

Biostratinomy of echinoderms from the Muschelkalk (Middle Triassic) of Poland

By

ROBERT NIEDZWIEDZKI, MICHAL ZATON & MARIUSZ A. SALAMON

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Addresses of the authors:

ROBERT NIEDZWIEDZKI
Wroclaw University
Institute of Geological Sciences
Department of Stratigraphical Geology
Pl. M. Borna 9
50-204 Wroclaw
Poland
e-mail: rned@ing.uni.wroc.pl

MICHAL ZATON
University of Silesia
Department of Earth Sciences
Laboratory of Ecosystem Stratigraphy
Bedzinska Str. 60
41-200 Sosnowiec
Poland
e-mail: mzaton@wnoz.us.edu.pl

M.A. SALAMON
University of Silesia
Department of Earth Sciences
Laboratory of Palaeontology & Biostratigraphy
Bedzinska Str. 60
41-200 Sosnowiec
Poland
e-mail: paleo.crinoids@poczta.fm

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Abstract

Among the echinoderm remains of the Polish Muschelkalk the most common are crinoids. Ophiuroids, on the other hand, are numerous only in single layers whereas echinoids are very scarce. Mass occurrences of crinoidal elements can be seen exclusively in the Lower Muschelkalk and the lowermost Middle Muschelkalk (only the Upper Silesia area). Contrary to that, in the upper part of the Middle Muschelkalk echinoderms are totally absent. In the Upper Muschelkalk, echinoderm remains are very rare and of low taxonomic diversity.

The presented study shows that the echinoderms noted in the Polish part of the Germanic Basin belong to different taphonomic types and grades, reflecting variable times of their exposure on the sea bottom. In the investigated samples disarticulated elements are predominating; traces of abrasion and sorting of columnals indicate redeposition of the most parts of the crinoid remains. Regular echinoid test fragments, without signs of abrasion, may have undergone disarticulation *in situ* during long-lasting exposure. Mass occurrences of complete ophiuroids are interpreted as result of their rapid burial during storm-related events.

1. Introduction

Biostratinomy, as a part of taphonomy, is understood in two different ways (FERNANDEZ-LOPEZ & FERNANDEZ-JALVO 2002): 1) as a type of process or environment of fossilization, and 2) a phase or stage of fossilization. In the first case, biostratinomy concerns physical, mechanical or sedimentary processes, such as disarticulation, abrasion, transport, dispersal, sorting and re-sedimentation. In the second case, biostratinomy comprises all processes occurring after the death of an organism until its burial. Then the fossil-diagenesis begins (see FERNANDEZ-LOPEZ & FERNANDEZ-JALVO 2002 for comprehensive review). Some authors (FERNANDEZ-LOPEZ & FERNANDEZ-JALVO 2002) consider 'initial burial' and others (see AUSICH 2001) 'final burial' as a limit between biostratinomy and fossil-diagenesis. Echinoderms, possessing different skeletal architecture in various groups, are prone to disarticulate after death in

different way and time during their exposure on the sea-floor. In general, however, their disarticulation is rather fast. Therefore they are very useful for evaluating the sedimentation processes, especially the episodic ones. In this study, the Muschelkalk echinoderms (despite the asteroids and holothurians which currently were not documented) of the Polish part of the Germanic Basin in the context of their post-mortem modifications versus sedimentary regime, are presented. In the main chapter the term *taphonomy* is used only for maintenance the order in relation to terminology of BRETT et al. (1997).

