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Does reservoir substrate type and palaeo-depth affect the Middle Jurassic taxonomic diversity of crinoids?

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Crinoids are, with a few exceptions, benthonic organisms are generally considered as good indicators for determining environmental conditions. Their presence is also associated with marine environments where currents steadily supply planktonic food. Crinoids are also considered robust proxies for inferring changes in salinity and sedimentation rate and for inferring substrate type. Some crinoid groups (e.g., comatulids, cyrtocrinids, millericrinids) also have a depth preference, thus, making them sound proxies for paleodepth estimation. The hypothesis that crinoids are good proxies for inferring substrate type and paleodepth is tested here based on (a) archival Bathonian-Callovian (Middle Jurassic) crinoid occurrences from Poland and (b) newer finds from five borehole data from eastern Poland. Analysis suggests that isocrinids frequently occur in both in carbonate and siliciclastic rocks. The cyrtocrinids and roveacrinids occur within carbonate rocks, whereas the comatulids are exclusive to siliciclastics; the cyclocrinids occur in both rock types. Most crinoid groups dominate in shallow environments with the sole exception of cyrtocrinids, that are equally common in shallow (near shore and shallow marine) and slightly deeper (deeper sublittoral to open shelf) settings. Both *Chariocrinus andreae* and *Balanocrinus subtrees* (isocrinids) are found to be cosmopolitan. Their occurrence is independent of both substrate type (carbonate or siliciclastic), and paleodepth (shallow marine and open-shelf environments). Hence, based on the present analysis and the ubiquitous occurrences of some crinoids (mainly isocrinids), the use of crinoids as reliable proxies for inferring reservoir depth (paleodepth) and substrate type, should be considered with caution.

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Abstract

Crinoids are, with a few exceptions, benthonic organisms are generally considered ~~as~~ good indicators for determining environmental conditions. Their presence is also associated with marine environments where currents steadily supply planktonic food. Crinoids are also considered robust proxies for inferring changes in salinity and sedimentation rate and for inferring substrate type. Some crinoid groups (e.g., comatulids, cyrtocrinids, millericrinids) also have a depth preference, thus, making them sound proxies for paleodepth estimation. The hypothesis that crinoids are good proxies for inferring substrate type and paleodepth is tested here based on (a) archival Bathonian-Callovian (Middle Jurassic) crinoid occurrences from Poland and (b) newer finds from five borehole data from eastern Poland. Analysis suggests that isocrinids frequently occur in both ~~in~~ carbonate and siliciclastic rocks. The cyrtocrinids and roveacrinids occur within carbonate rocks, whereas the comatulids are exclusive to siliciclastics; the cyclocrinids occur in both rock types. Most crinoid groups dominate in shallow environments with the sole exception of cyrtocrinids,

that are equally common in shallow (near shore and shallow marine) and slightly deeper (deeper sublittoral to open shelf) settings. Both *Chariocrinus andreae* and *Balanocrinus subtrees* (isocrinids) are found to be cosmopolitan. Their occurrence is independent of both substrate type (carbonate or siliciclastic), and paleodepth (shallow marine and open-shelf environments). Hence, based on the present analysis and the ubiquitous occurrences of some crinoids (mainly isocrinids), the use of crinoids as reliable proxies for inferring reservoir depth (paleodepth) and substrate type, should be considered with caution.

Key words: echinoderms, crinoids, Jurassic, Bathonian, Callovian, Poland, boreholes.

Introduction

The Middle Jurassic (especially Bajocian and Callovian) strata of the epicratonic Poland are well-known for their excellently preserved and strongly diversified fossil fauna and flora (e.g., Kopik, 1974, 1976, 1979a, b, 1998, 2006; Zatoń et al., 2006a, b). These occur within clays and carbonate concretions and are represented by ammonites, gastropods, scaphopods, bivalves, belemnites, brachiopods, bryozoans, echinoids, asteroids, ophiuroids, wood fragments, and many others (for details see Matyja & Wierzbowski, 2000, 2003; Gedl et al., 2003; Kaim, 2004; Zatoń & Marynowski, 2004, 2006; Zatoń et al., 2006a, b; Zatoń, 2010a, b). The Callovian fauna, within the carbonates, is both diverse and abundant (see Zatoń et al., 2011 and literature cited therein)), however in eastern Poland ammonites are very rare (Niemczycka, 1965, 1979). Crinoids, the group under study, are also abundant in these sediments (especially common in the boreholes of eastern Poland), often forming encrinites that represent bioclast-crinoid rocks in which all or most of the grains are crinoid ossicles (e.g., Salamon & Feldman-Olszewska, 2018). Despite such diversity and abundance, the crinoid data from the Middle Jurassic of Poland has largely been relegated to either brief mentions of species occurrences or of citing crinoid-containing localities (see Salamon & Feldman-Olszewska, 2018 and literature cited therein).

~~Hence~~, an attempt is now made to bridge or at least narrow this gap, spanning the uppermost Bathonian-Callovian duration (for exact age see Table 1), by documenting new crinoid records from five boreholes from eastern Poland (see Fig. 1). Additionally, for sake of taxonomic standardization, a comprehensive taxonomic analysis is also provided with remarks on previous collections (e.g., Wójcik, 1910; Makowski, 1952; Różycki, 1953; Hess, 1975; Dayczak-Calikowska, 1980; Radwańska & Radwański, 2003).

During the Bathonian-Callovian duration, the Polish Basin was a part of the epicratonic Central European Basin that separated the Fennoscandian plains on the north from the Western Tethys on the south. Only the extreme southern part of Poland (Tatra Mountains and Pieniny Klippen Belt) was part of the Tethyan realm (see Fig. 1). These two realms are defined by the occurrence of ammonites; the identified assemblages display highly distinctive provincial characteristics (Hallam, 1975; Brand, 1986). ~~Hence~~, an analysis of the Middle Jurassic crinoid taxonomic diversity within these two palaeo-geographic provinces, i.e., Tethyan and Central European, is also detailed.

Thus, the present contribution aims to address two hypotheses, (a) Do Callovian crinoids occur equally and frequently in both deep and shallow water environmental settings (palaeo-depth dependency)? and (b) Do Bathonian and Callovian crinoids occur equally and frequently in both carbonate and siliciclastic facies (substrate dependency)?

Previous work

The Middle Jurassic (Callovian) crinoids of the epicratonic basins of Poland have been recorded from the Polish Jura Chain ('A' on Fig. 1) and the Mesozoic margin of the Holy Cross Mountains ('B' on Fig. 1). Early records only mentioned Middle Jurassic crinoid localities (e.g., Wójcik, 1910; Makowski, 1952; Różycki, 1953). Later, Dayczak-Calikowska (1980) listed the following Middle Jurassic taxa - *Balanocrinus* aff. *subteroides*, *Cyclocrinus macrocephalus*, *Mespilocrinus macrocephali*, *Pentacrinus nodosus*, *P. cingulatus*, *P. pentagonalis*, and *P. cristahalli*. However, ~~he~~ did not mention the sample repository as well as the exact locations where the crinoid specimens were collected. Furthermore, neither description, nor illustration, or even basic assignment to any broad taxonomic groups, such as cyclocrinids, isocrinids or balanocrinids, was provided; most of these specimens, however, belonged to balanocrinids.

More recently, Radwańska & Radwański (2003) recorded Callovian columnals of *Cyclocrinus macrocephalus* and Oxfordian cyclocrinid of *Cyclocrinus couiavianus* from northern Poland. From a collection of 45 isolated remains, Salamon & Zatoń (2006) erected a new species of balanocrinid (*Balanocrinus hessi*) from the Callovian marly limestones of the

Zalas Quarry in southern Poland ('A' in Fig. 1; see also Table 2). But, a re-examination of this material prompted Krajewski et al. (2019) to synonymize this species with *Balanocrinus pentagonalis*. Salamon & Gorzelak (2007), from the same locality, also described few isolated remains of indeterminable cyrtocrinids associated with the cyrtocrinid cup of *Dolichocrinus* cf. *aberrans* (see Table 2). Salamon & Zatoń (2007), from a collection of ~1500 remains of columnals, pluricolumnals, brachials and cups, illustrated 11 crinoid taxa, including some isocrinids, comatulids, millecrinids and cyclocrinids (see Table 2). These specimens came from three Bajocian, several Bathonian and two Callovian localities of the southern part of the Polish Jura Chain and the Mesozoic margin of the Holy Cross Mountains (see Salamon & Zatoń, 2007). Current re-examination of this material led to the actual assignment of the columnals described as *Millericrinina* to the cyrtocrinids, Cyrtocrinida indet. (see Salamon & Feldman-Olszewska, 2018) (see Table 2). Later, Salamon (2008a, b) recorded several crinoid taxa from two Callovian localities, namely the "glacial drift" of Łuków in eastern Poland ('C' in Fig. 1) and the Polish Jura Chain ('A' in Fig. 1). The "glacial drift" assemblage of Łuków ('C' in Fig. 1), consisting of ~400 remains of both isolated plates and complete individuals from the black clays, is dominated by isocrinids with associated comatulids. The carbonate rocks of the Polish Jura Chain yielded a rich assemblage of cyrtocrinids with dozens of complete individuals and a few isolated isocrinid remains. Recently, Salamon & Feldman-Olszewska (2018) described a collection of five isocrinid taxa with some unidentifiable cyrtocrinids from the Callovian crinoidal limestones of the Żebrak IG 1 borehole located in eastern Poland ('D' in Fig. 1) (see Table 2). This collection contained a relatively small number of complete or nearly complete individuals, as a side-effect of the maceration process. Before the maceration process, the samples formed a typical encrinite and consisted largely of crinoids, as is also the case in the present study, yielding only fragmentary crinoids (see Table 2). Additionally, the Middle Jurassic (Bathonian-Callovian carbonates exposed in southern Poland) crinoids have also been reported from the Tethyan province ('E' and 'F' in Fig. 1) containing isocrinids, cyrtocrinids, roveacrinids, and cyclocrinids (see Głuchowski, 1987; see Table 2).

