

Some newly described archaeocete remains from the Eocene of the Helmstedt region, Germany

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Our beloved friend Bernd Vahldiek unexpectedly died on 27-10-2023. His knowledge and his collections of the Eocene sediments of the Helmstedt region were of tremendous value for our studies of German archaeocetes.

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Adding up to the 36 basilosaurid remains from Bartonian to Priabonian strata at the open cast mines in the Helmstedt region, Germany that were published in the past, ten other finds from this region are described here. Most or all the finds were collected by Rudolf Mundlos in the second half of the twentieth century. The most significant remains consist of a fragmentary lumbar (maybe thoracic) vertebra of *Pachycetus* sp. with a large part of the neural arch preserved, a radius of a large archaeocete, and a small posterior thoracic or lumbar vertebral centrum of a small dorudontine.

KEY WORDS: Basilosauridae, whales, Eocene, Helmstedt, Germany

Introduction

Van Beneden was the first to describe cetacean remains from what was then thought to be Oligocene strata with phosphorites ('Phosphoritlagerstätten') in the Helmstedt region, Germany (Van Beneden, 1883). He regarded the remains as belonging to mysticetes and named two different species: a large vertebra (NsT90) and a large rib fragment (NsT92-A) were called *Pachycetus robustus* Van Beneden, 1883 and three smaller vertebrae (NsT91, NsT93 and NsT94) plus two rib fragments (NsT37 and an unnamed one) *Pachycetus humilis* Van Beneden, 1883. He did not provide figures. The material is now kept in the Senckenberg Naturhistorische Sammlungen Dresden.

Fifty years later Kuhn (1935) redescribed the four vertebrae (NsT90, NsT91, NsT93 and NsT94) which had been described by Van Beneden (1883) and added to these three other, small vertebrae, without catalogue number, from the same region. These three vertebrae, which were kept at the Natural History Museum of Munich, got lost

during World War II. Kuhn correctly assigned the three vertebrae, as well as the vertebrae published by Van Beneden (1883), to Eocene archaeocetes. He added figures of two vertebrae (NsT90 and NsT94) published by Van Beneden and two of the newly published vertebrae. Like Van Beneden, he discerned two species, a large and a small one, but rejected the name *Pachycetus* for being 'inconsistent'. For several reasons, amongst others by referring to a personal communication of Everhard J. Slijper, he used the genus name '*Zeuglodon*' (with apostrophes) instead of *Basilosaurus*, although remarking that '*Zeuglodon*' 'nowadays' (1935) maybe needed to be replaced by the older name *Basilosaurus*. He assigned the large vertebra NsT90, *P. robustus* to '*Zeuglodon*' cf. *isis*. Furthermore, he ascribed the three newly published, small vertebrae, as well as the three earlier published small vertebrae NsT91, NsT93 and NsT94, called *P. humilis* by Van Beneden (1883) to '*Zeuglodon*' sp. indet. cf. *osiris* (Kuhn, 1935). Nevertheless, he added that the species name *humilis* might possibly be restored in later years.

Although referring to Van Beneden's publication (1883) about the cetacean remains from the Helmstedt region, in his review of the then known archaeocetes Kellogg (1936) did not mention archaeocetes from this region. Another 50 years later Lienau (1984) described and figured not earlier published archaeocete remains from the Helmstedt region: a vertebra referred to *P. humilis* and one referred to *P. robustus* as well as a rib fragment, all without catalogue numbers. Lienau maintained the names *P. humilis* and *P. robustus*, but added that the genus *Pachycetus* probably had to be replaced by *Basilosaurus*. A non-figured tooth fragment and a premolar fragment (GPIM P 4010), were assigned to Dorudontidae gen. et sp. indet.

In 2020 Van Vliet and colleagues reviewed the earlier described cetacean remains and added more than 25 remains (skull fragments, dental elements and postcrania like vertebrae and rib fragments) from the same region. Van Vliet *et al.* (2020) found that vertebra NsT90 and a large rib fragment (most probably NsT92-A) that Van Beneden (1883) assigned to *P. robustus*, had all characteristics in common with vertebrae and ribs of *Zeuglodon paulsonii* Brandt, 1873 from Ukraine, a species referred to the new genus *Platysophys* by Kellogg (1936). Therefore Van Vliet *et al.* (2020) considered the genus *Platysophys* a junior synonym of *Pachycetus*. Van Vliet *et al.* (2020) assigned NsT91, NsT93 and NsT94 (the latter with some doubts), to *Pachycetus* sp. The dental element GPIM P 4010, referred by Lienau (1984) to a half premolar of a dorudontine archaeocete, was assigned to a possible upper molar of *Pachycetus* sp. Van Vliet *et al.* (2020) referred the three vertebrae published by Kuhn (1935), a thoracic vertebra published by Lienau (1984) as well as some newly published remains (a partial rostrum, an incisor, some vertebrae and rib fragments), to a small, indeterminable dorudontine species.

Describing the new subfamily Pachycetinae, Gingerich *et al.* (2022) remarked that *P. robustus* and possibly also *P. humilis* are known from the Helmstedt region. It was suggested that probably all remains of large species of *Pachycetus* now known from Europe belong to *P. paulsonii*. Gingerich *et al.* (2022) also suggested that the vertebra NsT94 (published by Van Beneden, 1883 and referred to *P. humilis*) belongs to an archaeocete different from *Pachycetus*.

Finally, in a detailed study, Davydenko *et al.* (2023) tentatively assigned a tibia fragment from Helmstedt to an archaeocete. Van Vliet *et al.* (2020) earlier assigned the tibia fragment to *incertae sedis*, but noticed that its features point to an archaeocete.

The here described ten remains of archaeocetes from the Helmstedt region of Germany were not published before. They are housed in the collections of the State Museum of Natural History in Stuttgart. The fossils were collected by Rudolf Mundlos in the second half of the twentieth century and were donated to the museum.

Geological setting

In the open cast mines in the Helmstedt region, Palaeogene lignite bearing sediments have been exploited on large scale in the twentieth century (Fig. 1). These sediments, partly terrestrial and fluvial, partly marine in origin, are of Thanetian to Lutetian age. They are capped by Lutetian to Rupelian marine sediments. The geology of the region was described by amongst others Van Vliet *et al.*, (2020) and Davydenko *et al.*, (2023) and we refer to these articles, confining us to the Gehlberg Formation from which all archaeocete remains were derived (Bachmayer & Mundlos, 1968; Lienau, 1984; Lotsch, 1998; Schleich *et al.*, 1994; Vahldiek in Schleich *et al.*, 1994). This formation consists of three units: the Lower Green Unit, partly Bartonian, partly Priabonian in age (Erbacher, 2008), capped by the Upper Brown Unit, and the Upper Green Unit, both Priabonian in age. The Lower Green Unit only has a few phosphorite horizons, from bottom to top KIV, a stratum with phosphorite concretions, containing crab fossils ('Phosphoritlage mit Krebsen', see Vahldiek in Schleich *et al.*, 1994) and above it G5, a phosphorite stratum ('Phosphoritgeröll-Lage') with sparse concretions (Lienau, 1984). G4, a stratum with phosphorite concretions, is located at the base of the Upper Brown Unit; in this unit also the strata with phosphorite concretions KII-III and G3 are located. G2, a stratum with phosphorite concretions, is located at the base of the Upper Green Unit, and above it, G1, also a stratum with phosphorite concretions. Stratum KI is located in the overlying Priabonian to Rupelian Silberberg Formation (Lienau, 1984) (Fig. 2). In the past, greensands with the layers of phosphorite concretions were exposed in clay pits in Helmstedt, Büddenstedt and Alversdorf (Schmid, 2006). Nowadays, some of these localities, for example those in Büddenstedt, are lost, probably because of later expansions of the open cast mine Treue (Bachmayer & Mundlos, 1968). The strata with phosphorite concretions have been interpreted as storm deposits (Hillmer & Mundlos, 1981), but are possibly erosional horizons during periods of lowered sea levels (Vahldiek in Schleich *et al.*, 1994). The Gehlberg Formation with cross-beddings, limonite concretions and with a high diversity of colours, was probably deposited in rapidly moving currents in a relatively shallow sea with a depth of 50-70 m (Lienau, 1984: p. 94), or less than 100 m (Vahldiek in Schleich *et al.*, 1994).

