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The enigma of Enaliosuchus, and a reassessment of the Lower Cretaceous fossil record of Metriorhynchidae

Citation for published version:

Sachs, S, Young, M & Jahn, H 2020, 'The enigma of Enaliosuchus, and a reassessment of the Lower Cretaceous fossil record of Metriorhynchidae', *Cretaceous Research*, vol. 114.
<https://doi.org/10.1016/j.cretres.2020.104479>

Digital Object Identifier (DOI):

[10.1016/j.cretres.2020.104479](https://doi.org/10.1016/j.cretres.2020.104479)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Cretaceous Research

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Manuscript Details

Manuscript number	YCRES_2019_400_R1
Title	The enigma of Enaliosuchus, and a reassessment of the Lower Cretaceous fossil record of Metriorhynchidae
Article type	Full Length Article

Abstract

Enaliosuchus macrospondylus Koken, 1883 was one of the first thalattosuchian taxa from the Cretaceous to be described. The type series includes an atlas-axis complex, remnants of three post-axial cervical vertebrae, several dorsal vertebrae, a caudal vertebra, an incomplete femur and a fragmentary sacral rib from the upper Valanginian of northern Germany. Additionally, two isolated, non-thalattosuchian, tooth crowns from the uppermost Valanginian to lowermost Hauterivian of different localities in northern Germany were tentatively assigned to *E. macrospondylus* by Koken. The taxon was established for the distinctive the atlas-axis morphology, in particular the apparent lack of an axis parapophysis. *Enaliosuchus macrospondylus* has been considered a valid taxon in recent studies, based upon a largely complete metriorhynchid specimen from the Valanginian of France that had been referred to this taxon, an assignment that has never been questioned. Here we provide a detailed re-description of the *E. macrospondylus* holotype specimen and determine whether it is diagnostic, and if a referral of the French specimen to *E. macrospondylus* is justified. We also discuss whether *E. macrospondylus* and another metriorhynchid specimen from the Valanginian of northern Germany, described as *Enaliosuchus schroederi*, are conspecific. Finally, we provide an overview of the current knowledge of metriorhynchid diversity during the Cretaceous.

Keywords	Crocodylomorpha; Thalattosuchia; Metriorhynchidae; Lower Cretaceous; Germany
Taxonomy	Systematic Paleontology, Vertebrate Paleontology
Corresponding Author	Sven Sachs
Corresponding Author's Institution	Naturkunde-Museum Bielefeld
Order of Authors	Sven Sachs, Mark Young, Jahn Hornung
Suggested reviewers	Michela Johnson, Yana Herrera, Davide Foffa, Eric Wilberg
Opposed reviewers	Stéphane Jouve, Stephane Hua, Jeremy Martin

Submission Files Included in this PDF

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Sachs-Hornung-Young-Enaliosuchus_revised.docx [Manuscript File]

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Dear Eduardo,

we are grateful for the comments on our manuscript “The enigma of *Enaliosuchus*, and a reassessment of the Lower Cretaceous fossil record of Metriorhynchidae” are we are pleased to resubmit a revised version. We incorporated most of the suggested changes and provide a detailed response in a separate file. Both reviews were very fair and helped to improve the quality of our paper.

We hope you will find our revised manuscript suitable for publication in *Cretaceous Research*.

Best wishes,

Sven Sachs

1 The enigma of *Enaliosuchus*, and a reassessment of the Lower 2 Cretaceous fossil record of Metriorhynchidae

3

4 Sven Sachs^{a, b *}, Mark T. Young^c, Jahn J. Hornung^d

5

6 ^A Naturkunde-Museum Bielefeld, Abteilung Geowissenschaften, Adenauerplatz 2, 33602 Bielefeld, Germany

7 ^B Im Hof 9, 51766 Engelskirchen, Germany

8 ^cSchool of GeoSciences, Grant Institute, The King's Buildings, University of Edinburgh, James Hutton Road,
9 Edinburgh, EH9 3FE, United Kingdom

10 ^D Niedersächsisches Landesmuseum Hannover, Willy-Brandt-Allee 5, 30169 Hannover, Germany

11

12 *Corresponding author.

13 E-mail addresses: Sachs.Pal@gmail.com (Sven Sachs), Mark.Young@ed.ac.uk (Mark T. Young),

14 jahn.hornung@yahoo.de (Jahn J. Hornung)

15

16 ABSTRACT

17 *Enaliosuchus macrospondylus* Koken, 1883 **was** one of the first thalattosuchian taxa from the Cretaceous **to be**
18 **described**. The type series includes an atlas-axis complex, remnants of **three** post-axial cervical vertebrae, **several** dorsal
19 vertebrae, a caudal vertebra, **an incomplete femur** and **a fragmentary sacral rib** from the upper Valanginian of northern
20 Germany. Additionally, two isolated, non-thalattosuchian, tooth crowns from the uppermost Valanginian to lowermost
21 Hauterivian of different localities in northern Germany were tentatively assigned to *E. macrospondylus* by Koken. The
22 taxon was established for the distinctive the atlas-axis morphology, in particular the apparent lack of an axis
23 parapophysis. *Enaliosuchus macrospondylus* has been considered a valid taxon in recent studies, based upon a largely
24 complete metriorhynchid specimen from the Valanginian of France that had been referred to this taxon, an assignment
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26 and determine whether it is diagnostic, and if a referral of the French specimen to *E. macrospondylus* is justified. We
27 also discuss whether *E. macrospondylus* and another metriorhynchid specimen from the Valanginian of northern

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Keywords:

Crocodylomorpha

Thalattosuchia

Metriorhynchidae

Lower Cretaceous

Germany

1. Introduction

Thalattosuchian crocodylomorphs are considered to be rare in Lower Cretaceous strata. These specimens include the youngest recorded examples of the group, which so far is documented to the lowermost Aptian (see discussion below). In Germany, the first Cretaceous thalattosuchian remains were described by Ernst Koken from the Valanginian of Lower Saxony as a new genus and species, *Enaliosuchus macrospondylus* Koken, 1883. The holotype material comprises a number of cervical, dorsal and caudal vertebrae, along with limb and rib elements. Additionally, Koken (1883) tentatively referred two isolated teeth from two separate localities to his new taxon. Due to its geological age and the well preserved atlas-axis complex, the type specimen of *E. macrospondylus* sparked controversy and curiosity into the diversity and taxonomy of Cretaceous thalattosuchians (e.g. Schroeder 1921; Kuhn 1936; Hua *et al.*, 2000; Karl *et al.*, 2006), and also the diversity of cervical osteology in crocodylomorphs (e.g. Koken 1883, 1887; Baur 1886; Jaekel 1904; Boschma 1922). However, the *E. macrospondylus* holotype has never received an in-depth reappraisal, and its purported relationships with other thalattosuchian specimens (Kuhn 1936; Hua *et al.*, 2000; Karl *et al.*, 2006) have largely been based upon Koken's (1883) description. This original description was extensive, but it was limited by a lack of comparative metriorhynchid specimens during the late 19th

54 Century. Here we redescribe the holotype of *E. macrospondylus*, and assess the impact this has for
55 the taxonomy of Early Cretaceous metriorhynchids.

56

57 1.1 Historical overview

58 Koken (1883) established *Enaliosuchus macrospondylus* as a new genus and species because of the
59 seemingly novel morphology of the atlas-axis complex. In particular, the presence of atlas rib facets
60 being placed anteroventrally on the atlas centrum was listed as a peculiar feature for *Enaliosuchus*
61 (Koken 1883: 799). Koken (1883) compared the atlas-axis complex to those of modern
62 crocodylians, teleosauroids and the basal metriorhynchoid *Pelagosaurus typus* Bronn, 1841 (see
63 Koken 1883: 809, table therein); but not with metriorhynchids.

64 A second specimen, comprising an incomplete cranium and lower jaw, with the atlas-axis
65 and first post-axial cervical vertebra from the lower to middle Valanginian Stadthagen Formation of
66 north-western Germany was referred to *Enaliosuchus* by Schroeder (1921). The basis for this
67 referral was that the atlas-axis complex had similar atlas rib placement as that described by Koken
68 (1883) for *Enaliosuchus macrospondylus* (see Schroeder 1921: 364). Interestingly, Schroeder
69 (1921) neither explicitly referred the new specimen to *E. macrospondylus*, nor did he erect a new
70 species for it. This was carried out later by Kuhn (1936) who named the specimen *E. schröderi*
71 Kuhn, 1936. Note, that the use of the umlaut in the specific epithet by Kuhn (1936) was a
72 hypercorrection, as the correct spelling of Schroeder's name is with the *oe*. Furthermore, usage of
73 diacritic marks is not acceptable in a scientific name, in accordance with Article 27 of the ICZN
74 Code. Thus, the correct spelling is *E. schroederi*.

75 The acceptance of *E. schroederi* as a distinct species has been disputed. While some papers
76 have accepted both species as being valid (e.g. Steel 1973; Young & Andrade, 2009), they did not
77 base their opinions on a detailed comparison of the holotypes. Sickenberg (1961) was the first to
78 ask whether *E. schroederi* was distinct from *E. macrospondylus*, principally because Schroeder

79 (1921) was unsure in his original description whether the two specimens were conspecific (due to
80 the limited overlap between them) and only assigned the specimen to the genus *Enaliosuchus*,
81 leaving the species open. Hua *et al.* (2000) were the first to formally considered *E. schroederi* to be
82 a subjective junior synonym of *E. macrospondylus*, rendering *Enaliosuchus* a monospecific genus.
83 Jouve (2009) followed the taxonomy of Hua *et al.* (2000). Karl *et al.* (2006: 56) considered the
84 establishment of *E. schroederi* to be “completely unnecessary”, and could not preclude that the two
85 species were conspecific.

86 A third putative *Enaliosuchus* specimen, an incomplete skeleton from the lower Valanginian
87 (*Busnardoites campylotoxus* ammonite Zone) of south-eastern France, was referred to *E.*
88 *macrospondylus* by Hua *et al.* (2000). This specimen (catalogue number 990201 from the collection
89 of the Clément, Réserve Naturelle Géologique de Haute Provence in Digne les Bains – here later
90 referred to as RNGD 990201) comprises most of the cranium and mandible, an incomplete atlas-
91 axis complex, as well as five post-axial cervical and 15 dorsal vertebrae. While there is only minor
92 overlap with the *Enaliosuchus macrospondylus* holotype material, this referral was accepted
93 without comment in subsequent publications (e.g. Young & Andrade, 2009; Parrilla-Bel & Canudo,
94 2015; Sachs *et al.*, 2019). The cranial rostrum of RNGD 990201 is highly distinctive with its
95 posterodorsally retracted external nares, and Hua *et al.* (2000) used this specimen to emend the
96 diagnosis of *E. macrospondylus*. For the first time *Enaliosuchus* was clearly defined, and shown to
97 be distinct from other metriorhynchid taxa.

98 *Enaliosuchus* has been considered to be a poorly known metriorhynchid (von Huene 1956;
99 Steel 1973). Note, Young & Andrade (2009) altered the generic composition of *Geosaurus*, which
100 from 1901 – 2008 was considered to be a Late Jurassic longirostrine form, and moved several
101 species from *Geosaurus* to *Cricosaurus* and *Rhacheosaurus*. This unfortunately complicates the
102 next two paragraphs and their discussion on previous hypotheses on the position of *Enaliosuchus* in
103 Metriorhynchidae. Buffetaut (1982: 26) considered the *E. schroederi* holotype to be very similar to

104 *Geosaurus* Cuvier, 1824 (*Cricosaurus* Wagner, 1858 and *Rhacheosaurus* von Meyer, 1831 sensu
105 Young & Andrade, 2009), and based on the *E. schroederi* holotype, Buffetaut (1982) concluded that
106 the genus was distinct and valid. In Vignaud's (1995) unpublished PhD thesis, he considered
107 *Enaliosuchus* to be similar to *Geosaurus gracilis* (von Meyer, 1831) (*Rhacheosaurus* sensu Young
108 & Andrade, 2009), although he noted that the *E. schroederi* holotype and '*G.*' *gracilis* can be
109 differentiated on prefrontal and tooth enamel ornamentation characters. Vignaud (1995) therefore
110 provisionally retained *Enaliosuchus* as a valid genus. Neither Buffetaut (1982) nor Vignaud (1995)
111 examined a potential synonymy between *E. macrospondylus* and *E. schroederi*, although Vignaud
112 (1995) did state that Kuhn (1936) did not provide a diagnosis for *E. schroederi*. Moreover, it is clear
113 that the retention of *Enaliosuchus* as a valid genus by both Buffetaut (1982) and Vignaud (1995)
114 was based on the anatomy of the *E. schroederi* holotype, not the *E. macrospondylus* holotype.

115 The evolutionary relationships of *Enaliosuchus* have been further discussed since the
116 description of the French specimen by Hua *et al.* (2000) who considered *Enaliosuchus* to be closely
117 related to *Geosaurus* (*Cricosaurus* and *Rhacheosaurus* sensu Young & Andrade, 2009). The
118 evolutionary relationships of *Enaliosuchus* was first tested by Wilkinson *et al.* (2008), who found *E.*
119 *macrospondylus* (scoring based on the *E. macrospondylus* holotype and the French specimen) to be
120 within a clade formed by *Geosaurus* species (pre-Young & Andrade, 2009 metriorhynchid
121 taxonomy). Jouve (2009) however recovered *Enaliosuchus macrospondylus* (scoring based on the
122 *E. schroederi* holotype and the French specimen) as the sister taxon to *Dakosaurus* Quenstedt,
123 1856. It is unclear whether the different specimen scoring sources, and/or the different character and
124 taxon sets, are responsible for these differences.

125 The validity of the genus *Enaliosuchus* has been questioned, in different ways, by Karl *et al.*
126 (2006) and Young & Andrade (2009). Karl *et al.* (2006) referred both *E. macrospondylus* and *E.*
127 *schroederi* to the genus *Metriorhynchus* von Meyer, 1832, but did not retain either species as valid.
128 Whereas, based on their phylogenetic analysis, Young & Andrade (2009) considered *Enaliosuchus*

129 to be a subjective junior synonym of *Cricosaurus*, as *E. macrospondylus* and *E. schroederi* were
130 recovered as a subclade within their *Cricosaurus* clade. Young & Andrade (2009) chose not to
131 retain *Enaliosuchus*, as under their evolutionary hypothesis it would render *Cricosaurus*
132 paraphyletic, or demand the creation of multiple new genera. Note however, that they followed the
133 emended diagnosis of *Enaliosuchus* from Hua *et al.* (2000) without comment; and that the *E.*
134 *macrospondylus* operational taxonomic unit (OTU) scored by Young & Andrade (2009) was based
135 on the referred French specimen and the holotype. Interestingly, further iterations of the
136 phylogenetic dataset used by Young & Andrade (2009) have found *E. macrospondylus* and *E.*
137 *schröderi* to be distantly related, albeit both within Rhacheosaurini (datasets starting from Young
138 *et al.*, 2017).

139 In sum, *Enaliosuchus* is one of the most poorly understood metriorhynchid genera. Previous
140 studies have questioned the validity of the genus, and the validity of the second species assigned to
141 the genus (*E. schroederi*). Some studies that accept the validity of *Enaliosuchus* have done so based
142 on the anatomy of the *E. schroederi* holotype, not the *E. macrospondylus* holotype. The referral of
143 the highly diagnostic French specimen to *E. macrospondylus* was used to emended the specific
144 diagnosis, and for the first time clearly define *Enaliosuchus* and show it to be distinct from other
145 metriorhynchid taxa. Therefore, the following questions need to be addressed, and will be herein:
146 (1) is the *E. macrospondylus* holotype diagnostic; (2) do the holotypes of *E. macrospondylus* and *E.*
147 *schröderi* share synapomorphies that would justify assigning them to the same species (i.e. the
148 monospecific hypothesis of Hua *et al.* (2000)); and (3) was the referral of the highly diagnostic
149 French specimen to *E. macrospondylus* justified?

150

151 1.2. Institutional Abbreviations

152 MB – Museum für Naturkunde, Berlin, Germany; MNHN, Muséum national d'Histoire naturelle,
153 Paris, France; NHMUK – Natural History Museum, London, UK; RMH – Roemer und Pelizaeus

154 Museum, Hildesheim, Germany; RNGD – Réserve Naturelle Géologique de Haute Provence, Digne
155 les Bains, France; MM – Mindener Museum, Minden, Germany.

156

157 2. Geological settings

158 The material that constitutes the holotype of *Enaliosuchus macrospondylus* and the referred teeth
159 were found in two different locations in southern Lower Saxony, Germany and are actually
160 separated by a significant stratigraphical gap. With regard to the holotype, Koken (1883: 792)
161 specified the “Hils [strata] of the Osterwald” as the locality, and the horizon as “level of *Ammonites*
162 (*Olcostephanus*) *marginatus*”. Unfortunately, this information is somewhat ambiguous by present-
163 day concepts and need to be further elucidated. Geographically, the term “Osterwald” describes a
164 small mountainous region, ca. 30 km south-southwest of Hannover; as well as to the town of
165 Osterwald, which is located in the southern margin of those hills (Fig. 1A-B). The grammatical
166 form used by Koken (“des Osterwaldes”) indicates that he referred to the mountains rather than to
167 the settlement proper. Most of the Osterwald mountain range is formed by strata from the Jurassic
168 and the non-marine Berriasian – the marine Lower Cretaceous is exposed only in a small area in the
169 southeastern part due to a southeasterly dip of the succession (Albrecht 1913). While there are
170 numerous fossils from the marine Lower Cretaceous with the label “Osterwald” in museum
171 collections, as well as mentioned in the literature, details of the exact nature of this or these
172 outcrop(s) are rarely given. Von Koenen (1902) mentioned two important sources of such material
173 from Osterwald:

174 (1) the now abandoned brickworks clay-pit of the town of Osterwald, located c. 0.5 km to the east
175 of the settlement. It exposed upper Hauterivian clay- and marlstones with an abundance of the
176 heteromorph ammonite *Aegocrioceras capricornu* (Roemer 1841), preserved in calcareous
177 concretions (see also Stolley 1908).

178

179 (2) The Osterwald Tiefbauschacht, an abandoned mine shaft, c. 1.3 km east of the town of
180 Osterwald, that penetrated Valanginian marine strata to reach the Berriasian coal seams below
181 (Albrecht 1913). The mine shaft was constructed between 1879 and 1890 (Grimme, 2010).

182

183 The lithostratigraphic term “Hils [Formation]”, used by Koken, that denotes marine, mostly pelitic
184 deposits of Valanginian through Albian age in northern Germany, is currently superseded by the
185 Minden Braunschweig Group (Erbacher *et al.*, 2014a). In the Osterwald region, it can include beds
186 of Valanginian through Hauterivian age.

187 Unfortunately, the sedimentary matrix of the type specimen, consisting of a reddish sideritic
188 claystone (“rothbrauner Thoneisenstein” in the terminology of Koken) is not conclusive, as this
189 lithotype may occur in the Valanginian as well as in the Hauterivian of the region (e.g. Mutterlose
190 1984). The biostratigraphic information provided by Koken for the stratum typicum is problematic
191 as well. His “*Ammonites (Olcostephanus) marginatus*” obviously refers to the occurrence of the
192 ammonite species described by Neumayr & Uhlig (1881: 157) as “*Olcostephanus marginatus*
193 (Phill?) Römer” from Osterwald. These authors – following Roemer (1841) - redefined the species
194 *Ammonites marginatus* Phillips, 1829, based on a poorly figured and described juvenile individual
195 from England, to include some specimens from Lower Saxony. However, von Koenen (1902, 1909)
196 separated the Lower Saxonian material as *Polyptychites marginatus* (Neumayr & Uhlig, 1881) from
197 the English *Ammonites marginatus* Phillips, 1829. The latter was revised as *Simbirskites*
198 *marginatus* (Phillips, 1829), a zone index fossil from the upper Hauterivian, by Rawson (1971).

199 The referred material of “*Polyptychites marginatus*” sensu Neumayr & Uhlig (1881),
200 figured and discussed by von Koenen (1902, 1909), was subsequently partly reassigned to
201 *Polyptychites keyserlingi* (Neumayr & Uhlig, 1881) by Jeletzky & Kemper (1988), and partly to
202 *Polyptychites polyptychus* (von Keyserling, 1846) by Bogomolov (1989). *Polyptychites keyserlingi*
203 is clearly a middle lower Valanginian taxon, while *P. polyptychus* was reported from the lowermost

204 upper Valanginian (Jeletzky and Kemper 1988). With regard to the original material of
205 “*Olcostephanus*” *marginatus* from Neumayr & Uhlig (1881), Jeletzky & Kemper (1988: 29)
206 noticed some doubts about the source stratum, suggesting that it may be “misplaced” from the
207 Jurassic.

208 Nevertheless, Koken (1883) also clearly associated the horizon of “*Ammonites (Olcostephanus)*
209 *marginatus*” with the “Hils Formation”, and the matrix lithology supports a Lower Cretaceous
210 origin of the *Enaliosuchus macrospondylus* postcranial material. Considering that the taxa currently
211 comprising von Koenen’s (1902, 1909) concept of his Lower Cretaceous “*Polyptychites*
212 *marginatus*” (that was in turn based on Neumayr & Uhlig 1881) range from the middle lower to
213 lowermost upper Valanginian (Jeletzky & Kemper 1988, Bogomolov 1989), it is the most plausible
214 assumption that the holotype of *Enaliosuchus macrospondylus* originates from this
215 chronostratigraphic interval of the lower Stadthagen Formation in the Minden Braunschweig Group
216 (sensu Erbacher *et al.* 2014a). The locality was possibly the Tiefbauschacht Osterwald mine shaft
217 near the town of Osterwald. This localization is also in concordance with the information in von
218 Koenen (1902) for the ammonite material from “Osterwald”. It remains unclear, on what basis Karl
219 *et al.* (2006) correlated the stratum typicum with the “Astierenschichten”. The “Astierenschichten”
220 (“Astierien beds”, an obsolete lithostratigraphic term) are lowermost Hauterivian in age according to
221 Mutterlose (1992a).

