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New finds of well-preserved Tithonian (Late Jurassic) fossils from Owadów–Brzezinki Quarry, Central Poland: a review and perspectives

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Key words: Late Jurassic, Tithonian, marine and terrestrial fossils, palaeontology, palaeobiogeography.

Abstract. Here we briefly report the discovery of new, exceptionally well-preserved Late Jurassic (Tithonian) fossils from Owadów–Brzezinki quarry – one of the most important palaeontological sites in Poland. These finds which comprise organisms living originally in different environments indicate that the Owadów–Brzezinki site represents a link – most probably in a form of open marine passages – betweeen distinct palaeobiogeographical provinces. This creates an unprecedented opportunity for better recognition of the regional palaeobiogeography of adjacent European areas during the Late Jurassic.

INTRODUCTION

The palaeontological site located in Owadów–Brzezinki quarry (Fig. 1) is one of the most important palaeontological discoveries described in recent years from Poland (Kin *et al*., 2013). Unusually well preserved fossils of marine and terrestrial organisms of Late Jurassic (Tithonian) age, many of them new to science, provide a very good opportunity for studying the taphonomy of the ecosystem, evolutionary dependencies of taxa, and palaeoenvironmental changes. The sedimentary pattern observed in the Owadów–Brzezinki section indicates shallowing of the depositional environment from offshore to nearshore, even lagoonal (Błażejowski *et al*., 2014), and such a transition allows for comparative studies with other sites where conditions were comparable to those of the interval of the Owadów–Brzezinki section studied.

Remarkable similarities to the well-known Late Jurassic (Early Tithonian) sites from the Solnhofen area in southern Germany have already been reported (Kin, Błażejowski, 2012; Kin *et al*., 2012). These sites, only slightly older than Owadów–Brzezinki (placed near the Early/Late Tithonian boundary after Matyja *et al*., 2016) share many features, such as a coastal-lagoonal setting, and a great abundance of well-preserved fossils. These Bavarian sites have a very long history of study exceeding 150 years and have provided some of the greatest milestones in the history of palaeontology. In contrast, Owadów–Brzezinki has just been discovered and has not had such a long history of research, yet it has also provided very important fossils, for example a rich collection of very well preserved horseshoe crabs.

The recent examinations of the classic Tithonian sites in Bavaria show that many of them are of different stratigraphic age and their faunas are also different (Schweigert, 2007; Ebert, Kölbl-Ebert, 2012; Ebert, 2016). The Owadów–Brzezinki site appears to be a new "taphonomic window" into the world of the latest Jurassic and clearly represents a very important palaeontological "supplement" to the Tithonian Solnhofen Archipelago sites, thereby significantly expanding our palaeogeographical and palaeobiological

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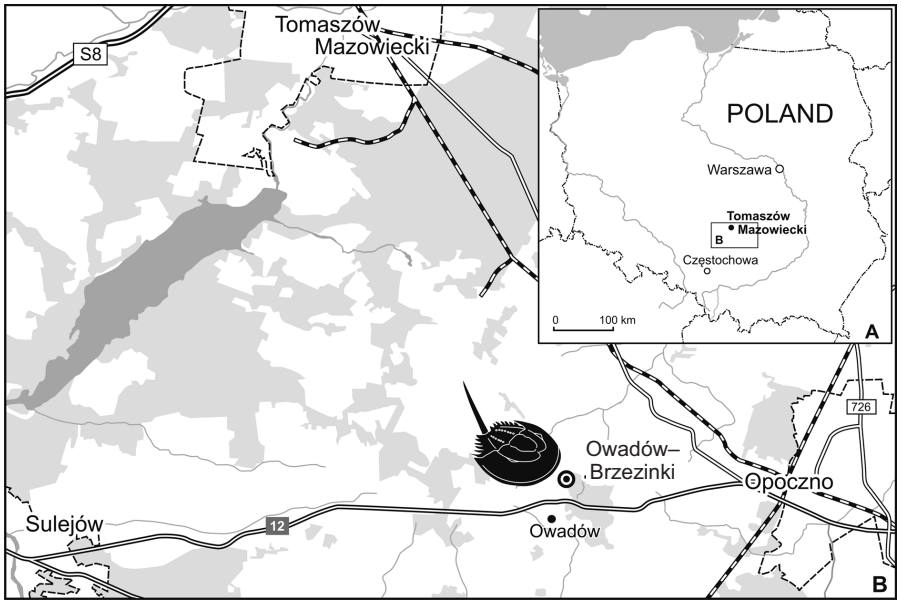