Apart from redeposited Mesozoic fossils, originating from the Triassic and the Cretaceous (Schleich *et al.*, 1994), the phosphorite concretion bearing strata yield a rich Palaeogene fauna. It consists of elasmobranchian and teleost remains, as well as reptilian remains, represented by cheloniids (*Chelyopsis raabei* Karl & Schleich, 1994), and maybe also marine crocodiles. Terrestrial or semiaquatic mammals are represented by scarce, fragmental remains of *Lophiodon* (aff.) *rhinoceros* Rüttemeyer, 1862 (Geinitz, 1883a-b; Kuhn, 1935; Lienau, 1984) and *Propalaeotherium* sp. (Kuhn, 1935; Lienau, 1984). About 44 bones of archaeocetes were described from the Gehlberg Formation (Van Beneden, 1883; Kuhn, 1935;

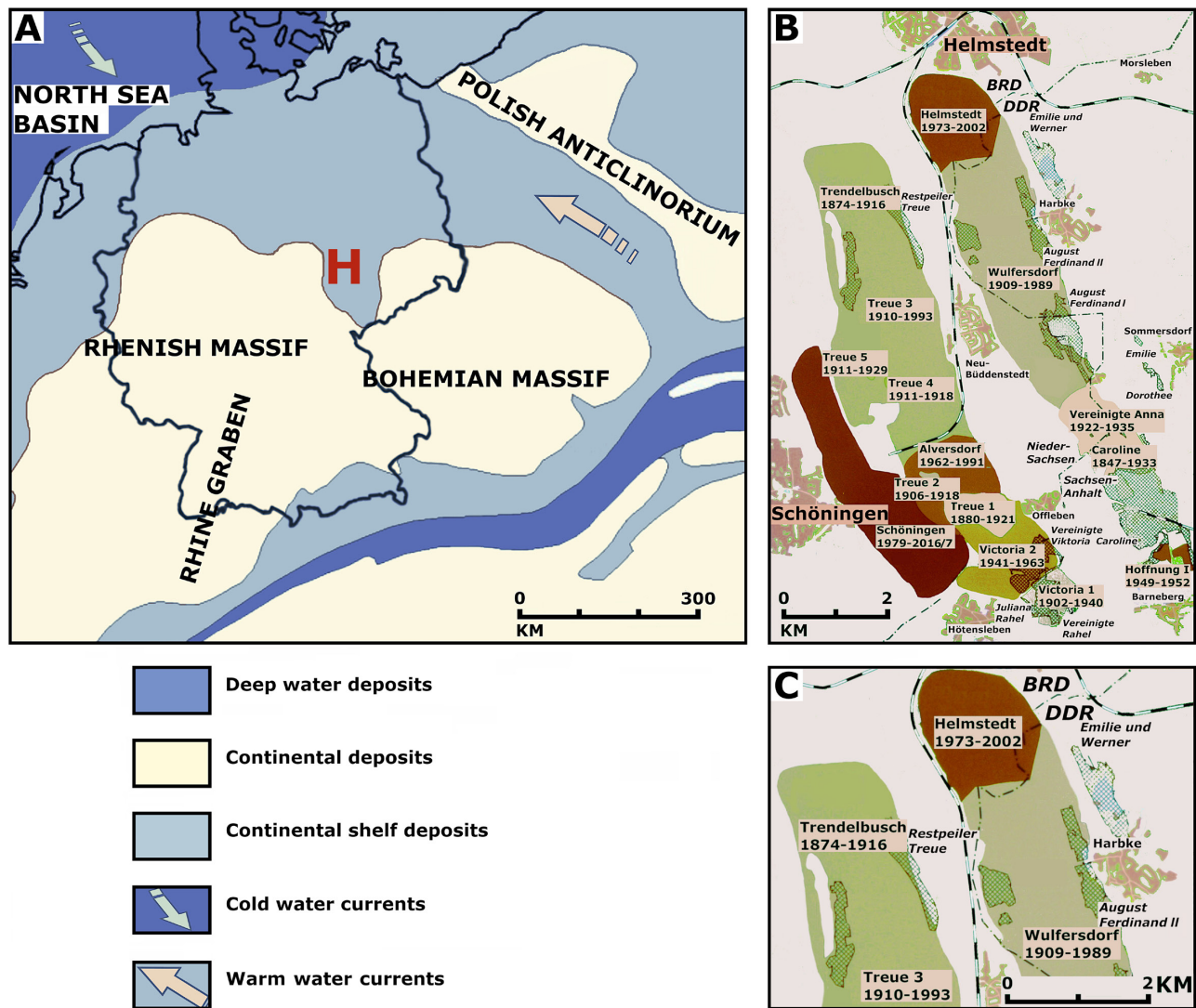


Fig. 1. (Palaeo)geographic maps. A: Map of Germany and surroundings during the Bartonian to Priabonian, with the North Sea Basin in the NW and the Paratethys in the SE. The borders of present Germany are indicated; the ‘H’ indicates the Helmstedt region. Modified after the combined figures of Lenz *et al.* (2021: fig. 1), and Ring *et al.* (2020: fig. 1b). B: The location of the open cast mines in the region of Helmstedt, with in each mine the years during which lignite was excavated. C: Magnification of a part of B, showing the two open cast mines Helmstedt and Treue 3, where the bones have been found. B and C modified after a map in the Heimatmuseum of Schöningen, published in Mitteldeutsches Braunkohlenrevier 14, Wandlungen und Perspektiven, Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft.

Lienau, 1984; Van Vliet *et al.*, 2020; Davydenko *et al.*, 2023). All are isolated bones, comprising a skull fragment, three dental elements, vertebral centra, rib fragments, a tibia and some unidentifiable bones. This paper deals with some not earlier described fossils of archaeocetes from this formation. All bones are isolated finds and often fragmentary.

Material and methods

All measurements were taken with digital calipers. All values were rounded to a millimeter.

The relative length (Rel L) of a vertebral centrum is calculated by dividing the dorsal length by the anterior

transverse width: $Rel L = L_d / W_a$; the relative width of a vertebral centrum is calculated by dividing the anterior width by the anterior height: $Rel W = W_a / H_a$.

Quite a few labels indicate that the corresponding fossils were found in “Treue 4”, sometimes with the specification “North ramp”. Instead of “Treue 4”, maybe the open cast mine Helmstedt is meant, which did have a North ramp; otherwise, the open cast mine “Treue 3” is meant, as this was the only mine called “Treue”, still open in 1969 (see Fig. 1B).

Terminology – We follow Uhen (2004) and Martínez-Cáceres *et al.* (2017) for anatomical and osteological terms, and Gingerich *et al.* (2022) for the nomenclature.

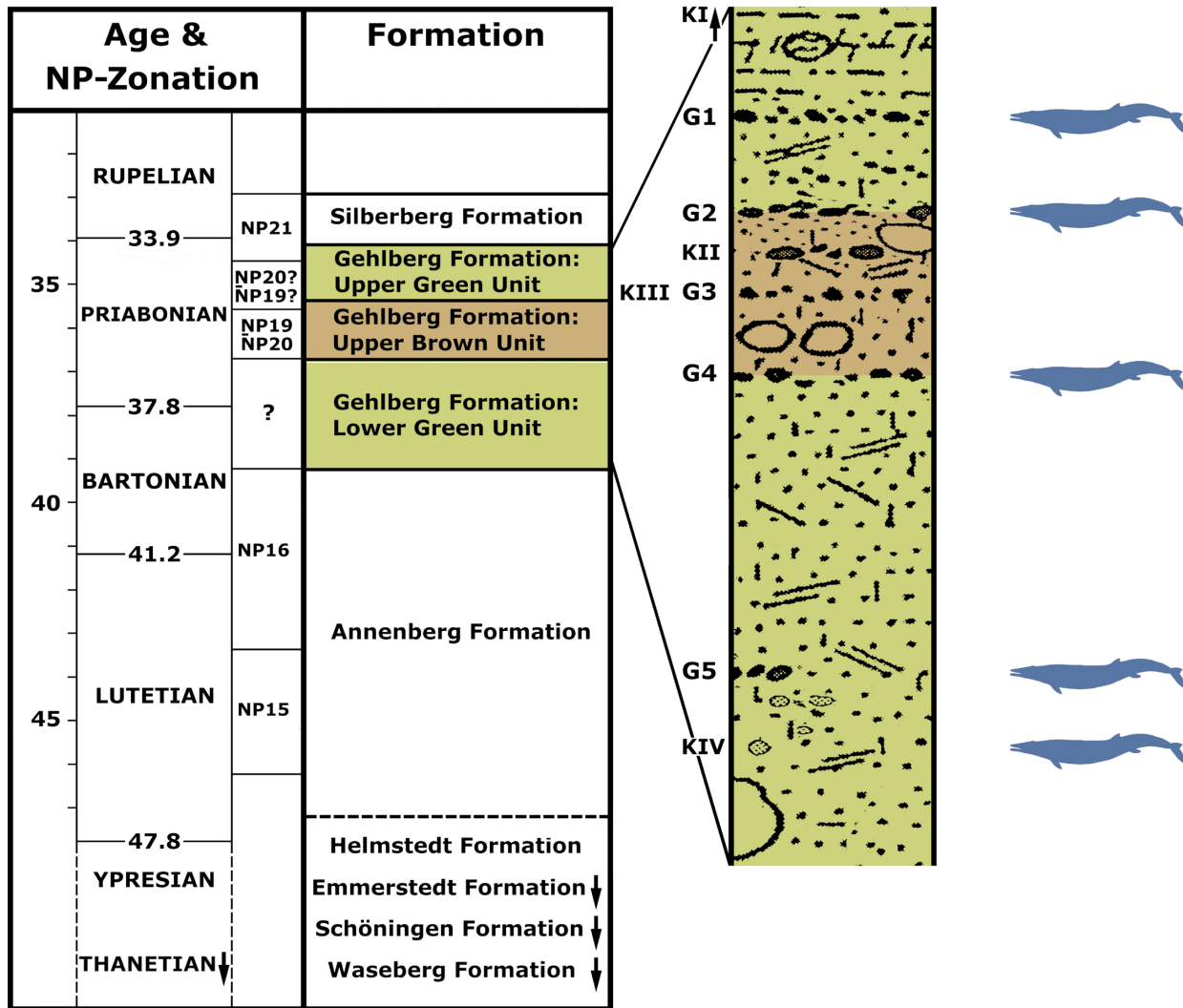


Fig. 2. Stratigraphy of the Palaeogene sediments in the region of Helmstedt (modified after the combined figures of Lienau, 1984: fig. 9 (left) and Mundlos, 1975: fig. 1 (right) in combination with data from Erbacher (2008) and data from the International Chronostratigraphic Chart of the International Commission on Stratigraphy).

