A new phylogeny of Stegosauria (Dinosauria, Ornithischia)

Online Supplementary Material

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RH: RAVEN AND MAIDMENT—A NEW STEGOSAUR PHYLOGENY

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APPENDIX S1: CHARACTER LIST

1. Snout, depth: depth to length ratio of maxilla coded as continuous.

2. Teeth: number coded as meristic.

3. Teeth: Number of denticles on mesial side of maxillary teeth.

4. Premaxilla: Height to length ratio of subnarial portion coded as continuous.

5. Cervical vertebrae: number coded as meristic.

6. Dorsal vertebrae: neural arch to neural canal height ratio as continuous.

7. Dorsal vertebrae: centrum height to neural arch height ratio coded continuously.

8. Dorsal vertebrae: centrum height to neural arch height ratio coded continuously.

9. Dorsal vertebrae: number coded as meristic.

10. Scapula: proximal plate area to coracoid area ratio coded continuously.

11. Humerus: ratio of width of distal end to minimum shaft width coded continuously.

12. Humerus: ratio of transverse width of distal end to length coded continuously.

13. Humerus: anterior iliac process length to humerus length coded continuously.

14. Ulna: proximal width to length ratio coded continuously.

15. Ratio of ulna length to humerus length coded continuously.

16. Ratio of radius length to humerus length coded continuously.

17. Metacarpal II to humerus length ratio coded continuously.

18. Ilium: anterior iliac process to acetabular length ratio coded continuously.

19. Ilium: ratio of acetabular length to dorsoventral height of pubic peduncle of ilium coded continuously.

20. Pubis: prepubis to postpubis length ratio coded continuously.

21. Pubis: postpubis to acetabular length ratio coded continuously.

22. Femur: length to humerus length ratio coded continuously.

23. Femur: length to tibia length ratio continuously.

24. Metatarsal IV: ratio of length to width coded as continuous. Maximum length and maximum widths used.

25. Skull, overall shape in posterior view: deeper than wide (0); wider than deep (1).

26. Premaxilla: process projecting caudodorsally from caudolateral corner - gracile (0); robust (1).

27. Premaxilla: Caudodorsally projecting process from craniomedial border extends dorsally to be- visibile on skull roof in dorsal view (0); not visible on skull roof (1).

28. Premaxilla: Broad ‘V’ or ‘U’ shaped notch between premaxillae on the midline absent (0); present (1).

29. Maxilla: tooth row inset medially from the lateral surface of the maxilla absent (0); present (1).

30. Lacrimal: contacts prefrontal (0); doesn’t contact prefrontal (1).

31. Frontals: rostrocaudally longer than wide transversely (0); wider than long (1).

32. Frontals: form the dorsal rim of the orbit (0); supraorbital elements form the dorsal rim of the orbit (1).

33. Parietals, dorsal surface: convex (0); flat (1).

34. Quadrate: fossa/fenestra absent (0); present (1).

35. Quadrate: proximal head strongly transversely compressed, absent (0); present (1)

36. Quadrate: head is strongly arched posteriorly relative to the shaft, absent (0); present (1).

37. Quadrate: axis extending through condyles in posterior view orientated transversely (0); orientated strongly ventromedially (1).

38. Quadrate: contact with paroccipital process unfused (0); fused (1).

39. Quadrate: lateral ramus present (0); absent (1).

40. Quadratojugal: rectangular shape (0); possesses dorsal process that extends to craniolateral surface of quadrate in lateral view (1).

41. Basioccipital: exit for vagus nerve braincase: posterior surface (0); lateral surface (metotic fissure) (1).

42. Jaw joint: ventral to tooth row (0); level with tooth row (1).

43. Dentary: postdentary bones greater in rostrocaudal length than dentary (0); shorter (1).

44. Dentary: tooth row in lateral view visible (0); not visible (1).

45. Dentary: tooth alveoli face dorsally (0); dorsomedially (1).

46. Dentary: tooth row in lateral view straight (0); sinuous (1).

47. Tooth crowns: striations not confluent with denticles (0); confluent with denticles (1).

48. Tooth crowns: asymmetric (0); symmetric (1).

49. Teeth: diastema between predentary facet on the dentary and first tooth present (0); absent (1).

50. Premaxillary teeth: present (0); absent (1).

51. Maxillary teeth: cingulum absent (0); present (1).

52. Skull roof: cortical remodelling absent (0); present (1).

53. Skull roof: cortical remodelling present in only some bones (0); present in all bones, along with the fusion of dermal ossifications, so that the antorbital and supratemporal fenestrae are closed (1).