Fig. 1. Road map with the location of Owadów–Brzezinki Quarry and its proximity to Tomaszów Mazowiecki in Central Poland

knowledge beyond the areas explored so far. On the other hand, the relations with the open-marine environments of the Subboreal Province – both its north-eastern and north-western parts (Matyja *et al*., 2016; Matyja, Wierzbowski, 2016; Tyborowski, 2016) give the Owadów–Brzezinki site a large paleobiogeographical and stratigraphical importance. The continuous change of the environment which is visible in the shallowing-upward trend of the Owadów–Brzezinki succession provides a great opportunity for studying transitions within faunistic assemblages and helps us to understand palaeobiological spatial relationships.

Fieldworks conducted over last three years at Owadów–Brzezinki Quarry has provided several discoveries showing the large palaeontological potential of the site and its palaeobiogeographical importance. The section is located within both the Brzostówka marls of the topmost part of the Pałuki Formation and the overlying limestones of the Kcynia Formation (Fig. 2). Comments on the occurrence of faunal assemblages in particular parts of the succession studied are given below.

GENERAL OVERVIEW OF THE MOST IMPORTANT PALAEONTOLOGICAL FINDS

The black, blue-grey and yellow-blue marls (*c.* 1.6 m thick) with intercalations of thin oyster-bearing and marly limestone beds (Błażejowski *et al*., 2014) exposed in the lowermost part of Owadów–Brzezinki Quarry belong to the uppermost part of the Pałuki Formation. These strata contain the oldest fossils found in this site (Fig. 2) comprising abundant ammonites, bivalves, decapod crustaceans and large actinopterygian fish bones. Hundreds of carapaces of exceptionally preserved lobster-like decapod crustaceans (Glypheoidea: Mecochiridae) have been found to date, almost all with unusually well preserved ornamentation and appendages (Fig. 3). The specimens appear to have been quickly buried alive, suggesting episodes of rapid sedimentation, and the conditions (palaeoecological, sedimentological) which led to such a phenomenon are as yet unclear. Mecochiridae are well known and commonly found also in the Solnhofen-Eichstätt Plattenkalk (Garassino, Schweigert, 2006), and thus their occurrence suggests an open connection with the Submediterranean Province of the Tethyan Realm, as – in terms of biogeographical distribution – the region of the so-called Solnhofen Archipelago can be considered.

The main part of the Owadów–Brzezinki section comprises limestones of the Kcynia Formation which can be subdivided into four units (Kutek, 1994; Błażejowski *et al*., 2014), each containing specific and unique fossils (Fig. 2).

Unit I (*c.* 9.1 m thick) consists of massive, fine-grained, chalky limestone characterized by a general absence of sedimentary structure. Deep-burrowing bivalves *Pleuromya* sp. accompanied by oysters *Deltoideum delta* (Smith) and unidentified trigoniid bivalves, rhynchonellid brachiopods, small gastropods, crinoids and ammonites are common, especially in the lower part of this unit. A rather monotonous ostracod assemblage has been reported in the Unit I deposits