222 The first isolated tooth referred to *E. macrospondylus* by Koken (1883: 824; MB.R.3636)
223 was found at the Elligser Brink, a hill ca. 0.6 km south of the town of Delligsen in the Hils
224 Mountains, about 50 km south of Hannover. Koken (1883) noted that it originates from the
225 collection of Friedrich Koch. Koch & Dunker (1837) described an assortment of vertebrate remains
226 in the marine Lower Cretaceous strata of this locality, that became known as the “Elligserbrink
227 bed”. As Koken (1883) did not mention otherwise, it is plausible that the tooth came from the same
228 horizon. This is corroborated by the fact that Koken referred also to this collection, stratum, and

locality, when describing the disputed pterosaur “*Ornithocheirus*” *hilsensis* in the same work (Koken 1883: 824f.). According to Burri (1956), the “Elligserbrink bed” dates to the uppermost Valanginian or lowermost Hauterivian (Stadthagen Formation, Minden-Braunschweig-Group).

The second isolated tooth Koken (1883) referred to *E. macrospondylus* (RMH uncatalogued [2]) originates from the “Hils conglomerate of the Osterwald”. According to Erbacher *et al.* (2014b) the lithostratigraphic name “Hils Conglomerate” in its classic sense (Roemer 1841) is obsolete and defines various homonymous units, ranging from the Berriasian to the Cenomanian. However, in a more strict and regional sense it is synonymous to the Grenzlerburg Member of the Salzgitter Formation (uppermost Valanginian through lower Hauterivian, Erbacher *et al.* 2014b).

From a palaeoenvironmental point of view, all localities were situated in an open marine, euhaline, oxygenated shallow-water setting with fine-grained sedimentation and low background sedimentation rates. The Grenzlerburg Member represents partly a transgressive carbonatic conglomerate in a marginal setting with abundant fauna (e.g. Mutterlose 1984, 1992a, b; Mutterlose & Bornemann, 2000; Fig. 1C)

3. Description of Koken’s hypodigm of *Enaliosuchus macrospondylus*

3.1. Status of the type material

Koken (1883: 792) described the majority of his material as **if** it came from a single individual, although it was in a largely disarticulated and dissociated state when he studied it. He based his assumption on the fact that it derived from a single locality and stratum, the fitting proportions and the lack of duplicate skeletal elements. Consequently, the remains received one accession **MB.R.1943 (with 16 subnumbers MB.R.1943.1-16)** and are considered the holotype of *Enaliosuchus macrospondylus*. Koken (1883) mentioned that the material was initially part of the Henne collection, but the exact whereabouts of the discovery remain unknown. It is also unknown if all parts of the axial skeleton were found in association (Koken 1883 p. 792 only mentioned that

some ribs and limb elements were found separately). Therefore we cannot be certain the elements found at the type locality all come from the same individual.

Additionally, Koken (1883) referred an isolated dorsal vertebra (RMH uncatalogued (1)) from another collection but the same locality and stratum, and two isolated tooth crowns (RMH uncatalogued (2) and MB.R.3636) to his new taxon. The latter were added by Koken for being identified as “crocodilian” and originating from marine strata of similar age and region. A fragmentary phalanx (MB.R.1939), likewise from the Henne collection and from the same locality and stratum, is present in MB collection, but was not described by Koken (1883). These four specimens need to be excluded from the type material, as is described in the Systematic Synopsis below.

Below the material is described as it was summarised by Koken (1883).

3.2. Teeth

Koken (1883) assigned two teeth to the *Enaliosuchus macrospondylus* hypodigm, one from the MB collection and one from the RHM collection (Fig. 2). Both teeth were found separately from the remainder of the skeleton (see the geological history section above) and the referral to *Enaliosuchus* was not justified. Curiously, the RHM houses two teeth which are labelled *Enaliosuchus macrospondylus*, but following Koken’s (1883) description of the tooth crown being incomplete, the right specimen in Fig. 2C appears to be the correct referred specimen.

The tooth crown MB.R.3636 (Fig. 2A, B) is conical, slightly lingually curved and bears pronounced apicobasally aligned enamel ridges that are contiguous from the base of the crown to the apex. Such enamel ridges are rare in Thalattosuchia, as most ridged teeth have both long ridges and shorter ridges, generally closely packed, but the ridges rarely are contiguous along the entirety of the crown (see the tooth close-up photographs in Young *et al.* 2013, 2014a). The enamel ridges in MB.R.3636 become closer to one another apically. The apex itself is not present, as the crown is

279 extensively worn in that region. Whether it is taphonomic or biological in origin is unclear without
280 scanning electron microscopy. Carinae are formed mesially and distally, bearing fine denticles. The
281 basal enamel ornamentation is reminiscent of *Anteophthalmosuchus* Salisbury & Naish, 2011 (see
282 Ristevski *et al.* 2018); however, given the lack of a complete tooth crown, and the lack of an in-
283 depth study into the dental variation within Goniopholididae, this specimen can only be referred to
284 as ?Goniopholididae. The RMH (uncatalogued (2)) tooth crown (Fig. 2C) is largely damaged and
285 bears more enamel ridges that are place closer to one another.

286 As these remains cannot be demonstrated to belong to the holotype or *Enaliosuchus*
287 *macrospondylus* at all, they have to be excluded from the type material. In consequence no cranial
288 material is known from *Enaliosuchus macrospondylus*.

289

290 3.3. Atlas-axis complex

291 The atlas-axis complex (MR.R.1943.2) comprises the atlas intercentrum, the atlas and axis centra,
292 parts of the atlas and axis neural arches, as well as the axis neural spine (Fig. 3). A fragmentary left
293 atlas rib is also preserved. The atlas intercentrum forms the ventral part of the atlas cup (Fig. 3A). It
294 is semicircular in anterior view, and slightly displaced from its original position. Dorsally the atlas
295 intercentrum reaches to about mid-height of the atlas centrum, where it meets the atlas neural arches
296 (Fig. 3A, B, E). Posteriorly and ventrally the atlas intercentrum contacts the atlas centrum.
297 Posteroventrally, the slightly convex ventral side of the atlas intercentrum meets the anterior surface
298 of the axis centrum (Fig. 3F). Laterally the atlas intercentrum forms the anterior part of the atlas rib
299 facet, of which the remainder is formed by the atlas centrum (Fig. 3B, E). The anterior fragment of
300 the left atlas rib is still attached to the rib facet. The atlas rib is slightly posterolaterally inclined and
301 becomes transversely narrower posteriorly (Fig. 3B).

302 The atlas centrum has a sub-triangular shape in right lateral aspect. Anteriorly the atlas
303 centrum bears a flat surface that forms the posterior demarcation of the atlas cup (Fig. 3A). The

304 ventral side of the atlas centrum is **contacted** by the atlas intercentrum and dorsally the atlas neural
305 arches are attached. The posterior side of the atlas centrum is fused to the axis centrum but keeps an
306 open, in lateral view slightly oblique running suture (Fig. 3B, E). On the right side, the
307 anteroventral region on both sides of the suture, is strongly rugose, passing indistinctly into the
308 parapophyseal facet ventrally. On the left side, the same region is much smoother. The rugosities
309 may be pathological in origin.

310 The atlas neural arches form the dorsal part of the atlas cup. Their concave anteromedial
311 sides bear a sharp anterior margin (Fig. 3A). Dorsally, at the base of the neural canal, there is a gap
312 between the left and right atlas neural arch (Fig. 3A). Posteriorly the atlas neural arches **contact** the
313 atlas centrum. The posterodorsally **inclined** atlas **postzygapophysis** (Fig. 3E) is **present in its**
314 **original position** on the right side, **whereas the left one is preserved isolated**. The atlas
315 **postzygapophysis** narrows **posteriorly, contacts the axis prezygapophysis and** frames an oval
316 foramen (Fig. 3E).

317 The axis centrum has a quadratic shape in lateral view (Fig. 3B, E). Anteriorly the axis
318 centrum sutures to the atlas centrum and anteroventrally a short contact with the atlas intercentrum
319 is established. The posterior side of the axis centrum bears a high-oval articular surface that is
320 largely filled with matrix (Fig. 3D). Ventrally an anteriorly damaged midline ridge is formed. In
321 ventral aspect, the axis centrum is expanded anteriorly and posteriorly, and is constricted in the
322 middle (Fig. 3F). On both sides of the axis the diapophyses are preserved as robust transversal
323 projections of dorsoventrally compressed, rhomboidal cross-section, that originate immediately
324 below the neural arch. The articular facets are not preserved. The fragment of an axis rib that was
325 described and figured by Koken (1883: pl. XXIV, fig. 5) in articulation with the left diapophysis, is
326 missing in the material as preserved. The parapophysis is a small, anteroposteriorly elongate,
327 tuberosity located anteroventrally on the axis centrum, **adjacent to the atlas centrum (Fig. 3B)**. The

328 shallow parapophyseal facet extends for a small portion anteriorly onto the posteroventral region of
329 the atlas centrum. It is therefore divided by the suture between the atlas and axis centra.

330 The axis neural arches originate somewhat anterior to the dorsal rim of the articular face of
331 the axis centrum (Fig. 3B, E). The axis prezygapophyses is obscured by the atlas postzygapophysis
332 on the right side of the specimen (Fig. 3E). Laterally the ventrally protruding neural arches extend
333 to about mid-height of the axis centrum. This protruding lateral portion bears the diapophyses for
334 the axis ribs which are damaged on both sides. The axis neural spine is largely broken off and only
335 the transversely thin bases are still preserved (Fig. 3C, E).

336

337 3.4. Postaxial cervical vertebra

338 Parts of three postaxial cervical vertebrae are preserved; an isolated centrum (MR.R.1943.3, Fig.
339 4A-E) with attached neurapophyses, and a nearly complete vertebra, embedded in matrix with part
340 of the neurapophysis of the preceding vertebra attached to it (MR.R.1943.1, Fig. 4F, G). The centra
341 of MR.R.1943.1 and MR.R.1943.3 are longer than wide/high. The articular faces of MR.R.1943.3
342 are oval (Fig. 4B, D), whereas those of MR.R.1943.1 are more circular (Fig. 4F). In both specimens
343 the slightly indented articular faces are surrounded by thickened rims. Only the left diapophysis of
344 MR.R.1943.3 is well preserved, the other diapophyses are either damaged, broken off or embedded
345 in matrix. The complete diapophysis is ventrally and slightly posteriorly inclined and reaches to a
346 point dorsal to the dorsoventral midsection of the centrum (Fig. 4A). It bears a long-oval and
347 slightly indented rib facet. The parapophyses are both broken off in the isolated centrum. Their
348 bases indicate that they were about equally large and slightly more anteriorly placed than the
349 diapophyses, which indicates a placement in the anterior part of the neck. In MR.R.1943.1 the right
350 parapophysis is preserved, which has a circular shape and a slightly indented surface (Fig. 4G). It is
351 considerably smaller than the base of the diapophysis and placed anteroventral to the latter. This
352 indicates a placement in the posterior part of the neck. The ventral side of the centrum is well

353 preserved in [MR.R.1943.3](#) and bears a pronounced and rounded midline [keel](#) adjacent to which the
354 centrum is dished (Fig. 4E). The anterior and posterior sections of the ventral side of the centrum
355 are thickened and the anterior one also protrudes slightly ventrally (Fig. 4A). Dorsally remnants of
356 the zygapophyses are preserved in the isolated vertebra. Here the right prezygapophysis is more
357 complete and terminates approximately in line with the lateral margin of the centrum (Fig. 4B). The
358 left prezygapophysis is also preserved in [MR.R.1943.1](#) and still articulated with the
359 postzygapophysis of the preceding cervical (Fig. 4G). The postzygapophyses are otherwise largely
360 broken off in both specimens.

361 The neural spine is preserved in [MR.R.1943.1](#). It is considerably higher than the centrum
362 and slightly posteriorly inclined. It bears an almost straight anterior edge and a slightly convex
363 dorsal side. The posterior edge of this neural spine is damaged. The second neural spine adjacent to
364 the afore described, is incomplete but appears shorter (Fig. 4G).

365

366 3.5. Dorsal vertebrae

367 Remnants of [seven](#) dorsal vertebrae ([MB.R.1943.4-10](#)) are preserved in the [holotype](#) material (Fig.
368 [5A-H](#)). An additional dorsal centrum (Fig. [5J-N](#)) was assigned to the same individual by Koken
369 (1883) and is kept in the collection of the Roemer- und Pelizaeus-Museum (RMH uncatalogued
370 (1)). It is herein excluded from the type material of *Enaliosuchus macrospondylus* and referred to an
371 indeterminate thalattosuchian.

372 All centra are elongate and bear oval and slightly indented articular faces which are
373 surrounded by a thin rim. Laterally, adjacent to the articular faces, some longitudinal rugosities are
374 present. The lateral sides of the centra, [showing open neurocentral sutures](#), are gently concave and
375 so are their ventral sides. The transverse processes are elongate, thin, have a subtriangular cross-
376 section and gradually narrow laterally, which indicates a placement in the anterior part of the dorsal
377 vertebral column. The laterally placed diapophysis is sub-circular and [well](#) preserved in

378 MB.R.1943.4 (Fig. 5A). In dorsal view the posterior sides of the transverse processes of
379 MB.R.1943.4 and MB.R.1943.5 are almost straight, while the anterior ones curve from the
380 diapophysis slightly anteromedially to meet the parapophysis (Fig. 5C). In the RMH specimen (Fig.
381 5J-N) part of the right transverse process is preserved which extends straight lateromedially and is
382 wider than the transverse processes in the aforementioned vertebrae. A similar pattern is indicated
383 by the broken off bases of the transverse processes in another dorsal centrum (MB.R.1943.6, Fig.
384 5E, F). These vertebrae seem to have had a more posterior placement in the dorsal vertebral
385 column.

386 The parapophyses are preserved in the isolated neuropophyseal fragment (MB.R.1943.7,
387 Fig. 5G, H) and in the anterior dorsal vertebra (MB.R.1943.4, Fig. 5A-D). In both specimens they
388 are slightly anteriorly inclined, placed at the anterior end of the neural arch, and are surrounded by a
389 thin edge. The zygapophyses are broken off and the neural canal is filled with matrix in all of the
390 dorsal vertebrae. The transversely thin neural spine is preserved in the neuropophyseal fragment
391 (MB.R.1943.7, Fig. 5G, H). It has a high rectangular appearance with an almost straight anterior
392 margin, a slightly convex dorsal side and bears a gently concave posterior side.

393

394 3.6. Dorsal ribs

395 A largely complete, lateroventrally curved dorsal rib is present in the block that contains the almost
396 complete cervical vertebra (MB.R.1943.1, Fig. 5I). Several rib fragments are preserved
397 (MB.R.1943.9, 12, 13) which show subcircular cross-sections. Additional rib fragments are present
398 in the RHM collections.

399

400 3.7. Caudal vertebra

401 An isolated caudal centrum (MB.R.1943.11, Fig. 5O-S) is preserved. The elongate centrum bears
402 oval and slightly concave articular faces (Fig. 5P, R) of which the posterior one extends further

403 ventrally than the anterior articular face (Fig. 5O). The ventral side of the centrum is deeply
404 concave. Two semi-circular hemapophyseal facets are present posteroventrally (Fig. 5Q).
405 Dorsolaterally remnants of the broken off transverse processes are preserved. Their large size
406 indicates that the vertebra derives from the proximal part of the tail. Ventral to the transverse
407 processes the lateral sides of centrum are concave, giving it an hourglass-like shape in ventral view
408 (Fig. 5Q). Dorsally, in the mid-section of the centrum, the bases of the broken off neural arches are
409 preserved. They start adjacent to the centrum's posterior articular face but terminate approximately 1
410 cm posterior to the anterior articular face. The preserved portion of the neural canal was narrowest
411 at about midlength of the neural arch.

412

413 3.8. *Femur*

414 An incomplete, possibly left, femur is preserved (MR.R.1943.15.1+2, Fig. 6A-D). Koken (1883)
415 initially identified the two fragments as one tibia broken apart in the middle, the uniform
416 morphology indicates that these are indeed parts of one element, but given its size and curvature the
417 element is in fact a femur. The element has an oval cross-section, with the distal end being more
418 strongly compressed mediolaterally (Fig. 6A, D) and the shaft, as preserved, is gently curved. The
419 proximal (Fig. 6A) and distal ends (Fig. 6B) are irregular, lacking well defined epiphyses. While all
420 metriorhynchids characteristically lack well defined distal epiphyses (e.g. see Andrews 1913), this
421 is one of the few metriorhynchids found where the proximal epiphyses also look to be poorly
422 defined. Given that proximal end appears to be either damaged and/or has some sort of pathology,
423 we cannot ascertain whether this feature is an artefactual or represents a more cartilaginous hip
424 articulation.

425

426 3.9. *Additional elements*

427 Koken (1883: 818) mentioned and briefly described a proximal end of a metatarsal. This specimen
428 (MB.R.1943.16, Fig. 7A, B) is slightly curved and bears a shallow furrow on the supposed ventral
429 side. It resembles the sacral ribs of the second sacral vertebra (see e.g. Andrews 1913, fig. 64).
430 Another specimen from the Henne collection (MB.R.1939, Fig. 6C, D) that derives from the same
431 locality as the reminder of the material was catalogued as proximal fragment of a metapodial
432 element of *E. macrospondylus*. This element of which the original hour-glass like shape is still
433 indicated, nicely resembles a phalanx from the hind limb.

434

435 4. Discussion

436 4.1. The Koken (1883) character set

437 Koken (1883) faced difficulties in defining his new genus *Enaliosuchus*, partly due to the
438 incompleteness of the material available to him, and partly from a lack of comparative material and
439 descriptions. He never stated an autapomorphy-based diagnosis, but presented what can be
440 considered by modern standards a comparative diagnosis. He focused on the atlas-axis complex and
441 compared a total of nine characters with a range of extant and fossil crocodylians, and
442 thalattosuchians. These include:

443

- 444 (1) the contact of the proatlas with the atlas neurapophyses: with the proatlas sitting atop, or in an
445 excavation of the atlas neurapophyses;
- 446 (2) complete fusion of atlas centrum to the axis centrum;
- 447 (3) medial contact of the atlas neurapophyses;
- 448 (4) presence of an atlas intercentrum (atlas hypapophysis *sensu* Koken 1883);
- 449 (5) presence of a diapophysis on the axis;
- 450 (6) presence of a parapophysis on the axis;
- 451 (7) morphology of the ventral surface of the axis centrum;

452 (8) position of the atlas rib articulation: on the atlas intercentrum, on the atlas centrum, or between
453 both;
454 (9) position and morphology of the axial ribs: single-headed or double-headed, articulating solely
455 with the axis centrum, or with the axis and (fused) atlas centrum.

456

457 His comparative taxa included the crocodylid *Osteolaemus tetraspis* Cope, 1861 (“*Crocodylus*
458 *frontatus*” *sensu* Koken, 1883), the alligatorids *Alligator mississippiensis* (Daudin, 1802), and
459 *Diplocynodon darwini* (Ludwig, 1877) (“*Crocodylus ebertsi*” and “*Alligator darwini*” *sensu* Koken
460 1883), as well as the thalattosuchians *Machimosaurus mosae* Sauvage & Lienard, 1879,
461 *Teleosaurus cadomensis* Lamouroux, 1820, *Steneosaurus bollensis* (Jaeger, 1828) (“*Mystriosaurus*
462 *tiedemanni*”, “*Mystriosaurus longipes*”, and “*Mystriosaurus mandelslohi*” in Koken, 1883), and
463 *Pelagosaurus typus* (including “*Teleosaurus temporalis*” *sensu* Koken 1883). As a consequence,
464 from his original list of 11 taxa, only 7 are considered valid today, while 4 are actually subjective
465 junior synonyms of other species on the list.

466 From his characters, (1) is unknown due to preservation in many fossil taxa; (2) is
467 undiagnostic, because it is controlled ontogenetically in many crocodyliform taxa (e.g. Viera *et al.*
468 2018), (3) is common in Thalattosuchia (e.g. *Metriorhynchus superciliosus*, ‘*M.*’ *brachrhynchus*,
469 *Gracilineustes leedsi*; Arthaber 1906, Andrews 1913), (4) is ubiquitous in crocodyliform taxa
470 (Romer 1956); (5) and (6) are not diagnostic on less inclusive systematic levels; (7) may have some
471 significance but the character distribution is not clear, and this area is not well preserved in the *E.*
472 *macrospendylus* holotype; (8) and (9) may have a more differentiated taxonomic significance, but -
473 as will be discussed below – Koken’s (1883) interpretation of these characters are fraught with
474 some misinterpretations.

475 From his overall comparisons Koken (1883: 807) concluded that the genus “*Teleosaurus*”
476 may be the closest relative of his new species. However, it must be noted that only one of the two

477 species in his “*Teleosaurus*” is still included in this genus, the type species *T. cadomensis*. His
478 second species, “*T. temporalis*”, is a subjective junior synonym of *Pelagosaurus typus*. From
479 context it appears that he mostly referred to the latter, as the atlas-axis-complex was discussed
480 extensively by Eudes-Deslongchamps (1864), while it was only incompletely known in *T.*
481 *cadomensis*.

482 According to Koken (1883), “*Teleosaurus*” shares with *E. macrospondylus* the following
483 characters:

- 484 (1) the proatlas is nested within an anterior excavation of the atlas neurapophyses [the element
485 questionably identified as proatlas in *E. macrospondylus* by Koken 1883 is herein identified as atlas
486 *postzygapophysis*];
487 (2) well developed diapophyses and inconspicuous parapophyses (“tuberosities”) on the axis
488 centrum;
489 (3) the presence of a groove on the ventral side of the axis centrum;
490 (4) the “general morphology” of the atlas neurapophyses.

