Middle/Upper Devonian brachiopod shell concentrations from the intra-shelf basinal carbonates of the Holy Cross Mountains (central Poland)

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ABSTRACT:


A huge isolated accumulation, more than 3 m thick and 10 m wide, of densely packed, uncrushed brachiopods has been found in Józefka Quarry within the Middle/Upper Devonian Szydlówek Beds deposited in a relatively deep environment of an intrashelf basin (Kostomloty facies zone, western Holy Cross Mountains, Poland). The low-diversity assemblage is strongly dominated by the atrypide *Desquamatia globosa jozefkae* Baliński subsp. nov. and, to a lesser degree, by the rhynchonellide *Coeloterorhynchus dillanus* (Schmidt, 1941), which constitute 72.8% and 22.1% of the fauna, respectively. Less frequent are specimens representing the genera *Hypothyridina*, *Schizophoria* and *Phlogoiderynchus*. According to the conodont fauna found within the coquina bed, the stratigraphic position of the shell accumulation is close to the Givetian/Frasnian boundary. The brachiopods are associated with numerous crinoids and less frequent bryozoans, receptaculitids (Palaeozoic problematica), sponges and solitary corals. Although it is difficult to entirely exclude the autochthonous nature of the brachiopod coquina member, its allochthonous origin and redeposition of the brachiopod shells to the deep basin by gravity flows is much more probable. Such conclusion is supported by the following facts: (1) the position of the complex in a succession of deep-marine basinal facies impoverished in oxygen; (2) its lateral thinning-out and composite internal stratification; (3) the lens-shaped geometry of the coquina bed in the section perpendicular to the bedding dip; (4) high variability of the sediments preserved within the shells; and (5) the preferred orientation of the shells. The brachiopods mixed with crinoidal debris were probably transported by low-velocity, high-density, gravity-induced debris flows. Lack of fossils typical of the Middle Devonian shallows, such as massive stromatoporoids, amphiportoids and tabulates, indicates that the source area of the bioclastic material was not located in the shallowest part of the shelf, but most probably on a submarine sea-mount to the north of present-day Józefka, as suggested by earlier investigators. The triggering mechanism of the allochthonous deposition was an earthquake rather than storm activity. The enormous thickness of the brachiopod complex is probably caused by the sinking of bioclastic material, transported in succeeding depositional multi-events, in a soft, muddy bottom, typical of the Szydlówek Beds deposition.

**Keywords:** Devonian; brachiopods; Holy Cross Mountains; allochthonous origin of coquina.
INTRODUCTION

The incentive to the investigations reported in this paper was the finding of a huge lens of brachiopod coquina within the Middle/Upper Devonian intra-shelf basin succession in the Holy Cross Mountains (central Poland). The brachiopod shell accumulation was discovered during a field reconnaissance in the MSc thesis area of Inga Zawadzka, supervised by the first author. The extent of the lens exceeded 10 m, whereas its maximal thickness was about 3 m. The huge size of the densely packed brachiopod coquina, rarely found in Phanerozoic successions (except of the upper Silurian to Upper Devonian successions of the Moroccan Meseta), triggered numerous questions on the sedimentological and taphonomic nature of such brachiopod occurrence.

The appearance of brachiopod beds in the Devonian bituminous limestones/marls of Józefka Hill near Górno village in the Holy Cross Mountains, Poland (Text-fig. 1A, C) has been known for a long time, and expansion of the quarry located on the top of the hill during the last 30 years has disclosed a large number of thin brachiopod beds. In spite of their attractiveness for collectors, they have remained palaeontologically undescribed, with only short remarks being published by Szulczewski (1971), Małkowski (1981), Racki (1993a, b) and Vierek (2008, 2014). The first stricte palaeontological monograph dedicated to brachiopods from some parts of the Józefka succession appeared just 2 years ago (Baliński et al. 2016).

More than 20 years ago the first author had the pleasure to collect the perfectly preserved and locally abundant brachiopods in the small Józefka Quarry together with the late Professor Andrzej Radwański. The specific feature of these brachiopods was the frequent infilling of their shells with black, dense hydrocarbon fluids. Professor Radwański’s passion for collecting beautiful fossils was commonly known, and it was a recurrent view when he patiently dusted his collection of Devonian trilobites, Miocene shark teeth or Jurassic echinoids. Parts of this collection have been already described (see publication list in Walaszczyk, 1985; Racki and Bultynck 1993; Baliński et al. 2016).

According to Baliński et al. (2016), the lower part of the exposed Devonian succession is composed of the following informal stratigraphic units (in ascending order): (1) dolomites, (2) Laskowa Góra Beds, and (3) Szydłówek Beds with their uppermost time-equivalent Wietrznia Beds (Text-fig. 2). This succession is covered by deposits of the Kostomloty Beds, composed of nodular limestones intercalated with litho- and bioclastic limestones, intraformational breccias and conglomerates, interpreted as gravity flow deposits, transported from the southern carbonate platform or its slope to the northwardly located basin (Szulczewski 1971, 1995). The sequence records the early stages of drowning of the carbonate platform margin. The bulk of the dolomites represents its dolomitised part, originally composed mainly of stromatoporoid-coral limestones, and the Laskowa Góra Beds correspond to its marginal, retrograding wedge. The Szydłówek Beds are initial intra-shelf slope-to-basin deposits, which encroached upon the carbonate platform after its tectonic disintegration and drowning of its northern external parts (Szulczewski et al. 1996). The brachiopod shell accumulation, which is the main focus of
this paper, occurred within the Szydlówka Beds in the north-western wall of the quarry, but at present it is completely removed by quarry activities.

Even at a short distance from the road leading to the western part of the quarry the stratigraphic succession differs substantially from the basic scheme presented above. The Laskowa Góra Beds are not present in this part of the section and the Szydlówka Beds contact directly with the dolomites. However, the uppermost part of the dolomites is partly black here and the only recognisable fossils they contain are abundant remains of crinoids and brachiopods,
locally even atrypid coquinas. These primary features indicate that the original, later dolomitised deposits, had much in common with the directly overlying Szydłówek Beds. The main primary difference between the two units is that the dolomites are thick-bedded here, whereas the Szydłówek Beds are generally comprehended as thin-bedded, marly-shale rhythmic deposits (Biernat and Szulczewski 1975; Racki 1993b).