Figure 1 around here

Material and methods

The archival cores (72 core samples) drilled in eastern Poland (G1-G5 on Figs. 1 and 2) were investigated for crinoids. These cores are stored in the Polish Geological Institute National Research Institute, Warsaw (Poland). The samples selected for the maceration process were selected from the following boreholes at respective depths: 1) Kock IG 2 (core depth: 859.0 m; age: Callovian?); 2) Maciejowice IG 1 (core depth: 1,431.5 m; age: late Bathonian?); 3) Magnuszew IG 1 (core depths: 1,505.7 m, 1,507.3 m, 1,508.65 m, and 1,522.4 m; age: middle and late Callovian respectively); 4) Siedliska IG 1 (core depths: 824.65 m, 828.25 m, 828.77 m, 830.8 m, and 837.65 m; age: late Bathonian?-early Callovian); 5) Tłuszcz IG 1 (core depth: 1,047.7 m and 1,049.95 m; age: late Callovian?-early Oxfordian); 6) Żyrzyn IG 1 (core depths: 1,134.95 m, 1,137.7 m, 1,147.9 m, and 1,155.4 m; age: late Bathonian-Callovian) (for a summary see Table 2). The present paper also includes a large collection of Callovian crinoids from Poland collected by Mariusz Salamon and Bartosz Płachno (2006-present) and others, mentioned in the *Acknowledgements* section.

The first step for the current analysis consisted of examining the drill cores under a binocular microscope ~~fr~~ crinoids. Thereafter, the carbonate samples were soaked with Glauber's salt. Based on sample cohesion, these were then successively boiled and freezed. The residues was then washed under running tap water and sieved on a sieve column (mesh sizes: Ø1.0, 0.315 and 0.1 mm, respectively). The final step consisted of drying the screened residues at 170-180˚C (following the methodology outlined by Krajewski et al., 2019).

In the case of the sandstone sample Maciejowice IG 1 (core depth: 1,431.5 m; age: late Bathonian?) and of the carbonate sample Magnuszew IG 1 (core depth: 1,505.7 m; age: late Callovian), they were naturally macerated and left outside for 30 days (from January 22nd to February 21st, 2021). The average temperature during this period varied from -9˚C to 20˚C. As a result of this natural maceration, the samples partially disintegrated. In addition to this, several thin sections (TS) and polished slabs (PS) were also elaborated. All crinoids were hand-picked from the maceration residue and photographed using a Canon Eos 350D digital camera, LeicaWildM10 coupled with a NikCamPro1 microscope and a Scanning Electron Microscope Philips XL−20. All specimens are housed in the Institute of Earth Sciences of the University of Silesia in Katowice, Poland, and catalogued under registration number GIUS 8-3734. Other Middle Jurassic specimens used in the current study are also housed at the Institute of Earth

Sciences of the University of Silesia in Katowice, Poland, and catalogued under: GIUS 8–2510, 8–2569, 8–2571, 8 - 3460Cr, 8-3466, 8-3678/1-6, 8-3734.

Table 1 around here

Taxonomic standardisation

The cyrtocrinids are identified at the specific level based on their cups. In some cases, when the cups were preserved fragmentarily or some typical features were not visible, the samples were assigned to the generic level, only. Most of the disarticulated remains of cyrtocrinids (holdfasts, columnals, radials, basals, brachials, etc.) are assigned under Cyrtocrinida indet.

As for comatulid centrodorsals, where cups with basals and radials were not available for additional information, they were also classified at the generic level. The brachial with muscular articulation on the proximal side and syzygial one on the distal side are classified as Paracomatulidae sp. et gen. indet.

The isolated remains of isocrinids, consisting of columnals, pluricolumnals, cirrals, cup plates, and brachials, are classified at the specific level. If they were found in different levels, they are described as Isocrinida indet.

A complete individual of cyclocrinid has not been found so far. Despite this, the uniqueness of their remains (e.g., large cylindrical columnals with peculiar tuberculate facets) allows us to identify them at the specific level (see detailed discussion in Radwańska & Radwański, 2003). Głuchowski (1987) assigned some remains from the Pieniny Klippen Belt to *Cyclocrinus* sp. due to the incompleteness of columnals.

All roveacrinids (saccocomids) were classified by Głuchowski (1987) as *Saccocoma* sp.; the latter were recorded both as isolated cup remains and as sections, observed in thin sections (TS).

~~Hence~~, the dataset used in the present study is taxonomically standardised. The crinoids classified in the present study are given in Tables 1-4. A summary of all data with their respective inferred palaeo-depth and species diversity (number of taxa) is given in Table 3 (see also Fig. 3).

Tables 2, 3 around here

Results

The present study identified several crinoid remains of cups, columnals, cirrals and brachials from the 5 boreholes drilled in eastern Poland (Fig. 1). Only two pluri-columnals were recorded. The first one consists of three or four columnals observable on the surface of a rock fragment from the Maciejowice IG 1 core (depth: 1,522.4 m). The second one consists of two columnals and comes from the sample of Siedliska IG 1 (depth: 828.77 m).

The crinoid assemblages from the upper Bathonian and the Callovian are almost identical (see also Table 1). The other echinoderms observed on slab surfaces include numerous partly preserved cidaroid spines, cidaroid interambulacral plates and asteroid marginal plates. The echinoderm remains were also observed in thin sections and on the surface of polished slabs. In addition to these echinoderm remains, bivalves, gastropods and ostracods were observed both on the slab surfaces and in the macerated residues. In the sample late Bathonian Maciejowice IG 1 specimen, the remains of carbonized plant were also observed (for a summary of the above data see Table 4).

The other investigated Middle Jurassic crinoids were represented by numerous cups, cup remains, brachials, columnals, pluri-columnals, cirri, cirrals, and holdfasts (for details see Głuchowski, 1987; Salamon & Gorzelak, 2007; Salamon & Zatoń, 2007; Salamon, 2008a-c; Salamon & Feldman-Olszewska, 2018).

Table 4 around here

State of preservation

The preservation of crinoids was examined only on the non-macerated surfaces of fresh core fragments. These were screened for signs of abrasion, bio-erosion traces, chemical alteration of ossicle structure, evidence of epibionts, and predation traces. Most of the crinoids display a high degree of disarticulation (almost 100%). However, they all are well preserved and do not reveal any traces of lateral surface abrasion. Excellent preservation and lack of abrasion are also noticed for columnal articular surfaces; the crenulae, petal floors, perilumens and lumens are complete. The two pluri-columnals also show no signs of abrasion. Additionally, the studied crinoid remains are very rarely bio-eroded (bioerosion was only noticed in case of three columnals) in the form of small and rounded holes. These may be ascribed to acrothoracican cirripedes, algae, fungi, polychaetes, sipunculans, or to sponge activities (for more details see Salamon & Zatoń, 2006; Zatoń et al., 2007; Salamon & Gorzelak, 2010).

Donovan (1991) suggested that under normal oxygenated conditions, complete crinoid disarticulation takes place within two weeks. However, Brett et al. (1997) argued that under certain circumstances, complete disarticulation may occur even after a year. In living comatulids, disarticulation starts just after death and by the end of the first week, only isolated calyx and a few arm fragments remain articulated (Ausich, 2001). Under high water temperatures and with increased physical disturbance, the disarticulation process speeds up, significantly (see Ausich, 2001; Hess, 2006). Baumiller & Ausich (1992) noted that after 19 days, the isocrinid stem disarticulates into noditaxes and after 22 days, the column segments disarticulate into isolated columnals. Gorzelak & Salamon (2013) noted that under constant transportation in high-energy conditions, and at room temperature, disarticulation of the crinoid skeleton is nearly complete after 17 days, where only a few articulated arms and cirral ossicles remain intact.

In the present study, the crinoid remains are preserved as cups, isolated columnals, brachials, and cups. Therefore, these remains can confidently be classified as taphonomic types 2 and 3 *sensu* Brett et al. (1997). Type 2 includes isocrinids and some remains of cyrtocrinid that undergo rapid postmortem disarticulation, on account of weak sutures. Type 3 comprises of cyrtocrinid cups in which major portions of the skeleton are resistant to disarticulation.

Thus, for the present study, all the data suggest that the recorded crinoids are autochthonous with negligible or no post-mortem transportation. Possibly, after death, they had remained for some time on the sea bottom, but were not subjected to significant transportation before burial, or they were shortly covered by sediment, as suggested by the lack of abrasion surfaces. Additionally, no trace of chemical alteration, predation traces and epibionts were noticed, suggesting that the inferred palaeoecological and palaeodepth signals are primary.

Discussion

Depositional environment of the Łuków glacial draft

The Łuków glacial drift is a 30 m-thick Callovian unit containing black clays with carbonate concretions exposed in eastern Poland ('C' in Fig. 1) (see also Mizerski & Szamałek, 1985), deposited in an offshore setting (e.g., Olempska & Błaszczyk, 2001; Kaim, 2004). However, recently, based on the presence of a high diversity asteroid assemblage, a varied environment (ranging from coastal to deep-shelf) was proposed (Villier, 2008). This unexpected high diversity is likely a reflection of ossicles being transported by currents from shallow- to deep-water offshore environments (Villier, 2008). According to Salamon (2008a), based on the ecology of crinoids, the Łuków clays was deposited in a relatively shallow environment; Gedl (2008) using dinoflagellate cysts, also arrived at the same conclusion. Gedl (2008) noted that either that these originated presumably from shallow marine, shelf environments deposited in less favourable environments for dinoflagellates, or that sedimentary processes, e.g., high dynamic environments, caused taphonomic depletion. Additionally, based on the presence of macro- and micro-remains of land flora (see also Brand, 1986; Marynowski et al., 2008), the Łuków clays was inferred to have been deposited in ~~a sea reservoir located not too far from the land.~~ Sedimentological investigations of the Aalenian-Bathonian (Middle Jurassic) claystones and shales from central Poland indicate that their sedimentation took place in offshore (below storm wave base) and transition (between normal and storm wave base) zones of the epeiric sea (see Feldman-Olszewska, 2007, 2008, 2012a, b; Pieńkowski et al., 2008). ~~The sea~~ depth corresponds to the *Cruziana* ichnofacies but shallower than the *Zoophycus* ichnofacies (see Knaust & Bromley, 2012). The same depositional environment is expected for the Callovian clays from Łuków. In this study, these sediments are ~~interpreted likewise, i.e.,~~ a shallow marine depositional setting.

