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Geologos 31, 1 (2025): 17–30
https://doi.org/10.14746/logos.2025.31.1.02

GEOLOGOS

Palaeozoic arthropods in Baltoscandian erratics from the coastal cliffs near Gdynia in northern Poland

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Abstract. Fossils recovered from Baltoscandian erratic boulders and cobbles, collected on the beach near Orłowo and Oksywie Cliff (the latter for the first time) near Gdynia in northern Poland constitute an interesting lot. Several trilobite taxa have been discovered, such as *Calymene*? sp., *Acaste*? sp., Chasmopsinae indet., *Encrinurus* sp. and Proetidae indet. Another group of arthropods represented here is Ostracoda, mostly comprising taxa of the family Beyrichiidae, assigned to the order Palaeocopida. The preservation of all fossils certainly leaves much to be desired. Nevertheless, after preparation it has turned out possible to provide some taxonomic identification and the estimated stratigraphical provenance of the erratics studied. In addition, on the basis of taxonomic composition, palaeoecological and palaeogeographical patterns have been worked out. The present paper ranks amongst the very few recent publications dedicated to erratic fossils from Poland in general and those on arthropods specifically.

Key words: Ordovician, Silurian, trilobites, ostracods, taxonomy

1. Introduction

Erratic fossils, from cobbles and boulders brought by continental ice sheets from their area of provenance over considerable distances (Górska, 2003), appear to constitute the least popular category in palaeontological studies, although private collectors have been interested in these objects, even since the nineteenth century. In northern Germany, for example, there are numerous publications and a general interest in such fossils (e.g., Schöning, 2010; Schöning & Popp, 2015). In Poland, a few papers have appeared in print (e.g. Chrząstek & Pluta, 2017 and others; see below), but the topic of erratic fossils is far from exhausted. Here, only arthropod material collected by one of us (AK) during recent years, is presented.

On the sea coast of northern Poland, a vast array of fossils may be collected from erratics embedded in glacial tills or found loose. Sedimentary rock types amongst these have been shown to contain fossils typical of various time intervals, ranging from Cambrian to Pleistocene (Woźniak et al., 2009). Amongst the fossils, different groups of organisms are represented, their general diversity being considerable and offering opportunities for a range of palaeontological interpretations.

As mentioned above, the present note focuses on arthropod remains (namely, trilobites and ostracods) from erratic boulders collected on the beach near Orłowo Cliff (Fig. 1) and Oksywie Cliff in Gdynia (Fig. 2), the main aim being taxonomic and stratigraphical identification of this material. The next step is to provide comparisons with Scandinavian faunas and thus an attempt to establish the provenance of these fossil-bearing erratics and former ice sheet direction of movement. Finally, palaeoecological reconstructions may be presented, including hints at palaeogeographical patterns so as to document that also the Pomeranian region within Poland has valuable palaeontological and touristic contributions to make.

2. History of previous research

In Poland, only few papers on arthropods from erratic boulders have appeared in print. For in-

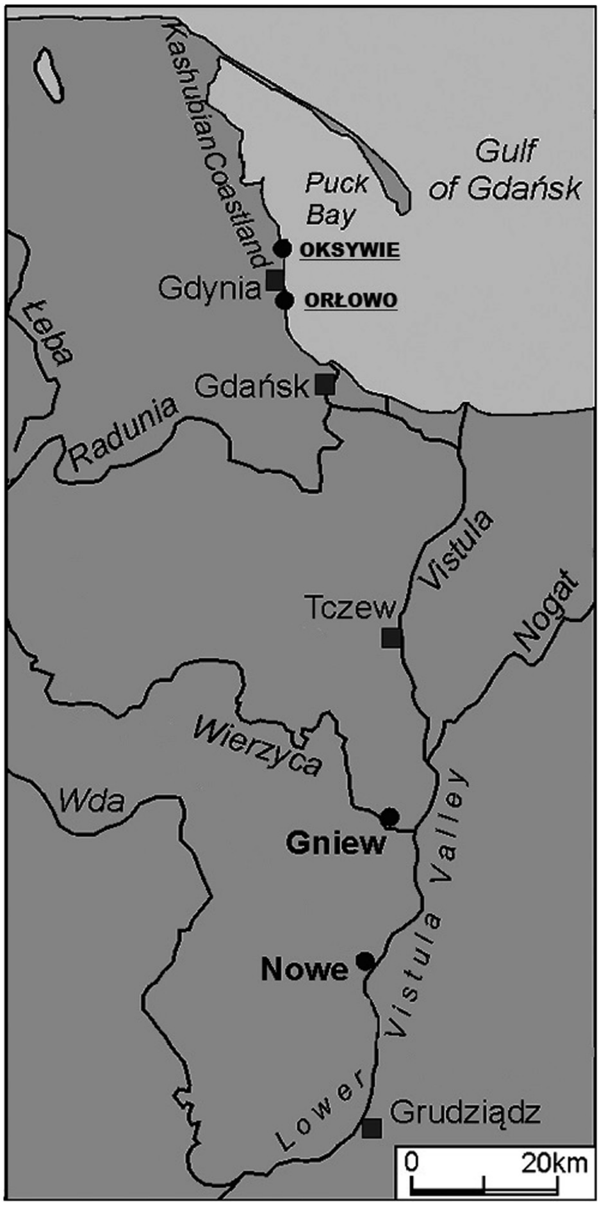

Fig. 1. Location of Orłowo and Oksywie cliffs (based on Woźniak & Czubla, 2016).

stance, Jurassic ostracods from Łuków were studied by Olempska & Błaszyk (2001), while a new genus and species of Silurian conodonts, *Erraticodon balticus* Dzik, 1978, was described from an erratic boulder of Baltic origin found at Garcz near Kartuzy, Pomerania. In addition, there are records of trilobites from cobbles at Mielenko Drawskie by Borowski (2004, 2008, 2016, 2021). One of us (AK) recorded some arthropod fossils from erratic boulders collected near Orłowo Cliff in Gdynia in 2020 and a year later in her MSc thesis (Kowalewska, 2020, 2021). The first part of the present study was published by Kowalewska in 2023, focusing on some trilobites and ostracods from *Beyrichia* limestones collected between 2019 and 2022. The newest finds and a general summary are presented herein.