Anatomical and other abbreviations:

- | | | | |
|------|--|--------|----------------------|
| a | anterior | NA | neural arch |
| adil | attachment area for the distal interosseus ligament anterior | palm | palmar |
| apil | attachment area for the proximal interosseus ligament | post | posterior |
| arc | angle radial crest | prox | proximal |
| d | dorsal | rc | radial crest |
| dist | distal | Rel L | relative length |
| dors | dorsal | Rel W | relative width |
| e | estimated | rt | radial tuberosity |
| H | height | tot | total |
| h | height | trpr | transverse processes |
| Ha | anterior height | ventr | ventral |
| L | length | w | width |
| Ld | dorsal length | Wa | anterior width |
| mid | midpart diaphysis | +epi's | with both epiphyses |
| Mc | metacarpal | > | more than |
| | | < | less than |
| | | ? | unknown |

Institutional abbreviations:

BKB	Braunschweigischen Kohlen-Bergwerke
GSP-UM	Geological Survey of Pakistan-University of Michigan collection, housed in Quetta, provincial capital of Balochistan
MNHN	Muséum national d'Histoire naturelle, Paris, France
MUSM	Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Lima, Peru
NsT (= MMG: NsT)	Museum für Mineralogie und Geologie: Niedersachsen Tertiär, Senckenberg Naturhistorischen Sammlungen, Dresden
SMNS	Staatliches Museum für Naturkunde in Stuttgart (State Museum of Natural History in Stuttgart)
UM	University of Michigan Museum of Paleontology, Ann Arbor, Michigan, United States of America
USNM	United States National Museum of Natural History, Smithsonian Institution, Washington DC, United States of America

Systematic palaeontology

Cetacea Brisson, 1762
 Archaeoceti Flower, 1883
 Basilosauridae Cope, 1868
 Pachycetinae Gingerich *et al.*, 2022
 Genus *Pachycetus* Van Beneden, 1883

***Pachycetus* sp.**

Figure 3, Table 1

Material – A collection of two large fragments and about 15 small bone fragments, belonging to a single, partial anterior lumbar (or posterior thoracic?) vertebra, labeled Nr. 40666.

Comments – Label Staatl. Museum für Naturkunde in Stuttgart with the text: *Nr. 40666; Cetacee; vertebra; Nordrand des Tagebaus Helmstedt (Braunschweigische Kohlenbergwerke); Obereocän; leg. Mundlos 1979* (No. 40666; cetacean; North ramp of the open cast mine Helmstedt (Braunschweigische Kohlenbergwerke); upper Eocene; legit Mundlos 1979).

Description – SMNS 40666 is a partial vertebra (Fig. 3). A large part of the vertebral centrum is not preserved, apart from the cortex; the reconstructed dimensions of the original vertebra are given below ('Discussion'). The cortex consists of compact, multi-layered bone. The surface has multiple punctae. The left and a right parts of the anterior epiphyseal side are preserved, showing a radiating pattern, as the epiphysis is lacking. The posterior side

of the vertebra is missing. A large part of the neural arch is preserved. The pedicles are elongated. The metapophyses on the anterior side and the neural spine are lacking. The postzygapophyses on the posterior side of the neural arch are broken, leaving two fracture sites, separated by a clear triangular depression. The onset of the transverse processes is elongated. Only the anterior part of the transverse processes is preserved; the remaining part of the left process is larger than the right one. The transverse processes are directed ventrolaterally. The vertebra is, judging by its weight mineralized, not abraded, and yellowish-brown in colour. For dimensions, see Table 1.

Discussion – The elongated transverse processes, the compact, multi-layered cortex, the multiple punctae and the vertebral dimensions point to a large species of *Pachycetus*. The position of the two main fragments of SMNS 40666 in Figs 3A-B is based on the figure by Fedorovsky, 1912, plate 2:6 (Lu'5' in Kellogg, 1936: table 24; see Fig. 4A). The reconstructed anterior width and height of the epiphyseal side of SMNS 40666 (135 resp. 129 mm) are 0.82 times the width and height of Lu'5' (164 resp. 157 mm). The length of SMNS 40666 is 174 mm; the original length of the vertebra (without epiphyses) is estimated to have been less than 225 mm (0.82 x 274 mm length of Lu'5'= with both epiphyses). With a present length of 174 mm, less than 50 mm is probably missing in SMNS 40666; the remaining parts comprise about 80% of the original vertebra's length. The estimated original length of SMNS 40666 would be in accordance with lumbar vertebrae assigned to *Pachycetus* sp., large species from Het Scheur, Belgian-Dutch border (Van Vliet *et al.*, 2022, table 3a). The neural arch is estimated 70 mm in width. Because of the ventral position of the transverse processes, SMNS 40666 is probably a lumbar vertebra, but a posterior thoracic position cannot be excluded, because of the width of the neural arch.

The two postzygapophyses are broken, but the fracture sites are rather large, which suggests that the postzygapophyses were large too. The neural arch, NMR-12333, of a potential central thoracic vertebra of *Pachycetus*, large species, from the Belgian-Dutch border, has two large postzygapophyses (>34 mm from the base of the triangular notch to the tip of the postzygapophyses) (Van Vliet *et al.*, 2022: figs 11c-d) (Figs 4C-D). Kellogg (1936) mentioned that the metapophyses of lumbar vertebrae of *P. paulsonii* from the Kharkiv region of Ukraine are large, but that the postzygapophyses are 'nipple-like', which seems to suggest that they are much reduced. The postzygapophyses in a lumbar vertebra (Lu'5') of *P. paulsonii* are however rather large (e23 mm), as seen in a figure by Fedorovsky (1912) (Fig. 4B). Considering the size of the postzygapophyses, it is likely they were functional and did articulate with the prezygapophyses, also in the lumbar vertebrae.

In thoracic vertebrae of *P. wardii* Uhen, 1999, the postzygapophyses are rather large as seen in figures 2 and 3 in Uhen (2001). The lumbar vertebra LuE (USNM 310633) has large metapophyses with prezygapophyses, but the postzygapophyses are very small and do not reach the epiphyseal end of the centrum. The articular surface with

Collection number and species	Fig.	Bone	Stratigraphy	Length	Neural arch (=NA)	Breadth ant-post	Width	Height	Rel L = Ld/Wa	Rel W = Wa/Ha
SMNS 40666 <i>Pachycetus</i> sp. (large species)	Fig. 3	Ant Lu (post th?) vertebra*)	Late Eocene	>136.4 (mid) >174 <e225 (if +epi's)	e70.4 (w) (ant) e35.8 (h) (ant)		<136.9 (ant) e135 (ant)*** 223 (ant + trpr) ? (post)	>84.3 (ant) e129 (ant)*** 209 (ant + NA) ? (post)	e<1.67	
SMNS 40667 Indet. basilosaurid	Fig. 5	Radius**)	Late Eocene	178.0		21.9 (prox) 43.8 (at angle) 46.1 (dist)	31.5 (prox) 26.8.0 (at angle) 26.9 (dist)			
SMNS 44699 Indet. dorudontine (small species)	Fig. 6	Post Th/ant Lu vertebra*) remnants of one epiphysis	G1, upper Unit Gehlberg Formation	50.8 (dors) 48.8 (ventr)	32.8 (ant) ? (post)		70.6 (ant) 70.6 (post) 96.1 (tot)	64.6 (ant) 62.7 (post) 85.8 (tot)	0.720	1.093
SMNS 44700 Indet basilosaurid (large species)	Fig. 7	Unidentifiable bone fragment (metacarpal?)	G1, Upper Unit Gehlberg Formation	>62.1		21.0 (prox) 27.1 (mid) 19.8 (dist)	>19.0 (prox) 15.8 (dist)			
SMNS ID.01 Mammalia indet.	Fig. 8A	Unidentifiable bone fragment	Upper Unit Gehlberg Formation	>219		>123.7	>23.6			
SMNS ID.02 Indet basilosaurid	Fig. 8B	Rib fragment	G2, upper Unit Gehlberg Formation	>101.2		30.5 31.4	17.5 21.0			
SMNS ID.03 Mammalia indet.	Fig. 8C	Unidentifiable bone fragment	G2, upper Unit Gehlberg Formation	>65.7		14.1 13.6	10.2			
SMNS ID.04 cf. <i>Pachycetus</i> sp.	Fig. 8D	Vertebra fragment	Upper Unit Gehlberg Formation	>115.1			>84.8	>39.1		
SMNS ID.05 Mammalia indet.	Fig. 8E	Unidentifiable bone fragment (skull fragment?)	Upper Unit Gehlberg Formation	>71.8		42.3	15.2			
SMNS ID.06 Mammalia indet.	Fig. 8F	Unidentifiable bone fragment (skull fragment?)	Upper Unit Gehlberg Formation	>91.8		65.8				

*) without epiphyses; **) with one epiphysis; ***) estimations based on Fedorovskiy, 1912: Tafel II, Fig. 6 (= Lu'5')

Table 1. Dimensions cetacean bones from the Priabonian of Helmstedt (in mm).