These relationships show that the front of mesogenic dolomitisation considerably changed its stratigraphic position even at such short distance from the Józefka Hill area, similarly as it was shown by M. Narkiewicz (1990) in other parts of the Holy Cross Mountains. It also proves that the two-step drowning of the carbonate platform is recorded in this succession, first within the dolomites of the western section, and secondly at the base of the Szydłówek Beds (compare record of eustatic events in the Devonian of the Holy Cross Mountains illustrated by Baliński et al. 2016, text-fig. 3).

Conodonts are the only available biostratigraphic tools in the Szydłówek Beds facies. Although their frequency is very low, they prove that the Szydłówek Beds straddle the Middle/Upper Devonian boundary and their base is diachronous (Racki 1985). According to Racki and Bultynck (1993, p. 21), the position of this boundary changes along the regional occurrence of the Szydłówek Beds from the Klapperina disparilis Zone in the west to the lowermost Mesotaxis falsiovalis Zone in the east (Górno). They also suggested that the boundary between the Laskowa Góra Beds and the Szydłówek Beds is placed on Józefka Hill near the disparilis–falsiovalis zonal boundary (Racki and Bultynck 1993, p. 13).

Recent investigations have changed this opinion, since according to Baliński et al. (2016, p. 113, text-fig. 4) the conodonts found in Józefka in the lowermost part of the Szydłówek Beds “suggest strongly the assignment of the Józefka succession to the Lower Frasnian [Palmatolepis] transitans Zone”. Our investigations on the conodont fauna were limited only to the studied shell bed, but their results contradict the latter opinion. Among several samples taken from the brachiopod coquina only one proved stratigraphically useful. It contains the following conodont species: Icriodus excavatus Weddige, 1984; Mehlinia gradata Youngquist, 1945; Polygnathus alatus Huddle, 1934; Polygnathus dubius Hinde, 1879; Polygnathus pollocki Druce, 1976 and Polygnathus webbi Stauffer, 1938. All these species display long ranges and zonal index forms are missing in the sample. Nevertheless, its age can be determined according to their overlapping ranges, which were compiled by K. Narkiewicz and Bultynck (2007, fig. 3; 2010, fig. 9; 2011, fig. 3) and K. Narkiewicz (2011, fig. 3). The concurrent occurrence of I. excavatus and P. webbi indicates that the sample comes from an interval between the upper part of the lower falsiovalis Zone to the upper falsiovalis Zone, and possibly also part of the transitans Zone. This interval falls within wider ranges of the remaining species. It is possible that the upper range of P. dubius excludes the transitans Zone (K. Narkiewicz and Bultynck 2010, fig. 9), but K. Narkiewicz (2011, fig. 3) has shown that it extends many zones above.

The stratigraphic position of the shell accumulation studied (Text-fig. 2) is close to the Givetian/Frasnian boundary, i.e., the Middle/Upper Devonian boundary. However, its more precise relation to this boundary may not be determined, since, according to Sandberg et al. (1989), the position of the discussed boundary falls in an undetermined position within the falsiovalis Zone.
LITHOLOGY OF THE ROCKS SURROUNDING THE COQUINA BED

The coquina bed is located within deposits that in terms of microfacies correspond to the Szydlów Bed, although macroscopically they are evidently different from the typical examples of this unit, composed of black shales intercalated with limestones (compare Szulczewski 1995; Racki et al. 2004; Vierek 2008, 2014). Shale intercalations are less numerous here than in the typical Szydlów Bed. On the other hand the limestone layers are more bioclastic, sometimes even coarse-grained. Generally they are developed as bituminous, dark grey and fine-grained limestones/marls, with a generally low number of macrofossils, except of a few layers.

The unit directly underlying the coquina bed is composed of thin-bedded, strongly bituminous, fine-grained bioclastic wackestones, with peloids, sometimes aggregated into grapestones, fine-grained micritic intraclasts and single styliolins (Text-figs 3, 4A). As an exception appear two layers, several centi-
metres thick, which represent grainstones/packstones with intraclasts, and crinoid and brachiopod bioclasts (Text-fig. 4B). The matrix of the brachiopod coquina lying above is identical with the dominating wackestone lithology.

The rocks above the interval with the brachiopod coquina are more diversified. They are dominated by medium-bedded wackestones and mudstones. Fossils are represented by fragments of brachiopods, crinoids, rare styliolinids and single ostracodes. Relatively numerous are coarse-grained packstones, composed of peloids, crinoids, bryozoans and brachiopods. Sporadically occur biotported intraclasts (Text-figs 3A, 4C). The densely packed and disarticulated brachiopods occur in several beds, forming few-centimetres-thick coquina beds (e.g., Text-fig. 3B). The only exception in this lithological spectrum is a thick bed composed of broken massive stromatoporoids, amphiporoids, alveolitid tabulates, rugose corals and lithoclasts (bed X in Text-fig. 3). The matrix of this layer is completely different from the other beds, being composed of peloids and calcispherids (Text-fig. 3C).

A specific feature of the entire complex is its partial dolomitisation, especially in the layers terminating the investigated part of the Józefka section (Text-fig. 3). This part is represented by coarse-grained crystalline dolomites, similar to the dolomites from the lowermost lithostratigraphic complex exposed in the quarry.

According to numerous descriptions of the Szydłówek Beds (i.e., Szulczewski 1971, 1995; Mokowski 1981; Racki et al. 1985; Racki and Bultynck 1993; Vierek 2008, 2010, 2014; Balinski et al. 2016), this unit is interpreted as deposits of an intra-shelf, stagnant basin. These beds represent an environment deeper than the shallow-water carbonate platform with stromatoporoid-coral carbonates developed in the central part of the Kielce Region. A rapid deepening of sedimentation is interpreted (Racki 1993a; Racki and M. Narkiewicz 2000; Pisarzowska et al. 2006) as an effect of eustatic rise (11b event sensu Johnson et al. 1985). The Szydłówek Beds were deposited in a hemipelagic environment, with the bottom waters impoverished in oxygen. The sediments are generally poor in fossils (even conodonts), but locally they are intercalated with bioclastic deposits transported from the neighbouring platform. Storms, tsunamis or tectonic movements (earthquakes) are mentioned (Szulczewski 1971, 1995; Vierek 2008, 2014) as mechanisms triggering the gravity flows of bioclastic material transported from the platform. The unit is usually sub-divided into 3 parts (A–C according to Racki and Bultynck 1993), of which the lower one is transitional between shallow and deeper deposits, whereas the upper one is most typical of the unit, with numerous intercalations of bituminous shales. Racki et al. (2004) and Vierek (2008) suggested dysoxic conditions in bottom waters during this stage of deposition. In this context the beds in-
vestigated here fully represent the lower unit of the Szydłówek Beds, with only impoverishment of the oxygen content, large enough to a nearly complete absence of benthic fauna. Surprisingly different in respect to the greater size of the bioclasts and their specific spectrum is bed X (Text-fig. 3); its environmental significance is discussed in detail below.