Problems with isolated isocrinid classification

The isocrinids are a dominant crinoid group in the Middle Jurassic sediments of Poland. However, their correct classification into families and genera is quite complicated, ~~even for experts.~~ The ideal situation is when complete crinoid findings are available (e.g., Simms, 1989; Hess, 1999c, d; Hess & Messing, 2011), but these are rare due to the unique structure of their skeletons (see *State of preservation*). There are of course also isocrinids that have a unique structure of columnals and it is ~~basically impossible to confuse~~ them with any others. A classic example is that of *Balanocrinus subteres* or *B. pentagonalis*. Both have been characterised and illustrated many times (e.g., Klikushin, 1992; Hess, 2014a, b; Krajewski et al., 2016, 2019, 2020). Hess (2014a, b) even stated that the columnals of *B. subteres* could be associated with its isolated calyx elements. Likewise, with remains of *Pentacrinites dargniesi* or *Isocrinus nicoleti*, which display a unique shape and ornamentation of the articular facets. Additionally, *P. dargniesi* has a characteristic, ellipsoidal cirrals.

There is ~~a real~~ issue concerning non-balanocrinid isocrinids, which have columnals of a similar morphology, and which were erected on the basis of isolated skeletal remains. There are many such forms in the Middle and Upper Jurassic strata of Poland.

According to de Loriol (1887), the most similar taxon to *Isocrinus amblyscalaris* is *I. munieri*. However, this author stressed that there are some noticeable differences between them, alsoi.e., height of columnals and the ornamentation of latera. Hess (2014a) added that *Pentacrinus pellati* with low columnals alternating with higher ones, and ridges occurring on its latera, is also a very similar form. He concluded that both species are of middle Oxfordian age and therefore may be conspecific. In turn, Bather (1898) suggested that *Isocrinus amblyscalaris* collected from the Oxfordian and Kimmeridgian of Poland is a synonym of *I. pendulus*. These authors emphasis~~z~~ed the lack of genuine differences between both these taxa. Moreover, Hess (1975) added that both these species originated from the same middle Oxfordian strata (Bärschwil Fm, NW Switzerland). On the other hand, Klikushin (1992) stated that there is a series of morphological differences between these two species that supersedes Bather's (1898) opinion. The latter author, elsewhere in his monograph, however, proposed to consider *I. pendulus*, Oxfordian *I. amblyscalaris*~~,~~ and Callovian-Oxfordian *I. oxyscalaris* as junior synonyms of the Oxfordian *I. desori*. Krajewski et al. (2019) differed from this view and emphasised that there are some differences in the facet morphology of the mentioned taxa. Apart from the differences in the articular facets (i.e., the presence of deep furrows between petal floors), the shape of columnals may also be different (compare Hess, 1975, p. 55, text-fig. 8, pl. 19, fig. 4; Klikushin, 1992, pl. 11, fig. 1-7 vs. pl. 13, fig. 8-10; Radwańska, 2005, fig. 8/4; Salamon, 2009a, fig. 2H).

Taking into account all of the above, it is difficult to say unequivocally whether there are one or more biological species within the Middle/Upper Jurassic strata of Poland. Therefore, such forms , whose taxonomic affiliation raises serious doubts (*Balanocrinus berchteni*, *Isocrinus bajocensis, I. bathonicus*, and *I. pendulus*), must be evaluated with great caution in any analysis.

Taxonomic status of cyclocrinids

The Cyclocrinids (Cyclocrinidae) were classified by Biese (1935-1937) as millericrinids (Millericrinida, Apiocrinitidae). Sieverts-Doreck (1953, in Ubaghs) and later Hess (1975) placed the cyclocrinids within cyrtocrinids (Cyrtocrinida). According to Radwańska & Radwański (2003) cyclocrinid columnals are elements of radical cirrals and therefore belong to bourgueticrinids (Bourgueticrinida). Following Hess (2008) the ordinal position of *Cyclocrinus* and of the family Cyclocrinidae is left in open nomenclature though the form has some resemblance to the Early Jurassic millericrinid genus *Amaltheocrinus*. Hess & Messing (2011) placed *Cyclocrinus* within uncertain order pending proper classification of its cup plates that still remain unknown.

One of the previously investigated Callovian sections (the abandoned Wysoka Quarry placed within the Polish Jura Chain; 'A' in Fig. 1), exposes sandy limestones where numerous cyclocrinid columnals were collected from a narrow level. Remains of other crinoids were not found there. Along with these columnals, several "millericrinid"-like brachial (see Fig. 3) plates were found, which probably belong to the same crinoid as the columnals. Brachials display a proximal synostosis and a muscular distal side, sometimes with a pinnule socket. Both facets are parallel. This seems to confirm Hess's (2008) idea of linking cyclocrinids to millericrinids. On the other hand, the "bourgueticrinid"-like, strongly abraded cup was found by us in the Czerwieniec locality. This cup is very similar in shape and size to bourgueticrinid cup that may suggests that cyclocrinids really belong to bourgueticrinids as suggested by Radwańska & Radwański (2003); see Fig. 3C.

Figure 3 around here

Cyclocrinids from Poland

Wójcik (1910) ~~was~~ first listed the occurrence of *Cyclocrinus macrocephalus* in Poland as also the occurrence of columnals in the sands of Filipowice, Polish Jura Chain ('A' in Fig. 1). Głuchowski (1987) indicated the occurrence of *Cyclocrinus rugosus* and *Cyclocrinus* sp. within the Bathonian and/or Callovian crinoidal limestones of the Tatra Mountains and the Pieniny Klippen Belt ('E' and 'F' in Fig. 1). Radwańska & Radwański (2003) questioned ~~the correctness of~~ this assignment, claiming that the sketches and photographs are not of sufficient quality and specimens are poorly preserved. They added that the 'cyclocrind' specimens were small-sized. Re-examinations of Głuchowski specimens (1987, fig. 13/1, 13/4 and pl. 1, fig. 1-6), stored at the Institute of Earth Sciences of the University of Silesia in Katowice, Poland, prove that they are significantly smaller than columnals collected from other areas. Simultaneously they are cylindrical, low and with a slightly convex latera, suggesting that they may well belong to cyclocrinids. Therefore, the original designations of Głuchowski (1987) are currently upheld. Moreover, Radwańska & Radwański (2003) recognised four cyclocrinid species within the Middle and Upper Jurassic strata of Poland, namely: *Cyclocrinus rugosus* from the Bajocian, *C. macrocephalus* from the Callovian, *C. areolatus* from the Oxfordian, and *C. couiavianus* from the upper Oxfordian. They stated that all mentioned taxa with the exception of *C. couiavianus* lie within the variability of *C. rugosus* (Radwańska & Radwański, 2003). Though describing columnals with articular surfaces covered by numerous and irregular tubercles, Salamon & Zatoń (2007) decided to include these remains in *C. macrocephalus*. Re-observation of columnals coming from the same Callovian levels of the Polish Jura Chain, both ornamented by and devoid of tubercles, confirm the suggestion of Radwańska & Radwański (2003) that all these cyclocrinids actually belong to a single species, *Cyclocrinus rugosus*.

Distribution of crinoids within particular facies. Does it really work?

Hans Hess in several of his papers pointed out that the ~~existence~~ of certain species of crinoids is closely related to strictly defined sediments (substrate) and depths. He claimed that *Chariocrinus andreae* ~~existed on~~ muddy bottoms and its dense colonies occurred in somewhat deeper waters, below fair-weather wave base, i.e. at depths around 10-15 m (Hess, 1972, 1999a). In this study, *Chariocrinus andreae* occurs in large amount in both carbonate and siliciclastic rocks: *Balanocrinus subteres* is one of the most cosmopolitan crinoids ever recorded and is known from both shallow and deeper environments (compare Table 3 and Fig. 2). Hess, (1999a) claimed that another very common Middle Jurassic crinoid taxon, *Isocrinus nicoleti*, frequently occurring in Poland, may also occur within both ooid shoals of the carbonate shelf and in slightly deeper environments, represented by intercalating marls and bio-clastic limestones. Tang et al. (2000) recorded this species from shallow-water tidal facies of the Middle Jurassic Carmel Formation in Mount Carmel Junction (USA). Hunt & Underwood (2009) concluded that the distribution of crinoids corresponds quite nicely to particular facies (but see also the comment on this paper by Salamon et al., 2010). Hunt & Underwood (2009) further noticed that *Isocrinus nicoleti* from the Bathonian of England and France, occurred only in shallow-water sediments, represented by low-energy, inner muddy shelf and outer lagoon, oolitic high-energy shoal system, carbonate/muddy low-energy, marine lagoon complex and in the shallow subtidal zone. All these are actually consistent with our own observations that ~~prove that~~ *I. nicoleti* (Tables 2 and 3) occurred in both carbonate and siliciclastic rocks, although it preferred shallow-water carbonates. Hunt & Underwood (2009) also collected *Pentacrinites* cf. *dargniesi* from these shallow, muddy and carbonate habitats. *Pentacrinites dargniesi*, despite being predominantly found in carbonates, also occurs in offshore claystones of Poland (see Table 2 and 3). However, we must keep in mind that it was a pseudo-planktonic crinoid that transported on the lower surfaces of driftwood fragments: therefore, it is likely to occur in varied facies (see Simms, 1999; Hess, 1999a).

The most numerous isocrinids within the Middle Jurassic of Poland are balanocrinids (*Balanocrinus subteres* and *B. pentagonalis*). Hess (2014a, b) argued that balanocrinids settled mostly on hardgrounds: however, they are also be found in mudstone-dominated settings, possibly on swells of the fine-grained bottom. The largest species of the genus (*Balanocrinus subteres*) was reported from bottom elevations, below storm wave-base (Hess & Spichiger, 2001), where these slender crinoids could thrive due to ample nutrient availability and well-oxygenated bottom waters (Hess, 2014a, b).