491

492 In contrast Koken (1883) listed the following characteristics that *Enaliosuchus* had, but
493 “*Teleosaurus*” lacked:

- 494 (5) the broad head of the atlas ribs covers the axis parapophyses (which are reduced to mere
495 tuberosities) in lateral view;
496 (6) the atlas centrum contacts the atlas ribs, the rib facet is jointly formed by the atlas intercentrum
497 and atlas centrum;
498 (7) the axis centrum bears single-headed ribs that articulate with the diapophysis and points straight
499 ventrally;
500 (8) the contact between the atlas intercentrum and the atlas neurapophyses is short;
501 (9) the atlas intercentrum bears a strongly concave morphology;

502 (10) the atlas neurapophyses are separated from each other along their whole anteroposterior length;
 503 (11) the axis centrum is fused to the atlas centrum, but separated by a visible, oblique suture.
 504
 505 Of these characters, (1) cannot be proven, as the small fragment, questionably identified by Koken
 506 (1883) as the proatlas in *E. macrospondylus* is considered here as the atlas *postzygapophysis*, (2)
 507 occurs in other metriorhynchids. Koken (1883) described the axis parapophyses as “tuberosities”
 508 and doubted that they articulated with the axis rib, speculating that they may have contacted the
 509 atlas rib. Jaekel (1904) supported this interpretation but stated that similar “tuberosities” were
 510 present in *Metriorhynchus superciliosus* (= *M. jaekeli* in Jaekel 1904). In contrast Baur (1886)
 511 already interpreted these “tuberosities” correctly as parapophyses, which was confirmed by von
 512 Arthaber (1906). The latter clearly figured that in *Metriorhynchus superciliosus* the parapophyseal
 513 facet extends across the suture of the atlas and axis centra. Boschma (1922, based on the figure in
 514 Jaekel 1907) located the parapophyseal facet in *Enaliosuchus macrospondylus* solely on the axis
 515 centrum and found this an important contrast to *Metriorhynchus superciliosus* in which the
 516 parapophyseal facet is located on the axis as well as on the axis centrum. However, the latter
 517 condition actually also occurs in *Enaliosuchus macrospondylus* (Fig. 3). (3) is inconclusive, as the
 518 type material of *E. macrospondylus* is damaged in this region. The absence of a sharp keel is
 519 widespread among crocodyliforms and thalattosuchians. (4) is unspecific. (5) and (7) result from a
 520 misinterpretation due to a lack of preservation. As shown by von Arthaber (1906), the parapophyses
 521 in metriorhynchids are in the same position and similarly inconspicuous. However, they articulate
 522 with the capitulum of a flat, bicapitate rib that forms almost a right angle with the tuberculum. The
 523 “straight, ventrally pointing” axis rib of Koken (1883: 806 and pl, XXIV, fig. 5) is therefore only
 524 the shaft of the tuberculum that tapered strongly distally. However, Koken (1883: 806) himself
 525 wrote that this rib fragment was originally embedded “closely” to the diapophysis and was removed
 526 during preparation. In lateral view, the axis rib capitulum (if it would have been preserved) is

527 hidden by the head of the atlas rib, which has been discussed and clarified for *Enaliosuchus*
528 *macrospondylus* by Baur (1886).

529 (6) and (8) through (11) are shared by metriorhynchids (von Arthaber 1906, Andrews 1913).

530 Although Koken (1883) made detailed observations and tried to make a comprehensive comparison,
531 he entirely omitted metriorhynchid material or references. This is understandable, as detailed
532 studies of the corresponding anatomy in this group were not available before the 20th Century. It
533 also explains the peculiarities that he observed in his material, and his conclusion that it represents a
534 new taxon. Unfortunately, a synoptic view of metriorhynchid morphology results in the conclusion
535 that the characters he found distinguishing are more widely distributed in this group.

536 The other metriorhynchid elements described for *Enaliosuchus macrospondylus* by Koken
537 (1883) show the general morphology seen in various taxa and are of no diagnostic value.

538

539 4.2. The Schroeder (1921) character

540 Schroeder (1921) referred a new metriorhynchid specimen from the Lower Cretaceous of northern
541 Germany to *Enaliosuchus* based on the morphology of the axis ribs (this is the specimen Kuhn 1936
542 establish as the *Enaliosuchus schroederi* holotype). His new specimen preserved axis ribs in which
543 the capitulum and tuberculum remained unfused, effectively resulting in two axis ribs on each side.
544 Schroeder (1921: 364) claimed the same condition to be present in the *E. macrospondylus* holotype.
545 However, this cannot be substantiated as the axis ribs are no longer preserved in the *E.*
546 *macrospondylus* holotype, and the fragment that was described by Koken (1883) is not
547 unambiguous in interpretation (see above).

548

549 4.3. The Hua et al. (2000) character set

550 The *Enaliosuchus* taxonomy of Hua et al. (2000) is a monospecific hypothesis, with all three
551 specimens included in *E. macrospondylus*. However, the only elements shared by all three

specimens are the atlas-axis complex and one post-axial cervical vertebra. The emended diagnosis of *Enaliosuchus* by Hua *et al.* (2000: 472) focussed largely on cranial characters, which thus cannot be applied for the holotype specimen (MB.R.1943.1-16). However, Hua *et al.* (2000) considered five characters in the atlas-axis complex to be diagnostic for *Enaliosuchus*: (1) a massive atlas centrum that is sub-quadrangular in lateral view, (2) the atlas ribs inserted on both the atlas intercentrum and axis centrum, (3) the diapophyses are placed on the axis neural arches, (4) presence of a ventral midline keel on the axis centrum, and (5) the axis neural spine is curved and anteriorly inclined. Unfortunately, these five characters do not unite these three specimens to the exclusion of other metriorhynchids:

(1) In the *Enaliosuchus macrospondylus* holotype specimen (MB.R.1943.2), the atlas centrum is partly obscured by the atlas neural arches and the atlas intercentrum, but the morphology is clearly more triangular than quadrangular in lateral view (Figs. 3, 6A), similar to the condition present in *Metriorhynchus superciliosus* de Blainville, 1853 (Fig. 7D). The shape of the atlas centrum in *E. schroederi* cannot be seen because the atlas intercentrum, atlas neural arches and atlas ribs obscure most of the element (Fig. 7B).

(2) The atlas rib facets in MB.R.1943.2 are largely formed by the atlas intercentrum and atlas centrum (Figs. 3, 6A). In other metriorhynchids such as *Cricosaurus vignaudi* (Frey, Buchy, Stinnesbeck & López-Oliva, 2002) (see Frey *et al.* 2002: fig. 6), '*Metriorhynchus*' *brachyrhynchus* Eudes-Deslongchamps, 1868 (Fig. 7E) and *Gracilineustes leedsi* (Andrews, 1913) (Fig. 7F) they are mainly borne by the atlas centrum. The participation of the atlas intercentrum in the formation of the rib facet was described for *Metriorhynchus jaekeli* Schmidt, 1904 (see Jaekel 1904: fig. 1) and is figured for *M. superciliosus* (see Andrews 1913: fig. 61). In *E. schroederi* the atlas ribs obscure the rib facets on both sides (Fig. 7B, I), but it appears that the atlas intercentrum might have participated in the atlas rib facet. In the referred specimen of *E. macrospondylus* (RNGD 990201)

576 the rib facet is borne on the atlas centrum (Fig. 7C). Whether or not the atlas intercentrum took part
577 in the formation of the atlas rib facet is unclear as this element is not preserved in RNGD 990201.

578 (3) The diapophyses are present on the axis neural arches in all examined metriorhynchid
579 taxa, such as *M. superciliosus* (Fig. 7D), '*M.*' *brachyrhynchus* (Fig. 7E) and *Cricosaurus vignaudi*
580 (see Frey *et al.* 2002: fig. 6), and thus this character is of no diagnostic value.

581 (4) A ventral ridge on the axis centrum is present on MB.R.1943.2, although its anterior
582 portion is damaged (Fig. 3E). This ridge is very indistinct in *E. schroederi* (Fig. 7I), especially
583 when compared with the pronounced ridges that occur in other metriorhynchids such as *G. leedsi*
584 (Fig. 7G) and *M. superciliosus* (Fig. 7H).

585 (5) The shape of the axis neural spine cannot be compared between RNGD 990201 and the
586 *E. macrospondylus* and *E. schroederi* holotypes as it is incomplete in the German specimens (Fig.
587 7A, B). A similar shape of the RNGD 990201 axis neural spine is, however, present in *M.*
588 *superciliosus* (Fig. 7D).

589 Therefore, based upon the five characters listed by Hua *et al.* (2000), the referral of the
590 French material to *Enaliosuchus macrospondylus* cannot be supported. The shape of the atlas
591 centrum differs between the specimens. It was described as sub-quadrangular in RNGD 990201,
592 whereas it is triangular in MB.R.1943.2. The atlas rib facet is borne by the atlas intercentrum and
593 atlas centrum in MB.R.1943.2, whereas the atlas intercentrum is missing in RNGD 990201 but a
594 large rib facet is evident at the atlas centrum. The diapophyses are consistently placed on the axis
595 neural arches in metriorhynchids, and a ventral keel on the axis centrum is not unique. Finally, the
596 shape of the axis neural spine is largely damaged in MB.R.1943.2 and cannot be compared.
597 Moreover, the length-to-height ratio of the axis centrum likewise differs between MB.R.1943.2
598 (1:1) and RNGD 990201 (1:0.7). Although, in the latter the transverse compression may impact this
599 ratio. A longer ratio also occurs in *Metriorhynchus superciliosus* (NHMUK PV R 2051, 1:1.16),

600 *Gracilineustes leedsi* (NHMUK PV R 3014, 1:1.16) and ‘*M.*’ *brachyrhynchus* (NHMUK PV R
601 2039, 1:1.08 and NHMUK PV R 3804, 1:1.11).

602 The referral of the *Enaliosuchus schroederi* holotype by Hua *et al.* (2000) to the
603 *Enaliosuchus macrospondylus* hypodigm is also questionable. Several elements in the atlas-axis
604 complex of this specimen differ from MB.R.1943.2, such as the atlas intercentrum that extends
605 more dorsally, and the atlas neural arches which have a carved anteroventral portion for the
606 articulation with the atlas intercentrum (Fig. 7B). A re-description of the *E. schroederi* holotype is
607 forthcoming, which will discuss the atlas-axis in more detail.

608

609 4.4. The Karl *et al.* (2006) taxonomy

610 Curiously, Karl *et al.* (2006) assigned the holotypes of both *E. macrospondylus* and *E. schroederi* to
611 the genus *Metriorhynchus*, as *Metriorhynchus* sp.. The arguments in Karl *et al.* (2006) are very
612 superficial, no detailed comparisons were made, and their phylogenetic analysis had an odd sample-
613 set for testing the internal position of *Enaliosuchus* within Metriorhynchidae. *Enaliosuchus*
614 *schröderi* can be distinguished from *Metriorhynchus* spp. with the same atlas-axis characters by
615 which it differs from *E. macrospondylus*, whereas several characters present in *E. macrospondylus*
616 do indeed occur in *M. superciliosus* (Fig. 7D) and ‘*M.*’ *brachyrhynchus* (Fig. 7E) (see discussion
617 above). However, given that the atlas-axis complex is only known and well-described in a limited
618 number of metriorhynchid taxa, and that most characters listed by Koken (1883), Hua *et al.* (2000),
619 and Karl *et al.* (2006) have a widespread distribution in Metriorhynchidae (see discussion above),
620 we cannot agree with the unambiguous referral of the *E. macrospondylus* and *E. schroederi*
621 holotypes to the genus *Metriorhynchus* as proposed by Karl *et al.* (2006).

622 Oddly, the cranial morphology of the *E. schroederi* holotype alone is enough to readily
623 distinguish it from *Metriorhynchus* (e.g. smooth dermatocranium, very large sclerotic rings, jugal
624 excluded from the preorbital fenestrae). As stated above, the phylogenetic analysis of Young &

625 Andrade (2009) recovered *E. schroederi* and the French specimen referred to *E. macrospondylus* as
626 derived metriorhynchines, thus supporting its distinction from *Metriorhynchus*. The phylogenetic
627 analysis of Jouve (2009) recovering *Enaliosuchus* as the sister taxon to *Dakosaurus* similarly
628 falsifies the *Metriorhynchus* subjective synonymy hypothesis. This contrasts with the strange taxon
629 and character sample set in the phylogenetic analysis of Karl *et al.* (2006), which had a single
630 metriorhynchid OTU, referred to as “*Enaliosuchus/Metriorhynchus*”. The remaining OTUs were
631 four crocodylians, three teleosauroids and the basal metriorhynchoid *Pelagosaurus typus* (the same
632 taxon-sample as Koken 1883). The specimens that were the basis for scoring their OTUs is not
633 given. Only ten characters were included, three cranial characters, and seven out of the nine atlas-
634 axis characters from Koken (1883). While the Karl *et al.* (2006) phylogenetic analysis does show
635 that most of the atlas-axis characters used by Koken (1883) to establish *E. macrospondylus* has a
636 wide distribution in crocodyliforms, it does not support their contention that *Enaliosuchus* is a
637 subjective junior synonym of *Metriorhynchus*. Principally because they never tested it. It is not
638 clear why Karl *et al.* (2006) used a phylogenetic analysis to highlight the distribution of atlas-axis
639 characters rather than a comparative plate figuring the characters.

640 Moreover, in using a sub-sample of Koken’s (1883) atlas-axis character set, and the same
641 limited taxon set as Koken (1883), Karl *et al.* (2006) compound the original issue Koken had: the
642 lack of comparative data with metriorhynchids. The difference being, the lack of comparative
643 material is understandable in Koken (1883). Finally, Karl *et al.* (2006) did not mention the Hua *et*
644 *al.* (2000) study. It appears they were unaware of the third putative *Enaliosuchus* specimen, and the
645 new atlas-axis characters proposed by Hua *et al.* (2000).

646

647

648

649 5. Cretaceous metriorhynchids

650 The fossil record of Metriorhynchidae is poorer in the Cretaceous than in the Jurassic. Early
651 overviews of metriorhynchid evolution and species diversity found metriorhynchid biodiversity was
652 affected by an extinction at the Jurassic-Cretaceous boundary (Pierce *et al.* 2009; Young *et al.*
653 2010), with Cretaceous metriorhynchids characterised as a “dead clade walking” (Young *et al.*
654 2010). However, over the past decade the two-phase extinction hypothesis (end-Tithonian
655 biodiversity crash and Valanginian-Hauterivian boundary final extinction) posited by Young *et al.*
656 (2010) has been falsified. Re-examination of Cretaceous fossils found that at least four
657 metriorhynchid lineages are known to have survived into the Cretaceous (Young *et al.* 2014b). It is
658 unclear whether some of the metriorhynchid specimens from the Vaca Muerta Formation of
659 Argentina, such as the *Purranisaurus potens* Rusconi 1948 holotype and those referred to
660 *Cricosaurus* sp. and *Dakosaurus andiniensis* Vignaud & Gasparini, 1996 are **uppermost** Tithonian
661 or **lowermost** Berriasian in age (Herrera *et al.* 2015; Fernández *et al.* 2019; Herrera pers. comm.
662 2019). Thus, potentially six metriorhynchid lineages crossed the Jurassic–Cretaceous boundary. An
663 incomplete metriorhynchid skull from Berriasian strata of the Neuquén basin is known (Fernández
664 *et al.* 2019). The specimens from the **uppermost** Tithonian or **lowermost** Berriasian of Russia are
665 taxonomically indeterminate (Ochev 1981).

666 From the Valanginian of France and Germany four different lineages of metriorhynchid are
667 known: Geosaurina, Plesiosuchina and two lineages of Rhacheosaurini (Table 1). These include the
668 holotype of the nomen dubium *Neustosaurus gigondarum* Raspail, 1842, the holotype of
669 *Enaliosuchus macrospondylus*, the holotype of *Enaliosuchus schroederi*, the holotype of *Geosaurus*
670 *lapparenti* (Debelmas & Strannoloubsky, 1957), the French specimen referred to *Enaliosuchus*
671 *macrospondylus*, a specimen referred to as cf. *Geosaurus lapparenti* and an indeterminate
672 Plesiosuchina specimen (Raspail 1842; Debelmas & Stannoloubsky 1956; Debelmas 1958; Hua *et*
673 *al.* 2000; Karl *et al.* 2006; Young *et al.* 2014b). A skull from the Valanginian of Colombia has been
674 referred to cf. *Cricosaurus* (Larsson *et al.* 2012).

675 From the upper Valanginian or lower Hauterivian of France an indeterminate
676 metriorhynchid is known (Debelmas & Demians D'Archimbaud 1956), and from the lower
677 Hauterivian of France an incomplete skeleton has been referred to *Geosaurus lapparenti*
678 (Debelmas, 1952).

679 Post-Hauterivian metriorhynchids are exceptionally rare. A poorly preserved incomplete
680 skull from the Barremian of Spain had been considered to be a possible metriorhynchid (Parrilla-
681 Bel *et al.*, 2012), although this seems less likely now (Parrilla-Bel pers. comm. 2017). Chiarenza *et*
682 *al.* (2015) referred an isolated tooth crown from the lowermost Aptian of Sicily to Plesiosuchina
683 based on a series of apomorphies. This tooth significantly increased the known geological range of
684 Metriorhynchidae. Curiously, Fischer *et al.* (2015) raised the issue that the Sicilian tooth could in
685 fact be a brachauchenine pliosaurid, like *Makhaira rossica* Fischer, Arkhangelsky, Stenshin,
686 Uspensky, Zverkov & Benson, 2015. However, they did not address the list of apomorphies
687 Chiarenza *et al.* (2015) gave when they referred the tooth to Plesiosuchina (such as the presence of
688 contiguous microdenticles, the denticles being rectangular in shape, and the presence of 'weak'
689 carina flanges). The convergences between the Sicilian tooth and *Makhaira rossica* are interesting,
690 but it is based on superficial similarities and not on apomorphies. In fact, *Makhaira rossica* lacks all
691 of the plesiosuchin apomorphies observable in the Sicilian tooth. As such, Fischer *et al.* (2015)
692 inadvertently strengthened the referral of the Sicilian tooth to Plesiosuchina (as Cretaceous
693 pliosaurids did not seem to evolve the apomorphies seen in metriorhynchids), not the reverse.
694 Although, in the absence of more complete material, the specimen still needs to be considered cf.
695 Plesiosuchina. Post-Hauterivian survival of Metriorhynchidae needs confirmation with more
696 complete material. However, with the description of a Barremian teleosauroid specimen (see Cortés
697 *et al.*, 2019), it does seem that thalattosuchians persisted for longer than previously realised closer
698 to the equator. Their continued presence could have acted as a barrier to large-bodied neosuchians
699 colonising Lower Cretaceous marine ecosystems.

700

701 **6. Are *Enaliosuchus* and *Neustosaurus* congeneric?**

702 The poorly ossified proximal femoral epiphyses seen in *Enaliosuchus macrospondylus* Koken, 1883
703 (Fig. 6), as mentioned above, are either artefactual, pathological, or evidence of a shift in femoral
704 morphology during the Cretaceous. The holotype of *Neustosaurus gigondarum* Raspail, 1842 is a
705 largely complete post-dorsal postcranial skeleton from the Valanginian of France. Considered to be
706 a nomen dubium by Young & Andrade (2009), the whereabouts of the holotype has never been
707 ascertained (although a cast of a very small portion of the skeleton is on display in the MNHN).
708 Raspail (1842) figured both femora, and they look strikingly similar to our reconstruction of the
709 femur in *Enaliosuchus macrospondylus* (Fig. 6).

710 That being said, the obvious problems are: (1) the *E. macrospondylus* femur is incomplete,
711 and (2) the *N. gigondarum* femora cannot be checked first-hand. With these caveats in mind, the
712 peculiar sigmoidal shape and the oddly flat proximal epiphyses are unique to these two specimens.
713 Should both of these features prove to be genuine (which we cannot be certain of), it hints a
714 possible relationship between these two genera. New discoveries of Valanginian metriorhynchids
715 are needed to elucidate femoral morphotypes, thus it is premature to posit *Enaliosuchus* as a
716 subjective junior synonym of *Neustosaurus*. But this is a hypothesis that should be tested when
717 more data becomes available.

718

719 **7. Conclusions**

720 In conclusion, the holotype specimen of *Enaliosuchus macrospondylus* (MB.R.1943.1-16) lacks
721 unique anatomical traits (although see our discussion on the femur above), and preserved axial
722 skeleton largely resembles the morphology present in other metriorhynchids such as
723 *Metriorhynchus superciliosus*, ‘*M.*’ *brachyrhynchus* and *Gracilineustes leedsi*. The atlas-axis
724 complex preserved with the *E. schroederi* holotype shows several symplesiomorphic

metriorhynchid traits, but the *E. macrospondylus* holotype lacks the peculiar morphology of the atlas intercentrum and atlas neural spine, which indicates that they are distinct taxa. The French specimen (RNGD 990201) referred to *Enaliosuchus macrospondylus* by Hua *et al.* (2000) is distinct from MB.R.1943.1-16 in the shape of the atlas centrum, and possibly in the placement of the atlas rib facet and the proportions of the axis centrum.

Given these morphological differences, the monospecific hypothesis of Hua *et al.* (2000) (with the *Enaliosuchus macrospondylus* and *E. schroederi* holotypes and the French specimen RNGD 990201 all referred to the same species) is not justifiable. With the lack of evidence to refer other specimens to this taxon, only the holotype specimen (MB.R.1943.1-16) can be referred to as *Enaliosuchus macrospondylus*. While the femur is incomplete, it shows a striking resemblance to those of *Neustosaurus gigondarum* (a species known from a single specimen, which unfortunately cannot be examined first-hand). Due to the lack of verifiable autapomorphies, *E. macrospondylus* is here considered a nomen dubium that is best classified as Metriorhynchidae gen. et sp. indet. As the Cretaceous fossil record of Metriorhynchidae improves, new discoveries could resurrect *E. macrospondylus*, and test a possible synonymy between *Enaliosuchus* and *Neustosaurus*. Until then, we consider *E. macrospondylus* to be a nomen dubium, '*E.*' *schröderi* to be a valid taxon, and the French specimen an unnamed distinct species. As the location of the *Neustosaurus gigondarum* holotype is still unknown, we follow Young & Andrade (2009) in considering it to be a nomen dubium.

744

8. Systematic synopsis

746

Crocodylomorpha Hay, 1930 (*sensu* Nesbitt, 2011)

Crocodylomorpha gen. et sp. indet.

749

750 *Material:* RMH uncatalogued (2), an isolated tooth crown (Fig. 2C).

751

752 *Locality:* “Osterwald [Mountains]” (Koken 1883), southern Lower Saxony, northern Germany.

753

754 *Stratigraphy:* “Hils-Conglomerat” (Koken 1883); i.e. Grenzlerburg Member, Salzgitter Formation,
755 Minden Braunschweig Group, uppermost Valanginian to lowermost Hauterivian, Lower
756 Cretaceous.

757

758 Goniopholididae Cope, 1875

759 ?Goniopholididae gen. et. sp. indet.

760

761 *Material:* MB.R.3636, an isolated tooth crown (Fig. 2A,B).

762

763 *Locality:* Elligser Brink near Delligsen, southern Lower Saxony, northern Germany (Koken 1883).

764

765 *Stratigraphy:* “Elligserbrink-Schicht”, Stadthagen Formation, Minden Braunschweig Group,
766 uppermost Valanginian to lowermost Hauterivian.

767

768 Metriorhynchidae Fitzinger, 1843 (*sensu* Young & Andrade, 2009)

769 ?Metriorhynchidae gen. et sp. indet.

770

771 *Material:* MB.R.1939. Fragmentary phalanx. RMH uncatalogued (1). Dorsal vertebra (Fig. 4Q-U).