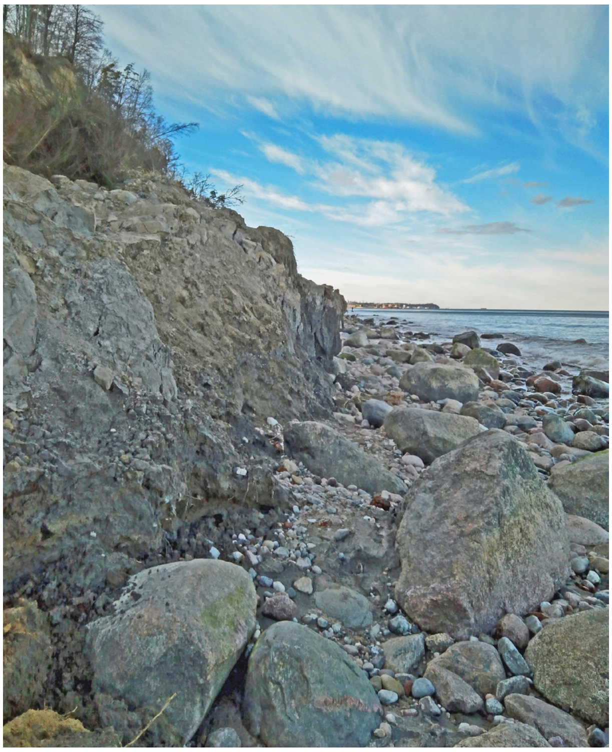

Fig. 2. Orłowo Cliff in Gdynia.

There are papers on other groups of organisms from erratic boulders in Poland. Kiepura (1962) described Ordovician bryozoans, whilst Mierzejewski (1978, 2001) worked on Ordovician and Silurian graptolites. Some publications focused on radiolarians (Górka, 1994), sponges (Rhebergen, 2004), hyoliths (Malinky, 2007), and even trace fossils (Chrząstek & Pluta, 2017).

The literature on erratic faunas in the Baltic countries is much more comprehensive. The first works appeared in the 19th century (Kiesow, 1884; Pompeckji, 1890; Jentszch, 1892). A century later, Schallreuter, over more than a decade, provided a compilation of ostracod taxa collected from erratic boulders in Germany (Schallreuter, 1984, 1988, 1993, 1994, 1998). In addition, Silurian ostracods from *Beyrichia* limestones were described by Hansch & Siveter (1994), while Ordovician species found in Finland were characterised by Nölvak et al. (1995).

Other descriptions of fossils (including arthropods) from erratics were published by Schrank (1970a; calymenid trilobites), Neben & Krueger (1971, 1973, 1979), Rohde (2007), Rudolph et al. (2010), Weidner et al. (2015), Mychko (2022) and Chlachula & Mychko (2023). Even new species of trilobites were recorded by Schöning (2010), such as proetids and other notable contributions include a compilation of

Ordovician trilobites from erratics found in northern Germany (Schöning, 2017) and a description of Silurian taxa from the same area (Schöning, 2022).

3. Locality

The present research has focused on two sites along the southern coast of the Baltic Sea in northern Poland (Fig. 1). The first is a beach near Orłowo Cliff (Fig. 2), marking the eastern edge of the Redłowo Plateau (a moraine plateau along the Kashubian Coastland; Woźniak et al., 2018). Administratively, this is the territory of Gdynia Redłowo. The cliff stretches between 81,3 and 81,95 km along the coast. There is permanent abrasion here, the rate of retreat of the till cliff being about 1 m/year (Kaulbarsz, 2005).

The second site is an area near the cliff that is part of the eastern edge of the Oksywie Plateau (moraine plateau) (Fig. 3), located above Puck Bay. The cliff is mostly 30–40 m in height and has an abrasive-type edge. It stretches from Mechelinki through Babie Doły to Gdynia Oksywie. Material from this locality has become the subject of study for the first time.

A sea cliff is "a steep coastal slope" (Stembridge, 1982). They are formed by processes of erosion and the effects of gravity. Sea cliffs are defined as surfaces along coasts with slope angles larger than 20°.

Both cliff sections studied comprise fluvioglacial and glacial deposits, presented mostly by moraine clays and tills. Oksywie Plateau and Redłowo Plateau are isolated from each other by depressions. The material probably is of the similar age, mostly late and middle Weichselian (Woźniak & Czubla, 2016; Woźniak et al., 2018). Embedded in these sediments are erratic cobbles and boulders, representing igneous, metamorphic and sedimentary rocks, the last-named with fossil content. The beaches at the foot of the cliffs are littered with such erratic boulders (Figs. 2, 3).

Fig. 3. Cliff in Gdynia Oksywie.

4. Material and methods

During fieldwork, cobbles and boulders of sedimentary rocks were selected to be smashedusing a geological hammer and subsequently viewed under a field microscope Carson Microflip LED 100–250x. Next, these specimens were taken to the laboratory for further preparation with chisels, needles and an engraving tool (Dremel). Preparation under the microscope was necessary for part of the material because of the small (1–20 mm) size. Hydrochloric and acetic acids were occasionally also used to highlight details of specific elements (UO-ZP-AK01; UO-ZP-AK06; UO-ZP-AK48).