2. General account

2.1. Study area

The samples with echinoderms were collected during the years 1998 – 2003 in the Holy Cross Mountains, Upper Silesia Region and the North-Sudetic Basin (Fig. 1). In the Holy Cross Mountains, a several hundreds of investigated points have been checked, but for the purpose of the current study only 134 most interesting points were chosen (for detailed descriptions and localities see SALAMON 2003). Similarly, in the Upper Silesia region a several tens of investigated points were analysed (see NIEDZWIEDZKI 2000 and SALAMON & BOCZAROWSKI in press). In the North-Sudetic Basin, on the other hand, the only one, huge and now closed quarry at Raciborowice was investigated (see SALAMON et al. 2003). Crinoids were collected mainly in the southern and western margin of the Holy Cross Mountains and in the North-Sudetic Basin (see GLUCHOWSKI & SALAMON 1998, SALAMON 2003, SALAMON et al. 2003, GLUCHOWSKI & SALAMON submitted). Of minor significance (because of small number of specimens found) were specimens found in the sediments from the northern margin of the Holy Cross Mountains and Upper Silesia.

The largest number of currently investigated ophiuroids (ca. a few thousand of specimens) comes from several investigated points within the Upper Silesia Region (see SALAMON & BOCZAROWSKI in press, SALAMON & ZATON 2004) and from five sites in the Holy Cross Mountains (see SALAMON 2004). At last, the investigations of echinoid fauna were based solely upon a few sites in the Holy Cross

