

# An introduction to the palaeoenvironmental reconstruction of the Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn, Kraków-Silesia Homocline, Poland

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## ABSTRACT:

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This paper provides introductory data for multidisciplinary studies on palaeoenvironmental reconstructions of the Bathonian (Middle Jurassic) ore-bearing clays exposed at Gnaszyn, southern Poland. These dark-coloured fine-clastic deposits have been studied for micropalaeontology, sedimentology and geochemistry (published in separate papers within this volume). Brief outlines of the Middle Jurassic palaeogeography of the Polish epicontinental basin and the geology of the Kraków-Silesia Homocline are given. A description of the ore-bearing clays succession exposed in the clay-pit at Gnaszyn is provided, including locations of the sections studied, their ammonite biostratigraphy, brief lithology and macrofossil distribution. The sample positions collected for micropalaeontological and geochemical studies are specified.

**Key words:** Poland; Kraków-Silesia Homocline; Middle Jurassic; Bathonian ore-bearing clays; Dark deposits.

## INTRODUCTION

The Gnaszyn clay-pit exposes Middle Jurassic (Bathonian) marine dark-coloured clays with layers of siderite concretions, which represent a part of a widespread facies of the so-called ore-bearing clays. This informal lithostratigraphic unit has been a subject of geological studies for more than 200 years. However, despite the relative richness of fossils, almost no group has been the subject of a comprehensive study (except for recent contributions on gastropods by Kaim 2004, bryozoans by Zatoń and Taylor 2009, 2010, and am-

monites by Zatoń 2010a, b). The majority of published papers, apart from recently published geochemical and isotopic data (Szczepanik *et al.* 2007; Wierzbowski and Joachimski 2007; Marynowski *et al.* 2007; Zatoń *et al.* 2009) are only minor contributions. Our study, focused on the Middle–Upper Bathonian part of the ore-bearing clays exposed at Gnaszyn, was undertaken with the aim of reconstructing the environmental conditions throughout the Middle and Late Bathonian in this part of the epicontinental basin. In this context, the results of a multidisciplinary study consisting of sedimentological, micro- and macropalaeontological, and geochemical

approaches carried out on a complete succession of the Middle–Upper Bathonian ore-bearing clays exposed at Gnaszyn are presented in this volume (for preliminary results see Gedl *et al.* 2003, 2006). The main advantage of our study is that a variety of methods applied here was tested on the same set of samples. These methods employed geochemical analysis of main and trace elements, pyrite development, mineralogical analysis, palaeontological study of several micro- and macrofossil groups including echinoderms, foraminifers, calcareous nannoplankton, organic-walled dinoflagellate cysts, sporomorphs, gastropods, bivalves, scaphopods, shark teeth, and trace fossils. The Gnaszyn clay-pit represents the largest and best-exposed outcrop of the ore-bearing clays and stratigraphically spans the greatest time interval of all the clay-pits in the Kraków-Silesia Homocline.

## GEOLOGICAL BACKGROUND

The epicontinental marine Middle Jurassic in Poland is associated with a transgression which started in the Early Aalenian and lasted throughout the whole Middle Jurassic, with short regressive episodes (Early/Late Bajocian, Subfurcatum Ammonite Zone, and earliest Callovian, Typicus Ammonite Zone). The Middle Jurassic transgressions entered from the Tethyan area through the Slobodia-Dobrudja gate, and left most complete sequences in the mid-Polish trough (Dayczak-Calikowska 1997; see also Zatoń and Marynowski 2006). During most of the Middle Jurassic, the Polish epicontinental marine basin was surrounded by emerged areas: Fennosarmatia to the north and east; and the Bohemian Massif to the south-west (e.g., Ziegler 1988; Text-fig. 1A). Because of this, the north-eastern part of Poland was not covered by the sea before the latest Bajocian transgression. During this transgressive pulse (Schloenbachii–Valida ammonite zones) the emerged area of the Bohemian Massif (Sudety-Silesia and Małopolska lands) was partly flooded and these two land areas were separated (Text-fig. 1A, B). The main phase of deposition of the ore-bearing clays started during this transgression. With subsequent (Middle Bathonian) expansion of this transgression, the sea further encroached on the Małopolska Land, which became an island area (Text-fig. 1B). During the Late Bathonian, the sea entered the north-eastern land area causing the cessation of deposition of the ore-bearing clays, followed by sedimentation of oolitic deposits (Dayczak-Calikowska and Moryc 1988; Dayczak-Calikowska 1997).