THE BRACHIOPOD COQUINA BED

The investigated brachiopod coquina forms a massive body, with its marginal parts cut by two faults (Text-fig. 5B). It is lens-shaped in a cross-section that is most probably perpendicular to the body elongation. The base of the lens is convex down; the boundaries of this form are conspicuous but not elongation. The base of the lens is convex down; the boundaries of this form are conspicuous but not erosional (Text-fig. 5). The coquina bed is densely packed and its fabric seems to be chaotic at first glance (Text-fig. 5C), but detailed observations of a large-scale polished slab reveal a rather regular horizontal orientation of the brachiopod shells and complex internal stratification (Text-fig. 6). The brachiopod assemblage is strongly dominated by the atrypide Desquamatia globosa jozefkai Bálniński subsp. nov. (Text-figs 7, 8) and, to a lesser degree, by the rhynchonellide Coeloterorhynchus dillanus (Schmidt, 1941) (Text-fig. 9A–J, P), which constitute 72.8% and 22.1% of the fauna (N=290 specimens), respectively. These two species contribute to nearly 95% of the assemblage. The remaining three species: Schizophoria (S.) schnuri prohibita Halamski, 2012 (Text-figs 7, 8) and, to a lesser degree, by the rhynchonellide Coeloterorhynchus dillanus (Schmidt, 1941) (Text-fig. 9A–J, P), which constitute 72.8% and 22.1% of the fauna (N=290 specimens), respectively. These two species contribute to nearly 95% of the assemblage. The remaining three species: Schizophoria (S.) schnuri prohibita Halamski, 2012 (Text-fig. 9K, L), Phlogoiderhynchus polonicus (Roemer, 1866) (Text-fig. 9O) and Hypothyridina sp. (Text-fig. 9M, N) are very rare and less important.

Crinoids are equally numerous as brachiopods in the investigated coquina bed. They are randomly scattered, or occur in the form of more or less regular intercalations or irregular concentrations (Text-fig. 6). Thin crinoidal intercalations within the generally massive body of the coquina bed, as for example the beds presented in Text-fig. 6, are treated here as indicators of the sedimentary surface.

Fistuliporid bryozoans, mostly representing the species Canutrypa francoana Bassler, 1952 (Text-fig. 10D) are another, relatively frequent component of the coquina bed. A specific feature of this species is its abundant appearance in the Devonian of the Holy Cross Mountains only in the study area and in some parts of the Chęciny area. According to Morozova et al. (2002, p. 308), the section on Józefka Hill near Górno is “the most productive bryozoan locality in the Kielce Region”. However, this fauna, connected with open-shelf, ramp slope or intershoal facies, is of little significance as a facies indicator.

Other components of the assemblage are limited to rare specimens of rugose corals (Text-fig. 10A), receptaculids (Text-fig. 11D) and lithistid demosponges (Text-fig. 10E). Although receptaculids are relatively often mentioned in the descriptions of Devonian fossil assemblages from Poland (Szulczewski 1971; Racki 1993b), these enigmatic fossils have not attained a monographic description yet. Usually they are regarded as components of reefal communities (Szulczewski 1971; Mierzejewska and Mierzejewski 1973; Bálniński et al. 2016). Different groups of sponges are a more frequent element of the Devonian biotopes in the Holy Cross Mountains (Rigby et al. 2001 with complete references), but usually they were described from younger strata (upper Frasnian), limited to the southern part of the region; according to Rigby et al. (2001) they have not been reported from the Łysogóry–Kostomłoty regions. In the Kielce Region they were usually associated with the brachiopod-coral-sponge assemblages that inhabited the deep slope of the central carbonate platform in a hemipelagic setting.

Additional, very valued information on the distribution of fossils within the coquina bed is provided by a polished slab (about 1000 cm²) achieved by cutting of a large block of brachiopod limestone (Text-fig. 6). The measurements made on its surface indicate a very regular orientation of the shells. Measurements of the longer axis of brachiopod shell sections were performed in relation to the level of a thin crinoidal intercalation within the coquina, assumedly more or less horizontal during sedimentation. The second reference level was located below, on the boundary between the area of crushed shells and shells that were not deformed during compaction. The crinoidal concentration below this level is irregular and resembles deformational structures caused by a reversed density gradient (compare Dżułyński and Kubicz 1975; Biernat and Szulczewski 1993). As a result, three parts of the slab were distinguished and the presented measurements are related to each part separately (Text-fig. 6). In parts A and C both valves of brachiopod specimens are preserved and all brachiopods are undeformed. In part B both valves are usually also preserved but the specimens are mostly compressed and flattened. However, in many cases both valves of a single specimen were not separated but flattened together. Statistically, in the upper parts (A and B) the longer axes of shells are arranged in a position parallel to the reference level. More than 50% of the measured shells are located in intervals at 0–20° and
Text-fig. 5. Outcrop of the brachiopod coquina bed in Józefka Quarry (state as in 2015). A – General view of the north-western wall of the quarry; direction of wall is more or less parallel to the orientation of the overthrust surfaces; yellow arrow indicates direction of the view presented in B; D₄ – dolomite unit, D₃ – Frasnian units, D₂ – Famennian units; B – General view of the brachiopod coquina lens (yellow boundaries); C – close-up of the investigated brachiopod coquina bed.
160–180°. In the lowermost part C the orientation of the shells is more scattered and only 38% of them are located in these intervals. A significant number of shells oriented perpendicularly to the reference level was also observed in this part.