772

773 *Locality*: “Osterwald [Mountains]” (Koken 1883), probably the former Osterwald Tiefbauschacht
774 mine shaft, c. 1.3 km east of the town of Osterwald, southern Lower Saxony, northern Germany
775 (approx. 52°06’34’’N, 9°38’37’’E).

776

777 *Stratigraphy*: Lower part of Stadthagen Formation, Minden Braunschweig Group. Most probably
778 middle lower to lowermost upper Valanginian, Lower Cretaceous.

779

780

781 Metriorhynchidae Fitzinger, 1843 (*sensu* Young & Andrade, 2009)

782 Metriorhynchidae gen. et sp. *indet.*

783 *Enaliosuchus macrospondylus* Koken, 1883

784 (nomen dubium)

785 *Figs. 3-6*

786

787

788 *Holotype*: MB.R.1943.1-16. Atlas-axis complex, remnants of *three* post-axial cervical vertebrae,
789 *eight* dorsal vertebrae, *several fragmentary dorsal ribs*, *one caudal vertebra*, *an incomplete femur*,
790 *fragment of a sacral rib*.

791

792 *Type locality*: “Osterwald [Mountains]” (Koken 1883), probably the former Osterwald
793 Tiefbauschacht mine shaft, c. 1.3 km east of the town of Osterwald, southern Lower Saxony,
794 northern Germany (approx. 52°06’34’’N, 9°38’37’’E).

795

796 *Stratigraphy*: Lower part of Stadthagen Formation, Minden Braunschweig Group, most probably
797 middle lower to lowermost upper Valanginian, Lower Cretaceous.

798

799 **Acknowledgements**

800 We would like to thank D. Schwarz (MB) for providing access to the specimen in her care, and for
801 information and photographs of the material. Yanina Herrera is thanked for helpful discussion. MT
802 Young is supported by a Leverhulme Trust Research Project grant (number RPG-2017-167), and
803 received support for his collection visits to Paris and Berlin from the SYNTHESYS Project, which
804 is financed by the European Community Research Infrastructure Action, under the FP7 "Capacities"
805 Program. We thank Yanina Herrera and an anonymous reviewer for their helpful comments that
806 improved the quality of this paper.

807

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1021 Figure captions

1022

1023 Figure 1: Geographic, palaeogeographic and geological situation of the *Enaliosuchus*
1024 *macrospondylus* material. A) General location map, B) Geological situation in the vicinity of the
1025 Osterwald Mountains, with location of the potential type localities Osterwald clay-pit (1) and
1026 Tiefbauschacht Osterwald mine shaft (2). Geological data from Landesamt für Bergbau, Energie
1027 und Geologie (NIBIS® Kartenserver, 2014), C) Palaeogeographical sketch map for the
1028 Valanginian, showing the location of Osterwald and Elligser Brink. Note that during the earliest
1029 Hauterivian the shoreline shifted further landward due to transgression. After Mutterlose (1984),
1030 modified.

1031 [Intended for page width]

1032

1033 Figure 2. Teeth initially referred to *Enaliosuchus macrospondylus*. ?Goniopholidae gen. et sp. indet.
1034 (MB.R.3636), uppermost Valanginian to lowermost Hauterivian of Elligser Brink near Delligsen in
1035 (A) distal and (B) labial views. (C) Crocodylomorpha gen. et. sp. indet. (RMH uncatalogued),
1036 uppermost Valanginian to lowermost Hauterivian of the Osterwald Mountains. Note that only the
1037 tooth on the right side, shown in labial view, is mentioned in Koken (1883). Scale bar equals 1 cm.

1038 [Intended for page width]

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1040 Figure 3. Atlas-axis complex (MB.R.1943.2) of the *Enaliosuchus macrospondylus* holotype
1041 specimen, middle to upper Valanginian of the Osterwald Mountains in (A) anterior, (B) left lateral,
1042 (C) dorsal, (D) posterior, (E) right lateral and (F) ventral view. Scale bar equals 5 cm.
1043 Abbreviations: apo, atlas postzygapophysis; apr, axis prezygapophysis; atc, atlas centrum; atic, atlas
1044 intercentrum; atn, atlas neural arch; atr, atlas rib; ap, axis parapophysis; axc, axis centrum; axn, axis
1045 neural arch; dia, axis diapophysis.

1046 [Intended for page width]

1047

1048 Figure 4. Postaxial cervical vertebrae of the *Enaliosuchus macrospondylus* holotype from the
1049 middle to upper Valanginian of the Osterwald Mountains. Cervical vertebra (MB.R.1943.3) in (A)
1050 lateral, (B) anterior, (C) posterior, (D) dorsal and (E) ventral view. Posterior cervical vertebra
1051 (MB.R.1943.1) in (F) posterior and (G) lateral view. Scale bars equal 5 cm. Abbreviations: dia,
1052 diapophysis; mk, midline keel; ns, neural spine; pap, parapophysis; prz, prezygapophysis.

1053 [Intended for page width]

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1055 Figure 5. Additional postaxial vertebrae and ribs of the *Enaliosuchus macrospondylus* hypodigm
1056 from the lowermost upper Valanginian of the Osterwald [Mountains]. Dorsal vertebra
1057 (MB.R.1943.4) in (A) lateral, (B) posterior, (C) dorsal and (D) anterior view. Dorsal centrum
1058 (MB.R.1943.6) in (E) anterior and (F) lateral view. Neurapophysis of a dorsal vertebra
1059 (MB.R.1943.7) in (G) lateral and (H) anterior view. (I) Rib fragments (MB.R.1943.9). RMH
1060 uncatalogued. Dorsal vertebra referred to *Enaliosuchus macrospondylus* by Koken (1883) in (J)
1061 lateral, (K) anterior, (L) ventral, (M) posterior and (N) dorsal view. Caudal vertebra
1062 (MB.R.1943.11) in (O) lateral, (P) anterior, (Q) ventral, (R) posterior and (S) dorsal view. Scale
1063 bars equal 5 cm. Abbreviations: bn, base of neural arch; hf, hemapophyseal facet; ns, neural spine;
1064 pap, parapophysis; tp, transverse process.

1065 [Intended for page width]

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1067 Figure 6. Incomplete, possibly left, femur (MB.R.1943.15.1+2) of the *Enaliosuchus*
1068 *macrospondylus* holotype specimen from the lowermost upper Valanginian of the Osterwald
1069 [Mountains] with the missing part of the shaft being based upon *Neustosaurus gigondarum*. (A)
1070 proximal, (B) medial, (C) lateral and (D) proximal view. Scale bar equals 5 cm.

1071 [Intended for ½ page width]

1072 Figure 7. Additional elements of the *Enaliosuchus macrospondylus* hypodigm from the lowermost

1073 upper Valanginian of the Osterwald [Mountains]. (A, B) supposed proximal portion of a sacral rib

1074 (MB.R.1943.16), (C, D) fragmentary phalanx (MB.R.1939). Scale bars equal 1 cm.

1075 [Intended for ½ page width]

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1077 Figure 8. Comparison of metriorhynchid atlas-axis components of (A) *Enaliosuchus*

1078 *macrospondylus* holotype (MB.R.1943.1-16) in lateral view, (B) *Enaliosuchus schroederi* holotype

1079 (MM uncatalogued) in lateral view, (C) referred specimen of *Enaliosuchus macrospondylus*

1080 (RNGD 990201) in lateral view, (D) *Metriorhynchus superciliosus* (NHMUK PV R 2051) in lateral

1081 view, (E) ‘*Metriorhynchus*’ *brachyrhynchus* (NHMUK PV R 3804) in lateral view, (F)

1082 *Gracilineustes leedsi* (NHMUK PV R 3015) in lateral view, (G) *Gracilineustes leedsi* (NHMUK

1083 PV R 3014) in ventral view, (H) *Metriorhynchus superciliosus* (NHMUK PV R 2051) in ventral

1084 view, (I) *Enaliosuchus schroederi* holotype (MM uncatalogued) in ventral view. Abbreviations: arf,

1085 atlas rib facet; atc, atlas centrum; atic, atlas intercentrum; atr, atlas rib; axc, axis centrum; **axp**, axis

1086 **parapophysis**; dia, diapophysis; vk, ventral keel. Scale bars equal 1 cm.

1087 [Intended for page width]

1088 Table 1. Table of all published thalattosuchian specimens from the Cretaceous. Note that all the French Cretaceous metriorhynchids are from the
1089 Région Provence-Alpes-Côte d'Azur, and the German Cretaceous metriorhynchids are from Lower Saxony. Furthermore, the age of the Russian
1090 material is either **uppermost** Jurassic or **lowermost** Cretaceous.

	Specimen	Age	Locality	Reference
1	<i>Dakosaurus andiniensis</i> referred specimen	Upper Tithonian or Lower Berriasian	Yesera del Tromen-Pampa Tril area, Neuquén Province, Argentina	Herrera <i>et al.</i> 2015; Fernández <i>et al.</i> 2019
2	<i>Purranisaurus potens</i> holotype	Upper Tithonian or Lower Berriasian	Malargüe Department, Mendoza Province, Argentina	Herrera <i>et al.</i> 2015; Fernández <i>et al.</i> 2019
3	<i>Cricosaurus</i> sp.	Upper Tithonian or Lower Berriasian	Arroyo Durazno, Mendoza Province, Argentina	Fernández <i>et al.</i> 2019
4	Metriorhynchidae indeterminate	Upper Tithonian or Lower Berriasian	Arroyo Paulino, Mendoza Province, Argentina	Fernández <i>et al.</i> 2019
5	Metriorhynchidae indeterminate	Upper Tithonian or Lower Berriasian	Khoroshevskii Island, Volga Region, Russia	Ochev 1981
6	Metriorhynchidae indeterminate	Lower Berriasian	Arroyo Paulino, Mendoza Province, Argentina	Fernández <i>et al.</i> 2019
7	<i>Neustosaurus gigondarum</i> holotype	Lower Valanginian	Département du Vaucluse, France	Raspail 1842
8	' <i>Cricosaurus</i> ' <i>macrospondylus</i> referred specimen	Lower Valanginian	Département des Hautes-Alpes, France	Hua <i>et al.</i> 2000
9	<i>Cricosaurus schroederi</i> holotype	Lower Valanginian	Landkreis Schaumburg, Germany	Karl <i>et al.</i> 2006
10	cf. <i>Geosaurus lapparenti</i>	Lower Valanginian	Département du Vaucluse, France	Debelmas 1958
12	<i>Enaliosuchus macrospondylus</i> holotype	Lower upper Valanginian	Landkreis Hamelin-Pyrmont, Germany	Koken 1883
13	cf. <i>Cricosaurus</i>	Upper Valanginian	Colombia	Larsson <i>et al.</i> 2012
14	Plesiosuchina indeterminate	LowerUpper Valanginian	Département des Bouches-du-Rhône, France	Young <i>et al.</i> 2014b
15	<i>Geosaurus lapparenti</i> holotype	Upper Valanginian	Département du Var, France	Debelmas & Stannoloubsky 1957
16	Metriorhynchidae indeterminate	Upper Valanginian or Lower Hauterivian	Département du Vaucluse, France	Debelmas & Demain D'Archimbaud 1956

17	<i>Machimosaurus rex</i> holotype	Hauterivian? (Upper Jurassic– Lower Cretaceous)	Touil el Mhahir, Tataouine Governorate, Tunisia	Fanti <i>et al.</i> 2016 (but see Cortés <i>et al.</i> , 2019)
18	<i>Geosaurus lapparenti</i> referred specimen	Lower Hauterivian	Département du Var, France	Debelmas 1952
19	Teleosauroida gen. et sp. indet.	Upper Barremian	Loma La Cabrera, Colombia	Cortés <i>et al.</i> , 2019
20	cf. Plesiosuchina	Lowermost Aptian	Montagna Grande area, Sicily	Chiarenza <i>et al.</i> 2015

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Response to comments of reviewers and editor

Please ensure the text of your paper is double-spaced and has consecutive line numbering – this is an essential peer review requirement

This has been done

- Chronostratigraphy versus geochronology - When referring to rocks (formations, deposits, strata, ...) refer to the chronostratigraphic attributes upper/lower (Stages), when dealing with time (geochronology) to late/early (Ages).

In addition, when referring to fossil specimens, use the chronostratigraphic notation Lower/Upper (see Owen, 2009. Stratigraphy, vol. 6, no. 2, p. 110: "In discussing the age relationships of fossils, the clearest terminology would be to refer to fossils as lower, middle, and upper as in Upper Cretaceous fossils. In discussing the living organisms that later became fossils, the clearest terminology would be early, middle, and late, as in Late Cretaceous dinosaur behavior."

For instance,

Title: change FROM "Early Cretaceous fossil record" TO "Lower Cretaceous fossil record"

Please check and correct the usage in the manuscript.

We carefully checked this and altered the text accordingly

- Scale bars have to be provided to all figured specimens and details.

Figure 6: Though it is mentioned that "No scale intended.", if possible please add scale bars

Scale bars have been added

Order of Figures: All figures must be presented in the same sequence that have their first citations in the manuscript text. Please check and correct carefully the order of figures in the manuscript and their corresponding first citations. Delete out-of order citations and/or rearrange them if necessary. Check also for missing citations.

This has been done

ACKNOWLEDGEMENTS: Though it is not mandatory, it is always very much appreciated when authors thank the reviewers in the Acknowledgments, by name if his/her identity has been revealed, or as "anonymous reviewers" if you do not know their names.

This has been done

-Reviewer 1

1) I think that the portions of the tibiae are the proximal and distal ends of the left femur (see picture attached in the pdf). Also, I think that the metacarpal is the distal end of a sacral rib. I have pictures of the material that the authors mentioned that were not found in the collection of MB or RHM. I can share the files.

We are grateful for this comment and agree that this is the left femur. The description and figure has been modified accordingly.

2) The authors have to ask for a new collection number for the ?Goniopholididae gen. et. sp. indet. or for Metriorhynchidae gen. et sp. indet. Currently, both have the same collection number.

This has been done

There is not any mention of the neurocentral suture that is open in most of these dorsal vertebrae

Thanks for the comment. We added it to the description.

I was working on the collection of the MB (December 2015), and the material was at the collection. If the authors need, I can share the pictures

We are grateful for this comment. We added the supposed missing elements to the description and compiled new figures showing the material.

The same collection number than ?Goniopholididae gen. et. sp. indet. One of these specimens requires a new collection number

This has been fixed. The tooth has a different collection number.

-Reviewer 2

- Sachs et al. redescribe the holotype material of *Enaliosuchus macrospondylus* in light of current understanding of metriorhynchid diversity and morphology. They compare it with overlapping material from the referred French specimen and *E. schroederi* (as well as other metriorhynchids). They find *E. macrospondylus* to be a nomen dubium as the holotype material lacks autapomorphies. This is a much-needed revision of this taxon and is clearly written. I appreciate the detailed comparisons with other material. I do not have any major suggestions for revision. I have made a number of minor comments throughout the annotated pdf copy of the manuscript. The figures could be improved with some relatively minor modifications detailed below.

We are grateful for this comment

Comments on Figures:

Figure 3 – There are some fairly heavy shadows in these images that make interpretation of some of the morphology a little difficult. The figure may be more informative if the authors were to draw lines over the sutures and facets discussed in the text. Additionally, some of the lines for the labels are difficult to trace across the dark parts of the photographs; the addition of a white line (or shadow) immediately adjacent to the black would make it easier to follow across changing colors. Additionally, it might be helpful to label the facet for the atlas rib (on the right side).

A new figure with new photos has been compiled that is more informative than the original one.

Figure 3 caption – “axc” is missing

Thank you. It has now been added.

Figure 5 – Presumably this figure shows both tibiae? A & B appear to be the same bone from different angles, but C (labeled as “medial view”) looks like a different bone (and I can’t tell if D is the distal end of B or C). These should be more clearly labeled.

This has been changed and is clarified in the text.

Figure 6 – The text labels on part C are very difficult to read against the dark background. I see that the authors added a thin white outline to the text in an effort to make it stand out, but at print size, this is barely perceptible. Perhaps making this white border thicker would help the letters stand out better? Or maybe lightening the surrounding matrix in photoshop so the black labels are legible (which would have the added bonus of making the bone stand out better too). As in Figure 3, some of the black lines indicating labeled features are difficult to follow across dark portions of the photographs and white shadow lines would be helpful (as in part C). Finally, maybe outlining (or placing a translucent polygon over) the atlas rib facet would be helpful as its borders are not particularly obvious on some of the specimens.

This figure has been modified so that all lines in darker parts are nicely visible. Also the labels in part C have also been enhanced. The position of the atlas ribs are well visible in all images (image A has been renewed and an interpretation is available in figure 3).

(2) the atlas ribs inserted on both the atlas intercentrum and axis centrum,
The reviewer notes that it should be the axis centrum and he is correct. But this text is a translation of the original text of Hua et al. (2000) and these authors indeed (and incorrectly) refer to the axis and not the atlas centrum. We, however, discussed this in the text.

1 The enigma of *Enaliosuchus*, and a reassessment of the Lower 2 Cretaceous fossil record of Metriorhynchidae

3

4 Sven Sachs^{a, b *}, Mark T. Young^c, Jahn J. Hornung^d

5

6 ^A Naturkunde-Museum Bielefeld, Abteilung Geowissenschaften, Adenauerplatz 2, 33602 Bielefeld, Germany

7 ^B Im Hof 9, 51766 Engelskirchen, Germany

8 ^cSchool of GeoSciences, Grant Institute, The King's Buildings, University of Edinburgh, James Hutton Road,

9 Edinburgh, EH9 3FE, United Kingdom

10 ^D Niedersächsisches Landesmuseum Hannover, Willy-Brandt-Allee 5, 30169 Hannover, Germany

11

12 *Corresponding author.

13 E-mail addresses: Sachs.Pal@gmail.com (Sven Sachs), Mark.Young@ed.ac.uk (Mark T. Young),

14 jahn.hornung@yahoo.de (Jahn J. Hornung)

15

16 ABSTRACT

17 *Enaliosuchus macrospondylus* Koken, 1883 was one of the first thalattosuchian taxa from the Cretaceous to be
18 described. The type series includes an atlas-axis complex, remnants of three post-axial cervical vertebrae, several dorsal
19 vertebrae, a caudal vertebra, an incomplete femur and a fragmentary sacral rib from the upper Valanginian of northern
20 Germany. Additionally, two isolated, non-thalattosuchian, tooth crowns from the uppermost Valanginian to lowermost
21 Hauterivian of different localities in northern Germany were tentatively assigned to *E. macrospondylus* by Koken. The
22 taxon was established for the distinctive the atlas-axis morphology, in particular the apparent lack of an axis
23 parapophysis. *Enaliosuchus macrospondylus* has been considered a valid taxon in recent studies, based upon a largely
24 complete metriorhynchid specimen from the Valanginian of France that had been referred to this taxon, an assignment
25 that has never been questioned. Here we provide a detailed re-description of the *E. macrospondylus* holotype specimen
26 and determine whether it is diagnostic, and if a referral of the French specimen to *E. macrospondylus* is justified. We
27 also discuss whether *E. macrospondylus* and another metriorhynchid specimen from the Valanginian of northern

Germany, described as *Enaliosuchus schroederi*, are conspecific. Finally, we provide an overview of the current knowledge of metriorhynchid diversity during the Cretaceous.

Keywords:

Crocodylomorpha

Thalattosuchia

Metriorhynchidae

Lower Cretaceous

Germany

1. Introduction

Thalattosuchian crocodylomorphs are considered to be rare in Lower Cretaceous strata. These specimens include the youngest recorded examples of the group, which so far is documented to the lowermost Aptian (see discussion below). In Germany, the first Cretaceous thalattosuchian remains were described by Ernst Koken from the Valanginian of Lower Saxony as a new genus and species, *Enaliosuchus macrospondylus* Koken, 1883. The holotype material comprises a number of cervical, dorsal and caudal vertebrae, along with limb and rib elements. Additionally, Koken (1883) tentatively referred two isolated teeth from two separate localities to his new taxon. Due to its geological age and the well preserved atlas-axis complex, the type specimen of *E. macrospondylus* sparked controversy and curiosity into the diversity and taxonomy of Cretaceous thalattosuchians (e.g. Schroeder 1921; Kuhn 1936; Hua *et al.*, 2000; Karl *et al.*, 2006), and also the diversity of cervical osteology in crocodylomorphs (e.g. Koken 1883, 1887; Baur 1886; Jaekel 1904; Boschma 1922). However, the *E. macrospondylus* holotype has never received an in-depth reappraisal, and its purported relationships with other thalattosuchian specimens (Kuhn 1936; Hua *et al.*, 2000; Karl *et al.*, 2006) have largely been based upon Koken's (1883) description. This original description was extensive, but it was limited by a lack of comparative metriorhynchid specimens during the late 19th

54 Century. Here we redescribe the holotype of *E. macrospondylus*, and assess the impact this has for
55 the taxonomy of Early Cretaceous metriorhynchids.

56

57 1.1 Historical overview

58 Koken (1883) established *Enaliosuchus macrospondylus* as a new genus and species because of the
59 seemingly novel morphology of the atlas-axis complex. In particular, the presence of atlas rib facets
60 being placed anteroventrally on the atlas centrum was listed as a peculiar feature for *Enaliosuchus*
61 (Koken 1883: 799). Koken (1883) compared the atlas-axis complex to those of modern
62 crocodylians, teleosauroids and the basal metriorhynchoid *Pelagosaurus typus* Bronn, 1841 (see
63 Koken 1883: 809, table therein); but not with metriorhynchids.

64 A second specimen, comprising an incomplete cranium and lower jaw, with the atlas-axis
65 and first post-axial cervical vertebra from the lower to middle Valanginian Stadthagen Formation of
66 north-western Germany was referred to *Enaliosuchus* by Schroeder (1921). The basis for this
67 referral was that the atlas-axis complex had similar atlas rib placement as that described by Koken
68 (1883) for *Enaliosuchus macrospondylus* (see Schroeder 1921: 364). Interestingly, Schroeder
69 (1921) neither explicitly referred the new specimen to *E. macrospondylus*, nor did he erect a new
70 species for it. This was carried out later by Kuhn (1936) who named the specimen *E. schröderi*
71 Kuhn, 1936. Note, that the use of the umlaut in the specific epithet by Kuhn (1936) was a
72 hypercorrection, as the correct spelling of Schroeder's name is with the *oe*. Furthermore, usage of
73 diacritic marks is not acceptable in a scientific name, in accordance with Article 27 of the ICZN
74 Code. Thus, the correct spelling is *E. schroederi*.