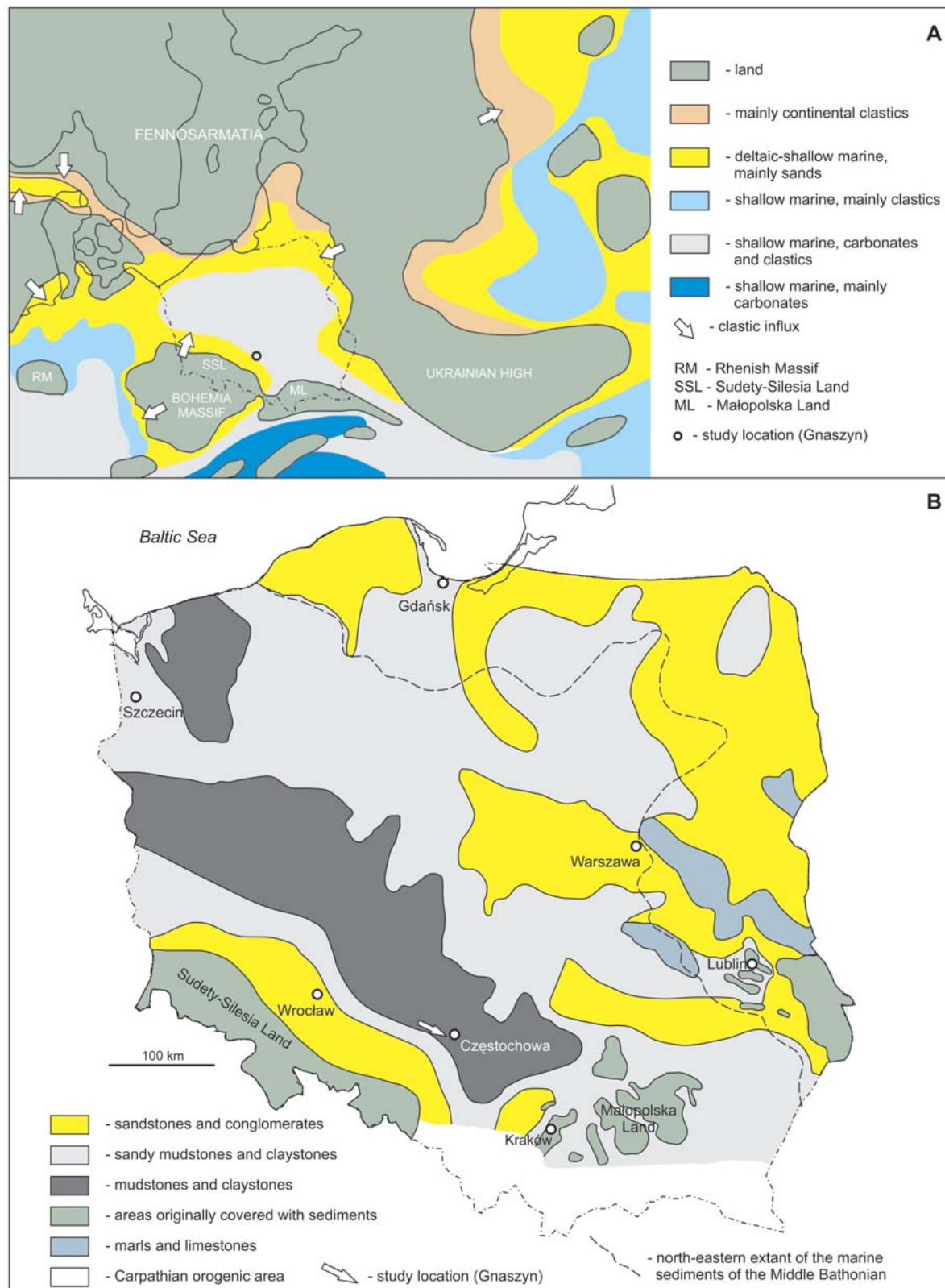
As a consequence, a relatively uniform and the most complete marine sequence of the Middle Jurassic is

known in the central part of the epicontinental Polish Basin, where it rests upon the Lower Jurassic (continental deposits prevail in the north-western part of Poland). In the southern part of the epicontinental basin, the Middle Jurassic sequence is less complete and more variable in facies. This is well seen in the Kraków-Silesia Homocline: the Middle Jurassic sequence in its northern part (Wieluń–Częstochowa–Zawiercie region (the northern sedimentary region *sensu* Różycki 1953) is characterized by low facies diversity and it rests conformably upon the Lower Jurassic (Text-fig. 2). The Middle Jurassic in the southern part of the Kraków-Silesia Homocline (the southern sedimentary region *sensu* Różycki 1953) is much less complete: in the southernmost area in particular, the basal part of the Middle Jurassic is missing and the remaining part is highly variable, with numerous hiatuses (Kontkiewicz 1890; Różycki 1953; Zatoń *et al.* 2006).

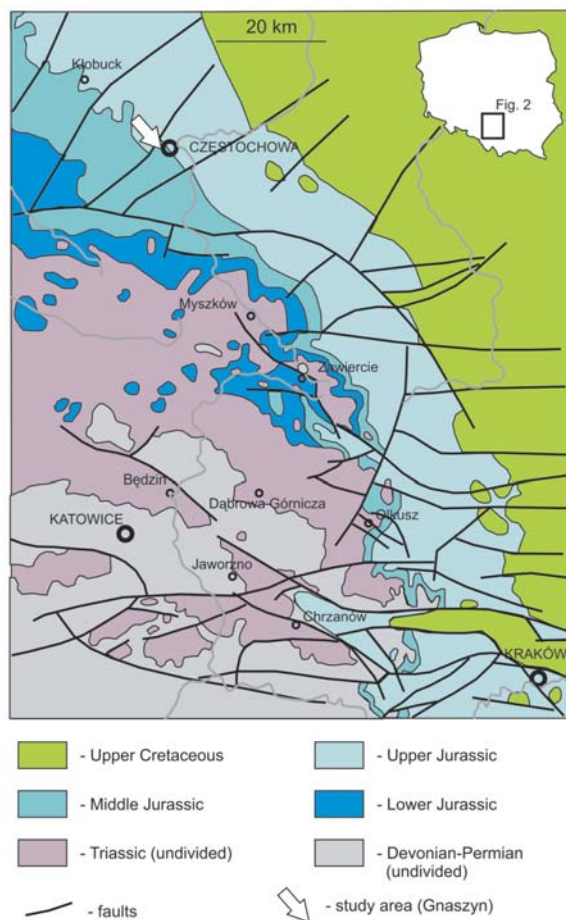
During the Late Bajocian transgression, sedimentation started of a dark-coloured silty facies with frequent siderites, distinguished as the ore-bearing clays (called informally the Częstochowa ore-bearing clay formation). It shows its most complete development in the northern area, where it reaches its maximum thickness of 180 m in the vicinity of Wieluń. These muddy and sandy deposits thin gradually southward: they are up to 45 m thick in the vicinity of Ogrodzieniec, and are only few metres thick in the Olkusz area. Farther to the south (Chrzanów, Olkusz, and the Kraków area) they finally disappear.

In the northern part of the Kraków-Silesia Homocline, the ore-bearing clays rest upon the so-called Kościelec beds, developed as sandy deposits with quartz gravels and siderite concretions (Text-fig. 3). Based on rare ammonites (Mossoczy 1947; Różycki 1953; Kopik 1967a; for discussion see Kopik 1998), the Kościelec beds are of Aalenian–Early Bajocian age. There is an hiatus between the Kościelec beds and the overlying ore-bearing clays: the earliest Late Bajocian Subfurcatum Ammonite Zone is missing (e.g., Kopik 1967b; Dayczak-Calikowska and Kopik 1976). In the northern part of the southern region (Ogrodzieniec–Olkusz area), the ore-bearing clays are underlain by Upper Bajocian coarse-grained deposits, called the Niegowonice conglomerates (e.g., Kontkiewicz 1890; Rehbinder 1913; Znosko 1953). In the southernmost part, where the ore-bearing clays are missing (Chrzanów, Olkusz and the Kraków area), the oldest Jurassic deposits consist of Bathonian continental [sand-loamy limnic Grojec (Mirów) clays (Bathonian?), coarse-grained Parcze conglomerate (Upper Bathonian?), Połomia conglomerates] and marine deposits (sandy and oolitic limestone) and Callovian sandy limestone (Text-fig. 3).