Because the brachiopod shells are mostly un-crushed or non-disarticulated, they usually serve as geopetal indicators; their orientation is presented as the position of a line perpendicular to the boundary between the internal sediment within the shell and the infilling cement. In parts A and B, the position of this line is identical (averagely 93°), whereas in part C it is slightly larger (106°). Although in the case of these measurements the standard deviation is relatively large, they indicate that the geopetal structures are generally parallel to the longer axis of the shells.
The occurrence of a completely opposite position of geopetal structures (cement in the lower part of the shell) is sporadic and a few specimens displaying this property (not illustrated in Text-fig. 6) are found only in part C.

The infillings of brachiopod shells strongly vary even among neighbouring shells (see Text-figs 10B, 11C; 11C) and are different from the coquina matrix. These differences are visible even in microscopic view: the infillings of shells is usually light grey whereas the matrix is dark grey or black (Text-fig. 10). In microscopic view the material within the shells represents three microfacies: bioclastic MF composed of crinoidal debris (Text-fig. 10B), peloidal/micritic
MF (Text-fig. 10D), and dolosparitic MF (Text-fig. 10A, B). The presence of dolomite in the investigated brachiopod coquina bed is a common feature, but the process of dolomitisation was multistage and differed spatially. Generally, its first stage corresponds to the formation of a completely dolomitised infilling of brachiopod shells (Text-fig. 10A), which were later transported and deposited within a bioclastic matrix that is not dolomitised. The second stage of the process took place after the formation of the entire succession, and its expression is partial dolomitisation of the coquina matrix together with the material infilling the brachiopod shells. Thereby, the shells without traces of dolomitisation, which are situated within the dolomitised matrix (Text-fig. 10E), were infilled by primary micritic material, lithified enough and isolated from the surrounding sediment, so that the dolomitization process was impossible or limited. A similar process of late dolomitization is known in a larger scale from several Devonian successions, e.g., that observed in the Skały section succession in the northern part of the Holy Cross Mountains (Skompski and Szulczewski 1994), where dolomicritic layers are preserved in primary form within a succession of coarse-grained epigenetic dolosparites.

ORIGIN OF BRACHIOPOD MASS OCCURRENCES

Brachiopod mass occurrences as densely packed coquinas generally have three possible interpretations: (i) autochthonous/parautochthonous occurrences, controlled by ecological and sedimentological factors, with accumulation of specimens in their life place or its direct neighbourhood, (ii) autochthonous occurrences, usually stimulated by cold-seep activity, and (iii) allochthonous occurrences, controlled by sedimentological processes, with transport of specimens far from their life places. In the first case, recorded by most of the brachiopod shell concentrations, the final sedimentary record is the effect of reciprocal relation of 3 factors: bioproduction, rate of shell disintegration and rates of net sedimentation (Kidwell 1986; Kidwell et al. 1986; Tomašových et al. 2006). However, it should be emphasised that the models presented in the cited papers refer mostly to the autochthonous/parautochthonous concentrations (“i”). In specific conditions, Ceno-/Mesozoic brachiopods are able to form very thick in situ concentrations despite a relatively low carbonate production (see examples and thorough discussion of the problem in: Tomašových et al. 2006; Reolid et al. 2012; Tomašových and Kidwell 2017). More often brachiopods occur, especially in the Palaeozoic, as a dominating element in beds with thicknesses of several to several tens of centimetres. Such types of coquinas have been described from Silurian and Middle Devonian strata (Pentamerus layers of Johnson 1989; Bornhardtina layer described by: Biernat 1953; Hladil 1983; Skompski and Szulczewski 1994). In these cases the rapid growth of the brachiopod population was stimulated by the post-storm “fertilization” of the sea floor. Similar atrypid-dominated
deposits (mainly *Desquamatia globosa*) from the Middle Devonian of the Holy Cross Mountains and the Cracow area have been analysed by Racki and Baliński (1981) and Racki (1993a). A significant feature of these occurrences was the co-existence of brachiopods with crinoids and the relative scarcity of fauna typical of shallow Middle Devonian seas, i.e., massive stromatoporoids, amphiporoids and tabulates. According to the papers cited above, the sedimentary environment of the investigated deposits has been interpreted as poorly aerated intershoal areas or restricted lagoons with fluctuating or even lowering salinity. Regarding the superficial similarity of the brachiopod beds described by Racki and Baliński (1981) to those described in the present paper, the principal difference is the level of brachiopod packing, evidently more dense in the Józefka succession, and the location of the brachiopod bed from Józefka in a basinal rather than a shallow-water succession.

Comparison of the brachiopod beds investigated here not only with Palaeozoic but also Mesozoic and Cenozoic brachiopod shell concentrations (Taddei Ruggiero 1994 with references; Reolid *et al.* 2012) indicates difficulties in finding direct analogies. An analogous situation is related to the largest occurrence of facies composed of redeposited brachiopods mixed with crinoids – the Jurassic Hierlatz facies of the Calcareous Alps and Carpathians (Bernoulli and Jenkyns 1974). This facies overlies Triassic carbonate platforms or infills large-scale (up to 10 m wide) neptunian dykes. According to Vörös (1986, 1991) and Uchman and Tchoumatchenko (1994), brachiopods and crinoids, which compose the dominating component of the Hierlatz limestones, were redeposited from seamount tops, where they lived at moderate water depths.

In the succession quoted above, the brachiopods are markedly dominating, but the beds cannot be classified as densely packed coquinas, because the brachiopods are usually more or less scattered within a detrital matrix. The shape of the brachiopod limestone bodies is either unknown or they form long horizontal layers.

