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# Analysis of marrow cavity fillings as a tool to recognise diverse taphonomic histories of fossil reptile bones: Implications for the genesis of the Lower Muschelkalk marine bone-bearing bed (Middle Triassic, Żyglin, S Poland)

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ABSTRACT

The bone-bearing bed from Żyglin (S Poland), which likely represents the oldest Lower Muschelkalk accumulation of reptile remains in the SE part of the Germanic Basin, has been investigated in order to determine its genesis. The basic methods were supported by petrographic analysis of the marrow cavity and large inter-trabecular pore space fillings of fossil bones, which was used to check its usefulness to identify the environments where the bones were initially deposited and to decipher taphonomic histories of the remains. The bone-bearing bed is a composite deposit, which consists of three distinct layers (from bottom to top): micritic limestone (mudstone, bioturbated autochthonous mud), crinoidal limestone (grainstone to packstone, calcirudite), and shell-rich limestone (packstone to wackstone, calcirudite). The crinoidal limestone layer, the main bone-bearing bed, is recognised as the proximal tempestite deposited in the mid-ramp zone. The petrographic analysis of the fillings reveals the prevalence of minute ostracod carapaces, accompanied by other grains, embedded together with micrite to microspar. Such compositions suggest that these sediments may have been inserted into the bone pore spaces in lagoons and tidal-flat ponds. Features of some bones record their early diagenetic burial and lithification before the final redeposition. The isopachous spar, blocky spar and weathered pyrite document changes in the chemical composition of fluids that flowed into the bone interiors. The burrow found in the marrow cavity of specimen IGUAM-ZOV-7 provides evidence that some remains were inhabited by minute or juvenile invertebrates. All recognised features indicate that both invertebrate and vertebrate bioclasts, included in the tempestite, were initially deposited in various settings of the carbonate ramp and in the end redeposited as a result of a heavy storm or a hurricane. The examined bone-bearing bed represents time-averaged assemblage, which originated due to hydraulic concentration of the vertebrate bioclasts. The petrographic analysis of the fillings is a valuable tool to identify complex taphonomic pathways of vertebrate bioclasts.

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## 1. Introduction

Skeletal and dermal hard parts of fish, amphibians and reptiles have been found in the Röt, Muschelkalk and Keuper facies of the Germanic Basin at least since the 19th century (e.g., von Meyer, 1847–1855; Gürich, 1884; Kunisch, 1888; Schrammen, 1899; Schröder, 1914; Schmidt, 1928, 1938). The vertebrate remains are mostly disarticulated, and bones, teeth, scales, scutes and other elements are typically disseminated within beds, although their accumulations have also been found (e.g., Schultze et al., 1986; Dzik et al., 2000; Oosterink et al., 2003; Dzik and Sulej, 2007; Lucas et al., 2007; Bardziński et al., 2008; Diedrich, 2009; Bodzioch and Kowal-Linka, 2012; Diedrich, 2012; Kowal-Linka and Bodzioch, 2012a; Kowal-Linka and Bodzioch, 2012b; Reolid et al., 2014). The major Muschelkalk bone-bearing beds, which occur in the western part of the Germanic Basin (NW Germany), have been recognised as terebratulid-dominated carbonate tempestites in terms of their origin (e.g., Diedrich, 2009, 2011, 2012). In the south-eastern part of the Germanic Basin (S Poland), the Muschelkalk vertebrate material is quite abundant, but commonly scattered in beds of diverse genesis (e.g., Chudzikiewicz, 1983; Liszkowski, 1993; Chrząstek and Niedźwiedzki, 1998; Chrząstek, 2008; Surmik et al., 2014). The most concentrated accumulation of vertebrate skeletal hard parts was found within the Lower Muschelkalk carbonates in Żyglin (Upper Silesia, S Poland; Kowal, 1998; Bardziński et al., 2008; Surmik, 2010; Kowal-Linka et al., 2014). Tentative observations suggested that the hard parts from this locality are enclosed in a crinoid-dominated carbonate tempestite (Kowal, 1998; Surmik, 2010; Kowal-Linka et al., 2014).

