The results of palaeontological excavations in the Sadowa Góra quarry (2012–14)

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Abstract
Palaeontological fieldwork (2012–14) in the Sadowa Góra quarry carried out under the auspices of the University of Silesia, within the framework of a research project supported by the National Science Centre, helped to document the taxonomic diversity of Middle Triassic marine vertebrates from the Cracow-Silesia region. Accumulations of fossil bones are correlated with storm deposition and are time-averaged.

Key words: palaeontology, taphonomy, Middle Triassic, marine reptiles, Jaworzno

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Introduction

Palaeontological excavations carried out in the abandoned quarry of Sadowa Góra in Jaworzno (now the *GEOsfera* – Education Centre of Nature and Geology; 50°13′38″N 19°16′27″E, Fig. 1A, B, see also Woźniak and Krzeczyńska 2014), led to numerous documented occurrences of remains of marine vertebrates, including the semi-aquatic reptile *Nothosaurus*. The bone-bearing beds, include the lower part of the Upper Gogolin Formation (Kowal-Linka 2008, and the literature cited therein), also contain numerous reptile coprolites (Fig. 1C).

In the Middle Triassic, the epicontinental sea of Germanic Basin was filled with different marine and semi-aquatic reptiles, such as ichtyopterygians, pachypleurosaurs, pistosaurs, nothosaurs and placodonts, and terrestrial tanystropheids and archosaurs (Surmik 2010a,b, and literature cited therein). The most of these animals lived in near-shore environment and over the time they conquered the open seas. The biological diversity of Middle Triassic aquatic reptiles is documented from several important localities of Southern Poland (Bardziński et al. 2008; Surmik 2010a,b, and literature cited therein; Kowal-Linka et al. 2014). The Sadowa Góra quarry is another fossil site that documents paleographical distribution as well as evolution of *Nothosaurus* genus.

Geological settings

The carbonates of the Lower Muschelkalk (Middle Triassic) Cracow-Silesian region have been the subject of interest since the second half of the nineteenth century (Kuźniar 1930; Assmann 1944; Siedlecki 1949). The first mentions of remains of prehistoric animals from the Jaworzno area were highlighted in Zeuschner (1836). Later works focused on lithostratigraphy and palaeogeography (Bojkowski 1955; Gruszczyk 1956; Ekiert

1959; Aleksandrowicz and Aleksandrowicz 1960; Śliwiński 1964, 1969; Aleksandrowicz 1966, 1971a, 1971b; Wyczółkowski 1971; Kowal-Linka 2008; Kowal-Linka et al. 2014). Sedimentological studies have been rare (Bojkowski 1955; Bogacz et al. 1968; Kubicz 1971; Chudzikiewicz 1975, 1983). More recent works have debated Muschelkalk lithostratigraphy, mainly in the Opole region (Niedźwiedzki 2000; Kowal-Linka 2008, 2009), and bio-, magneto-, and sequence stratigraphy (Zawidzka 1975; Hagdorn and Głuchowski 1993; Nawrocki and Szulc 2000; Szulc 2000; Narkiewicz and Szulc 2004). Based on isolated remains of crinoids and echinoids, Hagdorn and Głuchowski (1993) presented four biostratigraphic zones.

