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Late Cretaceous sharks in the Opole Silesia region (SW Poland)

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Abstract The upper Cretaceous deposits of the Opole Trough contain rare but relatively diverse shark teeth, mainly from ptychodontid sharks (*Ptychodus latissimus* Agassiz, 1843, *Ptychodus polygyrus* Agassiz, 1843 and *Ptychodus mammillaris* Agassiz, 1843), Anacoracidae (*Squalicorax* sp.), Mitsukurinidae (*Scapanorhynchus raphiodon* (Agassiz, 1843)), Alopiidae (*Paranomotodon angustidens* (Reuss 1845)) and Cretoxyrhinidae. *Paranomotodon angustidens* has not previously been reported from the Opole Trough. The selachians from the Opole Basin can be divided into two trophic groups: bottom-dwelling ptychodontid sharks with a diet consisting of shelly invertebrates, and pelagic Lamniformes, which were active predators feeding on fast-swimming fish and reptiles. The morphology of the teeth, signs of abrasion and the analysis of the invertebrate assemblage from the Opole Cretaceous suggest that the ptychodontids fed on inoceramid bivalves, while the lamniform sharks fed mostly on fish.

Lamniformes live in all marine environments, and their remains are numerous in all the lithostratigraphic units of the Upper Cretaceous in the Opole Trough. The teeth of deep-water ptychodontid sharks are only abundant in the middle part of the Middle Turonian sediments. Nearshore shark remains are extremely rare in the Cretaceous deposits of the Opole Trough. This indicates that the Middle Turonian (middle *I. lamarcki* Zone) represents the deepest environment of the Opole Cenomanian and Turonian.

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INTRODUCTION

The Opole Basin was one of the Circum Sudetic Trap Basins surrounding the Sudetic Islands. Therefore, the evolutionary behaviour of the Opole Basin was similar to the evolutionary behaviour of the Bohemian Basin, the Saxonian Basin and the North Sudetic Basin (Walaszczyk, 1992). The purpose of this paper is to describe the shark assemblage of the Upper Cretaceous of the Opole Trough and its meaning in terms of the interpretation of the paleoenvironment.

There are various ways of grouping sharks ecologically (Cappetta, 1987; Williamson *et al.*, 1989; Rees, 1999). One of the most important criteria is their trophic adaptation. The pelagic sharks, e.g. *Cretolamna* Glückman, 1958, Squalicorax falcatus (Agassiz, 1833–1843), and especially *Cretoxyrhina mantelli* (Agassiz, 1843), fed on large marine reptiles like mosasaurs and plesiosaurs (Siverson, 1992; Shimada, 1997). Clear evidence of this has been found in the form of reptile remains in shark stomach content, shark teeth embedded in mosasaur bones, and shark bite marks on reptile bones (Shimada, 1997). Ptychodontids fed on prey with resistant shells. According to Cappetta (1987), species of *Ptychodus* with a high crown and relatively narrow triturating zone (e.g. *P. mammillaris* Agassiz, 1843, *P. rugosus* Dixon, 1850) attacked thin-shelled prey, while ptychodontids with a flatter crown and a broad triturating zone (e.g. *P. polygyrus* Agassiz, 1843, *P. latissimus* Agassiz, 1843, *P. decurrens* Agassiz, 1843) fed on thick-shelled bivalves. Possible ptychodontid tooth impressions on found *Inoceramus* shells, the positive correlation existing between the abundance of *Ptychodus* and *Inoceramus* (Kauffman, 1972, *fide* Williamson *et al.*, 1991), and the abundant inoceramid shell biodetritus in *Ptychodus* coprolites all suggest that inoceramids were the main diet of *Ptychodus*, although they probably also ate ammonites (Cappetta, 1987). Selachian teeth thus have a great potential for paleobathymetric interpretation.

Cretaceous selachian remains are rare in the studied area. The shark remains of this region were first studied by Roemer (1870), but the largest collection from the Opole Cretaceous was described by Leonhard (1897–98). The latter reported the first Cenomanian fish (e.g. *P. mammillaris*) from the region. Teeth belonging to *Hybodus dentalus* (Leonhard 1897–98), *Hexanchus microdon*

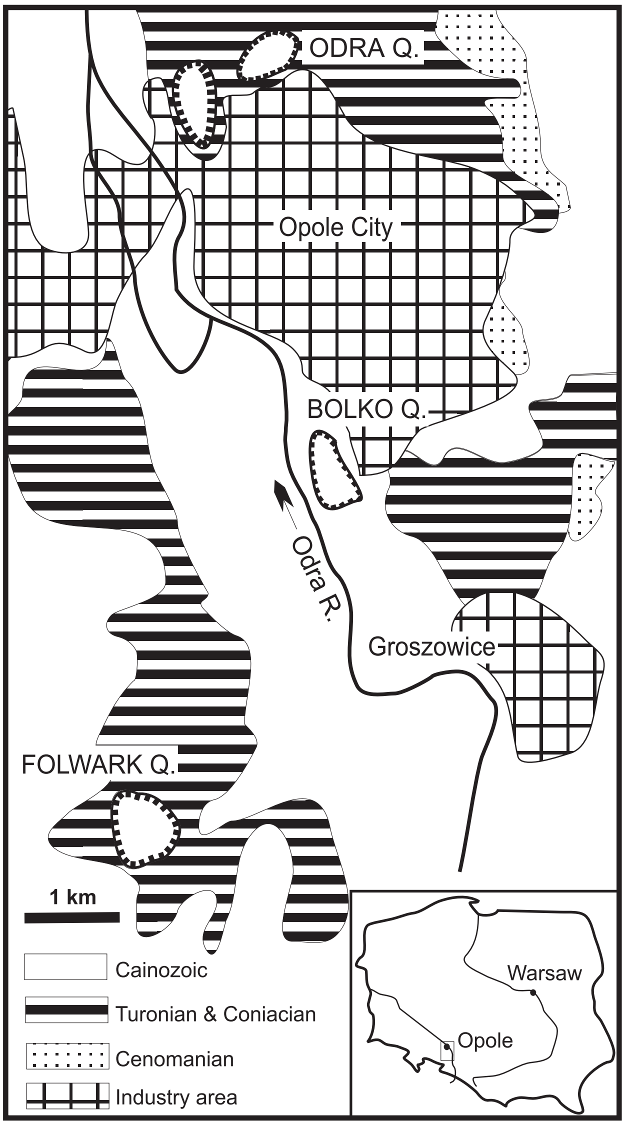


Fig. 1. Geological sketch-map of the Opole area (after Walaszczyk, 1988; simplified).