Current observations also corroborate Klikushin's (1992) observation, that *Balanocrrinus subteres* is another most cosmopolitan Mesozoic crinoid species. It occurs in both carbonate and siliciclastic facies and in environments of varying depth, from near shore (close to a beach) to the open shelf, but usually below normal wave base (Table 3 and Fig. 2). On the other hand, Hunter & Underwood (2010) concluded that occurrences of balanocrinids (*Balanocrinus* cf. *subteres*) were restricted to neritic mudstone facies and brachiopod-rich limestones (i.e., within the offshore, low-energy shelf setting). Hunter & Underwood (2010) also noted that the comatulids show a wide range of distribution from offshore, low-energy shelf up to oolitic high-energy shoal system encompassing their lithofacies 2-7 (2: nodular limestones and shelly silty marls; 3: bioclastic limestones of; 4-5: oolitic shelly clean-washed limestone and oolitic limestones; 6: shelly mudstones, silty-oolitic limestone; 7: oolitic limestones). In the present study, the comatulids are restricted to siliciclastic rocks of near shore, below the wave-base (Table 3 and Fig. 2), corroborating previous observations (e.g., Hunt & Underwood, 2010). Hess (1999b) argued that the comatulids predominated in shallow reef environments (in the western Caribbean costal area, they only occur around 1-3 m of depth), and that their maximum depth of occurrence is 70 m. Interestingly, records (though less numerous) from greater depths (of several thousand metres) have also been documented (e.g., Messing, 1985, 2008).

The cyrtocrinids are considered as suggestive of relatively deep-sea depths and with carbonate facies association (e.g., Arendt, 1974; Hess, 1975; Žítt, 1973, 1974, 1975, 1978a-d, 1979a, b, 1982, 1983). According to Ausich et al. (1999 and references cited therein), the cyrtocrinids prefer depths exceeding 100 m. Recent cyrtocrinids such as *Cyathidium foresti* live at depths ranging from 380 to 900 m, and *C. plantei* lives at a depth of 200 m (Hess, 1999b). Nevertheless, rare single reports also indicate their presence in shallow (and extremely shallow) environments (e.g., Salamon & Gorzelak, 2007; Salamon, 2019; Krajewski et al., 2020). From the Jurassic Yátova Formation of Spain, Zamora et al. (2018) illustrated the spongiolithic facies as having been deposited in relatively shallow and open platform areas with depths not exceeding 60 m, with the following cyrtocrinid cups: *Eugeniacrinites* sp., *Pilocrinus* sp., *Gammarocrinites* sp.; and a basal circlet of Tetracrinidae indet. that actually belongs to *Tetracrinus moniliformis* (see fig. 9e in Zamora et al., 2018). *Gammarocrinites* sp., *Pilocrinus moussoni* and *Tetracrinus moniliformis* presented in the current study occur exclusively in carbonates of near shore and shallow marine, to deeper sublittoral under storm influence to open shelf environments.

The roveacrinids represented by the genus *Saccocoma* are exclusive to the shallow marine Bathonian and/or Callovian carbonates of the Tatra Mountains and the Pieniny Klippen

Belt; none have been recorded from the Callovian of the Polish Basin or until the Oxfordian. Kowal-Kasprzyk et al. (2020) mentioned saccocomids from the Oxfordian-Kimmeridgian exotic clasts of the Outer Carpathians in southern Poland. Earlier Matyszkiewicz (1996, 1997) did mentioned the *Saccocoma*-calciturbidites resting on the slope beds of Oxfordian cyanobacterial-sponge carbonate buildups formed in the Polish epi-continental basin (for summary see Fig. 2).

The cyclocrinids are not considered in this chapter due the fact that their taxonomic assignment raises serious doubts.

Conclusion

Almost all Bathonian and Callovian crinoids recorded from Poland dominate in relatively shallow environments. The only exception are cyrtocrinids, that are equally common in both shallow and deeper settings. Isocrinids, most commonly recorded, occur frequently in both carbonate and siliciclastic rocks. Cyrtocrinids also occur in both carbonates and siliciclastics, but dominate in carbonates. Roveacrinids are exclusive to carbonates, whereas Cyclocrinids occur in both carbonates and siliciclastics. The Comatulids occur exclusively in siliciclastics. The most cosmopolitan crinoids are the isocrinids, *Chariocrinus andreae* and *Balanocrinus subtrees*, occurring both in carbonate and siliciclastic rocks, as well as in shallow and open-shelf environments.

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Competing interests

We declare we have no competing interests.

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References

Arendt, Y.A., 1974. Morskie lilii. Tsirtokrinidy (Sea lilies, Cyrtocrinids). Trudy Paleontologicheskego Instituta, Akademia Nauk SSSR 144, 251 pp.

Ausich, W.J., 2001, Echinoderm taphonomy. In: Jangoux, M., Lawrence, J.M. (eds.), Echinoderm studies 6. Balkema, Rotterdam, 171–227.

Ausich, W.I., Donovan, S.K., Hess, H., Simms, M.J., 1999. Fossil occurrence. In: Hess, H., Ausich, W.I., Brett, C.E., Simms, M.J. (eds), Fossil crinoids. Cambridge University Press, Cambridge, 41–49.

Bather, F.A., 1898. *Pentacrinus*, a name and its history. Natural Sciences, 12, 245–256.

Baumiller, T.K., Ausich, W.J. 1992. The broken-stick model as a null hypthesis for crinoid stalk taphonomy and as a guide to the distribution of connective tissue in fossils. Paleobiology, 18, 288–298.

Biese, W., 1935-37: Crinoidea jurassica I. In: Quenstedt, W. (ed.), Fossilium Catalogus, I. Animalia, pt. 70, 73, 76. W. Junk. s'Gravenhage, 739 pp.

Brand, U. 1986. Paleoenvironrnental analysis of Middle Jurassic (Callovian) ammonoids from Poland: trace elements and stable isotopes. Journal of Paleontology, 60, 293–301.

Brett, C.E., Moffat, H.A., Taylor, W.L., 1997. Echinoderm taphonomy, taphofacies and Lagerstätten. In: Waters, J.A., Maples, C.G. (eds), Geobiology of echinoderms 3. The Paleontological Society Papers, 147–190.

Dayczak-Calikowska, K., 1980. Crinoidea. In: Malinowska, L. (ed.), Budowa Geologiczna Polski. T. 3, Atlas skamieniałości przewodnik i charakterystycznych. Cz. 2b. Mezozoik, Jura. Wydawnictwa Geologiczne, Warszawa, 249 pp.

Dayczak-Calikowska, K., Moryc, W., 1988. Evolution of sedimentary basin and palaeotectonics of the Middle Jurassic in Poland. Kwartalnik Geologiczny, 32, 117–136.

Feldman-Olszewska, A., 2007. Jura środkowa. Analiza sedymentologiczna. In: Ciechocinek IG 2. Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego, 117, 54-65.

Feldman-Olszewska, A., 2008. Wyniki badań sedymentologicznych utworów jury środkowej w otworze wiertniczym Brześć Kujawski IG 2. In: Feldman-Olszewska, A. (ed.), Brześć Kujawski IG 1, IG 2, IG 3. Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego, 125, 151-154.

Feldman-Oolszewska, A., 2012a. Wyniki badań sedymentologicznych utworów jury środkowej w wierceniu Wojszyce IG 3. In: Wojszyce IG 1/1a, Wojszyce IG 3, Wojszyce IG 4. Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego, 137, 152-158.

Feldman-Olszewska, A., 2012b. Wyniki badań sedymentologicznych utworów jury środkowej w wierceniu Wojszyce IG 4. In: Wojszyce IG 1/1a, Wojszyce IG 3, Wojszyce IG 4. Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego, 137, 158-166.

Gedl, P., 2008. Dinoflagellate cysts from Callovian of Łuków (Poland) – a reexamination. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 247, 209–269.

Gedl, P., Kaim, A., Boczarowski, A., Kędzierski, M., Smoleń, J., Szczepanik, P., Witkowska, M., Ziaja, J., 2003. Rekonstrukcja paleośrodowiska sedymentacji środkowojurajskich iłów rudonośnych Gnaszyna (Częstochowa) - wyniki wstępne. Tomy Jurajskie, 1, 19–27.

Głuchowski, E., 1987. Jurassic and early Cretaceous Articulate Crinoidea from the Pieniny Klippen belt and the Tatra Mts, Poland. Studia Geologica Polonica 94, 6–102.

Gorzelak, P., Salamon, M.A., 2013. Experimental tumbling of echinoderms – taphonomic patterns and implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 386, 569–574.

Hallam, A. 1975. Jurassic Environments. Cambridge University Press, Cambridge, 269 pp.

Hess, H., 1972. *Chariocrinus* n. gen. für *Isocrinus andreae* Desor aus dem unteren Hauptrogenstein (Bajocien) des Basler Juras. Eclogae geologicae Helvetiae, 65, 197–210.

Hess, H., 1975. Die fossilen Echinodermen des Schweizer Juras. Veröffentlichungen aus dem Naturhistorischen Museum Basel 8, 130 pp.

Hess, H., 1999a. Middle Jurassic of Northern Switzerland. In: Hess, H., Ausich, W.I., Brett, C.E., Simms, M.J. (eds), Fossil Crinoids. Cambridge University Press, Cambridge, 203–215.

Hess, H., 1999b. Recent. In: Hess, H., Ausich, W.I., Brett, C.E., Simms, M.J. (eds), Fossil Crinoids. Cambridge University Press, Cambridge, 237–244.

Hess, H., 2006. Crinoids (Echinodermata) from the Lower Jurassic (Upper Pliensbachian) of Arzo, southern Switzerland. Schweizerische Paläontologische Abhandlungen 126, 1–144.

Hess, H., 2008. *Cyclocrinus*, an enigmatic Jurassic–Cretaceous crinoid. Swiss journal of Geoscience, DOI 10.1007/s00015-008-1273-1.