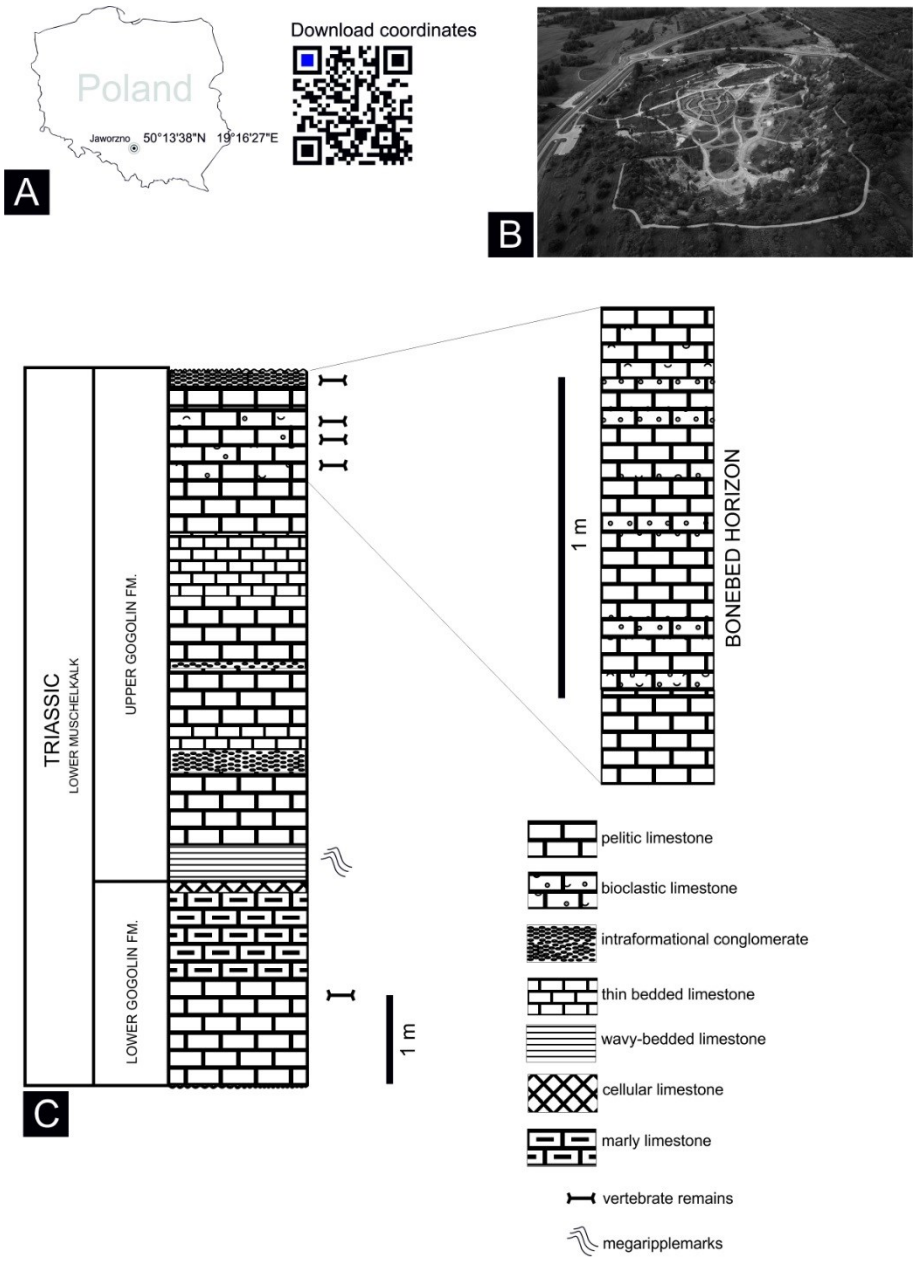

Fig.1. A) Location of the Sadowa Góra quarry in Jaworzno, southern Poland; **B)** An aerial photograph of the *GEOsfera* – Education Centre of Nature and Geology, located in the western part of the Sadowa Góra quarry (photo credit: City Hall of Jaworzno, reproduced with permission); **C)** Geological section of the southern wall of the Sadowa Góra quarry

This paper focusses on one lithostratigraphic unit, limestones with *Entolium* and *Dadocrinus*, where a huge accumulation of vertebrate remains was found. According to Hagdorn and Głuchowski (1993), the *Dadocrinus* zone corresponds to the Lower Anisian. These limestones are mostly thin- to medium-bedded, wavy-bedded and crumpled marly pelitic, thick- to medium-bedded crinoid, and thin- to medium-bedded bioclastic limestones and intraformational conglomerates with marly intercalations consisting mainly of crinoids and bivalve shells with their debris (Kowal-Linka 2008). The shells are scattered throughout the sediment and have no preferred orientation (compare Chudzikiewicz 1983) The intraformational flat-pebble conglomerate occurs at the top of the bone beds. In many places *Rhizocorallium* burrows have been found together with the remains of fish, reptiles and coprolites.