75 The acceptance of *E. schroederi* as a distinct species has been disputed. While some papers
76 have accepted both species as being valid (e.g. Steel 1973; Young & Andrade, 2009), they did not
77 base their opinions on a detailed comparison of the holotypes. Sickenberg (1961) was the first to
78 ask whether *E. schroederi* was distinct from *E. macrospondylus*, principally because Schroeder

79 (1921) was unsure in his original description whether the two specimens were conspecific (due to
80 the limited overlap between them) and only assigned the specimen to the genus *Enaliosuchus*,
81 leaving the species open. Hua *et al.* (2000) were the first to formally considered *E. schroederi* to be
82 a subjective junior synonym of *E. macrospondylus*, rendering *Enaliosuchus* a monospecific genus.
83 Jouve (2009) followed the taxonomy of Hua *et al.* (2000). Karl *et al.* (2006: 56) considered the
84 establishment of *E. schroederi* to be “completely unnecessary”, and could not preclude that the two
85 species were conspecific.

86 A third putative *Enaliosuchus* specimen, an incomplete skeleton from the lower Valanginian
87 (*Busnardoites campylotoxus* ammonite Zone) of south-eastern France, was referred to *E.*
88 *macrospondylus* by Hua *et al.* (2000). This specimen (catalogue number 990201 from the collection
89 of the Clément, Réserve Naturelle Géologique de Haute Provence in Digne les Bains – here later
90 referred to as RNGD 990201) comprises most of the cranium and mandible, an incomplete atlas-
91 axis complex, as well as five post-axial cervical and 15 dorsal vertebrae. While there is only minor
92 overlap with the *Enaliosuchus macrospondylus* holotype material, this referral was accepted
93 without comment in subsequent publications (e.g. Young & Andrade, 2009; Parrilla-Bel & Canudo,
94 2015; Sachs *et al.*, 2019). The cranial rostrum of RNGD 990201 is highly distinctive with its
95 posterodorsally retracted external nares, and Hua *et al.* (2000) used this specimen to emend the
96 diagnosis of *E. macrospondylus*. For the first time *Enaliosuchus* was clearly defined, and shown to
97 be distinct from other metriorhynchid taxa.

98 *Enaliosuchus* has been considered to be a poorly known metriorhynchid (von Huene 1956;
99 Steel 1973). Note, Young & Andrade (2009) altered the generic composition of *Geosaurus*, which
100 from 1901 – 2008 was considered to be a Late Jurassic longirostrine form, and moved several
101 species from *Geosaurus* to *Cricosaurus* and *Rhacheosaurus*. This unfortunately complicates the
102 next two paragraphs and their discussion on previous hypotheses on the position of *Enaliosuchus* in
103 Metriorhynchidae. Buffetaut (1982: 26) considered the *E. schroederi* holotype to be very similar to

104 *Geosaurus* Cuvier, 1824 (*Cricosaurus* Wagner, 1858 and *Rhacheosaurus* von Meyer, 1831 sensu
105 Young & Andrade, 2009), and based on the *E. schroederi* holotype, Buffetaut (1982) concluded that
106 the genus was distinct and valid. In Vignaud's (1995) unpublished PhD thesis, he considered
107 *Enaliosuchus* to be similar to *Geosaurus gracilis* (von Meyer, 1831) (*Rhacheosaurus* sensu Young
108 & Andrade, 2009), although he noted that the *E. schroederi* holotype and '*G.*' *gracilis* can be
109 differentiated on prefrontal and tooth enamel ornamentation characters. Vignaud (1995) therefore
110 provisionally retained *Enaliosuchus* as a valid genus. Neither Buffetaut (1982) nor Vignaud (1995)
111 examined a potential synonymy between *E. macrospondylus* and *E. schroederi*, although Vignaud
112 (1995) did state that Kuhn (1936) did not provide a diagnosis for *E. schroederi*. Moreover, it is clear
113 that the retention of *Enaliosuchus* as a valid genus by both Buffetaut (1982) and Vignaud (1995)
114 was based on the anatomy of the *E. schroederi* holotype, not the *E. macrospondylus* holotype.

115 The evolutionary relationships of *Enaliosuchus* have been further discussed since the
116 description of the French specimen by Hua *et al.* (2000) who considered *Enaliosuchus* to be closely
117 related to *Geosaurus* (*Cricosaurus* and *Rhacheosaurus* sensu Young & Andrade, 2009). The
118 evolutionary relationships of *Enaliosuchus* was first tested by Wilkinson *et al.* (2008), who found *E.*
119 *macrospondylus* (scoring based on the *E. macrospondylus* holotype and the French specimen) to be
120 within a clade formed by *Geosaurus* species (pre-Young & Andrade, 2009 metriorhynchid
121 taxonomy). Jouve (2009) however recovered *Enaliosuchus macrospondylus* (scoring based on the
122 *E. schroederi* holotype and the French specimen) as the sister taxon to *Dakosaurus* Quenstedt,
123 1856. It is unclear whether the different specimen scoring sources, and/or the different character and
124 taxon sets, are responsible for these differences.

125 The validity of the genus *Enaliosuchus* has been questioned, in different ways, by Karl *et al.*
126 (2006) and Young & Andrade (2009). Karl *et al.* (2006) referred both *E. macrospondylus* and *E.*
127 *schroederi* to the genus *Metriorhynchus* von Meyer, 1832, but did not retain either species as valid.
128 Whereas, based on their phylogenetic analysis, Young & Andrade (2009) considered *Enaliosuchus*

129 to be a subjective junior synonym of *Cricosaurus*, as *E. macrospondylus* and *E. schroederi* were
130 recovered as a subclade within their *Cricosaurus* clade. Young & Andrade (2009) chose not to
131 retain *Enaliosuchus*, as under their evolutionary hypothesis it would render *Cricosaurus*
132 paraphyletic, or demand the creation of multiple new genera. Note however, that they followed the
133 emended diagnosis of *Enaliosuchus* from Hua *et al.* (2000) without comment; and that the *E.*
134 *macrospondylus* operational taxonomic unit (OTU) scored by Young & Andrade (2009) was based
135 on the referred French specimen and the holotype. Interestingly, further iterations of the
136 phylogenetic dataset used by Young & Andrade (2009) have found *E. macrospondylus* and *E.*
137 *schröderi* to be distantly related, albeit both within Rhacheosaurini (datasets starting from Young
138 *et al.*, 2017).

139 In sum, *Enaliosuchus* is one of the most poorly understood metriorhynchid genera. Previous
140 studies have questioned the validity of the genus, and the validity of the second species assigned to
141 the genus (*E. schroederi*). Some studies that accept the validity of *Enaliosuchus* have done so based
142 on the anatomy of the *E. schroederi* holotype, not the *E. macrospondylus* holotype. The referral of
143 the highly diagnostic French specimen to *E. macrospondylus* was used to emended the specific
144 diagnosis, and for the first time clearly define *Enaliosuchus* and show it to be distinct from other
145 metriorhynchid taxa. Therefore, the following questions need to be addressed, and will be herein:
146 (1) is the *E. macrospondylus* holotype diagnostic; (2) do the holotypes of *E. macrospondylus* and *E.*
147 *schröderi* share synapomorphies that would justify assigning them to the same species (i.e. the
148 monospecific hypothesis of Hua *et al.* (2000)); and (3) was the referral of the highly diagnostic
149 French specimen to *E. macrospondylus* justified?

150

151 1.2. Institutional Abbreviations

152 MB – Museum für Naturkunde, Berlin, Germany; MNHN, Muséum national d'Histoire naturelle,
153 Paris, France; NHMUK – Natural History Museum, London, UK; RMH – Roemer und Pelizaeus

154 Museum, Hildesheim, Germany; RNGD – Réserve Naturelle Géologique de Haute Provence, Digne
155 les Bains, France; MM – Mindener Museum, Minden, Germany.

156

157 **2. Geological settings**

158 The material that constitutes the holotype of *Enaliosuchus macrospondylus* and the referred teeth
159 were found in two different locations in southern Lower Saxony, Germany and are actually
160 separated by a significant stratigraphical gap. With regard to the holotype, Koken (1883: 792)
161 specified the “Hils [strata] of the Osterwald” as the locality, and the horizon as “level of *Ammonites*
162 (*Olcostephanus*) *marginatus*”. Unfortunately, this information is somewhat ambiguous by present-
163 day concepts and need to be further elucidated. Geographically, the term “Osterwald” describes a
164 small mountainous region, ca. 30 km south-southwest of Hannover; as well as to the town of
165 Osterwald, which is located in the southern margin of those hills (Fig. 1A-B). The grammatical
166 form used by Koken (“des Osterwaldes”) indicates that he referred to the mountains rather than to
167 the settlement proper. Most of the Osterwald mountain range is formed by strata from the Jurassic
168 and the non-marine Berriasian – the marine Lower Cretaceous is exposed only in a small area in the
169 southeastern part due to a southeasterly dip of the succession (Albrecht 1913). While there are
170 numerous fossils from the marine Lower Cretaceous with the label “Osterwald” in museum
171 collections, as well as mentioned in the literature, details of the exact nature of this or these
172 outcrop(s) are rarely given. Von Koenen (1902) mentioned two important sources of such material
173 from Osterwald:

174 (1) the now abandoned brickworks clay-pit of the town of Osterwald, located c. 0.5 km to the east
175 of the settlement. It exposed upper Hauterivian clay- and marlstones with an abundance of the
176 heteromorph ammonite *Aegocrioceras capricornu* (Roemer 1841), preserved in calcareous
177 concretions (see also Stolley 1908).

178

179 (2) The Osterwald Tiefbauschacht, an abandoned mine shaft, c. 1.3 km east of the town of
180 Osterwald, that penetrated Valanginian marine strata to reach the Berriasian coal seams below
181 (Albrecht 1913). The mine shaft was constructed between 1879 and 1890 (Grimme, 2010).

182

183 The lithostratigraphic term “Hils [Formation]”, used by Koken, that denotes marine, mostly pelitic
184 deposits of Valanginian through Albian age in northern Germany, is currently superseded by the
185 Minden Braunschweig Group (Erbacher *et al.*, 2014a). In the Osterwald region, it can include beds
186 of Valanginian through Hauterivian age.

187 Unfortunately, the sedimentary matrix of the type specimen, consisting of a reddish sideritic
188 claystone (“rothbrauner Thoneisenstein” in the terminology of Koken) is not conclusive, as this
189 lithotype may occur in the Valanginian as well as in the Hauterivian of the region (e.g. Mutterlose
190 1984). The biostratigraphic information provided by Koken for the stratum typicum is problematic
191 as well. His “*Ammonites (Olcostephanus) marginatus*” obviously refers to the occurrence of the
192 ammonite species described by Neumayr & Uhlig (1881: 157) as “*Olcostephanus marginatus*
193 (Phill?) Römer” from Osterwald. These authors – following Roemer (1841) - redefined the species
194 *Ammonites marginatus* Phillips, 1829, based on a poorly figured and described juvenile individual
195 from England, to include some specimens from Lower Saxony. However, von Koenen (1902, 1909)
196 separated the Lower Saxonian material as *Polyptychites marginatus* (Neumayr & Uhlig, 1881) from
197 the English *Ammonites marginatus* Phillips, 1829. The latter was revised as *Simbirskites*
198 *marginatus* (Phillips, 1829), a zone index fossil from the upper Hauterivian, by Rawson (1971).

199 The referred material of “*Polyptychites marginatus*” sensu Neumayr & Uhlig (1881),
200 figured and discussed by von Koenen (1902, 1909), was subsequently partly reassigned to
201 *Polyptychites keyserlingi* (Neumayr & Uhlig, 1881) by Jeletzky & Kemper (1988), and partly to
202 *Polyptychites polyptychus* (von Keyserling, 1846) by Bogomolov (1989). *Polyptychites keyserlingi*
203 is clearly a middle lower Valanginian taxon, while *P. polyptychus* was reported from the lowermost

204 upper Valanginian (Jeletzky and Kemper 1988). With regard to the original material of
205 “*Olcostephanus*” *marginatus* from Neumayr & Uhlig (1881), Jeletzky & Kemper (1988: 29)
206 noticed some doubts about the source stratum, suggesting that it may be “misplaced” from the
207 Jurassic.

208 Nevertheless, Koken (1883) also clearly associated the horizon of “*Ammonites (Olcostephanus)*
209 *marginatus*” with the “Hils Formation”, and the matrix lithology supports a Lower Cretaceous
210 origin of the *Enaliosuchus macrospondylus* postcranial material. Considering that the taxa currently
211 comprising von Koenen’s (1902, 1909) concept of his Lower Cretaceous “*Polyptychites*
212 *marginatus*” (that was in turn based on Neumayr & Uhlig 1881) range from the middle lower to
213 lowermost upper Valanginian (Jeletzky & Kemper 1988, Bogomolov 1989), it is the most plausible
214 assumption that the holotype of *Enaliosuchus macrospondylus* originates from this
215 chronostratigraphic interval of the lower Stadthagen Formation in the Minden Braunschweig Group
216 (sensu Erbacher *et al.* 2014a). The locality was possibly the Tiefbauschacht Osterwald mine shaft
217 near the town of Osterwald. This localization is also in concordance with the information in von
218 Koenen (1902) for the ammonite material from “Osterwald”. It remains unclear, on what basis Karl
219 *et al.* (2006) correlated the stratum typicum with the “Astierenschichten”. The “Astierenschichten”
220 (“Astierien beds”, an obsolete lithostratigraphic term) are lowermost Hauterivian in age according to
221 Mutterlose (1992a).

222 The first isolated tooth referred to *E. macrospondylus* by Koken (1883: 824; MB.R.3636)
223 was found at the Elligser Brink, a hill ca. 0.6 km south of the town of Delligsen in the Hils
224 Mountains, about 50 km south of Hannover. Koken (1883) noted that it originates from the
225 collection of Friedrich Koch. Koch & Dunker (1837) described an assortment of vertebrate remains
226 in the marine Lower Cretaceous strata of this locality, that became known as the “Elligserbrink
227 bed”. As Koken (1883) did not mention otherwise, it is plausible that the tooth came from the same
228 horizon. This is corroborated by the fact that Koken referred also to this collection, stratum, and

locality, when describing the disputed pterosaur “*Ornithocheirus*” *hilsensis* in the same work (Koken 1883: 824f.). According to Burri (1956), the “Elligserbrink bed” dates to the uppermost Valanginian or lowermost Hauterivian (Stadthagen Formation, Minden-Braunschweig-Group).

The second isolated tooth Koken (1883) referred to *E. macrospondylus* (RMH uncatalogued [2]) originates from the “Hils conglomerate of the Osterwald”. According to Erbacher *et al.* (2014b) the lithostratigraphic name “Hils Conglomerate” in its classic sense (Roemer 1841) is obsolete and defines various homonymous units, ranging from the Berriasian to the Cenomanian. However, in a more strict and regional sense it is synonymous to the Grenzlerburg Member of the Salzgitter Formation (uppermost Valanginian through lower Hauterivian, Erbacher *et al.* 2014b).

From a palaeoenvironmental point of view, all localities were situated in an open marine, euhaline, oxygenated shallow-water setting with fine-grained sedimentation and low background sedimentation rates. The Grenzlerburg Member represents partly a transgressive carbonatic conglomerate in a marginal setting with abundant fauna (e.g. Mutterlose 1984, 1992a, b; Mutterlose & Bornemann, 2000; Fig. 1C)

3. Description of Koken’s hypodigm of *Enaliosuchus macrospondylus*

3.1. Status of the type material

Koken (1883: 792) described the majority of his material as if it came from a single individual, although it was in a largely disarticulated and dissociated state when he studied it. He based his assumption on the fact that it derived from a single locality and stratum, the fitting proportions and the lack of duplicate skeletal elements. Consequently, the remains received one accession MB.R.1943 (with 16 subnumbers MB.R.1943.1-16) and are considered the holotype of *Enaliosuchus macrospondylus*. Koken (1883) mentioned that the material was initially part of the Henne collection, but the exact whereabouts of the discovery remain unknown. It is also unknown if all parts of the axial skeleton were found in association (Koken 1883 p. 792 only mentioned that

254 some ribs and limb elements were found separately). Therefore we cannot be certain the elements
255 found at the type locality all come from the same individual.

256 Additionally, Koken (1883) referred an isolated dorsal vertebra (RMH uncatalogued (1))
257 from another collection but the same locality and stratum, and two isolated tooth crowns (RMH
258 uncatalogued (2) and MB.R.3636) to his new taxon. The latter were added by Koken for being
259 identified as “crocodilian” and originating from marine strata of similar age and region. A
260 fragmentary phalanx (MB.R.1939), likewise from the Henne collection and from the same locality
261 and stratum, is present in MB collection, but was not described by Koken (1883). These four
262 specimens need to be excluded from the type material, as is described in the Systematic Synopsis
263 below.

264 Below the material is described as it was summarised by Koken (1883).

265

266 3.2. Teeth

267 Koken (1883) assigned two teeth to the *Enaliosuchus macrospondylus* hypodigm, one from the MB
268 collection and one from the RHM collection (Fig. 2). Both teeth were found separately from the
269 remainder of the skeleton (see the geological history section above) and the referral to *Enaliosuchus*
270 was not justified. Curiously, the RHM houses two teeth which are labelled *Enaliosuchus*
271 *macrospondylus*, but following Koken’s (1883) description of the tooth crown being incomplete,
272 the right specimen in Fig. 2C appears to be the correct referred specimen.

273 The tooth crown MB.R.3636 (Fig. 2A, B) is conical, slightly lingually curved and bears
274 pronounced apicobasally aligned enamel ridges that are contiguous from the base of the crown to
275 the apex. Such enamel ridges are rare in Thalattosuchia, as most ridged teeth have both long ridges
276 and shorter ridges, generally closely packed, but the ridges rarely are contiguous along the entirety
277 of the crown (see the tooth close-up photographs in Young *et al.* 2013, 2014a). The enamel ridges
278 in MB.R.3636 become closer to one another apically. The apex itself is not present, as the crown is

279 extensively worn in that region. Whether it is taphonomic or biological in origin is unclear without
280 scanning electron microscopy. Carinae are formed mesially and distally, bearing fine denticles. The
281 basal enamel ornamentation is reminiscent of *Anteophthalmosuchus* Salisbury & Naish, 2011 (see
282 Ristevski *et al.* 2018); however, given the lack of a complete tooth crown, and the lack of an in-
283 depth study into the dental variation within Goniopholididae, this specimen can only be referred to
284 as ?Goniopholididae. The RMH (uncatalogued (2)) tooth crown (Fig. 2C) is largely damaged and
285 bears more enamel ridges that are placed closer to one another.

286 As these remains cannot be demonstrated to belong to the holotype or *Enaliosuchus*
287 *macrospondylus* at all, they have to be excluded from the type material. In consequence no cranial
288 material is known from *Enaliosuchus macrospondylus*.

289

290 3.3. Atlas-axis complex

291 The atlas-axis complex (MR.R.1943.2) comprises the atlas intercentrum, the atlas and axis centra,
292 parts of the atlas and axis neural arches, as well as the axis neural spine (Fig. 3). A fragmentary left
293 atlas rib is also preserved. The atlas intercentrum forms the ventral part of the atlas cup (Fig. 3A). It
294 is semicircular in anterior view, and slightly displaced from its original position. Dorsally the atlas
295 intercentrum reaches to about mid-height of the atlas centrum, where it meets the atlas neural arches
296 (Fig. 3A, B, E). Posteriorly and ventrally the atlas intercentrum contacts the atlas centrum.
297 Posteroventrally, the slightly convex ventral side of the atlas intercentrum meets the anterior surface
298 of the axis centrum (Fig. 3F). Laterally the atlas intercentrum forms the anterior part of the atlas rib
299 facet, of which the remainder is formed by the atlas centrum (Fig. 3B, E). The anterior fragment of
300 the left atlas rib is still attached to the rib facet. The atlas rib is slightly posterolaterally inclined and
301 becomes transversely narrower posteriorly (Fig. 3B).

302 The atlas centrum has a sub-triangular shape in right lateral aspect. Anteriorly the atlas
303 centrum bears a flat surface that forms the posterior demarcation of the atlas cup (Fig. 3A). The

304 ventral side of the atlas centrum is contacted by the atlas intercentrum and dorsally the atlas neural
305 arches are attached. The posterior side of the atlas centrum is fused to the axis centrum but keeps an
306 open, in lateral view slightly oblique running suture (Fig. 3B, E). On the right side, the
307 anteroventral region on both sides of the suture, is strongly rugose, passing indistinctly into the
308 parapophyseal facet ventrally. On the left side, the same region is much smoother. The rugosities
309 may be pathological in origin.

310 The atlas neural arches form the dorsal part of the atlas cup. Their concave anteromedial
311 sides bear a sharp anterior margin (Fig. 3A). Dorsally, at the base of the neural canal, there is a gap
312 between the left and right atlas neural arch (Fig. 3A). Posteriorly the atlas neural arches contact the
313 atlas centrum. The posterodorsally inclined atlas postzygapophysis (Fig. 3E) is present in its
314 original position on the right side, whereas the left one is preserved isolated. The atlas
315 postzygapophysis narrows posteriorly, contacts the axis prezygapophysis and frames an oval
316 foramen (Fig. 3E).

317 The axis centrum has a quadratic shape in lateral view (Fig. 3B, E). Anteriorly the axis
318 centrum sutures to the atlas centrum and anteroventrally a short contact with the atlas intercentrum
319 is established. The posterior side of the axis centrum bears a high-oval articular surface that is
320 largely filled with matrix (Fig. 3D). Ventrally an anteriorly damaged midline ridge is formed. In
321 ventral aspect, the axis centrum is expanded anteriorly and posteriorly, and is constricted in the
322 middle (Fig. 3F). On both sides of the axis the diapophyses are preserved as robust transversal
323 projections of dorsoventrally compressed, rhomboidal cross-section, that originate immediately
324 below the neural arch. The articular facets are not preserved. The fragment of an axis rib that was
325 described and figured by Koken (1883: pl. XXIV, fig. 5) in articulation with the left diapophysis, is
326 missing in the material as preserved. The parapophysis is a small, anteroposteriorly elongate,
327 tuberosity located anteroventrally on the axis centrum, adjacent to the atlas centrum (Fig. 3B). The

328 shallow parapophyseal facet extends for a small portion anteriorly onto the posteroventral region of
329 the atlas centrum. It is therefore divided by the suture between the atlas and axis centra.

