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Trilobites, their traces and associated sedimentary structures as indicators of the Cambrian palaeoenvironment of the Ocieseki Range (Holy Cross Mountains, Poland)

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Enrolled specimens of trilobite species *Strenuella polonica*, partly preserved within their escape structures and burrows from the Cambrian Series 2 Ocieseki Sandstone Formation, are described. The specimens are interpreted as buried during storm episodes. Their occurrence in a few horizons, the presence of non-bioturbated tempestites with combined wave-current ripples and groovemarks interbedded with bioturbated beds suggest a depositional environment between normal and storm wave base. The trace fossils *Monomorphichnus* and some *Rusophycus* have been interpreted as structures formed during the storm when animal tried to take refuge. Well-preserved syndepositional *Rusophycus* and its different taphonomic variants are discussed. The part of the Ocieseki Sandstone Formation studied is interpreted as deposited on a lower shoreface with storm influence.

Key words: trilobites, ichnology, sedimentology, Holy Cross Mountains, Ocieseki Formation, Cambrian Series 2.

INTRODUCTION

The trilobites of the Ocieseki Sandstone Formation have been the subject of several studies (Czarnocki, 1926, 1927; Samsonowicz, 1959a, b, c; Orłowski, 1974, 1985a, 1987; Żylińska, 2013a, b). The articles cited concentrate on systematic descriptions and biostratigraphic data of the trilobites but do not indicate the precise location of trilobites within the sections. Żylińska (2013a, b) presented new data and interpretation on the evolution of trilobites and biogeographical connections during Cambrian Series 2 and 3. Orłowski (1992b), Orłowski and Żylińska (2002) and Stachacz (2012) described the diverse trilobite trace fossils of this formation.

Trilobites are known as arthropods able to ventrally flex and enroll their carapaces. This ability was very useful and effective as defence against predators and also stressful environment conditions. Such behavior in trilobites has been documented from the Early Cambrian onwards (Ortega-Hernández et al., 2013 and references cited there).

Recently, Żylińska and Kin (see Żylińska, 2013b) described a defense strategy of the trilobite *Strenuella polonica* Czarnocki, 1926 from the Ocieseki Sandstone Formation, in which individuals enroll when attacked by a predator. *Strenuella polonica* has been introduced twice by Czarnocki (1926, 1927: p. 190) without any figures or systematic description, and it is clearly a nomen nudum (see Żylińska, 2013b for details). This species was correctly described for the first time by Samsonowicz (1959c). However, Żylińska (2013b) ascribed this species to Czarnocki's publication of 1926, and this assignation is accepted herein.

The depositional structures of the Ocieseki Sandstone Formation have never been described in detail. Based on lithology and some sedimentary structures observed in cores Studencki (1988) ascribed sandstones of the Ocieseki Formation to a transitional zone between littoral sands and shelf muds. According to him, sandstones with silty intercalations were deposited in shallow marine environments distant from the coastline. According to Orłowski (1989), the rocks of the lower part of the Ocieseki Sandstone Formation originated from near to wave base, however, his interpretation was based only on trace fossil assemblages.

This study provides an interpretation of the preservation of complete and enrolled specimens of *Strenuella polonica* from the Ocieseki Range, their escape structures and possibly bioturbational structures. Droser and Bottjer's (1986) diagram was used for ichnofabric analysis. The six categories of the diagram are equivalents of the following percentage of deposit disturbance: (1) non-bioturbated, all primary sedimentary structures preserved; (2) isolated trace fossils, up to 10% of original bedding disturbed; (3) burrows are mostly isolated, but locally overlap, 10–40% of original bedding disturbed; (4) burrows overlap, only relics of bedding are visible, 40–60% disturbed; (5) bedding is completely disturbed, but fabric is not mixed; (6) bedding is totally or almost totally homogenized. However, it must be emphasized that Droser and Bottjer (1986) used a 10 cm scale

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in their diagram and, consequently, medium or thick beds interpreted as moderately-bioturbated can be composed of a series of bioturbated and non-bioturbated layers.

The present paper focuses on event-beds showing primary depositional structures, mostly current-wave ripples and groove marks. The paper critically evaluates the taphonomy of some trilobites, their trace fossils and their taxonomical and palaeoecological significance.

GENERAL GEOLOGICAL SETTING

The Holy Cross Mountains are traditionally subdivided into the Łysogóry and Kielce regions. The northern Łysogóry Region lies within the Łysogóry Block, whereas the southern Kielce Region forms the northern part of the larger Małopolska Block (e.g., Buła, 2000; Cocks and Torsvik, 2005). Both tectonic units may have been situated near to the Baltica palaeocontinent (Cocks and Torsvik, 2005; Malinowski et al., 2005; Nawrocki and Poprawa, 2006). According to these authors, the Małopolska Block was a proximal terrane although others have suggested an exotic origin of the unit (e.g., Belka et al., 2000).

The Cambrian system in the Holy Cross Mountains comprises a succession of siliciclastic deposits with a total thickness of at least 2500 m (e.g., Orłowski, 1975, 1988, 1992a, 1997; Kowalczewski et al., 2006). The Ociesęki Sandstone Formation contains mostly fine-grained sandstones with thin intercalations of siltstones (Orłowski, 1975; Kowalczewski et al., 2006). Sedimentary structures and diverse trace fossils assemblage indicate deposition in a shallow marine environment (Studencki, 1988; Orłowski, 1989, 1992a; Mizerski et al., 1999; Orłowski and Żylińska, 2002). The study area is situated in the central part of the Kielce Region, where the Ociesęki Sandstone Formation occurs over an extended area (e.g., Orłowski, 1975; Mizerski et al., 1991; Fig. 1A).

The entire section of the Ociesęki Sandstone Formation shows numerous and diverse trace fossils, with several ichnotaxa of trilobite traces (Orłowski, 1989, 1992b; Orłowski and Żylińska, 2002; Stachacz, 2012). The sections described here are typical of the lower part of the Ociesęki Sandstone Formation. This part of the formation contains the following trilobites: *Holmia marginata* Orłowski, 1974, *H. glabra* Orłowski, 1974, *Kjerulfia orcina* Orłowski, 1974, *K. orienta* Orłowski, 1974, *Schmidtiellus panovi* (Samsonowicz, 1959), *Sch. nodosus* Orłowski, 1985; *Strenuella polonica* Czarnocki, 1926, *S. sandomirensis* Orłowski, 1985 and *S. zbelutkae* Orłowski, 1985, which clearly suggest a biostratigraphic level in the *Schmidtiellus*–*Holmia* Superzone of the Cambrian Series 2 (e.g., Orłowski, 1974, 1985a; Żylińska, 2013b). *Berabichia oratrix* (Orłowski, 1985); *Strenuella polonica* Czarnocki, 1926; *Holmia marginata* Orłowski, 1974; *Kjerulfia orcina* Orłowski, 1974; *Schmidtiellus nodosus* Orłowski, 1985; *Acanthomicmacca klimontowi* Orłowski, 1985; *Postfallotaspis spinatus* Orłowski, 1985 and *Atops granulatus* Orłowski, 1985 have been described from the Ociesęki Range exposures at Sterczyna, Jaźwina and the Igrzyczna hills and have confirmed the *Schmidtiellus*–*Holmia* Superzone (Żylińska, 2013b).