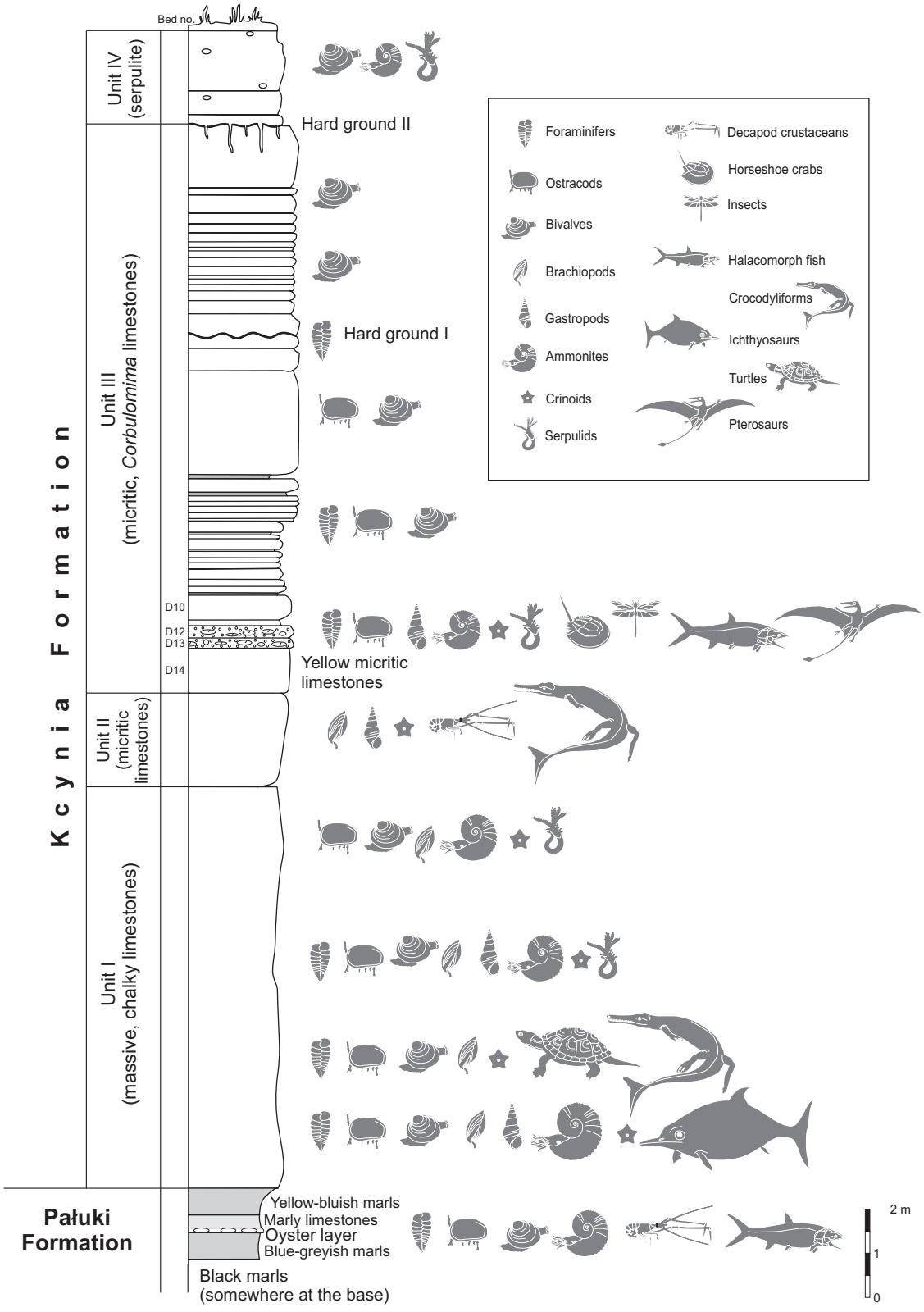

Fig. 2. Lithological succession of the Owadów–Brzezinki Quarry. The topmost part of the Pałuki Formation and overlying limestones of the Kcynia Formation (Units I–IV). Upper Jurassic (Tithonian)