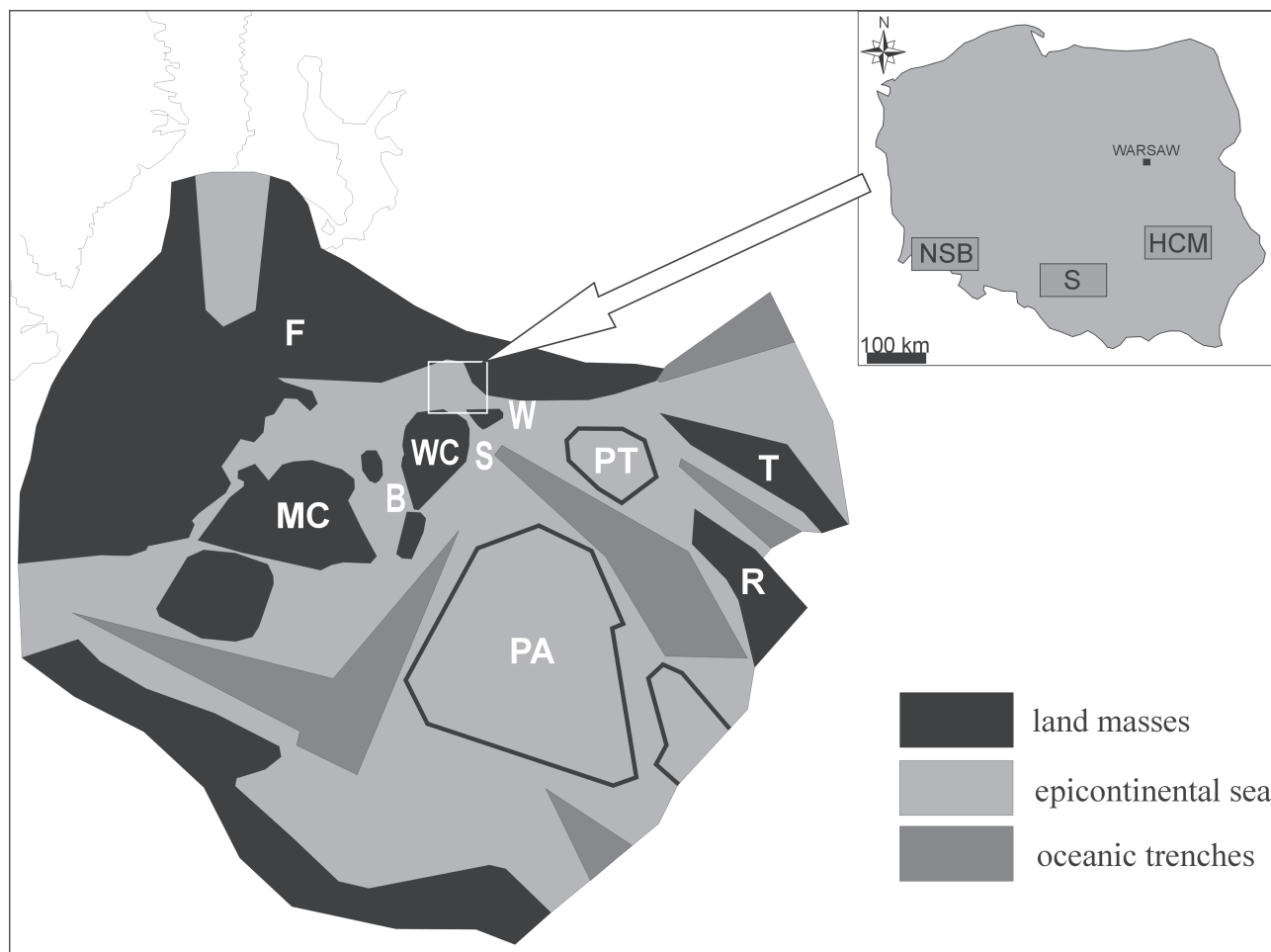


Fig. 1: Schematic palaeogeographic map of the Northern Peritethys with area of Poland signed (according to SZULC 2000, modified). F – Fennoscandia, MC – Central Massif, WC – Vindelic-Bohemian Massif, PT – Tisia Plate, PA – Adria Plate, R – Rodopes, T – Transcaucasus, W – East-Carpathian Gate, S – Silesian-Moravian Gate, B – Western Gate, NSB – North-Sudetic Basin, S – Silesia, HCM – Holy Cross Mountains.

Mountains (see SALAMON & NIEDZWIEDZKI 2003) and Upper Silesia (unpublished data by SALAMON).

2.2. Palaeogeographical background and geological setting

At the beginning of the Triassic, in Europe and its adjacent areas, in the places of late Palaeozoic tectonic breaks, the system of tectonic depressions have continued to form since the Permian (for details see GOLONKA 2000). In these times, a system of the North Sea rifts and the Polish-Danish Aulacogen have started to form as well. The Northern Peritethys (= Germanic Basin; Fig. 1) was situated at the north-western margin of the Tethys Ocean. The basin was bordered by Fennosarmatian Land from NE and E, and by the Hercynian blocks of Western Europe. To the south, the basin was separated from the Tethys by the Vindelic-Bohemian Massif and the Pre-Carpathian Land (e.g. NARKIEWICZ & SZULC 2004). The water exchange between the Germanic Basin and the Tethys Ocean was provided by a system of tectonically controlled depressions (gates),

characterized by their diachronic development. These gates had the primary influence on the echinoderm emergence.

In the Holy Cross Mountains, the first echinoderms often occur already in the uppermost Röt deposits (SALAMON 2003; Fig. 2), which is represented by alternations of thin-bedded pelitic, marly and organodetrital limestones (TRAMMER 1975). The beginning of the Muschelkalk, the Wolica Beds, are developed as pelitic limestones with intercalations of grained and marly limestones. In the upperlying Wellenkalk Beds of the pelitic, nodular and wavy limestones dominate, in some places intercalated with grainy and shelly limestones. The Lukowa Beds are composed mainly of micritic and grained limestones. At last, the *Plagiostoma striatum* Beds, being the top of the Lower Muschelkalk predominantly comprise bivalve coquinas with intercalations of unfossiliferous pelitic and nodular limestones (TRAMMER 1975). In the Middle Muschelkalk of the Holy Cross area, the marine fauna is not documented. The sequence of the Upper Muschelkalk is started with the *Entolium discites* Beds, in which coquinas and nodular limestones dominate. The top of the Upper Muschelkalk, the *Ceratites* Beds, are composed of pelitic limestones with intercalations of