In that respect, a “brachiopod nest” most similar
Text-fig. 10. Examples of microfacies from the brachiopod coquina bed. A – atrypid shell completely filled with dolomitic crystals, single rugose coral is arrowed; matrix partly dolomitized, B – atrypid shell filled with bioclastic material; two different stages of geopetal structures are visible; C – shells with different types of infilling material: bioclastic (black arrow) and micritic (white arrow); D – concentrations of bryozoan *Canutrypa francqana* Bassler, 1952 (white arrows) detritus within brachiopod coquina; peloidal/micritic infilling of shell is visible (arrowed); E – fragment of lithistid demosponge within brachiopod coquina; notice different infilling of brachiopod shell and coquina matrix.
to the studied brachiopod coquina bed is known from the intensively investigated Moroccan sites: the upper Silurian *Septatrypa* Mound (Ager *et al.* 1976) and the Devonian Aferdou El Mrakib reef/mound in the eastern Anti-Atlas (Kaufmann 1998, Tessitore *et al.* 2013). The brachiopod assemblage described from the...
second locality is dominated by the atrypide *Kerpina vineta* Struve, 1961 and the pentameride *Ivedlinia pulchra* Franchi, Schemm-Gregory and Klug, 2012 (Halamski and Baliński 2013). The brachiopods are extremely densely packed, the shells are usually uncrushed and non-disarticulated. The thickness of the bed is extremely large (several metres), but the sedimentological and facies characteristics of this coquina have not been recognised to date. Kaufmann (1998) interpreted the lens of brachiopods as deposited in situ and, based on the comparison with other reef-dwelling faunas (Godefroid and Racki 1990), attributed these brachiopods to semi-protected, intermittently agitated habitats. Franchi *et al.* (2012) suggested that the brachiopod assemblage lived there during an earlier stage of reef development, although it is not connected with any traditional reef guild. Compared to the Józefka coquina, the most significant difference is the nearly complete absence of crinoids in the Aferdou El Mrakib mound and the location of the brachiopod coquina in its direct proximity, not in the basinal facies.

Concerning model “ii” (concentrations stimulated by cold-seep activity), the Silurian *Septatrypa* Mound (Ager *et al.* 1976) is the best example of densely packed brachiopod coquinas of large thickness, composed of articulated shells and interpreted as the effect of a chemosynthetic process, stimulated by fluid seepage. An exceptional feature of this succession is the intercalation of the brachiopod coquina with microbial stromatolitic layers (Ager *et al.* 1976). This remarkable attribute of the mound resulted in an interpretation of the sedimentary environment as an isolated shoal within a muddy basin. Following more detailed investigations (Barbieri *et al.* 2004, p. 537) there are three features, which induce the hypothesis about the contribution of hydrocarbon seepage in the formation of the brachiopod concentration: “... (1) the presence of a dense faunal assemblage surrounded by faunally poor siliciclastic deposits, which is (2) embedded in carbonate deposits, and (3) is monospecific ...”. Buggisch and Krumm (2005) and Jakubowicz *et al.* (2017, 2018) have confirmed the seep-nature origin of the discussed mound based on isotopic analysis.

All circumstances quoted by Barbieri *et al.* (2004) have been more or less fulfilled in the case of the Józefka coquina bed; moreover, the Szydłowiek Beds are saturated by hydrocarbons to an exceptionally high degree compared to other units of the Devonian in the Kostomłoty facies zone. The possibility of the formation of the Józefka brachiopod coquina bed as a seep-induced assemblage has been seriously considered in the beginning of our investigations, but it was definitely excluded after the analysis of the isotopic composition of the shells, matrix and cements (Text-fig. 12). The isotopic measurements are generally in accordance with the marine signals typical of the Givetian/Frasnian transition (Buggisch and Joachimski 2006). In comparison to other examples of seep carbonates (Buggisch and Krumm 2005; Paull *et al.* 2007; Jakubowicz *et al.* 2015 with references), the carbon isotopic values seem to be too high (from 0.39 to 3.94‰ PDB). Moreover, it is necessary to add that other features expected in the case of seep deposits (tube worms, microbial fabrics, specific fibrous cements, sulphide-sulphate mineral deposits, etc.; for discussion see e.g., Campbell and Bottjer 1995; Jakubowicz *et al.* 2017) were not observed here.

**ORIGIN OF THE JÓZEFKA BRACHIOPOD COQUINA BED**

The review of the different hypotheses on the nature of brachiopod coquinas presented above shows that it is difficult to find an exact analogy for the Józefka brachiopod accumulation. However, it seems
that in this case gravitational transport of the brachiopod shells to a deeper basin is the most plausible explanation. There are five basic arguments pointing to this hypothesis: (1) massive lithology and palaeontological contrast between the coquina and the surrounding deposits; (2) high diversification of the internal sediment within the shells, different than the coquina matrix; (3) a lens-shape geometry of the brachiopod unit in a cross-section perpendicular to the bedding dip; (4) complex internal stratification; and (5) preferred orientation of the brachiopod shells. Each of these arguments treated separately could be also explained in terms of autochthonous growth of the brachiopod concentration. For example, the lens-shape geometry of the brachiopod body may be typical of a biogenic mound. However, we have observed only one specific cross-section of the coquina bed and therefore on this basis its difficult to forejudge the mound shape geometry of the entire bed. Differences in the type of sediment preserved within the shells could be explained as a diagenetic feature, especially the abundance of dolomite crystals. On the other hand, the differences of infilling of brachiopod shells (micritic or bioclastic) have a simpler explanation in the different primary location of the shells than in a later infill during storms and burial processes.

It seems that the composite treatment of the arguments presented above caused that the hypothesis of an allochthonous accumulation of the brachiopods is most reasonable. The bioclastic material (brachiopod shells mixed with crinoidal debris) was transported as low-velocity, high-density, gravity-induced debris flows. The specific feature of the investigated coquina is the high contribution of articulated shells. Most probably this fact indicates rapid burial of the original biogenic material. On the other hand, dense packing of the shells caused their parallel orientation. Some shells were empty during transport or were only partially infilled with an internal sediment, which is proved by the post-sedimentary parallel orientation of the geotopal indicators. It is obvious that even in the case of gravitational transport, the brachiopod shell material should be preliminary concentrated in the initial site of brachiopod growth, located not far from the place of final deposition. As it is discussed in the next chapter, the most probable location of the original growth place of the brachiopod population was a submarine high to the north of the Józefka area. The nature of this initial concentration and the reasons of the assumed high brachiopod productivity remains unknown. The subsequent relative enrichment of the flowing bioclastic material was probably connected with the winnowing of mud during transport. All specimens of brachiopods have been obtained from hard limestone, which means that the lack of small specimens may be regarded as a sampling bias. It seems that an analogical – to some respect – process was observed in another lens-shaped bioclastic unit in the Palaeozoic of the Holy Cross Mountains – the lower Carboniferous limestones near Gałęzice (Belka and Skompski 1988; Belka et al. 1996). In that case the crinoidal-brachiopod material was transported in a similar way, but on a longer distance and generally larger scale, which is recorded in the evidently greater thickness of the limestone unit, located within the basinal Culm shales.