The southern part of the Germanic Basin was a habitat for a variety of invertebrates (Hagdorn and Głuchowski 1993; Salamon et al. 2012, and the literature cited therein), fish (Liszkowski 1993; Chrząstek 2008) and reptiles (Rieppel and Hagdorn 1997; Chrząstek 2008; Surmik 2010a, b). The characteristic environment of the Triassic epicontinental sea indicates low-energy conditions, interrupted by many phases of high-energy pulses (Chudzikiewicz 1983; Szulc 2000).

Material and methods

We collected multiple samples of fossilized bones, ichthyolites and coprolites during fieldwork in 2012–14 in the Sadowa Góra quarry. Limestone fragments containing bone and numerous ichthyolites were treated in weak buffered carboxylic acid to remove the carbonate matrix and extract material of interest. The specimens were photographed using a Panasonic Lumix DMC-FZ38 digital camera equipped with a JJC Macro LED Ring Light 60 lamp in a shadowless tent. Pictures were processed using Adobe Photoshop CS2 and CorelDRAW Graphics Suite X6.

Results

Palaeontology.

During fieldwork, well-preserved bones, including femora, radials, coracoids, ischia, pubes, teeth, vertebrae, gastralia and ribs from the different region of the skeleton (Fig. 2) of *Nothosaurus* Münster 1834, were found, including one isolated bone from the temporal region of the skull. One massive specimen of placodont rib was also found. In total, several dozen nothosaur bones were found, ranging in size from 20 to almost 300 mm. The most common types of bone were isolated vertebral centra, vertebral neural arches and ribs. Fish scales of miscellaneous genera, including actinopterygian *Saurichthys* Agassiz 1834, *Birgeria* Stensiö 1919, and numerous vertebrate coprolites from the same bone horizon were also recorded. Invertebrate fauna consisted of the very common crinoids *Dadocrinus* v. Meyer 1847, bivalve *Entolium* Meek 1865, and other molluscs and rare ophiuroids: *Aspiduriella* Bolette 1998 (compare Salamon and Boczarowski 2003; Salamon and Zatoń 2004; Salamon et al. 2012) and probably *Ophiomusium* Lyman 1869 (Fig. 3).

Sedimentology and taphonomy.

The mega-ripple marks (Fig. 4) exposed in the lower part of the Jaworzno quarry are evidence of tsunami backflows and indicate seismic-tsunami succession interrupting quiet, low-energy sedimentation (Szulc 2000; see also Hagdorn and Szulc 2007). Tsunami and storm events as well as currents and waves during normal weather resulted in lesser or greater time-averaging of the assemblage of skeletal remains. As a consequence of normal-weather wave currents and combined currents, the

arrangement of the long bones show a bimodal orientation, observed in some cases on the surfaces of rock layers. There is no apparent orientation in the case of flat and irregular bones, which are chaotically distributed in the bone bed. The long axes of long bones, particularly bones of the limbs, are approximately oriented in the direction of the water current transporting them, or of the bottom current generated by oscillating wave processes (compare Surmik 2010b). In several examples the mineral halos surrounding bones in fine-grained limestones are distinct (Fig. 5). Their origin is most likely associated with soft tissue decay which led to local pH changes and formation of these structures in relatively slow normal carbonate sedimentation. Intraformational conglomerates resulting from rapid high hydrodynamic events contain damaged and chaotically oriented bone fragments and mollusc shells along with irregularly-shaped grains formed by syndepositional erosion of partially lithified sediment.

