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Cambrian Series 2 shallow marine siliciclastics at the margin of the East European Craton: the Ocieseki Formation in Dziewiątle Quarry (Holy Cross Mountains, Poland)

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ABSTRACT:

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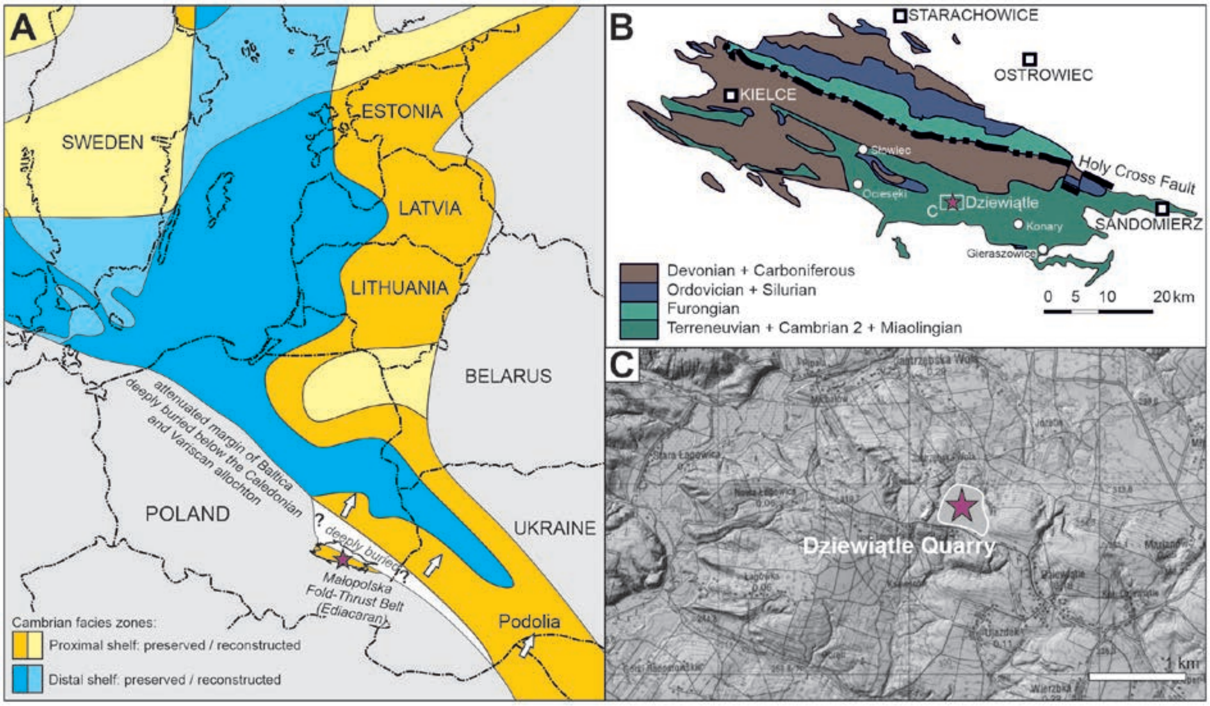
The Cambrian rocks of the Palaeozoic inlier of the Holy Cross Mountains (HCM) in Poland offer a unique window into the sedimentary record on the margin of the Baltica palaeocontinent. The sedimentary features and ichnofossils in the upper part of the Cambrian Ocieseki Formation, which is a siliciclastic shallowing-upward succession exposed in the newly established Dziewiątle Quarry located in the southern HCM, reflect evolution of the depositional environment from offshore to middle, and even upper, shoreface. The age of the succession is constrained by 1) acritarch assemblages suggestive of the Cambrian Series 2 *Volkovia–Liepaina* Zone in the underlying rocks, and 2) the directly overlying strata representing the Cambrian Series 2-Miaolingian boundary interval. A major erosional disconformity observed in the quarry is interpreted as a 1st order sequence boundary that can be correlated with the base of the När Lowstand in Scandinavia. An exceptionally thick (7 m!) interval of hummocky and swaley cross-stratified sandstones indicates storm deposition during transgressive conditions in the aftermath of that event.