54. Axis: neural spine triangular in lateral view (0); sub-rectangular in lateral view (1).

55. Axis: ventral margin in lateral view flat (0); concave (1).

56. CV3: centrum ventral margin straight (0); concave upwards (1).

57. Cervical vertebrae: longer anterposteriorly than wide transversely (0); wider than long (1).

58. Posterior cervical vertebrae: postzygapophyses not greatly elongated (0); greatly elongated and project over the back of the posterior centrum facet (1).

59. Anterior dorsal vertebrae: prezygapophyses are separated and face each other dorsally (0); joined ventrally and face dorsomedially (1).

60. Dorsal vertebrae: cranial and caudal articular facets on centra flat to slightly concave (0); strongly convex (1).

61. Dorsal vertebrae: all centra longer than wide (0); wider than long (1).

62. Dorsal vertebrae: transverse processes project approximately horizontally (0); at a high angle to the horizontal (1).

63. Dorsasacral vertebrae ribs: don’t fuse (0); fuse to dorsal margins of first true sacral vertebrae (1); fuse to medial margin of preacetabular process of ilium (2).

64. Sacral rod vertebrae: keel present (0); absent (1).

65. Anterior caudal vertebrae: dorsal process on transverse process absent (0); present (1).

66. Anterior caudal vertebrae: dorsal process transverse process proximal to centrum (0); distal to centrum (2).

67. Anterior caudal vertebrae: transverse processes on cd3 posteriorly are directed laterally (0); directed strongly ventrally (1).

68. Anterior caudal vertebrae: neural spine height less than or equal to the height of the centrum (0); greater than the height of the centrum (1).

69. Anterior caudal vertebrae: bulbous swelling at tops of neural spines absent (0); present (1).

70. Caudal vertebrae: prezygapophyses extend craniodorsally (0); extend cranially (1).

71. Caudal vertebrae: postzygapophyses extend cranially over caudal articular facet (0); do not (1).

72. Caudal vertebrae: transverse processes on distal half of tail present (0); absent (1).

73. Caudal vertebrae: neural spines bifurcated (0); not bifurcated (1).

74. Posterior caudal vertebrae: centra are elongate (0); equidimensional (1).

75. Scapula: acromial process in lateral view, convex upwards dorsally (0); quadrilateral with a posterordorsal corner (1).

76. Scapula: acromial process projects dorsally (0); projects laterally (1).

77. Scapula: blade, distally expanded (0); parallel sided (1).

78. Coracoid: sub-circular outline (0); anteroposteriorly longer than dorsoventrally high (1).

79. Coracoid: in lateral view, foramen present (0); notch present (1).

80. Humerus: triceps tubercle and descending ridge posterolateral to the deltopectoral crest absent (0); present (1).

81. Radius: expanded transversely at proximal end (0); not expanded (1).

82. Metacarpals I and V: shorter than metacarpals II, III and IV (0); longer (1).

83. Ungual phalanges: Manual and pedal unguals claw–shaped (0); hoof–shaped (1).

84. Ilium: anterior iliac process lies approximately horizontally (0); strongly angled ventrally (1).

85. Ilium: anterior iliac process projects roughly parallel to the parasagittal plane (0); diverges widely from the parasagittal plane (1).