The upper part of the Ociesęki Sandstone Formation (not studied here) yields the trilobites *Kingaspidoides santacrucensis* (Samsonowicz, 1959) and *Issafeniella orlowinensis* (Samsonowicz, 1959) which indicate the *Protolenus*–*Issafeniella* Zone of the Cambrian Series 2 (Orłowski, 1985a; Mizerski et al., 1986; Żylińska and Szczepanik, 2009; Żylińska, 2013a). The presence of the trilobites *Ornamentapsis guerichi* (Orłowski, 1959), *O. opatowi* (Orłowski, 1985), *O. puschi* (Orłowski, 1985) and *Orodes usarzowi* (Orłowski, 1985) in the uppermost part of the Ociesęki Sandstone Formation suggests a biostratigraphic level near the base of Series 3, assigned to the *Paradoxides insularis* Zone (Orłowski, 1985b; Mizerski et al., 1986; Żylińska and Szczepanik, 2009; Żylińska, 2013a).

DESCRIPTION OF LOCALITY

The rocks studied crop out in a few small exposures along the Ociesęki Range, on the Sterczyna, Jaźwina and Igrzyczna hills (Fig. 1B). The first exposure is a small quarry near the peak of Sterczyna Hill (Sterczyna Quarry on Fig. 1B, GPS coordinates: N 50°43'45.2''; E 20°58'15.5''), the second is in a small pit on the eastern slope of the Sterczyna Hill (Sterczyna East on Fig. 1B, GPS coordinates: N 50°43'24.7''; E 020°58'44.2''), the third comprises natural exposures by the Grodno Stream

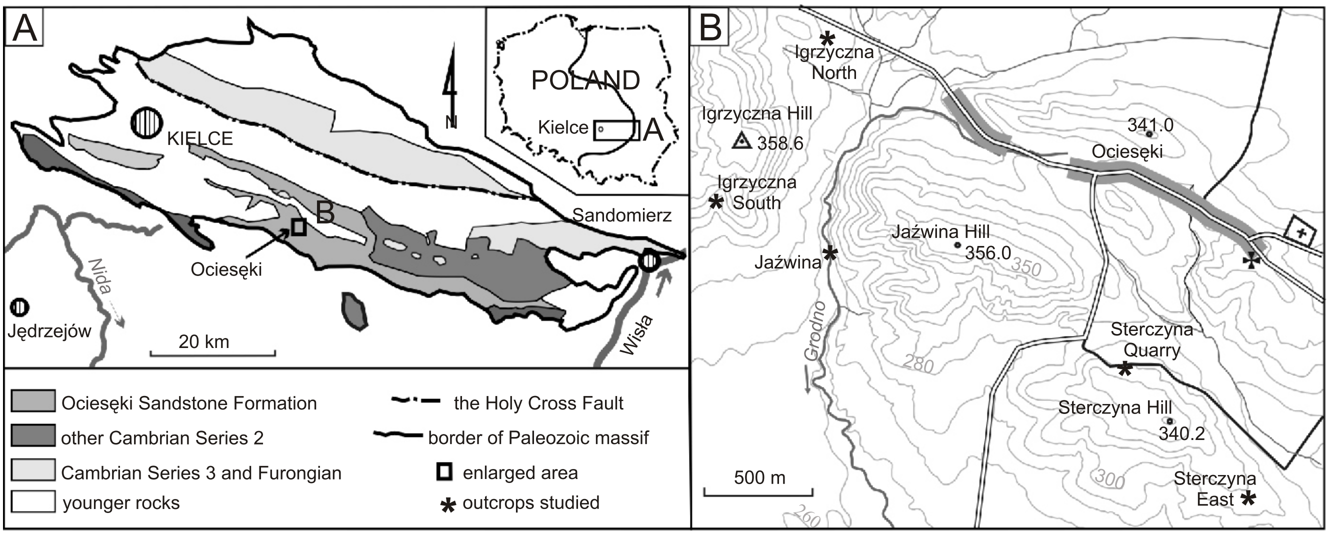

Fig. 1A – locality and simplified geological map of the Paleozoic core of the Holy Cross Mountains (geology according to Orłowski, 1975 and Mizerski et al., 1991); B – topographic map of the Ociesęki area showing locations of the exposures

(Jaźwina on Fig. 1B, GPS coordinates: N 50°44'4.7''; E 20°57'08.8''). The fourth and the fifth exposures lie on the slope of Igrzyczna Hill (Igrzyczna North and South on Fig. 1B). All of the exposures represent the lower part of the Ociesęki Sandstone Formation (e.g., Mizerski et al., 1986), which consists mainly of fine-grained, thin- to medium-bedded greywackes and quartz arenites. However, a monotonous series of almost burrow-churned quartz arenite or greywacke without skeletal fossils predominate. The trilobites, including completely preserved and enrolled specimens, were collected exclusively in the Sterczyna Quarry and at the Igrzyczna North exposure. The Sterczyna Quarry exposes a four-metre-thick section of yellowish gray quartz arenite with a few greywacke beds (Fig. 2A) and the small pit at Sterczyna East exposes a 1.6-m-thick section of quartz arenites intercalated with wackes and rare beds of siltstone (Fig. 2B). Jaźwina Hill exposes 3 m of thick, thin- to medium-bedded arenites and wackes (Fig 2C), The Igrzyczna North exposure shows 1.3 metres of quartz arenites and wackes, and contains at least one bed with completely preserved and enrolled trilobites (Fig. 2D) while Igrzyczna South exposes 3 m of similar rocks without skeletal fossils. The greywackes and arenites of all the sections studied are predominantly composed of poorly abraded quartz grains and uncommon mica flakes.