Key words: Cambrian Series 2; Holy Cross Mountains; Hummocky cross-stratification (HCS); Siliciclastic deposits; Ocieseki Formation; Acritarcha; Offshore/shoreface transition.

INTRODUCTION

During the breakup of Rodinia, the Cryogenian to Ediacaran opening of the Iapetus and Tornquist oceans created two passive margins of the Baltica palaeocontinent (Cocks and Torsvik 2005; Żelaźniewicz *et al.* 2020). While the sedimentary succession of the Iapetus shelf of Baltica is well documented in the Caledonian foreland and the Scandinavian nappes (e.g., Gee *et al.* 2017), the Tornquist margin in its southern part (= Trans-European Suture Zone, TESZ) is mostly buried below the Caledonian and Variscan orogens thrust over the attenuated craton margin (for review see Narkiewicz and Petecki 2017) with the exception of the small inlier of the Holy Cross Mountains (HCM) in Central Poland.

The shelves of Baltica located in the high latitudes of the southern hemisphere during the Cambrian were dominated by siliciclastic deposits, traditionally regarded as sourced from the Archean–Proterozoic



Text-fig. 1. Location of Dziewiątle Quarry (violet star) with regard to: A – Palaeogeography and general facies distribution during the late part of Cambrian Stage 2 in the SW part of Baltica; based on Rozanov and Łydka (1987), Nielsen and Schovsbo (2011), Stadnik *et al.* (2019, fig. 8), and Wendorff (2019); white arrows point to transport directions, those for Podolia (Ukraine) are according to Paszkowski *et al.* (2021); B – Generalized geological map of the Palaeozoic inlier of the Holy Cross Mountains (after Czarnocki 1957), and C – LiDAR map, background map downloaded from https://mapy.geoportal.gov.pl accessed on 19.04.2024.

continent interior. This source is interpreted as having existed in the NW part of Baltica (Lorentzen *et al.* 2018), whereas for the remaining part of the palaeocontinent, numerous studies have pointed out the important role of younger (Neoproterozoic) orogens surrounding Baltica to the north-east, east, south, and south-west (present-day coordinates) for the supply of clastic material (e.g., Valverde-Vaquero *et al.* 2000; Isozaki *et al.* 2014; Paszkowski *et al.* 2021).

One of the areas located in the most external part of the TESZ margin of Baltica is the Małopolska Block (= Ediacaran Małopolska Fold-Thrust Belt in Text-fig. 1A). Its sedimentary cover is exposed in the Kielce Region of the HCM, and its pivotal and thickest Cambrian component (c. 1200 m; e.g., Mizerski *et al.* 1986; Orłowski 1988) comprises the Ociesęki Sandstone Formation representing most of the Cambrian exposure in the southern HCM (Text-fig. 1B). This unit is characterised by its large thickness, scattered finds of shallow-marine body fossils (mostly trilobites; see Żylińska 2013 and references therein), and omnipresent trace fossils (Orłowski *et al.* 1970; Paczeŝna 1985; Orłowski 1989, 1992; Orłowski and Żylińska 2002; Stachacz 2010, 2012, 2013, 2016). Understanding its position at the margin of the Baltica palaeocontinent is of profound importance, and this can be achieved by an improved interpretation of the facies succession and analysis of the evolution of the Cambrian sedimentary environments in the HCM in the context of recent palaeogeographic interpretations (e.g., Paszkowski *et al.* 2021).

Despite the large thickness of the Cambrian succession in the HCM inferred from geological mapping, there have never been any large artificial exposures of Cambrian strata that would enable the performing of detailed sedimentological analyses. Therefore, knowledge of the Cambrian sedimentary environment in the Kielce Region was meagre so far, being based on scattered observations in small exposures (e.g., Mizerski *et al.* 1986, 1999; Studencki 1988; Stachacz 2010, 2013, 2016). Fortunately, a new, large quarry in Cambrian rocks was established in 2011 in the eastern part of the Kielce Region (Text-fig. 1B, C). This quarry face exposes over 50 m of the Ociesęki Sandstone Formation and thus, for the first time, enables a detailed insight into a representative fragment of the facies succession and ichnofossil assemblages.