A more evident sedimentological analogy to the Józefka brachiopod bed has been described by Biernat and Szulczewski (1993). The brachiopod *Zilimia polonica* assemblage, together with numerous crinoids, has been deposited as nearly 0.5 m thick intercalation within the Famennian marly limestones and shale complex deposited in the intra-shelf basin. The authors gave numerous arguments for a sediment gravity flow mechanism as the decisive factor of the deposition.

On the other hand, the interpretation of some features observed in the Józefka brachiopod coquina bed are not as obvious and require a more detailed explanation:

1. **Preservation of non-disarticulated shells.** Highly dynamic transport of biogenic material usually causes disintegration and crushing of shells. As documented by the large block illustrated in Text-fig. 6, the layers of non-disarticulated specimens (intervals A and C) are separated by flattened shells (interval B). This indicates that transport of bioclastic material was performed in several phases and the final sedimentary effect was caused by the type of original biogenic material.

2. **Lack of an erosional boundary in the sole of the coquina bed.** The presence of an erosional boundary in the sole of gravity flow deposits is commonly expected. Such boundaries are widely observed in the slightly younger Kostomłoty Beds in the nearby Górno Quarry (Szulczewski 1968). In the case of the atyrid coquina bed at Józefka, the sole boundary is distinct but not erosional in nature. Most probably this is the result of the low cohesiveness of the muddy bottom, which was an effect of the marly composition of the bottom deposits.

3. **Large thickness and massive structure of the coquina bed.** The thickness of the investigated coquina bed is several times larger than the average bed thickness in the investigated succession. Almost certainly the deposition of the coquina bed was an effect of multiple flows and gradual sinking of the
efficiency of the lophophore was probably further enhanced by the deflection of the anterior commissure (uniplication), which enabled these brachiopods to separate inhalant and exhalant water currents. This was especially evident in C. dillanus, which possessed a very long, dorsally directed ventral tongue. It is usually accepted that in brachiopods having spirally coiled brachia and uniplicate shells, the nutrient-rich inhalant water current flew from the sides of the shell through the apices of spiral cones, whereas the exhalant current removed waste products anteriorly through the dorsal median fold (Copper 1986; Emig 1992; Williams et al. 1997; Halamski and Bałiński 2009). Although the spirolophous lophophore and deflection of the anterior commissure may occur in forms inhabiting various water depths, they are particularly advantageous adaptations for forms dwelling in deeper, quiet and/or nutrient-poor settings.

Shells of D. globosa jozefkæ have a distinct ventral interarea and a pedicle opening (Text-fig. 8F, G) suggesting that they retained a functional pedicle throughout their whole life. They were attached to hard substrates (e.g., other shells of dead or living co-occurring brachiopods) by their pedicle, but probably partially supported part of their weight by resting on the sea floor. Coeloterorhynchus dillanus, subordinate in the assemblage, was also most probably attached by its pedicle in the early stages of growth, but later, in result of progressive curvature of the ventral beak, which was pressed against the apex of the dorsal valve, the pedicle most probably atrophied and the shells freely lay on the sea floor.

Conodonts accompanying the brachiopod shell accumulation constitute a low diversity association, with polygnathids highly prevailing over icriodids. Among polygnathids predominate lanceolate, narrow-platform [P1] elements. Such conodont association is typical of the Szydłowiek Beds. It represents the polygnathid–icrioid biofacies (Racki 1985; Racki and Bultynck 1993), one of the globally distributed biofacies distinguished by Sandberg et al. (1989) in the Middle and Upper Devonian.

As summarized by K. Narkiewicz and Bultynck (2007, p. 422), the narrow-platform representatives of Polygnathus display a much wider range of distribution over the shelf areas than the polygnathid–icrioid biofacies. However, a specific feature of this biofacies in the stratigraphic interval containing the studied shell accumulation, is also the lack of broad-platform conodonts, especially Klapperina, Mesotaxis and Ancyrodelta, which contemporaneously occupied deeper, pelagic environments.

Generally, the distribution of conodont biofacies was controlled by regional palaeotectonic set-
tings, water depth, and distance from the shoreline (Sandberg et al. 1989; Ziegler and Sandberg 1990, p. 14). According to Racki and Bultynck (1993, p. 19), the elimination of broad-platform forms in the Szydlówek Beds was caused by ecological factors within a semi-closed intrashelf basin, with mostly stagnant and oxygen-stratified water. However, the same biofacies was identified by K. Narkiewicz and Bultynck (2010) in a similar stratigraphic position in the Lublin area, where it is situated within deeper shelf facies, and the influence of these causes on the conodont distribution does not seem obvious.

The anatomical analysis of the dominating brachiopod species presented above points to a relatively deep area for brachiopod growth and susceptibility of the brachiopod shells to transportation. According to the location of the Józefka area in the palaeogeographic pattern of the Holy Cross Mountains there are two possible places, where such requirements could be fulfilled. The first one was situated on the slope of the central carbonate platform (“Dyminy Reef” area) stretching to the south-west of present-day Józefka Hill. The assemblage of brachiopods, crinoids and bryozoans could develop on the limited area of the slope, relatively deeper than the assemblage of stromatoporoids, amphiporoids and tabulates, i.e., a typical fauna of the shallow water Givetian/Frasnian carbonate platform. However, as indicated by the presence of a thick, massive layer (Text-fig. 3, bed X) recognised above the coquina bed, the non-disarticulated brachiopods and shallow water material (stromatoporoids, tabulates, rugose corals, amphiporoids) were transported separately. Independently of the mechanism triggering the redeposition of bioclasts – storms, earthquakes – the debris flow deposits on the bottom of the basin should be composed of material derived from both zones of primary deposition.

Therefore the second hypothesis, assuming transportation of brachiopods and associated components from another direction, not related to the slope of the carbonate platform, seems more probable. Such possibility may be supported by the existence of a local elevation to the north of present-day Górno village (see Text-fig. 1B). The presence of such elevation was postulated by Baliński et al. 2016 (after data presented by Małkowski 1981) based on the regional distribution of coarse-grained material within the Kostomloty Beds. North-south transportation directions in this area were postulated also in the early papers of Szulczewski (1968, 1971). Baliński et al. (2016) discussed such possibility in the context of allochthonous material in a parautochthonous brachiopod assemblage reported from another section of Józefka Quarry. It seems that the Górno elevation (a submarine sea-mount), located at several kilometres from the shallows of the central platform, could function as a growth place of the studied brachiopod-crinoid population. It also explains the relative abundance of fistuliporid bryozoans, in contrast to the moderate frequency of these fossils in other areas of the Holy Cross Mts, especially in “Dyminy Reef” area.