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Text-fig. 1. Position of study area in (A) palaeogeographic map of central Europe during the Bajocian–Bathonian (from Ziegler 1988); and (B) palaeogeographic map of Poland during the Middle and Late Bathonian (Morrissi–Discus ammonite zones; from Dayczak-Calikowska 1997)



Text-fig. 2. Simplified tectonic sketch-map of the Kraków-Silesia Homocline (from Dadlez *et al.* 2000)

The age of the ore-bearing clays is based on ammonites (Kopik 1998). In the earliest reports (e.g., Buch 1805; Schultz 1816; Oeynhausien 1822; Pusch 1823, 1830, 1837), they were regarded as Late Jurassic or younger. Pusch (1884 in Pusch 1881-85), in his *post mortem* paper, suggested a late Early Jurassic age of the ore-bearing clays, but it was Beyrich (1844) who first documented their Middle Jurassic age. This view was confirmed by subsequent authors, e.g., Różycki (1953), Kopik (1998) and Matyja and Wierzbowski (2000, 2003, 2006), who detailed their time of deposition as earliest Late Bajocian (Garantiana Ammonite Zone) through early Late Bathonian (Heterocostatus Ammonite Zone: Kopik 1998; Retrocostatum Ammonite Zone: Matyja and Wierzbowski 2003). The oldest part of the ore-bearing clays (the lower part of Upper Bajocian – Garantiana–Subarictis ammonite zones) consists of basal sands and sandy clays with siderite concretions (the so-called basal exploitation iron ore level), and is known exclusively

from boreholes and mines (see e.g., Kopik 1967c). The younger part of the clays is exposed in several clay-pits located in the northern part of the Kraków-Silesia Homocline (Text-fig. 4; see Matyja and Wierzbowski 2003). It consists of dark coloured silts, muds and clays, locally arenaceous. Horizons with siderite concretions are scattered throughout the succession. The youngest part of the ore-bearing clays (lower part of Upper Bathonian – Retrocostatum Ammonite Zone) passes gradually into more sandy sediments and, higher up, into marls and limestones with ferruginous oolites (Text-fig. 3).

## MATERIAL

The ore-bearing clays of the Kraków-Silesia Homocline contain numerous horizons of sideritic concretions which have been exploited for iron ore since the Middle Ages. The iron ore exploitation has long been abandoned, and the ore-bearing clays are now the source of clay for the local “brick industry”. Several clay-pits in the northern part of the Kraków-Silesia Homocline (especially near Częstochowa; Text-fig. 4B) give an opportunity to study almost complete succession of the ore-bearing clays which, due to their consistency, rarely form natural outcrops.

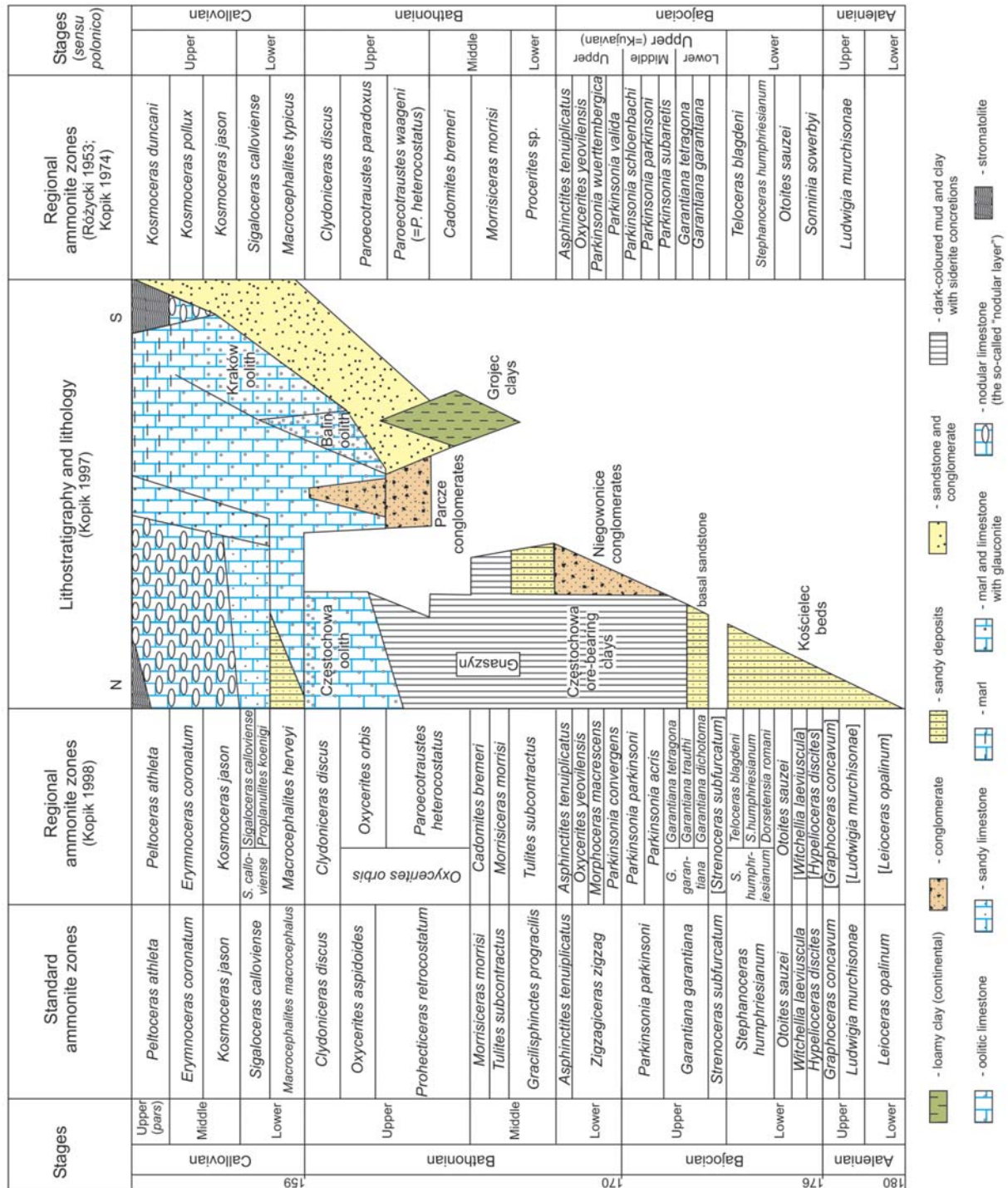
The investigated sections of the ore-bearing clays are located in a clay-pit at Gnaszyn, in the south-western suburb of Częstochowa (Text-figs 4–6). It has been exploited at least since the 1940s (e.g., Mossoczy 1947), and is known in the literature as the “Gnaszyn clay-pit”, or the “Gnaszyńscy clay-pit”. This clay-pit is now owned and exploited by Wienerberger AG.