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Despite the fact that the bonebed from Żyglin is the richest accumulation located in the SE part of the Germanic Basin, and likely the oldest one within the Lower Muschelkalk sequence (cf., Hagdorn and Rieppel, 1999; Rieppel, 1999; Bardziński et al., 2008), its sedimentological features and genesis neither have been described in detail nor genuinely recognised. Some attempts were undertaken by Surmik (2010), who claimed that the bone-bearing bed is a time-averaged assemblage, however, he did not provide convincing evidence. Moreover, Surmik (2010) incorrectly located the bonebed within the limestone with *Pecten* and *Dadocrinus* (the lowermost Muschelkalk).

The degree of skeletal disarticulation, spatial arrangement of vertebrate remains, features of the bones (e.g., the degree of their fragmentation, disintegration, abrasion, microbial infestation) have been commonly used to determine the derivation of vertebrate bioclasts, the distance of their transportation and the genesis of bone-bearing beds (e.g., Rogers and Kidwell, 2007; Lauters et al., 2008; Britt et al., 2009; Gangloff and Fiorillo, 2010; Lucas et al., 2010; Rogers and Brady, 2010; Tucker, 2011; Bodzioch and Kowal-Linka, 2012; Mukherjee and Ray, 2012; Rogers et al., 2013; Viglietti et al., 2013; Bell and Campione, 2014; Reolid et al., 2014; Szrek et al., 2014; Botfalvai et al., 2015). In contrast, the mineralogical and petrographic examinations of bone pore space fillings have been underused, although it appears to be a valuable source of information, at least with regard to terrestrial bone accumulations (e.g., Hubert et al., 1996; Clarke, 2004; Trueman et al., 2004; Wings, 2004; Harwood and Rogers, 2006; Suarez et al., 2010; Pfretzschner and Tütken, 2011; Bodzioch and Kowal-Linka, 2012; Colombi et al., 2012; Bodzioch, 2015).

This contribution has the following objectives: (1) to check the usefulness of the petrographic analysis of marrow cavity fillings as a tool for the determination of diverse taphonomic histories of the reptile bones, which were included in the examined marine bone-bearing bed, and (2) to determine the genesis of the bed using both petrographic and sedimentological analyses of the deposit itself, as well as by using the reptile bioclast attributes, and features of the bone void fillings.

## 2. Geological setting

Pieces of the bone-bearing bed were collected in two small quarries located in the vicinity of Żyglin (50°28′55″N, 18°57′52″E and 50°28′48″N, 18°57′58″E; S Poland, Central Europe), where the lower part of the Gogolin Formation (GF) has been exposed (Fig. 1A–C). The ~45-m-thick GF represents the lowermost lithostratigraphic unit of the Lower Muschelkalk (Middle Triassic) in Upper Silesia (Assmann, 1944; Kowal-Linka, 2008). From the Late Olenekian/Early Anisian to the Early Pelsonian, the sediments of the GF were deposited on a carbonate ramp situated in the southern part of a shallow epicontinental sea (the Germanic Basin) at about 25°–30°N (Bodzioch and Szulc, 1991; Nawrocki and Szulc, 2000; Szulc, 2000; Feist-Burkhardt et al., 2008). The area was affected by severe storms and hurricanes (Parrish, 1999; Szulc, 2008).

The lowermost unit (~8 m thick), the limestones with *Pecten discites* and *Dadocrinus kunishi*, comprises deposits of skeletal shoals (thick- and medium-bedded, cross-bedded bioclastic calcarenites and calcirudites, packstones and grainstones), and proximal tempestites (bioclastic packstones and wackstones), which were deposited on autochthonous, bioturbated calcareous mudstones in the inner ramp zone (Figs. 1B and 2A; cf., Burchette and Wright, 1992). The first horizon of wavy-bedded limestone (~4 m thick) is built of several types of rocks, within which the most common are autochthonous, highly bioturbated mudstones, and distal tempestites (mudstones, bioclastic wackstones to packstones and rarely grainstones, sandy limestones comprising land-derived non-calcareous grains; Figs. 1B and 2A). These sediments were deposited in the mid-ramp zone. Both units recorded gradual deepening of the sedimentary basin due to the Anisian transgression. The third unit, the cellular limestone, has been poorly exposed at this site, as its lowermost part (<0.5 m thick) crops out only near the present erosional level (Figs. 1B and 2A). The unit comprises predominantly orange-coloured, marly limestones (mostly calcitised dolostones) that represent sabkha deposits resulting from the emersion event (Bodzioch and Szulc, 1991; Szulc and Głuchowski, 1991; Szulc, 1993; Kowal, 1998; Szulc, 2000; Hagdorn and Szulc, 2007; Kowal-Linka and Bodzioch, 2011).

