip; (1) dorsoventrally flattened with blunt and rounded distal tips; (Chinnery and Weishampel 1998, character 64).
86. Manal and pedal penultimate phalanges, shape: (0) length exceeds width; (1) width exceeds length; (Sampson et at. 2010, character 137).

Pelvic girdle and hind limb

87. Ilium, lateral eversion of dorsal margin: (0) absent; (1) present; (Forster 1990, characters 108-109, modified).
88. Ilium, relative lengths of pubic and ischial peduncles: (0) pubic and ischial peduncles long, extend well below body of ilium approximately the same distance; (1) ischial peduncle reduced along ventral aspect, pubic peduncle projects further ventrally than ischial peduncle; (Sampson et al. 2010, character 139).
89. Pubis, prepubic process: (0) short and unexpanded distally; (1) elongate, distal end greatly expanded dorsoventrally; (Forster, 1990, character 111).
90. Pubis, position and length of postpubic rod: (0) relatively short but extends past ischial peduncle of ilium, arises ventral to acetabulum and lies along ventral and ventromedial margin of ischium; (1) very

abbreviated, terminates at level of ischial peduncle, arises medial to acetabulum and passes entirely medial to ischium; (Forster 1990, character 110).

91. Pubis and ischium, morphology of contributions to acetabulum: (0) pubic acetabular surface faces caudolaterally, pubis and pubic process of ischium contribute equally to ventral margin of acetabulum; (1) pubic acetabular surface faces laterally and forms a partial medial wall to the acetabulum, pubic process of ischium elongate and meets pubis close to anterior margin of acetabulum, ventral portion of pubic acetabular surface lies medial to pubic ramus of ischium; (Sampson et al. 2010, character 142).
92. Ischium, cross-sectional shape of shaft: (0) thick and ovoid; (1) laterally compressed and bladelike, tapered dorsally; (Forster 1990, character 112).
93. Ischium, orientation of shaft: (0) nearly straight or slightly decurved; (1) broadly and continuously curved; (Forster 1990, character 113).
94. Femur, morphology of greater and lesser trochanters: (0) trochanters distinct and located below the level of the femoral head; (1) trochanters coalesced and level with the femoral head; (Dodson et al. 2004, character 72).
95. Femur, size of fourth trochanter: (0) large and pendant; (1) small, reduced to low prominence; (Sereno 1999, character 154).
96. Femur-tibia proportion: (0) tibia longer than femur; (1) femur longer than tibia; (Forster 1990, character 103).
97. Pes, metatarsal proportions: (0) length of MT I two-thirds the length of MT II; (1) MT I reduced to one half or less the length of MT II; (Sampson et al. 2010, character 148).

Alternative codings

98-108. These characters are equivalent to characters 58-68, except that *Albertaceratops nesmoi*, *Diabloceratops eatoni*, and *Spinops sternbergorum* were coded in the “traditional” scheme where the elongated spike was treated as epiparietal locus P3. Loci lateral to this were numbered accordingly for these taxa.

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