The prepared specimens were examined and photographed with the help of a digital microscope LCD Digital Microscope inskam-307, with Realme 11 RMX3780 with macro lens 25x Selvim camera.

In total, the collection comprises 65 specimens of trilobite and numerous ostracods (see catalogue no. UO-ZP-AK01–65). Ostracods are often complete, while trilobites are predominantly represented by disarticulated sclerites such as 41 pygidia, 15 cephalic elements, 6 doublure and hypostome or single segments. Many specimens are partially eroded, documenting various states of preservation. Some other groups of fossil remains have also been recognised, but these are not described here in detail, merely mentioned as associated fauna, such as sponges, brachiopods, crinoids, graptolites and some molluscan groups. It should also be noted that numerous cobbles and boulders proved barren and that some remains are extremely poorly preserved; the latter were omitted from further study. In all, field trips between 2019 and 2024 yielded approximately 500 specimens.

5. Results

One of the aims of the present work is to determine the type of fossil-bearing rock, which is a prerequisite for comparisons with other (provenance) regions and for establishing the direction of movement of the former ice sheet.

However, the most important task of the work is the taxonomic assessment of fossils and their stratigraphical dating. The present collection comprises material from lower Palaeozoic sedimentary rocks, mostly of Ordovician and Silurian age. Representatives of four genera of trilobites, in one superfamily and five families are documented, as is a complex of beyrichioidean ostracods.

5.1. Types of rocks

Amongst erratics collected , it is possible to distinguish different types of rock based on their lithological characteristics and palaeontological content. As mentioned above, based on the present material, it may be concluded that the majority of the collected material is of Silurian age. However, some specimens are indicative of an Ordovician age, such as the so-called Backsteinkalk (Rudolph et al., 2010), a common rock type in the Baltic area of the Upper Ordovician, Sandbian Stage, Idavere Regional Stage (Mychko, 2022).

It has a high density and is hard, which makes it difficult to prepare. It is named after its properties that reminded people of bricks (‘Backsteine’ in German). Its area of provenance is the central Baltic and Sweden. Backsteinkalk has a typical greenish-grey colour and contains numerous representatives of three trilobite families (Illaenidae, Asaphidae and Cheiruridae), as well as brachiopods and bryozoans (Rudolph et al., 2010). Backsteinkalk has two types with main differences in fossils contents. Type 1 is distinguished from type 2 mostly by the presence of the alga *Apidium pygmaeum* Stolley, 1896 (van Keulen & Rhebergen, 2017).

In the study area, only a single representative of the family Asaphidae has been found (no. UO-ZP-AK02), but lithologically speaking, the rock that yielded it does not correspond to the Backsteinkalk type.

Another erratic rock type is the Macroura limestone, also known as Rollsteinkalk (Rudolph et al., 2010). This rock is of Late Ordovician age, occurs as large, rounded blocks and is characterised by various colours, such as grey with blue inside, yellow and green outside. Occasionally, there are reddish spots (iron oxide). It is important to note that it feels greasy when held between the fingertips. This rock is the commonest and most widely distributed in Öland (southern Sweden). It contains the trilobite *Toxochasmops macrourus* (Sjögren, 1851) (hence the name), as well as illaenid and proetid taxa, brachiopods and bryozoans (Rudolph et al., 2010). In the study area, some representatives of Ordovician trilobite families have been encountered, such as specimens representing the subfamily Chasmopinae (no. UO-ZP-AK34, 63) of the family Pterygometopidae. However, lithologically speaking, these erratics cannot be ascribed to the Rollsteinkalk type.

Orthoceras limestone is the second commonest Öland rock type (Rudolph et al., 2010), known from nearly the entire Ordovician. The commonest subtypes of this limestone are red and grey in colour but generally they have different ages and origins. Geologists distinguish: Upper grey *Orthoceras* limestone from the Darriwilian of the Baltics, Upper red *Orthoceras* limestone, Middle red *Orthoceras* limestone and Middle grey *Orthoceras* limestone from the Darriwilian of Sweden, Lower grey *Orthoceras* limestone from the Dapingian of Sweden and Lower red *Orthoceras* limestone from the Floian of Sweden (Rudolph et al., 2010).

This rock is very dense and compact, and is often used in buildings (numerous monuments). *Orthoceras* limestone contains numerous fossils of nautiloids, as well as members of the trilobite families Asaphidae and Illaenidae (Rudolph et al., 2010). In the study area, some cobbles with fossils of this type may have been collected, but arthropods are rarely represented, in contrast to crinoid, nautiloid and brachiopod remains. Thus, the collected material is considered not to include typical *Orthoceras* limestone.

In the present collection, Silurian-aged rock types are represented mostly by *Beyrichia* limestone (Rudolph et al., 2010), as noted previously (Kowalewska, 2020, 2023). This name is used for a large group of rock types, of different texture and fossil content. The range of parent deposits of these limestones extends from the island of Saaremaa (Estonia) through southern Gotland to Hoburgs Bank. Over a distance of 800 km, the appearance of the limestone and its characteristic fauna change. *Beyrichia* limestone derives from the generic name *Beyrichia*, an ostracod, but some types contain fewer ostracods. Steusloff (1892) identified 8 varieties of these rocks, while Reuter (1885) distinguished as many as 50.

One of the classifications was made by Roedel (1926). According to his work, the taxonomy of *Beyrichia* limestones is complex and requires a detailed study of the places of origin of each species. It is quite possible to distinguish such varieties on the basis of the dominating types of fossils, for example:

- *Nucula* limestone with the brachiopod *Microsphaeridiorhynchus nucula* (J. de C. Sowerby, 1839),

– *Chonetes* limestone with the brachiopod *Protochonetes striatellus* (Dalman, 1828),
– *Canalicula* limestone with the brachiopod *Levenea canaliculata*, Lindström, 1861,
– *Elevatus* limestone with the brachiopod *Delthyris* (*Delthyris*) *elevata* Dalman, 1828,
– *Ptilodictya* limestone with the bryozoans *Ptilodictya lanceolata* Goldfuss, 1826,
– fish limestone with fish remains.

