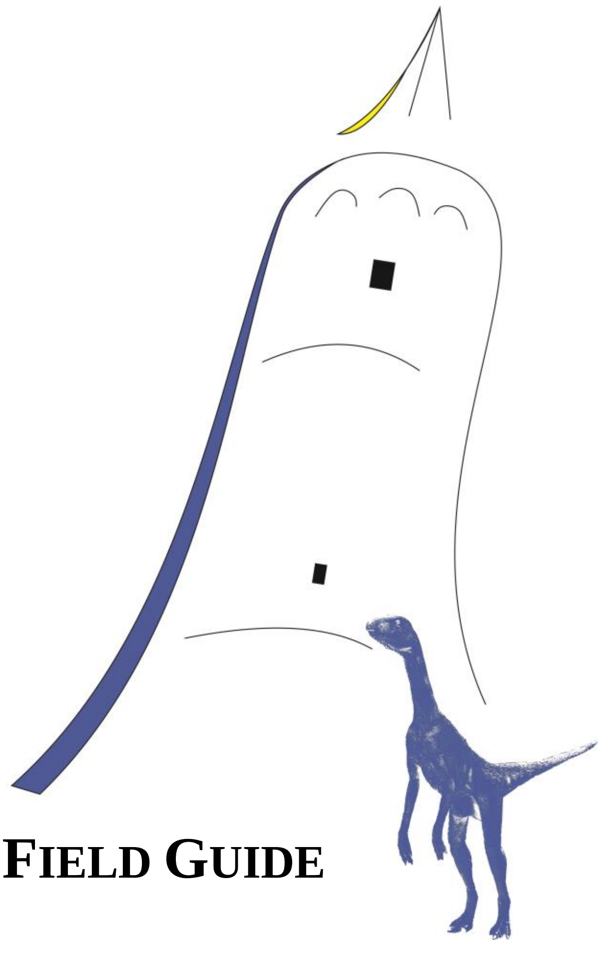
EUROPEAN ASSOCIATION OF VERTEBRATE PALAEONTOLOGISTS

XIII ANNUAL MEETING

OPOLE, POLAND, 8-12 JULY 2015



FIELD GUIDE

Logo – Silhouette of *Silesaurus opolensis*, a genus and species of dinosauromorph from the Upper Triassic of southwest Poland. Remains of *Silesaurus* have been recovered from the 'Keuper' claystone at Krasiejów near Opole (Silesia, Poland), from which it takes its name. The building next to *Silesaurus* is a stylised contour of the Piast Tower, a remnant of Piast Castle, one of the oldest structures of defensive architecture in Poland. It plays a key role as symbol of the city of Opole and of Opole Voivodeship (project: Roman B. Konietzko).

Front cover – In the foreground are silhouettes of *Silesaurus opolensis*, while the background presents a view of the inside of the pavilion at Krasiejów Jurapark, with an exhibit of *in-situ* Late Triassic vertebrate remains, mostly metoposauroids. Visible through the glass wall is a portion of the quarry. The pavilion belongs to Opole University (project: Roman B. Konietzko and Dorota Konietzko-Meier; photograph by R.B. Konietzko).

Back cover – Quarry views: **Top** - Gogolin, Middle Triassic, upper Oleneklan, portion of section with the third (i.e., the highest), bone-bearing horizon. The white scale bar on the top of the upper level equals 8.5 cm. **Centre** - Krasiejów, Upper Triassic, Keuper/Norian, view of the currently excavated northeastern quarry face - bones occur at the boundary between the brownish and greyish layers. **Bottom** - Odra quarry (Upper Cretaceous, middle-upper Turonian) – view of the currently excavated eastern face. Odra (new) quarry (Upper Cretaceous/middle-upper Turonian) - view of the eastern quarry face with two promiment marly levels in the 'Marly Limestones' unit (middle Turonian). Person for scale (photographs by A. Bodzioch, R.B. Konietzko and E.A. Jagt-Yazykova).

Book design by Dorota Konietzko-Meier.

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Upper Silesian Muschelkalk

Adam Bodzioch[1,*] and Monika Kowal-Linka[2]

[1]Opole University, Department of Biosystematics, ul. Oleska 22, 45-052 Opole, Poland, e-mail: abodzioch@uni.opole.pl (*corresponding author); [2]A. Mickiewicz University, Institute of Geology, ul. Maków Polnych 16, 61-606 Poznań, Poland

Upper Silesia held a unique palaeogeographical position during the Middle Triassic, at the mouth of the strait that connected the Tethys Ocean with the European epicontinental sea, and within the range of a tropical climate (Fig. 1). Consequently, carbonate facies appeared here earlier than in Germany, the marine transgression progressing from the east to the west. The base of the Muschelkalk equates with the boundary between the Lower and Middle Triassic (Fig. 2). The uppermost part of the Röt, as well as the Lower and Middle Muschelkalk are all well exposed in this area, and these deposits record a transgressive-regressive cycle of the Lower Muschelkalk sea.

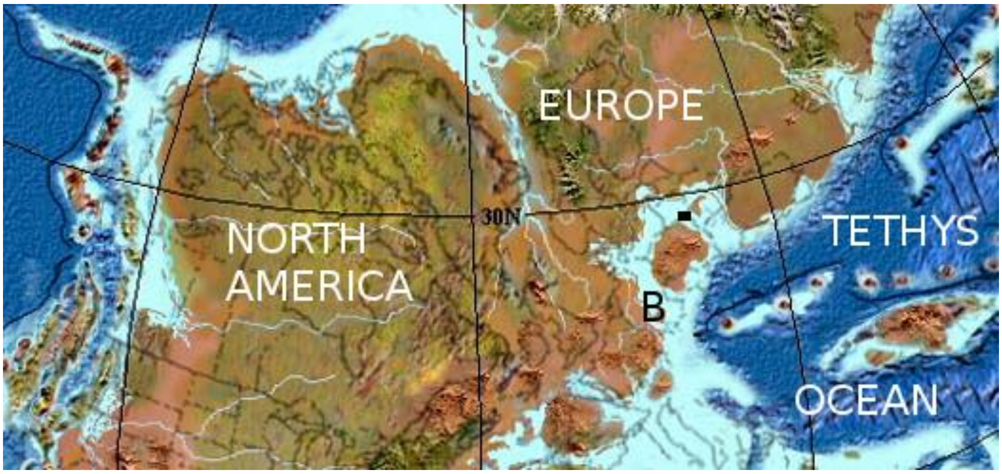

Fig. 1. General palaeogeographical position of Upper Silesia (small black rectangle) during the Olenekian and Anisian (background: ©Ron Blakey, Colorado Plateau Geosystems, Inc., courtesy by Dr Ron Blakey). B: Burgundy Gate, closed at the time; active connections existed only via the eastern straits (Silesian-Moravian and East Carpathian gates).