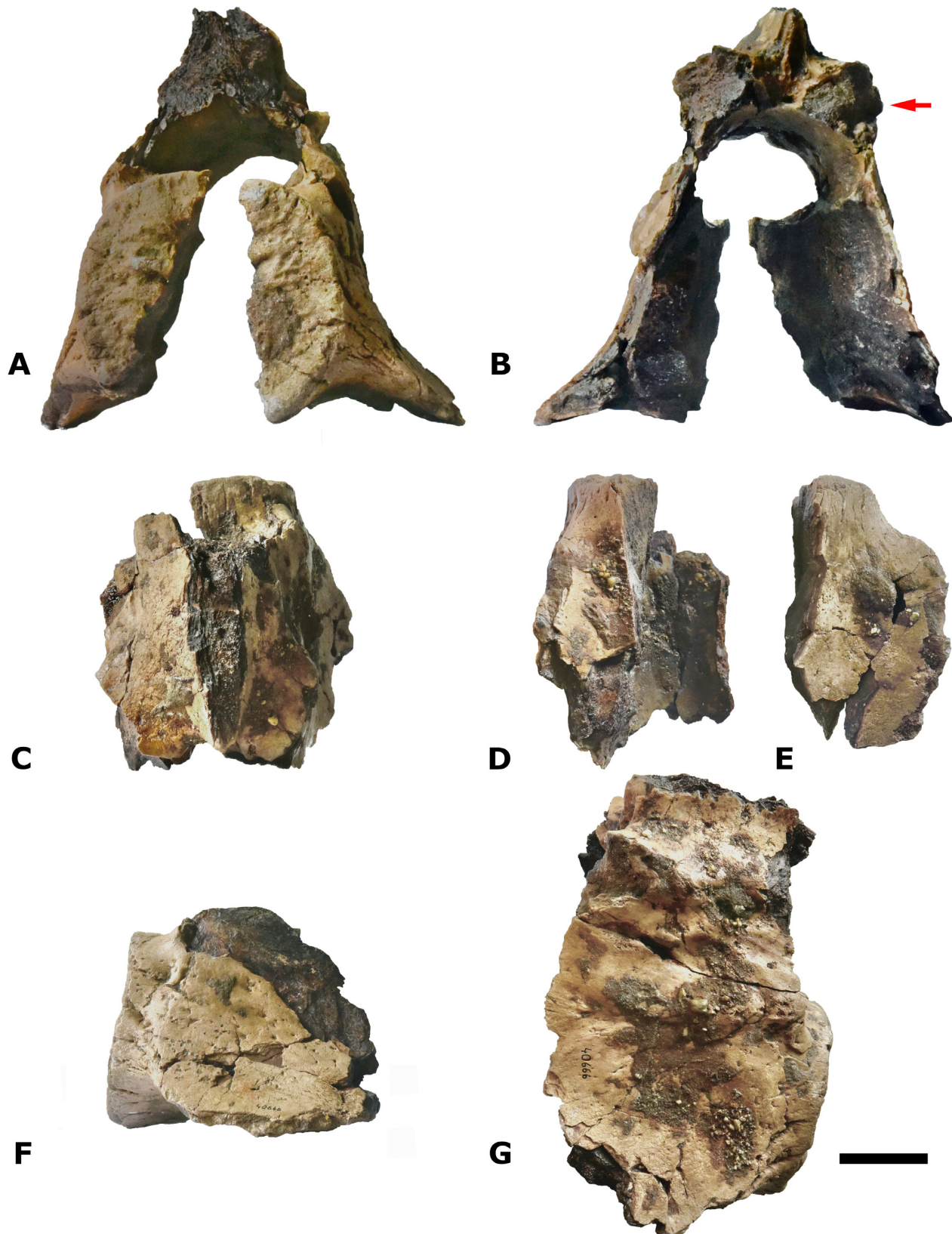


Fig. 3. A-G: Anterior lumbar (or posterior thoracic) vertebral centrum, SMNS 40666, large species of *Pachycetus* from the Priabonian of the Helmstedt region, Germany, in anterior (A), posterior (B), dorsal, left part (C), ventral, right part (D), ventral, left part (E), left lateral (F) and right lateral (G) view. Red arrow in B points to the fracture site of the relatively large postzygapophyses. Reconstructions in (A) and (B) based on Lu '5', Fedorovsky, 1912: plate 2, fig. 6 (see also Fig. 4A in this article). Scale bar 100 mm.

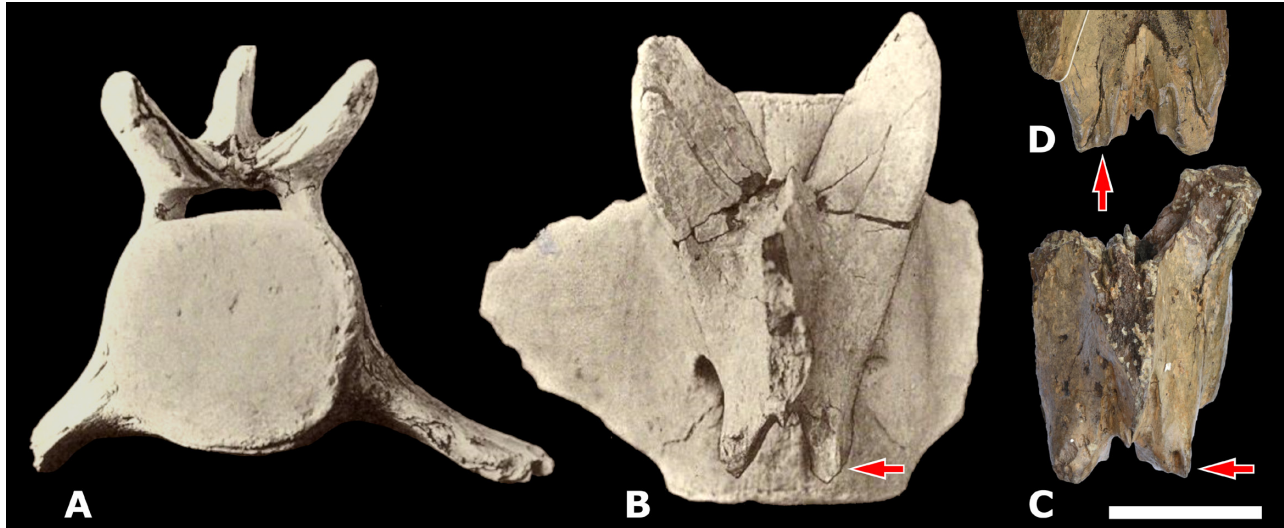


Fig. 4. A-B: Lumbar '5' *Pachycetus paulsonii* from the Bartonian or Priabonian of Korobov Khutor, Kharkiv, Ukraine, in anterior (A), and dorsal (B) view (modified after Fedorovsky, 1912: plate 2, figs 6 resp. 8). C-D: Neural arch of a presumed central thoracic vertebra, NMR-12333, large species of *Pachycetus* from the Bartonian of Het Scheur, Belgian-Dutch border in dorsal (C) and ventral (D) view. C modified after Van Vliet *et al.*, 2022: fig. 12c. Red arrows point to the relatively large postzygapophyses. Scale bar 100 mm.

the postzygapophyses, if present, is probably only small according to Uhen (1999). No mention is made about the pre- and postzygapophyses of Lu1-2 (NCSM 11284) (Uhen, 2001).

In the plesiomorphic basilosaurid *Stromerius nidensis* Gingerich, 2007, the thoracic vertebral column is poorly known. Lumbar vertebrae retain postzygapophyses and have large metapophyses. Pre- and postzygapophyses of the posterior lumbar vertebrae Lu 11-12 and even anterior caudal vertebrae articulate with each other, although the articular surface is small (Gingerich, 2007).

In *Z. kochii*, thoracic vertebrae have functional pre- and postzygapophyses and are 'rather firmly interlocked' (Kellogg, 1936). From Th13 and backward the prezygapophyseal facets become reduced and the postzygapophyseal facets small. According to Kellogg's description, the postzygapophyseal facets of lumbar vertebrae apparently become more and more reduced posteriorly; no mention is made whether they were still functional (Kellogg, 1936). In the thoracic vertebral column of other derived basilosaurids, the postzygapophyses diminish in size posteriorly. Postzygapophyses of lumbar vertebrae do not articulate anymore with the prezygapophyses.

In *Dorudon atrox* Andrews, 1906 the metapophyses with prezygapophyses and the postzygapophyses of thoracic vertebrae gradually change posteriorly; no mention is made whether they stop articulating in posterior thoracic vertebrae. The postzygapophyses of the lumbar vertebrae are small and do not articulate with the prezygapophyses (Uhen, 2004).

In *Cynthiacetus peruvianus* Martínez-Cáceres & de Muizon, 2011 the anterior thoracic vertebrae retain articulating pre- and postzygapophyses, but they decrease in size posteriorly. From Th10 and backward, the postzygapophyses are reduced and do not articulate with the prezygapophyses of the vertebra posterior to it. The

postzygapophyses of the lumbar vertebrae are progressively strongly reduced backwards (and without triangular notch) and do not articulate with the prezygapophyses (Martínez-Cáceres *et al.*, 2017).

In *Basilosaurus cetoides* Harlan, 1834 the anterior thoracic vertebrae also retain articulating pre- and postzygapophyses. From Th5 and backward the prezygapophyses become more and more reduced. From Th9 and posteriorly the prezygapophyses are very reduced or missing. The postzygapophyses do not reach the epiphyseal end of the vertebra. Pre- and postzygapophyses are absent in lumbar vertebrae (Kellogg, 1936).

On the other hand, in protocetids, more primitive than basilosaurids, the postzygapophyses in thoracic and lumbar vertebrae are large (see: <https://umorf.ummp.lsa.umich.edu/wp/protocetidae/>).

The presence of large postzygapophyses in lumbar vertebrae of *Pachycetus*, large species from Europe can be considered a plesiomorphic feature with phylogenetic importance, distinguishing vertebrae of this taxon from those of derived basilosaurids.

Maybe the remains of *Pachycetus* sp., found in Priabonian strata of the Helmstedt region have been washed out from Bartonian strata, but the surface of SMNS 40666 is remarkably 'fresh' and not-abraded, which can point to the existence of *Pachycetus* into the Priabonian (Fig. 3).