330 The axis neural arches originate somewhat anterior to the dorsal rim of the articular face of
331 the axis centrum (Fig. 3B, E). The axis prezygapophyses is obscured by the atlas postzygapophysis
332 on the right side of the specimen (Fig. 3E). Laterally the ventrally protruding neural arches extend
333 to about mid-height of the axis centrum. This protruding lateral portion bears the diapophyses for
334 the axis ribs which are damaged on both sides. The axis neural spine is largely broken off and only
335 the transversely thin bases are still preserved (Fig. 3C, E).

336

337 *3.4. Postaxial cervical vertebra*

338 Parts of three postaxial cervical vertebrae are preserved; an isolated centrum (MR.R.1943.3, Fig.
339 4A-E) with attached neurapophyses, and a nearly complete vertebra, embedded in matrix with part
340 of the neurapophysis of the preceding vertebra attached to it (MR.R.1943.1, Fig. 4F, G). The centra
341 of MR.R.1943.1 and MR.R.1943.3 are longer than wide/high. The articular faces of MR.R.1943.3
342 are oval (Fig. 4B, D), whereas those of MR.R.1943.1 are more circular (Fig. 4F). In both specimens
343 the slightly indented articular faces are surrounded by thickened rims. Only the left diapophysis of
344 MR.R.1943.3 is well preserved, the other diapophyses are either damaged, broken off or embedded
345 in matrix. The complete diapophysis is ventrally and slightly posteriorly inclined and reaches to a
346 point dorsal to the dorsoventral midsection of the centrum (Fig. 4A). It bears a long-oval and
347 slightly indented rib facet. The parapophyses are both broken off in the isolated centrum. Their
348 bases indicate that they were about equally large and slightly more anteriorly placed than the
349 diapophyses, which indicates a placement in the anterior part of the neck. In MR.R.1943.1 the right
350 parapophysis is preserved, which has a circular shape and a slightly indented surface (Fig. 4G). It is
351 considerably smaller than the base of the diapophysis and placed anteroventral to the latter. This
352 indicates a placement in the posterior part of the neck. The ventral side of the centrum is well

353 preserved in MR.R.1943.3 and bears a pronounced and rounded midline keel adjacent to which the
354 centrum is dished (Fig. 4E). The anterior and posterior sections of the ventral side of the centrum
355 are thickened and the anterior one also protrudes slightly ventrally (Fig. 4A). Dorsally remnants of
356 the zygapophyses are preserved in the isolated vertebra. Here the right prezygapophysis is more
357 complete and terminates approximately in line with the lateral margin of the centrum (Fig. 4B). The
358 left prezygapophysis is also preserved in MR.R.1943.1 and still articulated with the
359 postzygapophysis of the preceding cervical (Fig. 4G). The postzygapophyses are otherwise largely
360 broken off in both specimens.

361 The neural spine is preserved in MR.R.1943.1. It is considerably higher than the centrum
362 and slightly posteriorly inclined. It bears an almost straight anterior edge and a slightly convex
363 dorsal side. The posterior edge of this neural spine is damaged. The second neural spine adjacent to
364 the afore described, is incomplete but appears shorter (Fig. 4G).

365

366 3.5. Dorsal vertebrae

367 Remnants of seven dorsal vertebrae (MB.R.1943.4-10) are preserved in the holotype material (Fig.
368 5A-H). An additional dorsal centrum (Fig. 5J-N) was assigned to the same individual by Koken
369 (1883) and is kept in the collection of the Roemer- und Pelizaeus-Museum (RMH uncatalogued
370 (1)). It is herein excluded from the type material of *Enaliosuchus macrospondylus* and referred to an
371 indeterminate thalattosuchian.

372 All centra are elongate and bear oval and slightly indented articular faces which are
373 surrounded by a thin rim. Laterally, adjacent to the articular faces, some longitudinal rugosities are
374 present. The lateral sides of the centra, showing open neurocentral sutures, are gently concave and
375 so are their ventral sides. The transverse processes are elongate, thin, have a subtriangular cross-
376 section and gradually narrow laterally, which indicates a placement in the anterior part of the dorsal
377 vertebral column. The laterally placed diapophysis is sub-circular and well preserved in

378 MB.R.1943.4 (Fig. 5A). In dorsal view the posterior sides of the transverse processes of
379 MB.R.1943.4 and MB.R.1943.5 are almost straight, while the anterior ones curve from the
380 diapophysis slightly anteromedially to meet the parapophysis (Fig. 5C). In the RMH specimen (Fig.
381 5J-N) part of the right transverse process is preserved which extends straight lateromedially and is
382 wider than the transverse processes in the aforementioned vertebrae. A similar pattern is indicated
383 by the broken off bases of the transverse processes in another dorsal centrum (MB.R.1943.6, Fig.
384 5E, F). These vertebrae seem to have had a more posterior placement in the dorsal vertebral
385 column.

386 The parapophyses are preserved in the isolated neuropophyseal fragment (MB.R.1943.7,
387 Fig. 5G, H) and in the anterior dorsal vertebra (MB.R.1943.4, Fig. 5A-D). In both specimens they
388 are slightly anteriorly inclined, placed at the anterior end of the neural arch, and are surrounded by a
389 thin edge. The zygapophyses are broken off and the neural canal is filled with matrix in all of the
390 dorsal vertebrae. The transversely thin neural spine is preserved in the neuropophyseal fragment
391 (MB.R.1943.7, Fig. 5G, H). It has a high rectangular appearance with an almost straight anterior
392 margin, a slightly convex dorsal side and bears a gently concave posterior side.

393

394 3.6. *Dorsal ribs*

395 A largely complete, lateroventrally curved dorsal rib is present in the block that contains the almost
396 complete cervical vertebra (MB.R.1943.1, Fig. 5I). Several rib fragments are preserved
397 (MB.R.1943.9, 12, 13) which show subcircular cross-sections. Additional rib fragments are present
398 in the RHM collections.

399

400 3.7. *Caudal vertebra*

401 An isolated caudal centrum (MB.R.1943.11, Fig. 5O-S) is preserved. The elongate centrum bears
402 oval and slightly concave articular faces (Fig. 5P, R) of which the posterior one extends further

403 ventrally than the anterior articular face (Fig. 5O). The ventral side of the centrum is deeply
404 concave. Two semi-circular hemapophyseal facets are present posteroventrally (Fig. 5Q).
405 Dorsolaterally remnants of the broken off transverse processes are preserved. Their large size
406 indicates that the vertebra derives from the proximal part of the tail. Ventral to the transverse
407 processes the lateral sides of centrum are concave, giving it an hourglass-like shape in ventral view
408 (Fig. 5Q). Dorsally, in the mid-section of the centrum, the bases of the broken off neural arches are
409 preserved. They start adjacent to the centrum's posterior articular face but terminate approximately 1
410 cm posterior to the anterior articular face. The preserved portion of the neural canal was narrowest
411 at about midlength of the neural arch.

412

413 3.8. *Femur*

414 An incomplete, possibly left, femur is preserved (MR.R.1943.15.1+2, Fig. 6A-D). Koken (1883)
415 initially identified the two fragments as one tibia broken apart in the middle, the uniform
416 morphology indicates that these are indeed parts of one element, but given its size and curvature the
417 element is in fact a femur. The element has an oval cross-section, with the distal end being more
418 strongly compressed mediolaterally (Fig. 6A, D) and the shaft, as preserved, is gently curved. The
419 proximal (Fig. 6A) and distal ends (Fig. 6B) are irregular, lacking well defined epiphyses. While all
420 metriorhynchids characteristically lack well defined distal epiphyses (e.g. see Andrews 1913), this
421 is one of the few metriorhynchids found where the proximal epiphyses also look to be poorly
422 defined. Given that proximal end appears to be either damaged and/or has some sort of pathology,
423 we cannot ascertain whether this feature is an artefactual or represents a more cartilaginous hip
424 articulation.

425

426 3.9. *Additional elements*

427 Koken (1883: 818) mentioned and briefly described a proximal end of a metatarsal. This specimen
428 (MB.R.1943.16, Fig. 7A, B) is slightly curved and bears a shallow furrow on the supposed ventral
429 side. It resembles the sacral ribs of the second sacral vertebra (see e.g. Andrews 1913, fig. 64).
430 Another specimen from the Henne collection (MB.R.1939, Fig. 6C, D) that derives from the same
431 locality as the remainder of the material was catalogued as proximal fragment of a metapodial
432 element of *E. macrospondylus*. This element of which the original hour-glass like shape is still
433 indicated, nicely resembles a phalanx from the hind limb.

434

435 **4. Discussion**

436 *4.1. The Koken (1883) character set*

437 Koken (1883) faced difficulties in defining his new genus *Enaliosuchus*, partly due to the
438 incompleteness of the material available to him, and partly from a lack of comparative material and
439 descriptions. He never stated an autapomorphy-based diagnosis, but presented what can be
440 considered by modern standards a comparative diagnosis. He focused on the atlas-axis complex and
441 compared a total of nine characters with a range of extant and fossil crocodylians, and
442 thalattosuchians. These include:

443

- 444 (1) the contact of the proatlas with the atlas neurapophyses: with the proatlas sitting atop, or in an
445 excavation of the atlas neurapophyses;
- 446 (2) complete fusion of atlas centrum to the axis centrum;
- 447 (3) medial contact of the atlas neurapophyses;
- 448 (4) presence of an atlas intercentrum (atlas hypapophysis *sensu* Koken 1883);
- 449 (5) presence of a diapophysis on the axis;
- 450 (6) presence of a parapophysis on the axis;
- 451 (7) morphology of the ventral surface of the axis centrum;

452 (8) position of the atlas rib articulation: on the atlas intercentrum, on the atlas centrum, or between
453 both;
454 (9) position and morphology of the axial ribs: single-headed or double-headed, articulating solely
455 with the axis centrum, or with the axis and (fused) atlas centrum.

456

457 His comparative taxa included the crocodylid *Osteolaemus tetraspis* Cope, 1861 (“*Crocodylus*
458 *frontatus*” *sensu* Koken, 1883), the alligatorids *Alligator mississippiensis* (Daudin, 1802), and
459 *Diplocynodon darwini* (Ludwig, 1877) (“*Crocodylus ebertsi*” and “*Alligator darwini*” *sensu* Koken
460 1883), as well as the thalattosuchians *Machimosaurus mosae* Sauvage & Lienard, 1879,
461 *Teleosaurus cadomensis* Lamouroux, 1820, *Steneosaurus bollensis* (Jaeger, 1828) (“*Mystriosaurus*
462 *tiedemanni*”, “*Mystriosaurus longipes*”, and “*Mystriosaurus mandelslohi*” in Koken, 1883), and
463 *Pelagosaurus typus* (including “*Teleosaurus temporalis*” *sensu* Koken 1883). As a consequence,
464 from his original list of 11 taxa, only 7 are considered valid today, while 4 are actually subjective
465 junior synonyms of other species on the list.

466 From his characters, (1) is unknown due to preservation in many fossil taxa; (2) is
467 undiagnostic, because it is controlled ontogenetically in many crocodyliform taxa (e.g. Viera *et al.*
468 2018), (3) is common in Thalattosuchia (e.g. *Metriorhynchus superciliosus*, ‘*M.*’ *brachrhynchus*,
469 *Gracilineustes leedsi*; Arthaber 1906, Andrews 1913), (4) is ubiquitous in crocodyliform taxa
470 (Romer 1956); (5) and (6) are not diagnostic on less inclusive systematic levels; (7) may have some
471 significance but the character distribution is not clear, and this area is not well preserved in the *E.*
472 *macrospondylus* holotype; (8) and (9) may have a more differentiated taxonomic significance, but -
473 as will be discussed below – Koken’s (1883) interpretation of these characters are fraught with
474 some misinterpretations.

475 From his overall comparisons Koken (1883: 807) concluded that the genus “*Teleosaurus*”
476 may be the closest relative of his new species. However, it must be noted that only one of the two

477 species in his “*Teleosaurus*” is still included in this genus, the type species *T. cadomensis*. His
478 second species, “*T. temporalis*”, is a subjective junior synonym of *Pelagosaurus typus*. From
479 context it appears that he mostly referred to the latter, as the atlas-axis-complex was discussed
480 extensively by Eudes-Deslongchamps (1864), while it was only incompletely known in *T.*
481 *cadomensis*.

482 According to Koken (1883), “*Teleosaurus*” shares with *E. macrospondylus* the following
483 characters:

484 (1) the proatlas is nested within an anterior excavation of the atlas neurapophyses [the element
485 questionably identified as proatlas in *E. macrospondylus* by Koken 1883 is herein identified as atlas
486 postzygapophysis];

487 (2) well developed diapophyses and inconspicuous parapophyses (“tuberosities”) on the axis
488 centrum;

489 (3) the presence of a groove on the ventral side of the axis centrum;

490 (4) the “general morphology” of the atlas neurapophyses.

491

492 In contrast Koken (1883) listed the following characteristics that *Enaliosuchus* had, but
493 “*Teleosaurus*” lacked:

494 (5) the broad head of the atlas ribs covers the axis parapophyses (which are reduced to mere
495 tuberosities) in lateral view;

496 (6) the atlas centrum contacts the atlas ribs, the rib facet is jointly formed by the atlas intercentrum
497 and atlas centrum;

498 (7) the axis centrum bears single-headed ribs that articulate with the diapophysis and points straight
499 ventrally;

500 (8) the contact between the atlas intercentrum and the atlas neurapophyses is short;

501 (9) the atlas intercentrum bears a strongly concave morphology;

502 (10) the atlas neurapophyses are separated from each other along their whole anteroposterior length;
503 (11) the axis centrum is fused to the atlas centrum, but separated by a visible, oblique suture.
504

505 Of these characters, (1) cannot be proven, as the small fragment, questionably identified by Koken
506 (1883) as the proatlas in *E. macrospondylus* is considered here as the atlas postzygapophysis, (2)
507 occurs in other metriorhynchids. Koken (1883) described the axis parapophyses as “tuberosities”
508 and doubted that they articulated with the axis rib, speculating that they may have contacted the
509 atlas rib. Jaekel (1904) supported this interpretation but stated that similar “tuberosities” were
510 present in *Metriorhynchus superciliosus* (= *M. jaekeli* in Jaekel 1904). In contrast Baur (1886)
511 already interpreted these “tuberosities” correctly as parapophyses, which was confirmed by von
512 Arthaber (1906). The latter clearly figured that in *Metriorhynchus superciliosus* the parapophyseal
513 facet extends across the suture of the atlas and axis centra. Boschma (1922, based on the figure in
514 Jaekel 1907) located the parapophyseal facet in *Enaliosuchus macrospondylus* solely on the axis
515 centrum and found this an important contrast to *Metriorhynchus superciliosus* in which the
516 parapophyseal facet is located on the axis as well as on the axis centrum. However, the latter
517 condition actually also occurs in *Enaliosuchus macrospondylus* (Fig. 3). (3) is inconclusive, as the
518 type material of *E. macrospondylus* is damaged in this region. The absence of a sharp keel is
519 widespread among crocodyliforms and thalattosuchians. (4) is unspecific. (5) and (7) result from a
520 misinterpretation due to a lack of preservation. As shown by von Arthaber (1906), the parapophyses
521 in metriorhynchids are in the same position and similarly inconspicuous. However, they articulate
522 with the capitulum of a flat, bicapitate rib that forms almost a right angle with the tuberculum. The
523 “straight, ventrally pointing” axis rib of Koken (1883: 806 and pl, XXIV, fig. 5) is therefore only
524 the shaft of the tuberculum that tapered strongly distally. However, Koken (1883: 806) himself
525 wrote that this rib fragment was originally embedded “closely” to the diapophysis and was removed
526 during preparation. In lateral view, the axis rib capitulum (if it would have been preserved) is

527 hidden by the head of the atlas rib, which has been discussed and clarified for *Enaliosuchus*
528 *macrospondylus* by Baur (1886).

529 (6) and (8) through (11) are shared by metriorhynchids (von Arthaber 1906, Andrews 1913).

530 Although Koken (1883) made detailed observations and tried to make a comprehensive comparison,
531 he entirely omitted metriorhynchid material or references. This is understandable, as detailed
532 studies of the corresponding anatomy in this group were not available before the 20th Century. It
533 also explains the peculiarities that he observed in his material, and his conclusion that it represents a
534 new taxon. Unfortunately, a synoptic view of metriorhynchid morphology results in the conclusion
535 that the characters he found distinguishing are more widely distributed in this group.

536 The other metriorhynchid elements described for *Enaliosuchus macrospondylus* by Koken
537 (1883) show the general morphology seen in various taxa and are of no diagnostic value.

538

539 4.2. The Schroeder (1921) character

540 Schroeder (1921) referred a new metriorhynchid specimen from the Lower Cretaceous of northern
541 Germany to *Enaliosuchus* based on the morphology of the axis ribs (this is the specimen Kuhn 1936
542 establish as the *Enaliosuchus schroederi* holotype). His new specimen preserved axis ribs in which
543 the capitulum and tuberculum remained unfused, effectively resulting in two axis ribs on each side.
544 Schroeder (1921: 364) claimed the same condition to be present in the *E. macrospondylus* holotype.
545 However, this cannot be substantiated as the axis ribs are no longer preserved in the *E.*
546 *macrospondylus* holotype, and the fragment that was described by Koken (1883) is not
547 unambiguous in interpretation (see above).

548

549 4.3. The Hua et al. (2000) character set

550 The *Enaliosuchus* taxonomy of Hua et al. (2000) is a monospecific hypothesis, with all three
551 specimens included in *E. macrospondylus*. However, the only elements shared by all three

specimens are the atlas-axis complex and one post-axial cervical vertebra. The emended diagnosis of *Enaliosuchus* by Hua *et al.* (2000: 472) focussed largely on cranial characters, which thus cannot be applied for the holotype specimen (MB.R.1943.1-16). However, Hua *et al.* (2000) considered five characters in the atlas-axis complex to be diagnostic for *Enaliosuchus*: (1) a massive atlas centrum that is sub-quadrangular in lateral view, (2) the atlas ribs inserted on both the atlas intercentrum and axis centrum, (3) the diapophyses are placed on the axis neural arches, (4) presence of a ventral midline keel on the axis centrum, and (5) the axis neural spine is curved and anteriorly inclined. Unfortunately, these five characters do not unite these three specimens to the exclusion of other metriorhynchids:

(1) In the *Enaliosuchus macrospondylus* holotype specimen (MB.R.1943.2), the atlas centrum is partly obscured by the atlas neural arches and the atlas intercentrum, but the morphology is clearly more triangular than quadrangular in lateral view (Figs. 3, 6A), similar to the condition present in *Metriorhynchus superciliosus* de Blainville, 1853 (Fig. 7D). The shape of the atlas centrum in *E. schroederi* cannot be seen because the atlas intercentrum, atlas neural arches and atlas ribs obscure most of the element (Fig. 7B).

(2) The atlas rib facets in MB.R.1943.2 are largely formed by the atlas intercentrum and atlas centrum (Figs. 3, 6A). In other metriorhynchids such as *Cricosaurus vignaudi* (Frey, Buchy, Stinnesbeck & López-Oliva, 2002) (see Frey *et al.* 2002: fig. 6), '*Metriorhynchus*' *brachyrhynchus* Eudes-Deslongchamps, 1868 (Fig. 7E) and *Gracilineustes leedsi* (Andrews, 1913) (Fig. 7F) they are mainly borne by the atlas centrum. The participation of the atlas intercentrum in the formation of the rib facet was described for *Metriorhynchus jaekeli* Schmidt, 1904 (see Jaekel 1904: fig. 1) and is figured for *M. superciliosus* (see Andrews 1913: fig. 61). In *E. schroederi* the atlas ribs obscure the rib facets on both sides (Fig. 7B, I), but it appears that the atlas intercentrum might have participated in the atlas rib facet. In the referred specimen of *E. macrospondylus* (RNGD 990201)

576 the rib facet is borne on the atlas centrum (Fig. 7C). Whether or not the atlas intercentrum took part
577 in the formation of the atlas rib facet is unclear as this element is not preserved in RNGD 990201.

578 (3) The diapophyses are present on the axis neural arches in all examined metriorhynchid
579 taxa, such as *M. superciliosus* (Fig. 7D), '*M.*' *brachyrhynchus* (Fig. 7E) and *Cricosaurus vignaudi*
580 (see Frey *et al.* 2002: fig. 6), and thus this character is of no diagnostic value.

581 (4) A ventral ridge on the axis centrum is present on MB.R.1943.2, although its anterior
582 portion is damaged (Fig. 3E). This ridge is very indistinct in *E. schroederi* (Fig. 7I), especially
583 when compared with the pronounced ridges that occur in other metriorhynchids such as *G. leedsi*
584 (Fig. 7G) and *M. superciliosus* (Fig. 7H).

585 (5) The shape of the axis neural spine cannot be compared between RNGD 990201 and the
586 *E. macrospondylus* and *E. schroederi* holotypes as it is incomplete in the German specimens (Fig.
587 7A, B). A similar shape of the RNGD 990201 axis neural spine is, however, present in *M.*
588 *superciliosus* (Fig. 7D).

589 Therefore, based upon the five characters listed by Hua *et al.* (2000), the referral of the
590 French material to *Enaliosuchus macrospondylus* cannot be supported. The shape of the atlas
591 centrum differs between the specimens. It was described as sub-quadrangular in RNGD 990201,
592 whereas it is triangular in MB.R.1943.2. The atlas rib facet is borne by the atlas intercentrum and
593 atlas centrum in MB.R.1943.2, whereas the atlas intercentrum is missing in RNGD 990201 but a
594 large rib facet is evident at the atlas centrum. The diapophyses are consistently placed on the axis
595 neural arches in metriorhynchids, and a ventral keel on the axis centrum is not unique. Finally, the
596 shape of the axis neural spine is largely damaged in MB.R.1943.2 and cannot be compared.
597 Moreover, the length-to-height ratio of the axis centrum likewise differs between MB.R.1943.2
598 (1:1) and RNGD 990201 (1:0.7). Although, in the latter the transverse compression may impact this
599 ratio. A longer ratio also occurs in *Metriorhynchus superciliosus* (NHMUK PV R 2051, 1:1.16),

600 *Gracilineustes leedsi* (NHMUK PV R 3014, 1:1.16) and ‘*M.*’ *brachyrhynchus* (NHMUK PV R
601 2039, 1:1.08 and NHMUK PV R 3804, 1:1.11).