(Agassiz, 1843), *Odontaspis subulata* (Agassiz, 1844), *Synechodus major* (Agassiz, 1843), *Scapanorhynchus raphiodon* (Agassiz, 1843), *Cretolamna appendiculata* (Agassiz, 1843), *Cretoxyrhina mantelli* and *Squalicorax falcatus* were reported from the Turonian of the Opole region by Roemer (1870) and Leonhard (1897–98). Their precise stratigraphic location is unknown. The latter author also described several taxa of Teleostei fish and isolated teeth and bones of plesiosaurs and mosasaurs from the Turonian deposits. More recently, a single tooth of *Ptychodus rugosus* from the Middle Turonian of the Odra Quarry was found by Radwański & Marcinowski (1996). The scales and teeth of undetermined fish were mentioned by Tarkowski (1991) and Kaczorowski (1997). Tarkowski (1991) also described the first occurrence of Early Coniacian fish remains.

GEOLOGICAL SETTING

The Upper Cretaceous rocks (Fig. 1) are exposed in the eastern and southern part of the Opole Trough. Also, small isolated fragments of the Cretaceous cover crop out on Góra Św. Anny (e.g. Niedźwiedzki, 1994) and near Głubczyce.

The Opole Trough contains Middle Cenomanian through Middle Coniacian deposits (e.g. Walaszczyk, 1988, 1992). The Cenomanian comprises sands and sandstones with glauconite. In the upper part of the stage, intercalations of marly or argillaceous sandstones are common (Alexandrowicz & Radwan, 1973). The overlying Turonian–Middle Coniacian rocks are built of argillaceous marls, marls and marly limestones. In the whole succession, the content of terrigenous input gradually diminishes upwards, up to the lower Upper Turonian (with the minimum in the Marly Limestones Unit, Fig. 2); higher up, starting with the Upper Marls Unit, its content increases again. This symmetry is clearly visible in the informal lithostratigraphic subdivision (Fig. 2) of the Opole Cretaceous by Alexandrowicz & Radwan (1973). The highest, Middle Coniacian sequence, known exclusively from boreholes, includes mudstones and marly clays (Radwańska, 1969).

The Cenomanian sandstones contain rare but relatively diverse fossils (see Roemer, 1870; Leonhard, 1897–98; Tarkowski, 1991). Inoceramids and sponges dominate the Turonian–Middle Coniacian assemblages (Kaczorowski, 1997; and our own data). Ammonites, brachiopods and echinoids are less common. Crinoids, gastropods and Scleractinia (mainly solitary corals) are extremely rare (Roemer, 1870 and our observations). The whole succession contains abundant terrestrial plant remains and is intensively bioturbated (see Kędzierski & Uchman, 2001). The richest and the most diverse macrofossil assemblage characterises the Marly Limestones Unit, whereas the Lower Argillaceous Marls and Upper Argillaceous Marls Units are less fossiliferous (Alexandrowicz & Radwan, 1973; Kaczorowski, 1997; and our data). Fossils are moderately abundant in the other units. Both planktonic and benthonic foraminifera assemblages are common and diverse in the whole Turonian–Lower Coniacian succession (Alexandrowicz & Radwan, 1973; Kłapciński & Teisseyre, 1981).

THE PALEOENVIRONMENT OF THE OPOLE BASIN

The marine transgression reached the Opole region in the Middle Cenomanian. There are two interpretations of the further paleobathymetric history of the Opole Cretaceous. According to Tarkowski (1991), the abundant terrigenous quartz (grains up to 1 cm in diameter) and glauconite in the Cenomanian and lowermost Turonian indicates that these deposits were formed in a nearshore and shallow environment. The Lower Marls Unit (middle *I. lamarcki* Zone-lowermost *I. perplexus* Zone; Fig. 2) represents a deeper and more distal environment (Tarkowski, 1991). Based on ammonoids, Kaczorowski (1997) suggests that the Marly Limestones Unit (middle *I. perplexus* Zone-lower *M. scupini* Zone; Fig. 2) was deposited during the maximum transgression (depth about 100–150 m); this is consistent with Tarkowski's (1991) interpretation. Regression in the Opole Basin began in the middle Late Turonian and continued till the Middle Coniacian, when the bathymetric conditions and energy regime once again became similar to those of the Cenomanian (Tarkowski, 1991; Kaczorowski, 1997).

However, according to Kędzierski & Uchman (2001), the trace fossil assemblages of the Marly Limestones Unit represent a much shallower environment compared to the trace fossil assemblages of the Lower and Upper Marls Units.

The benthonic fauna in the Lower Argillaceous Marls and Upper Argillaceous Marls Units (Fig. 2) is scarce and poorly diversified. This could result from anoxia, indicated by numerous *Chondrites* and *Trichichnus* traces, which are characteristic for less oxygenated deposits (Kędzierski & Uchman, 2001). Abundant *Thalassinoides* trace fossils occur in the Lower and Upper Marls Units and in the Marly Limestones Unit (Kędzierski & Uchman, 2001); they are typical of well-oxygenated environments (Ekdale & Bromley, 1984; Savrda & Bottjer, 1989). Furthermore, there is a rich assemblage of benthonic fora-