OCCURRENCE OF THE ENROLLED TRILOBITES AND ASSOCIATED TRACE FOSSILS IN THE STERCZYNA AND IGRZYCZNA SECTIONS

The quarry on Sterczyna Hill (Fig. 1B) is known in the literature because it contains well-preserved trilobite remains (e.g., Orłowski, 1987; Żylińska, 2013a, b). By contrast, the Sterczyna East pit does not yield trilobite skeletal fossils, although trilobite trace fossils are common (Stachacz, 2012). Trilobite remains in the Sterczyna Quarry are generally common, but completely preserved specimens occur only in a few beds (Fig. 2A) and at least in one bed at Igrzyczna North (Fig 2C). At least twenty-two specimens of complete trilobites have been found by the present author. Only two straight specimens from the Sterczyna Quarry and one from the neighboring locality, Igrzyczna North, indicate that most of the complete trilobites are preserved as enrolled specimens (Fig. 3). The most frequent of the completely preserved trilobites analysed is *Strenuella polonica*. However, the weakly preserved, deformed specimens do not permit determination. Such enrolled specimens were mentioned by Samsonowicz (1959c), Żylińska and Kin (see: Żylińska, 2013b) and Żylińska (2013b), and usually occur in nest-like accumulations in thin to medium beds of quartz arenite beds (Fig. 3B–D). Beds with enrolled trilobites usually show less bioturbation. Some of the trilobites are found at the terminations of escape structures (fugichnia; Fig. 4A) or burrows (repichnia; Fig. 4B–D).

The trilobite escape structure illustrated (Fig. 4A) shows a zig-zag shaped, stratified backfill within the bioturbated and non-bioturbated layers of amalgamated beds. Infilling is composed of a set of downwardly curved spreite visible in vertical section. The lower part of the structure is more than 2 cm wide and shows subparallel spreite, which are distinctly steeper in the upper part.The exoskeleton of the enrolled trilobite is located not exactly in the termination of fugichnion but slightly higher. The length of the trilobite can be estimated as similar to the width of fugichnion in its lower part. In cross-section the burrows with enrolled trilobites show a typical backfill composed of curved, U-shaped laminae with their concave sides towards the trilobite; however, laminae are indistinct near the trilobites. The meniscate burrows with trilobites (Fig. 4B–D) are represented by at least three traces infilled by sediment reworked in different directions. These structures were formed by at least three burrowing trilobites preserved in the same bed. The burrows are oblique to bedding planes. Both escape structures and burrows with enrolled trilobites are visible only in a few sections and more precise identification is impossible.

SEDIMENTARY STRUCTURES AND ASSOCIATED TRACES OF DRAGGED TRILOBITES ON THE SEA FLOOR

Thin amalgamated beds (2–10 cm thick) of arenite predominate in the Sterczyna Quarry, whilst both arenite and wacke beds predominate in exposures on the Igrzyczna slopes. Thin- to thick beds (5–50 cm thick) of arenites and wackes are typical of Jaźwina. Thin- to medium beds (5–12 cm thick) of arenites separated by wackes occur at Sterczyna East. The greywacke and most of the arenite beds are completely or almost completely bioturbated (Fig. 2), and their original sedimentological structures are usually not preserved. In addition, amalgamated beds composed of thin layers with various degrees of bioturbation are quite common in the all the sections studied (Fig. 2). Completely bioturbated arenites without original sedimentary structures predominate in the Sterczyna Quarry, whilst bioturbated wackes intercalated with non-bioturbated arenites with ripple-cross lamination are typical of the pit on the eastern slope of the Sterczyna Hill, Jaźwina and Igrzyczna (Fig. 2). Most beds are amalgamated, composed of layers in which the bioturbation degree varies (Figs. 4–7). Isolated beds of quartz arenite are not bioturbated and show original sedimentary structures, mostly ripple-cross lamination (Figs. 2, 5 and 6A, B) and relics of horizontal lamination (Fig. 6C). Very few isolated non-bioturbated beds also show long straight and symmetrical or almost symmetrical usually rounded wave ripples on their surfaces with x-shaped lamination (Fig. 5; cf. Raaf et al., 1977), and there are some climbing ripples (Fig. 5A; cf. Jopling and Walker, 1968; Allen, 1970). Some of rippled beds, especially from Sterczyna East, show casts of groove marks and trace fossils including *Rusophycus* isp. and *Monomorphichnus lineatus* Crimes, Legg, Marcos and Arboleya, 1977 and ?*Monomorphichnus* isp. on their soles (Fig. 7B, C). One of the rippled beds of arenite contains a deformed cubichnion of *Rusophycus* isp. in the termination of a trilobite trace between repichnion and groovemark (Fig. 7A, arrowed). This trace does not show features typical of *Cruziana*, but only casts of scratchmarks from the carapace and possibly legs. The trace is curved, slightly inclined to other groovemarks, superficially imprinted and its depth increases toward the *Rusophycus*, whilst the *Rusophycus* is relatively deeply imprinted. Other specimens of deeply imprinted *Rusophycus* from Sterczyna East and the Igrzyczna hills are described as *R. carbonarius* Dawson, 1864, *R. dispar* Linnarsson, 1869 and *R. crebrus* (Orłowski, 1992b; Stachacz, 2012). Specimens of *R. crebrus* (Orłowski, 1992b: fig. 11, 12.5–6; Stachacz, 2012: fig. 3A) are characterized by delicate groovemark-like ridges on the lobes and occur on the sole of beds with distinct groovemarks. The specimens of *Monomorphichnus lineatus* and ?*Monomorphichnus* isp. are convex semireliefs composed of sets of slightly curved, almost mutually parallel, thin ridges and furrows. The set is wider in one termination and in the other it penetrates the bed. However, ?*Monomorphichnus* isp. is very similar to the casts of groovemarks of tools or dead arthropods, and closer determination is impossible.