602 The referral of the *Enaliosuchus schroederi* holotype by Hua *et al.* (2000) to the
603 *Enaliosuchus macrospondylus* hypodigm is also questionable. Several elements in the atlas-axis
604 complex of this specimen differ from MB.R.1943.2, such as the atlas intercentrum that extends
605 more dorsally, and the atlas neural arches which have a carved anteroventral portion for the
606 articulation with the atlas intercentrum (Fig. 7B). A re-description of the *E. schroederi* holotype is
607 forthcoming, which will discuss the atlas-axis in more detail.

608

609 4.4. The Karl *et al.* (2006) taxonomy

610 Curiously, Karl *et al.* (2006) assigned the holotypes of both *E. macrospondylus* and *E. schroederi* to
611 the genus *Metriorhynchus*, as *Metriorhynchus* sp.. The arguments in Karl *et al.* (2006) are very
612 superficial, no detailed comparisons were made, and their phylogenetic analysis had an odd sample-
613 set for testing the internal position of *Enaliosuchus* within Metriorhynchidae. *Enaliosuchus*
614 *schroederi* can be distinguished from *Metriorhynchus* spp. with the same atlas-axis characters by
615 which it differs from *E. macrospondylus*, whereas several characters present in *E. macrospondylus*
616 do indeed occur in *M. superciliosus* (Fig. 7D) and ‘*M.*’ *brachyrhynchus* (Fig. 7E) (see discussion
617 above). However, given that the atlas-axis complex is only known and well-described in a limited
618 number of metriorhynchid taxa, and that most characters listed by Koken (1883), Hua *et al.* (2000),
619 and Karl *et al.* (2006) have a widespread distribution in Metriorhynchidae (see discussion above),
620 we cannot agree with the unambiguous referral of the *E. macrospondylus* and *E. schroederi*
621 holotypes to the genus *Metriorhynchus* as proposed by Karl *et al.* (2006).

622 Oddly, the cranial morphology of the *E. schroederi* holotype alone is enough to readily
623 distinguish it from *Metriorhynchus* (e.g. smooth dermatocranium, very large sclerotic rings, jugal
624 excluded from the preorbital fenestrae). As stated above, the phylogenetic analysis of Young &

625 Andrade (2009) recovered *E. schroederi* and the French specimen referred to *E. macrospondylus* as
626 derived metriorhynchines, thus supporting its distinction from *Metriorhynchus*. The phylogenetic
627 analysis of Jouve (2009) recovering *Enaliosuchus* as the sister taxon to *Dakosaurus* similarly
628 falsifies the *Metriorhynchus* subjective synonymy hypothesis. This contrasts with the strange taxon
629 and character sample set in the phylogenetic analysis of Karl *et al.* (2006), which had a single
630 metriorhynchid OTU, referred to as “*Enaliosuchus/Metriorhynchus*”. The remaining OTUs were
631 four crocodylians, three teleosauroids and the basal metriorhynchoid *Pelagosaurus typus* (the same
632 taxon-sample as Koken 1883). The specimens that were the basis for scoring their OTUs is not
633 given. Only ten characters were included, three cranial characters, and seven out of the nine atlas-
634 axis characters from Koken (1883). While the Karl *et al.* (2006) phylogenetic analysis does show
635 that most of the atlas-axis characters used by Koken (1883) to establish *E. macrospondylus* has a
636 wide distribution in crocodyliforms, it does not support their contention that *Enaliosuchus* is a
637 subjective junior synonym of *Metriorhynchus*. Principally because they never tested it. It is not
638 clear why Karl *et al.* (2006) used a phylogenetic analysis to highlight the distribution of atlas-axis
639 characters rather than a comparative plate figuring the characters.

640 Moreover, in using a sub-sample of Koken’s (1883) atlas-axis character set, and the same
641 limited taxon set as Koken (1883), Karl *et al.* (2006) compound the original issue Koken had: the
642 lack of comparative data with metriorhynchids. The difference being, the lack of comparative
643 material is understandable in Koken (1883). Finally, Karl *et al.* (2006) did not mention the Hua *et*
644 *al.* (2000) study. It appears they were unaware of the third putative *Enaliosuchus* specimen, and the
645 new atlas-axis characters proposed by Hua *et al.* (2000).

646

647

648

649 5. Cretaceous metriorhynchids

650 The fossil record of Metriorhynchidae is poorer in the Cretaceous than in the Jurassic. Early
651 overviews of metriorhynchid evolution and species diversity found metriorhynchid biodiversity was
652 affected by an extinction at the Jurassic-Cretaceous boundary (Pierce *et al.* 2009; Young *et al.*
653 2010), with Cretaceous metriorhynchids characterised as a “dead clade walking” (Young *et al.*
654 2010). However, over the past decade the two-phase extinction hypothesis (end-Tithonian
655 biodiversity crash and Valanginian-Hauterivian boundary final extinction) posited by Young *et al.*
656 (2010) has been falsified. Re-examination of Cretaceous fossils found that at least four
657 metriorhynchid lineages are known to have survived into the Cretaceous (Young *et al.* 2014b). It is
658 unclear whether some of the metriorhynchid specimens from the Vaca Muerta Formation of
659 Argentina, such as the *Purranisaurus potens* Rusconi 1948 holotype and those referred to
660 *Cricosaurus* sp. and *Dakosaurus andiniensis* Vignaud & Gasparini, 1996 are uppermost Tithonian
661 or lowermost Berriasian in age (Herrera *et al.* 2015; Fernández *et al.* 2019; Herrera pers. comm.
662 2019). Thus, potentially six metriorhynchid lineages crossed the Jurassic–Cretaceous boundary. An
663 incomplete metriorhynchid skull from Berriasian strata of the Neuquén basin is known (Fernández
664 *et al.* 2019). The specimens from the uppermost Tithonian or lowermost Berriasian of Russia are
665 taxonomically indeterminate (Ochev 1981).

666 From the Valanginian of France and Germany four different lineages of metriorhynchid are
667 known: Geosaurina, Plesiosuchina and two lineages of Rhacheosaurini (Table 1). These include the
668 holotype of the nomen dubium *Neustosaurus gigondarum* Raspail, 1842, the holotype of
669 *Enaliosuchus macrospondylus*, the holotype of *Enaliosuchus schroederi*, the holotype of *Geosaurus*
670 *lapparenti* (Debelmas & Strannoloubsky, 1957), the French specimen referred to *Enaliosuchus*
671 *macrospondylus*, a specimen referred to as cf. *Geosaurus lapparenti* and an indeterminate
672 Plesiosuchina specimen (Raspail 1842; Debelmas & Stannoloubsky 1956; Debelmas 1958; Hua *et*
673 *al.* 2000; Karl *et al.* 2006; Young *et al.* 2014b). A skull from the Valanginian of Colombia has been
674 referred to cf. *Cricosaurus* (Larsson *et al.* 2012).

675 From the upper Valanginian or lower Hauterivian of France an indeterminate
676 metriorhynchid is known (Debelmas & Demians D'Archimbaud 1956), and from the lower
677 Hauterivian of France an incomplete skeleton has been referred to *Geosaurus lapparenti*
678 (Debelmas, 1952).

679 Post-Hauterivian metriorhynchids are exceptionally rare. A poorly preserved incomplete
680 skull from the Barremian of Spain had been considered to be a possible metriorhynchid (Parrilla-
681 Bel *et al.*, 2012), although this seems less likely now (Parrilla-Bel pers. comm. 2017). Chiarenza *et*
682 *al.* (2015) referred an isolated tooth crown from the lowermost Aptian of Sicily to Plesiosuchina
683 based on a series of apomorphies. This tooth significantly increased the known geological range of
684 Metriorhynchidae. Curiously, Fischer *et al.* (2015) raised the issue that the Sicilian tooth could in
685 fact be a brachauchenine pliosaurid, like *Makhaira rossica* Fischer, Arkhangelsky, Stenshin,
686 Uspensky, Zverkov & Benson, 2015. However, they did not address the list of apomorphies
687 Chiarenza *et al.* (2015) gave when they referred the tooth to Plesiosuchina (such as the presence of
688 contiguous microdenticles, the denticles being rectangular in shape, and the presence of 'weak'
689 carina flanges). The convergences between the Sicilian tooth and *Makhaira rossica* are interesting,
690 but it is based on superficial similarities and not on apomorphies. In fact, *Makhaira rossica* lacks all
691 of the plesiosuchin apomorphies observable in the Sicilian tooth. As such, Fischer *et al.* (2015)
692 inadvertently strengthened the referral of the Sicilian tooth to Plesiosuchina (as Cretaceous
693 pliosaurids did not seem to evolve the apomorphies seen in metriorhynchids), not the reverse.
694 Although, in the absence of more complete material, the specimen still needs to be considered cf.
695 Plesiosuchina. Post-Hauterivian survival of Metriorhynchidae needs confirmation with more
696 complete material. However, with the description of a Barremian teleosauroid specimen (see Cortés
697 *et al.*, 2019), it does seem that thalattosuchians persisted for longer than previously realised closer
698 to the equator. Their continued presence could have acted as a barrier to large-bodied neosuchians
699 colonising Lower Cretaceous marine ecosystems.

700

701 **6. Are *Enaliosuchus* and *Neustosaurus* congeneric?**

702 The poorly ossified proximal femoral epiphyses seen in *Enaliosuchus macrospondylus* Koken, 1883
703 (Fig. 6), as mentioned above, are either artefactual, pathological, or evidence of a shift in femoral
704 morphology during the Cretaceous. The holotype of *Neustosaurus gigondarum* Raspail, 1842 is a
705 largely complete post-dorsal postcranial skeleton from the Valanginian of France. Considered to be
706 a nomen dubium by Young & Andrade (2009), the whereabouts of the holotype has never been
707 ascertained (although a cast of a very small portion of the skeleton is on display in the MNHN).
708 Raspail (1842) figured both femora, and they look strikingly similar to our reconstruction of the
709 femur in *Enaliosuchus macrospondylus* (Fig. 6).

710 That being said, the obvious problems are: (1) the *E. macrospondylus* femur is incomplete,
711 and (2) the *N. gigondarum* femora cannot be checked first-hand. With these caveats in mind, the
712 peculiar sigmoidal shape and the oddly flat proximal epiphyses are unique to these two specimens.
713 Should both of these features prove to be genuine (which we cannot be certain of), it hints a
714 possible relationship between these two genera. New discoveries of Valanginian metriorhynchids
715 are needed to elucidate femoral morphotypes, thus it is premature to posit *Enaliosuchus* as a
716 subjective junior synonym of *Neustosaurus*. But this is a hypothesis that should be tested when
717 more data becomes available.

718

719 **7. Conclusions**

720 In conclusion, the holotype specimen of *Enaliosuchus macrospondylus* (MB.R.1943.1-16) lacks
721 unique anatomical traits (although see our discussion on the femur above), and preserved axial
722 skeleton largely resembles the morphology present in other metriorhynchids such as
723 *Metriorhynchus superciliosus*, '*M.*' *brachyrhynchus* and *Gracilineustes leedsi*. The atlas-axis
724 complex preserved with the *E. schroederi* holotype shows several symplesiomorphic

metriorhynchid traits, but the *E. macrospondylus* holotype lacks the peculiar morphology of the atlas intercentrum and atlas neural spine, which indicates that they are distinct taxa. The French specimen (RNGD 990201) referred to *Enaliosuchus macrospondylus* by Hua *et al.* (2000) is distinct from MB.R.1943.1-16 in the shape of the atlas centrum, and possibly in the placement of the atlas rib facet and the proportions of the axis centrum.

Given these morphological differences, the monospecific hypothesis of Hua *et al.* (2000) (with the *Enaliosuchus macrospondylus* and *E. schroederi* holotypes and the French specimen RNGD 990201 all referred to the same species) is not justifiable. With the lack of evidence to refer other specimens to this taxon, only the holotype specimen (MB.R.1943.1-16) can be referred to as *Enaliosuchus macrospondylus*. While the femur is incomplete, it shows a striking resemblance to those of *Neustosaurus gigondarum* (a species known from a single specimen, which unfortunately cannot be examined first-hand). Due to the lack of verifiable autapomorphies, *E. macrospondylus* is here considered a nomen dubium that is best classified as Metriorhynchidae gen. et sp. indet. As the Cretaceous fossil record of Metriorhynchidae improves, new discoveries could resurrect *E. macrospondylus*, and test a possible synonymy between *Enaliosuchus* and *Neustosaurus*. Until then, we consider *E. macrospondylus* to be a nomen dubium, '*E.*' *schröderi* to be a valid taxon, and the French specimen an unnamed distinct species. As the location of the *Neustosaurus gigondarum* holotype is still unknown, we follow Young & Andrade (2009) in considering it to be a nomen dubium.

744

745 8. Systematic synopsis

746

747 Crocodylomorpha Hay, 1930 (*sensu* Nesbitt, 2011)

748 Crocodylomorpha gen. et sp. indet.

749

750 *Material:* RMH uncatalogued (2), an isolated tooth crown (Fig. 2C).

751

752 *Locality:* “Osterwald [Mountains]” (Koken 1883), southern Lower Saxony, northern Germany.

753

754 *Stratigraphy:* “Hils-Conglomerat” (Koken 1883); i.e. Grenzlerburg Member, Salzgitter Formation,
755 Minden Braunschweig Group, uppermost Valanginian to lowermost Hauterivian, Lower
756 Cretaceous.

757

758 Goniopholididae Cope, 1875

759 ?Goniopholididae gen. et. sp. indet.

760

761 *Material:* MB.R.3636, an isolated tooth crown (Fig. 2A,B).

762

763 *Locality:* Elligser Brink near Delligsen, southern Lower Saxony, northern Germany (Koken 1883).

764

765 *Stratigraphy:* “Elligserbrink-Schicht”, Stadthagen Formation, Minden Braunschweig Group,
766 uppermost Valanginian to lowermost Hauterivian.

767

768 Metriorhynchidae Fitzinger, 1843 (*sensu* Young & Andrade, 2009)

769 ?Metriorhynchidae gen. et sp. indet.

770

771 *Material:* MB.R.1939. Fragmentary phalanx. RMH uncatalogued (1). Dorsal vertebra (Fig. 4Q-U).

772

773 *Locality*: “Osterwald [Mountains]” (Koken 1883), probably the former Osterwald Tiefbauschacht
774 mine shaft, c. 1.3 km east of the town of Osterwald, southern Lower Saxony, northern Germany
775 (approx. 52°06’34’’N, 9°38’37’’E).

776

777 *Stratigraphy*: Lower part of Stadthagen Formation, Minden Braunschweig Group. Most probably
778 middle lower to lowermost upper Valanginian, Lower Cretaceous.

779

780

781 Metriorhynchidae Fitzinger, 1843 (*sensu* Young & Andrade, 2009)

782 Metriorhynchidae gen. et sp. indet.

783 *Enaliosuchus macrospondylus* Koken, 1883

784 (nomen dubium)

785 Figs. 3-6

786

787

788 *Holotype*: MB.R.1943.1-16. Atlas-axis complex, remnants of three post-axial cervical vertebrae,
789 eight dorsal vertebrae, several fragmentary dorsal ribs, one caudal vertebra, an incomplete femur,
790 fragment of a sacral rib.

791

792 *Type locality*: “Osterwald [Mountains]” (Koken 1883), probably the former Osterwald
793 Tiefbauschacht mine shaft, c. 1.3 km east of the town of Osterwald, southern Lower Saxony,
794 northern Germany (approx. 52°06’34’’N, 9°38’37’’E).

795

796 *Stratigraphy*: Lower part of Stadthagen Formation, Minden Braunschweig Group, most probably
797 middle lower to lowermost upper Valanginian, Lower Cretaceous.

798

799 **Acknowledgements**

800 We would like to thank D. Schwarz (MB) for providing access to the specimen in her care, and for
801 information and photographs of the material. Yanina Herrera is thanked for helpful discussion. MT
802 Young is supported by a Leverhulme Trust Research Project grant (number RPG-2017-167), and
803 received support for his collection visits to Paris and Berlin from the SYNTHESYS Project, which
804 is financed by the European Community Research Infrastructure Action, under the FP7 "Capacities"
805 Program. We thank Yanina Herrera and an anonymous reviewer for their helpful comments that
806 improved the quality of this paper.

807

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1020

1021 Figure captions

1022

1023 Figure 1: Geographic, palaeogeographic and geological situation of the *Enaliosuchus*
1024 *macrospondylus* material. A) General location map, B) Geological situation in the vicinity of the
1025 Osterwald Mountains, with location of the potential type localities Osterwald clay-pit (1) and
1026 Tiefbauschacht Osterwald mine shaft (2). Geological data from Landesamt für Bergbau, Energie
1027 und Geologie (NIBIS® Kartenserver, 2014), C) Palaeogeographical sketch map for the
1028 Valanginian, showing the location of Osterwald and Elligser Brink. Note that during the earliest
1029 Hauterivian the shoreline shifted further landward due to transgression. After Mutterlose (1984),
1030 modified.

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1033 Figure 2. Teeth initially referred to *Enaliosuchus macrospondylus*. ?Goniopholidae gen. et sp. indet.
1034 (MB.R.3636), uppermost Valanginian to lowermost Hauterivian of Elligser Brink near Delligsen in
1035 (A) distal and (B) labial views. (C) Crocodylomorpha gen. et. sp. indet. (RMH uncatalogued),
1036 uppermost Valanginian to lowermost Hauterivian of the Osterwald Mountains. Note that only the
1037 tooth on the right side, shown in labial view, is mentioned in Koken (1883). Scale bar equals 1 cm.

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1040 Figure 3. Atlas-axis complex (MB.R.1943.2) of the *Enaliosuchus macrospondylus* holotype
1041 specimen, middle to upper Valanginian of the Osterwald Mountains in (A) anterior, (B) left lateral,
1042 (C) dorsal, (D) posterior, (E) right lateral and (F) ventral view. Scale bar equals 5 cm.
1043 Abbreviations: apo, atlas postzygapophysis; apr, axis prezygapophysis; atc, atlas centrum; atic, atlas
1044 intercentrum; atn, atlas neural arch; atr, atlas rib; ap, axis parapophysis; axc, axis centrum; axn, axis
1045 neural arch; dia, axis diapophysis.

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1048 Figure 4. Postaxial cervical vertebrae of the *Enaliosuchus macrospondylus* holotype from the
1049 middle to upper Valanginian of the Osterwald Mountains. Cervical vertebra (MB.R.1943.3) in (A)
1050 lateral, (B) anterior, (C) posterior, (D) dorsal and (E) ventral view. Posterior cervical vertebra
1051 (MB.R.1943.1) in (F) posterior and (G) lateral view. Scale bars equal 5 cm. Abbreviations: dia,
1052 diapophysis; mk, midline keel; ns, neural spine; pap, parapophysis; prz, prezygapophysis.

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1055 Figure 5. Additional postaxial vertebrae and ribs of the *Enaliosuchus macrospondylus* hypodigm
1056 from the lowermost upper Valanginian of the Osterwald [Mountains]. Dorsal vertebra
1057 (MB.R.1943.4) in (A) lateral, (B) posterior, (C) dorsal and (D) anterior view. Dorsal centrum
1058 (MB.R.1943.6) in (E) anterior and (F) lateral view. Neurapophysis of a dorsal vertebra
1059 (MB.R.1943.7) in (G) lateral and (H) anterior view. (I) Rib fragments (MB.R.1943.9). RMH
1060 uncatalogued. Dorsal vertebra referred to *Enaliosuchus macrospondylus* by Koken (1883) in (J)
1061 lateral, (K) anterior, (L) ventral, (M) posterior and (N) dorsal view. Caudal vertebra
1062 (MB.R.1943.11) in (O) lateral, (P) anterior, (Q) ventral, (R) posterior and (S) dorsal view. Scale
1063 bars equal 5 cm. Abbreviations: bn, base of neural arch; hf, hemapophyseal facet; ns, neural spine;
1064 pap, parapophysis; tp, transverse process.

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1067 Figure 6. Incomplete, possibly left, femur (MB.R.1943.15.1+2) of the *Enaliosuchus*
1068 *macrospondylus* holotype specimen from the lowermost upper Valanginian of the Osterwald
1069 [Mountains] with the missing part of the shaft being based upon *Neustosaurus gigondarum*. (A)
1070 proximal, (B) medial, (C) lateral and (D) proximal view. Scale bar equals 5 cm.

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1072 Figure 7. Additional elements of the *Enaliosuchus macrospondylus* hypodigm from the lowermost
1073 upper Valanginian of the Osterwald [Mountains]. (A, B) supposed proximal portion of a sacral rib
1074 (MB.R.1943.16), (C, D) fragmentary phalanx (MB.R.1939). Scale bars equal 1 cm.

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1077 Figure 8. Comparison of metriorhynchid atlas-axis components of (A) *Enaliosuchus*
1078 *macrospondylus* holotype (MB.R.1943.1-16) in lateral view, (B) *Enaliosuchus schroederi* holotype
1079 (MM uncatalogued) in lateral view, (C) referred specimen of *Enaliosuchus macrospondylus*
1080 (RNGD 990201) in lateral view, (D) *Metriorhynchus superciliosus* (NHMUK PV R 2051) in lateral
1081 view, (E) ‘*Metriorhynchus*’ *brachyrhynchus* (NHMUK PV R 3804) in lateral view, (F)
1082 *Gracilineustes leedsi* (NHMUK PV R 3015) in lateral view, (G) *Gracilineustes leedsi* (NHMUK
1083 PV R 3014) in ventral view, (H) *Metriorhynchus superciliosus* (NHMUK PV R 2051) in ventral
1084 view, (I) *Enaliosuchus schroederi* holotype (MM uncatalogued) in ventral view. Abbreviations: arf,
1085 atlas rib facet; atc, atlas centrum; atic, atlas intercentrum; atr, atlas rib; axc, axis centrum; axp, axis
1086 parapophysis; dia, diapophysis; vk, ventral keel. Scale bars equal 1 cm.