brachiopod lumachelles and nodular limestones (for more details see e.g. TRAMMER 1975). In the Upper Silesia area, the first echinoderms occur in the lowermost layer of the Gogolin Beds (Fig. 2), consisting mainly of marly, pelitic and nodular limestones. Above, the Gorazdze Formation (*sensu* NIEDZWIEDZKI 2000), is mostly represented by onkolitic and organodetrital limestones (ZAWIDZKA 1975). The Dziewkowie Formation (*sensu* NIEDZWIEDZKI 2000) is composed of pelitic and nodular limestones with intercalations of brachiopod coquinas. The next one, the Karchowice Formation (*sensu* BODZIOCH 1997), is built by organodetrital, crinoidal and echinoidal limestones intercalated by pelitic limestones. In the *Diplopora* Beds, being just the Middle Muschelkalk, echinoderms are still very common, and their composition is dominated by pelitic and onkolitic limestones and dolomites. The upper part of the Middle Muschelkalk in the Silesia, is lacked of any echinoderms - they occur again in the Upper Muschelkalk. In the Wilkowice Beds, fossiliferous pelitic limestones and dolomites occur; and in the Boruszowice Beds, being the top of the Upper Muschelkalk, are mainly build by silty and clayey shales (for more details see e.g. ZAWIDZKA 1975).

The marine Triassic deposits of the Sudetes Mountains only occur in the North-Sudetic Basin. Quite recently detailed lithological investigations of these sediments have been carried out by CHRZASTEK (2002). According to CHRZASTEK (2002) dolomitic limestones with no fossils are dominant in Unit A (Fig. 2). Unit B is built by crinoidal limestones, marls and pelitic limestones. In Unit C wavy limestones with intercalations of organodetrital limestones are common. Oncolitic limestones occur in Unit D, and finally, in Unit E nodular limestones intercalated with brachiopod coquinas occur (for more details see CHRZASTEK 2002).

2.3. Material and methods

The number of all analysed echinoderms (or their isolated elements) exceed tens of thousands of specimens. The investigated crinoids are preserved mainly as isolated columnals, pluricolumnals and brachials. They are derived from the Holy Cross Mountains and North-Sudetic Basin. Currently, they are housed in the Laboratory of Palaeontology and Stratigraphy of the University of Silesia (Catalogue Number GIUS 7 – 2225) and the Museum of the Geological Institute of Wrocław University (Catalogue Numbers MGUWr 5330s - 5331s, 5333s - 5334s). The analysed echinoid elements were collected in the Holy Cross Mountains and Upper Silesia region, and they are dominated by spines and interambulacral plates. They are housed in Laboratory of Palaeontology and Stratigraphy of the University of Silesia (Catalogue Number GIUS 7–2225) and the Museum of the Geological Institute of Wrocław University (Catalogue Numbers MGUWr 5330s - 5331s, 5333s - 5334s). And finally, the complete ophiuroids were collected in the Upper Silesia and North-Sudetic Basin. They are housed in the Museum of the Geological Institute of Wrocław University (Catalogue Numbers MGUWr 5329s, 5332s) and the Laboratory of Palaeontology and Biostratigraphy of University of Silesia (Catalogue Numbers 7 – 2083, 2325 – 2327, 2329 – 2331, 2446). A few tens of thousands of isolated skeletal elements were additionally obtained from the macerated rocks. The isolated echinoderm material (mainly ophiuroids) was retrieved from calcareous rocks using methods proposed by BOCZAROWSKI (1995). The samples of rocks were etched in calcium acid and buffered by calcium acetate. According to BOCZAROWSKI (1995), the best results can be obtained using a mixture of ½ of supersaturated acetate, ¼ of 30 % acetic acid, and ¼ of water. Finally, the remaining fragments were transferred into a glass vessel and residual acids were neutralised by adding of Na₂CO₃ (BOCZAROWSKI 1995). Each individual was further examined under binocular.