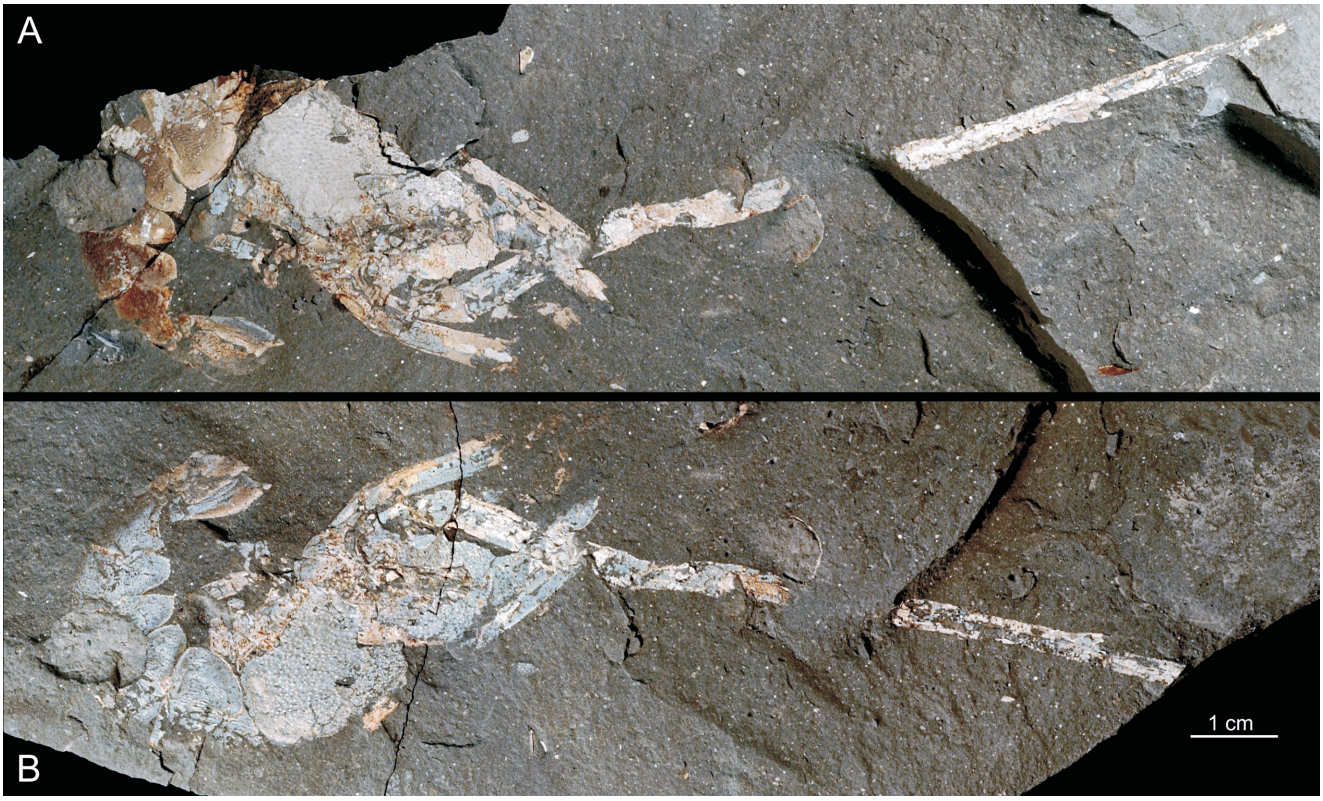

Fig. 3. Lobster-like decapod crustaceans *Mecochirus* sp. nov.

A. Negative (external mold); **B.** Positive (rock slab with imprint) (ZPAL Cr.11/O-B/15/1). Pałuki Formation, Upper Jurassic (Tithonian)

(Wierzbowski *et al*., 2016). Recently quite numerous bones of marine reptiles have been also recovered from Owadów–Brzezinki Quarry (Tyborowski *et al*., 2016). These are represented by ichthyosaurs, turtles and crocodylomorphs (isolated teeth and long bones) with a remarkably good quality of preservation. Based on osteological analysis, the ichthyosaur remains from Owadów–Brzezinki Quarry (Fig. 4) clearly belong to a member of the Ophthalmosauridae family and appear to be very similar to the genus *Cryopterygius*. The genus has been previously known only from the Agardhfjellet Formation of Spitsbergen (Druckenmiller *et al*., 2012; Hurum *et al*., 2012; Roberts *et al*., 2014; Tyborowski, 2016), thus the new finding in the Owadów–Brzezinki section clearly indicates palaeogeographical connections with "deep" Arctic Boreal areas. The unarticulated skeleton of a cryptodiran turtle, consisting of several bones: coracoid, femur and parts of the lower jaw and pelvic girdle, was also discovered. The characteristic V-shaped lower jaw, with a massive, spoon-like symphysis suggests that it was a durophagous reptile, living mostly in shallow water environments, and specialized for eating hard-shelled invertebrates like decapods or bivalves. It was probably a semiaquatic or primitive marine turtle. Representatives of this group are also known from the Solnhofen area (Joyce, 2000, 2003).