Basilosauridae indet.

Figure 5, Tables 1-2

Material – Radius, labeled SMNS 40667.

Comments – Label (Staatl. Museum für Naturkunde in Stuttgart) with the text: Nr. 40667 'costa sirenide'; Nordrand des Tagebaus Helmstedt; (Braunschweigische Kohl-

Collection number and taxon	Length	Relative position angle (%) ¹⁾	References
Basilosaurids			
SMNS 40667 Indet. basilosaurid	178 *)	45	This article
USNM 4675 Basilosaurus cetoides	250 (le) 254 (ri)	28	Kellogg, 1936: fig. 23, table 14
MNHN.F.PRU10 <i>Cynthiacetus peruvianus</i>	221	30	Martínez-Cáceres et al. 2017: fig. 83, table 13
USMN 4679 <i>Zygorhiza kochii</i>	158	33	Kellogg, 1936: fig. 72, pp. 162-163
SMNS 11239a <i>Zeuglodon</i> aff. <i>osiris</i> = ? <i>Saghacetus osiris</i>	125 *)	39	Stromer von Reichenbach, 1908: Tafel V, figs. 10-11, p. 125; Kellogg, 1936: pp. 203, 211; Gingerich, 1992: p.73
SMNS 11951b <i>Zeuglodon zitteli</i> = <i>Durodon stromeri</i> = <i>Durodon atrox</i>	160	?	Stromer, 1908: Tafel V, figs. 16-19, p. 128; Kellogg, 1936: p. 219; Gingerich, 1992: p. 73-74; Uhen, 2004
<i>Dorudon atrox</i> 4 specimens	156-161	38	Uhen, 2004: table 19
Protocetids			
GSP-UM 3475a <i>Maiacetus inuus</i>	100	75	Gingerich et al., 2009: fig. 7, table 1
MUSM 3580 <i>Peregocetus pacificus</i>	154	84	Lambert et al., 2019: fig. 1M, supplementary measurements

*) with one epiphysis

¹⁾ relative position angle in the radial crest on the total proximo-distal length of the radius

Table 2. Radius SMNS 40667, compared to that of several basilosaurids (in mm).

enbergwerke) Obereocän; Leg. Mundlos 1979 (No. 40667; sirenian rib; North ramp of the open cast mine Helmstedt; (Braunschweigische Kohlenbergwerke); upper Eocene; leg. it Mundlos).

Description – SMNS 40667 is a left radius of an archaeocete (Fig. 5). It is medio-laterally compressed. The radius is bent with the proximal part making a clear angle of 155° with the distal part on the anterior side. Only the proximal epiphysis is fused with the diaphysis. It is more or less rectangular in shape, although posteriorly slightly damaged. The articular facet with the humerus is saddle-shaped, with a shallow groove on both the anterior and posterior face. The midpart of the mediolateral axis bears a low eminence. Directly distally to the proximal articular surface a semi-circumferential groove is present with at the medial side three rounded pits. One of these pits is located directly proximal to a slight protuberance, surrounded by two small fossae.

On the posterior side a fragment, about 40% of the radius length is missing. It reveals a rather thin, compact cortex (2 mm thick) and spongy bone underneath. The distal epiphyseal side is wide and transversely compressed. The distal epiphysis is missing. The epiphyseal surface is irregular, suggesting that it was covered by cartilage (see Gingerich *et al.*, 2022). Notwithstanding some damage, the radius is otherwise exquisitely preserved. It is yellowish-brown in colour. On both the lateral and medial side, multiple bite marks of sharks are present. Drillholes of marine organisms on the proximal lateral side testify that the bone was exposed on the seafloor for some time, before being buried. For dimensions, see Table 1.

Discussion – The medio-laterally flattened radius is assigned to a basilosaurid (see e.g. Kellogg, 1936: figs 23 & 72; Uhen, 2004: fig. 102; Martínez-Cáceres *et al.*, 2017: fig. 83). As the distal epiphysis is lacking, SMNS 40667 is of a juvenile or subadult individual. Similarly, the distal

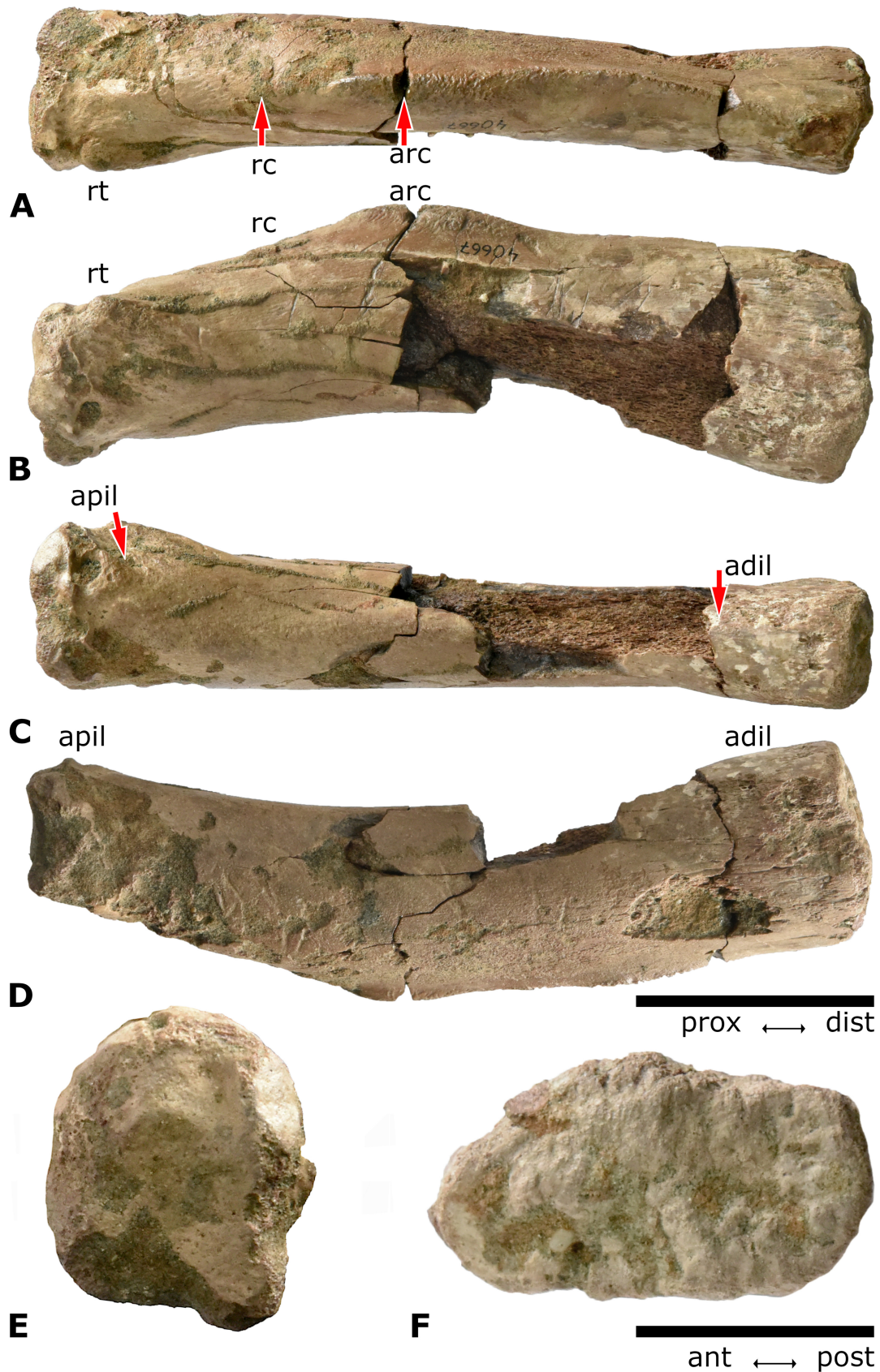


Fig. 5. A-F: Left radius, SMNS 40667, indet. basilosaurid (large species) from the Priabonian of the Helmstedt region, Germany, in anterior (A), in medial (B), posterior (C), lateral (D), proximal (E) and distal (F) view. adil, attachment area for the distal interosseus ligament; apil, attachment area for the proximal interosseus ligament; arc, angle radial crest; rc, radial crest; rt, radial tuberosity. Scale bar A-D 50 mm; scale bar E-F 25 mm.

epiphysis is lacking in a right radius of *Saghacetus osiris* Dames, 1894 (SMNS 12339a, Stromer von Reichenbach 1908: p. 125, Tafel V, fig. 10). In *C. peruvianus*, the distal epiphysis is not completely fused with the radius, contrary to the proximal epiphysis (Martínez-Cáceres *et al.*, 2017). This suggests that the distal radial epiphysis fused at a later ontogenetic age than the proximal epiphysis.

The radius is significantly larger than the radii of *S. osiris* (Stromer, 1908), *Zygorhiza kochii* Reichenbach in Carus, 1847 (Kellogg, 1936), or *D. atrox* (Uhen, 2004), but significantly smaller than the radii of *B. cetoides* (Kellogg, 1936) or *C. peruvianus* (Martínez-Cáceres *et al.*, 2017) (Table 2).

The damaged area of the diaphysis shows that the medullary cavity in SMNS 40667 is filled with loose spongy bone. The cortex is here rather thin, differing from what is seen in the protocetid *Maiacetus inuus* Gingerich *et al.* 2009 and the basilosaurid *D. atrox* which radii have a thick, compact cortex (Houssaye *et al.*, 2015).

