

SI. Morphological description of sampled humeri and femora

The classical bone bed localities from the Germanic Basin have largely produced isolated bones. As a result, alpha taxonomy of Sauropterygia is often essentially based on skull morphology and taxa are only incompletely known (Rieppel, 2000). Postcranial morphology of Triassic Sauropterygia is highly conservative and uniform. As a consequence taxonomical assignment of isolated bones is generally difficult. Previous studies suggested that, in sauropterygians, bone histological features can be used to support taxonomical assignment (e.g., Klein, 2010, 2012; Sander *et al.*, 2013). Bones of placodonts are rarer than those of eosauroptrygians such as Nothosauria and Pachypleurosauria. Additionally, isolated bones are often incompletely preserved or highly weathered, making taxonomic assignment still more problematic. The here described humeri and femora are assigned to Placodontia because their morphology (summarized in Rieppel, 2000) and histology (Buffrénil and Mazin, 1992; Klein, 2010) differs from that of Eosauroptrygia (e.g., Sander, 1990; Klein, 2010; Hugi, 2011; Hugi *et al.*, 2011; Krahl *et al.*, 2013). Placodont humeri are more massive and have a simpler morphology with less features than eosauroptrygian ones. This means that they are more adapted to an aquatic lifestyle when compared to Eosauroptrygia humeri. Femora are more curved (heads twisted), and display distinct condyli with a well-developed fourth trochanter. However, proximal and midshaft fragments of placodont humeri and femora are often hard to taxonomically identify. The assignment of the sampled bones is—if not mentioned otherwise—based on morphological features. The here described bones were compared in detail to published material (see references below). Their assignment is however, often only tentatively due to the lack of diagnostic and/or comparable material.

Both the humerus and femur of *Psephoderma* experienced distal taphonomic compaction. The humerus of *Psephoderma* PIMUZ A/III 1476 is long and slender with a laterally expanded and curved rectangular proximal head (S2C, D). The distinctly constricted narrow/slender midshaft has a postaxially curved and preaxially straight margin. The distal end is broad and flattened, the natural condition being undoubtedly amplified by the taphonomic compaction. The femur PIMUZ A/III 0735 is proximally incomplete and has a similar shape to the humerus except for a straight midshaft region and a less expanded proximal head. Both cross sections are round-oval with a slightly pointed preaxial side. For further morphological details and a comparison of the here included bones see Meyer (1858), Pinna and Nossotti (1989), and Renesto and Tintori (1995).

The humerus of *Henodus* belongs to one (GPIT/RE/7289) of the seven known specimens (Huene, 1936, 1938). The humerus is preaxially straight and postaxially concave with a constricted midshaft. The massive proximal head is thick and round to oval. The broad and flat distal end is twisted. The humerus is bent in a ventral direction and dorsoventrally flattened (S2E). The cross section is oval with a slightly convex dorsal margin and a straight ventral margin. Both lateral margins are convex with the preaxial side pointed. For further morphological details see Huene, 1936, 1938).

In the Muschelkalk, no *Cyamodus* skull has yet been found together with a humerus. Isolated humeri can thus only tentatively be assigned to *Cyamodus* (Vogt, 1983; Rieppel, 1995; Klein and Hagdorn, in press). Several humeri that share certain morphological and histological features were combined as Placodontia indet. aff. *Cyamodus*. However, this assignment is only tentatively and the group might include different taxa as is indicated by the study of the growth record (Klein *et al.*, unpubl. data). Humeri of Placodontia indet. aff. *Cyamodus* are morphologically variable (S2F-M), which could be the result of inter-specific variation, intra-specific variation or ontoegentic variation. They have a thick proximal head, a curved and slender midshaft, and a fan-shaped, flat distal end. The proximal head has a triangular shape with the dorsopreaxial margin forming the peak of the isolescent triangle. The proximal head is twisted ventrally in relation to the midshaft. The most distinct and unique character of humeri of Placodontia indet. aff. *Cyamodus* is a concavity at the ventropostaxial side of the proximal head (Klein and Hagdorn, in press). The distal end has an ectepicondylar groove, a capitellum and an entepicondyle. SMNS 59831 is a large, fan-shaped, and flat distal end of a humerus with a deep ectepicondylar groove and an entepicondyle. The preserved midshaft is constricted with