Unit II (*c.* 2.2 m thick) is represented by thin-bedded micritic limestones, which are underlain and overlain by very thin (2–4 cm) marly beds. Bivalves, decapod crustaceans (glypheoid lobsters), polychaete tubes and rare crinoids are found in these deposits. The new species of the glypheoid lobster *Jabaloya polonica* has been described from this unit by Feldmann *et al.* (2015), based on fragmentary material found in a loose block in 2013. This genus was known so far only from Upper Jurassic deposits of the Aragón region, Spain (Garassino *et al*., 2009). Recent finds of abundant and well preserved specimens of this species in the Owadów–Brzezinki section require further investigation. Unit II has also recently yielded an exceptional three-dimensionally preserved skeleton of crocodylomorph (metriorhynchiid). Metriorhynchids are known from the Aalenian (Middle Jurassic) to the Valanginian (Early Cretaceous) in both Hemispheres (Wilkinson *et al*., 2008; Young *et al*., 2010; Cau, Fanti, 2011; Carbot-Chanona, 2014), representing the only archosaurian group that can be defined as completely adapted to a pelagic marine life (Neill, 1971; Steel,

Fig. 4. A nearly complete skeleton of ichthyosaur (Ichthyosauria: Ophthalmosauridae) from Owadów–Brzezinki Quarry. Kcynia Formation (Unit I), Upper Jurassic (Tithonian)

1973). The specimen in question from Owadów–Brzezinki quarry, consists of the braincase (Fig. 5), teeth, osteoderms and caudal vertebrae. It has been investigated using X-ray microcomputer tomography (XMT), a non-invasive tool (Błażejowski *et al*., 2011, 2015a), which permits examination of its internal structure, and, after computer processing, to render a 3D model and precise images for histology studies. Preliminary observations indicate significant similarities to the crocodylomorphs described from the "Portlandian" of England (Benton, Spencer, 1995; Tyborowski *et al.*, 2016), suggesting a NW European Subboreal affinity.

Unit III consists of well-bedded micritic limestones (*c.* 12.8 m thick). The lowermost part (bed D14, 1 m thick) comprises thick-bedded, hard, yellow limestones. The overlying D13 and D12 beds (0.6 m thick) are paler in colour and very fossiliferous (Fig. 2).

Numerous specimens of horseshoe crabs (Fig. 6) have been found in Unit III in association with an enormously rich assemblage (mass-accumulations) of small elongated-shelled bivalves (either protobranchs or corbuloids), the remains of various fish and marine reptiles, rare ammonites, land insects (dragonflies, beetles, grasshoppers) and isolated pterosaur teeth (Kin *et al*., 2013; Błażejowski *et al*., 2014). The extraordinary collection of horseshoe crabs described from this unit has a great significance for extending current knowledge of the group (Błażejowski, 2015; Błażejowski *et al*., 2015b). The discovery of new, more or less three-dimensionally preserved Late Jurassic Xiphosurida arthropods, *Limulus darwini* (Kin, Błażejowski) and *Crenatolimulus* sp. nov., adds significantly to our understanding of a group which has a stratigraphic range throughout almost the entire Phanerozoic period. After a detailed analysis of limulids, Kin and Błażejowski (2014) showed that some of the horseshoe crabs collected at Owadów–Brzezinki feature no significant morphological differences with extant juvenile individuals of the genus *Limulus* (Müller, 1785), which inhabit brackish-marine, shallow water environments of the east coast of the United States. Kin, Błażejowski (2014) suggested that the relative evolutionary conservatism noticeable in *Limulus* (and all known representatives of Xiphosurida), may be related to a unique formula of adaptative strategy, and introduced the term **'**stabilomorphism', defined as a relative morphological stability of organisms in time and spatial distribution, within the genus level.