Stratigraphy		North-Sudetic Basin	Upper Silesia	Holy Cross Mountains
L	F	Lack of sediments	Boruszowice Beds	<i>Ceratites</i> Beds
			Wilkowice Beds	<i>Entolium discites</i> Beds
Tarnowice Beds	Middle Muschelkalk			
<i>Diplopora</i> Beds				
Illyrian	Muschelkalk		Karchowice Formation	<i>Plagiostoma striatum</i> Beds
		Unit E		
		Unit D	Łukowa Beds	
Pelsonian	Muschelkalk	Unit C	Wellenkalk	
		Unit B	Wolica Beds	
Lower Anisian	Röt	Unit A	Wilczkowice Beds	

Fig. 2: Lithostratigraphy and chronostratigraphy of the Middle Triassic in central and southern Poland (compiled after TRAMMER 1975, ZAWIDZKA 1975, GLUCHOWSKI & SALAMON, submitted).

3. Taphonomy

3.1. Background

Echinoderms belongs to a group of marine invertebrates which is characterized by their very low fossilization potential (e.g. DONOVAN 1991, BRETT et al. 1997, AUSICH et al. 1999, MARTIN 1999, AUSICH 2001). In normal-marine environment and under aerobic conditions, their complete disarticulation into isolated ossicles usually takes place within one to two weeks, depending to their structure, environmental conditions (see DONOVAN 1991, KIDWELL & BAUMILLER 1990, BRETT et al. 1997, AUSICH et al. 1999, DORNBOS & BOTTJER 2001) and especially if the remains experienced initial decay before further physical disturbances (KIDWELL & BAUMILLER 1990, BRETT et al. 1997). Therefore, the occurrence of intact fossil echinoderms affords strong evidence of their rapid and deep burial preventing them not to be re-excavated either by biotic or abiotic agents (e.g. DONOVAN 1991, AUSICH & SEVASTOPULO 1994, BRETT et al. 1997, AUSICH et al. 1999). BRETT et al. (1997) distinguished three taphonomic types (categories) of echinoderms on the basis of the varying times of their post-mortem exposure on the sea-floor, during which all biostratinomic processes occurred:

Type 1: This category consists of very weakly articulated forms, possessing plates which are bound together by ligaments or musculature, or loose ossicles embedded within the epidermis of their body. What is important, they do not contain modules of more rigidly articulated plates. Thus, their skeletons disarticulate very easily soon after death and are usually preserved as loose ossicles. This type includes helicoplacoids, most asteroids and ophiuroids, and many edrioasteroids.

Type 2: To this type belongs the echinoderms which some portions of their skeleton are more tightly sutured, while the another ones are more delicately bound. Therefore, such echinoderms may display a more varied spectrum of taphonomic grades. For example, crinoids can be preserved as completely isolated columnals or brachials, or more tightly sutured calyces. This group contain such echinoderms like most crinoids, blastozoans, eocrinoids, or many regular echinoids.

Type 3: This type consists of those echinoderms in which a major portion of the body is rigidly jointed, what is typical for irregular echinoids (see also MOFFAT & BOTTJER 1999) and certain crinoids or blastoids. Because of their resistance to decay, these echinoderms display fewer taphonomic grades and the occurrence of single skeletal elements may point to long-term post-mortem exposure on the sea-bottom in high-energy environment.

3.2. Taphonomy of studied echinoderms

The echinoderms under study represent different taphonomic types (*sensu* BRETT et al. 1997) and grades (*sensu* BRANDT 1989):