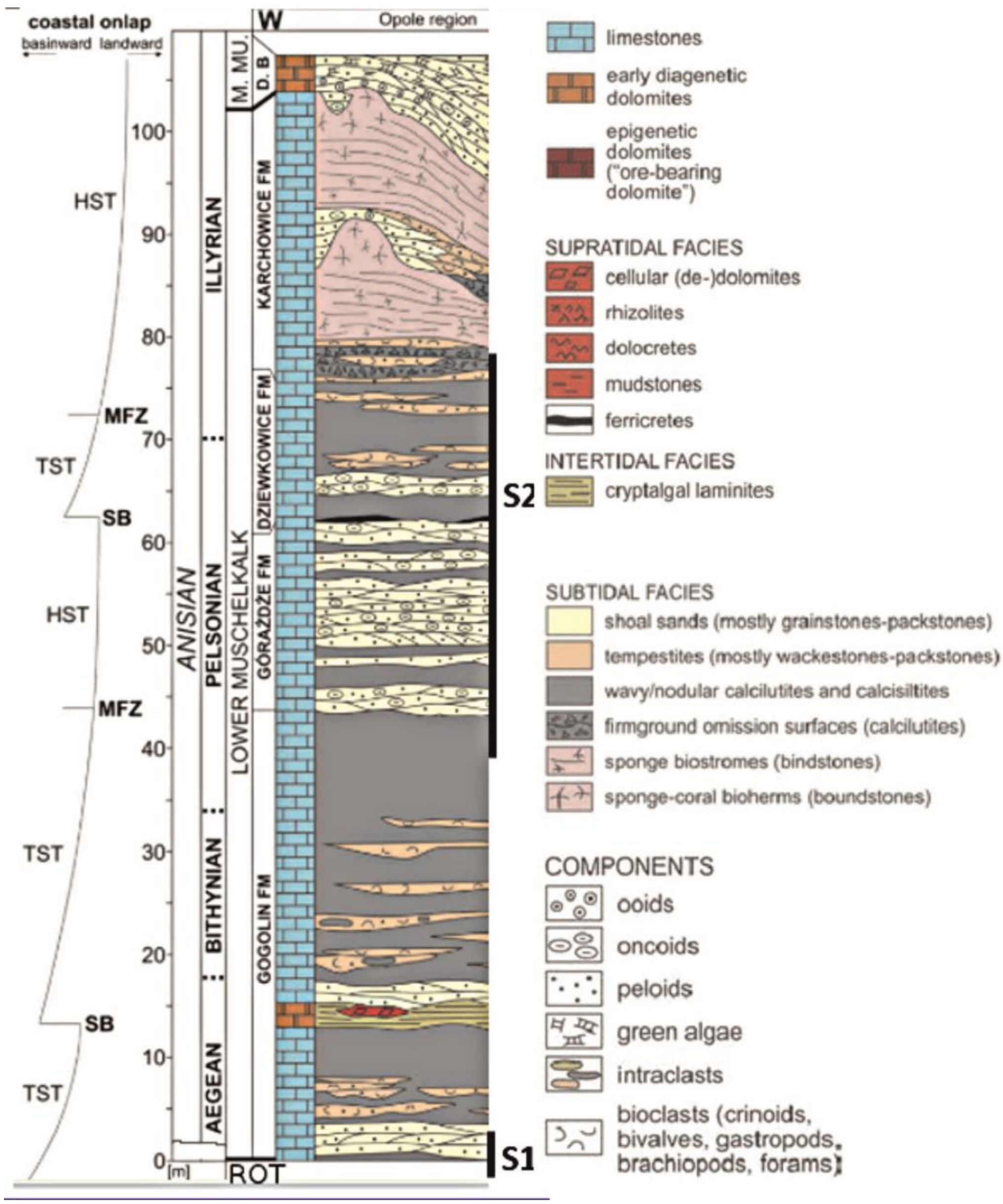

Fig. 2. General litho- and chronostratigraphy of the Lower to Middle Triassic sequence outcropping in the Opole region (after Matysik, 2014; slightly modified). Abbreviations: TST: transgressive systems tract; HST: highstand systems tract; SB: sequence boundary; MFZ: maximum flooding zone; M. MU: Middle Muschelkalk; D.B: Diplopora Beds. Thick black lines to the right of the log indicate intervals to be visited; S1: Stop 1; S2: Stop 2.

Stop 1. Gogolin (abandoned quarries, Fig. 3): Marine Transgression.

Fig. 3. Geographical setting of old abandoned quarries situated near Gogolin (from: http://maps.opolskie.pl/). A: the transgressive sequence; B: locality of bone horizons.

The sequence includes the Rötkalk (*sensu* Assmann, 1933), which consists of carbonate deposits of the supralittoral and eulittoral zones, and sediments of the lowermost part of the Muschelkalk were laid down in a marine setting (Fig. 4). The section starts with brown to orange coloured, coarse-crystalline cellular limestones (dedolomites) containing pseudomorphs after evaporites, desiccation cracks, collapse breccias or cellular structure, which provide evidence of deposition in sabkhas and ephemeral supralittoral ponds (*e.g.*, Bodzioch and Kwiatkowski, 1992; Kowal-Linka, 2010). Above, the sediment is gradually replaced by yellow to beige marly limestones containing remanié marine ostracods, foraminifera, gastropods and bivalves. These limestones, together with inserts of grey marl, were laid down in the eulittoral zone. Two grey bioclastic limestone layers with shell pavements and trace fossils, typical of the lowermost part of the Muschelkalk (Gogolin Formation, Zakrzów Crinoidal Limestone Member, Krapkowice Pelitic Limestone Bed *sensu* Kowal-Linka, 2009; compare Assmann, 1944) crop out in the higher part of the sequence. These are sublittoral sediments that were deposited under adverse weather conditions (storm deposits). Across this part of the section remains of cyanobacterial mats are commonly found, and they form at least three quite distinct horizons of insignificant thickness. Numerous remains of vertebrates, mainly marine reptiles (*Dactylosaurus*, *Cymatosaurus*, *Nothosaurus*) and a variety of fish are found in these (Fig. 5). The mats probably formed a trap for skeletal debris transported along the shoreline and induced accumulation of vertebrate skeletal parts (Kowal-Linka and Bodzioch, in prep.). The age of bone horizons discovered here is late Olenekian (Nawrocki and Szulc, 2000); as such, they are among the very few, oldest assemblages of Mesozoic vertebrate faunas (Kowal-Linka and Bodzioch, 2012).

Numerous tempestites (cross-bedded and graded-bedded bioclastic limestones), bioturbated autochthonous muds (ichnofossil-rich micritic limestones) and deposits of skeletal shoals (thick, cross-bedded bioclastic limestone layers) forming the upper part of the Zakrzów Crinoidal Limestone Member (= limestone with *Pecten* and *Dadocrinus*, *sensu* Assmann, 1944) record the further progress of the transgression. This unit is highly fossiliferous, but vertebrate remains occur only sporadically. The continuous sedimentation was interrupted by an earthquake, which resulted in deposition of submarine landslide sediments (Szulc, 1993, 2000), represented by intraformational conglomerate and marl (the Skała Marl Member = level of clayey marls). Subsequently, a temporary return to supralittoral conditions took place; this is documented by sabkha deposits of the Emilówka Cellular Limestone Member (marly limestones with cellular structure and voids after sulphates).

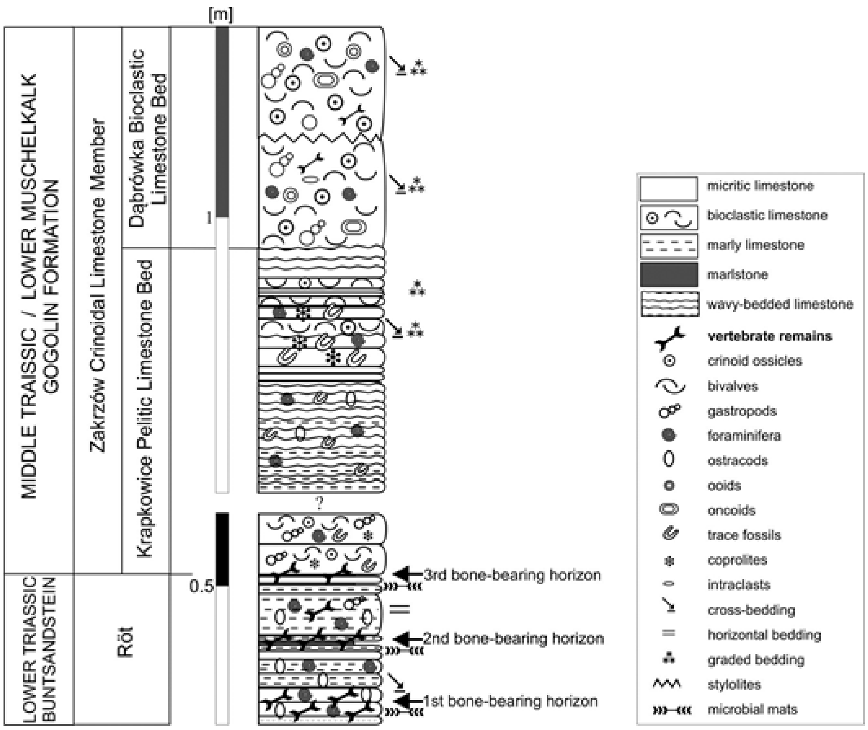

Fig. 4. The Röt/Muschelkalk boundary in the vicinity of Gogolin (after Kowal-Linka and Bodzioch, 2012; supplemented). Note the rare occurrence of bones also in the Dąbrówka Bioclastic Limestone Bed.