The middle and the upper part of Unit III consists mainly of thin-bedded micritic limestones with thinner marly limestone intercalations and has not yet yielded well-preserved fossils. U-shaped burrows with polygonal patches in the top surfaces of the beds are sometimes observed in the limestones from this interval (*cf.* Kin *et al*., 2013). Worth noting is the occurrence of hard grounds in the upper part of this unit III (Fig. 2). Mass-accumulations of small, unidentified bivalves occur in the younger deposits, but they are less common than in fossiliferous beds D12 and D13; the same applies to the ammonite fauna. Only a few small oyster shells were derived from Unit III and these rocks are devoid of crinoids (*cf.* Salamon *et al*., 2006; Kin *et al*., 2013). The preliminary study shows a rather monotonous ostracod as-

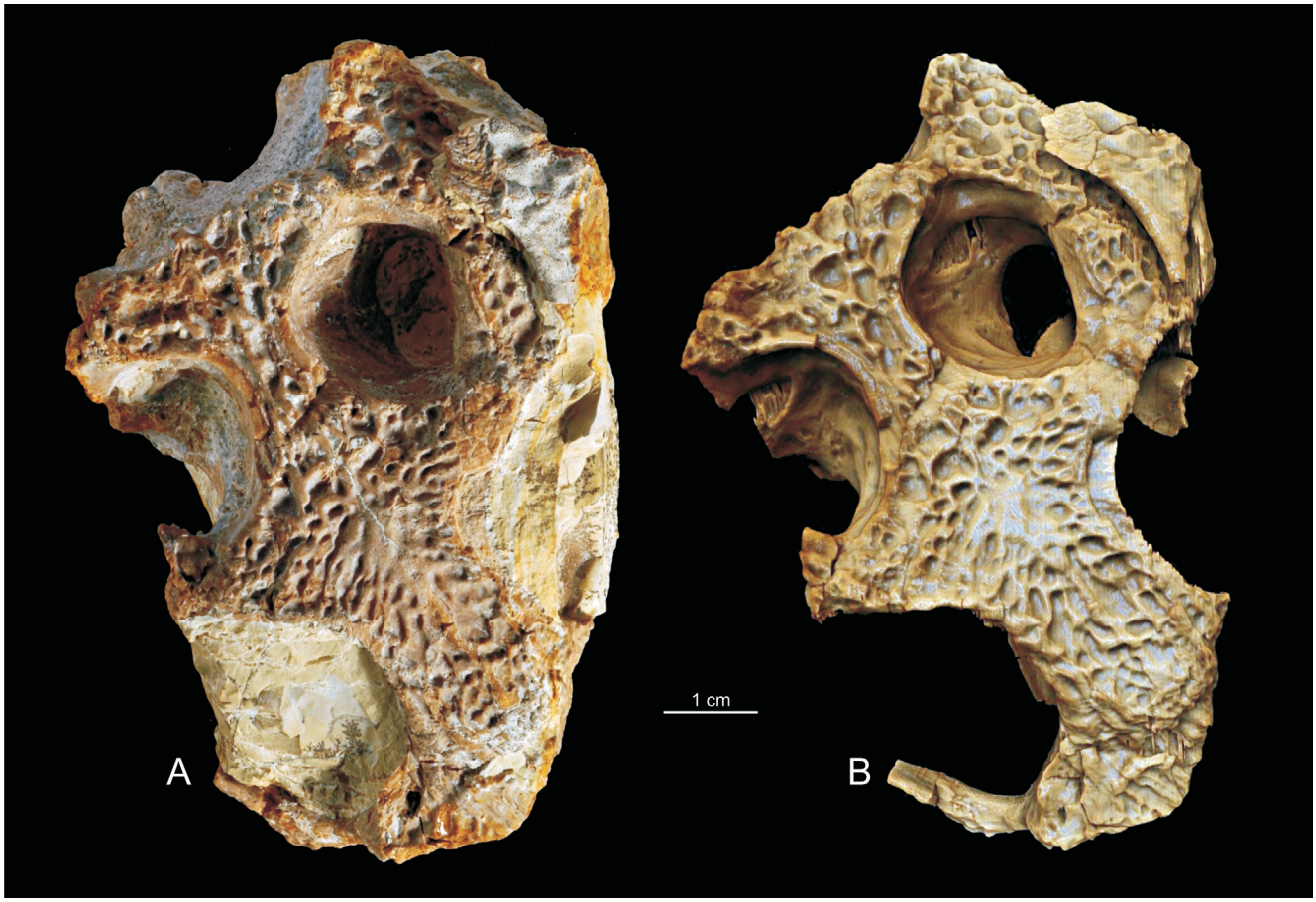

Fig. 5. Skull of marine crocodylomorph (Metriorhynchidae) from Owadów–Brzezinki Quarry in dorsal view

A. Specimen in piece of limestone (photography); **B.** 3D model of "virtual fossils" – view of the specimen after digital processing and analysis of tomographic data. Kcynia Formation (Unit II), Upper Jurassic (Tithonian)

semblage in the unit III deposits (Kin *et al*., 2013; Wierzbowski *et al*., 2016). The fossil remains of large, predatory actinopterygians are the most common fossils of vertebrates in this unit. Błażejowski *et al.