Crinoids

This group of echinoderms is among the main components of most of the organodetrital limestones in the Lower Mu-

schelkalk. However, they are represented mostly as disarticulated ossicles (for some strongly abraded examples of crinoid columnals recorded from Poland see: Pl. 1, Fig. A - B). The columnals are often abraded (about 80 % of whole investigated samples) and well sorted according to their size and shape. Fragments of stems or cups (whole cups are very rare but occur) are known mainly in the lower part of the Gogolin Beds in Upper Silesia and the Wolica Beds in the Holy Cross Mountains (Pl. 1, Fig. F, H). In the Karchowice Formation (Upper Silesia), the *Plagiostoma striatum* Beds (the Holy Cross Mountains) and in the lower part of the Middle Muschelkalk, even complete cups can be found (e.g. SALAMON 2003 and literature cited therein). Moreover, during the current investigations we have not found any milleriacrinid or encrinid holdfasts. BODZIOCH (1994), however, described numerous levels with *in situ* crinoid roots within the coral-sponge bioherms of the Karchowice Formation. In these levels, the unabraded columnals were also associated. In other levels of this formation, on the other hand, the columnals are quite considerably abraded. Columnals, brachials and cup plates are also relatively common in crinoid debris. They are commonest in the *Plagiostoma striatum* Beds of the Holy Cross Mountains and Unit C of the North-Sudetic Basin (Pl. 1, Fig. D, I). Occasionally columnals without signs of abrasion dominate in some layers of crinoidal limestone (e.g. within the Wolica Beds and the *Plagiostoma striatum* Beds in the Holy Cross Mountains).

These crinoids represent taphonomic type 2 and taphonomic grade C (partial calyces and stems), what is characterized by 50-10 % of fossil articulation and 50-75 % of fossil corrosion. This taphonomic type can result by ca. 2 weeks to 1 year of post-mortem exposure on the sea-floor (see BRETT et al. 1997, Fig.1), and taphonomic grade D (loose columnals, brachials and cup plates) – this state of crinoid preservation can result by more than 1 year of their post-mortem exposure (see BRETT et al. 1997, Fig.1). During this time the crinoid remains were prone to intensive transport and hence disarticulation, abrasion, as well as size-sorting. However, repeated reworking can not be excluded, since it is important factor in disarticulating the echinoderm endoskeleton (see DONOVAN 1991). Therefore, the crinoidal debris is thought to be accumulated below the original crinoid habitats.

Regular echinoids

This group appeared at the end of the Röt (the Holy Cross Mountains; SALAMON & NIEDZWIEDZKI 2003) and the Upper Gogolin Beds (Upper Silesia; see e.g. HAGDORN & GLUCHOWSKI 1993, NIEDZWIEDZKI 2002) and, being quite numerous in the Karchowice Formation. Until now, almost only isolated fragments of skeletons have been found (for details see SALAMON & NIEDZWIEDZKI 2003). Larger fragments of echinoids are extremely rare and they are not restricted to particular levels.

This state of preservation points to taphonomic type 2 and taphonomic grade D (completely disarticulated tests). In this grade more than 75 % of remains bear the signs of disarticulation and corrosion. Although the echinoid spines can fall off just after 1 day, the complete disarticulation of their tests can occur even not before 2 years (see DONOVAN

1991, BRETT et al. 1997). Laboratory experiments conducted by KIDWELL & BAUMILLER (1990) showed, that lower temperatures inhibit organic decomposition more effectively than anoxia, and that initial decay of their bodies preceding physical disturbances greatly increases disintegration rates. In the material studied, small degree of damages of the isolated skeletal elements, and lack of complete echinoids in the autochthonous sediments attest, that disarticulation of skeletons was not caused by transport but occurred *in situ*.

Ophiuroids

Mass occurrences of ophiuroids was recorded only in a few horizons of the Lower Muschelkalk: from the Upper Gogolin Beds in Upper Silesia (BOCZAROWSKI & SALAMON 2000, SALAMON & ZATON 2004) through the North-Sudetic Basin (SALAMON et al. 2003) and the Lukowa Beds of the Holy Cross Mountains (RADWANSKI 2002, SALAMON 2004). Numerous specimens possess central disks with proximal and middle part of the arms (Pl. 1, Fig. C, E), although central disks and single arms also occur (Pl. 1, Fig. G). The majority of specimens are preserved with their oral side turned upward (SALAMON & ZATON 2004; here Pl. 1, Fig. E). The ophiuroids are known to have fragile skeletons which are prone to fast disarticulation just after death, unless they are rapidly buried (see DONOVAN 1991, BRETT et al. 1997). Thus, BRETT et al. (1997) classified them into taphonomic type 1, as the weakest articulated echinoderms. The specimens under study fall into taphonomic grade A (whole bodies) to B (single disks, arms), where 90-50 % of fossils is articulated.