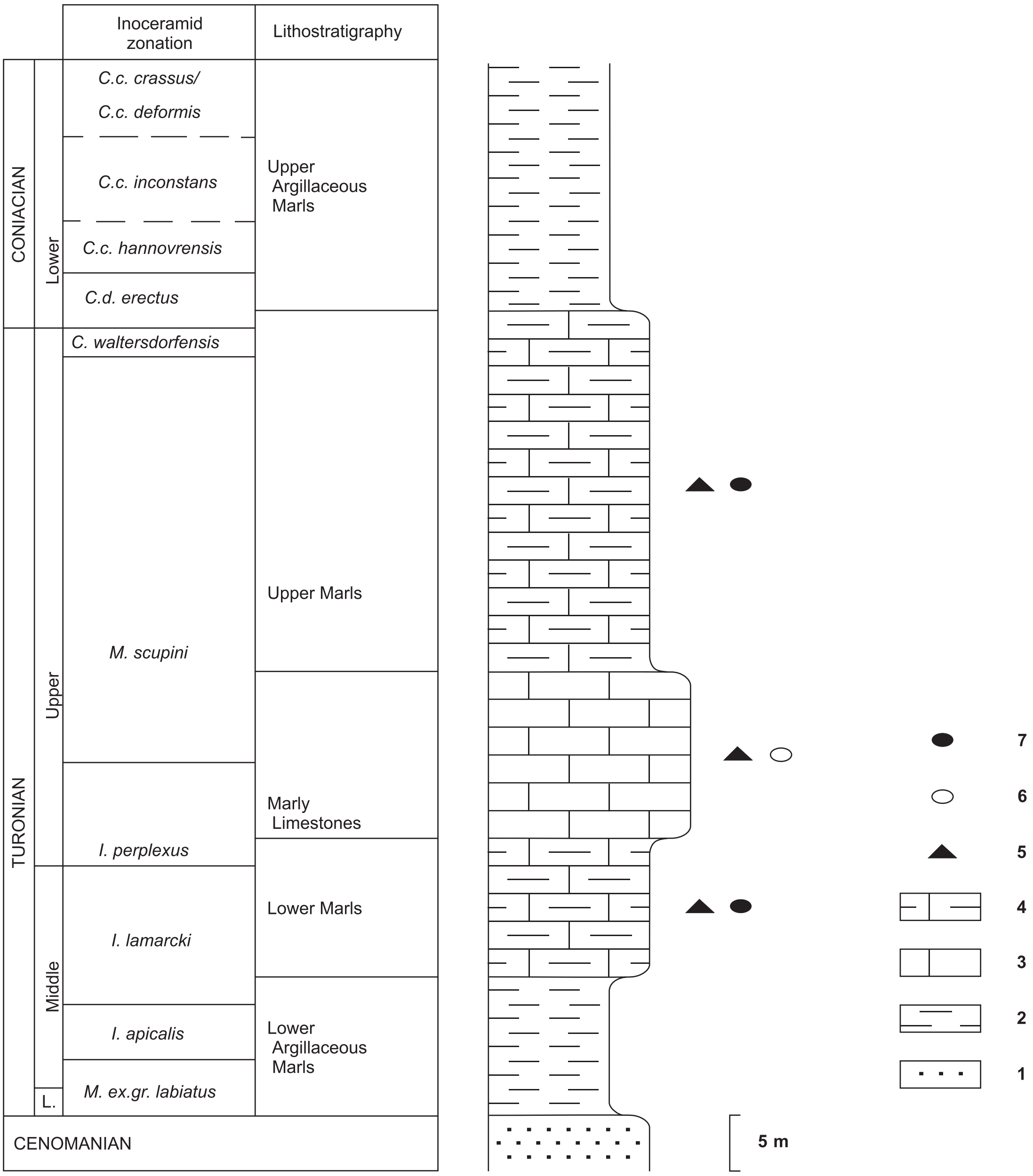


Fig. 2. Lithostratigraphic and biostratigraphic subdivisions of Opole Cretaceous (according to Alexandrowicz & Radwan, 1973; Walaszczyk, 1988, 1992; Kaczorowski, 1997; Walaszczyk & Wood, 1998; Walaszczyk & Cobban, 2000; Kędzierski & Uchman, 2001). *1* – sandstones; *2* – argillaceous marls; *3* – marly limestones; *4* – marls; *5* – numerous teeth of lamniform selachians; *6* – rare teeth of *Ptychodus*; *7* – numerous teeth of *Ptychodus*.

minifers (Alexandrowicz & Radwan, 1973), which also suggests well-oxygeneted conditions. The Lower and Upper Marls Units are probably relatively less fossiliferous than the Marly Limestones Unit because there was a very soft clayey bottom and the water was rich in clayey suspension during the deposition of the Lower and Upper Marls Units.

MATERIAL

The studied material was collected in the Odra, Bolko and Folwark quarries (Fig. 1). All the specimens are represented by isolated teeth (Fig. 3–5) and by rare partial vertebral centra. Neoselachii teeth (8–25 mm) are mostly incompletely preserved, without the base of the cusplets, roots and without the lateral cusplets (Fig. 4.4; Fig. 5.2), a state which hindered their precise taxonomic determination. The majority of the specimens come from the lower and middle part of the Lower Marls Unit (*I. lamarcki* Zone) of the Odra Quarry. The following specimens were recognised: 23 teeth of *Ptychodus mammillaris*, two teeth of *Ptychodus polygyrus*, a single tooth of *Scapanorhynchus raphiodon*, 5 teeth of Cretoxyrhinidae (e.g. Fig. 4.4), a fragment of a single Neoselachii tooth, four shark partial vertebral centra, and coprolites. Layers with *Ptychodus* contain relatively numerous inoceramids, while ammonites are represented by scarce, large *Lewesiceras* with thick shells. Radwański & Marcinowski (1996) also reported a single tooth of *Ptychodus rugosus* from the upper part of the Lower Marls Unit in the Odra Quarry.

A single tooth of *P. mammillaris* and two teeth of Cretoxyrhinidae were collected from the middle part of the Marly Limestones Unit (the uppermost *I. perplexus* Zone) of the Bolko Quarry. Numerous (more than 10 specimens) fragmentary teeth of Lamniformes were found. Two teeth of *Squalicorax* sp. and a single tooth of *Paranomotodon angustidens* (Reuss, 1845) comes from the same level of the Odra Quarry.

Abundant Lamniformes teeth (Cretoxyrhinidae, one tooth of *Squalicorax* sp.) were collected from the upper part of the Upper Marls Unit (the uppermost *M. scupini* Zone) of the Folwark Quarry (e.g. Fig. 5.2, 5.3). According to Walaszczyk (pers. comm.), teeth of *Ptychodus* are common but their precise stratigraphic location is not known.

Additionally, one tooth of *P. latissimus* from the Opole Turonian (precise geographic location unknown) from the old German collection is housed at the Geological Museum of Wrocław University.

TAXONOMIC DESCRIPTION

Taxonomy and terminology after Cappetta (1987).

Class Chondrichthyes HUXLEY 1880
Subclass Elasmobranchii BONAPARTE 1838
Cohort Euselachii HAY 1902
Superfamily Hybodontoidea ZANGERL 1981
Family Ptychodontidae JAEKEL 1898
Genus *Ptychodus* AGASSIZ 1838

Ptychodus latissimus Agassiz, 1843
(Fig. 3.1.)

1843. *Ptychodus latissimus* Agassiz; L. Agassiz, p. 157, Pl. 25a, Fig. 1-6, Pl. 25b, Fig. 24-26
1870. *Ptychodus latissimus* Agassiz; F. Roemer, p. 323, Pl. 36, Fig. 7
1878b. *Ptychodus latissimus* Agassiz; A. Frič, p. 15, Fig. 36
1927. *Ptychodus latissimus* Agassiz; M. Książkiewicz, p. 997; Pl. 24, Fig. 3, 4, 13

Material. One incomplete specimen (MGUWr 4098s). The back part of the crown is damaged and it has a fragmentarily-preserved marginal area.