* (2015a) described a large part of the upper jaw (maxilla) of a *Caturus*, also known to be one of the biggest predators in the Solnhofen Archipelago ecosystem (Lambers, 1994). Smaller predators, such as the members of the Furidae, are also known from Owadów–Brzezinki Quarry. A lower jaw (dentary bone) of the genus *Furo* was studied with X-ray microtomography revealing details of Jurassic fish teeth morphology and histology (Błażejowski *et al*., 2015a).

The beds of Unit III were most probably formed in shallow, stagnant waters with periodic episodes of anoxia (Wierzbowski *et al*., 2016). Such changes in the chemistry of the environment resulted in great transformations in the overall composition of the biota, including the appearance of specific bacteria and fungi; in turn, this might have had significant influence on the fossilization processes, *e.g.* of the especially fragile parts of horseshoe crabs.

The overlying deposits of Unit IV are the youngest rocks of the Owadów–Brzezinki section (Fig. 2). They contain rare ammonites, bivalves, and small bryozoan-serpulid bioherms. The deposits of this unit most probably belong to the lower part of the so-called "serpulite beds" (Bielecka, Sztejn, 1966). The successive Late Jurassic deposits some tens of meters thick are covered by Quaternary deposits and do not crop out. It is an open question if these deposits inaccessible on the surface represent the continuation of shallow-marine deposits similar to those seen in Owadów–Brzezinki quarry, or if the they at least partly represent a transition to the anhydrite-gypsum deposits of the Wieniec Evaporite Member, known from central parts of the latest Jurassic basin of Central Poland (Dembowska, 1979).