The specimens under study are preserved within very thin (ca. 4.5 mm) pelitic layer, which was interpreted (see SALAMON & ZATON 2004) as burial layer *sensu* BRETT (1990) of obrution deposits (see BRETT & BAIRD 1986, BRETT 1990, BRETT et al. 1997). Such deposits represent very rapid sedimentary event (like storms) that are responsible for preservation of many well-preserved phyla possessing very low fossilization potential (Lagerstätte deposits, see e.g. SEILACHER 1990, BRIGGS 2001). As DONOVAN (1991) and BRETT et al. (1997) stated, such fragile echinoderms can disarticulate completely within 1 day to 2 weeks. Therefore, the assemblages under discussion must have been buried rapidly by sudden event.

4. Conclusions

The Muschelkalk echinoderms from the Polish part of the Germanic Basin show different taphonomic types and grades. These features are the effects of variable time of residence and/or biostratinomic history of their skeletons on the sea-floor after death. Thus they are reliable indicator of sedimentation rate.

Taphonomic characteristics of echinoderm studied reveals well background and episodic taphonomic processes (see SPEYER & BRETT 1991). The background taphonomic processes are manifested by disarticulated ossicles of crinoids and echinoids. It can be resulted from longer residence time on the sea-floor what caused disarticulation

in situ (regular echinoids) in more quite environment, or by prolonged transport and abrasion in more agitate biotope (crinoids). The presence of partially preserved crinoid cups may point to more faster or deeper burial.

The complete preservation of ophiuroids, possessing much more fragile skeletons than any of mentioned echinoderms, is an excellent example of episodic taphonomic processes. Only the rapid and deep burial in environment without any bioturbators must have been responsible for their preservation. Therefore, such 'brittle-star beds' representing distinct taphofacies (see SPEYER & BRETT 1991), seem be important event-markers at least in the Polish part of the Germanic Basin.

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Plate 1

A – B, D. examples of isolated, strongly abraded columnals, cup and calyx elements from Polish Muschelkalk; scale bar 10 mm. GIUS 7 - 2225. A. *Dadocrinus* sp., proximal columnal, Wellenkalk Beds of the Holy Cross Mountains.

B. *Eckicrinus radiatus*, medial columnal, *Plagiostoma striatum* Beds of the Holy Cross Mountains.

D. *Carnallicrinus carnalli*, tertibrachial, *Plagiostoma striatum* Beds of the Holy Cross Mountains.

C. *Arenorbis squamosus* from the Upper Gogolin Beds of Upper Silesia; scale bar 30 mm. GIUS 7 – 2330.

E. *Aspiduriella similis* from the Upper Gogolin Beds of Upper Silesia; scale bar 5 mm. GIUS 7 – 2325.

F. Isolated dadocrinid skeletal elements from the Wolica Beds of the Holy Cross Mountains; scale bar 10 mm. GIUS 7 – 2225.

G. distal arm piece of ophiuroid from the *Plagiostoma striatum* Beds of the Holy Cross Mountains; scale bar 10 mm. GIUS 7 – 2225.

H. Dadocrinids from the Gogolin Beds of Upper Silesia; scale bar 10 mm. MGUWr 964s.

I. Isolated encrinid skeletal elements from Unit C of the North-Sudetic Basin; scale bar 10 mm. MGUWr 5333s. Arrows show isolated cup and calyx elements.