The succession in Gnaszyn represents the higher part of the ore-bearing clays sequence comprising the Middle–lower Upper Bathonian (Subcontractus–Retrocostatum zones; see Matyja and Wierzbowski 2006, fig. B10.1; Text-figs 3, 7). The succession, c. 25 m thick, consists of dark grey mudstones and muddy clays filled with shell detritus, which frequently form enriched lenses or layers (for a detailed sedimentological description see Leonowicz 2012, this issue). It contains at least seven continuous siderite concretion horizons, numbered N through T, according to the scheme of Matyja and Wierzbowski (2000; see also Majewski 2000; Matyja and Wierzbowski 2006, fig. B10.1). Frequent macrofossils occur throughout the succession. They include both neotonic and benthic forms: ammonites, belemnites, bivalves, scaphopods, gastropods as well numerous ichnofossils and sunken driftwood (Gedl *et al.* 2003; Text-figs 8, 9). Thirty four samples, c. 10 kg each, were collected from three,

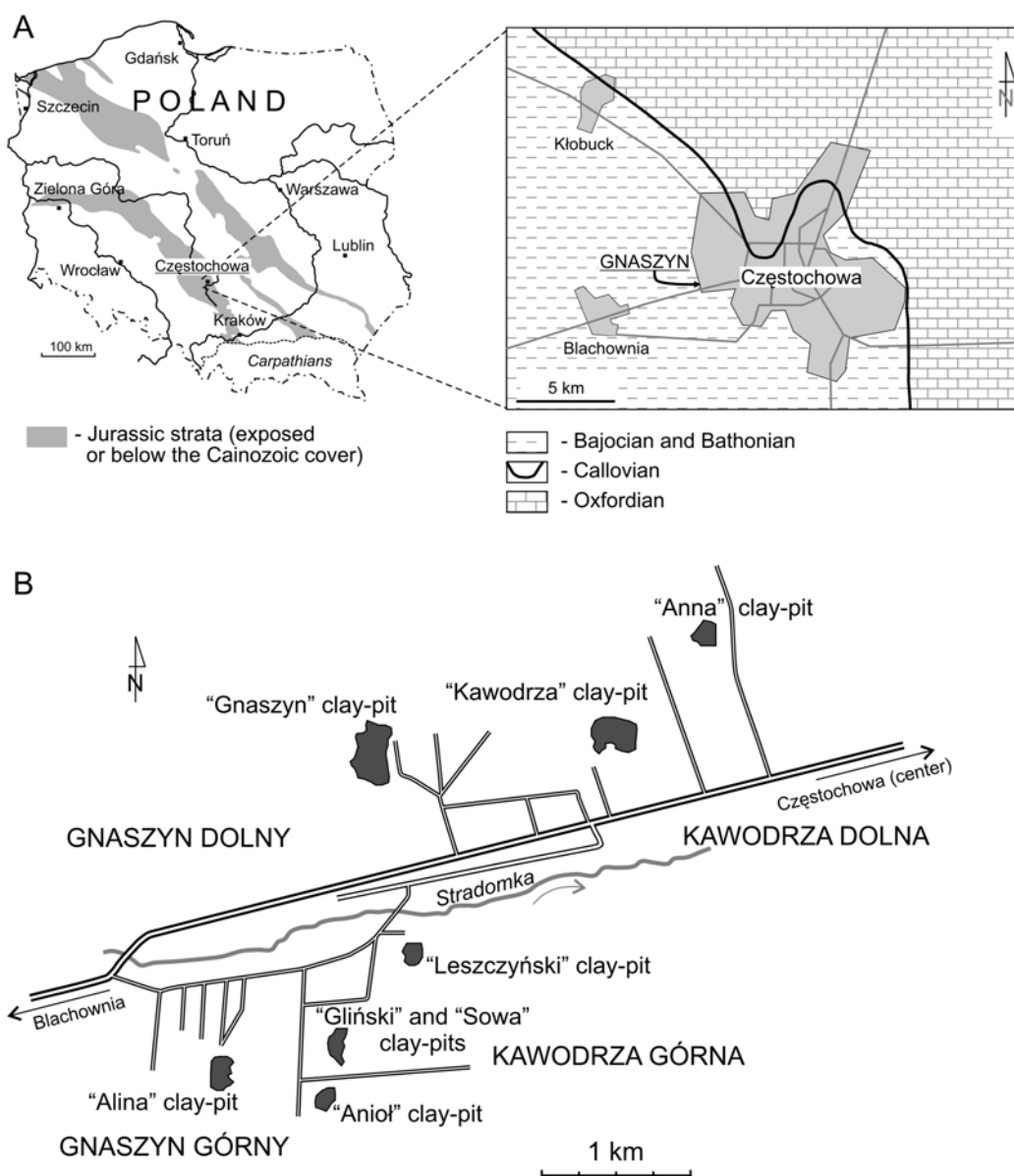
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partially overlapping sections: A, B and C (Text-fig. 7). The samples were collected from c. 10-cm thick intervals; due to bioturbation more precise sampling is unnecessary. Samples were taken unevenly; monotonous intervals were sampled less densely (Text-fig. 7).