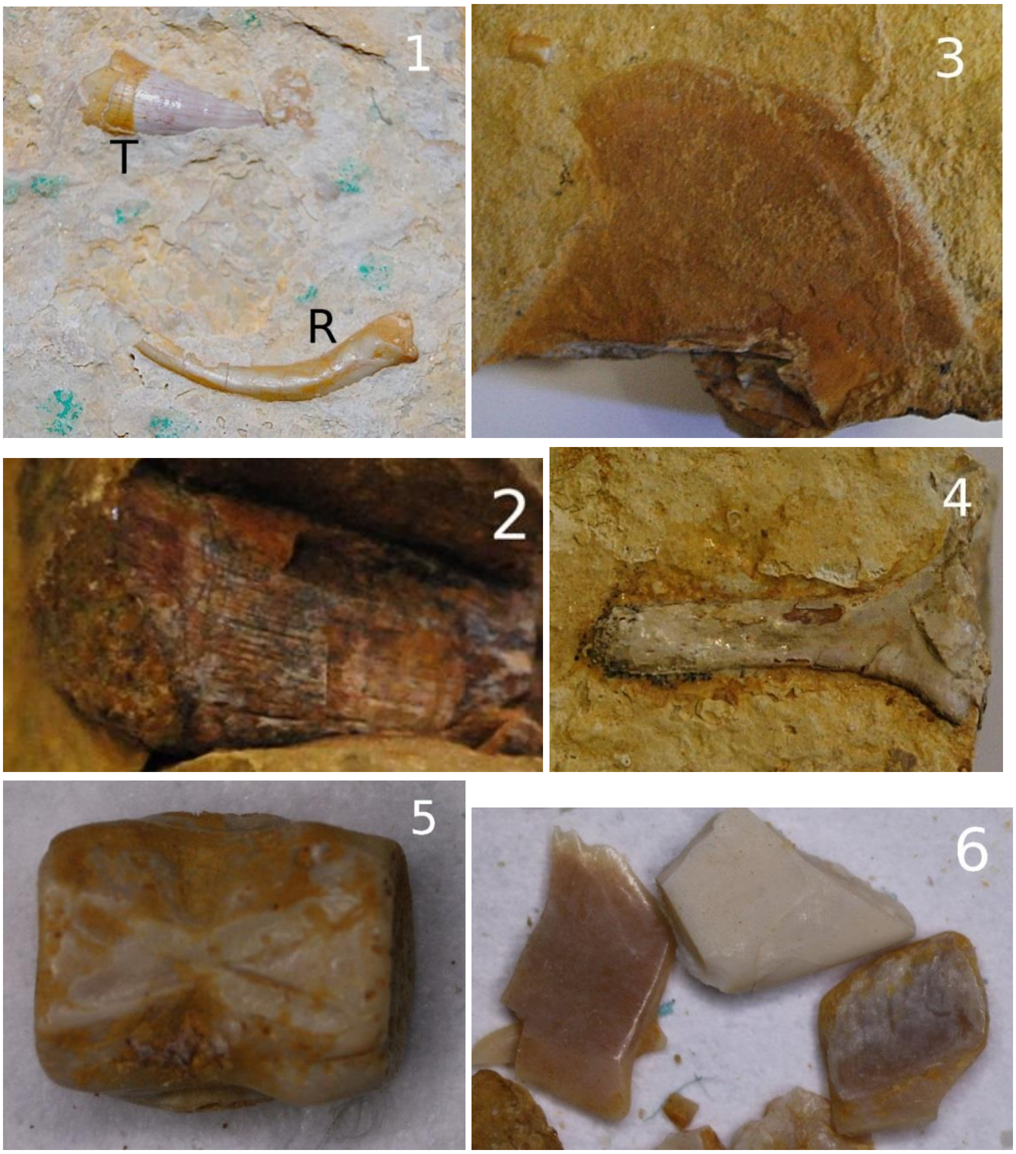

Fig. 5. Examples of vertebrate fossils from the Röt/Muschelkalk boundary at Gogolin. 1. T: reptile tooth (length 8,5 mm), R: reptile rib (length 14 mm); 2. Fragment of an unidentified long bone (length 22 mm); 3: Fragment of ilium, *Nothosaurus* (width 35 mm); 4: Spinous process, *Nothosaurus* (length 42 mm); 5: vertebra, *Dactylosaurus* (length 2 mm); 6: fish scales (each *c.* 2 mm).

Stop 2. Górażdże (active quarry, Fig. 6): The Lower Muschelkalk Sea.

At the Górażdże quarry the highest part of the Gogolin Formation is exposed (Ligota Górna Wavy-Bedded Limestone Member *sensu* Kowal-Linka, 2008), as are the Górażdże and Dziewkowice formations (*sensu* Niedźwiedzki, 2000) and the base of the Karchowice Formation (*sensu* Bodzioch, 1997).

The Górażdże Formation consists of beige, thick-bedded granular limestone with intercalations of pelitic limestone. Granular limestone usually shows large scale cross-stratification and large wave-formed ripple marks on their top surfaces. They mainly consist of oncoids accompanied by bioclasts, ooids, and sparite bonded peloids. Pelitic layers tend to show bioturbation structures produced by organisms living in the sediment, and their top surfaces contain numerous burrows left by non-skeletal animals. The whole formation represents a barrier facies of a carbonate ramp.

Fig. 6. Geographical setting of the Górażdże quarry (from: http://maps.opolskie.pl/). A: section to be visited.

The Górażdże Formation consists of beige, thick-bedded granular limestone with intercalations of pelitic limestone. Granular limestone usually shows large-scale cross-stratification and large wave-formed ripple marks on their top surfaces. They mainly consist of oncoids accompanied by bioclasts, ooids and sparite-bonded peloids. Pelitic layers tend to show bioturbation structures produced by organisms living in the sediment, and their top surfaces contain numerous burrows left by non-skeletonised animals. The whole formation represents the barrier facies of a carbonate ramp.

The Dziewkowice Formation is distinguished by its dark grey colour; it can be subdivided into three parts, as follows:

- lower: wavy-bedded pelitic limestone,
- middle (main crinoid bed): beige bioclastic limestone with large-scale cross-bedding,
- upper: brachiopod coquinas and pelitic limestone showing bioturbation structures in the lower part, and in the upper part wavy pelitic limestone with inserts of thin bioclastic limestone.

This formation represents an off-barrier facies, embedded in the deepest part of the Upper Silesian basin. This deepening can be explained by synsedimentary tectonic activity (Szulc, 1993, 2000). The rich fossil assemblage consists mainly of brachiopods, molluscs and echinoderms (*e.g.*, Kaim, 1997). Occasionally, however, vertebrate remains can also be found (*e.g.*, Chrząstek and Niedźwiedzki, 1998).

The Karchowice Formation represents reef facies that formed during regression of the Lower Muschelkalk sea (Bodzioch, 1997, 2005; Matysik, 2010). It consists of biohermal limestone built by hexactinellid sponges (Pisera and Bodzioch, 1991) and scleractinian corals (Morycowa, 1988; Morycowa and Szulc, 2006), accompanied by taxonomically highly diverse molluscs and echinoderms. Both sponges and corals of the Karchowice Formation are the oldest Mesozoic representatives of their orders. Similarly, the reefs themselves are also the oldest Mesozoic sponge-coral reefs.

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The Triassic world of Krasiejów

Kamil Gruntmejer[1*], Dorota Konietzko-Meier[1,2] and Adam Bodzioch[1]

[1] Uniwersytet Opolski, Katedra Biosystematyki (Paleobiologii), ul. Oleska 22, 45-052 Opole, Poland, **e-**mail: gruntmejerkamil@gmail.com (*corresponding author); [2] Steinmann Institut, Universität Bonn, Nussallee 8, 53115 Bonn, Germany

Krasiejów is a small village some 20 kilometres east of Opole. In recent years, it has rapidly become a mecca for lovers of palaeontology from all over the world. The prime reason is the sheer abundance of accumulated fossil vertebrates on the grounds of old brickworks for which claystones were excavated in an open-cast mine (Dzik and Sulej, 2007). The age of these rocks and the fossils that they contain is Late Triassic, but a more precise dating (*i.e.*, either Carnian, Norian or Rhaetian) still is ambiguous. Generally, the view is that the claystones at Krasiejów were not laid down earlier than latest Carnian (230-225 million years ago, Ma) and no later than middle Norian (220-210 Ma) (Gruszka and Zieliński, 2008). As far as the geological time scale is concerned, this is merely a narrow age range difference, but from the point of view of the evolution of terrestrial Triassic vertebrates it does make quite a difference!

Locality and geological setting

What did present-day Silesia look like during the Late Triassic? The wider surroundings of Krasiejów area were quite flat, except for the southwestern edges of Poland (Fig. 1), where elevated terrain remained, representing remains of deeply eroded Variscan rock formations. Mainly from there, rivers proceeded and formed more or less extensive backwaters and swamps, separating islands from the dry mainland. This area was situated much further south on the globe during the Triassic, under warm, subtropical climatic conditions and the impact of monsoon rains.

Because of these circumstances air temperatures were very similar to those of the present-day Mediterranean basin, with merely two seasons; a rainy (summer) and dry (winter) one. Under such conditions, rivers swelled during summer and extended far beyond their beds, whereas in winter they almost disappeared and marsh and swamp areas decreased in size. Occasionally, rainfall was very intense which locally led to flooding. Just as a result of one of such floods, the extensive accumulation of fossil bones came into being in what is now Krasiejów (Gruszka and Zieliński, 2008). The rapid rise of flood waters washed out skeletal remains from neighbouring areas, and transported them to their final site of burial (Fig. 2).