It should be noted here that in the investigated section appeared also several thin (several centimetre thick) intercalations of brachiopod coquinas, composed of disarticulated shells, with an erosional sole, graded bedding of biodetritic parts, and lamination in the topmost part of the layer (compare Text-figs 3B and 11E). This type of coquinas, completely different in each feature from the thick bed described in this paper, was interpreted by Vierek (2008) as deposits reworked by storms. Regardless the correctness of this interpretation it can be assumed that the triggering mechanism of gravitational transport of the articulated shells proposed here seems to be connected with seismic disturbances rather than with storms. In the case of storms and other high-energy hydrodynamic events, the material from different shallow zones should be mixed together. The investigated section indicates separation of sources of bioclastic material, which points to local, probably tectonic reasons of the mass flow movements.

SYSTEMATIC PALAEONTOLOGY
(A. Baliński)

The brachiopod material described in the present paper is reposited in the Institute of Palaeobiology of the Polish Academy of Sciences in Warsaw under collection number ZPAL Bp 81.

Order Orthida Schuchert and Cooper, 1932
Suborder Dalmanellidina Moore, 1952
Superfamily Enteletoidea Waagen, 1884
Family Schizophoriidae Schuchert and LeVene, 1929
Genus Schizophoria King, 1850

TYPE SPECIES: Conchylolithes Anomites resupinatus Martin, 1809; lower Carboniferous; Derbyshire, England, United Kingdom.

Subgenus Schizophoria (Schizophoria) King, 1850

TYPE SPECIES: as for the genus.
Schizophoria (S.) schnuri prohibita Halamski, 2012  
(Text-fig. 9K, L)


2016. Schizophoria schnuri prohibita Halamski, 2012; Halamski in Baliński et al., p. 145, pl. 10, figs 21, 22.

MATERIAL: Three complete to nearly complete shells and six broken dorsal valves. Dimension of the most complete specimen (in mm): length 31.9, width 35.7, thickness 20.0.

REMARKS: This subspecies was originally described in detail by Halamski (2012) from the same quarry as the presented material. It is noteworthy, however, that the holotype and stratotypic paratypes described by that author come from slightly younger layers exposed in the eastern wall of Józefka Quarry. More recently the subspecies was described from the same quarry and the nearby road-cut by Halamski (in Baliński et al. 2016) from layers representing the Szydłów and Wietrznia beds (late Givetian to early Frasnian).

The present material is identical externally with the type material of the subspecies. One of the investigated dorsal valves shows a wide dorsal muscle field characteristic of the taxon.

Order Rhynchonellida Kuhn, 1949  
Superfamily Uncinuloidea Rzhonsnitskaya, 1956  
Family Hypothyridinidae Rzhonsnitskaya, 1956  
Genus Hypothyridina Buckman, 1906  

TYPE SPECIES: Atrypa cuboides Sowerby, 1840; Givetian, United Kingdom.

Hypothyridina sp.  
(Text-fig. 9M, N)

MATERIAL: Five fragmentary shells.

REMARKS: The described specimens can be attributed to the genus Hypothyridina on the basis of their cuboidal shape, high and flat to weakly convex tongue and characteristic radial costae. However, the present material is too incomplete to be reliably attributed to a species.

Superfamily Camarotoechioidea Schuchert, 1929  
Family Septalariidae Havliček, 1960  

Genus Phlogoiderhynchus Sartenaer, 1970  

TYPE SPECIES: Uncinulus arefactus Vevers, 1959; lower Frasnian, Upper Devonian; Australia.

Phlogoiderhynchus polonicus (Roemer, 1866)  
(Text-fig. 9O)

1866. Camarotoechia? polonica; Roemer, p. 676, pl. 13, figs 9, 10.

2016. Phlogoiderhynchus polonicus (Roemer, 1866); Baliński et al., p. 147, pl. 11, figs 1–5 (with synonymy).


REMARKS: This species was recently described from Józefka and Radlin by Baliński (in Baliński et al. 2016 with detailed location of Radlin outcrops). Earlier, Biernat and Szulczewski (1975) revised the species and gave a detailed description of its morphology, internal structure and the range of intraspecific variability. The single available subadult shell fully agrees with the characteristics of P. polonicus described by Biernat and Szulczewski (1975).

Superfamily Pugnacoidea Rzhonsnitskaya, 1956  
Family Pugnacidae Rzhonsnitskaya, 1956  
Genus Coeloterorhynchus Sartenaer, 1966  

TYPE SPECIES: Coeloterorhynchus tabasensis Sartenaer, 1966; middle and upper Frasnian, Iran.

Coeloterorhynchus dillanus (Schmidt, 1941)  
(Text-figs 9A–J, P; 13)


2016. Coeloterorhynchus dillanus (Schmidt, 1941); Balinski in Balinski et al., pp. 147–149, text-figs 9, 10, pl. 11, figs 6–30, 32 (with synonymy).

MATERIAL: 26 complete to almost complete shells and 38 fragmentary specimens. Dimensions of three illustrated specimens (in mm), respectively: length 23.7, 25.6, 27.2, width 30.0, 32.5, 35.3, thickness 19.0, 24.7, 29.6.

REMARKS: This species was recently described in
details from the eastern wall of the Józefka Quarry and from the nearby road-cut by Baliński (in Baliński et al. 2016). Earlier, it was also described from the Wietrznia Beds of the Wietrznia Quarry (Baliński 2006). Detailed occurrences of the species were given by Baliński (in Baliński et al. 2016, pp. 148, 149).

Order Atrypida Rzhonsnitskaya, 1960
Family Atrypidae Gill, 1871
Genus Desquamatia Alekseeva, 1960

Desquamatia globosa (Gürich, 1896)
Desquamatia globosa jozefkae Baliński subsp. nov. (Text-figs 7, 8, 14, 15)

TYPE MATERIAL: Holotype (a complete articulated shell) ZPAL Bp 81/1 (Fig. 11 = 7Z–DD), 154 complete and 56 fragmentary shells, collection number ZPAL Bp 81/2–8, 17–19, 23–25.