**Section A.** Section A is located in the southern part of the Gnaszyn clay-pit (Text-figs 5, 6B). It exposes a c. 18-m thick succession, representing an almost complete sequence of the ore-bearing clays at Gnaszyn (Text-fig. 7). Six continuous horizons of siderite con-



Text-fig. 3. Lithostratigraphy, lithology and ammonite biostratigraphy of the Middle Jurassic of the Kraków-Silesia Homocline. Lithostratigraphy and lithology after Kopik (1997). Correlation of ammonite zones after Kopik (in: Kopik and Marcinkiewicz 1997) and Kopik (1998)



Text-fig. 4. Simplified geological map of the town of Częstochowa and its vicinity (A – after Majewski 2000); and location of the Gnaszyn clay-pit (B – after Matyja and Wierzbowski 2003)

cretions, numbered N through T, are recognised (horizon Q, which consists of relatively loosely spaced concretions, was not distinguished by Matyja and Wierzbowski 2006, fig. B10.1). Section A is twofold, consisting of sections A<sub>1</sub> and A<sub>2</sub>.

The oldest, 6-m thick part of this section crops out in the south-western part of the clay-pit (section A<sub>1</sub>; Text-figs 5, 6B). These are dark greyish mudstones with variable amounts of shell detritus and three concretion horizons (N–P). Seven samples (Gns32–38) were collected from this interval (Text-fig. 7). Sample Gns32 was taken 10 cm below the lowermost concre-

tion horizon N, from deposits representing the Subcontractus Zone (Matyja and Wierzbowski 2006, fig. B10.1). These are dark greyish mudstones with common shell detritus. A high enrichment in detritus (mainly bivalve remains) and common ichnofossils occurs within a 1-m thick interval just above concretion level N. Sample Gns33 was taken from this lithofacies, 80 cm above concretion horizon N and 10 cm below the exploitation base level. Higher up-section, there is a 1-m thick interval of dark greyish mudstones rich in detritus. It passes into an 80-cm thick interval with lower amounts of shell detritus (sample Gns34 was taken ap-

prox. 120 cm above the exploitation base level) and an almost 2-m thick interval enriched in detritus. Two concretion levels occur within this interval: concretion horizon O (250 cm above the exploitation base level) and concretion level P (90 cm above the O horizon). During her fieldwork Leonowicz (2012, this issue) observed that the O and P horizons were more than 2 m from each other and separated by another thin concretion level. We could not locate this third level in section A<sub>1</sub>; however we noted that the two horizons classified as O and P were much closer to each other and it is therefore possible that one of these levels may in fact represent the unnamed level of Leonowicz (2012, this issue). Well preserved bivalves occur commonly between these two concretion horizons. Sample Gns35 was taken just below the concretion horizon O, sample Gns36 10 cm below, and sample Gns37 10 cm above horizon P (Text-fig. 7). Horizon P is followed by a 1.2-m-thick clay mudstone; sample Gns38 was taken from its highest part (samples Gns36 and Gns37 represent the Morrisi Ammonite Zone; see Matyja and Wierzbowski 2006).

The higher, 12-m thick part of section A (section A<sub>2</sub>), is exposed in the north-western part of the Gnaszyn clay pit (Text-figs 5, 6B). The concretion horizons O and P are visible here below the exploitation base level in a small exposure; this enables correlation with the A<sub>1</sub> section. Moreover, horizon P is visible at its intersection with the exploitation base. This shows that the strata of the ore-bearing clays dip northwards at an angle of c. 3–5 degrees.

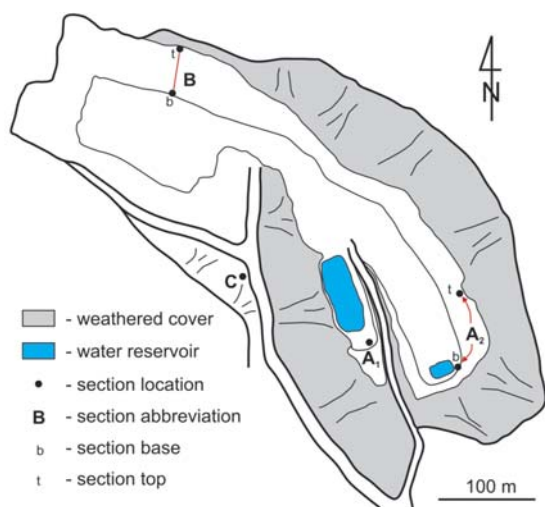
The basal part of section A<sub>2</sub> consists of monotonous dark-greyish mudstones with common muscovite and shell detritus. The dispersed macrofauna consists of bivalves (*Bositra* sp., *Pholadomya* sp.), scaphopods, belemnites, and ammonites. Samples Gns1 and Gns2 were taken 90 cm and 200 cm above the exploitation base level respectively. This means that sample Gns1 was collected c. 1.5 m above concretion horizon P, i.e. approximately 40 cm above sample Gns38. Sample Gns3 was taken 40 cm above sample Gns2 from similar lithology (sediment enriched in shell detritus). Higher up-section there is a 150-cm thick interval of clay mudstones – sample Gns4 was taken 30 cm above the base of this fine-grained interval. These mudstones pass up into a 90-cm thick interval of coarser sediment with rich shell detritus including a concretion level within its top. This level consists of loosely spaced siderite concretions and is named horizon Q (not distinguished by Matyja and Wierzbowski 2006). Two samples, Gns5 and Gns6, were collected 10 cm below and above horizon Q respectively. Wood remains occur at the level of sample Gns5, whereas sample Gns6 was collected from a lens

containing skeletal detritus (mainly echinoderm ossicles). The succeeding 5-m thick interval (three exploitation levels: the 2-m thick 3<sup>rd</sup>, the 1.7-m thick 4<sup>th</sup> and the 1.2-m thick 5<sup>th</sup> level) consist of similar dark-greyish mudstones with shell detritus. The macrofauna, similarly as below, is represented by relatively rare bivalves, belemnites, and ammonites. Sample Gns7 was taken 130 cm above sample Gns6. An horizon of sunken driftwood occurs 80 cm higher (top of the 3<sup>rd</sup> exploitation level). Sample Gns8 was collected 120 cm above sample Gns7. Sample Gns9 was taken 130 cm above sample Gns8, at the height of concretion horizon R, which is located at the top of the 4<sup>th</sup> exploitation level. Numerous burrows filled with pyrite occur at this height. Samples Gns1 through Gns9 are taken from an interval representing the Bullatimorphus Subzone of the Bremeri Zone (see Matyja and Wierzbowski 2006, fig. B10.1; Text-fig. 7).