Hess, H., 2014a. *Balanocrinus* and other crinoids from Late Jurassic mudstones of France and Switzerland. Swiss Journal of Palaeontology 133, 47–75.

Hess, H., 2014b. *Balanocrinus* (Crinoidea) from the Jurassic: species concept, reconstruction, ontogeny, taphonomy and ecology. Swiss Journal of Palaeontology 133, 35–45.

Hess, H., Messing, C.G., 2011. Treatise on Invertebrate Paleontology, part T, Echinodermata 2, Crinoidea 3. The University of Kansas, Paleontological Institute, Lawrence, 261 pp.

Hess, H., Salamon, M.A., Gorzelak, P., 2011. Late Jurassic-Early Cretaceous (Tithonian-Berriasian) cyrtocrinids from south-eastern Poland. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 260, 119–128.

Hess, H., Spichiger, U., 2001. *Argoviacrinus rarissimus* n. g. n. sp., a new crinoid (Echinodermata) from the Middle Oxfordian of Northern Switzerland. Eclogae geologicae Helvetiae, 94, 489–494.

Hunter, A.W., Underwood, C.J., 2009. Palaeoenvironmental control on distribution of crinoids in the Bathonian (Middle Jurassic) of England and France. Acta Palaeontologica Polonica, 54, 77–98.

Kaim, A., 2004. The evolution of conch ontogeny in Mesozoic open marine gastropods. Acta Palaeontologica Polonica, 62, 1–183.

Klikushin, V.G., 1992. Iskopaemye morskie lilii pentakrinidy i ikh rasprostranenie v SSSR. Leningrad Palaeontological Laboratory, Sankt Petersburg, 358 pp.

Knaust, D., Bromley, R.G. (editors), 2012. Trace fossils as indicators of sedimentary environments, Developments in Sedimentology 64, Elsevier, 924 pp.

Kopik J., 1974 - Genus *Cadomites* Munier-Chalmas, 1892 (Ammonitina) in the Upper Bajocian and Bathonian of the Cracow-Wieluń Jurassic range and the Góry Świętokrzyskie Mountains (Southern Poland). *Biuletyn IG* 276: 7-53.

Kopik, J., 1976. O przedstawicielach rodzin Phylloceratidae Zittel, 1884, Haploceratidae Zittel, 1884 i Oppeliidae Bonarelli, 1894 (Ammonoidea) w keloweju jury częstochowskiej. Biuletyn Instytutu Geologicznego, 295, 109-136.

Kopik, J., 1979a. Callovian of the Częstochowa Jura (South-Western Poland). Prace Instytutu Geologicznego, 93, 1-52.

Kopik, J., 1979b. Stratygrafia jury środkowej regionu bełchatowskiego. Kwartalnik Geologiczny, 23, 179-194.

Kopik, J., 1998. Jura dolna i środkowa północno-wschodniego obrzeżenia Górnośląskiego Zagłębia Węglowego. Biuletyn Państwowego Intytutu Geologicznego, 378, 67-120.

Kopik, J., 2006. Bathonian ammonites of the families Sphaeroceratidae Buckman and Tulitidae Buckman from the Polish Jura Chain (Southern Poland). Polish Geological Institute Special Papers, 21, 1-68.

Kowal-Kasprzyk, J., Krajewski, M., Gedl, P., 2020. The oldest stage of the Outer Carpathian evolution in the light of Oxfordian–Kimmeridgian exotic clast studies (southern Poland). Facies, 66, 11.

Krajewski, M., Olchowy, P., Salamon, M.A., 2019. Late Jurassic (Kimmeridgian) sea lilies (Crinoidea) from central Poland (Łódź Depression). Annales de Paléontologie, 105, 63–73.

Krajewski, M., Ferré, B., Salamon, M.A., 2020. Cyrtocrinids (Cyrtocrinida, Crinoidea) and other associated crinoids from the Jurassic (Kimmeridgian–Tithonian)–Cretaceous (Berriasian–Barremian) of the Carpathian Foredeep basement (western Ukraine). Geobios, 60, 61–77.

Krajewski, M., Olchowy, Felisiak, I., 2016. Late Jurassic facies architecture of the Złoczew Graben: implications for evolution of the tectonic-controlled northern peri-Tethyan shelf (Upper Oxfordian–Lower Kimmeridgian, Poland). Facies, 62, 1–19.

Loriol, P. de, 1877-1879. Monographie des crinoïdes fossiles de la Suisse. Mémoires de la Société Paléontologique Suisse, 4, 1–52; 5, 3–124; 6, 125–300.

Makowski, H., 1952. La faune Callovienne de Łuków en Pologne. Palaeontologia Polonica, 4, 1–62.

Marynowski, L., Philippe, M., Zatoń, M., Hautevelle, Y., 2008. Systematic relationships of the Mesozoic wood genus Xenoxylon: an integrative biomolecular and palaeobotanical approach. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 247, 177–189.

Matyja, B.A., Wierzbowski, A., 2000. Ammonites and stratigraphy of the uppermost Bajocian and Lower Bathonian between Częstochowa and Wieluń, Central Poland. Acta Geologica Polonica, 50, 191–209.

Matyja, B.A., Wierzbowski, A. 2003. Biostratygrafia amonitowa formacji częstochowskich iłów rudonośnych (najwyższy bajos–górny baton) z odsłonięcia w Częstochowie. Tomy Jurajskie, 1, 3–6.

Matyszkiewicz, J., 1996. The significance of *Saccocoma*-calciturbidites for the analysis of the polish epicontinental late Jurassic bas. An example from the Southern Cracow-Wieluń Upland (Poland). Facies, 34, 23–40.

Matyszkiewicz, J., 1997. Microfacies, sedimentation and some aspects of diagenesis of Upper Jurassic sediments from the elevated part ofthe Northern peri-Tethyan Shelf: a comparative study on the Lochen area (Schwäbische Alb) and the Cracow area (Cracow-Wieluń Upland, Poland). Berliner Geowissenschaftliche Abhandlungen E21, 1–111.

Messing, C.G., 1985. Submersible observations of deep-water crinoid assemblages in the tropical western Atlantic Ocean. In: Keegan, B.F. & O'Connor, B.D.S. (eds), Proceedings of the 5th International Echinoderm Conference. Galway, Balkema, 185–193.

Messing, C.G., 2008. A new species of five-armed feather star, *Pentametrocrinus paucispinulus* n. sp., from the eastern Pacific (Echinodermata: Crinoidea: Comatulida). Proceedings of the Biological Society of Washington, 121, 269–275.

Mizerski, W., Szamałek, K., 1985. Charakterystyka geologiczno-surowcowa kelowejskich skał ilastych kry lodowcowej w rejonie Gołaszyna k. Łukowa. Kwartalnik Geologiczny, 29, 369–392.

Niemczycka, T., 1965. Boundary of the Middle and Uplper Jurassic in the northern area of the Lublin region and in the Podlasie region. Geological Quarterly, 9, 603–615.

Niemczycka T., 1979 – Litho- and biostratigraphic boundary of the Middle and UpperJurassic in southern Podlasie. Geological Quarterly, 23, 803–817.
Olempska, E., Błaszyk, J., 2001. A boreal ostracod assemblage from the Callovian of the Łuków area, Poland. Acta Palaeontologica Polonica, 46, 553–582.
Pieńkowski, G., Schudack, M.E. (Coordinators), Bosák, P., Enay, R., Feldman-Olszewska, A., Golonka, J., Gutowski, J., Herngreen, G.F.W., Jordan, P., Krobicki, M., Lathuiliere, B., Leinfelder, R.R., Michalík, J., Mönnig, E., Noe-Nygaard, N., Pálfy, J., Pint, A., Rasser, M.W., Reisdorf, A., Schmid, D.U., Schweigert, G., Surlyk, F., Wetzel, A., Wong, T.E., 2008. Jurassic. In: McCann, T. (ed.), The Geology of Central Europe. Vol. 2: Mesozoic and Cenozoic. The Geologfical Society, London. 823-922.
Radwańska, U., 2005. Lower Kimmeridgian comatulid crinoids of the Holy Cross Mountains, Central Poland. Acta Geologica Polonica, 55, 269–282.
Radwańska, U., Radwański, A., 2003. The Jurassic crinoid genus *Cyclocrinus* d'Orbigny, 1850: still an enigma. Acta Geologica Polonica, 53, 301–320.
Różycki, S.Z., 1953. Górny dogger i dolny malm Jury Krakowsko-Częstochowskiej. Prace Instytutu Geologicznego, 17, 1–412.
Salamon, M.A., 2008a. The Callovian (Middle Jurassic) crinoids from the black clays of the Łuków area, eastern Poland. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 247, 133–146.
Salamon, M.A., 2008b. Jurassic cyrtocrinids (Cyrtocrinida, Crinoidea) from extra-Carpathian Poland. Palaeontographica Abt. A 285, 77–99.
Salamon, M.A., 2008c. The Callovian (Middle Jurassic) crinoids from northern Lithuania. Paläontologische Zeitschrift 82, 269–278.
Salamon, M.A., 2009. Early Cretaceous (Valanginian) sea lilies (Echinodermata, Crinoidea) from Poland. Swiss journal of Geosciences, 102, 77–88.
Salamon, M.A., 2019. A new prospect in crinoid (Crinoidea, Echinodermata) research: An example from the Lower Jurassic of Montenegro [Une nouvelle perspective dans l'étude des crinoïdes (Crinoidea, Echinodermata): Un exemple du Jurassique inférieur du Monténégro]. Carnets de Geologie, 19, 211–220.

Salamon, M.A., Feldman-Olszewska, A., 2018. Crinoids (Crinoidea, Echinodermata) from the Middle Jurassic (Callovian) of eastern Poland: A case study from the Żebrak IG1 Borehole. Annales Societatis Geologorum Poloniae 88, 273–283.

Salamon, M.A., Gorzelak, P., 2007. Evidence of shallow-water cyrtocrinids (Crinoidea) from the Callovian of Poland. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 244, 257–260.

Salamon, M.A., Gorzelak, P., 2010. Cyrtocrinids (Echinodermata, Crinoidea) from Upper Jurassic Štramberk-type limestones in southern Poland. Palaeontology, 53, 869–885.