TYPE LOCALITY: Józefka Quarry south of Górno, Holy Cross Mountains.

TYPE HORIZON: Szydłówek Beds, Givetian–Frasnian boundary beds.

ETYMOLOGY: jozefkae – after Józefka, the name of the village where the quarry is located.
the hill with the quarry, in which the studied material was found.

DIAGNOSIS: Medium-sized, rounded to transversally elliptical in outline, uniplicate; cardinal margin attains 44–62% of shell width, anterior margin usually truncated, rarely weakly arched or weakly indented; ventral interarea distinct, apsacline to orthocline; dorsal fold absent or very low; 11–13 ribs per 10 mm at distance of 20 mm from ventral beak.

DESCRIPTION: Shell medium-sized for the subgenus, typically 21–27 mm in width, largest up to 33 mm wide, rounded to transversally elliptical in outline, slightly wider than long to subequal (Text-fig. 15); cardinal margin nearly straight, attaining 44–62% of shell width, lateral margins rounded, anterior margin usually truncated.

Ventral valve weakly convex in lateral profile, with weakly convex to weakly concave flanks; sulcus wide, appears at midlength, shallow; tongue absent to very short; interarea distinct, almost flat to slightly concave, weakly apsacline to orthocline, reaching 1.4–1.8 mm in height; deltidial plates conjunct, delicate with apical foramen surrounded by distinct foraminal rim (Text-figs 7F, 8F–G).

Text-fig. 14. Transverse serial sections of Desquamatia globosa jozefkae Baliński subsp. nov. through two shells ZPAL Bp 81/18 (A) and ZPAL Bp 81/19 (B) from Józefka Quarry. Numbers refer to distances in mm from ventral umbo.
Dorsal valve more convex than ventral valve, regularly arched in lateral profile, with slightly swollen umbonal and median regions; fold absent or very low, poorly distinguishable near anterior margin of adult forms.

Ventral valve interior with strong teeth, small accessory lobe and small dental cavities or dental nuclei. Dorsal interior with flat, subhorizontal hinge plates separated by moderately wide cardinal pit, posteriorly lined with attachment of adductor muscles; median myophragm wide, triangular in transverse section posteriorly and domed more anteriorly, with shallow median groove (Text-fig. 14).

Ornamentation of tubular, bifurcating ribs, 11–13 per 10 mm measured at distance of 20 mm from ventral beak. Growth lamellae and micro-ornament not observed due to extensively decorticated shell exteriors.

REMARKS: Racki (1993a) discussed a wide range of morphological variability of *D. globosa* (Gürich, 1896) that he revealed from several localities in the south-western part of the Kielce Region. He proposed to regard those atrypids as representing different subspecies within *D. globosa*. Besides the nominative subspecies, he proposed *D. globosa aequiconvexa* Racki, 1993 and *D. globosa sitkovenensis* Racki, 1993. He also noted (Racki 1993a, p. 322) that discrimination of different subspecies of *D. globosa* from different localities or beds, but on a rather limited area in the south-eastern part of the Holy Cross Mountains is biologically more realistic than attributing these forms to similar species known from distant areas of the world. The present author agrees with this point of view and prefers to regard the atrypid from Józefka as a new subspecies within *D. globosa*.

The present subspecies is externally similar to *D. g. globosa* (Gürich, 1896) described by Gürich (1896) and re-described by Racki and Baliński (1981) and Racki (1993a) from the Givetian to Frasnian transitional beds in the Checiny area, Holy Cross Mountains. Both subspecies have a high and distinct ventral interarea and attain a similar shell size and

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**Text-fig. 15.** Diagrams of shell dimensions in *Desquamatia globosa jozefkae* Baliński subsp. nov. from Józefka Quarry. A – scatter plot of shell width (solid diamonds) and shell thickness (white squares) to shell length. B – scatter plot of shell width index (width/length) to shell length. C – scatter plot of shell thickness index (thickness/length) to shell length. D – size-frequency distribution. n is the number of specimens measured.
The enormous thickness of the brachiopod complex is probably caused by the sinking of bioclastic material in a soft, muddy bottom, similarly to other limestone units, composed of basinal marls, intercalated with allochthonous bioclastic layers.

CONCLUSIONS

An isolated accumulation of densely packed brachiopods, more than 3 m thick and 10 m wide, has been found in Józefka Quarry in the central part of the Holy Cross Mountains. The complex was deposited most probably as an allochthonous bed within the Middle/Upper Devonian Szydłówek Beds. The low-diversity assemblage is dominated by the atrypide Desquamatia globosa jozefkae Babiński subsp. nov. and, to a lesser degree, by the rhychonellide Coeloterorhynchus dillanus. Less frequent are specimens representing the genera: Hypothyridina, Schizophoria and Phlogoiderynchus. Analysis of the internal morphology of the dominating forms allows us to conclude that the assemblage represents forms which might have been well adapted to deeper water settings characterized by lower nutrient concentrations.

Conodonts found within the coquina bed indicate that the stratigraphic position of the shell accumulation is close to the Givetian/Frasnian boundary. This confirms an earlier statement that the lower boundary of the Szydłówek Beds is diachronous.

The brachiopods are associated with numerous crinoids and less frequent bryozoans, receptaculitids (Palaeozoic problematica), sponges and solitary corals. Several sedimentary features of this unit support the conclusion that it formed by redeposition to a deeper part of the intrashelf basin, characterizing the sedimentation of the Szydłówek Beds. However, the high degree of brachiopod shell articulation and the only partial infilling of shells, indicate a rather short distance of redeposition. The brachiopods mixed with crinoid debris were transported by low velocity, high-density gravity-induced debris flows.

The comparison of the spectrum of bioclasts from higher parts of the investigated section indicates that the source area for the coquina material was not located in the shallow parts of the central platform ("Dyminy Reef"), but most probably it was transported from the submarine sea-mount to the north of present-day Józefka. A characteristic spectrum of biota within the coquina bed, devoid of forms typical of the Middle Devonian shallow-water faunal associations, allows us to conclude that the triggering mechanism of allochthonous deposition was rather an earthquake than storm activity.

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