The aim of this study is to describe the facies succession and interpret the sedimentary environments in the upper part of the Ocieseki Formation. An attempt is also made to bracket the age of the exposed succession as accurately as possible. Despite careful search, no trilobites have been found in the quarry, and the age determinations have had to be based on analysis of acritarch assemblages coupled with lithostratigraphic relations to the adjacent units. The large scale of the exposure provides a perfect opportunity for a discussion on the sedimentary environment of this part of the Ocieseki Formation, as well as its correlation with local units and sequence stratigraphic schemes (Pacześna and Poprawa 2005; Nielsen and Schovsbo 2011, 2015; Wendorff 2019). A more precise identification of Cambrian sedimentary environments in the HCM makes for an improved understanding of the palaeogeography in the marginal part of Baltica (Jaworowski 2000; Stadnik *et al.* 2019; Wendorff 2019; Paszkowski *et al.* 2021).

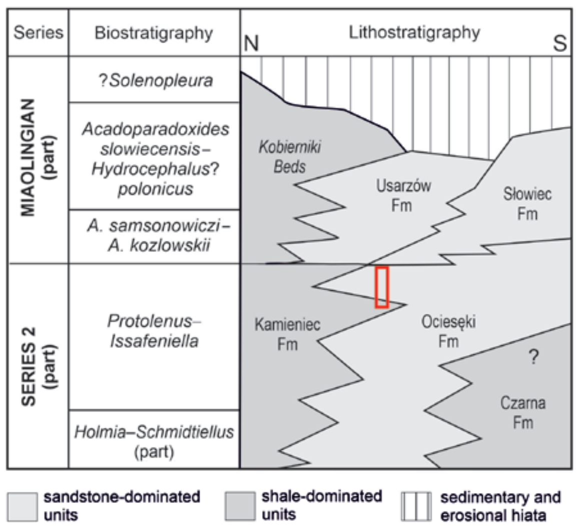
Our inspiration was study of the Lower Devonian siliciclastic succession exposed in Bukowa Góra Quarry in the northern HCM, a topic pursued by Michał Szulczewski, to whom this issue of *Acta Geologica Polonica* is devoted (Szulczewski 1996; Szulczewski and Porębski 2008).

GEOLOGICAL SETTING

The Cambrian succession of the HCM is exposed within the Palaeozoic inlier surrounded by Mesozoic strata present to the north, west and south-west, and Cenozoic rocks to the south and south-east (for overview see Żylińska 2023). This area was part of the Mid-Polish Trough, a major Mesozoic sedimentary basin, which was inverted to form the Mid-Polish Anticlinorium prior to the Cenozoic; this resulted in the erosion of a thick overburden of Mesozoic strata and exhumation of Palaeozoic rocks. Traditionally, the Palaeozoic inlier is sub-divided into the Kielce (southern) and the Łysogóry (northern) regions, based on the differing successions and the position of the major stratigraphic hiatuses and angular unconformities (e.g., Żylińska 2023; Konon and Kozłowski in press). Two separate Cambrian successions are present: a lower but not lowermost Terreneuvian to mid-Miaolingian in the Kielce Region, and an uppermost Miaolingian and the Furongian in the Łysogóry Region (e.g., Kowalczewski *et al.* 2006). In the Kielce Region, the Cambrian probably rests unconformably (Kowalczewski 1990, fig. 4) on a thick pile of folded and thrust Ediacaran (Compston *et al.* 1995) siliciclastic rocks of the Małopolska Fold-Thrust Belt and is unconformably overlain by the upper Furongian (only in the Lenarczyce IG-1 well; Szczepanik *et al.* 2004; Trela *et al.* submitted) and/or Tremadocian strata (Czarnocki 1939). In turn, the Cambrian in Łysogóry is conformably overlain by an undisturbed succession of Ordovician to Devonian rocks (Czarnocki 1950; Kozłowski 2008). The Kielce Cambrian was deformed during at least four diastrophic events, i.e., Sandomirian (Samsonowicz 1934; Czarnocki 1939), Caledonian (Bednarczyk *et al.* 1966, fig. 4), Variscan and Alpine (Lamarche *et al.* 1999), whereas the Cambrian in Łysogóry (i.e., upper Miaolingian and Furongian) was deformed only during the latter two events. Hence, both successions are often regarded as representing two independent basins, or two parts of one basin, but with different tectonic evolution (see e.g., Szulczewski 1995; Narkiewicz 2002; Nawrocki *et al.* 2007).