In the work of Noetling (1882), a list of varieties of *Beyrichia* limestones was also supplied, including some of the above-mentioned, as well as *Murchisonia* limestone with gastropods *Murchisonia cingulata* Hisinger, 1829, crinoid *Beyrichia* limestone with crinoid remains, and so on.

Occasionally, *Beyrichia* limestone is used in a broader sense, comprising rocks of late Ludlow to late Pridoli age. In a more restricted sense, it is of middle and late Pridoli age (Hansch, 1985). The fossil fauna of *Beyrichia* limestones is rich, comprising trilobites (calymenids, acastids and encrinurids), ostracods (*Neobeyrichia*, *Nodibeyrichia*, *Kloedenia* and *Frostiella*) and associated taxa such as tentaculitids, crinoids, bryozoans, molluscs, fish remains and brachiopods (Rudolph et al., 2010). It has many colours, being mostly grey, but occasionally with yellow and brown stains and streaks. There is also a rare subtype of so-called red *Beyrichia* limestone. In each type lots of fragments are weathered. This rock comes predominantly from Gotland, but Estonia and the Baltic sea floor have also been suggested as provenance area (Hansch & Siveter, 1994; Rudolph et al., 2010).

Another common erratic type noted in the present collection (NN UO-ZP-AK04, UO-ZP-AK07, UO-ZP-AK08, UO-ZP-AK10, UO-ZP-AK14, UO-ZP-AK18, UO-ZP-AK19, UO-ZP-AK42, UO-ZP-AK45, UO-ZP-AK60) is *Encrinurus* limestone (as defined by Siebs, 1917). It is a light brownish to grey, dense, heterogeneous limestone with incomplete specimens of the trilobite *Encrinurus punctatus* (Wahlenberg, 1821). Pygidia and cephala are always found separately. Other fossils encountered comprise the brachiopods *Atrypa reticularis* Linnaeus, 1758, *Strophomena* sp. and *Chaetetes* sp. (Siebs, 1917).

Another Silurian rock type that is common in the Baltic area is the so-called Graptolithen-Gestein (Rudolph et al., 2010). It is a greenish-grey rock of Wenlock-Ludlow age, rich in fossils. This rock occurs as concretions in thick levels of shales, testifying to deposition in quiescent waters. Erratics often are loaf-shaped and easy to split. Graptolithen-Gestein originates from Öland and contains not only graptolites but also brachiopods, ostracods, as well as calymenid and odontopleurid trilobites (Rudolph et al., 2010). In the study area, such rocks have not been found yet.

A rather uncommon type is the so-called Leperditien-Gestein (Rudolph et al., 2010), of Silurian age and brown to grey in colour, having a fine-grained texture. It yields the ostracod genus *Leperditia*, brachiopods and stromatoporids and originates from Gotland, Saarema and the Baltic sea floor (Rudolph et al., 2010).

5.2. Characteristics of trilobites and ostracods

The body of a trilobite (Fig. 4) comprises three sections: cephalon, thorax and pygidium. In the middle of the cephalon, there is a hump, called glabella. In the thorax and pygidium, axial rings and pleurae indented by pleural furrows may be distinguished (Radwańska, 2007). There are pleural ribs on the pleurae and interpleural furrows between them (Gon III, 2007).

The cephalon comprises a few conjoined segments; cranidium (glabella with furrows, fixigena) and librigena. There may be three types of plates on the ventral side: hypostome, doublure and rostrum (Lehmann & Hillmer, 1987). Ventral and dorsal sutures may also be distinguished (Radwańska, 2007).

Ostracod segmentation is poorly visible but it is possible to distinguish head, thorax and regressed abdomen. Their outer shell consists of two valves connected by a hinge. The shell is either smooth or has ornament of varying types and complexities

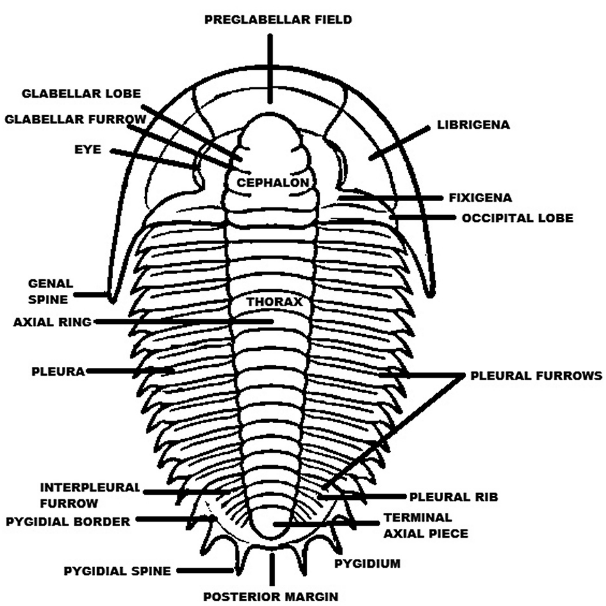

Fig. 4. Trilobite morphology (based on Gon III, 2007).

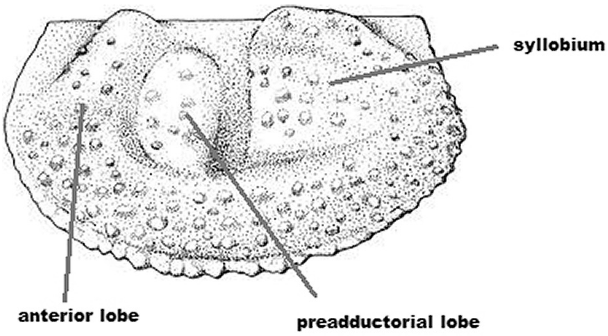

Fig. 5. Beyrichiid shell morphology (based on Siveter, 2022).