Salamon, M.A., Zatoń, M., 2006. *Balanocrinus hessi*, a new crinoid (Echinodermata) from the Callovian (Middle Jurassic) of southern Poland. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 240, 1–17.

Salamon, M.A., Gorzelak, P., Zatoń, M., 2010. Comment on "Palaeoenvironmental control on distribution of crinoids in the Bathonian (Middle Jurassic) of England and France" by Aaron W. Hunter and Charlie J. Underwood. Acta Palaeontologica Polonica, 55, 172–173.

Salamon, M.A., Zatoń, M., 2007. Late Bajocian trough Callovian (Middle Jurassic) crinoid fauna from the epicontinental deposits of Poland. Swiss journal of Geosciences, 100, 153–164.

Simms, M. J., 1989. British Lower Jurassic crinoids. The Palaeontological Society, London, 102 pp.

Simms, M. J., 1999. *Pentacrinites* from the Lower Jurassic of Dorset Coast of Southern England. In: Hess, H., Ausich, W.I., Brett, C.E., Simms, M.J. (eds), Fossil Crinoids. Cambridge University Press, Cambridge, 177–182.

Šimkevičius, P., Ahlberg, A., Grigelis, A., 2003. Jurassic smectite and kaolinite trends of the East European Platform: implications for palaeobathymetry and palaeoclimate. Terra Nova, 15, 225–229.

Tang, C.M., Bottjer, D.J., Simms, M.J., 2000. Stalked crinoids from a Jurassic deposit in western North America. Lethaia, 33, 46–54.

Ubaghs, G., 1953. Sous-Classe 4. Articulata J. S. Miller. In: Piveteau, J. (Ed.), Traité de Paléontologie, 3. Masson, Paris, 756–765.

Villier, L., 2008. Sea star ossicles from the Callovian black clays of the Łuków area, eastern Poland. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 247, 147–160.

Wójcik, K., 1910. Bat, kelowej i oxford okręgu krakowskiego (stratygrafia). Rozprawy Wydziału Matematyczno-Przyrodniczego Akademii Umiejętności w Krakowie, Seria B, 50, 409–511.

Zamora, S., Aurell, M., Veitch, M., Saulsbury, J., López-Horgue, M.A., Ferratges, F.A., Arz, J.A., Baumiller, T.K., 2018. Environmental distribution of post-Palaeozoic crinoids from the Iberian and south-Pyrenean basins, NE Spain. Acta Palaeontologica Polonica, 63, 779–794.

Zatoń, M., 2010. Bajocian-Bathonian (Middle Jurassic) ammonites from the Polish Jura. Part 1: Families Phylloceratidae, Nannolytoceratidae, Sonniniidae, Strigoceratidae, Oppeliidae and Lissoceratidae. Palaeontographica, Abt. A, 292, 65–113.

Zatoń, M., 2010. Bajocian-Bathonian (Middle Jurassic) ammonites from the Polish Jura. Part 2: Families Stephanoceratidae, Perisphinctidae, Parkinsoniidae, Morphoceratidae and Tulitidae. Palaeontographica, Abt. A, 292, 115–213.

Zatoń, M., Barbacka, M., Marynowski, L., Krzystanek, J., 2006b. *Sagenopteris* (Caytoniales) with its possible preserved biomarkers from the Bathonian of the Polish Jura, south-central Poland. Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, 7, 385–402.

Zatoń, M., Marynowski, L., 2004. Konzentrat-Lagerstatte - type carbonate concretions from the uppermost Bajocian (Middle Jurassic) of the Częstochowa area, South-Central Poland. Geological Quarterly, 48, 339–350.

Zatoń, M., Marynowski, L., 2006. Ammonite fauna from uppermost Bajocian (Middle Jurassic) calcitic concretions from the Polish Jura - biogeographical and taphonomical implications. Geobios, 39, 426–442.

Zatoń, M., Marynowski, L., Bzowska, G., 2006a. Konkrecje hiatusowe z iłów rudonośnych Wyżyny Krakowsko-Częstochowskiej (Jura Polska). Przegląd Geologiczny, 54, 131–138.

Zatoń, M., Villier, L., Salamon, M.A., 2007. Signs of predation in the Middle Jurassic of south-central Poland: evidence from echinoderm taphonomy. Lethaia, 40, 139–151.

Zatoń, M., Wilson, M.A., Zavar, E., 2011. Diverse sclerozoan assemblages encrusting large bivalve shells from the Callovian (Middle Jurassic) of southern Poland. Palaeogeography, Palaeoclimatology, Palaeoecology, 307, 232–244.

Žítt, J., 1973. Entoneutral system of the *Sclerocrinus*. Věstník Ústředního ústavu geologického 48, 25–29.

Žítt, J., 1974. *Sclerocrinus* Jaekel, 1891 and *Proholopus* Jaekel, 1907 (Crinoidea, Cyrtocrinida) from the Lower Cretaceous of Štramberk (Czechoslovakia). Sborník geologických Věd, Paleontologie 16, 7–32.

Žítt, J., 1975. *Sclerocrinus kotoucensis* sp. n. (Cyrtocrinida, Crinoidea) from the Lower Cretaceous of Štramberk (Czechoslovakia). Věstník Ústředního ústavu geologického 50, 115–117.

Žítt, J., 1978a. Deformations of *Phyllocrinus malbosianus* d'Orbigny from Štramberk (Czechoslovakia). Časopis pro mineralogii a geologii 23, 277–284.

Žítt, J., 1978b. *Phyllocrinus* d'Orbigny, 1850 (Crinoidea, Cyrtocrinida) from the Lower Cretaceous of Štramberk (Czechoslovakia). Časopis pro mineralogii a geologii 23, 39–58.

Žítt, J., 1978c. Phyllocrinid microcrinoids (Cyrtocrinida) from the Lower Cretaceous of Štramberk (Czechoslovakia). Věstník Ústředního ústavu geologického 53, 145–151.

Žítt, J., 1978d. *Apsidocrinus* Jaekel and *Psalidocrinus* Remeš (Crinoidea, Cyrtocrinida) from the Lower Cretaceous of Štramberk (Czechoslovakia). Sborník geologických Věd, Paleontologie 21, 107–124.

Žítt, J., 1979a. Hemibrachiocrinidae Arendt, 1968 (Crinoidea, Cyrtocrinida) from the Lower Cretaceous of Štramberk (Czechoslovakia). Věstník Ústředního ústavu geologického, 54, 341–348.

Žítt, J., 1979b. *Strambergocrinus* gen. n. (Cyrtocrinida) from the Lower Cretaceous of Štramberk (Czechoslovakia). Časopis pro mineralogii a geologii 24, 237–247.

Žítt, J., 1982. A new type of stem in *Eugeniacrinites*. Acta Universitatis Carolinae-Geologica 4, 409–420.

Žítt, J., 1983. Spoon-like crinoids from Štramberk (Lower Cretaceous, ČSSR). Sborník Národního Muzea v Praze 39B, 69–114.

Figure captions:

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Polish Jura; B – Bathonian and Callovian exposures of the southern margin of the Holy Cross Mountains; C– Callovian exposure of the glacial drift in Łuków; G1-G5 – location of the Bathonian- Callovian boreholes described in this constribution (Kock IG 2, Maciejowice IG 1, Siedliska IG 1, Tłuszcz IG 1, and Żyrzyn IG 1), D location of borehole Żebrak IG 1 (details in Salamon & Feldman-Olszewska, 2018); E – Bathonian and Callovian exposures of the Tatra Mountains; F – Bathonian and Callovian exposures of the Pieniny Klippen Belt. **B.** Map of Callovian lithofacies noted in Poland (modified after Dayczak-Calikowska & Moryc, 1988).

Figure 2. Model showing distribution of selected Callovian crinoids.

Figure 3. Cyclocrinid remains from southern Poland. A. Cup, lateral view. Czerwieniec. B. Columnal, articular facet. C. Brachial plates. Scale bar equals 1 mm for A, B, and 2 mm for C. Blue arrows mark granules covering the articular facet of columnal.

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Table 1. Bathonian-Callovian crinoids collected in particular boreholes in eastern Poland.

Table 2. Bathonian and Callovian crinoid list recorded in different areas of Poland.

Table 3. Distribution of Bathonian-Callovian crinoids recorded in Poland within different facies and settings.

Table 4. Number of collected crinoid remains during observation of respective cores and maceration process.

Table 1(on next page)

Table 1

Bathonian-Callovian crinoids collected in particular boreholes in eastern Poland.

Borehole	Depth (in m)	Age	Lithology	determinable crinoid taxa
Kock IG 2	859.0	Callovian?	Yellowish grey, crinoidal limestone	Isocrinida indet. *Balanocrinus subteres*
Maciejowice IG 1	1,431.5	late Bathonian	Dark grey, medium-size sandstone	none
	1,505.7	late Callovian	Yellowish grey, crinoidal limestone	Isocrinida indet. *Balanocrinus subteres* *Pentacrinites dargniesi*
	1,507.3	late Callovian	Yellowish grey, crinoidal limestone	Isocrinida indet. *Pentacrinites dargniesi*
	1,508.65	late Callovian	Grey crinoidal limestone	Isocrinida indet. *Balanocrinus subteres* *Pentacrinites dargniesi*
	1,522.4	middle-late Callovian	Yellow-brown, crinoidal limestone	Isocrinida indet. *Isocrinus nicoleti* *Balanocrinus subteres* *Balanocrinus pentagonalis* *Pentacrinites dargniesi*
Siedliska IG 1	824.65	early Callovian	Beige-grey, crinoidal limestone	Isocrinida indet. *Pentacrinites dargniesi*
	828.25	early Callovian	Beige-grey, crinoidal limestone	Isocrinida indet. *Balanocrinus subteres* *Pentacrinites dargniesi*
	828.77	early Callovian	Beige-grey, crinoidal limestone	Isocrinida indet. *Isocrinus nicoleti* *Balanocrinus subteres* *Pentacrinites dargniesi* Cyrtocrinida indet.
	830.8	late Bathonian?	Yellow-brown, crinoidal limestone	none
	837.65	late Bathonian?	Yellow crinoidal limestone	Isocrinida indet. *Chariocrinus andreae* *Balanocrinus subteres* *Balanocrinus pentagonalis* *Pentacrinites dargniesi*
Tłuszcz IG 1	1,047.7	late Callovian?-early Oxfordian	Beige-grey, crinoidal limestone	none
	1,049.95	late Callovian	Cream crinoidal limestone	Isocrinida indet. *Balanocrinus pentagonalis* *Pentacrinites dargniesi* *Phyllocrinus* sp.
Żyrzyn IG 1	1,134.95	Callovian	Yellowish grey, crinoidal limestone	Isocrinida indet. *Chariocrinus andreae* *Pentacrinites dargniesi* Cyrtocrinida indet.
	1,137.7	late Bathonian?	Beige-grey, crinoidal limestone	none
	1,147.9	late Bathonian	Beige-grey, crinoidal limestone	Isocrinida indet. *Isocrinus nicoleti* *Chariocrinus andreae* *Balanocrinus subteres* *Pentacrinites dargniesi* Cyrtocrinida indet.
	1,155.4	late Bathonian	Yellow-brown, crinoidal limestone	Isocrinida indet. *Isocrinus nicoleti* *Balanocrinus pentagonalis* *Pentacrinites dargniesi*

Table 2(on next page)

Table 2

Bathonian and Callovian crinoid list recorded in different areas of Poland.