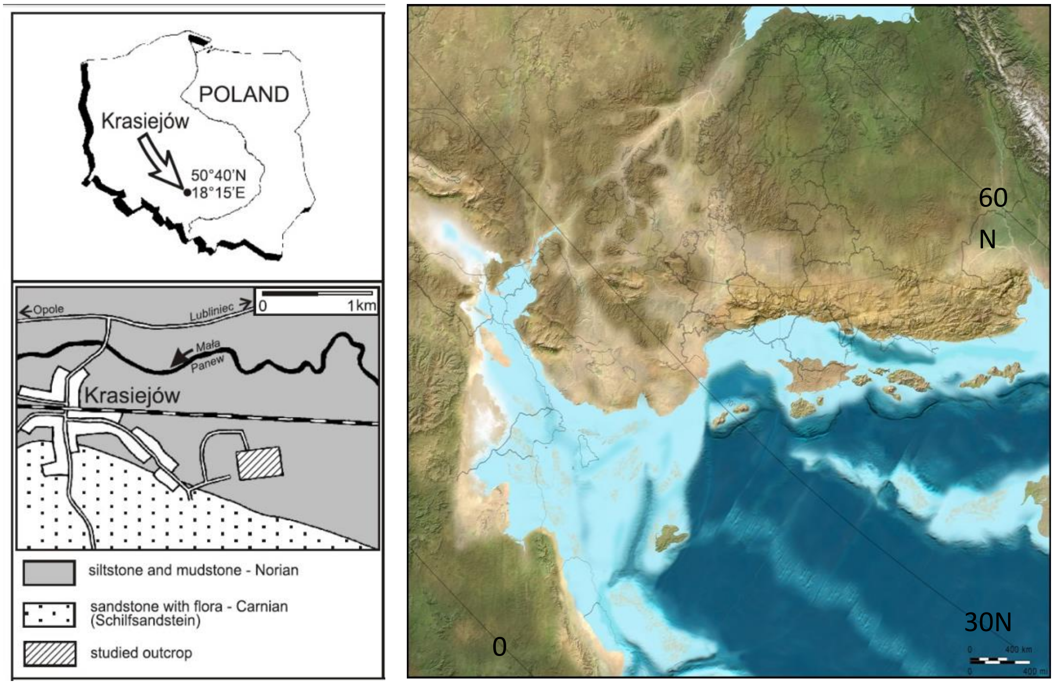
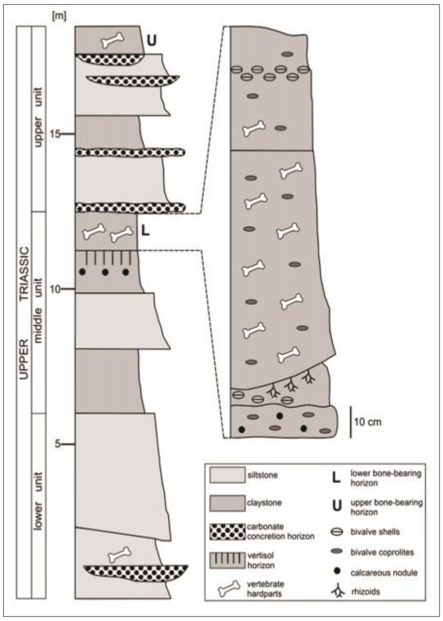


Fig. 1. Position of the Krasiejów site within Poland (left; from Gruszka and Zieliński, 2008) and location of Europe during the latest Triassic (right: ©Ron Blakey, Colorado Plateau Geosystems, Inc., courtesy by Dr Ron Blakey).

During transportation and prior to deposition, material was segregated, intermingled and often damaged as well (Bodzioch and Kowal-Linka, 2012). This explains why entire skeletons with proper anatomical arrangement of all elements are rare at Krasiejów. However, the rapid process of bone bed accumulation meant that interspersed bones of various animal species are now very numerous. Remains of large-sized vertebrates are present in both upper and lower claystone horizons (bone beds). These two levels are separated by a several layers of claystones and siltstones with a thin veins of carbonate concentration (Fig. 3). The lower bone-bearing horizon is situated about 10 metres below ground surface and is still exploited for fossils. This comprises the richest bone accumulation of aquatic (*Metoposaurus* and *Paleorhinus*), semi-aquatic (*Cyclotosaurus*) and terrestrial (*Stagonolepis* and *Polonosuchus*) taxa (Bodzioch and Kowal-Linka, 2012). The upper horizon is at two metres below ground level, and has already been exploited within the limits of the Krasiejów bone bed. The most famous taxon from Krasiejów, the dinosauromorph *Silesaurus opolensis*, stems from this particular horizon.



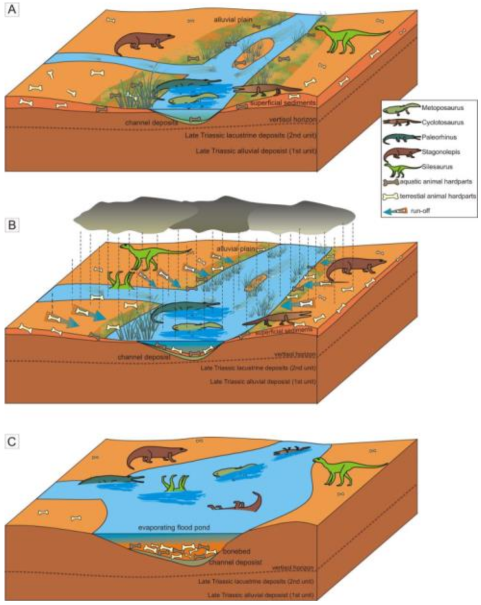


Fig. 2 (left). Schematic lithostratigraphic log of the Krasiejów site.
Fig. 3 (right). Schematic model illustrating how the lower bone-bearing bed might have formed (after Bodzioch and Kowal-Linka, 2012).

Plants, invertebrates and small vertebrates

In general, plant remains are poorly preserved at Krasiejów, but there are sufficient data to provide a landscape characteristic. The large accumulations of oospores (spore cells) indicates that green algae occupied inland waters. The wetlands were covered mostly by large horsetails and ferns, while in drier areas conifers could develop.

The fauna of small aquatic invertebrates was dominated by bivalves. A new genus and species, *Silesunio parvus* Skawina and Dzik, 2011, has recently been described from Krasiejów, on the basis of numerous moulds. Apart from bivalves, fossils of a cycloid, a crab-like crustacean (*Opolanka decorosa*), ostracods and phyllopods were recovered here (Dzik, 2008). Coleoptera (beetles) are on record from sediments formed beyond the aquatic environments.

Remains of ganoid and dipnoan fishes comprise scales, teeth and larger fragments of the skeleton; these are awaiting publication. The same holds true for skeletal material of sphenodonts, pterosaurs and very numerous, tiny bones of unknown animals – perhaps small mammals.

Larger vertebrates

Metoposaurus was the commonest aquatic vertebrate of the Upper Triassic wetlands. Recent microscopic studies of this huge amphibian have focused on long bones and vertebrae (Konietzko-Meier and Sander, 2013; Konietzko-Meier et al., 2013); currently, the skull and mandible bones receive most attention (Fig. 4). Remains of metoposaurids are known also from Morocco, North America, India and Germany. The German species, which was described in 1842 by Hermann von Meyer, is, anatomically speaking, the most closely similar to the Polish taxon. Both of them are considered to belong to the same species, *Metoposaurus diagnosticus*, but small differences in skull anatomy led Sulej to distinguish two subspecies in 2002, namely *Metoposaurus diagnosticus diagnosticus* for older form from Germany and *Metoposaurus diagnosticus krasiejowensis* from Krasiejów. Brusatte et al. (2015) described a new species of *Metoposaurus* from the Algarve, southern Portugal, and raised the Polish *Metoposaurus* to species rank, *Metoposaurus krasiejowensis*.

Metoposaurids were huge, 2-m-long aquatic temnospondyl amphibians with dorso-ventrally flattened bodies (Sulej, 2007). They probably lived at the bottom of shallow-water reservoirs, as ambush predators hunting for fish and other small vertebrates (Fig. 5). For air, they had to resurface regularly and the main mode of locomotion (swimming) was via the long and laterally flattened tail. The most characteristic feature of their skull is the location of the orbits; these did not lie on the top posterior parts of the skull, like in extant crocodiles, but were located in the anterior skull region, near the nostrils. Such placement of the orbits helped this aquatic predator in its search for prey and during swimming in the murky waters (Sulej, 2007).

Fig. 4. *Metoposaurus krasiejowensis* – skull and left ramus of mandible.