The slight protuberance, surrounded by two small fossae distally to the proximal articulation is the proximal attachment of the interosseous membrane (“apil” in Figs 6C-D), which connected radius and ulna (Martínez-Cáceres *et al.*, 2017). At the other epiphyseal end, the distal attachment of the interosseous membrane is present (“adiI” in Figs 6 C-D). The semi-circumferential groove near the proximal epiphysis of a radius in *B. cetoides* was interpreted by Kellogg (1936) as a possible attachment for a capsular cartilage. The groove in SMNS 40667 resembles an articular circumference on the epiphyseal side, but is very shallow at the posterior side, articulating with the ulna. This could contradict the ability of pronation-supination, just as seen in *C. peruvianus* and *D. atrox* (Uhen, 2004; Martínez-Cáceres *et al.*, 2017) (Fig. 6C-D). The radial tuberosity (“rt” in Figs 6A-B) is located on the distal part of the medial side and has an extension with a rather rough surface both anteriorly and medially. Kellogg (1936) and Martínez-Cáceres *et al.* (2017) interpreted the radial tuberosity to be the insertion of the m. biceps brachii. A radial crest (“rc” in Fig. 6A-B) is present on the anterior side; it is most pronounced where the angle of 155° between the proximal and distal part is seen. This crest and the medial side of the diaphysis was interpreted by Kellogg (1936) and Martínez-Cáceres *et al.* (2017) as the insertion of the m. pronator teres, but by Uhen (2004) as the insertion of the m. brachialis.

The angle in the radial crest on the posterior side of the radius (“arc” in Figs 6A-B) is positioned on 45% of the total proximal to distal length of the radius, which is more distally than in other large basilosaurids. The angle is positioned at about 30% of the total proximal to distal radius length in the large basilosaurids *B. cetoides* (Kellogg, 1936: fig. 23) and *C. peruvianus* (Martínez-Cáceres *et al.* 2017: fig. 83). It is positioned more distally in the small dorudontine basilosaurids *Z. kochii* (Kellogg, 1936: fig. 72), *D. atrox* (Uhen, 2004: fig. 102) and the juvenile specimen of *S. osiris* (SMNS 12339a, without distal epiphysis): at 33-38% of the total radius length (Table 2). The angle in the radii of two protocetids *M. inuus* and *Peregoctes pacificus* Lambert *et al.*, 2019 is positioned far more dis-

tally, at about 80% of the total radius length (Table 2).

A radius with a length of 201 mm from the Bartonian of Highcliffe, Barton, England, housed in the collections of the NHM of London, also shows an angle which is positioned more distally than in derived large basilosaurids: at 41-42% of the proximodistal length. In this specimen, the distal epiphysis in this radius is fused with the diaphysis. Because of its age and length, the radius from Highcliffe can very probably be ascribed to a large species of *Pachycetus*. The radius SMNS 40667, in which the distal epiphysis is lacking, would become longer, especially on its distal side when fully-grown and the angle in the radial crest would have a more proximal position, comparable to the radius from Barton. The radius from Highcliffe, which will be described in a future study, is otherwise slightly different from SMNS 40667.

It is tempting to assign SMNS 40667 to a large species of *Pachycetus*, as this is the only known large archaeocete from the Helmstedt region. Notwithstanding the comparable positions of the angle, differences between SMNS 40667 and the radius from Highcliffe hampers a definite assignment to *Pachycetus* sp. and at least two other taxa of large basilosaurids are known from Bartonian to Priabonian strata of the Netherlands and Belgium (Van Vliet *et al.*, 2019, 2022).

As these regions and the Helmstedt region of Germany were parts of the Bartonian and Priabonian North Sea Basin, it cannot be excluded that this isolated radius belongs to another taxon than *Pachycetus*.

Dorudontinae Miller, 1923

Dorudontinae indet.

Figure 6, Table 1

Material – Posterior thoracic or anterior lumbar vertebra, labeled Nr. 44699.

Comments – Label (Staatl. Museum für Naturkunde in Stuttgart) with the text: Nr. 44699; Archaeocetide; vertebra lumbalis; Ober-Eozän, Gehlberg-Schichten, obere Schichtengr.; Tagebau Treue, Helmstedt; Sammlung Mundlos 1988 (No. 44699; Archaeocetid, lumbar vertebra; upper Eocene, Gehlberg Formation, upper part of the formation; open cast mine Treue, Helmstedt; collection Mundlos 1988).

On the vertebra: Treue 4, '68; Nordrand; Grüns. (=Grünsand)/Phos.-Hor. G1, 44699 (Treue 4; North ramp; Upper Green Unit; layer with phosphorites G1, 44699).

A stratum with phosphorite concretions, G1, is present halfway of the Upper Green Unit of the Gehlberg Formation; this stratum is Priabonian in age.

Description – SMNS 44699 is a posterior thoracic, or an anterior lumbar vertebral centrum (Fig. 6). The epiphyseal disc on the anterior surface is partly preserved, albeit abraded and obscures almost completely the pattern of epiphyseal ridges. The anterior side is more or less pen-

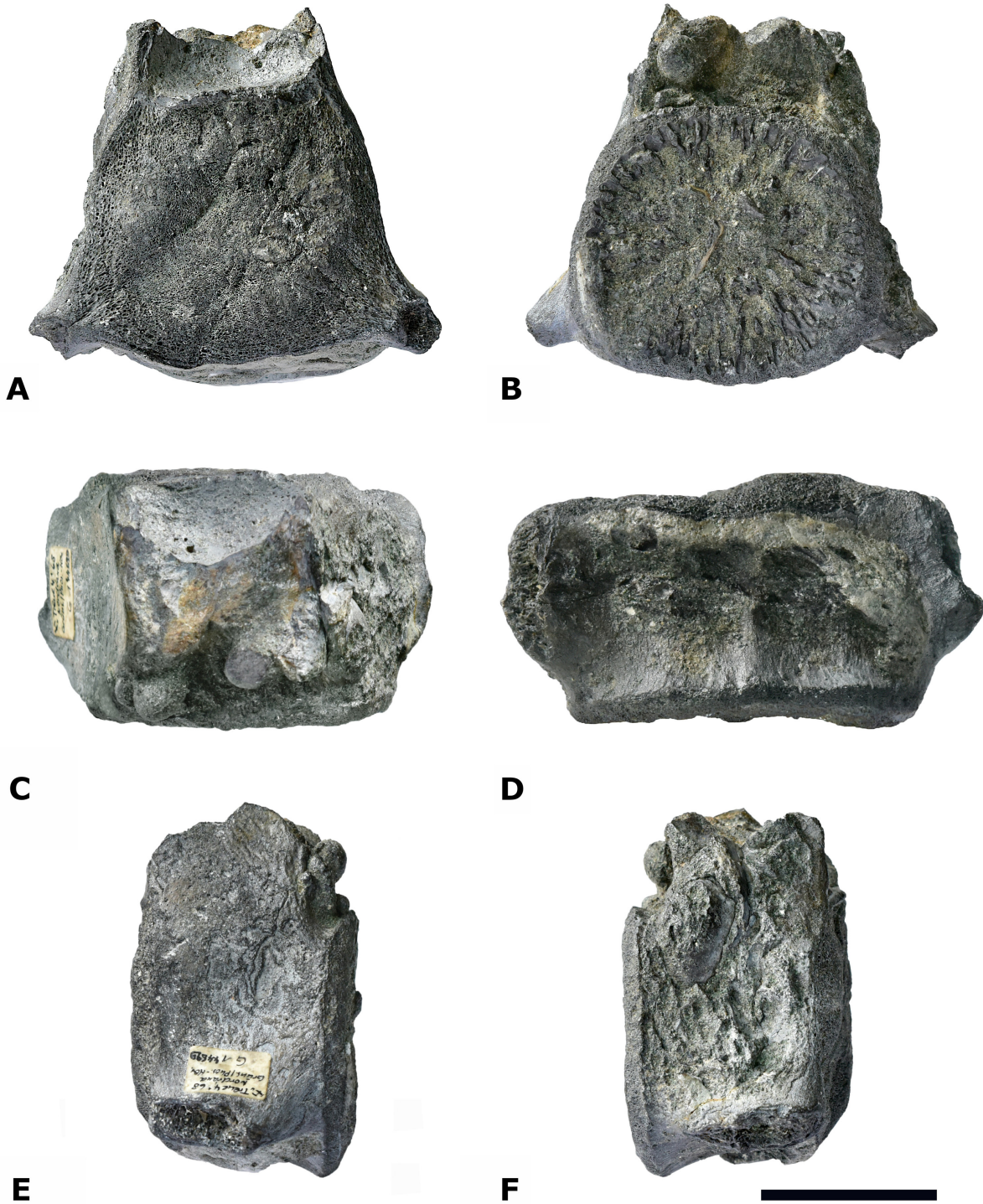


Fig. 6. A-F: Posterior thoracic or anterior lumbar vertebral centrum, SMNS 44699, indet. basilosaurid (small dorudontine species) from the Priabonian of the Helmstedt region, Germany, in anterior (A), posterior (B), dorsal (C), ventral (D), left lateral (E) and right lateral (F) view. Scale bar 50 mm.

tagonal. The posterior epiphysis is lacking and the surface shows a radiating pattern. The posterior side is more or less oval. The neural arch is anteriorly 32.8 mm in width. The preserved part of the pedicles of the neural arch are about 25 mm in height. Most parts of the transverse processes are missing. The transverse processes are directed anteroventrally. There is a ventral keel, with a fossa at

each side. No ventral foramina are seen. At the left lateral side, the cortex is abraded and some layers of compact bone are present. The centrum is abraded, mineralized judging by its weight and black to grey in colour. The vertebral centrum is partly overgrown with phosphorite with imprints of molluscs, especially between the pedicles of the neural arch and on the right lateral side. The

phosphorite incrustations show several imprints of molluscs. For dimensions, see Table 1.