The higher samples Gns10 and Gns11 represent the Fortecostatium Subzone of the Bremeri Zone. This 2-m thick subzone was identified ca. 1–3 metres above concretion level R (see Matyja and Wierzbowski 2006, fig. B10.1; Text-fig. 7). Sample Gns10 was collected from dark greyish mudstones 90 cm above sample Gns9; and sample Gns11, 80 cm higher.

The highest part of section A<sub>2</sub> consists of dark-brownish mudstones and includes one concretion level – the S horizon. Two further samples were taken from its vicinity: sample Gns12 just below the concretion level (90 cm above sample Gns11) and sample Gns13 collected immediately above it. The deposits that occur just below and above the S horizon have no clear biostratigraphical position (Matyja and Wierzbowski 2006, fig. B10.1). Matyja and Wierzbowski (pers. comm. 2004) found a few ammonites in the talus that are typical of the lowermost Upper Bathonian Quercinus Subzone of the Retrocostatum Zone; they must come from this subzone, which was recently covered by talus. Coeval strata are presumably exposed in our section C, where we noted an acme of the bivalve *Nicaniella* (*Trautscholdia*) sp. (Text-fig. 8J; see also Gedl *et al.* 2003). In the neighbouring clay-pit “Anna”, a similar acme occurs between a pair of concretion levels, which presumably represent the Retrocostatum Zone (see Matyja and Wierzbowski 2003).

**Section B.** This 13-m thick section of the ore-bearing clays is exposed in the northern part of the Gnaszyn clay-pit (Text-figs 5, 6A). It was erroneously treated by Gedl *et al.* (2003) as a continuation of section A. The biostratigraphic data of Matyja and Wierzbowski (2006) have shown that section B is coeval with the middle part of section A (Morrisi–Bremeri zones).



Text-fig. 5. Sketch of Gnaszyn clay-pit with location of the sections investigated (by P. Gedl)

The lowermost part of section B is characterised by the occurrence of the two concretion levels: O and P (Text-fig. 7). The host sediment is dark-greyish mudstone with common muscovite and shell detritus. Enrichment in the latter is observed between the O and P concretion horizons. Bivalves, usually in “life position”, occur commonly at this horizon (Text-fig. 8C, G, D, E); scaphopods, ammonites, belemnites and ichnofossils are also very frequent in this interval. Sediment between these two concretion levels, as well ca. 1 m

above this interval, represents the Morrissi Zone (Matyja and Wierzbowski 2006, fig. B10.1). Sample Gns14A was collected from just below concretion level O, sample Gns14 just above it and sample Gns15 40 cm above this concretion horizon. The following samples, Gns16A and Gns16, were taken from just below and above concretion level P, which is located ca. 150 cm above concretion horizon O (Text-fig. 7).

The higher part of the ore-bearing clays exposed in section B consists of monotonous dark-greyish mudstones with much less common macrofauna and shell detritus. Sample Gns17 was collected 120 cm above concretion horizon P from a biostratigraphically undetermined interval (Text-fig. 7). Higher up-section there is a more than 5-m thick interval representing the Bullatimorphus Subzone of the Bremeri Zone (see Matyja and Wierzbowski 2006, fig. B10.1; Text-fig. 7). Six samples were taken from this interval (Text-fig. 7). Samples Gns18 and Gns19 were taken 1.8 m and 2.4 m above sample Gns17. An horizon of sunken driftwood occurs between these two samples (Kaim 2011; Text-fig. 7). Sample Gns20 was taken 1 m above sample Gns19, sample Gns21 was collected 130 cm higher, and sample Gns22 was taken 90 cm above Gns21. Concretion horizon Q is located ca. 20 cm above sample Gns21. The highest part of the ore-bearing clays succession exposed in section B, a more than 3-m thick interval, consists of similar lithofacies to that below, i.e., dark-greyish mudstones with ubiquitous muscovite. Concretion



Text-fig. 6. Gnaszyn clay-pit (years 2003–2004) and location of the sections investigated: A – view from south-east corner of the clay-pit; B – view of the southern wall of the clay-pit (photos by P. Gedl)



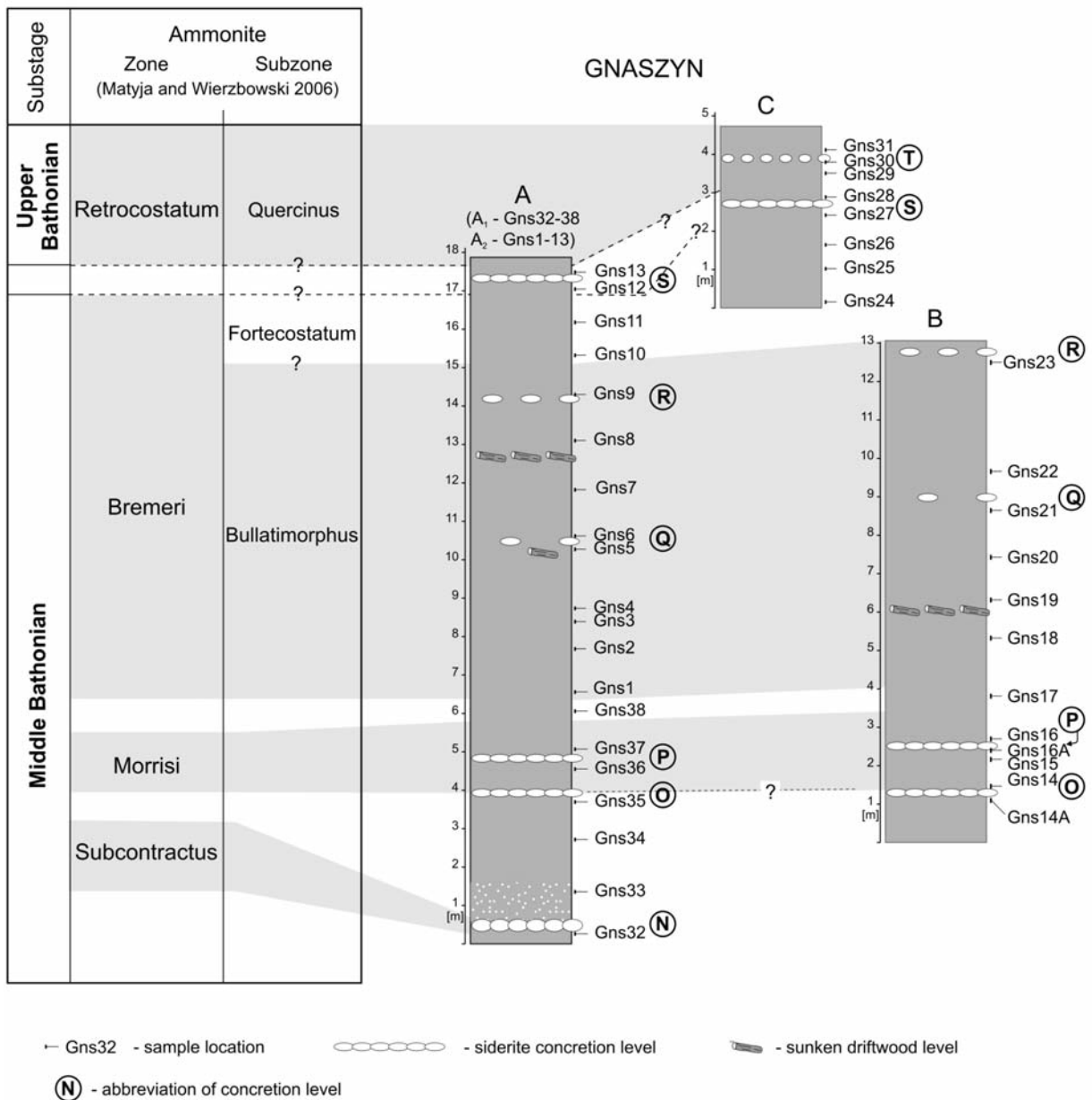
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horizon R is located in the highest part of this interval; sample Gns23 was taken 20 cm below it.