Description. The crown is low (Tab. 1). The triturating zone is of quadratic shape and is flat and broad. This zone is covered with seven very prominent, sharp, transverse, slightly wavy ridges. In the foreground and background of the zone, the ridges pass into discontinuous ridges or into a series of granules which are parallel to the ridges. The ridges extend down on the lateral faces of the central convexity to the marginal area. There are big granules on the lower ends of the ridges. The labial face is ornamented by granulation. This granulation is arranged parallel to the ridges in the upper part of the face and it is irregular in the middle and lower parts of the labial side. Narrow marginal areas are characterised by the presence of short wrinkles. They sometimes pass into the elongated granules. The wrinkles are slightly oblique to the central convexity. The upper part of the root is preserved. The root is massive and broad but narrower than the crown. MGUWr 4098s originates from the middle rows of the teeth.

Occurrence: Turonian–Campanian. USA, Europe, Saghalin. In Poland, this species is known from the Polish Jura Chain (Turonian, Campanian – see Książkiewicz, 1927) and the Opole Trough (Turonian).

Ptychodus mammillaris Agassiz, 1843
(Fig. 3.2 and 3.3; Fig. 4.1–4.3)

1843. *Ptychodus mammillaris* Agassiz; L. Agassiz p. 151, Pl. 25b, Fig. 12-20
1870. *Ptychodus mammillaris* Agassiz; F. Roemer, p. 324, Pl. 36, Fig. 8
1878a. *Ptychodus mammillaris* Agassiz; A. Frič, p. 98, Fig. 36
1878b. *Ptychodus mammillaris* Agassiz; A. Frič, p. 14, Fig. 33
1912-1913. *Ptychodus mammillaris* Agassiz; H. Scupin, p. 90, Pl. 3, Fig. 2

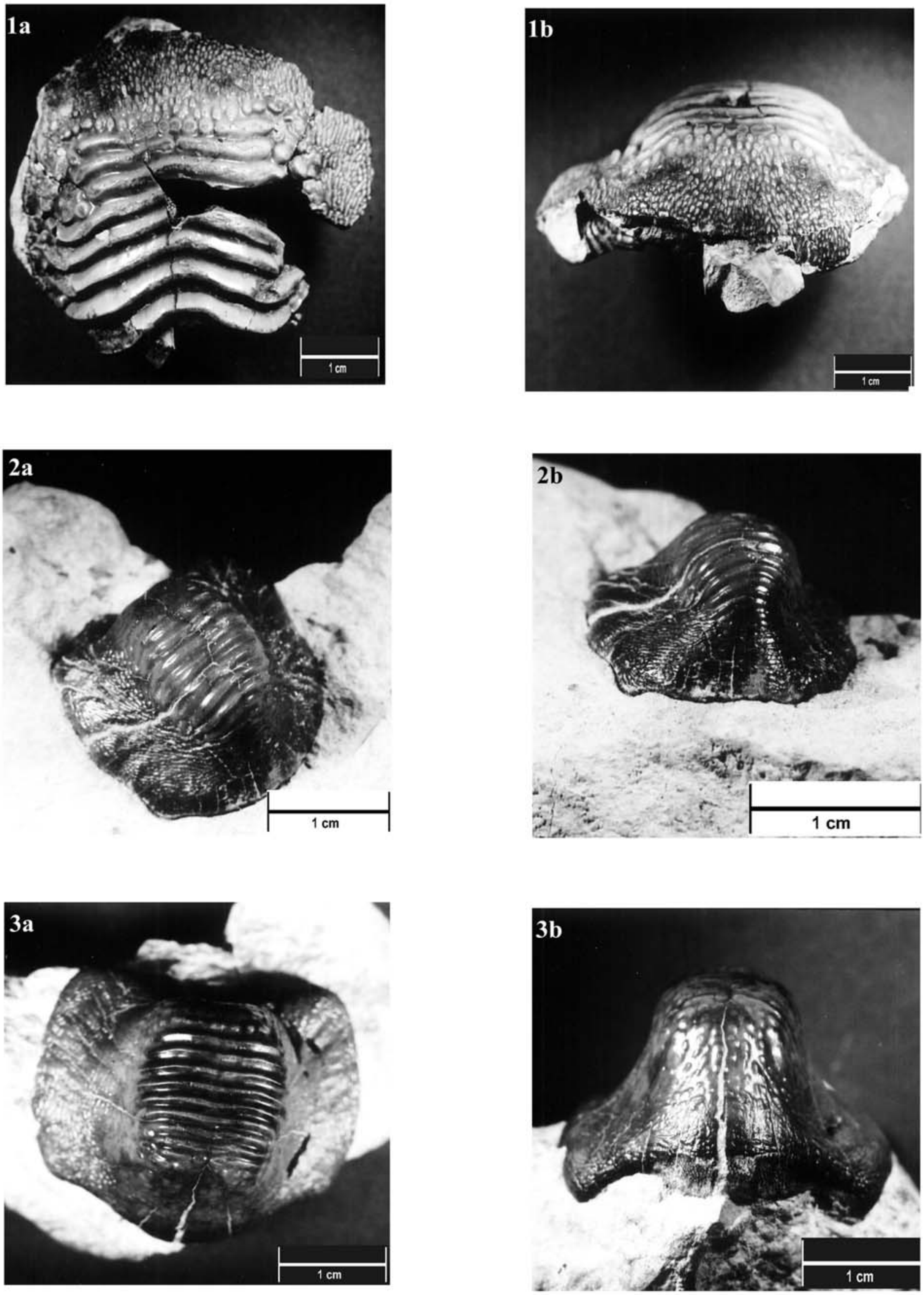


Fig. 3. 1. *Ptychodus latissimus* Agassiz, 1843. 1a – occlusal view; 1b – labial view. MGUWr 4098s, Turonian, Opole region; **2.** *Ptychodus mammillaris* Agassiz, 1843. 2a – occlusal view; 2b – labial view. MK.I.10.1; **3.** *Ptychodus mammillaris* Agassiz, 1843. 3a – occlusal view; 3b – labial view. MK.I.10. Specimens 2, 3: Odra Quarry; Turonian (Lower Marls Unit; *I. lamarcki* Zone).

Table 1

Measurements of specimens of *Ptychodus*
All dimensions in millimetres. Length (LC) – distance between the labial and lingual edges of the marginal area. Breadth (BC) – distance between the lateral edges of the marginal area (square with length). Height (HC) – distance between the base of the marginal area and the ridges of the triturating zone. The length, breadth and height (LCC, BCC, HCC) of the central crown (convexity) were measured from the base of the crown.