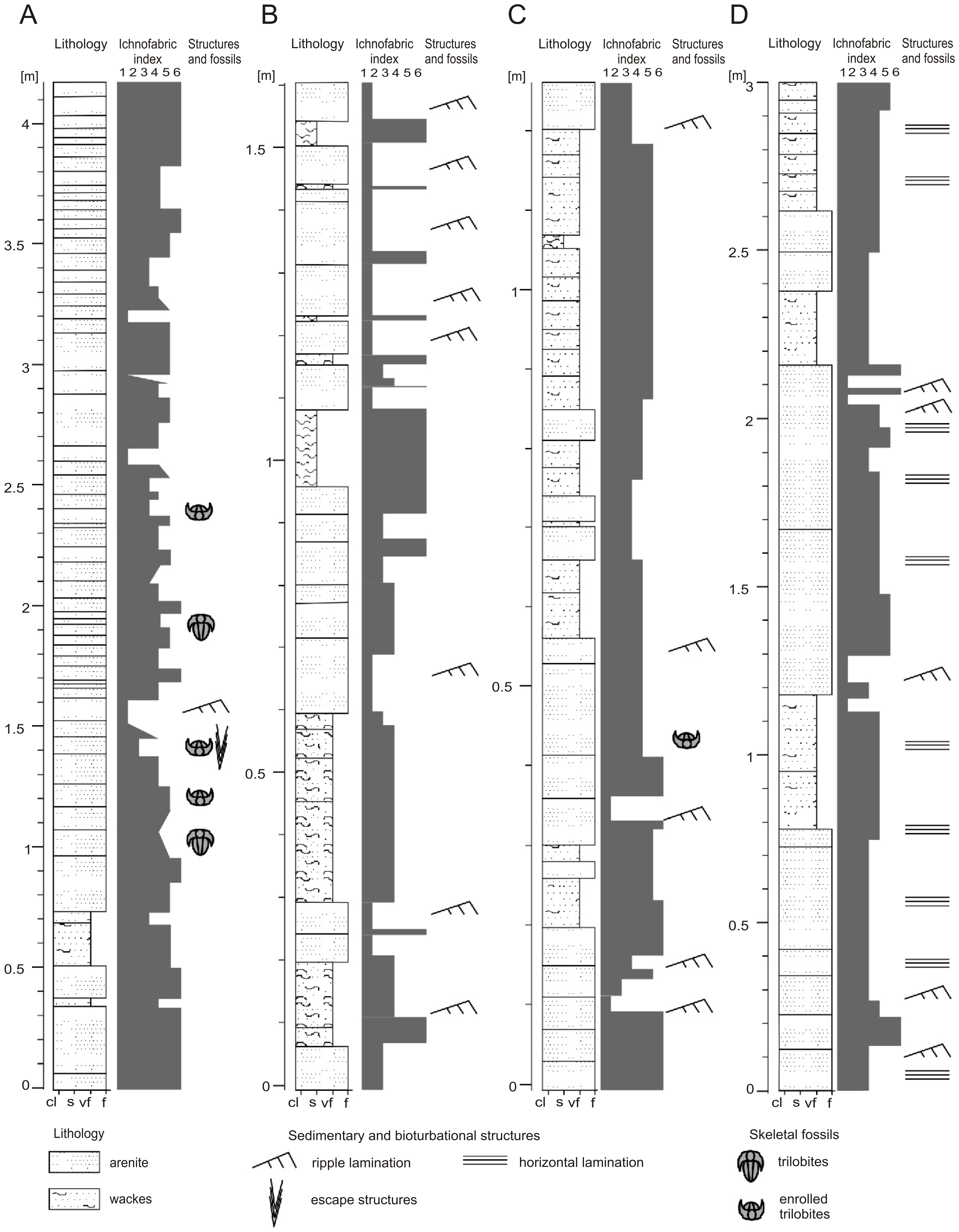

Fig. 2. Lithological columns for the selected sections

A – Sterczyna Quarry, **B** – Sterczyna East, **C** – Igrzyczna North, **D** – Jaźwina; ichnofabric index determined the method of Droser and Bottjer (1986)

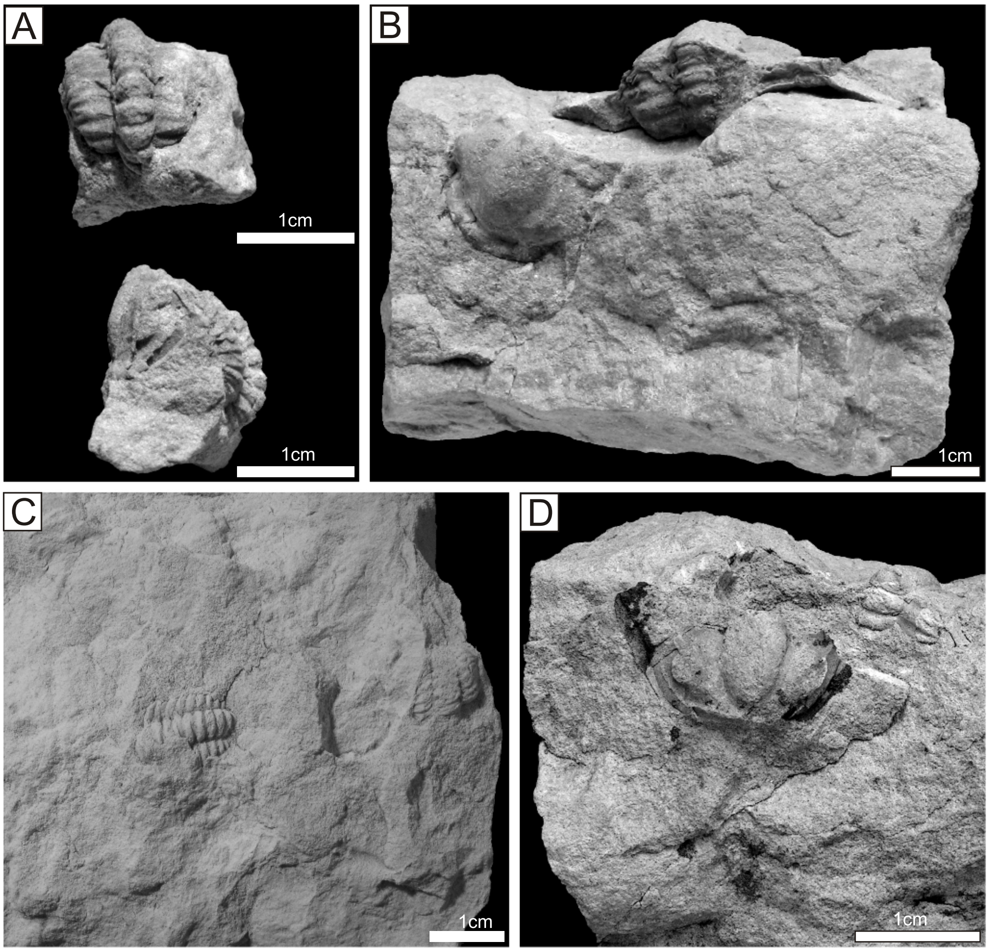

Fig. 3. ***Strenuella polonica*** **Czarnocki, 1926 from the Sterczyna section**

A – a single enrolled specimen, INGUJ214P/T31; **B**–**D** – a pair enrolled specimens occurring in thin beds of moderately bioturbated sandstone: B – INGUJ214P/T13, C – non catalogued, D – INGUJ214P/T17

DISCUSSION

Body fossils are not usually found with their corresponding trace fossils (Fuchs, 1895). However, some exceptions are known. Well-preserved trilobites, buried in life position in heterolithic muddy-silty-sandy rocks in South China were noted by Degan et al. (1995). Completely preserved and enrolled trilobites were recorded from the Cambrian of Greenland (Geyer and Peel, 2011) and Canada (Ortega-Hernández et al., 2013). Other occurrences of trilobites preserved *in situ* with their burrows, such as *Thalassinoides* nets with *Asaphus raniceps*, are known from carbonate facies of the Swedish Ordovician (Cherns et al., 2006). Enrolled trilobites have been recorded from early Middle Cambrian strata in the Lemdad Syncline, High Atlas Mountains by Geyer et al., (1995) and Geyer and Landing (2006).