Location area (see also details in Fig. 1 and its caption)	Age	Number of crinoid taxa	List of crinoids
A – glacial drift in Łuków	Callovian	10, including: 8 isocrinids and 2 comatulids	**Isocrinids:** *Chariocrinus andreae* *Balanocrinus berchteni* *Balanocrinus pentagonalis* *Balanocrinus subteres* *Isocrinus* sp. *Isocrinus nicoleti* *Isocrinus pendulus* *Pentacrinites* cf. *dargniesi* **Comatulids:** Paracomatulidae sp. et gen. indet. *Palaeocomaster* sp.
B – boreholes in eastern Poland (Kock IG 2, Maciejowice IG 1, Siedliska IG 1, Tłuszcz IG 1, Żyrzyn IG 1)	latest Bathonian-Callovian	8, including: 6 isocrinids and 2 cyrtocrinids	**isocrinids:** Isocrinida indet. *Chariocrinus andreae* *Balanocrinus subteres* *Balanocrinus pentagonalis* *Isocrinus nicoleti* *Pentacrinites dargniesi* **Cyrtocrinids:** Cyrtocrinida indet. *Phyllocrinus* sp.
B – Żebrak IG 1	Callovian	6, including: 5 isocrinids and 1 cyrtocrinid	**isocrinids:** *Chariocrinus andreae* *Balanocrinus* cf. *subteres* *Isocrinus* sp. *Isocrinus* cf. *nicoleti* *Pentacrinites* sp. **Cyrtocrinids:** Cyrtocrinida indet.
C – southern margin of the Holy Cross Mountains	Bathonian	3, including: 2 isocrinids and 1 comatulid	**Isocrinids:** *Chariocrinus andreae* *Balanocrinus berchteni* **Comatulids:** *Paracomatula helvetica*
C – southern margin of the Holy Cross Mountains	Callovian	2, including: 1 isocrinid and 1 cyclocrinid	**Isocrinids:** *Chariocrinus andreae* **Cyclocrinids** (order uncertain according to Hess & Messing, 2011): *Cyclocrinus macrocephalus*
D – southern part of the Polish Jura	Bathonian	6, including: 3 isocrinids, 2 comatulids and 1 cyrtocrinid	**Isocrinids:** *Chariocrinus andreae* *Balanocrinus berchteni* *Isocrinus bajociensis* **Comatulids:** *Paracomatula helvetica* *Palaeocomaster* sp. **Cyrtocrinids:** Cyrtocrinida indet. (=Millericrinina in Salamon & Zatoń, 2007)

D – southern part of the Polish Jura	Callovian	15, including: 3 isocrinids, 11 cyrtocrinids and 1 cyclocrinid	**Isocrinids:** *Chariocrinus andreae* *Balanocrinus subteres* *Balanocrinus pentagonalis* (=*Balanocrinus hessi* in Salamon & Zatoń, 2006) **Cyrtocrinids:** Cyrtocrinida indet. (=Millericrinina in Salamon & Zatoń, 2007) *Phyllocrinus* sp. *Phyllocrinus stellaris* *Phyllocrinus belbekensis* *Tetracrinus moniliformis* *Sclerocrinus* sp. *Cyrtocrinus* sp. *Pilocrinus moussoni* *Dolichocrinus aberrans* *Fischericrinus ausichi* *Lonchocrinus dumortieri* **Cyclocrinids**: *Cyclocrinus macrocephalus*
E – Tatra Mountains	Bathonian	8, including: 6 isocrinids, 1 cyrtocrinid and 1 cyclocrinid	**Isocrinids:** *Isocrinus* sp. *Isocrinus bathonicus* *Isocrinus nicoleti* *Isocrinus pendulus* *Balanocrinus* sp. *Pentacrinites dargniesi* **Cyrtocrinids:** Cyrtocrinida indet. **Cyclocrinids:** *Cyclocrinus rugosus*
E – Tatra Mountains	Callovian	3, including: 1 isocrinid, 1 cyrtocrinid and 1 roveacrinid	**Isocrinids:** *Isocrinus* sp. **Cyrtocrinids:** Cyrtocrinida indet. **Roveacrinids:** *Saccocoma* sp.
F – Pieniny Klippen Belt	Bathonian	16, including: 10 isocrinids, 5 cyrtocrinids and 1 roveacrinid	**Isocrinids:** *Chariocrinus andreae* *Isocrinus* sp. *Isocrinus bathonicus* *Isocrinus nicoleti* *Isocrinus pendulus* *Balanocrinus* sp. *Balanocrinus berchteni* *Balanocrinus pentagonalis* *Balanocrinus subteres* *Pentacrinites dargniesi* **Cyrtocrinids:** Cyrtocrinida indet. *Plicatocrinus tetragonus* *Lonchocrinus dumortieri* *Remisovicrinus* sp. *Dolichocrinus* sp. *aberrans* **Roveacrinids:** *Saccocoma* sp.

F – Pieniny Klippen Belt	Callovian	14, including: 2 isocrinids, 9 cyrtocrinids, 1 roveacrinid, and 2 cyclocrinids	**Isocrinids:** *Balanocrinus subteres* *Balanocrinus pentagonalis* **Cyrtocrinids:** Cyrtocrinida indet. *Lonchocrinus dumortieri* *Remisovicrinus* sp. *Dolichocrinus* cf. *aberrans* *Eudesicrinus* sp. *Pilocrinus moussoni* *Gammarocrinites* sp. *Sclerocrinus compressus* *Phyllocrinus* sp. **Roveacrinids:** *Saccocoma* sp. **Cyclocrinids:** *Cyclocrinus* sp. *Cyclocrinus rugosus*

Table 3(on next page)

Table 4

Number of collected crinoid remains during observation of respective cores and maceration process.

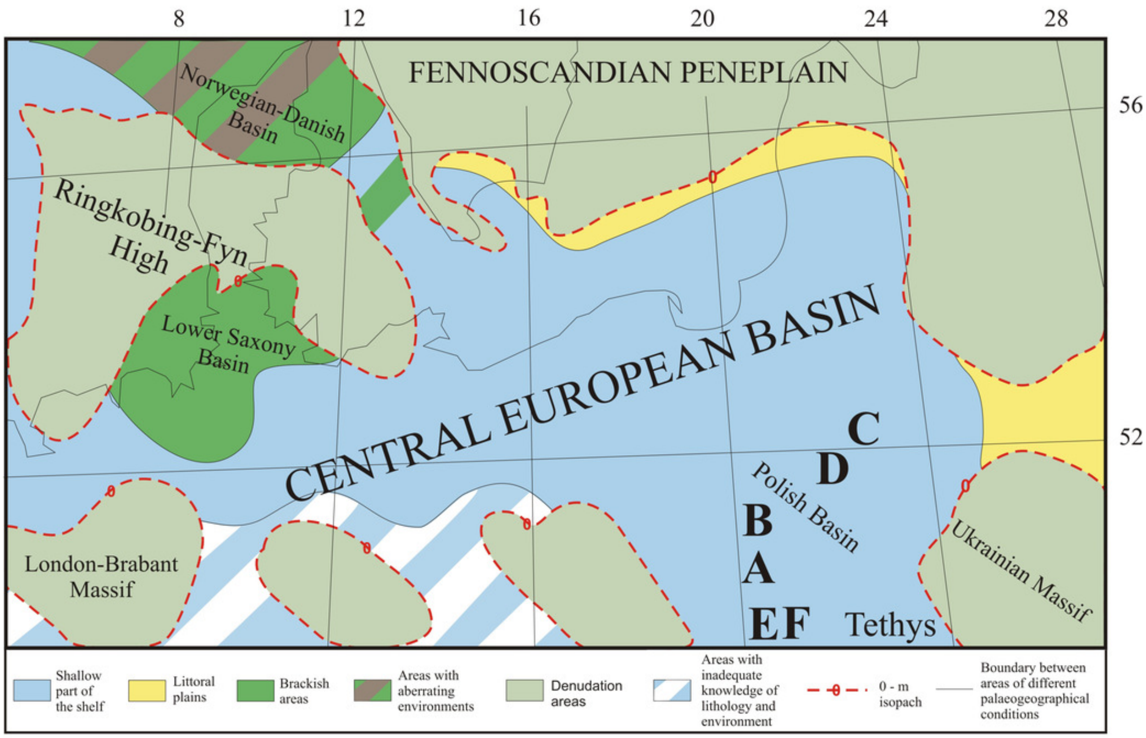
Species	**Details**
Isocrinida indet.	Plenty of more or less complete columnals, brachials~~,~~ and cirrals
Isocrinus nicoleti (Desor, 1845)	Plenty of more or less complete, isolated columnals
Chariocrinus andreae (Desor, 1845)	Plenty of more or less complete, isolated columnals
Balanocrinus subteres (Münster in Goldfuss, 1826)	Plenty of more or less complete, isolated columnals
Balanocrinus pentagonalis (Goldfuss, 1826-1844)	21 almost complete columnals
Pentacrinites dargniesi Terquem & Jourdy, 1869	Plenty of cirrals, 14 almost complete columnals
Cyrtocrinida indet.	Plenty of cup remains and partly preserved columnals and 27 nearly complete columnals
Phyllocrinus sp.	Two cups