86. Ilium: horizontal lateral enlargement absent (0); present (1).

87. Ilium: horizontal lateral enlargement incipient (small) (0); large (1).

88. Ilium: supra–acetabular flange projects at 90 degrees from the anterior iliac process absent (0); present (1).

89. Ilium: posterior iliac process, distal shape tapers (0); blunt (1).

90. Ilium: medial processes on posterior iliac processes absent (0); present (1).

91. Ilium: ventromedial flange backing the acetabulum absent (0); present (1).

92. Ilium: preacetabular process has inverted C-shaped cross section that is laterally convex and medially concave (0); does not i.e. transversely compressed (1).

93. Ilio–sacral block: Five or more sacral vertebrae (0); four or fewer sacral vertebrae (1).

94. Ilio–sacral block: Posterior sacral rib angled laterally (0); posterolaterally (1).

95. Ilio–sacral block: dorsal shield of sacrum is perforated by foramina in between ribs (0); is solid with no foramina (1).

96. Ischium: convex proximal margin within the acetabulum absent (0); present (1).

97. Ischium: dorsal surface of shaft is straight (0); has a distinct angle at approximately midlength (1).

98. Ischium: posterior end of ischium, expanded relative to the shaft (0); not expanded and tapers (1).

99. Pubis: obturator notch is backed by posterior pubic process absent (0); present (1).

100. Pubis: acetabular portion faces laterally, posteriorly and dorsally (0); faces wholly laterally (1).

101. Pubis: anterior end of prepubis expanded dorsally absent (0); present (1).

102. Femur: Fourth trochanter prominent and pendant (0); present as a rugose ridge (1); absent (2).

103. Femur: anterior trochanter fusion to greater trochanter in adults - unfused (0); fused (1).

104. Metatarsal V: present (0); absent (1).

105. Pedal digit I: present (0); absent (1).

106. Pedal digit III: has 4 or more phalanges (0); has 3 phalanges (1); has 2 or fewer phalanges (2). Code as ordered.

107. Pedal digit IV: has 5 phalanges (0); has 4 phalanges (1); has 3 or fewer phalanges (2). Code as ordered.

108. Dermal armour: including scutes, and/or spines and/or plates absent (0); present (1).

109. Plates and spines: two parasagittal rows of plates and/or spines absent (0); present (1).

110. Cervical collars: U–shaped cervical collars composed of keeled scutes absent (0); present (1).

111. Osteoderms: mosaic of small osteoderms between larger osteoderms on the ventral surfaces of the neck, trunk, and proximal portions of the limbs absent (0); present (1).

112. Parascapular spine: absent (0); present (1).

113. Dorsal plates: have a thick central portion like a modified spine (0); have a generally transversely thin structure, except at the base (1).

114. Parasagittal rows of dermal armour: paired (0); alternating either side of the midline (1).

115. Ossified epaxial tendons: present (0); absent (1).

APPENDIX S2: JUSTIFICATION FOR CHANGES TO CHARACTER LIST OF MAIDMENT (2010)

Character 21: Atlas: neural arch, contact with intercentrum in adults, not fused (0); fused (1) Removed as neural arch fusion varies intraspecifically and interspecifically (SCRM pers. Obs. 2004-2016).

Character 24: Cervical ribs: contact with para– and diapophyses of cervical vertebrae: unfused (0); fused (1). Removed as fused cervical ribs are present only in *Miragaia longicollom* and therefore is an autapomorphy of that taxon.

Character 30: Dorsal vertebrae: prezygapophyses are fused only in middle and posterior dorsals (0); fused on all dorsals (1). Replaced with: Character 59: Anterior dorsal vertebrae: prezygapophyses are separated and face each other dorsally (0); joined ventrally and face dorsomedially (1). Character has been reworded as the new description more accurately the conditions seen in taxa.

Character 33: Anterior caudal vertebrae: dorsal process on transverse process absent (0); present (1). Updated to become: Character 65: Anterior caudal vertebrae: dorsal process on transverse process absent (0); present and proximal to centrum (1); present and distal to centrum (2). The position of the dorsal process on the transverse processes varies in proximity to the centrum and so multi-state character statements more accurately describe the morphology (SCRM pers. Obs. 2004-2016).

Character 42: Scapula and coracoid: unfused (0); fused (1). Removed as Maidment et al. (2015) noted that fusion between the scapula and the coracoid was probably ontogenetic.