Discussion – As the vertebra is small in size and not elongated, it is assigned to a small dorudontine species. According to Uhen (1998), the small dorudontine vertebrae from Europe cannot be determined at genus level. No small dorudontine remains are known from Wielingen/Het Scheur at the Belgian-Dutch border.

Basilosauridae indet.

Figure 7, Tables 1, 3

Material – Metacarpal?, labeled Nr. 44700.

Comments – Label (Staatl. Museum für Naturkunde in Stuttgart) with the text: *Archaeocetide, ?Costa-Fragment; Ober Eozän, Gehlberg-Schichten, obere Schichtengr., Tagebau Treue, Helmstedt, Sammlung Mundlos* (archeocete, ?costa fragment, upper Eocene, Gehlberg Formation, upper Unit, Tagebau Treue, collection Mundlos).

Label with the text: *Archaeoceti? Kopf einer Rippe? Phosphoritenstratum; Nr. 44700* (archeocete, caput of rib?; stratum with phosphorites, No. 44700).

Label glued on the bone with the text: *Helmstedt, 1969; [symbol] "Treue 4"; Nordrand; Gehlbg.-Schichten; Nr. 44700; G1* (Helmstedt, 1969, [symbol] "Treue 4"; North ramp; Gehlberg Formation, No. 44700; G1).

A stratum with phosphorite concretions, G1, is present halfway of the Upper Green Unit of the Gehlberg Formation; this stratum is Priabonian in age.

Description – SMNS 44700 is a fragmental, elongate and flattened bone (Fig. 7). The flat articular facet where the bone widens, could be the proximal end. Just below the articular facet, a fragment is missing. The bone tapers toward the presumed distal end. The presumed distal articular side is missing. The surface of the bone shows multiple drilling holes made by marine organisms. The bone is abraded, mineralized judging by its weight and

black in colour. The fracture site looks rather fresh. For dimensions, see Table 1.

Discussion – The bone rather closely resembles an element of the manus of a basilosaurid. It is too large to be a part of the foot. SMNS 44700 could be a metacarpal, because the cross section of the diaphysis of phalanges is rounded in basilosaurids, whereas that of the metacarpals is medio-laterally compressed (Kellogg, 1936; Uhen, 2004). It is concave at one side, which could be the palmar side, as seen in Mt 2 and Mt 5 of *D. atrox* (Uhen, 2004) and Mt 5 of *C. peruvianus* (Martínez-Cáceres *et al.*, 2017). In having a (partly damaged) lateral expansion, it resembles Mt 5 of *D. atrox* and *Z. kochii*: which has a process at the ulnar side (Uhen, 2004: figs 104-105, resp. Kellogg, 1936: fig. 74). In both *D. atrox* and *Z. kochii* the maximum anterior-posterior breadth is smaller (Table 3); if a metacarpal, the size points to a large archaeocete. SMNS 44700 is tentatively assigned to a metacarpal of a large basilosaurid, but its fragmentary state precludes a definite identification.

Bone fragments without collection numbers

?Basilosauridae indet.

Figure 8A, Table 1

Material – Unidentifiable bone without catalogue number, here provisionally labeled SMNS ID.01.

Comments – Two labels (Staatl. Museum für Naturkunde in Stuttgart) with the text:

First label: *Säuget indet; (Knochenbruchst); ?Pelvis-Bruchst [Säugetier indeterminabilis; Knochenbruchstück; ?Pelvis-Bruchstück]* (indeterminable mammal; (bone fragment); ?pelvis fragment).

Second label: *Ober-Eozän; Gehlberg-Schichten; obere Schichtengr.; Tagebau Treue, Helmstedt; Sammlung Mundlos, 1988* (upper Eocene; Gehlberg Formation; upper Unit; open cast mine Treue, Helmstedt; collection Mundlos; 1988).

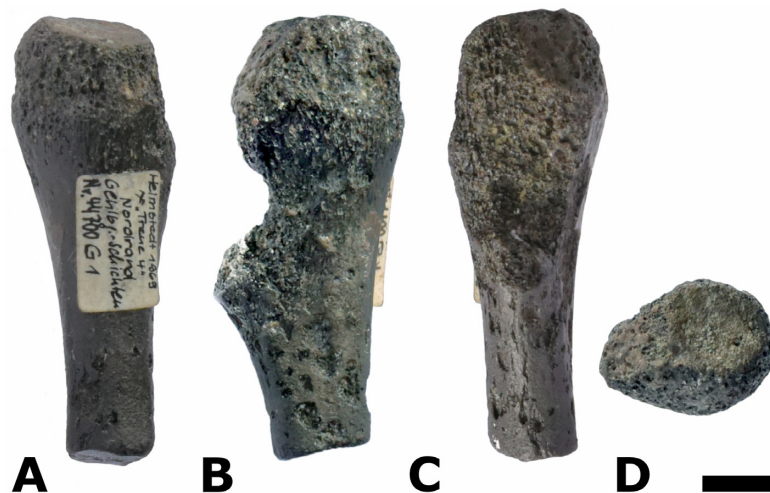


Fig 7. A-D: Unidentifiable bone fragment, metacarpal?, SMNS 44700, indet. basilosaurid (large species) from the Priabonian of the Helmstedt region, Germany, in posterior? (A), palmar? (B), anterior? (C) and proximal? (D) view. Scale bar 10 mm.

Collection number and taxon	Metacarpal	Length	Breadth (ant-post)	Breadth (palm-dors)	References
SMNS 44700	?	>62.1	>21.0 (prox) 27.1 (mid) 19.8 (dist)	>19.0 (prox) 15.8 (dist)	This article
MNHN.F.PRU10 <i>Cynthiacetus peruvianus</i>	- Mc II Mc III Mc IV Mc V	48.4	22.6 (prox) 27.1 (prox) 22.3 (prox) 23.4 (prox)	11.9 (prox) 16.8 (prox) 13.9 (prox) 17.2 (prox)	Martínez-Cáceres <i>et al.</i> 2017: table 15
USNM 4679 <i>Zygorhiza kochii</i>	- Mc II - Mc IV Mc V	63	19.7 (prox) 15.0 (prox) 16.4 (prox)		Kellogg, 1936: pp. 165-6
<i>Dorudon atrox</i> 1-5 specimens	Mc I Mc II Mc III Mc IV Mc V	44.3 (max) 59.6 (max) 71.6 (max) 65.8 (max) 48.2 (max)	11.3 (prox) *) 22.0 (prox) *) 24.6 (prox) *) 19.7 (prox) *) 24.4 (prox) *)		Uhen, 2004: table 20

*) maximum proximal breadth; distal breadth is smaller

Table 3. Possible metacarpal, SMNS 44700, compared to metacarpals of several basilosaurids (in mm).

Although the Upper Unit is not specified, both the Upper Brown and the Upper Green Unit of the Gehlberg Formation are Priabonian in age.

Description – SMNS ID.01 is a large, flattened, more or less rectangular piece of bone (Fig. 8A). The bone is slightly concave. There is one projecting part. At one side, a sulcus is running to what could have been a large foramen. The bone is severely damaged, somewhat abraded, judging by its weight mineralized and the colour is dark-grey to black. For dimensions, see Table 1.

Discussion – The resemblance of the bone with a pelvis fragment was noticed by an unknown researcher (Mundlos?) in the past (see text first label). SMNS ID.01 superficially resembles the partial pelvis, USNM 310633 of *P. wardii* (Uhen, 1999: fig.6) (Fig. 10). Its fragmentary state and damage at places where possibly the acetabulum and obturator foramen would have been, makes the assignment to an archaeocete pelvis uncertain.

Basilosauridae indet.

Figure 8B, Table 1

Material – Rib fragment, without catalogue number, here provisionally labeled SMNS ID.02.

Comments – Label glued on the bone with the text: *Helmstedt 69; BKB “Treune 4”; Gehlb.-Schichten; ob. Sch.-*

Gr. Basis (Helmstedt 69; BKB “Treune 4”; Gehlberg Formation; Upper Unit, basis).

A stratum with phosphorite concretions, G2, is at the basis of the Upper Green Unit of the Gehlberg Formation; this stratum is Priabonian in age.

Description – SMNS ID.02 is a more or less rectangular rib fragment (Fig. 8B). One side is thicker than the other. The centrum is slightly or not abraded, judging by its weight mineralized and brown to black in colour. Traces of phosphorite concretions are present on one side. For dimensions, see Table 1.

Discussion – The absence of an open medullary cavity points to an adaptation to a marine environment (De Buffrénil *et al.*, 1990). Texture of the broken ends is similar to what is seen in archaeocetes, whereas ribs in sea cows are more compact. Thickening of the rib at its distal end is seen in basilosaurids: *Pachycetus* sp. (Zvonok, 2012: fig. 2; Van Vliet *et al.*, 2020: plate 2e-f), *B. cetoides* (Kellogg, 1936), *C. peruvianus* (Martínez-Cáceres *et al.*, 2017) and *D. atrox* (Uhen, 2004).

Mammalia indet.

Figure 8C, Table 1

Material – Unidentifiable bone fragment, without catalogue number, here provisionally labeled SMNS ID.03.