Specimen	LCC	BCC	HCC	LC	BC	HC	Abrasion	Location
P. latissimus								
MGUWr 4098s	-	36	8	-	26 (=0.5 BC)	14	-	?
P. mammillaris								
MK.I.1.10	23	17	9	25	30	15	-	Lower Marls Unit
MK.I.1.10.1	13	10	6	16.5	17	9	+	Lower Marls Unit
MK.I.1.4.1	8	5.5	5	-	-	7	+	Lower Marls Unit
MK.I.1.4.2	8	5	5	9	about 10	6	-	Lower Marls Unit
MK.I.1.4.3	8.5	6	6	11.5	15	10	+	Lower Marls Unit
MK.I.1.4.4	-	5	5	-	-	-	-	Lower Marls Unit
MK.I.1.4.5	-	10	6	-	-	8.5	-	Lower Marls Unit
MK.I.1.4.6	14	8	7	17	-	12	+	Lower Marls Unit
MK.I.1.4.7	-	-	-	6	4	4	-	Lower Marls Unit
MK.I.1.4.8	-	-		10.0	-	5	+	Lower Marls Unit
MK.I.1.4.9	-	-	6.5	7	7.5	3	+	Lower Marls Unit
MK.I.1.4.10	-	-	6	-	6	4	-	Lower Marls Unit
MK I.4.11	8.5	7	6	-	-	-	+	Lower Marls Unit
MK I.4.12	4.5	3	2	-	-	4.5	-	Lower Marls Unit
MK I.4.13	-	-	5.5	-	-		?	Lower Marls Unit
MK I.4.14	10	7	4,5	13	15	8	+	Lower Marls Unit
MK I.4.15	6.5	4	3.3	10	-	7	+	Lower Marls Unit
MK I.2.5.1	9	9	5	-	-	-	+	Lower Marls Unit
MK I.1.3	7.5	6	4	-	-	-	?	Lower Marls Unit
MGUWr 5296s	17	13	6.5	-	-	10	+	Lower Marls Unit
MGUWr 5297s	14	10	7	17	-	11	+	Lower Marls Unit
MGUWr 5298s	8	6	5	-	-	7	+	Lower Marls Unit
MGUWr 5299s	6	3.5	3	-	-	5.5	?	Marly Limestones Unit
MGUWr 5344s	6	4	3	9	-	5.5	+	Lower Marls Unit
P. polygyrus								
MK.I.2.5.	9.5	10	4	-	-	-	-	Lower Marls Unit
MK I.1.9	-	17	5.5	-	14 (=0.5 BC)	14.5	+	Lower Marls Unit

1927. *Ptychodus mammillaris* Agassiz; M. Książkiewicz, p. 999; Pl. 24, Fig. 10
1980. *Ptychodus mammillaris* Agassiz; J. Małecki, p. 53, Pl. Fig. 2, 5, 6
1983. *Ptychodus mammillaris* Agassiz; R. Marcinowski & A. Radwański, Pl. 8, Fig. 7
1999. *Ptychodus mammillaris* Agassiz; J. Trbušek, p. 54, Pl. 1, Fig. 9-10

Material. Twenty-four teeth, including eight central convexities and sixteen specimens with central convexities and well-preserved or partially-damaged marginal areas. The roots are not preserved with the exception of specimens MK I.1.4.9 and MK I.4.15.

Description. All the teeth are characterised by high crowns (Tab. 1), a broad marginal area and a broad and shallow furrow on the lingual face. The central convexity is surrounded by a flat marginal area covered with concentrically-arranged, slightly wavy wrinkles. The wrinkles can split or unite and they are locally discontinuous.

There are two types of tooth in the studied collection. The teeth of the first type (e.g. MK.I.1.10 and MGUWr 5296s) are large with a moderately high crown. The labial and lingual faces (with the exception of the furrows) are covered with irregular granulations. The triturating zone is flat and broad with a rectangular contour. It is crossed by eight regular, prominent, transverse ridges. In the foreground and background of the triturating zone, the ridges become discontinuous and then change into granulations