(Błaszak, 2011). Beyrichiid ostracods often have shells with clearly visible lobation and ornament (Kesling & Rogers, 1957) and a division into an anterior lobe, preadductorial lobe and syllobium (Fig. 5) (see Schallreuter & Hinz-Schallreuter, 2010). A typical morphological element of beyrichiids is also a crumina (brood pouch), which was formed by fusion of distal edge of the dolonal pouch with the contact margin (Martinsson, 1960).

5.2.1. Palaeontological description of trilobites

Class: Trilobita Walch, 1771
Order: Phacopida Salter, 1864
Suborder: Calymenina Swinnerton, 1915
Family: Calymenidae H. Milne Edwards, 1840
Subfamily: Calymeninae H. Milne-Edwards, 1840
Calymene Brongniart, 1822
Type species: *Calymene blumenbachii* Brongniart, 1822, by subsequent designation (Shirley, 1933).
Calymene? sp.
Fig. 6A

Material: Nine specimens; UO-ZP-AK01, 03, 05, 24a, 28, 48, 56, 58 and 59, from Gdynia Orłowo and Gdynia Oksywie.

Description: Semi-rounded pygidium, 10 to 20 mm in width, flat or convex, axis convex and fusiform, three times narrower than whole pygidium, with 7–8 axial rings, five pairs of pleural ribs cut by pleural furrows at the ends, the last pair parallel to the axis, pleurae reaching border, terminal axial piece not reaching the border. Some specimens with visible granulation; two incomplete smooth cephalons present; with deep glabellar furrows; possessing distinct glabellar lobation; visible roundish L1 and L2; fragment of fixigena and librigena visible.

Discussion: *Calymene* is a common trilobite genus in Silurian Baltoscandian erratics. The present cephalons could belong to this genus because of the separation of the second and third lobes (Whittington et al., 1997). There is also a separation between the end of the third lobes and the occipital ring. The specimen is similar to GIT 174 (see www.fossiilid.info).

The available pygidia show similarities to a pygidium described as *Calymene* sp. (see number GIT 187-61, www.fossiilid.info). This generic affiliation relies on the five pairs of pleurae and the position of the last pair of pleurae, which is parallel to the axis (Siveter, 1985). Other representatives of the subfamily Calymeninae could be ruled out on the basis of the number of axial rings on the pygidium. For instance, the genus *Alcymene* Ramsköld, Adrain, Edgecombe & Siveter, 1994 is characterised by five or occasionally six axial rings (Ramsköld et al., 1994). The genus *Liocalymene* Raymond, 1916 may be excluded because of the lack of a smooth median part of the axis (Whittington, 1971); the same goes for the genus *Diacalymene* Kegel, 1928, on account of the presence of interpleural grooves (Whittington et al., 1997). *Papillicalymene* Shirley, 1936 is another candidate, but for this the cephalon is needed. However, the lack of granulation of the outer portions of the pleurae would rule out this genus (Whittington, 1971), provided that this did not fall victim to erosion.

It is nearly impossible to determine species accurately based solely on pygidia; the most diagnostic element usually is the glabella. Specimens which co-occur with chonetid brachiopod, beyrichiid ostracods and tentaculitids probably belong to *C. tentaculata* von Schlotheim, 1820, which is often found in *Beyrichia* limestone of Pridoli age on Gotland (Schrank, 1970a). Most specimens resemble *Calymene tentaculata*, especially in the possession of eight axial rings (Schrank, 1970a). Another specimen (UO-ZP-AK24a) could belong to *C. blumenbachii* Brongniart, 1817 or *C. blumenbachii neotuberculata* Schrank, 1970a, which co-occur, for example, with *Encrinurus* sp. in Wenlockian-aged erratics. The pygidium of *C. blumenbachii* is similar to that of *C. tentaculata*, but it usually has visible granulation (Schrank, 1970a).

Suborder: Phacopina Struve, 1959
Superfamily: Acastoidea Delo, 1935
Family: Acastidae Delo, 1935
Acaste Goldfuss, 1843
Type species: *Acaste downingiae* Murchison, 1839
Acaste? sp.
Fig. 6B

Material: Five specimens, UO-ZP-AK06a-b, 11, 31, 64; from Gdynia Orłowo and Gdynia Oksywie.

Description: Small pygidia (about 5 to 10 mm in length), mostly semi-convex to convex, semi-rounded to subtriangular; possessing five or six pairs of pleural ribs and 7–8 visible axial rings. Pleurae are