Mutual exclusion of skeletal and the trace fossils is clearly visible in the Sterczyna East pit, where the trilobite body fossils do not occur, while well-preserved *Rusophycus* fossils are abundant (Stachacz, 2012). However, in the case of the Sterczyna Quarry, rare remains of trilobites occur partly together with trace fossils obviously produced by trilobites.

The beds with completely preserved and enrolled trilobites and isolated, usually non-bioturbated beds with combined current-wave ripples, groovemarks, trilobite scratchmarks and some *Rusophycus* are interpreted here as tempestites. The arrangement of the enrolled trilobites and their occurrence in nest-like accumulations in beds deposited during storms suggests that the trilobites were covered by sediment alive. After burial and death, the body would have relaxed and returned to the outstretched position. Therefore, the preservation of enrolled trilobites requires rapid burial of individuals during the life (Ortega-Hernández et al., 2013 and references cited there). Some of the individuals attempted to escape to the surface but died within the sediment. It is assumed that death was caused by suffocation. Some individuals formed distinct escape traces directed more or less directly towards the sediment surface. A spreite-like ecsape structure (Fig. 8) was probably formed by a wriggling trilobite moving upwards. The enrolled trilobite at this escape structure is not located exactly in the termination of fugichnion but has been moved, probably by taphonomic processes. Nevertheless, the occurrence of completely preserved and enrolled trilobites in strongly bioturbated sediment points to rapid deposition and burial during their lifetime. Similarly well-preserved Cambrian trilobites in life position have been in-

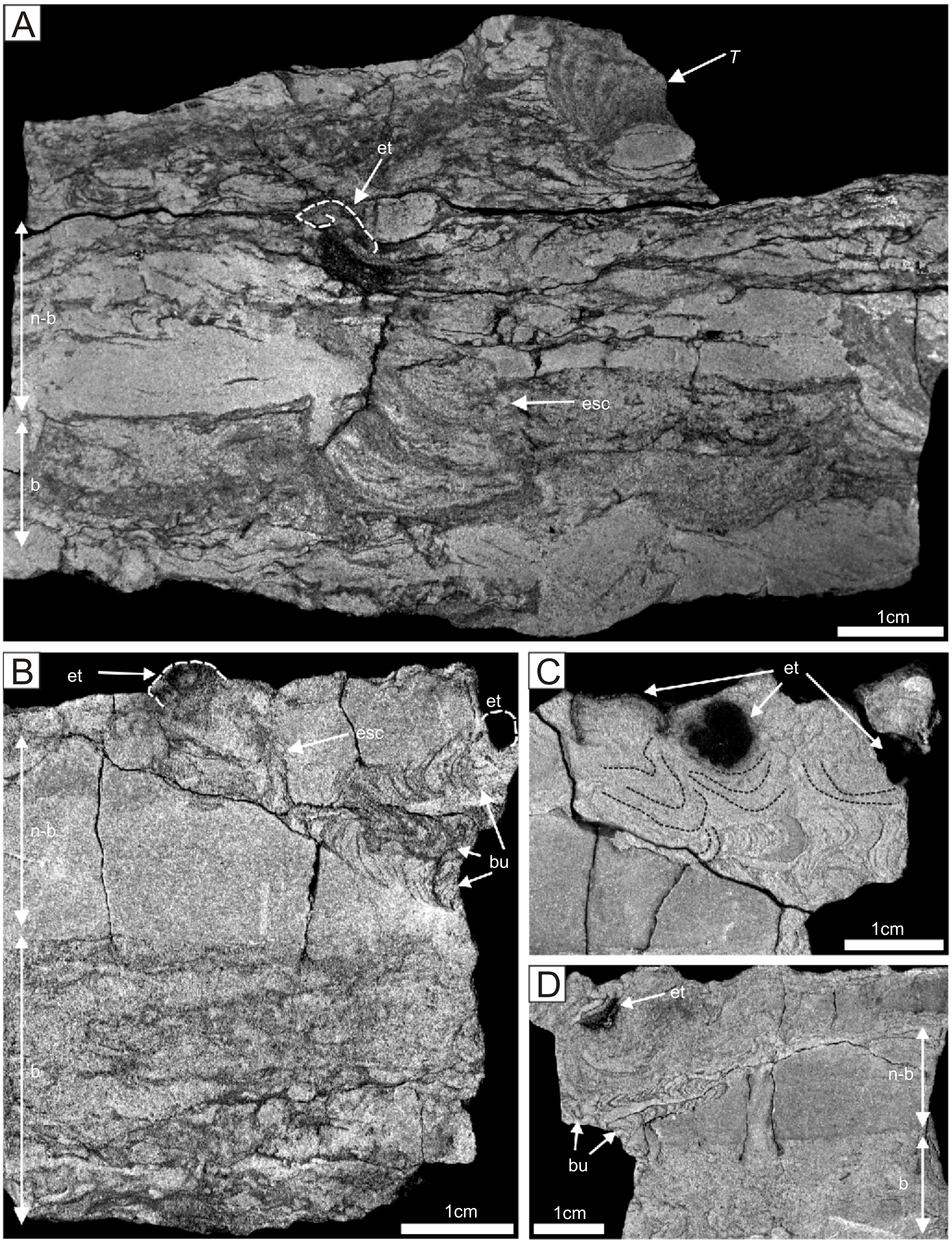

Fig. 4. Vertical section of a thin sandstone bed with trilobite remains and burrows

A – specimen of *Strenuella polonica* (et) with its escape structure; **B**–**D** – views of the same sandstone bed with several specimens of *S. polonica* and their burrows; symbols: n-b – non-bioturbated rock, b – bioturbated, *T* – *Trichophycus* isp., et – enrolled trilobites, esc – escape structures, bu – burrows with sediment reworked in different directions; indistinct spreite-like structures contoured (dotted lines)

terpreted as rapidly buried within mud rocks interbedded with hummocky cross-stratified sandstones (Degan et. al., 1995).