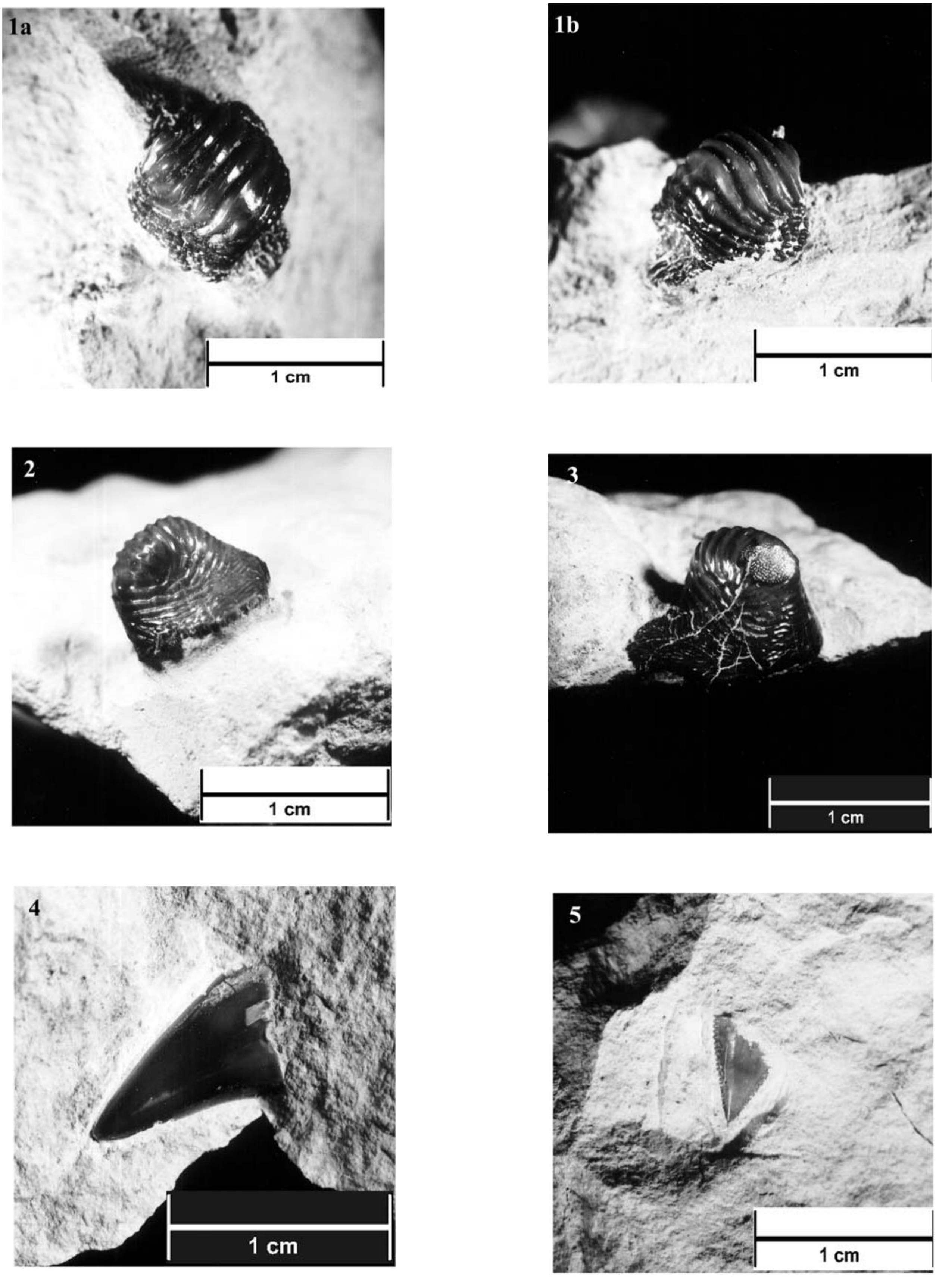
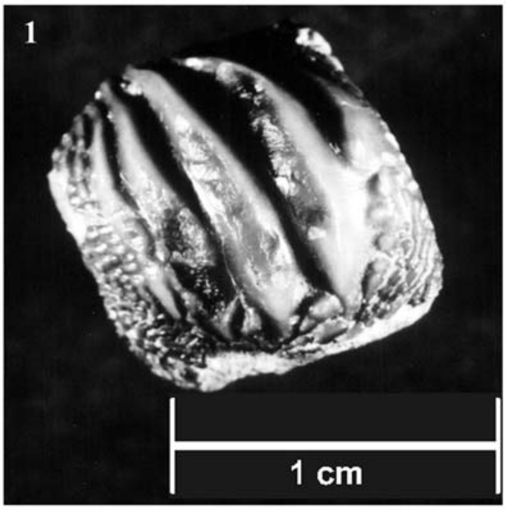
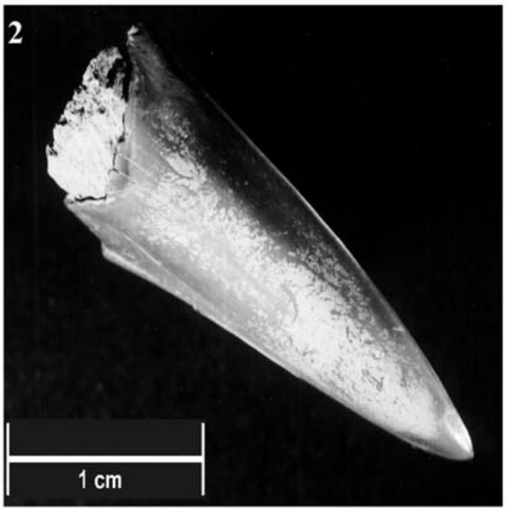


Fig. 4. **1.** *Ptychodus mammillaris* Agassiz, 1843. 1a – occlusal view; 1b – lateral view. MK.I.4.5; **2.** *Ptychodus mammillaris* Agassiz, 1843. Lateral view. MGUWr 5298s; **3.** *Ptychodus mammillaris* Agassiz, 1843. Lateral view. MK.I.4.3; **4.** Cretoxyrhinidae. MK.I.1.11. Labial face of the crown. Specimens 1–4: Odra Quarry; Turonian (Lower Marls Unit; *I. lamarcki* Zone); **5.** *Squalicorax* sp. MGUWr 5323s. Labial face of the crown. Turonian (Marly Limestones Unit; *I. perplexus* Zone), Odra Quarry.





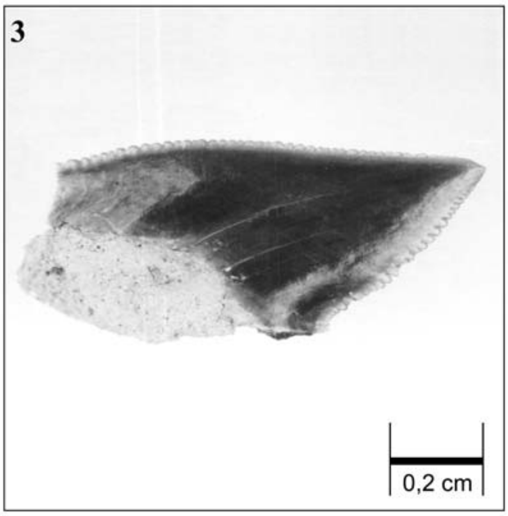


Fig. 5. 1. *Ptychodus polygyrus* Agassiz, 1843. Occlusal view. MK.I.2.5., Turonian (Lower Marls Unit; *I. lamarcki* Zone), Odra Quarry; **2.** Cretoxyrhinidae. MGUWr 5326s. Labial face of the crown; **3.** *Squalicorax* sp. MGUWr 5324s. Labial face of the crown. Specimens 2, 3: Folwark Quarry; Turonian (Upper Marls Unit; the uppermost part of the *M. scupini* Zone).

parallel to the ridges. The ridges extend down on the lateral faces of the central convexities to the marginal area but do not continue into marginal wrinkles. MK.I.1.10 and MGUWr 5296s originate from the middle rows of teeth. The second type is represented by smaller teeth with a very high crown. The triturating zone is convex and narrow with an oval contour, and is crossed by six to ten transverse or slightly oblique ridges. The ridges pass down the lateral wall of the central convexity and often unite towards the edges of the convexity. Granulation is absent from the labial and lingual faces. Teeth of this type originate from the lateral rows of teeth. Forms transitional between both types are present (MK.I.1.10.1). The roots (MK I.1.4.9 and MK I.4.15) are short, massive and broad, and slightly narrower than the crown.

Remarks. Several teeth show wear facets on the triturating zone (Tab. 1). MacLeod (1982) investigated 533 teeth of *Ptychodus rugosus* from Texas, and he mentioned that there was a complete lack of abrasion on the crowns. However, fourteen of the twenty-one teeth of *P. mammillaris* and one tooth of *P. polygyrus* from the Opole Trough show wear facets on the lateral or central sides of the triturating zone. Similar signs of abrasion are visible on the *Ptychodus* specimen illustrated by Roemer (1870, Pl. 36, Fig. 7). Signs of abrasion on the marginal area of *P. decurrens* were also described by Williamson *et al.* (1991). It is possible that the lack or presence of abrasion depends on the diet (e.g. thickness of the shell).