straight margins (S2F). SMNS 15937 is a complete dorso-ventrally flattened humerus with poorly preserved proximal and distal ends. The flat proximal head is shorter than the half-round and flat distal end. The proximal head is ventro-preaxially flat/straight rather than concave (S2J). MHI 2112-6 is a large, slender, and slightly curved humerus. The broad proximal head is ventro-postaxially slightly concave. The shaft is slender and constricted. The distal end is broad and flat but due to preparation morphological details are obscured (S2G). Humerus SMNS 54569 has at the broad proximal head the characteristic concavity at the ventropostaxial side. Although the distal end of SMNS 54569 is missing the curvature of the slender shaft is obvious (S2I). SMNS 15891 is only poorly preserved and confidently establish its morphology is not possible. The humerus SMNS 15891 has a dorso-ventrally flattened shape; the midshaft is slightly curved, and it has a symmetrical broadened half-round distal end (S2H). The distal humerus fragment MHI 697 is only poorly preserved, consisting of a constricted, slender and curved shaft. The distal end is flattened; fan shaped, and has an ectepicondylar groove (S2L). SMNS 54582 is the distal half of a humerus. The shaft is constricted and postaxially slightly curved. The distal end is fan-shaped with striations on the ventral and dorsal sides. An ectepicondylar groove is developed. The entire bone is dorsoventrally very flat (S2K). MHI 1096 is the proximal half of a humerus with a slightly curved midshaft. The broad proximal head is incomplete, poorly preserved, and the characteristic proximal concavity described for *Placodontia* indet. aff. *Cyamodus* (Klein and Hagdorn, in press) is not visible. The postaxial half is flat rather than concave (S2M). MHI 1096 is similar to the much larger humerus fragment SMNS 54569. The overall shape of the midshaft cross sections is oval with a slightly convex dorsal margin and a straight ventral margin that becomes postaxially convex. Both lateral margins are convex and the preaxial side is pointed. In SMNS 54582 and MHI 697 the cross section is dorsoventrally flattened, whereas that of MHI 1096 is rounder, when compared to the others.

In the Muschelkalk, so far no *Placodus* skull has been found together with a humerus. The humerus associated with the nearly complete *Placodus* skeleton described by Drevermann (1933) belongs to a nothosaur (Rieppel 1995). Isolated humeri can thus only tentatively be assigned to *Placodus* (Vogt, 1983; Rieppel, 1995; Klein and Hagdorn, in press). Femur morphology of *Placodus* was described by Drevermann (1933) and Rieppel (1995).

It has a slender and straight midshaft region. The proximal head is characterized by a well-developed trochanter. Humeri assigned to aff. *Placodus* possess a rectangular shaped proximal head, which means that no proximal margin is protruding. The postaxial side is covered with striations. The proximal head is not twisted in relation to shaft or distal end, resulting in a general dorsoventrally flattened shape. The midshaft is constricted, postaxially curved but preaxially nearly straight. The symmetrical broadened distal end of aff. *Placodus* humerus is divided into an entepicondyle, an ectepicondylar groove, and an ectepicondyle (Rieppel, 1994). In humerus SMNS 59827 a partially broken off entepicondylar foramen is also identified (S2O). The shape of the midshaft cross section resembles that of humeri of *Placodontia* indet. aff. *Cyamodus*.

Humerus PIMUZ T 5845 and femur PIMUZ T 5845 are assigned to *Paraplagodus* based on their morphology (see Peyer, 1935, Rieppel, 2000a, b). Both bones are distally extremely flattened as a result of taphonomic processes. The midshaft region underwent very slight compaction in the humerus and little to no compaction in its proximal part. The humerus also experienced proximally some surface erosion. The humerus of *Paraplagodus* (PIMUZ T 5845) has a postaxially concave and preaxially straight margin. The proximal head is rectangular with a straight postaxial surface and a well set off margin (S2A, B) and not distinctly broadened. The constricted midshaft leads to a broad and flat distal end. The femur of *Paraplagodus* (PIMUZ T 5845) has a thick and massive proximal end, a slender constricted shaft. The broad proximal articular surface carries at the postaxial portion a distinct concave indentation. Postaxially, the bone is shorter and more curved than the preaxial side. It has an oval midshaft cross section. The flat distal end is less broad than the proximal head and the roughly equally sized condyli are not easy to distinguish. The femur is dorsoventrally curved. Due to bone ratio and find situation both bones can well belong to the same individual. For further morphological details on humerus and femur morphology of *Paraplagodus* see Peyer (1935) and Rieppel (2000). The humerus (PIMUZ T5845) cross section is elliptical with a convex dorsal, a concave

ventral side and a preaxially more pointed side than postaxially (S4A). The femur (PIMUZ T 5845) cross section is round-oval (S4B).