The bone beds included in the Upper Gogolin Formation in the Sadowa Góra quarry contain principally isolated bones of one identified reptile taxon, *Nothosaurus*. Other indeterminate bone fragments are very small; nevertheless, they can be associated with other semi-aquatic reptiles.

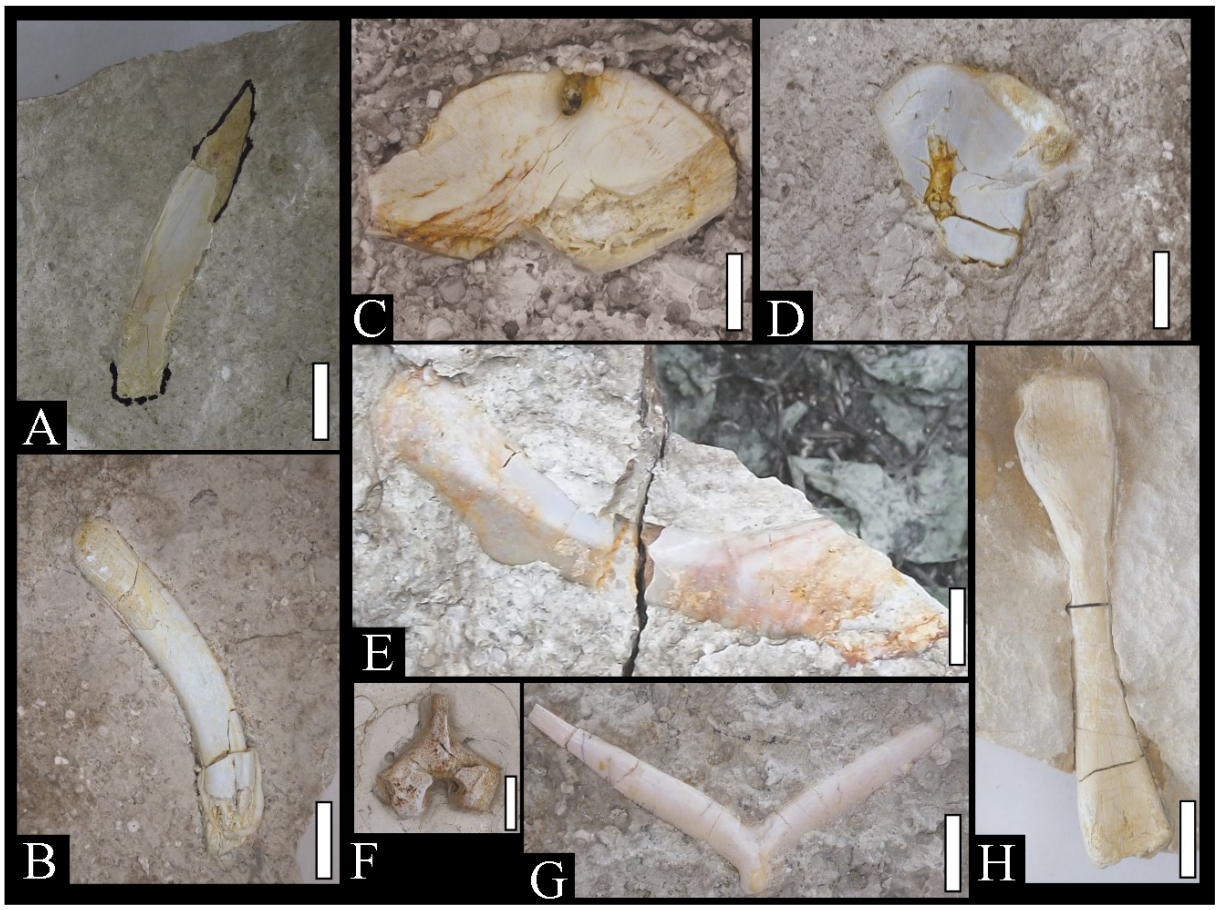

Fig.2. Specimens of *Nothosaurus* bones from the Sadowa Góra quarry (from fieldwork in 2012–14) – **A)** skull fragment from temporal region; **B)** tibia; **C)** and **D)** pubis; **E)** humerus; **F)** neural arch; **G)** gastral rib; **H)** femur. Scale bars equal 10 mm.