The bone-bearing bed under study is located in the lower part of the first horizon of wavy-bedded limestone (Figs. 1 B–C and 2A–B). Apart from abundant fish remains belonging to *Acrodus*, *Hybodus*, *Colobodus*, *Saurichthys*, *Gyrolepis* and other genera, numerous *Nothosaurus* sp. skeletal parts, and scanty pachypleurosaur and placodont remains were found in the bed (Bardziński et al., 2008; Surmik, 2010; Kowal-Linka et al., 2014). Moreover, Surmik (2010) noted the occurrence of vertebral centra that may belong to *Tanystropheus*. The reptile bone assemblage is dominated by vertebral centra and ribs, while the coracoids, pubes, humeri, femora, as well other flat and long bones are found less often (Bardziński et al., 2008; Surmik, 2010; Kowal-Linka et al., 2014). The accumulation can be classified as a multitaxic microfossil bonebed (Rogers and Kidwell, 2007).

## 3. Materials and methods

The fieldwork was carried out in order to collect pieces of the bone-bearing bed and skeletal hard parts, to identify the location of the vertebrate remains within the bonebed, and to determine the position of the bonebed with regard to the adjacent layers. The pieces of the bed were collected from debris that was lying at the bottom of the quarries, by the walls. The bed is located at ~8.5 m above the quarry bottom, in the ~10-m-tall quarry wall (Fig. 2A), hence its fragments are available only occasionally when quarry workers, who excavate rock slabs manually, exploit the proper horizon.

The examined bone assemblage comprises 29 specimens, including 12 vertebra and 17 long and flat bones. Most of them likely belong to *Nothosaurus* sp. (Reptilia, Sauropterygia, Eosauropterygia, Eusauropterygia, Nothosauroidea, Nothosauria, Nothosauridea; taxonomy after Rieppel, 2000). The bones were previously used by Kowal-Linka et al. (2014) for other purposes, and the authors already provided their taxonomic identification, basic description and pictures in the aforementioned contribution.

Standard polished thin sections of the bones and the bone-bearing bed were examined using an Olympus Provis AX70 petrographic microscope with an attached Olympus DP-50 video camera system to determine petrography of the materials, preservation of the bones, their diagenetic features and the types of fillings in bone pore spaces (i.e. in internal voids initially occupied by soft tissues). Size measurements were performed using AnalySIS 3.1 software.

## 4. Results

### 4.1. Petrography of the bone-bearing bed

The bone-bearing bed is a composite deposit, which typically consists of three distinct layers (from bottom to top): micritic limestone, crinoidal limestone, and shell-rich limestone (Fig. 2C).

The up to 5-cm-thick bottom layer consists of grey micrite to microspar (mudstone) with a small admixture of detrital non-carbonate grains and tiny bioclasts (Fig. 2C). *Palaeophycus* and *Thalassinoides* typically occur in the upper part of the layer, while *Rhizocorallium* is present on the top only when the deposit reaches its maximum thickness. The ichnofossils commonly show geopetal fillings in their upper and terminal sections, which consist of micrite (with coprolites and/or tiny bioclasts) at the base and spar at the top (the right geopetal arrangement). Some burrows must have been empty before the deposition of the middle layer (crinoidal limestone), as they are partly filled with its components (Fig. 2D). The horizontal and low-angle cross laminations are preserved when bioturbations are locally

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