The following humeri and femora have placodont affinities due to their morphology and histology but did not match any described taxon and are thus assigned to Placodontia indet. Due to morphological, histological and microanatomical differences these bones represent more than one taxon (see also Klein *et al.*, unpubl. data). Humerus MB.R. 454 (S2P) and IGWH 9 (S2Q) share a distinct midshaft cross section with a slightly convex dorsal margin and a divided ventral margin. The preaxial half of the ventral margin is straight but the postaxial half convex. Both lateral margins are convex with a pointed preaxial side. IGWH-9 is a complete left humerus, which was already figured and described in Klein (2010). It has a simple morphology with a roughly crescent-shaped form. Although poorly preserved, the proximal head seems to have been originally rectangular. The incomplete distal end is broad and flat and carries an ectepicondylar groove. The shaft is only minimally constricted. The postaxial margin is curved the preaxial one straight and the entire humerus dorso-ventrally flattened. The midshaft cross section has a convex dorsal margin, preaxially the ventral margin is straight, but it becomes postaxially convex. Both lateral margins are convex with a pointed preaxial side. Humerus MB.R. 454 has a simple rectangular proximal head, a postaxial striation pattern, a postaxially curved midshaft, and a dorso-ventrally flattened general shape. The distal end is not symmetrical broadened which, however, can be obscured due to preservation and preparation artifacts.

Femora SMNS 84545 (S2R) and IGWH 23 (S2S) share an obconical shaped cross section. The ventral margin is long and slightly convex; the dorsal margin is shorter and straight (minimal convex in IGWH 23). The lateral margins of SMNS 84545 are both in their dorsal portion concave but in the ventral half convex that of IGWH 23 are both convex. IGWH 23 is the incomplete proximal end of a right femur, which was already figured and described in Klein (2010). The proximal head is rectangular; the shaft is straight. The midshaft cross section has a rather untypical form. The ventral margin is long and concave; the dorsal one short and convex. Both lateral margins are convex. SMNS 54578 is only incompletely preserved and the morphology of the proximal and distal ends cannot be established. The bone represents a femur, because the proximal head is longer than wide (Table 1), the midshaft cross section is round-oval, and the midshaft has straight margins. SMNS 84545 is a ?proximally poorly preserved and ?distally incomplete femur. The midshaft area however, is well preserved and exhibits a very special cross section, comparable to that of IGWH 23.

Femora MB. R. 814.2 (S2T), MB.R. 961 (S2U), SMNS 54578 (S2V), MB.R. 812 (S2W) share a round oval cross section. MB.R. 814.2 is a poorly preserved and broken, hollow/cavernous midshaft. Femora MB.R. 961 and MB.R. 812 both have only incompletely preserved proximal and distal ends and the morphology cannot be established. Due to their size, their straight and round midshaft regions taxonomical affinities to pachypleurosaur or nothosaur can be excluded (but not those to pistosaurs). Their assignment to Placodontia and their identification as femora is solely based on the shape of their cross sections and their bone histology (see below). The cross section of femur MB.R. 965 (S2X) is largely round but with a distinct peak preaxially, indicating the position of the 4th trochanter.

The taxon *Horaffia kugleri* is only based on five humeri, most likely representing a growth series (Klein and Hagdorn, in press). Humeri of *H. kugleri* are pachyostotic and have a dorsopreaxially elongated margin, a massive and ventrally protruding triangular proximal head as well as a preaxially slanted asymmetrical distal end. They are easy to distinguish from *Cyamodus*, Placodontia indet. aff. *Cyamodus*, aff. *Placodus* and *Placodus* humeri and all other here described long bones (S2N) However, although their phylogenetic relationship and possible placodont affinities remain unresolved their bone histology and microanatomy largely resembles those of aff. *Cyamodus* (Klein and Hagdorn, in press), which is the reason why *Horaffia* is included into the current study.