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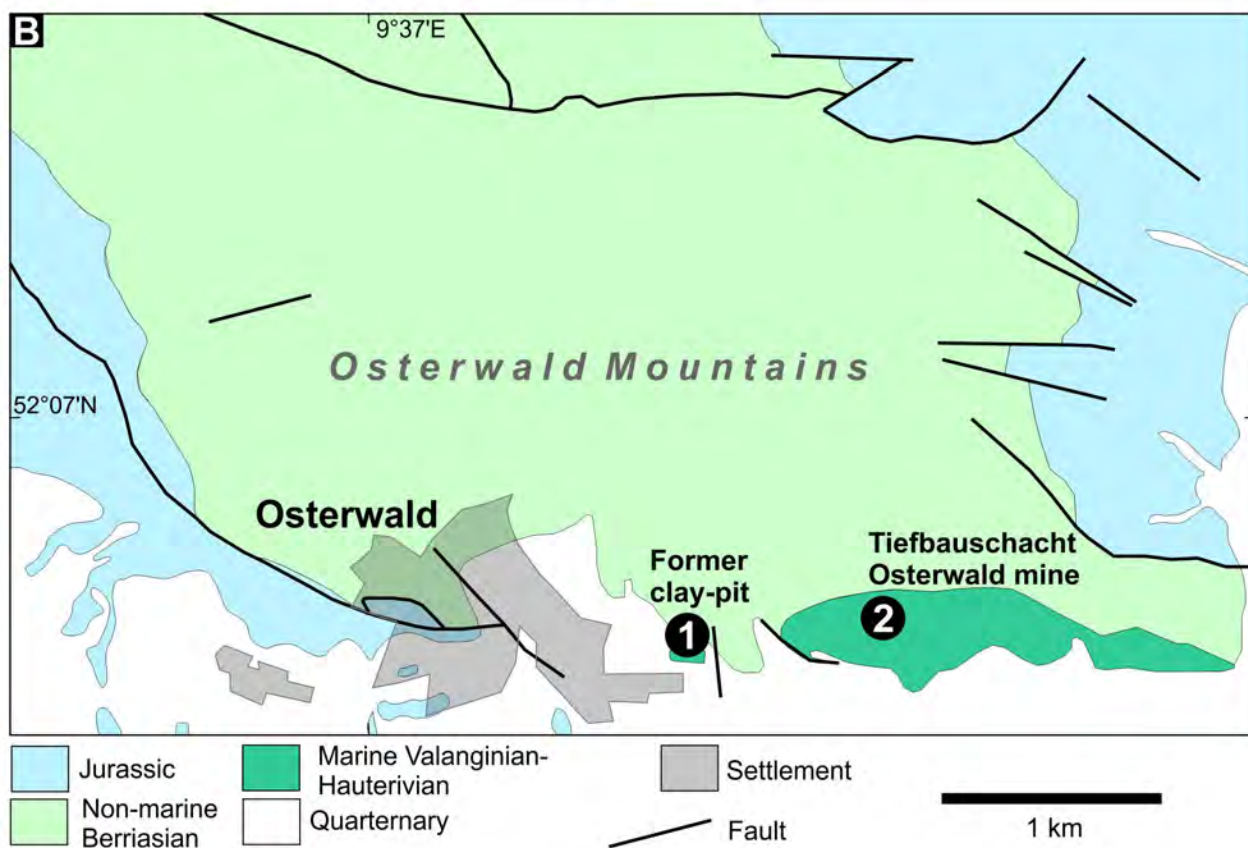
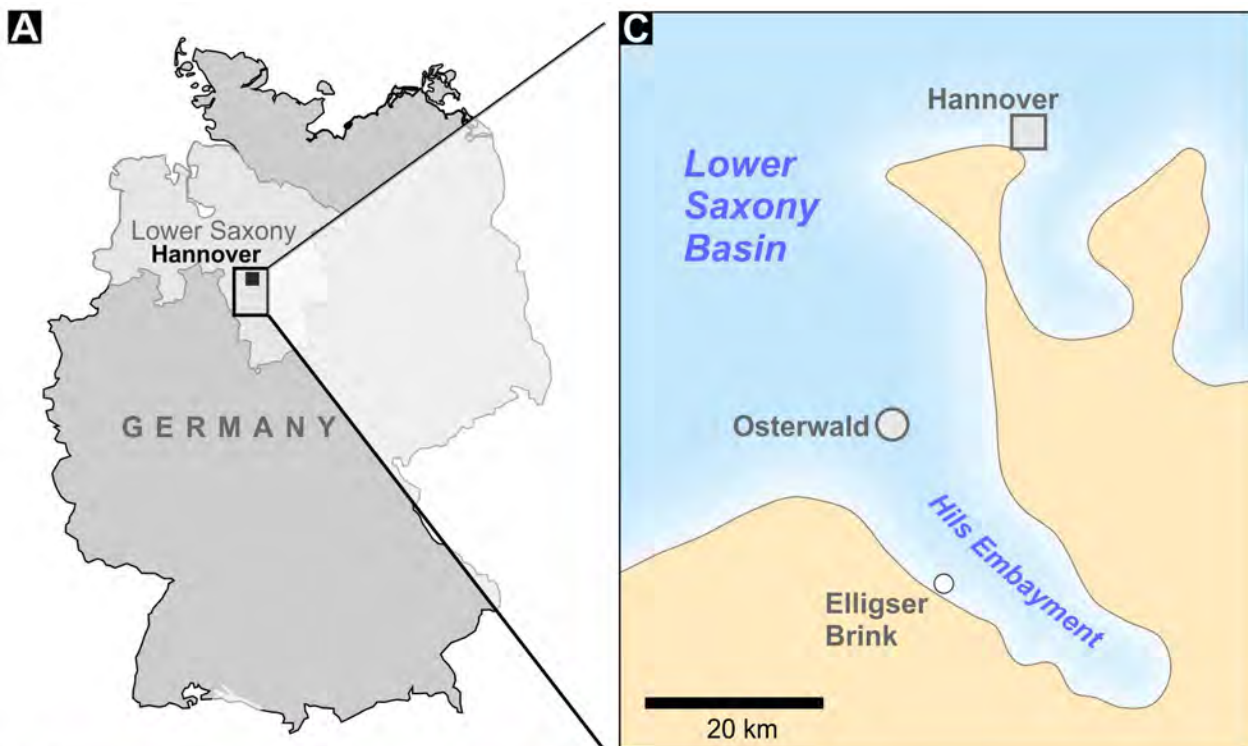
1088 Table 1. Table of all published thalattosuchian specimens from the Cretaceous. Note that all the French Cretaceous metriorhynchids are from the
1089 Région Provence-Alpes-Côte d'Azur, and the German Cretaceous metriorhynchids are from Lower Saxony. Furthermore, the age of the Russian
1090 material is either uppermost Jurassic or lowermost Cretaceous.

	Specimen	Age	Locality	Reference
1	<i>Dakosaurus andiniensis</i> referred specimen	Upper Tithonian or Lower Berriasian	Yesera del Tromen-Pampa Tril area, Neuquén Province, Argentina	Herrera <i>et al.</i> 2015; Fernández <i>et al.</i> 2019
2	<i>Purranisaurus potens</i> holotype	Upper Tithonian or Lower Berriasian	Malargüe Department, Mendoza Province, Argentina	Herrera <i>et al.</i> 2015; Fernández <i>et al.</i> 2019
3	<i>Cricosaurus</i> sp.	Upper Tithonian or Lower Berriasian	Arroyo Durazno, Mendoza Province, Argentina	Fernández <i>et al.</i> 2019
4	Metriorhynchidae indeterminate	Upper Tithonian or Lower Berriasian	Arroyo Paulino, Mendoza Province, Argentina	Fernández <i>et al.</i> 2019
5	Metriorhynchidae indeterminate	Upper Tithonian or Lower Berriasian	Khoroshevskii Island, Volga Region, Russia	Ochev 1981
6	Metriorhynchidae indeterminate	Lower Berriasian	Arroyo Paulino, Mendoza Province, Argentina	Fernández <i>et al.</i> 2019
7	<i>Neustosaurus gigondarum</i> holotype	Lower Valanginian	Département du Vaucluse, France	Raspail 1842
8	' <i>Cricosaurus</i> ' <i>macrospondylus</i> referred specimen	Lower Valanginian	Département des Hautes-Alpes, France	Hua <i>et al.</i> 2000
9	<i>Cricosaurus schroederi</i> holotype	Lower Valanginian	Landkreis Schaumburg, Germany	Karl <i>et al.</i> 2006
10	cf. <i>Geosaurus lapparenti</i>	Lower Valanginian	Département du Vaucluse, France	Debelmas 1958
12	<i>Enaliosuchus macrospondylus</i> holotype	Lower upper Valanginian	Landkreis Hamelin-Pyrmont, Germany	Koken 1883
13	cf. <i>Cricosaurus</i>	Upper Valanginian	Colombia	Larsson <i>et al.</i> 2012
14	Plesiosuchina indeterminate	LowerUpper Valanginian	Département des Bouches-du-Rhône, France	Young <i>et al.</i> 2014b
15	<i>Geosaurus lapparenti</i> holotype	Upper Valanginian	Département du Var, France	Debelmas & Stannoloubsky 1957
16	Metriorhynchidae indeterminate	Upper Valanginian or Lower Hauterivian	Département du Vaucluse, France	Debelmas & Demains D'Archimbaud 1956

17	<i>Machimosaurus rex</i> holotype	Hauterivian? (Upper Jurassic–Lower Cretaceous)	Touil el Mhahir, Tataouine Governorate, Tunisia	Fanti <i>et al.</i> 2016 (but see Cortés <i>et al.</i> , 2019)
18	<i>Geosaurus lapparenti</i> referred specimen	Lower Hauterivian	Département du Var, France	Debelmas 1952
19	Teleosauroida gen. et sp. indet.	Upper Barremian	Loma La Cabrera, Colombia	Cortés <i>et al.</i> , 2019
20	cf. Plesiosuchina	Lowermost Aptian	Montagna Grande area, Sicily	Chiarenza <i>et al.</i> 2015

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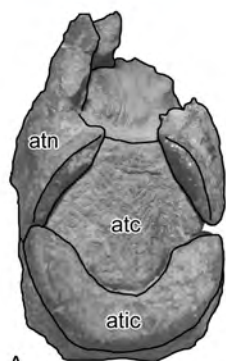
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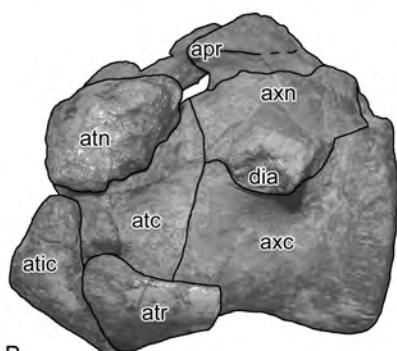
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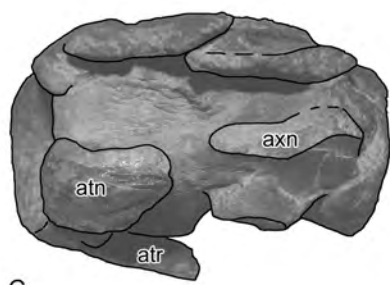
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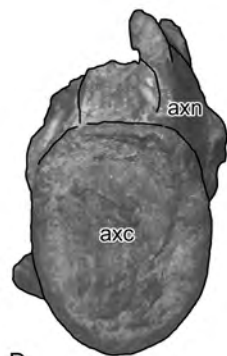
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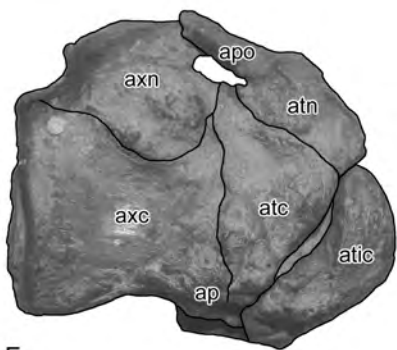
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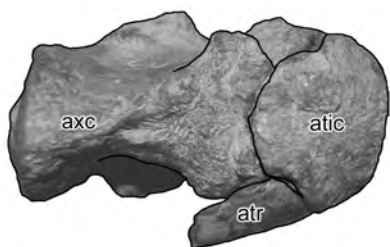
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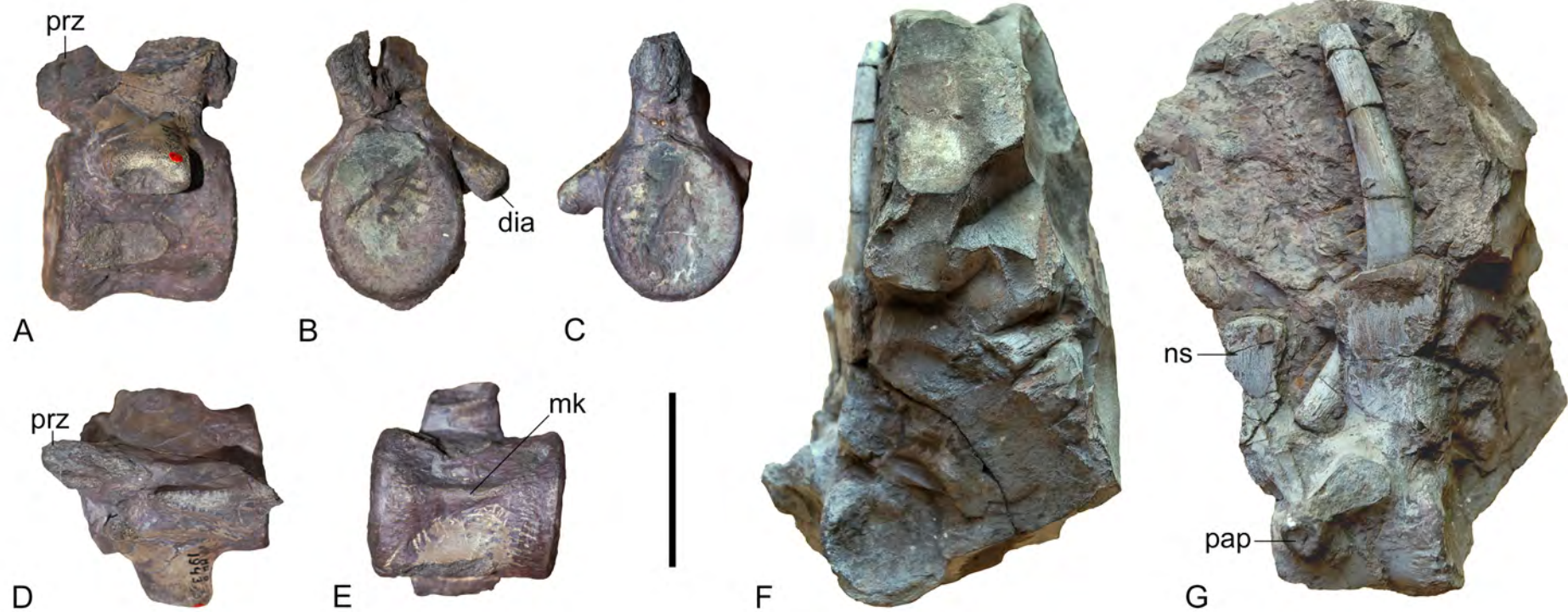
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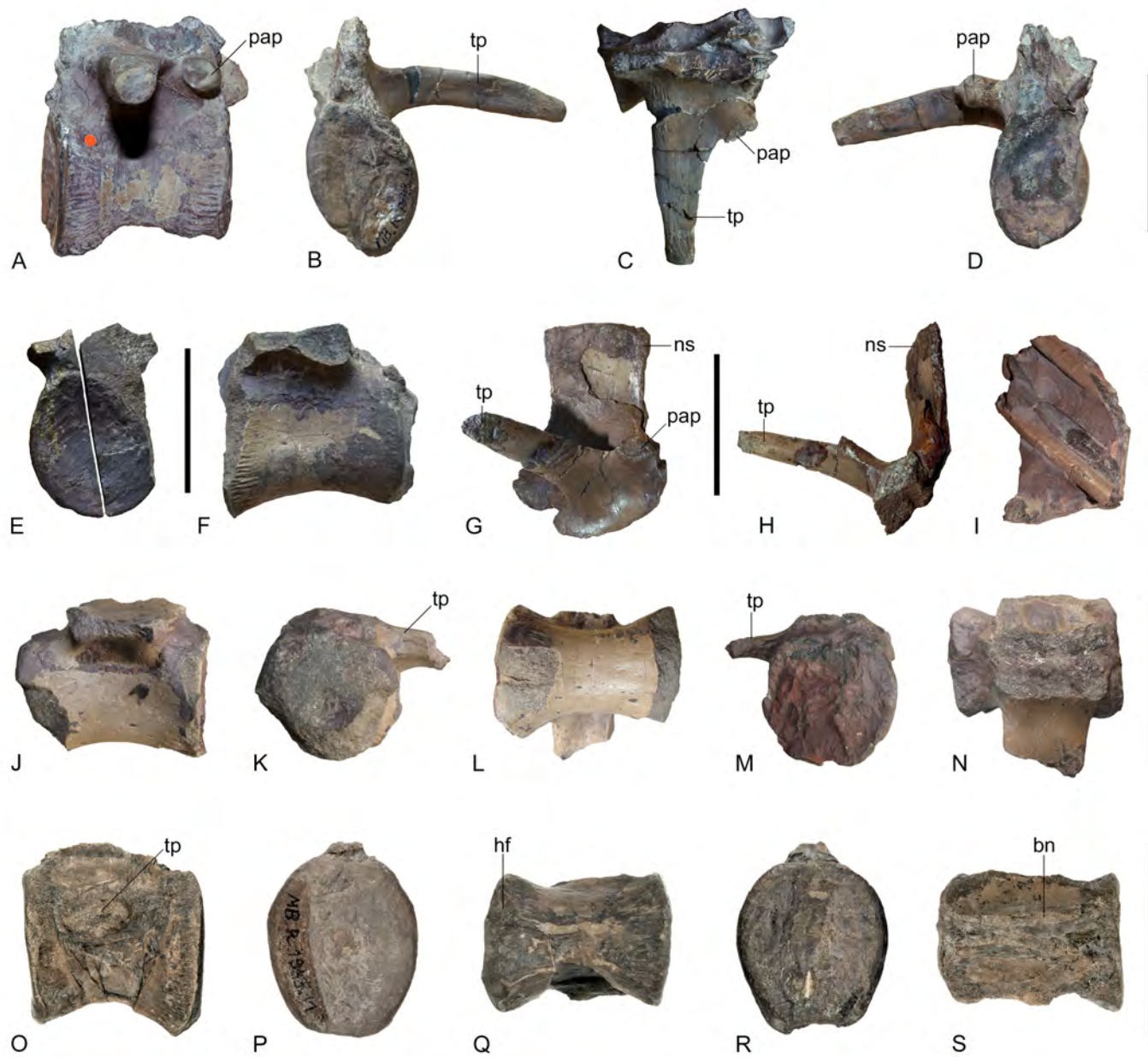


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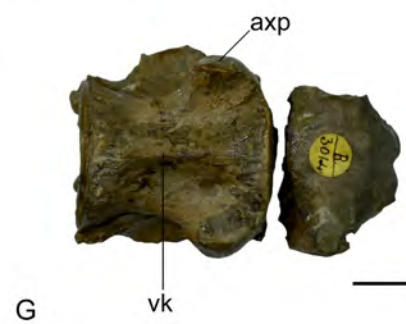
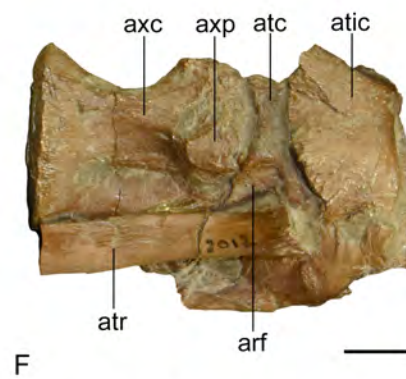
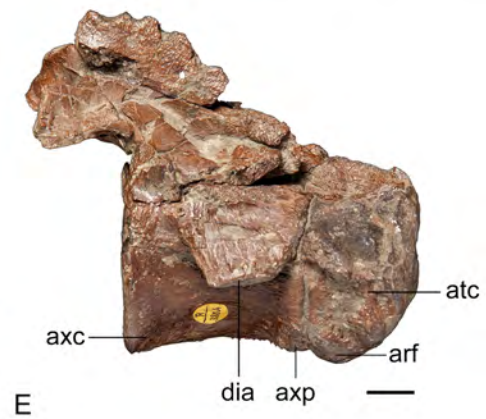
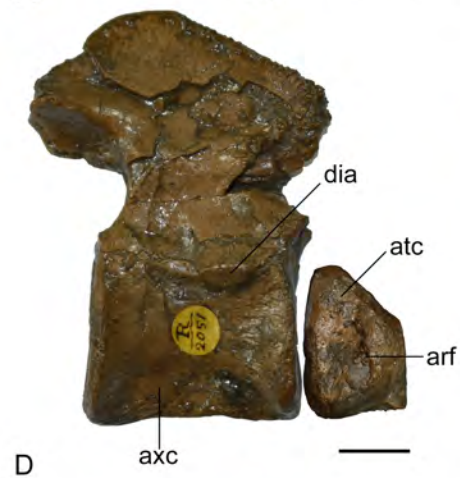
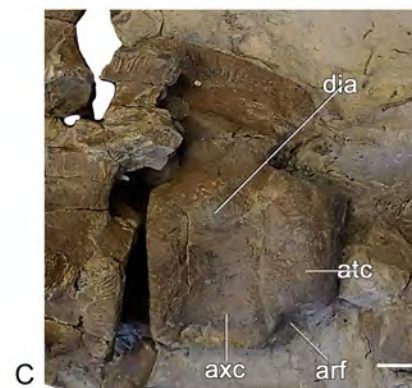
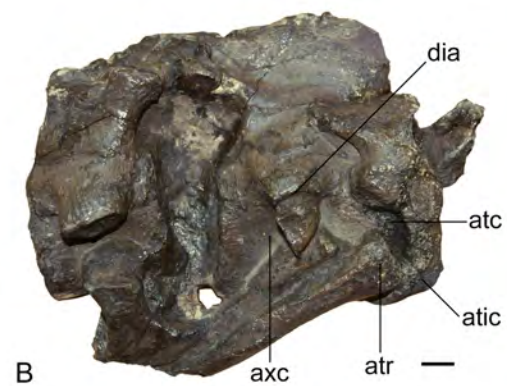
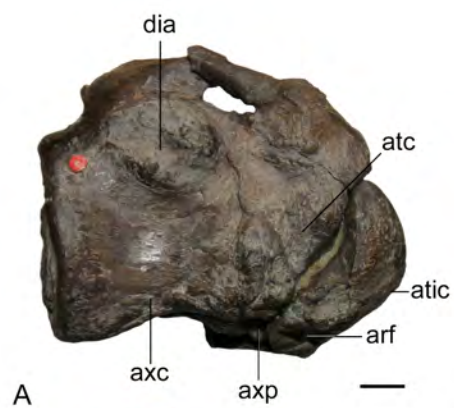
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C



D



There are no conflicts of interest

All authors

Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing, Review & Editing