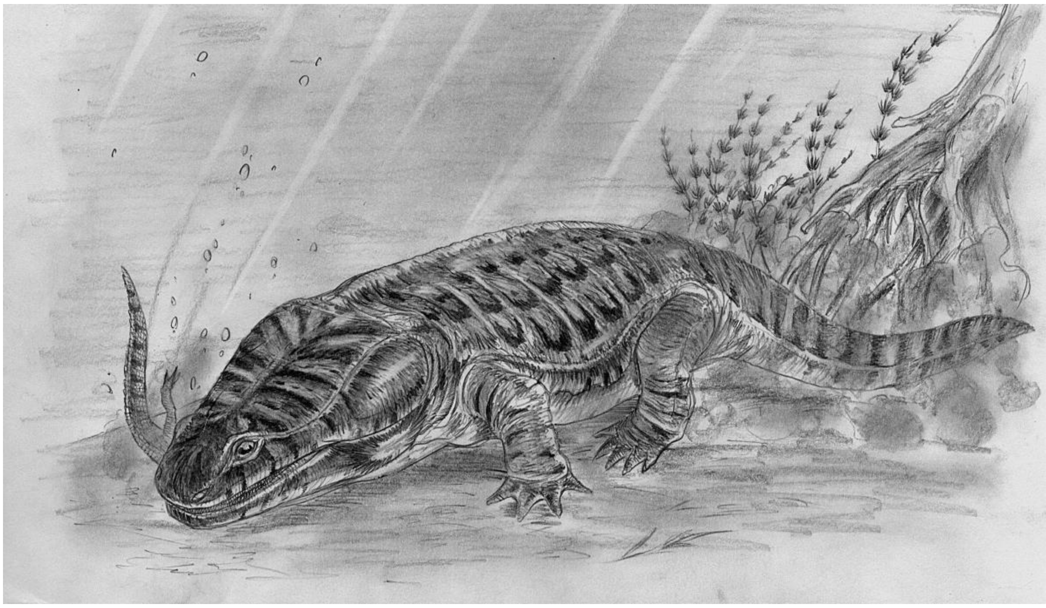


Fig.5. Reconstruction of *Metoposaurus krasiejowensis* during seizure of a small phytosaur.(project Kamil Gruntmejer; drawing by Jakub Kowalski).

Phytosaurs are the second commonest group of large vertebrates at Krasiejów, occurring in the lower bone bed. *Paleorhinus* sp. was a 3,5-m-long, semi-aquatic predator (Fig. 6), closely similar to extant gavials. Its skull was narrow, markedly elongated and possessed numerous, sharply pointed teeth adapted for a piscivorous habit. Features differentiating phytosaurs from Krasiejów from extant crocodylomorphs include the weak construction of the pelvis in the former, and the development of a secondary palate and a shift of the nostrils to the forehead as in extant whales (Dzik, 2001). The long jaws, slender body and extension of epiphyses in caudal vertebrae suggest that *Paleorhinus* was a fast and active predator in the waters at Krasiejów.

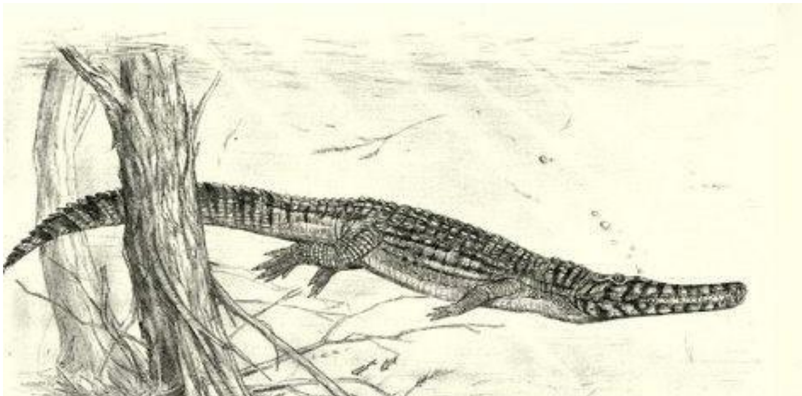


Fig. 6. Reconstruction of *Paleorhinus* sp. (drawing by Jakub Kowalski).

Capitosaurid temnospondyls are represented in Krasiejów by a single species, *Cyclotosaurus intermedius* (Fig. 7). This semi-aquatic, 3,5-m-long amphibian was a larger relative of *Metoposaurus*. Cyclotosaurids were the main predators near the edges of the bodies of water, their behaviour having been similar to extant crocodiles and alligators. The loss of lateral lines on their skull surface indicate that *Cyclotosaurus* was adapted for a predatory life style both in the water and in terrestrial habitats (Sulej and Majer, 2005). The location of the orbits in the posterior part of the skull and closure of the otic notch during evolution made capitosaurids hunt efficiently, from ambush, and exert a strong biting force.

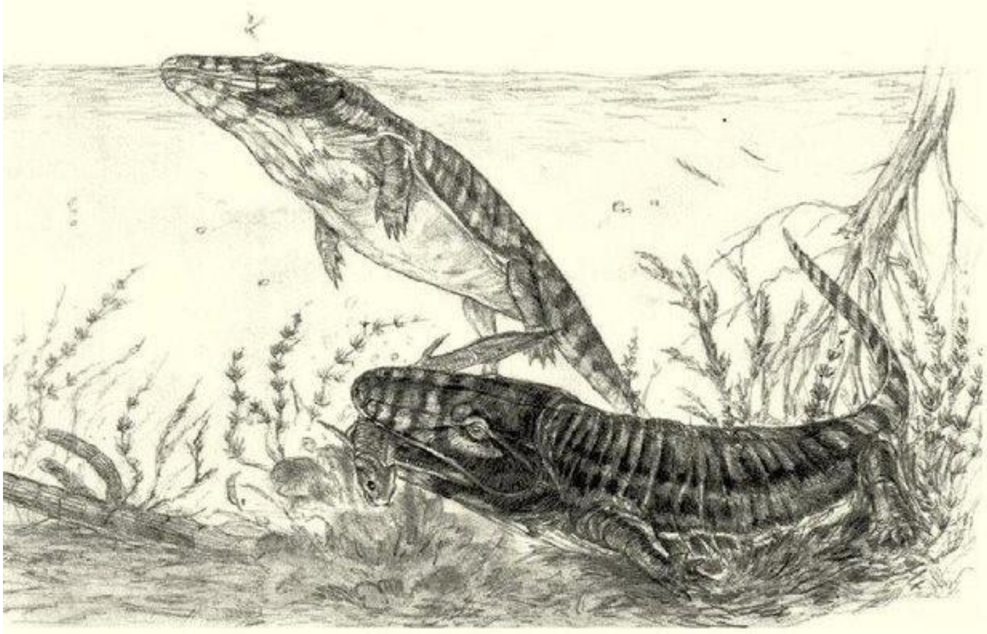


Fig. 7. Reconstruction of *Cyclotosaurus intermedius* (drawing by Jakub Kowalski).

Aetosaur remains (*Stagonolepis olankae*) are known from the lower and upper bone beds at Krasiejów. *Stagonolepis* was a herbivorous, 3,5-m-long archosaur with a heavily armoured body (Fig. 8). This natural armour played a protective role against attacks of large predators. The osteoderms overlapped closely and possessed diagnostic features used to differentiate amongst aetosaur species. Osteoderm morphology of the Polish aetosaur at first appeared to indicate its conspecificity with the Scottish species, *Stagonolepis robertsoni*. Subsequent studies of skull anatomy have shown this conclusion to be erroneous; the Krasiejów aetosaur is now considered a distinct species, *Stagonolepis olankae*. The skull of *Stagonolepis* was small and equipped with conical teeth and a horny beak on the mandible and a fleshy snout on the upper jaw (Sulej, 2010). Jaw morphology and tooth shape suggest that *Stagonolepis* used its snout to poke around amongst rhizomes and in the muddy bottom, in search of small invertebrate prey.

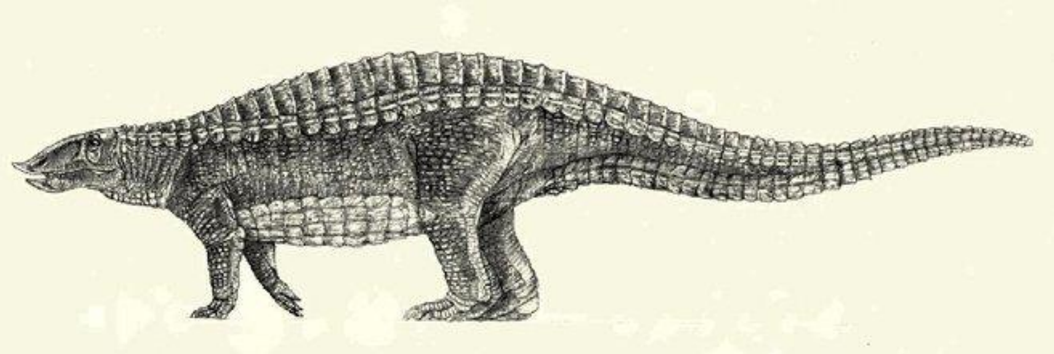


Fig. 8. Reconstruction of *Stagonolepis olankae* (drawing by Jakub Kowalski).

Polonosuchus silesiacus was the largest rauisuchian predator in the terrestrial habitat of Krasiejów. This 4-m-long archosaur was a seasoned hunter, specialising mainly in chasing armoured aetosaurs (Fig. 9). The Polish *Polonosuchus* is a smaller relative of the German genus *Teratosaurus* and the North American *Postosuchus*. At Krasiejów, rauisuchian remains were found in a thin layer of siltstones, between the upper and lower bone beds. All that is known at present are a single, incomplete skull, several vertebrae and isolated teeth. The most specific skull feature is the elastic and mobile connection of adjoining bones in the anterior part (Sulej, 2005). This elasticity of the skull made that teeth slipped from the aetosaur osteoderm surface during biting, to penetrate the soft tissues between these dermal plates. It is also possible that *Polonosuchus* could have been an ambush predator that went for smaller, yet faster animals.