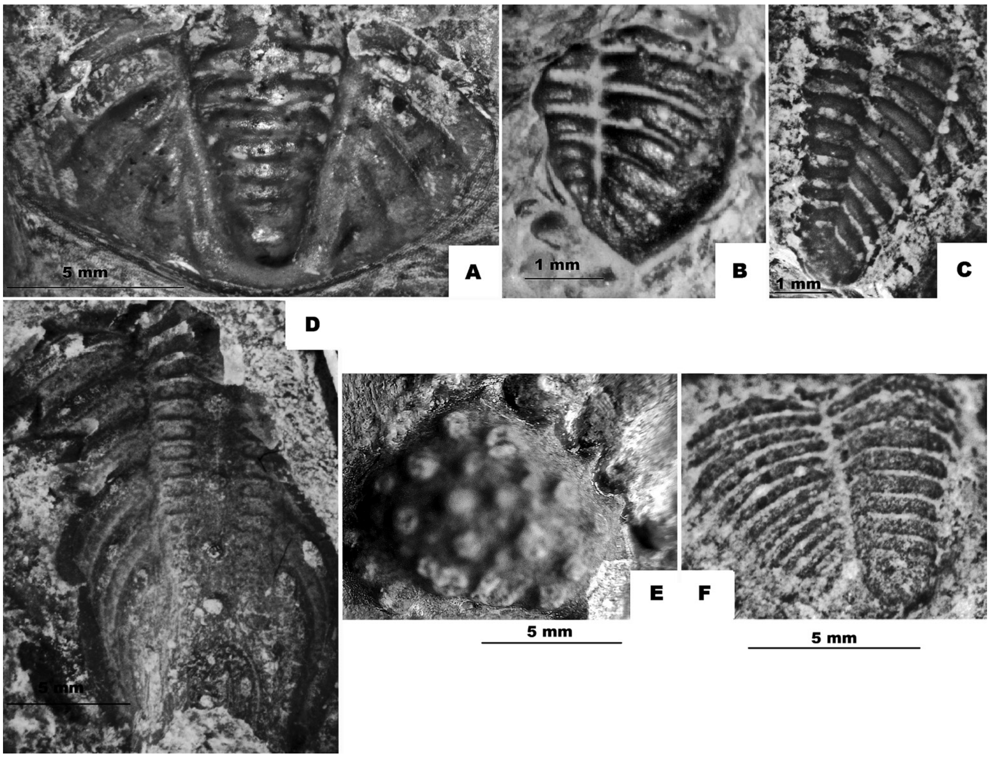

Fig. 6. Trilobites: **A –** Pygidium of *Calymene*? sp., UO-ZP-AK05; **B –** Pygidium of *Acaste*? sp., UO-ZP-AK06b; **C –** Pygidium of Chasmopinae indet., UO-ZP-AK34; **D –** Pygidium of *Encrinurus* sp., UO-ZP-AK32b; **E –** Glabella of *Encrinurus* sp., UO-ZP-AK32c; **F –** Pygidium of Proetidae indet., UO-ZP-AK53.

under the same angle., with intrapleural furrows not reaching the border and deep pleural furrows on all ribs and on the entire length of pleurae but best visible at the point of origin. Occasionally fine granulation is visible. Pleurae and terminal axial piece do not reach the border. Axis is convex and cylindrical.

Discussion: Specimens of pygidia belonging to the second morphotype described above appear to be assignable to the genus *Acaste*. This commonly occurs in *Beyrichia* limestone of Pridoli age, co-occurring with *Calymene* sp., for example *C. tentaculata*. Specimens of this genus are often flattened, probably due to sediment compaction.

Specimens recovered are similar to pygidia of the genus *Acaste* in view of shape, number of pleurae and axial rings, pleurae not reaching the border and strong pleural furrows. From other acastomorphs (e.g. genera *Acastella* Reed, 1925 and *Acastellina* Richter & Richter, 1954), it may be distinguished by the lack of denticulations of pygidial margins and a more roundish pygidium (Whittington et al., 1997). The present specimens resemble *Acaste* sp. published by Schrank (1970b).

Based on incomplete preservation, specific assignment is impossible. The present material might belong to *Acaste dayiana* Richter & Richter, 1954 (Schrank, 1970b).

Family: Pterygometopidae Reed, 1905
Subfamily: Chasmopsinae Pillet, 1954
Chasmopsinae indet.
Fig. 6C

Material: Two incomplete pygidia, UO-ZP-AK34, 63; from Gdynia Oksywie.

Description: Incomplete, probably elongated semi-convex, triangular in shape, narrow pygidia. 13 visible axial rings, 10 visible pairs of pleurae with different angles, ends of ribs bending posteriorly.

Discussion: Affiliation to the subfamily Chasmopsinae is indicated by the elongated nature of the pygidium with numerous axial rings and pleurae (Whittington et al., 1997). Recognition of the genus is impossible due to the incomplete preservation of this material, but it might represent *Toxochasmops* McNamara, 1979, on account of the probable number of segments between twelve and eighteen (McNamara, 1979).

Suborder: Cheirurina Harrington & Leanza, 1957
Family: Encrinuridae Angelin, 1854
Subfamily: Encrinurinae Angelin, 1854
Encrinurus Emmrich, 1844

Type species: *Entomostracites punctatus* Wahlenberg, 1821, by monotypy.

Encrinurus sp.

Figs. 6D–E

Material: 19 specimens, UO-ZP-AK04, 07, 08, 10, 14, 18a-b, 19a-b, 24b, 32a-c, 33a-c, 42, 45, 60; from Gdynia Orłowo and Gdynia Oksywie.

Description: pygidium about 10 mm in length, of triangular shape, convex, with few tubercles on axis, some tubercles on pleurae, possessing 6–7 pairs of pleural ribs, 15–17 axial rings shallower centrally, in some specimens pygidial spine present; convex glabellas with tubercles irregularly spaced.

Discussion: Affiliation to *Encrinurus* is suggested mostly on the basis of the elongated triangular nature of the pygidium with numerous axial rings and tubercles (Whittington et al., 1997). These trilobite remains probably belong (based on morphology and matrix type) either to *Encrinurus punctatus* Wahlenberg, 1821 or *E. macrourus* Schmidt, 1859. Both of these occur in erratics of Silurian age. *Encrinurus macrourus* is known from the Ludlow of Gotland, while *E. punctatus* has also been described from other Baltic areas, especially towards the east (Männil, 1978). Most material recorded is of Wenlockian and Ludlow age, and a range into the Pridoli is possible (Rohde, 2007). A distinction between these species based only on pygidium morphology only is impossible. *Encrinurus punctatus* and *E. macrourus* are both widely variable intraspecifically, as seen, for instance, in tuberculation. Tripp (1962) noted that specimens of *E. macrourus* were slightly smaller than *E. punctatus*, but this way of distinction calls for numerous fossils and subdivision into juveniles and adults.