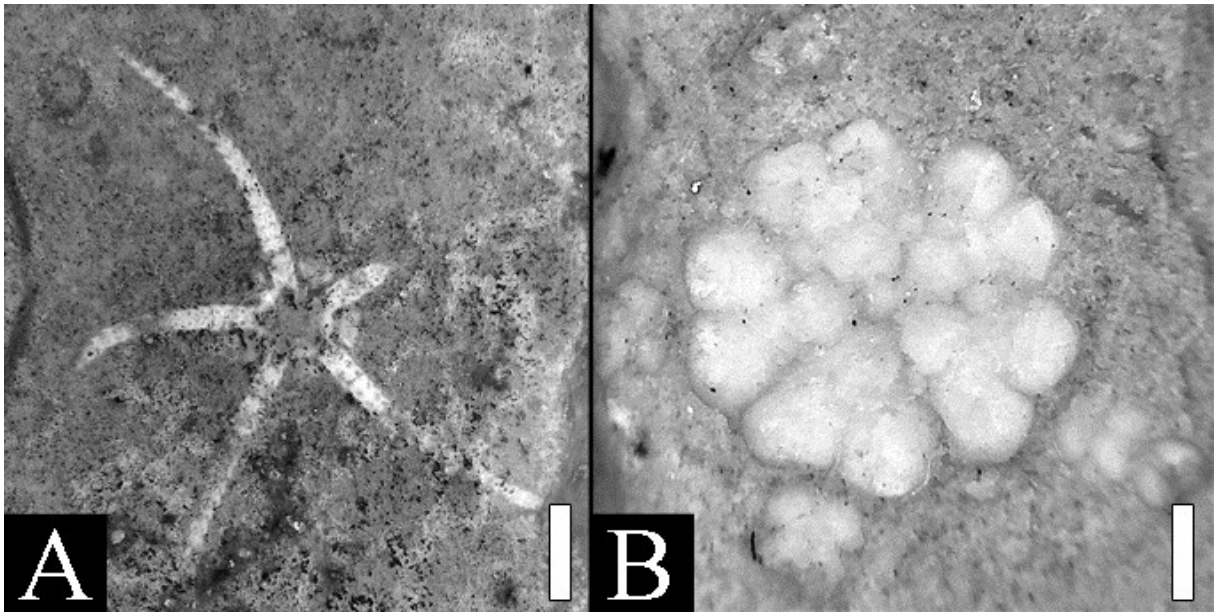

Fig.3. Specimens of ophiuroids from the Sadowa Góra quarry: **A)** *Ophiomusium* sp., scale bar equals 5 mm. **B)** *Aspiduriella* sp. (specimen donated by Dr. Mariusz A. Salamon, University of Silesia), scale bar equals 1 mm.

Fig.4. Mega-ripple marks occurring at the surface in several exposed places at the bottom of the Sadowa Góra quarry (photo credit: City Hall of Jaworzno, reproduced with permission). Scale bar equals 50 cm.