Figure 1

Figure 1

Figure1. A. Palaeogeographic map of central Europe during the Middle Jurassic (modified after Šimkevičius et al., 2003). A– Bathonian and Callovian exposures of the southern part of the Polish Jura; B – Bathonian and Callovian exposures of the southern margin of the Holy Cross Mountains; C– Callovian exposure of the glacial drift in Łuków; G1-G5 – location of the Bathonian- Callovian boreholes described in this constribution (Kock IG2, Maciejowice IG1, Siedliska IG1, Tłuszcz IG1, and Żyrzyn IG1), D location of borehole Żebrak IG1 (details in Salamon & Feldman-Olszewska, 2018); E – Bathonian and Callovian exposures of the Tatra Mountains; F – Bathonian and Callovian exposures of the Pieniny Klippen Belt. B. Map of Callovian lithofacies noted in Poland (modified after Dayczak-Calikowska & Moryc, 1988).

A



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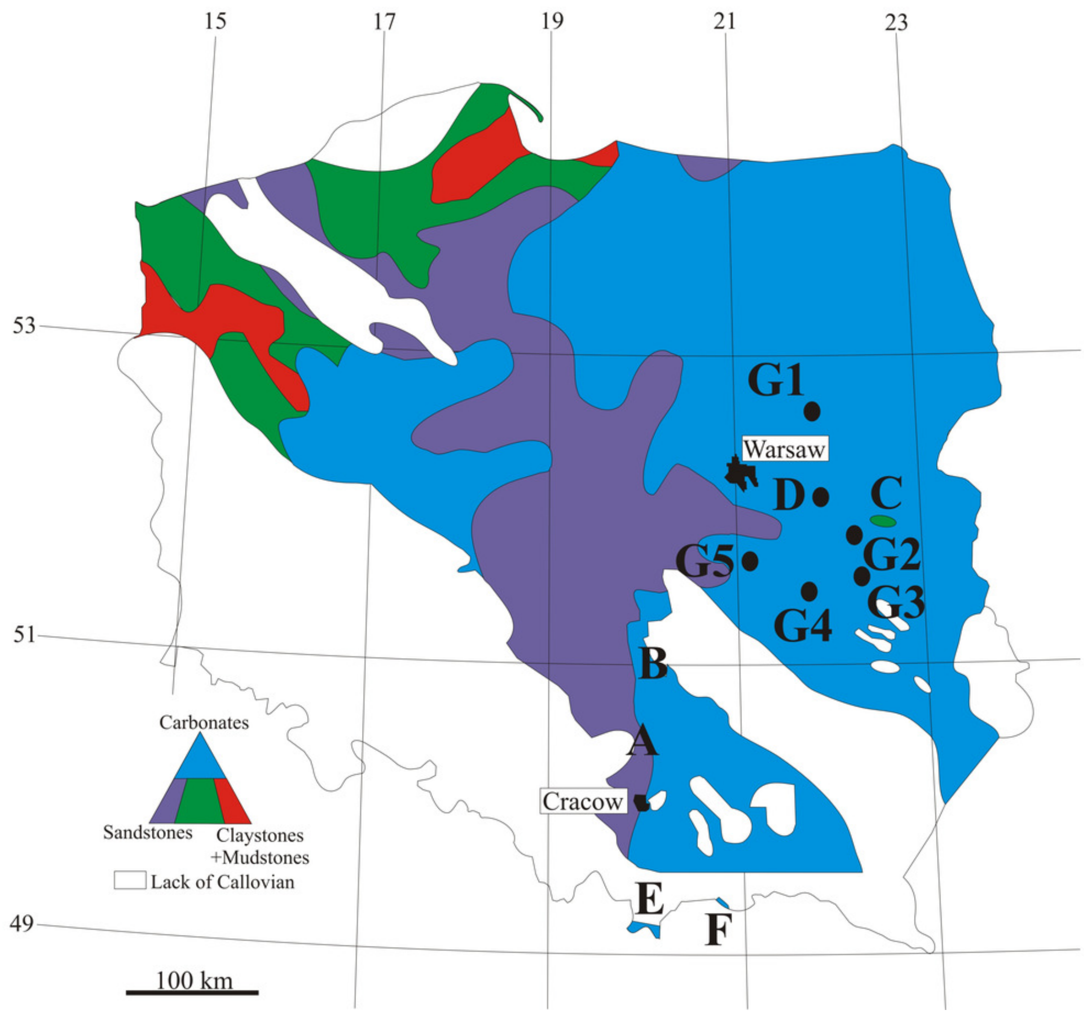
FENNOSCANDIAN PENEPLAIN
Norwegian-Danish Basin
Ringkobing-Fyn High
Lower Saxony Basin
CENTRAL EUROPEAN BASIN
C
D
Polish Basin
B
A
EF
Tethys
London-Brabant Massif
Ukrainian Massif
Shallow part of the shelf
Littoral plains
Brackish areas
Areas with aberrating environments
Denudation areas
Areas with inadequate knowledge of lithology and environment
0 - m isopach
Boundary between areas of different palaeogeographical conditions

B



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G1
Warsaw
D
C
G2
G3
G4
G5
B
A
Cracow
E
F
Carbonates
Sandstones
Claystones +Mudstones
Lack of Callovian
100 km

Figure 2

Figure 2

Figure2. Model showing distribution of selected Callovian crinoids.

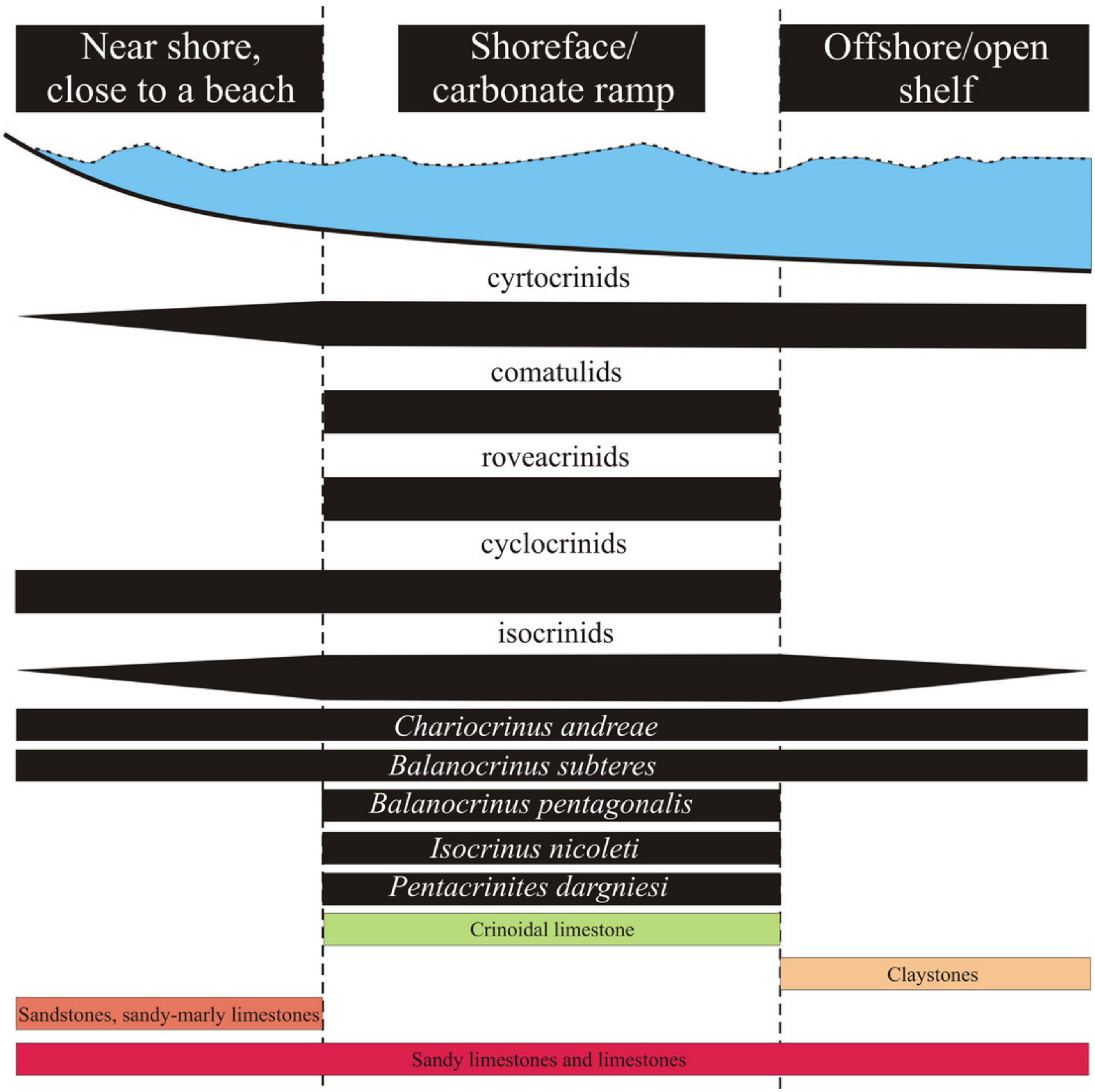

Figure 3

Figure 3

Figure 3. Cyclocrinid remains from southern Poland. A. Cup, lateral view. Czerwieniec. B. Columnal, articular facet. C. Brachial plates. Scale bar equals 1 mm for A, B, and 2 mm for C. Blue arrows mark granules covering the articular facet of columnal.