Order: Proetida Fortey & Owens, 1975

Family: Proetidae Salter, 1864

Proetidae indet.

Fig. 6F

Material: A single specimen, no. UO-ZP-AK53; from Gdynia Oksywie.

Description: incomplete imprint of pygidium (7 mm in length); fusiform axis with nine visible axial rings with deep furrows between them; six visible pairs of pleurae with deep pleural furrows along entire length; deep furrows between pleurae.

Discussion: The specimen could belong to the subfamily Proetinae but many genera may be ruled out on account of the possession of nine axial rings (Whittington et al., 1997). For instance, *Cyphoproetus* Kegel, 1928 has a pygidium with six to eight axial rings (Whittington et al., 1997). However, *Warburgella* Reed, 1931 is recognised by a narrower axis (Chlupáč, 1971).

From what is visible of morphological characters, the closest resemblance is with *Proetus concinnus* Dalman, 1827 or *P. signatus* Lindström, 1885 (Tomczykowa, 1990). Both of these species are found in Baltoscandian erratic boulders; *P. signatus* is dated mostly as Late Silurian on Gotland (Alberti, 1982), while *P. concinnus* is common in Wenlock-aged rocks. This applies especially to the nine axial rings in the pygidium and the six pairs of pleurae. However, the distinct pleural and intrapleural furrows raise some doubts over such assignment and even over placement in the genus *Proetus*. In connection with this, the authors have decided to refer to this specimen as Proetidae indet.

5.2.2. Ostracod remains

The present collection contains numerous ostracod shells, most of them being referable to the order Palaeocopida Henningsmoen, 1953. Probably, a single specimen (Fig. 7A) belongs to the order Leperditicopida Scott, 1961, representing the genus *Leperditia* Rouault, 1851. Of the order Palaeocopida, members of the family Beyrichiidae Jones, 1855 predominate (Fig.7B). The state of preservation of specimens makes it difficult to identify them in detail, but representatives of the genera *Neobeyrichia* Henningsmoen, 1954, *Nodibeyrichia* Henningsmoen,

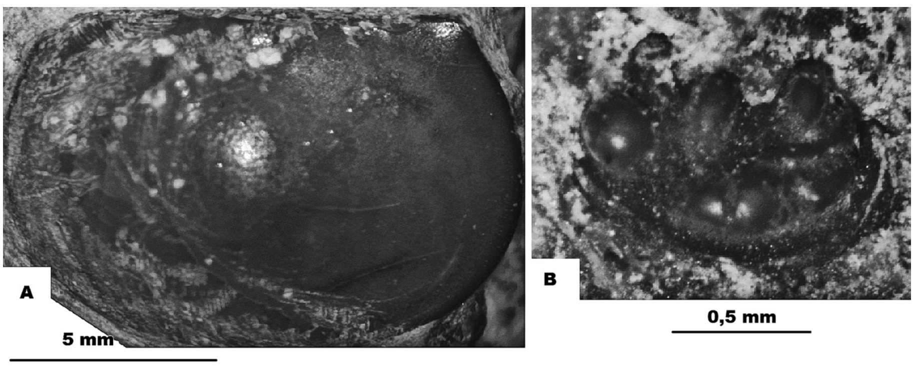

Fig. 7. Ostracods: **A –** Shell of *Leperditia* sp., UO-ZP-AK52; **B –** Shell of a beyrichiid, UO-ZP-AK29.

1954, *Kloedenia* Jones & Holl, 1886 and *Frostiella* Martinsson, 1963 have been noted, and probably some additional taxa.

Numerous beyrichiids are distinctive where shell ornamentation and lobation are concerned (Kesling & Rogers, 1957). They are common fossils in *Beyrichia* limestone (Hansch & Siveter, 1994).

6. Palaeoecological and palaeogeographical implications

Another aspect of the present study is to provide a comparison with Scandinavian regions in order to attempt to determine the area of provenance of these erratics and thus illustrate the direction of ice sheet advancement.

The sedimentary rocks of Ordovician and Silurian age collected in the study area may have originated from one or more of cliffs ('klint') that extend all around the Baltic Sea. The first is the Baltic Klint (Fig. 8), also known as the Ordovician Klint. This measures about 1,200 km in length and comprises erosional escarpments consisting of sedimentary rocks. The whole system has borders along the southern end of the isle of Öland (Sweden) and at Lake Ladoga (Russia). It has also been noted that Baltic Klint is connected with the boundary between the Fennoscandian Baltic Shield and the East European Platform (Soesoo & Miidel, 2007).

The Baltic Klint comprises Cambrian and Ordovician sedimentary rocks and may be subdivided into four regional klints; Öland Klint, Baltic Sea Klint, North Estonian Klint and Ingermanland Klint (Soesoo & Miidel, 2007). Ordovician strata are also present on the western side of the Gulf of Bothnia (Uścinowicz, 2011).

Parallel to the Baltic Klint, in the south, the Silurian Klint is distinguished, with a length of about 500 km. This structure is located on the line from Saaremaa to Gotland. On Gotland, this klint reaches its greatest height (Soesoo & Miidel, 2007).