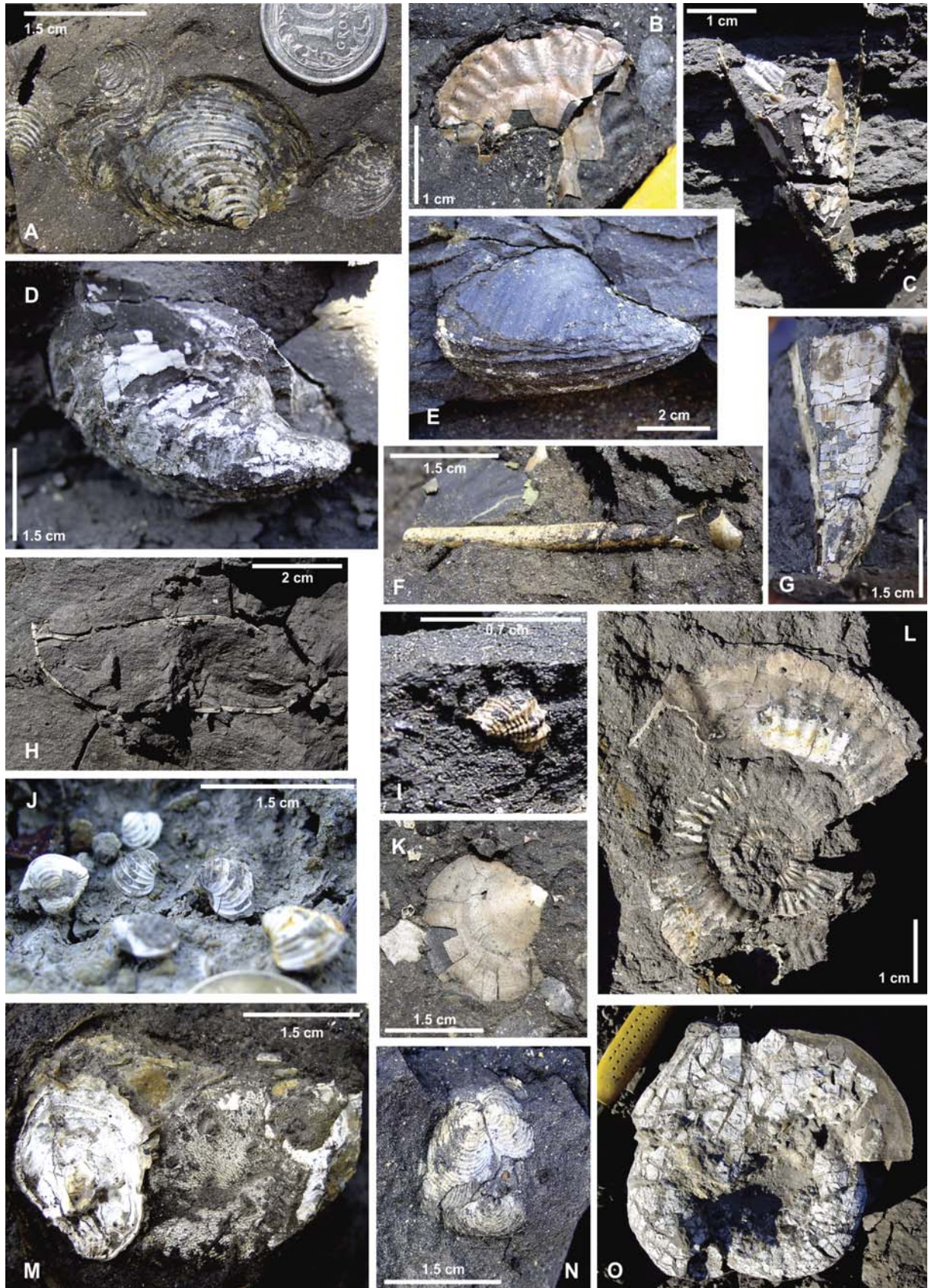
**Section C.** This section is located in the topmost part of the north-western wall of the clay-pit (Text-figs 5, 6A). This is a 5-m thick succession consisting of dark-greyish (in the lower part) and yellow-brownish mudstones (in the upper part). Two concretion horizons, S and T, occur in the higher part of the section within these yellow-brownish mudstones (Text-fig. 7). The common occurrence of the bivalve *Nicaniella (Trautscholdia)* sp. between these two concretion levels (Text-fig. 8J), also known from the stratigraphically higher succession ex-

posed in the Anna clay-pit, suggests that at least the upper part of section C (from about 1 m below concretion level T) represents the Upper Bathonian *Retrocostatum* Zone (cf. Matyja and Wierzbowski 2003).