Occurrence: Lower Cenomanian–Santonian, USA, Europe, Kazakhstan. In Poland, this species is known from the Polish Jura Chain (Cenomanian, Turonian – see Książkiewicz, 1927; Małecki, 1980), the Holy Cross Mountains (Cenomanian, Turonian; see Hakenberg, 1969; Marcinowski & Radwański, 1983) and the Opole Trough (Cenomanian, Turonian).

Ptychodus polygyrus Agassiz, 1843
(Fig. 5.1)

1843. *Ptychodus polygyrus* Agassiz; L. Agassiz, p. 156, Pl. 25a, Fig. 4, 5, 9, 11
1878a. *Ptychodus polygirus* Agassiz; A. Frič, p. 97
1878b. *Ptychodus polygirus* Agassiz; A. Frič, p. 14, Fig. 34
1927. *Ptychodus polygyrus* Agassiz; M. Książkiewicz, p. 998; Pl. 24, Fig. 1-2
1980. *Ptychodus polygyrus* Agassiz; J. Małecki, p. 55, Pl. Fig. 7
1983. *Ptychodus polygyrus* Agassiz; R. Marcinowski & A. Radwański, Pl. 8, Fig. 8

Material. Two incomplete specimens (MK.I.2.5 and MK I.1.9) represented by the crowns.

Description. The crown is low (Tab. 1). The triturating zone, of quadratic shape, is flat and broad. The triturating zone of the specimen MK.I.2.5 is covered with four very prominent, sharp, transverse ridges. In the foreground and background of the zone, the prominent ridges pass into discontinuous ridges or into a series of granules, parallel to the ridges. The ridges extend down on the lateral faces of the central convexity to the marginal area. The labial face is ornamented by granulation. This granulation is parallel to the ridges in the upper part of the face.

The triturating zone of the specimen MK.I.1.9 is covered with eight prominent, transverse ridges. The central convexity is surrounded by a marginal area covered with concentrically-arranged, slightly wavy wrinkles. The wrinkles can split or unite and they are discontinuous. The specimen MK.I.2.5 is from the lateral rows of the teeth. MK I.1.9 originates from the middle rows of teeth.
Occurrence: Cenomanian–Campanian. USA, Europe, Kazakhstan. In Poland, this species is known from the Polish Jura Chain (Turonian, Campanian – see Książkiewicz, 1927; Małecki, 1980; Marcinowski & Radwański, 1983) and the Opole Trough (Turonian).

Order Lamniformes Berg 1958
Family Anacoracidae Casier 1947
Genus *Squalicorax* Whitley 1939

Squalicorax sp.
(Fig. 4.5; Fig. 5.3)

Material. Three incomplete crowns (cusps).
Description. The crown is triangular, thin, and very wide. Specimen MGUWr 5323s: length 10 mm, breadth 8 mm; specimen MGUWr 5324s: length 6 mm, breadth 4 mm; specimen MK II.1.13: length 7 mm, breadth 11 mm. The cutting edges are serrated. The lingual face of the crown is flat and the labial face of the crown is slightly convex. The root and the basal part of the cusp are not preserved with the exception of that of specimen MK II.1.13. Root of the MK II.1.13 is high and flat.
Remarks. The three teeth described above are similar to *S. falcatus*. We have decided to leave these specimens in open nomenclature due to their only fragmentary preservation.
Occurrence of genus: All the continents except Antarctica; Albian–Maastrichtian (data see: Cappetta, 1987). In Poland, this genus is known from the Polish Jura Chain (Cenomanian, see: Marcinowski & Radwański, 1983) and the Opole Trough (Turonian).

Family Mitsukurinidae Jordan 1898
Genus *Scapanorhynchus* Woodward 1899

Scapanorhynchus raphiodon (Agassiz, 1843)

1843. *Lamna raphiodon* Agassiz; L. Agassiz, p. 296, Pl. 37a, Fig. 13-16
1845. *Odontaspis raphiodon* (Agassiz); A. Reuss, p. 7, Pl. 7, Fig. 15, Pl. 12, Fig. 3
1878b. *Lamna raphiodon* (Agassiz); A. Frič, p. 10, Fig. 17
1927. *Scapanorhynchus raphiodon* Agassiz; M. Książkiewicz, p. 990; Pl. 24, Fig. 22-24
1993. *Scapanorhynchus raphiodon* (Agassiz); Williamson *et al.*, p. 453, Fig. 5.1-5.5
1999. *Scapanorhynchus raphiodon* (Agassiz); J. Trbušek, p. 55, Pl. 2, Fig. 3-6

Material. Anterior tooth (crown), specimen M.K. I.1. 12.1.
Description. Tooth has a tall, slender cusp (length 13 mm, breadth about 5 mm) with a sigmoidal profile. The lingual crown face is convex and shows fine longitudinal striations. The labial face is smooth and flat. The root is not preserved.
Occurrence: Cenomanian–Coniacian, Campanian?. USA, Europe. In Poland, this species is known from the Polish Jura Chain (Turonian, Campanian – see Książkiewicz, 1927) and the Opole Trough (Turonian – see Leonhard, 1897-98).

Family Alopiidae Bonaparte 1838
Genus *Paranomotodon* Herman 1975

Paranomotodon angustidens (Reuss 1845)

1843. *Oxyrhina angustidens* Reuss; A. Reuss, p. 6, tab. 3, Fig. 7-13
1999. *Paranomotodon angustidens* (Reuss 1845); J. Trbušek, p. 56, Pl. 3, Fig. 6

Material. Lateral tooth, specimen MGUWr 5345 s.
Description. The tooth is triangular and slanting. The tooth has a smooth crown without cusplets (length 3.5 mm, breadth 5 mm) and a deep nutrient groove on the medial portion of the root. The base of the crown is broad. The cutting edges are not serrated. Dental band is present.
Occurrence: Cenomanian–Campanian. Kansas in USA (*Paranomotodon* sp., see Shimada, 1996), Europe. In Poland, this species is known from the Polish Jura Chain (Campanian, see Książkiewicz, 1927) and the North – Sudetic Basin (Cenomanian, Turonian, see Scupin, 1912–1913 and Kühn & Zimmermann, 1919). *Paranomotodon angustidens* has not previously been reported from the Opole Trough.