Apart from non-bioturbated beds without trilobite remains, some beds include combined current-wave ripples, which additionally suggests rapid burial of benthic animals by sandy material (e.g., Figs. 5–8). Climbing ripples (Fig. 5A) suggest rapid deposition of material by traction and suspension (Jopling and Walker, 1968; Allen, 1970). Such conditions were possible during storm conditions, when material was supplied from shallower environments (cf. Monaco, 1996).

The presence of casts of dragmarks and wave-ripple cross-lamination combined with an absence of graded bedding is typical of tempestites (e.g., Einsele and Seilacher, 1991; Monaco, 1996).

These structures suggest interpretation at least in part as storm deposits. Additionally, the presence of trilobite scratchmarks such as *Monomorphichnus* in rippled arenites indicates that some trilobites were moved by the currents during high energy episodes and that they tried to catch hold of the bottom. One specimen of *Rusophycus* in the termination of its dragmark (Fig. 6A) is interpreted as the trace of a trilobite which was moved by a current and took refuge in a silty deposit on the bottom. Possibly some of the well-preserved *Rusophycus* described by Stachacz (2012; Figs. 2A–D, 3A, B and 4) from the

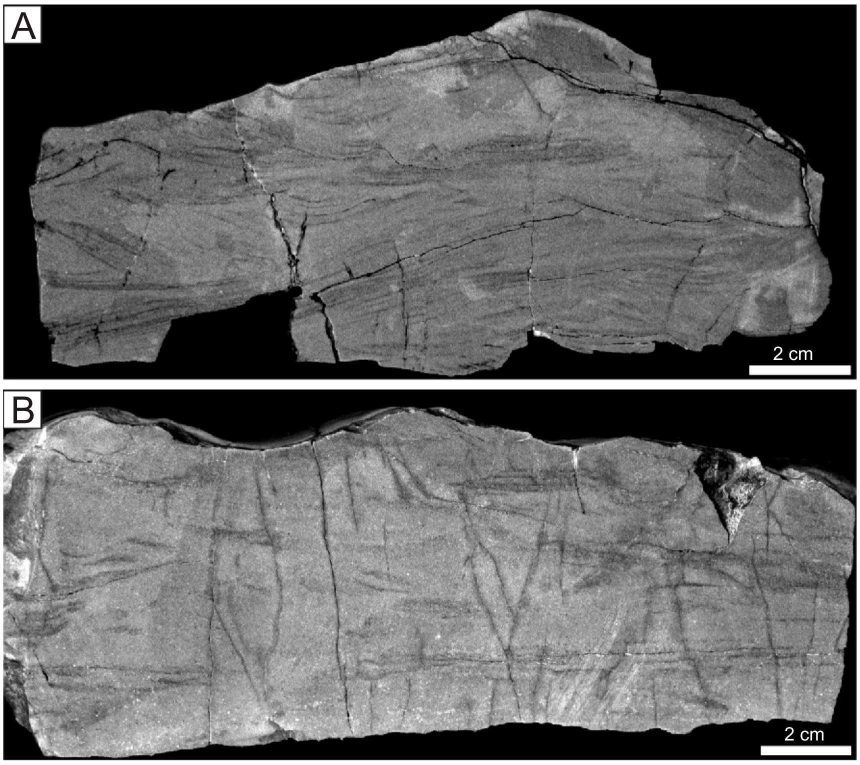

Fig. 5A – climbing ripples and ripple-cross lamination, Sterczyna Quarry; B – wave ripples and ripple-cross lamination, Sterczyna East

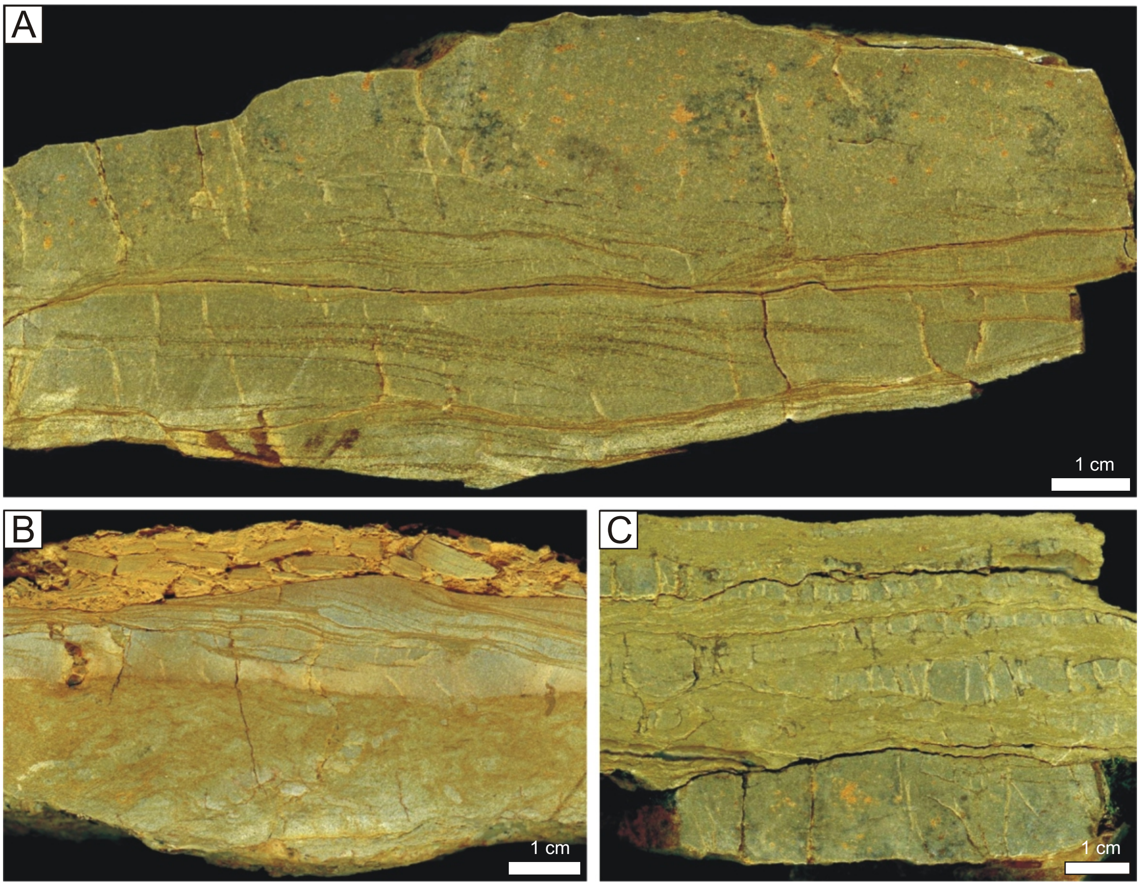

Fig. 6A – fragment of amalgamated bed: bioturbated wacke in the upper part and ripple cross-laminated sandstone in the lower part, Jaźwina; B – amalgamated bed composed of bioturbated wacke in the lower part and ripple-cross laminated sandstone in the upper part, Igrzyczna North; C – amalgamated bed composed of horizontal layers of non-bioturbated quartz arenite and bioturbated wacke, Jaźwina