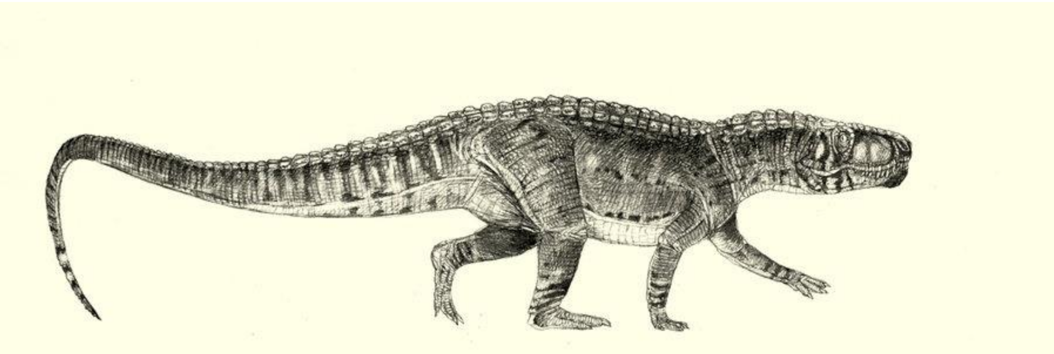


Fig. 9. Reconstruction of *Polonosuchus silesiacus* (drawing by Jakub Kowalski).

Bony remains of *Silesaurus opolensis* illustrate the unique and precious nature of the Krasiejów bone beds. *Silesaurus* was a small, *c.* 2-m-long, herbivorous dinosauromorph, *i.e.*, an intermediate form between archosaurs and dinosaurs (Fig. 10). The construction of its hind legs and pelvis and the open-work structure of the cervical vertebrae constitute features that are typical of the dinosaur lineage. On the other hand, skull morphology and tooth shape are characteristically archosaur. The delicate construction of the skeleton, and the fact that remains of several individuals were found accumulated in a single spot, suggest that *Silesaurus* was an agile, herbivorous animal (Dzik, 2003). During feeding the partially edentulous mandible with a horny beak at its end was used. Both its agility and life in a herd helped in spotting larger, yet slower, predators and in running from them. It is difficult to imagine that this small and inconspicuous species is closely related to the majestic, herbivorous ornithischian dinosaurs from the Jurassic and Cretaceous.

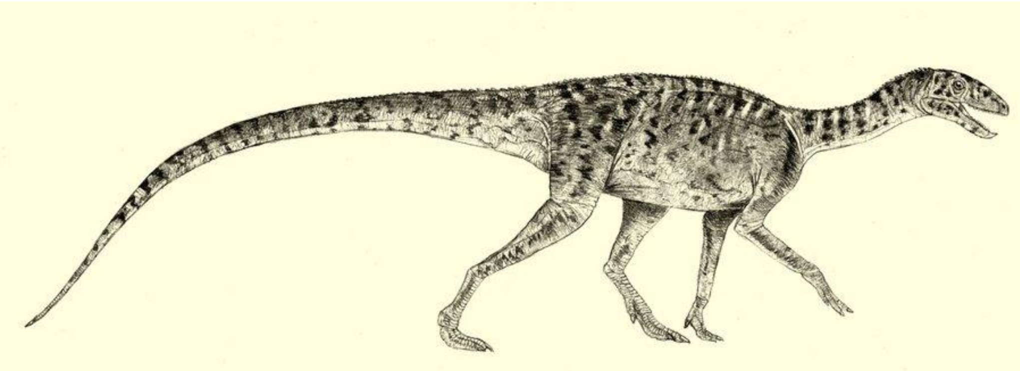


Fig. 10. Reconstruction of *Silesaurus opolensis* (drawing by Jakub Kowalski).

Agrotourism in Krasiejów

In recent years, the area of the former claystone pit at Krasiejów has been developed and in 2010 the 'Jurapark' opened its doors to the public It is the largest European object of science, amusement and agrotourism. Visitors can marvel at life-size models of prehistoric creatures, beginning from the Triassic and extending into the Cretaceous (Fig. 11A). Here also there is a palaeontological museum with exhibits of fossils and skeletal reconstructions of vertebrates from Krasiejów (Fig. 11B). During summer, visitors can experience what makes palaeontologists tick at special digs near the pavilion (Fig. 11C). Moreover, in 2014, just next to 'Jurapark' complex a new facility was opened, 'The Science and Human Evolution Park'. This modern object offers visitors a multimedia exploration of the museum which hosts life-size models of early hominids and illustrates the evolutionary process that led from our ancestors to modern man (Fig. 11D). Due to these tourist attractions and primarily because of the palaeontological excavations, young researchers from around the world visit Krasiejów every year. The sheer number of fossils and their unique nature (on a European scale) have turned Krasiejów into the largest bone bed of the Upper Triassic across Europe and the one that is most valued by research institutes abroad.

Fig. 11A-D. Tourist attractions in the 'Jurapark' complex. **A.** Life-size models of *Tyrannosaurus rex* and *Triceratops horridus*. **B.** Skeletal reconstructions of vertebrates from Krasiejów in the palaeontological pavilion. **C.** Palaeontological excavations in 2014. **D.** Life-size hominid model in the Science and Human Evolution Park.

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Stratigraphy and faunal content of Turonian strata in the Opole area, southwest Poland

Elena A. Jagt-Yazykova[1,*] and John W.M. Jagt[2]

[1]Uniwersytet Opolski, Katedra Biosystematyki, ul. Oleska 22, 45-052 Opole, Poland, e-mail: eyazykova@uni.opole.pl (*corresponding author); [2]Natuurhistorisch Museum Maastricht, de Bosquetplein 6-7, 6211 KJ Maastricht, the Netherlands

Scientific studies of Cretaceous marls and limestones in the Opole area (Fig. 1) are linked closely to the development of the cement industry (since the 1850s), ever since the introduction of the first types of Portland Cement. In 1841, Friedrich Adolf Roemer was the first to come up with the proper age assignment of these rocks, by equating the so-called 'Opole Cretaceous' with the Chalk Marl in Great Britain. The same author (F.A. Roemer, 1841, 1864) studied some fossils from the German Cretaceous, compared them with material from the Opole Cretaceous, and described twenty-one species from so-called 'scaphite beds' of the latter area. One of the most influential papers on the geology (and palaeontology) of Silesia is *Geologie von Oberschlesien* by Ferdinand Roemer (1870), who outlined the lithostratigraphy of Cretaceous strata in Opole, distinguishing sands and sandstones, calcareous marls and calcareous sandstones with muscovite. Later, German scholars visited these outcrops, and recorded various species of macrofossils (sponges, echinoids, ammonites). Of particular note was a paper by Leonhard (1898), who illustrated the geology of the region in a much more professional way, in particular the rocks of Turonian age. He distinguished between grey sandy-marly clays with pyrite nodules but barren of fossils, marly limestones with *Inoceramus brongniarti*, and beds with *Scaphites geinitzi*, as well as those with *Inoceramus cuvieri*. According to Leonhard, the Cenomanian was developed here only in a sandy facies and most of the fossils and sections described by the Roemer brothers were exclusively from the scaphite beds. In the upper part of the interval with *Inoceramus brongniarti* he noted two marly layers with the brachiopod *Terebratulina gracilis*.

The start of the twentieth century did not contribute much to our knowledge of the palaeontology of the Cretaceous in the area, but numerous new boreholes did enable a better understanding of the lithological column. Palaeontological studies were resumed by the publication of a paper by Wegner (1913), who described a few dozen species of sponge, coral, bryozoan, cephalopod, crinoid and others, some of them representing the only specimens ever to have been recorded from the area – this may be due either to improper classification and sampling or to a loss of outcrops from which this material had been collected.