Character 49: Ulna: olecranon horn absent (0); present (1). Removed as Maidment et al. (2015) noted that development of an ocelcranon horn of the ulna is ontogenetic.

Character 50: Ratio of humerus length to ulna length. Reworded to Character 15: Ratio of ulna length to humerus length coded continuously. This was done as more data was present in the literature for the new character statement (e.g. Maidment & Wei, 2006).

Character 57: Ilium: supra–acetabular flange present (0); absent (1). Removed as description was of the same feature as Character 85: Ilium: horizontal lateral enlargement absent (0); present (1).

Character 72: Pubis: posterior end of postpubis relative to shaft, not expanded (0); expanded dorsoventrally(1). Removed because this is intraspecifically variable (Maidment et al. 2015).

Character 76: Femur: anterior trochanter fused to greater trochanter in adults absent (0); present (1). Updated to become: Character 102 Femur: anterior trochanter fusion to greater trochanter in adults - unfused (0); fused (1). This is a more accurate description of the character states in the taxa.

ADDITIONAL LITERATURE CITED

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MAIDMENT, S. C. R., BRASSEY, C. and BARRETT, P. M. 2015. The postcranial skeleton of an exceptionally complete individual of the plated dinosaur *Stegosaurus stenops* (Dinosauria: Thyreophora) from the Upper Jurassic Morrison Formation of Wyoming, U.S.A. *PLoS One*, **10 (10)**, e0138352.

APPENDIX 3: SYNAPOMORPHIES

Thyreophora

Character 2 (increases)

 Character 24 (decreases)

 Character 54 (reversed in *Laquintasaura* + *Scutellosaurus*, *Loricatosaurus* and *Stegosaurus stenops*)

Thyreophora except *Lesothosaurus*

 Character 8 (decreases; reversed in *Gastonia* + *Euoplocephalus* and *Chungkingosaurus*)

 Character 29 (reversed in *Paranthodon* + *Tuojiangosaurus*)

 Character 46 (reversed in *Stegosaurus stenops*)

 Character 52

 Character 85

 Character 100 (reversed in *Dacentrurus* and *Miragaia*; equivocal in *Emausaurus*)

 Character 107 (reversed in *Laquintasaura*)

*Scutellosaurus + Laquintasaura*

 Character 54 (reversal to 0)

*Emausaurus* + Thyreophoroidea

Thyreophoroidea

 Character 9 (increases, reversed in *Stegosaurus stenops*)

 Character 12 (increased; equivocal in *Emausaurus*)

 Character 18 (increased)

 Character 21 (decreased, equivocal in *Emausaurus*)

 Character 23 (increase; equivocal in *Emausaurus*)

*Alcovasaurus* + Eurypoda

 Character 32

 Character 37

 Character 62, reversed in *Gigantspinosaurus*

 Character 86 (equivocal in *Emausaurus*)

 Character 96 (reversed in *Euoplocephalus* and *Dacentrurus*; convergent in *Laquintasaura*)

 Character 97

Eurypoda

 Character 10 (increases; equivocal in *Alcovasaurus*)

 Character 13 (Increased; reversed in *Dacentrurus*)

 Character 15 (increased; equivocal in *Alcovasaurus*)

 Character 17 (equivocal in *Alcovasaurus*)

 Character 39 (equivacol in *Alcovasaurus*)

 Character 50 (equivocal in *Alcovasaurus*)

 Character 51 (equivocal in *Alcovasaurus*, reversed in *Huayangosaurus* and *Gastonia*)

 Character 59 (equivocal in *Alcovasaurus*, reversed in *Stegosaurus stenops*)

 Character 82 (equivocal in *Alcovasaurus*)

 Character 84 (equivocal in *Alcovasaurus*; reversed in *Huayangosaurus* + *Chungkingosaurus*)

 Character 90 (state 0; equivocal in *Alcovasaurus*; reversed in *Kentrosaurus*)

 Character 91 (state 0; equivocal in *Alcovasaurus*)