DISCUSSION

Geographic distribution of the described sharks

In contrast to older data which suggested distinct differences between the ptychodontid faunas of Eurasia and North America, there is now good evidence that ptychodontid faunas contain a large number of cosmopolitan taxa. *P. rugosus*, *P. polygyrus*, *P. latissimus* and *P. decurrens* were previously only reported from Eurasia (Roemer, 1870; Leonhard, 1897–98; Yabe & Obata, 1930; Tan, 1949; Cappetta, 1987), whereas we now know that the majority of *Ptychodus* species from Eurasia also occur in the USA and Mexico (MacLeod, 1982; Williamson *et al.*, 1991; Williamson *et al.*, 1993; González-Rodríguez & Applegate, 2000; Cicimurri, 2001). *P. decurrens* is also known from Greenland (Hoch, 1992). Endemic species are rare; e.g. according to Cappetta, 1987; Williamson *et al.*, 1993 and Blanco *et al.*, 2001, *P. whipplei* Marcou, 1858 and *P. mortoni* Agassiz, 1843 are known only from North America. Additionally, the taxonomic status of some American species is doubtful; for example, *Ptychodus connellyi* Macleod & Slaughter,1980 is considered to be a junior synonym of *Ptychodus martini* (Williston, 1900) (Shawn, 2002). Exclusively cosmopolitan taxa occur in the Opole Cretaceous.

Numerous shark taxa in the surroundings of the Opole Trough were described from the Bohemian and the Saxonian Basins (Reuss, 1845; 1846; Oswald, 1851; Frič, 1878a, 1878b; Andert, 1934; Trbušek, 1999). These Cenomanian and Turonian assemblages are very similar to shark fauna from the Opole Trough. Only a few species of the shark fauna of the Bohemia Basin (e.g. *Ptychodus occidentalis* Leidy, 1868, *Cretodus crassidens* (Dixon, 1850) and *C. semiplicatus* (Münster) in Agassiz, 1843)) have never been found in the Opole Cretaceous, although they represent cosmopolitan taxa. Their geographic distribution extends into South Dakota or Texas (Williamson *et al.*, 1993; Cicimurri, 2001). *C. semiplicatus* was found also in the Lebanon and Siberia (Williamson *et al.*, 1993). Data about selachians from the North – Sudetic Basin are rare. Scupin (1912–1913) and Kühn & Zimmermann (1919) found *Squalicorax falcatus*, *Cretolamna appendiculata*, *Scapanorhynchus raphiodon*, *Cretoxyrhina mantelli*, *Paranomotodon angustidens* and *Ptychodus mammillaris* in the Cenomanian deposits and *Cretolamna appendiculata* and *Paranomotodon angustidens* in the Turonian. Taken as a whole, the shark assemblages of the Bohemian Basin, the Saxonian Basin and the North – Sudetic Basin are of very close similarity to the selachian fauna of the Opole region. The small differences in selachian fauna composition between these regions are probably the result of inadequate collections.

Bathymetric distribution of Selachian assemblages from the Opole Basin

The assemblage of *C. mantelli* - *Ptychodus* (e.g. *P. cf. mammillaris* and *P. decurrens*) from the Cenomanian and Turonian of the USA (e.g. Williamson *et al.*, 1993; Cicimurri, 2001) was restricted to a deep-water environment (peak transgression). These taxa are absent or extremely rare in nearshore deposits, where numerous hybodont sharks occur (Williamson *et al.*, 1991; Williamson *et al.*, 1993; Rees, 1999). Therefore, this assemblage is considered indicative of deeper environments (Williamson *et al.* 1991; Williamson *et al.* 1993). The selachian assemblage from the Opole Trough contains mainly deep-water forms (*Ptychodus*, *Cretoxyrhina mantelli, Scapanorhynchus raphiodon*, *Paranomotodon angustidens* – compare to Cappetta, 1987; Williamson *et al.*, 1993; Shimada, 1996) accompanied by eurytypic taxa e.g. *Cretolamna*, *Squalicorax falcatus* (compare to Williamson *et al.*, 1993). Nearshore sharks are absent (e.g. *Ptychotrygon*) or they are very rare (e.g. *Hybodus* – see Leonhard, 1897–98). It is very characteristic that the remains of *Ptychodus* are common in the middle *I. lamarcki* Zone. They are very rare in the Marly Limestones Unit (middle *I. perplexus* Zone to lower *M. scupini* Zone). On the other hand, this unit contains very common inoceramids and ammonites, which were the major prey of *Ptychodus* sharks. Favourable conditions for the preservation of teeth during sedimentation of the upper *I. perplexus* Zone and lower *M. scupini* Zone are well evidenced by the numerous Lamniformes teeth. This may suggest that the deposition of the middle *I. lamarcki* Zone took place in deeper environments than the sedimentation of the upper *I. perplexus* Zone and lower *M. scupini* Zone, in support of the previous conclusion by Kędzierski & Uchman (2001), based on trace fossil assemblages. This is also consistent with the data from the British region (Hancock, 1990), where the transgression peak is dated for the middle part of the *Collignoniceras woollgari* Zone (= the *I. apicalis* and lower *I. lamarcki* Zones, see Walaszczyk, 1992), while the peak of regression is dated for the lower *Subprionocyclus neptuni* Zone (= *I. perplexus* Zone).

CONCLUSIONS

The selachian assemblage from the Opole Trough contains mainly Lamniformes, which live in all marine environments, and deep-water ptychodontid sharks. The remains of nearshore sharks are extremely rare.

The remains of Lamniformes are numerous throughout the Upper Cretaceous succession of the Opole Trough, whereas selachian teeth of genus *Ptychodus* are abundant only in the middle *I. lamarcki* Zone. This suggests that the deposition of the middle *I. lamarcki* Zone represents the deepest environment of the Opole Cenomanian and Turonian.

The teeth of *Ptychodus* occur in the deposits where inoceramid shells were dominant over ammonite shells. The teeth of Lamniformes are abundant in deposits where fish remains are common, whereas reptile remains are extremely rare. This indicates that the large Cretaceous Lamniformes frequently preyed upon fish and ptychodontid sharks fed on inoceramid bivalves.

In the Turonian and Coniacian of the Opole Trough, thin-shelled ammonites dominated (based on the collections described by Tarkowski, 1991; Kaczorowski, 1997 and our own collection, 90 % of the c. 600 specimens of ammonites were thin-shelled), but thin-shelled inoceramids are as numerous as thick-shelled ones. Therefore, there were good trophic opportunities for both trophic groups of *Ptychodus*.

Abbreviations of cited repositories: MGUWr – Geological Museum of the Institute of Geological Sciences of Wrocław University; MK – collection of Marcin Kalina.

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