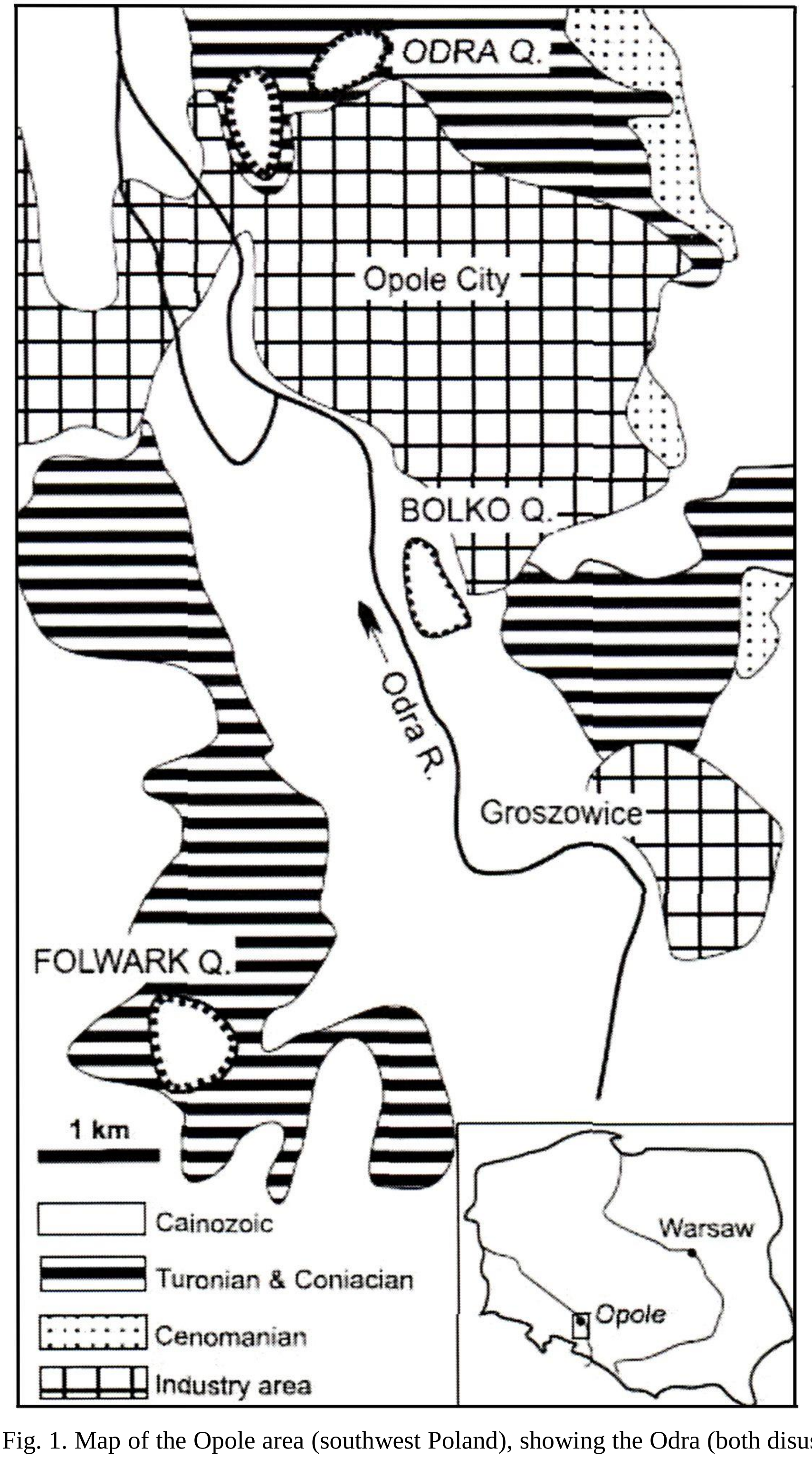


Fig. 1. Map of the Opole area (southwest Poland), showing the Odra (both disused and currently exploited), Bolko (disused/flooded) and Folwark quarries (from Mazurek, 2008).

Much more recently, in 1960, Biernat presented a geological map of the city of Opole. Some macro- and microfossils were also described, and the lithological zonation was corrected. As far as the biostratigraphy of Turonian strata is concerned, the *Inoceramus labiatus* Zone (exclusively on the basis of microfossils) was distinguished, as were the zones of *I. lamarcki* and *Scaphites geinitzi*. Other high-ranking papers include that by Aleksandrowicz (1974).

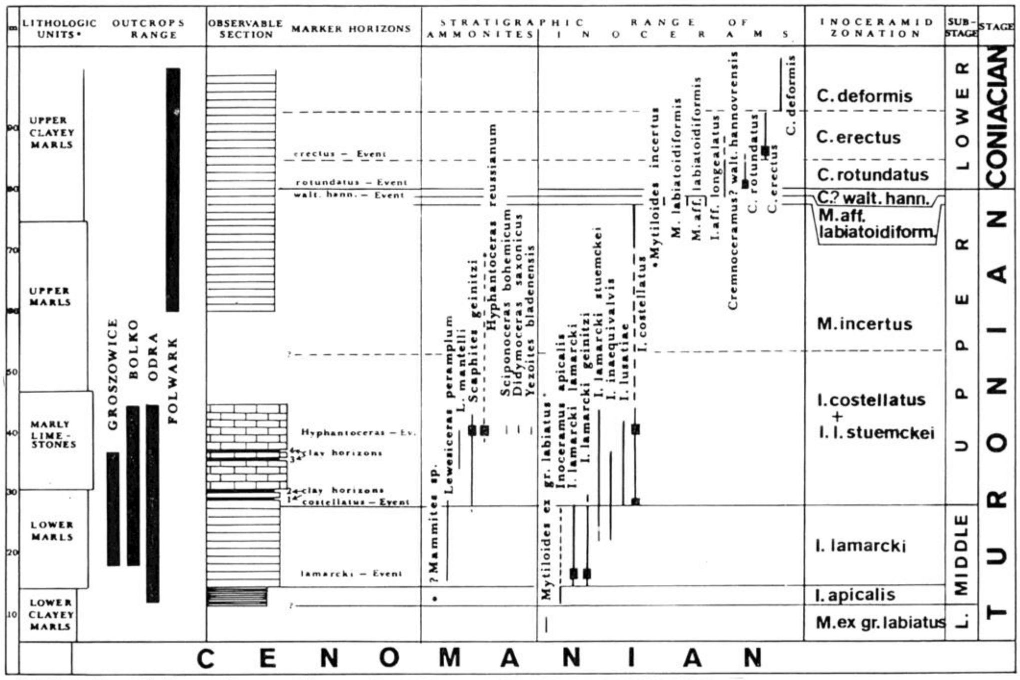
Following analysis of borehole cores and extensive outcrop sampling, the following lithological scheme could be presented (Figs 2, 3):

1. Sands and sandstones (Cenomanian);
2. Lower clayey marls (lower-middle Turonian);
3. Lower marls (middle Turonian);
4. Marly limestones (upper Turonian);
5. Upper marls (upper Turonian);
6. Upper clayey marls (upper Turonian-lower Coniacian).

NOTE: At the Odra quarry, only units 2, 3 and 4 are exposed to date. Units 2-6 were referred to as the Prószków Formation.

An attempt at synthesis of all current data on the Opole Cretaceous was made by Tarkowski (1991), who focused on biostratigraphy and macrofaunas. A more workable biozonation can be found in a subsequent paper (Tarkowski, 1996). The macrofaunal assemblages described in these papers are in need of re-evaluation and additional comments. Independent work on biozonations was done by Walaszczyk (1988, 1992), who presented clear divisions based on well-known inoceramid taxa (Fig. 2).

Kędzierski (1995) discussed microfaunas, and recently detected lower Turonian strata at the Odra quarry (see Kędzierski, 2008; Fig. 3), while Kędzierski & Uchman (2001) presented an outline of ichnofossil assemblages (ichnofabrics). Olszewska-Nejbert (2007) recorded irregular echinoids from the upper part of the section exposed at the Odra quarry, noting numerous specimens of *Micraster* and *Echinocorys*.



*) Lithologic subdivision and inoceramid range *after* ALEXANDROWICZ & RADWAN (1973)

Fig. 2. Lithostratigraphy, ammonite and inoceramid bivalve ranges and inoceramid biostratigraphy of Turonian strata in the Opole area (see Fig. 1; from Walaszczyk, 1988).

Vertebrates

At the Odra quarry (all Turonian; Figs 2, 3) and at other outcrops in the Opole area (Folwark and Bolko quarries; Cenomanian-Coniacian), fish remains are quite abundant, but usually of small size (and thus easily overlooked) and often undiagnostic, which explains why the ichthyofauna is rather poorly known. Sharks usually occur as isolated teeth or tooth crowns, whereas teleosts (the commonest group of osteichthyans) can be collected as isolated teeth, scales or bones, or in concentrations in connection with trace fossils (in particular *Lepidenteron lewesiensis*; see Jurkowska & Uchman, 2013; Bieńkowska-Wasiluk et al., 2015), burrows (i.e., bottom current resedimentation) or residues/regurgitates of piscivorous animals.

Leonhard (1898) described three shark species, *Hybodus dentatus*, *Notidanus microdon* and *Ptychodus mammillaris*, and also found some unidentified corprolites and vertebrae. Ganoids recorded are all pycnodonts: *Coelodus complanatus*, *Coelodus cretaceus* and *Ganoideorum*? sp., while teleosts noted include *Enchodus halocyon*, *Osmeroides lewesiensis*, *Beryx zippei*, *Beryx* sp., *Saurocephalus marginatus* and *Protosphyraena ferox*.