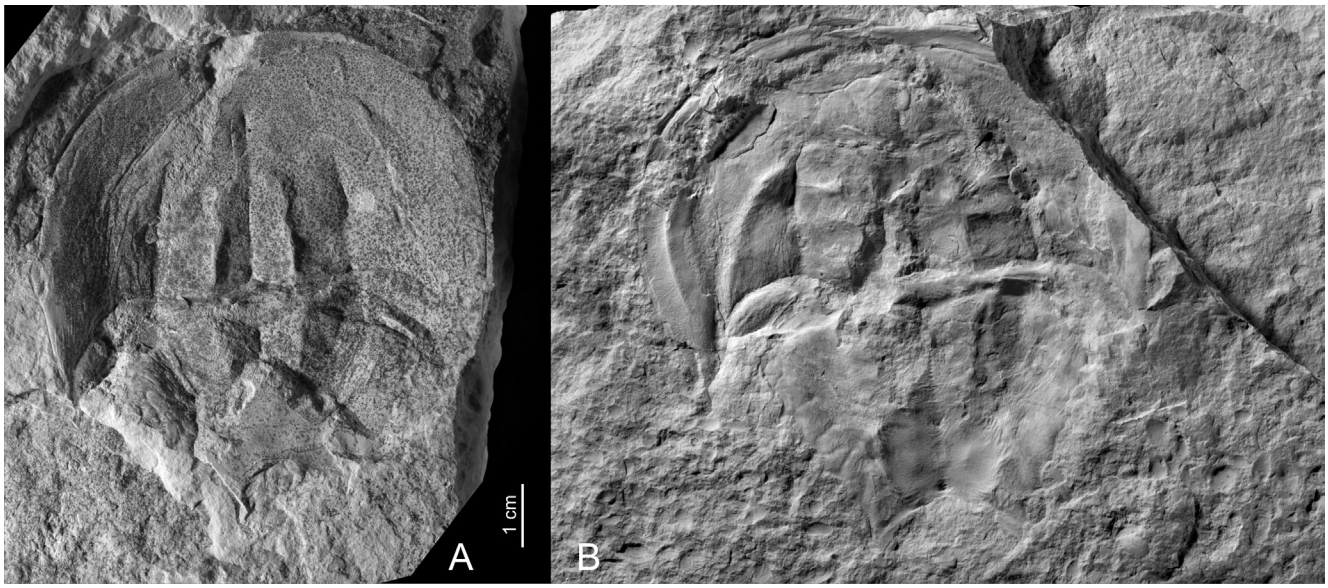

Fig. 6. Late Jurassic horseshoe crabs from Owadów–Brzezinki Quarry

A. Nearly complete exuvia of *Limulus darwini* (ZPAL X.1/O-B/XA 15/3); **B.** *Crenatolimulus* sp. nov. (ZPAL X.1/O-B/XA 15/8), positive (rock slab with imprint), no telson preserved. Kcynia Formation (Unit III), Upper Jurassic (Tithonian)

GENERAL REMARKS

The palaeobiogeographical interpretation of the faunal assemblages recognized from Owadów–Brzezinki quarry has to take into account their diversity: they comprise both fully marine organisms (ammonites, brachiopods and most of the bivalves), but also forms which may be interpreted as indicative of more restricted environments (such as decapod crustaceans). The ammonite faunas are composed of representatives of the subfamilies Virgatitinae and Pavloviinae showing open marine connections with NE European Russian seas, as well as NW European English seas – both representing Subboreal areas (Matyja *et al*., 2016; Matyja, Wierzbowski, 2016). This observation is confirmed by recent finds of marine reptiles demonstrating the marine connection with Boreal Arctic areas (Tyborowski, 2016; Tyborowski *et al*., 2016). Such palaeobiogeographical relations of the faunal assemblages with those of northern Europe open a new perspective for their studies – especially by their comparison with specimens of the British Upper Kimmeridge Clays ("Bolonian") and the "Portlandian". On the other hand, there are marked similarities between the terrestrial and "special" marine faunal assemblages (lobster-like decapod crustaceans and turtles) from the Owadów–Brzezinki site and the Submediterranean areas – represented mostly by the Solnhofen sites, but it should be remembered that some of decapod crustaceans could represent forms of a wider but poorly recognized geographical distribution (*e.g.* Cope, 2015). Of larger stratigraphical importance is the newly discovered level with Tethyan microfossils (*Chitinoidella*) in the Owadów–Brzezinki section (Pszczółkowski in: Matyja *et al*., 2016; Pszczółkowski, 2016) which indicates even more strongly incidental Mediterranean influences. Such a palaeobiogeographical position of the Owadów–Brzezinki site is therefore unique, because it enables tracing of the interactions between the Late Jurassic biogeographic regions from the Boreal Arctic to the Submediterranean–Mediterranean areas in Europe. Moreover, it gives the basis for recognition of the character of a barrier which existed between the Submediterranean and Mediterranean areas from one side, and the Subboreal–Boreal areas from the other. This barrier was possibly related to the existence of the belt of the Štramberk type coral reefs and associated shallow-water carbonate in the front of the Mediterranean Tethys – also in Polish territory (Matyja, 2009).

The recently unearthed palaeontological material from Owadów–Brzezinki Quarry seems to shed new light on our understanding of the local ecology and regional palaeobiogeography of the interconnected system of European basins during the latest Jurassic. Possible comparative studies with faunas from sites of similar character creates a welcome opportunity for extended evolutionary studies.

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