 Character 102 (places *Alcovasaurus* outside of Eurypoda)

 Character 106 (state 2; equivocal in *Alcovasaurus*, state 1 in *Sauropelta*)

Ankylosauria

 Character 14 (increased; convergent with *Stegosaurus*)

 Character 25

 Character 34 (reversal to 0)

 Character 38

 Character 47 (convergent in *Paranthodon* + *Tuojiangosaurus*)

 Character 53

 Character 71 (convergent in *Scutellosaurus*, *Loricatosaurus* + *Stegosaurus*)

 Character 75

 Character 109 (convergent in *Scelidosaurus*)

 Character 110

*Gastonia* + *Euoplocephalus*

 Character 8 (increases, reversal)

 Character 28, convergent in *Stegosaurus stenops*

 Character 95

Stegosauria

 Character 6 (increases, reversals in *Kentrosaurus* and *Miragaia* + *Hesperosaurus*)

 Character 35

 Character 70 (reversed in *Loricatosaurus*)

 Character 79

 Character 99 (convergent in *Euoplocephalus*)

 Character 104 (convergent in *Euoplocephalus*)

 Character 108

*Huayangosaurus* + *Chungkingosaurus* + *Paranthodon* + *Tuojiangosaurus*

 Character 26, convergent in *Scelidosaurus*

 Character 83 (convergent in *Stegosaurus* and *Euoplocephalus*)

*Huayangosaurus* + *Chungkingosaurus*

 Character 84 (reversal to state 0)

*Paranthodon* + *Tuojiangosaurus*

 Character 29 (state 0)

 Character 47 (convergent in Ankylosauria)

*Jiangjunosaurus* to *Stegosaurus*

 Character 5 (increases)

 Character 36

*Gigantspinosaurus* to *Stegosaurus*

 Character 101 (state 2; equivocal in *Jiangjunosaurus*)

 Character 111 (equivocal in *Jiangjunosaurus*; reversed in *Stegosaurus*)

*Kentrosaurus* to *Stegosaurus*

 Character 7 (decreases; reversed *Miragaia* + *Hesperosaurus*)

 Character 19 (increased, equivocal in *Gigantspinosaurus* and *Jiangjunosaurus*)

 Character 24 (decrease; equivocal in *Gigantspinosaurus* and *Jiangjunosaurus*)

 Character 44, convergent in *Tuojiangosaurus*

 Character 68, convergent in *Alcovasaurus*

 Character 73 (equivocal in *Jiangjunosaurus* and *Gigantspinosaurus*)

 Character 76 (convergent in Sauropelta)

 Character 94

 Character 105 (state 2; equivocal in *Gigantspinosaurus*)

 Character 114 (reversed in *Hesperosaurus*)

*Dacentrurus* to *Stegosaurus*

 Character 11 (decreased/low. Convergent in *Scutellosaurus*; reversed in *Hesperosaurus*)

 Character 88 (convergent in *Scelidosaurus*)

*Loricatosaurus* to *Stegosaurus*

 Character 69 (State 0)

 Character 71 (convergent in Ankylosauria and *Scutellosaurus*)

 Character 112

*Stegosaurus*

 Character 14 (increased; convergent with Ankylosauria)

 Character 22 (increased; convergent with *Gastonia*

 Character 40 (state 0; equivocal in *Gigantspinosaurus*, *Kentrosaurus*, *Loricatosaurus*, *Dacentrurus*)

 Character 58

 Character 66

 Character 74 (equivocal in *Dacentrurus* and *Loricatosaurus*)

 Character 77 (state 0; equivocal in *Dacentrurus* and *Loricatosaurus*)

 Character 83 (convergent in *Huayangosaurus* to *Tuojiangosaurus* and *Euoplocephalus*)

 Character 87

 Character 89 (equivocal in *Loricatosaurus*)

 Character 111 (reversed to state 0)

*Stegosaurus homheni* + *Stegosaurus stenops*

*Miragaia* + *Hesperosaurus*

 Character 6 (reversal to decreased; convergent in *Kentrosaurus*)

 Character 7 (reversal to increased)