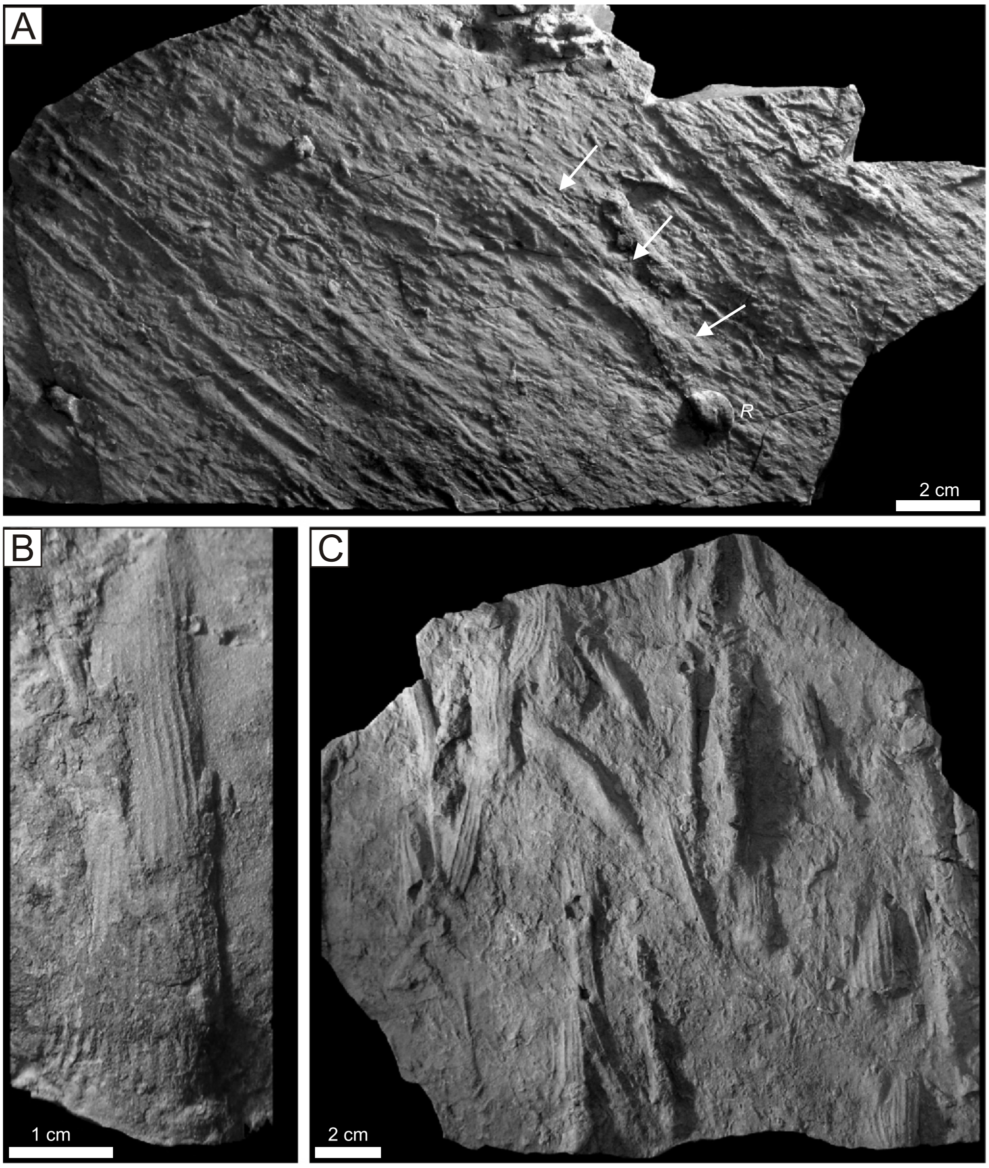

Fig. 7A – casts of dragmarks and deformed *Rusophycus* (*R*) in the termination of a curved trilobite repichnion (arrowed) discordant to the toolmarks, on the sole of a rippled arenite bed, Sterczyna East, INGUJ214PMr29; B – casts of scratchmarks *Monomorphichnus lineatus* Crimes, Legg, Marcos and Arboleya, 1977, hypichnion on the sole of a thin rippled bed of arenite, Sterczyna East, INGUJ214PMr47; C – ?*Monomorphichnus* isp., hypichnia on the sole of a thin rippled bed of arenite, Igrzyczna South, INGUJ214P/IgS9

Ociesęki Sandstone Formation were formed in this mode during the storm. Especially *R. crebrus* (Orłowski, 1992b), the diagnostic features of which are lobes covered by delicate sets of ridges which represent the trace of a trilobite which took refuge and was dragged for a short distance within silty deposits. The sets of ridges represent casts of groovemarks of trilobite exopodites transported by rapidly flowing water. In such case *R. crebrus* should be included in *R. polonicus* Orłowski, Radwański and Roniewicz, 1970 as a taphonomic variant of preservation.

The amalgamated beds composed of thin layers of non-bioturbated arenites and bioturbated wackes (Figs. 4 and 6) represent relics of very thin distal tempestites or tempestites slightly modified by shallow bioturbation (cf. Droser and Bottjer, 1988; Droser et al., 1999).

Very shallow burrowing of the sediments during the Cambrian (see Droser, 1991; Droser et al., 1994) suggests that the tempestites were only slightly thicker than the preserved storm-layers and usually less than 5 cm thick. Only *Teichichnus* or *Trichophycus* producers penetrated the complete tempestite. Horizontal domichnia such as *Monocraterion* are relatively rare in this environment. The preservation of very thin tempestites was controlled by frequent storms which determined whether the deposit feeders were able to survive or were buried (cf. Pemberton et al., 2001).