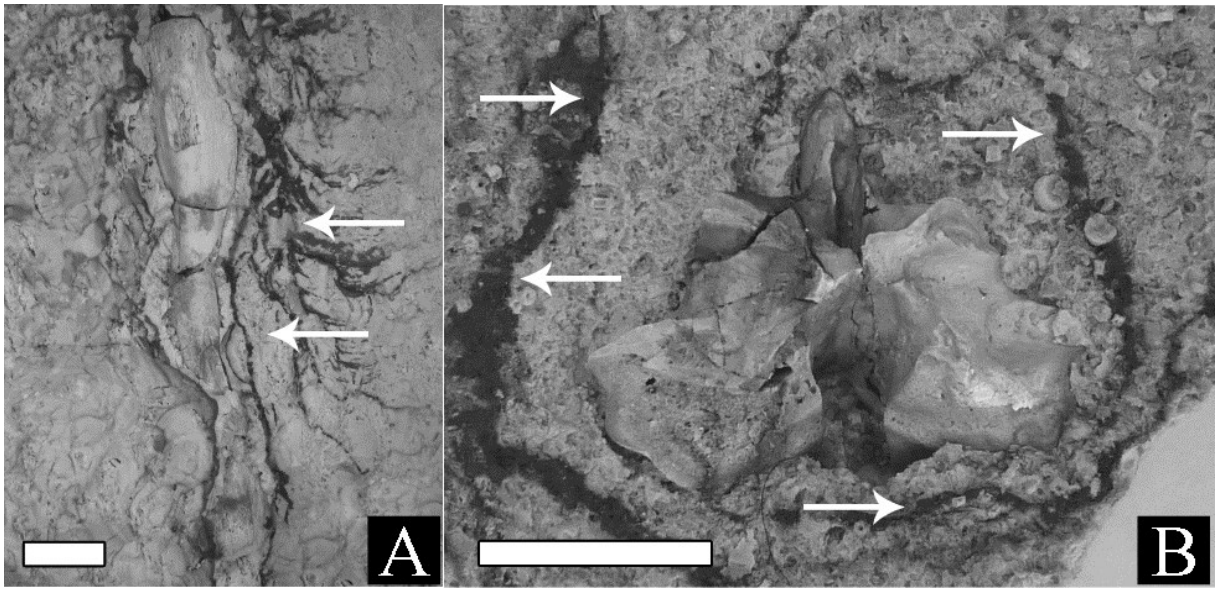

Fig.5. Ferruginous mineral halos surrounding bones, indicated by white arrows (A – femur, B – neural arch) in fine-grained limestones. Scale bars equal 10 mm.

Discussion and summary

The Sadowa Góra quarry represents a shallow-water marine carbonate succession which is rich in remains of Middle Triassic (Anisian) vertebrates. Vertebrate bone assemblages similar in age and environmental conditions are known from the Żyglin quarry near Miasteczko Śląskie (Bardziński et al. 2008; Surmik 2010a; Kowal-Linka et al. 2014) and other fossil sites from the Central Germanic Basin (Rieppel 1995; Rieppel and Hagdorn 1997; Diedrich 2013a, b; Diedrich and Grădinaru 2013). Nothosaurid remains from the studied fossil site suggest that these animals reached up to 4m in length and thus were probably apex predators, with no natural enemies.

The studied bone bed is almost monospecific and dominated by nothosaur remains, which is unusual and in contrast to other bone assemblages known from fossil localities of Upper Silesia (Bardziński et al. 2008; Surmik, 2010a). Nevertheless, environmental conditions, including time-averaging of the fossil assemblage, are the same as in other fossil sites from Upper Silesia. The skeletal remains were removed several times from their original burial site and subjected to secondary burial. These processes imply disarticulation of the skeletal remains, which occur mainly as isolated bones or bone fragments. The final burial of the remains took place when they were removed from the zone of active transport to a different part of the basin characterized by a distinctly hydrodynamic regime (Surmik 2010a, b).

Knowledge about the taxonomical diversity of invertebrates and vertebrates from the Middle Triassic of the Sadowa Góra quarry helped us to perform a scientific restoration of the Triassic marine ecosystem and the animals that lived there over 240 million years ago. These restorations can be seen in an indoor and outdoor exhibition in the *GEOsfera* – Education Centre of Nature and Geology, located in the Sadowa Góra quarry (Fig. 1A, B), ul. Św. Wojciecha 100, 43-600 Jaworzno, Poland.

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