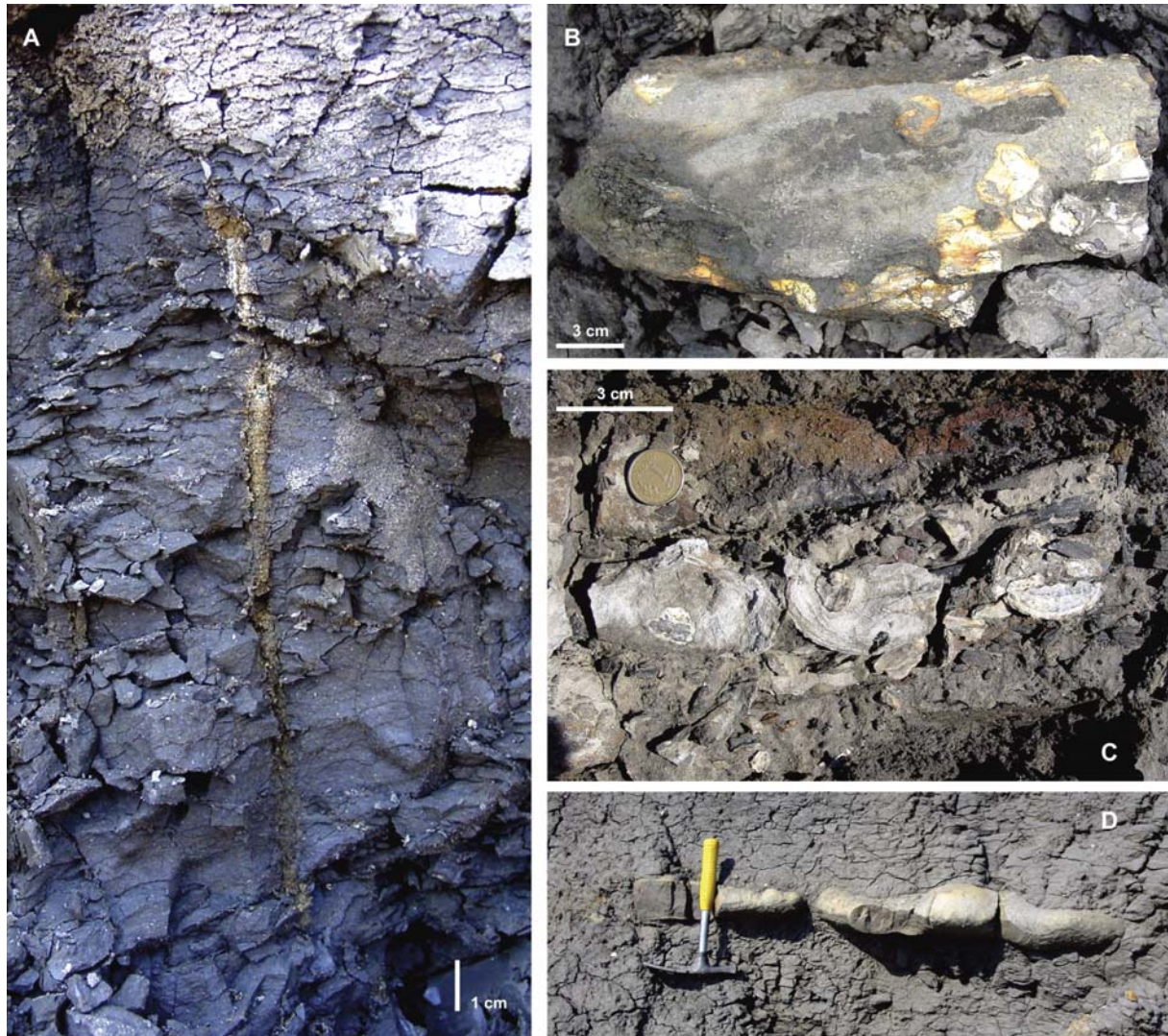
Eight samples, Gns24 to Gns31, were collected from this section (Text-fig. 7). Three samples were taken from basal mudstones, which may represent the *Fortecostatum* Subzone. The next two samples (Gns27 and Gns28) were collected just below and above concretion level S. Higher samples most likely represent the *Retrocostatum* Zone: Gns29 was collected from sandy mudstones; the highest samples, Gns30 and Gns31, from just below and above concretion level T.



Text-fig. 7. Lithologic logs of the sections of the ore-bearing clays at Gnaszyn with sample positions indicated (by P. Gedl)



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Text-fig. 9. Macrofossils and concretion level from the Bathonian of the Gnaszyn clay-pit. A – 15 cm long vertical burrow filled with pyrite; B, C – sunken driftwood with attached oysters; D – siderite concretion level (photos by P. Gedl)

METHODS

Each of the 34 samples was split so that each investigation in this project could be based on the same material. These investigations (reported in this volume) include: dynamics of sharks (Rees 2012), gastropods (Kaim 2012), bivalves and scaphopods (Kaim and Sztajner 2012), echinoderms (Boczarowski *in* Gedl *et al.* 2003, 2006), foraminifers (Smoleń 2012), calcareous nannoplankton (Kędzierski 2012), and dinoflagellate cysts (Gedl 2012). Terrigenous influx

was studied by means of palynofacies and changes in pollen-spore assemblages (Gedl and Ziaja 2012). Detailed sedimentological and ichnological analyses are provided by Leonowicz (2012). Clay minerals are analysed by Dudek (2012), concretions by Witkowska (2012) while the geochemistry of these deposits, based on the same set of samples, has been already published by Szczepanik *et al.* (2007; see also Zatoń *et al.* 2009). The palaeoenvironmental conclusions drawn from these analyses are provided in the summary paper at the end of this volume (Gedl *et al.* 2012).

Text-fig. 8. Macrofossils from the Bathonian of the Gnaszyn clay-pit. A, N – bivalve *Bositra* sp.; B – ammonite; C, G – bivalve *Pinna* sp. preserved in life position; D, E – bivalve *Pholadomya* sp. in life position; F – scaphopod; H – cross section through an unidentified bivalve; I – *Astandes* sp.; a gastropod common in the vicinity of sunken driftwood; J – bivalve *Nicaniella (Trautscholdia)* sp.; K – bivalve *?Entolium* sp.; L – ammonite; M – oyster and bryozoan colony attached to the sunken driftwood (bryozoans in Gnaszyn occur only at sunken driftwood); O – ammonite (photos by P. Gedl)

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