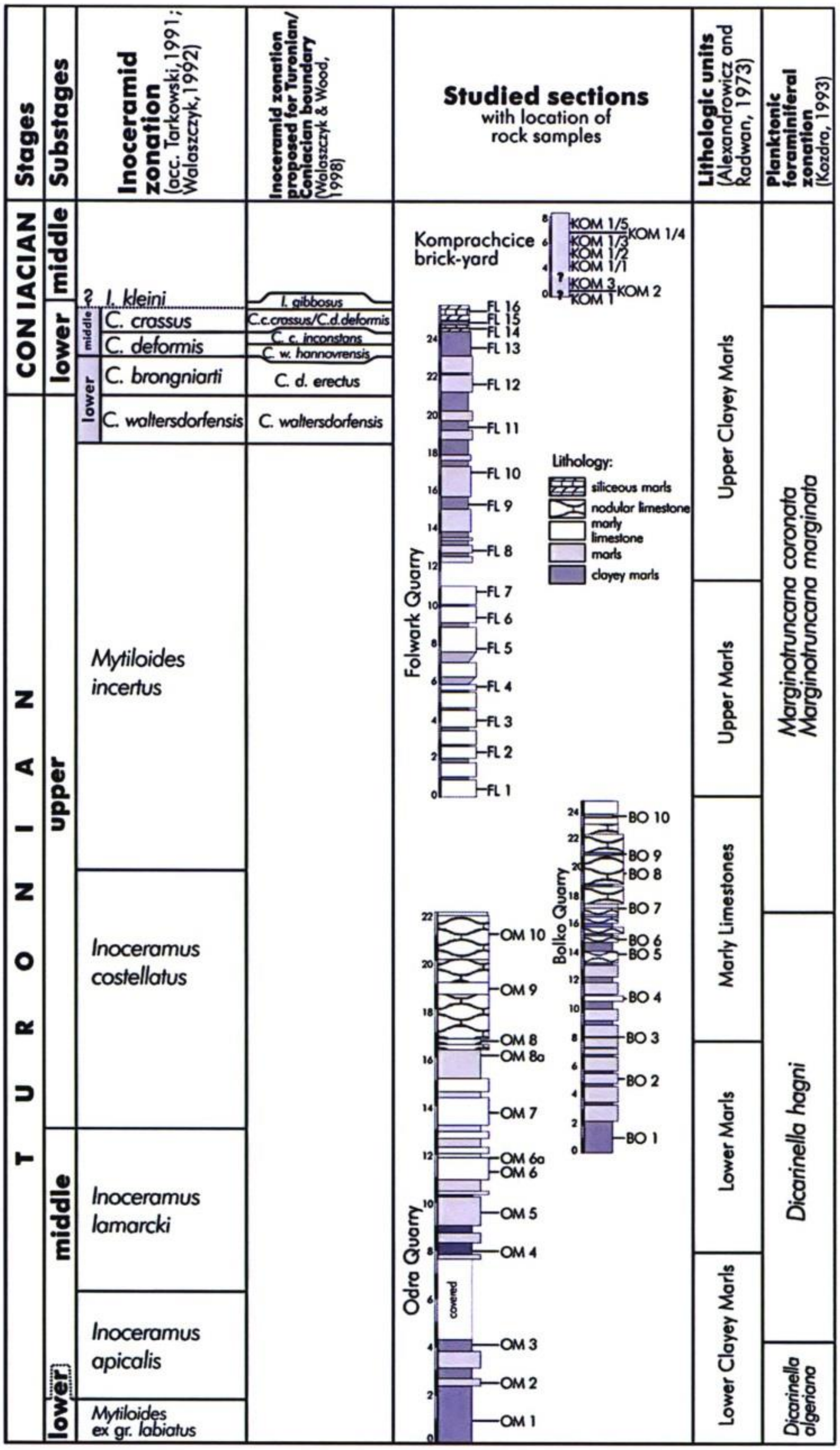


Fig. 3. Inoceramid biozones, lithostratigraphy and planktonic foraminiferal biostratigraphy of Turonian-Coniacian strata in the Opole area (see Fig. 1; from Kędzierski, 2008).

Osteichthyans have virtually remained unrecorded since then, whereas Niedźwiedzki & Kalina (2003) dealt with sharks from Opole, recording mainly ptychodontids, e.g., *Ptychodus latissimus*, *Ptychodus polygyrus* and *Ptychodus mammillaris*. Other sharks are represented as well, and include, according to those authors, anacoracids (*Squalicorax* sp.), mitsukurinids (*Scapanorhynchus raphiodon*), alopiids (*Paranomotodon angustidens*) and unidentified cretoxyrhinids.

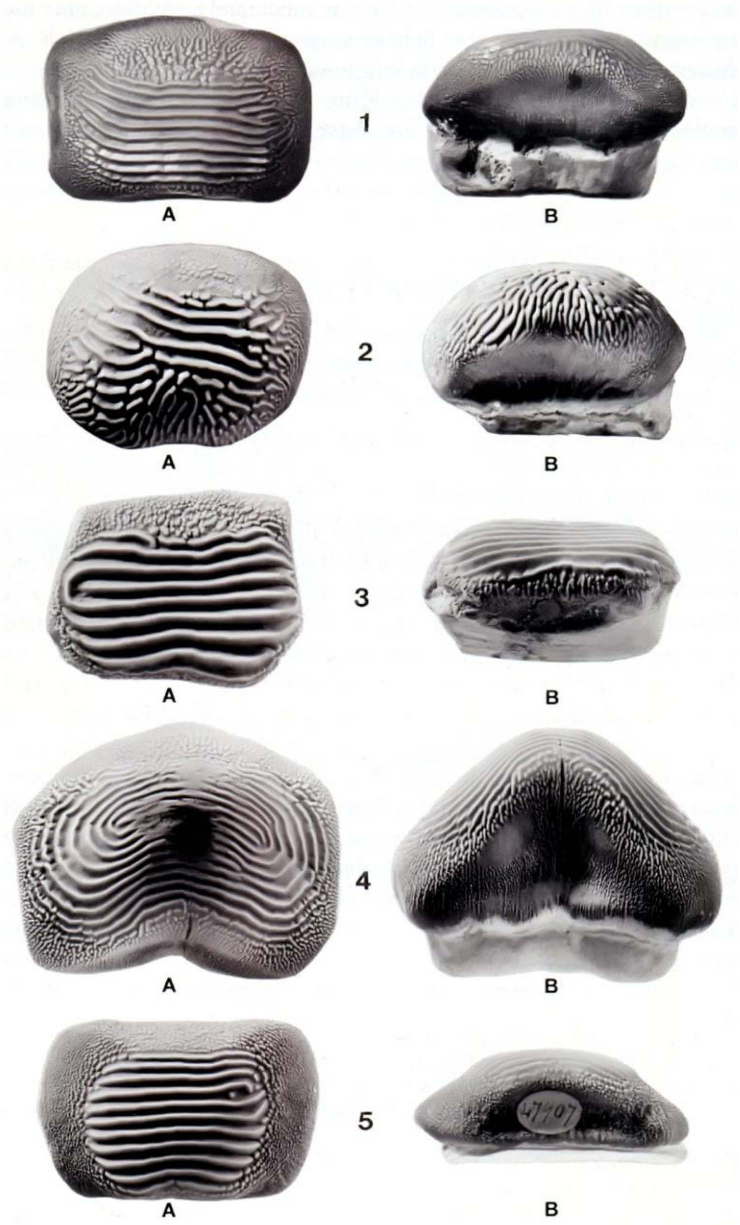


Fig. 4. Teeth of ptychodontid sharks, as follows: *Ptychodus decurrens* (1), *P. oweni* (2), *P. polygyrus* (3), *P. concentricus* (4) and *P. marginalis* (5) (after Longbottom & Patterson, 2002).

Ptychodus was a shell-crushing shark (Fig. 4). At the Odra quarry, accumulations of such teeth also occur; the Lower Marls, especially the lower part of that unit, have yielded a sample of mainly *P. mammillaris* teeth, which maybe linked to the common occurrence of small-sized inoceramid taxa and heteromorph ammonites here. Higher up section, *P. latissimus* and *P. polygyrus* also occur, associated with their preferred food items, i.e., large inoceramids. Other shark remains found recently comprise mainly cretoxyrhinid teeth, as well as numerous other lamniforms. A few unidentifiable shark coprolites (or intestinal fillings; see Hunt et al., 2015) have been collected as well; these appear to be fairly common in the Lower clayey marls, in particular below two prominent limestone levels (Fig. 3).

Other vertebrate taxa are virtually unknown from the Opole area, although possible turtle remains have been recovered in recent years.

Acknowledgements

We thank Dawid Mazurek (currently Polish Academy of Sciences, Institute of Paleobiology, Warszawa) for allowing us to use some of his unpublished notes on the Opole Cretaceous and its faunal assemblages, compiled subsequent to his master's thesis (Mazurek, 2008).

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FIELD NOTES

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