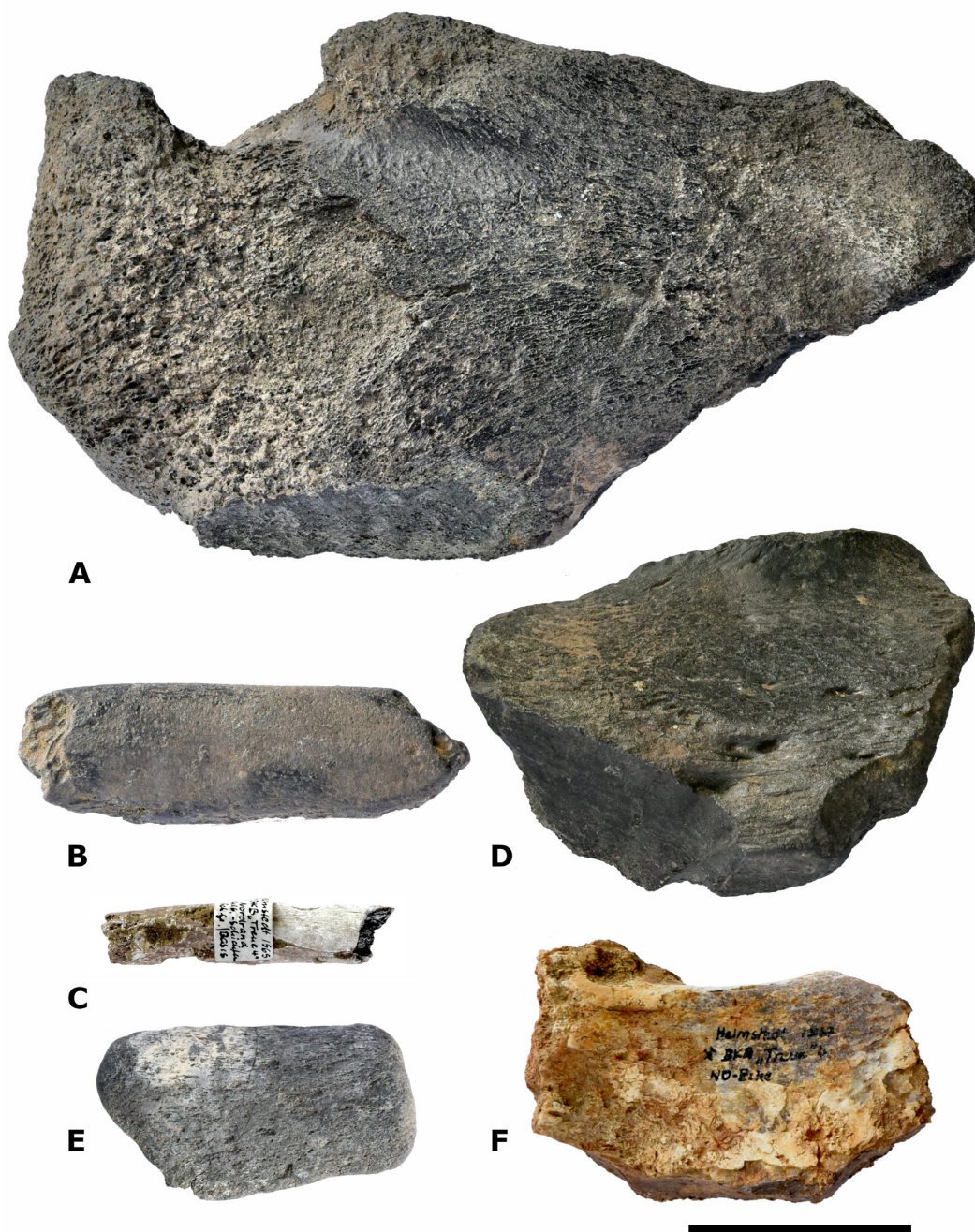


Fig. 8. Six bone fragments from the Priabonian of the Helmstedt region, Germany. A: Unidentifiable bone fragment, SMNS ID.01, Mammalia indet. B: distal rib fragment, SMNS ID.02, indet. basilosaurid. C: Unidentifiable bone fragment, SMNS ID.03, Mammalia indet. from the Priabonian of the Helmstedt region, Germany. D: Ventral fragment vertebra, SMNS ID.04, cf. *Pachycetus* sp. E: Unidentifiable bone fragment, SMNS ID.05, Mammalia indet., from the Priabonian of the Helmstedt region, Germany. F: Unidentifiable bone fragment, SMNS ID.06, Mammalia indet. Scale bar 50 mm.

Comments – Label glued on the bone with the text: *Helmstedt 1965; BKB “Treue 4”; Nordrand; Gehlb.-Schichten; ob. Sch/ Basis* (Helmstedt 1965; BKB “Treue 4”; North ramp; Gehlberg Formation; upper Unit/ basis).

A stratum with phosphorite concretions, G2, is at the basis of the Upper Green Unit of the Gehlberg Formation; this stratum is Priabonian in age.

Description – SMNS ID.03 is a fragment of a small, slightly curved, tube-like bone (Fig. 8C). The medullary cavity is filled with spongy bone. The bone is not abraded, judging by its weight not mineralized and is whitish to light-brown in colour. For dimensions, see Table 1.

Discussion – If a whale bone, SMNS ID.03 is too small to be a rib fragment. The fragmentary state precludes a definite identification.

Three bone fragments

Label with the text: *Indet.*; 3 Knochenbruchstücke; ober Eozän; Gehlb. Schichten; obere Schichtengr; Tagebau Treue, Helmstedt; Sammlung Mundlos, 1988 (indeterminable; 3 bone fragments; upper Eocene; Gehlberg Formation; upper Unit; open cast mine Treue, Helmstedt; Collection Mundlos, 1988).

Although the Upper Unit is not specified, both the Upper Brown and the Upper Green Unit of the Gehlberg Formation are Priabonian in age.

cf. *Pachycetus* sp.

Figure 8D, Table 1

Material – Vertebral fragment, without catalogue number, here provisionally labeled SMNS ID.04.

Description – SMNS ID.04 is a more or less rectangular piece of bone, slightly concave at one side (Fig. 8D). The surface of the concave side has multiple punctae and several foramina. The bone is abraded, judging by its weight mineralized and black in colour. For dimensions, see Table 1.

Discussion – The surface with multiple punctae is characteristic for vertebrae of *Pachycetus*. (Gol'din & Zvonok, 2013; Van Vliet *et al.*, 2020).

Mammalia indet.

Figure 8E, Table 1

Material – Unidentifiable bone fragment, a possible skull fragment, without catalogue number, here provisionally labeled SMNS ID.05.

Description – SMNS ID.05 is a more or less rectangular bone fragment (Fig. 8E). The bone is abraded, judging by its weight mineralized and gray in colour. For dimensions, see Table 1.

Discussion – The fragmentary state of the bone precludes a definite identification.

Mammalia indet.

Figure 8F, Table 1

Material – Unidentifiable bone fragment, without catalogue number, here provisionally labeled SMNS ID.06.

Description – SMNS ID.06 is a more or less rectangular bone fragment (Fig. 8F). The bone is not abraded, judging by its weight slightly mineralised and yellowish to pale brown in colour. For dimensions, see Table 1.

Discussion – The fragmentary state of the bone precludes a definite identification.

Conclusion

All here described archaeocete remains from the Helmstedt region, Germany, now housed in the Staatliches Museum für Naturkunde in Stuttgart were found in Priabonian strata of the open cast mines Helmstedt and Treue, Germany. Notwithstanding the fragmentary state of many of these isolated bones, at least two basilosaurid taxa, a large and a small one, can be discerned with certainty. The anterior lumbar or posterior thoracic vertebral centrum SMNS 40666 is assigned to a large species of *Pachycetus*. Given the large basis of the fracture sites, it originally must have had two large postzygapophyses. Indeed, a lumbar vertebrae of *P. paulsonii* from Ukraine and a thoracic or lumbar vertebra of *Pachycetus* sp. (large species) from the Dutch-Belgian border had far larger postzygapophyses than seen in more derived basilosaurids. This can be considered a new diagnostic feature. Being not-abraded, it can point to the existence of *Pachycetus* into the Priabonian. Because of its pock-marked surface, a fragmentary vertebra, provisionally labeled SMNS ID.04, is assigned to cf. *Pachycetus* sp. The exquisitely preserved radius SMNS 40667, assigned to a large basilosaurid, is remarkable, because the angle in the radial crest on the posterior side is positioned more distally than in the large basilosaurids *B. cetoides* and *Cynthiacetus peruvianus*, resembling in this respect radii of smaller dorudontine basilosaurids. As the distal epiphysis is lacking, it is possible that this angle would have had a relatively more proximal position, when the radius had reached its mature, fully-grown size. A fragmentary piece of bone, SMNS 44700 rather closely resembles the metacarpal of a large basilosaurid taxon. A small taxon is represented by the vertebral centrum SMNS 44699, assigned to a small, indeterminate dorudontine basilosaurid. Because most archaeocete remains from northwestern Europe are isolated bones, a definite assignment of these rare finds is often impossible.

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Dr. Günter Schweigert, Staatliches Museum für Naturkunde in Stuttgart in a very friendly spontaneously manner informed our friend Bernd Vahldiek of the presence of the here described bones in the collections. We are grateful to Dr. Eli Amson who was very helpful when we visited the collections of the Staatliches Museum für Naturkunde in Stuttgart. Dr. Mark Uhen was so kind to give us his opinion about the bone fragment resembling a piece of a pelvis of *P. wardii*. We want to thank Dr. Svitozar Davydenko and Dr. Pavel Gol'din for providing us with the illustrations and article of Fedorovsky, 1912 and Mr. Jaap van Leeuwen for making the photo of Fig. 4C. Finally, two anonymous reviewers were very helpful with useful remarks and suggestions for improving this article.

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