Encrinurus punctatus and *E. macrourus* are common species in Gotland, but their pygidia are not diagnostic on account of the wide range of intraspecific variation (Tripp, 1962). Remains of *Calymene* from the study area are similar to specimens described as *C. tentaculata*, which is common in Beyrichienkalk (Schrank, 1970a). Older *Calymene* re-

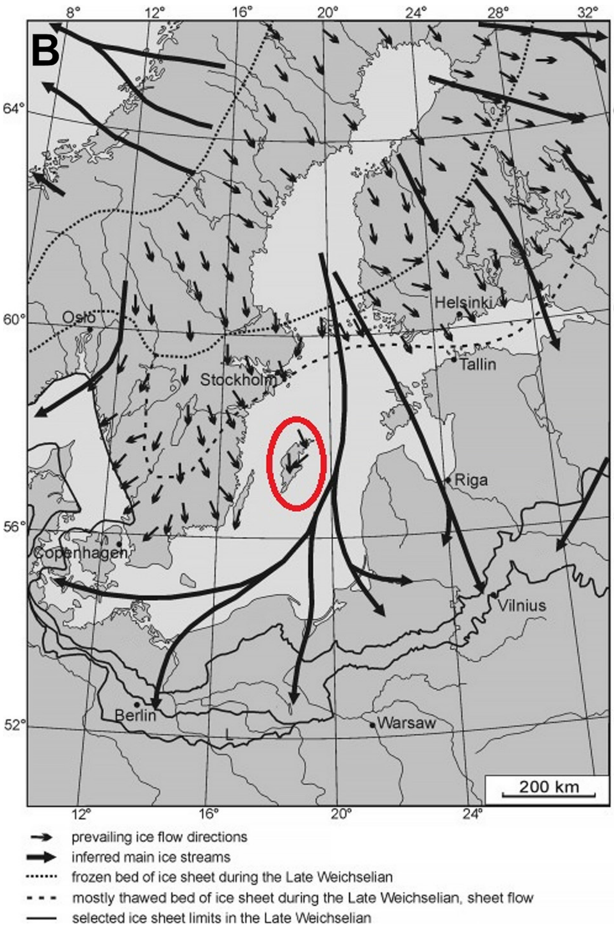

Fig. 8. Places of origin of erratic boulders. **A –** Map of Baltic Sea Klint and Silurian Klint (based on Soesoo & Miidel, 2007); **B –** Directions of ice sheet streams during the late Weichselian glaciation (based on Woźniak & Czubla, 2015).

mains might represent *C. blumenbachii*, which is also often found in Gotland strata.

The associated fauna also points to a provenance of the Gdynia material from Gotland, but not exclusively. *Ptilodictya lanceolata* Goldfuss, 1826 is often recorded from here, but there are also examples from Estonia (www.fossiilid.info). The same problem occurs with numerous brachiopods, for example, *Microsphaeridiorhynchus nucula*, *Protochonetes striatellus* (Dalman, 1828) or specimens belonging to the genus *Strophomena* Rafinesque, *in* de Blainville, 1824 (www.fossiilid.info). Therefore, arthropods appear to be more informative where the provenance area of these erratics is concerned.

A significant part of the collection comprises *Beyrichia* limestones. These erratics come mostly from the Beyrichienkalk Formation in Gotland and contain numerous beyrichiids. One of the genera often found on Gotland is *Neobeyrichia* (Hansch, 1985). Material referable to the genera *Nodibeyrichia* and *Kloedenia* is commoner in Estonia (www.fossiilid.info), which complicates our interpretation. Another frequent rock type is the *Encrinurus* limestone, the place of origin is Gotland as well (Siebs, 1917). It may be assumed that a large portion of the material collected at Gdynia stems from the Baltic sea floor near that island.

There are many versions of possible ways of ice advancement, but the main direction was probably from Sweden via Gotland (Fig. 8), matching research carried out by Woźniak et al. (2018) and based on petrographic compositions of tills at Orłowo Cliff. Another study, conducted at Babie Doły near Mechelinki (Oksywie) Cliff, yielded similar results (Woźniak & Czubla, 2015). However, it is still possible that the material studied herein stems from an earlier glaciation and included Estonia and other Baltic regions as provenance areas. For more precise data, additional research is called for.

Ostracods are known to be good palaeoecological indicators. Leperditiids inhabited very shallow waters, especially lagoons and estuarine complexes, while Silurian (Ludlow and Pridoli) beyrichioideans occupied shallow-marginal environments (Olempska, 2008). This is in line with trilobite data (e.g., *Calymene* sp.), which preferred reef areas (Turvey & Siveter, 2007). Thus, it is probable that most of the limestones at Gdynia formed in such environments.

7. Conclusions

Near the cliffs at Orłowo and Oksywie, numerous fossils may be collected from lower Palaeozoic erratic boulders and cobbles. Amongst these, arthropods constitute an interesting group, comprising trilobites as well as ostracods. They probably represent mostly Ordovician and Silurian and co-occur with different groups of associated fauna. Most of the trilobites recovered belong to the order Phacopida, while ostracods mostly represent the order Palaeocopida. No significant differences were noted between the erratic faunas of both cliffs, which is understandable in view of the short distance between them, i.e., just over 10 km in a straight line.

The findings recorded here differ from previously studied ones in new locations of research (Orłowo and Oksywie cliffs). This work comprises taxa which have not been described from these localities before. Another important point is that the taxonomy has changed, so Pompeckji 's dissertation (1890) and other works are in need of taxonomic revision. Taxa described here may be an introduction to further actions.

The present project has confirmed the need for research into erratics in the area of Polish cliffs. Fossils found in these rocks can be of value not only for scientific purposes but also for tourism. This creates the opportunity to organise fossil collecting trips for amateur palaeontologists, tourists, school kids and other groups.

Acknowledgements

The authors wish to thank Drs John W.M. Jagt, Mateusz Antczak and Dawid Mazurek for comments that greatly improved an earlier typescript and Dr Jakub Kowalski for technical assistance. We deeply appreciate comments, suggestions and corrections of both anonymous reviewers. Scientific work financed from the budget for science in the years 2020–2025 as a research project under the "Diamentowy Grant" (no. DI2019000149) program.

Catalogue of specimens – see Supplementary material on Geologos website.

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Manuscript submitted: 20 December 2024
Revision accepted: 1 February 2025