Such shallow trace fossils in tempestites are typical of the Early Paleozoic. During this time, in environments deeper than the *Skolithos* ichnofacies, the only sediment-reworkers were worm-like organisms (Sepkoski, 1978, 1979; Droser, 1991;

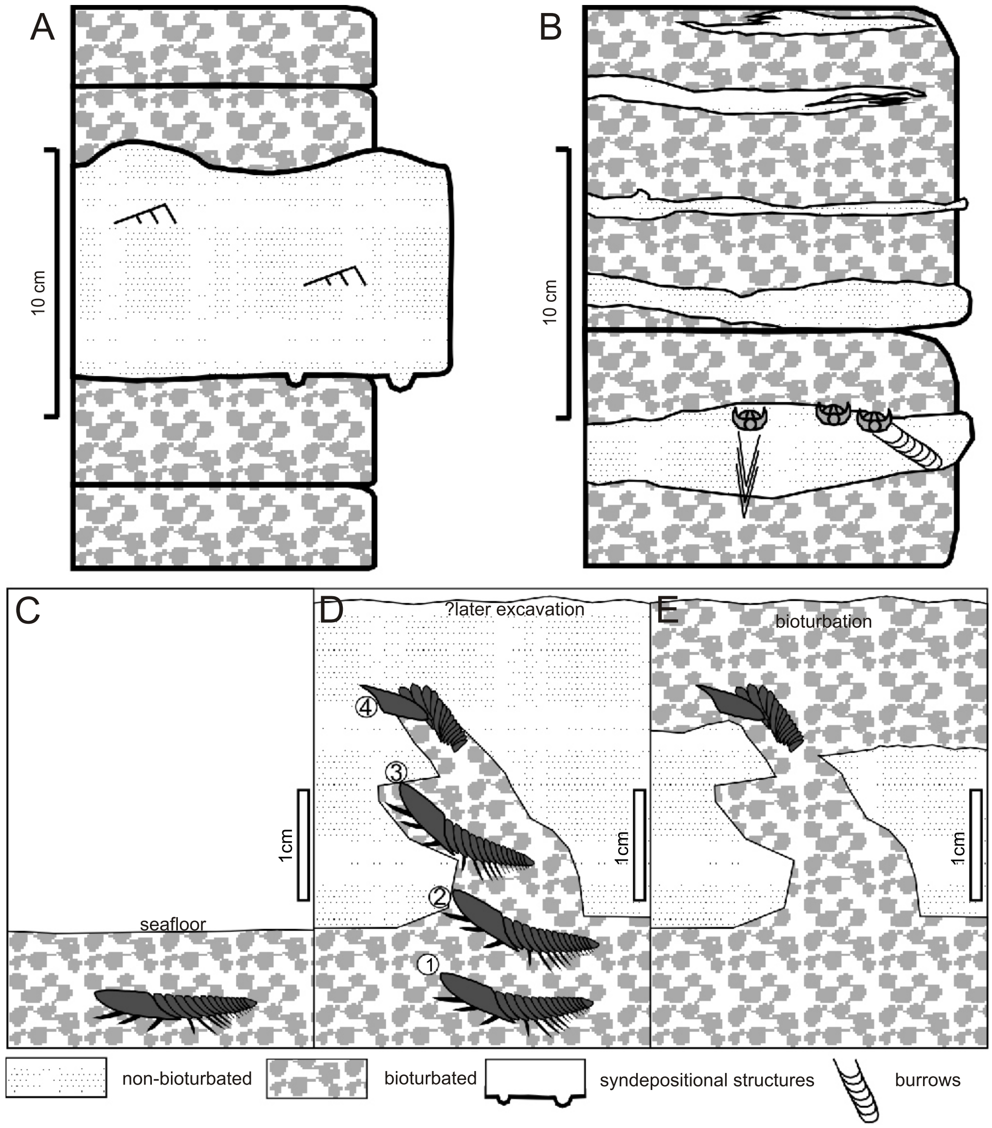

Fig. 8. Tempestite beds from the Ocieseki Range

A – schematic section with isolated, non-bioturbated tempestite bed with ripple cross-lamination and ripples within bioturbated greywacke beds; **B** – variable preservation of relict tempestites including a bed with enrolled trilobites and their escape structures and burrows; **C**–**E** – reconstruction of the formation of a trilobite escape structure; 1–4: stages of escape of the trilobites towards the surface of the sediment; other explanations as in Figure 2

Droser et al., 1994), probably mostly priapuloids (Vannier et al., 2010). Deeper-reaching burrowing only took place in middle shoreface and shallower environments during the Early Paleozoic (Droser, 1991; Droser et al., 1994). Recolonization of the seafloor was possible after a storm during phases with low water energy. Between storm episodes, a low sediment accumulation rate allowed reworking, which usually led to homogenization by intense burrowing. Therefore, storms were a strongly restrictive factor that controlled the presence or absence of benthic life and bioturbation on the shoreface (e.g., Reinson, 1984; Pemberton et al., 2001).

The dominant strongly bioturbated sandy and silty material (wacke and quartz arenite with silty intercalations) and distinct tempestites isolated by more silty intercalations indicate a depositional environment between the normal and storm wave bases (e.g., Reinson, 1984; Pemberton et al., 2001). Trace fossil assemblages typical of a proximal *Cruziana* ichnofacies (*sensu* Pemberton et al., 2001) also suggest an environment influenced by wave action (Pemberton et al., 2001).

The ichnological and sedimentological features, including dominance by sandstones with wave ripples and burrowed silty sandstones of this part of the Ocieseki Sandstone Formation, strongly suggest that this part has been deposited on a lower shoreface which corresponds to proximal *Cruziana* ichnofacies. The depth of deposition suggests an interval between normal and storm wave base (Pemberton et al., 2001 and references cited therein). However, the total thickness of the Ocieseki Sandstone Formation exceeds 2500 m and its upper part was possibly deposited in a different environment.

CONCLUSIONS

The Ocieseki Sandstone Formation of the Sterczyna section is dominated by bioturbated quartz arenites and wackes in which, in some beds, enrolled trilobites occur.

Some enrolled trilobites are visible at the ends of their escape structures or burrows. These are interpreted as tempestites and suggest that the trilobites were buried by sediment which resulted in trilobite death probably by suffocation.

The isolated non-bioturbated beds of quartz arenites, usually contain combined current-wave ripples, casts of dragmarks and syndepositional trace fossils.

The presence of ripple cross-lamination and wave-ripples in isolated beds is typical of tempestites. Domination of bioturbated sandy to silty material and the scattered distribution of tempestites points to deposition between normal and storm wave bases.

Some of the *Monomorphichnus* and *Rusophycus* were formed during storms, when animals tried to catch the hold of the bottom.

Sedimentological and ichnological features of the lower part of the Ocieseki Sandstone Formation suggest that this part was deposited on a lower shoreface.

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