References

- Buffrénil de V, Mazin J-M. 1992. Contribution de l'histologie osseuse à l'interprétation paléobiologique du genre *Placodus* Agassiz, 1833 (Reptilia, Placodontia). *Revue Paléobiologie* 11: 397-407.
- Drevermann FR. 1933. Die Placodontier. 3. Das Skelett von *Placodus gigas* Agassiz im Senckenberg-Museum. *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft* 38: 319-364.
- Huene v F. 1936. *Henodus chelyops*, ein neuer Placodontier. *Palaeontographica A* 84: 99-148.
- Huene v F. 1938. Der dritte *Henodus*, Ergänzungen zur Kenntnis des Placodontiers *Henodus chelyops* Huene. *Palaeontographica A* 89: 105-114.
- Hugi J, Scheyer TM, Sander PM, Klein N, Sánchez-Villagra MR. 2011. Long bone microstructure gives new insights into the life history data of pachypleurosaurids from the Middle Triassic of Monte San Giorgio, Switzerland/Italy. *Comptes Rendus Palevol* 10: 413-426.
- Hugi J. 2011. The long bone histology of *Ceresiosaurus* (Sauropterygia, Reptilia) in comparison to other eosauropterygians from the Middle Triassic of Monte San Giorgio (Switzerland/Italy). *Swiss Journal of Palaeontology* 130(2): 297-306.
- Klein N. 2010. Long Bone Histology of Sauropterygia from the Lower Muschelkalk of the Germanic Basin Provides Unexpected Implications for Phylogeny. *PLoSOne* 5(7): e11613. doi:10.1371/journal.pone.0011613.
- Klein N. 2012. Postcranial morphology and growth of the Winterswijk pachypleurosaur *Anarosaurus heterodontus* (Sauropterygia) from the Lower Muschelkalk of Winterswijk, The Netherlands. *Paläontologische Zeitschrift* 86(4): 389-408.
- Klein N, Hagdorn H. in press. Humerus morphology and histology of a new marine reptile (Diapsida) from the Muschelkalk-Keuper-Grenzbonebed (Middle Triassic, Ladinian) of Southwest Germany. *Paleodiversity*. X: X-X.
- Krahl A, Klein N, Sander PM. 2013. Evolutionary implications of the divergent long bone histologies of *Nothosaurus* and *Pistosaurus* (Sauropterygia, Triassic). *BMC Evolutionary Biology*, 13: 1-23.
- Meyer v H. 1858. *Psephoderma Alpinum* aus dem Dachsteinkalke der Alpen. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde* 1858: 646-650.
- Peyer, B. (1935). Die Triasfauna der Tessiner Kalkalpen. VIII. Weitere Placodontierfunde. *Abhandlungen der schweizerischen Palaontologischen Gesellschaft* 55: 1-26.
- Renesto S, Tintori A. 1995. Functional morphology and mode of life of the Late Triassic placodont *Psephoderma alpinum* Meyer from the Calcare di Zorzino (Lombardy, N Italy). *Rivista Italiana di Paleontologia e Stratigrafia* 101: 37-48.
- Rieppel O. 1994. Osteology of *Simosaurus gaillardoti*, and the phylogenetic interrelationships of stem-group Sauropterygia. *Fieldiana Geology, n. s.* 28: 1-85.
- Rieppel O. 1995. The genus *Placodus*: Systematics, morphology, paleobiogeography, and paleobiology. *Fieldiana (Geology), n.s.* 31: 1-44.
- Rieppel O. 2000a. Sauropterygia I. Pp 1-134 in: Wellnhofer P, ed., *Encyclopedia of Paleoherpetology*, Volume 12A. München: Friedrich Pfeil Verlag.
- Rieppel O. 2000b. *Paraplagodus* and the phylogeny of the Placodontia (Reptilia: Sauropterygia). *Zoological Journal of the Linnean Society*, London 130: 635-659.
- Sander PM. 1990. Skeletochronology in the small Triassic reptile *Neusticosaurus*. *Annales des Sciences Naturelles, Zoologie* (13)11: 213-217.
- Sander PM, Klein N, Albers PCH, Bickelmann C, Winkelhorst H. 2013. A skeleton of a basal Pistosauroida from the Lower Muschelkalk of the Germanic Basin (Winterswijk, The Netherlands) and a reworked and extended phylogenetic analysis of Triassic Sauropterygia. *Paläontologische Zeitschrift* 88: 55-71.
- Vogt C. 1983. *Evolutionäre Palökologie der Placodontier (Placodus, Henodus; Euryapsida, Trias)*. PhD Dissertation, Eberhard-Karls-Universität, Tübingen, Germany. p. 1-99.