The Cambrian succession of the HCM comprises thick siliciclastic and clayey deposits (in total up to 2.5–3.5 km) that are subdivided into a series of lithostratigraphic units (Orłowski 1975b, 1988; Kowalczewski *et al.* 2006; Text-fig. 2). Most units have a relatively good biostratigraphic documentation based on trilobites and/or acritarchs (see overview in Szczepanik and Żylińska 2016).

The Ocieseki Formation, the main focus of this research, contains relatively rich but patchily distributed trilobite assemblages, which have been extensively



Text-fig. 2. Lithostratigraphic scheme of the Cambrian in the Kielce Region of the Holy Cross Mountains, after Żylińska and Szczepanik (2009), modified and updated. Red rectangle shows the part of the succession exposed in Dziewiątle Quarry.

studied since the early 20th century (Samsonowicz 1918, 1920, 1959a, b, c; Czarnocki 1919, 1926, 1927, 1933; Orłowski 1974, 1975a, 1985; Żylińska and Szczepanik 2009; Żylińska 2013). This stratigraphically long-ranging unit (from Cambrian Series 2 to the lowermost Miaolingian; e.g., Mizerski *et al.* 1986; Żylińska and Szczepanik 2009) is furthermore characterised by its extremely rich ichnofossil assemblages (Orłowski *et al.* 1970; Orłowski 1989, 1992; Orłowski and Żylińska 2002; Stachacz 2010, 2012, 2013, 2016). The Cambrian Series 2 trilobite record shows Baltic affinities (the holmiids *Holmia* spp., *Kjerulfia* spp. and *Schmidtiellus* spp. in the lower part; Żylińska 2013) but with a distinct endemism at species level, and a locally high to dominant Avalonian–Gondwanan admixture (diverse ellipsocephalids in the upper part; Żylińska and Szczepanik 2009; Żylińska 2013). The biogeographically assumed peri-Baltic position of the HCM during the Cambrian is consistent with the clastic-dominated facies and palaeomagnetic data (cf. Nawrocki *et al.* 2007).

MATERIAL AND METHODS

The studied rocks of the Ociesęki Sandstone Formation are exposed in the active Dziewiątle [IPA[1]: ʥ͡εv’jOtle] Quarry located near Iwaniska (50º42’20.2”N 21º11’24.4”E; Text-fig. 1B, C) in the south-eastern part of the HCM, c. 2 km east of the Łagowica River valley. The quarry was established in 2011 within the western part of the W-E-oriented Wygiełzów Range (highest elevation at 385 m a.s.l.), which is bounded by the Łagowica River to the west and the Koprzywianka River to the east. Despite being folded at least four times (see above), the Cambrian strata in the quarry display a very gently inclined synclinal structure (Text-fig. 3), which may be explained by their being situated in the axis of the Wygiełzów Syncline, an eastwards-continuing Variscan fold (Mizerski and Orłowski 1993; Orłowski and Mizerski 1995; Konon 2007).

Field observations were made in the quarry between 2014–2024. In the early years, when only a very thin (≈10 m) succession was exposed, the field activities were aimed at collecting trace fossils, searching for body fossils, and taking samples of siltstone-claystone intercalations within the sandstone complex for palynologic analysis (e.g., Cybulska 2017; Kozłowski *et al.* 2017; ZS unpublished data). Unfortunately, no body fossils have been recovered so far, and all three samples collected at that time for palynologic analysis were almost completely barren, with fragments of carbonised organic matter, probably of microbial or algal origin, preserved in only one sample (Cybulska 2017; ZS unpublished data). The lithofacies exposed at that time was monotonous, although its high ichnofossil content and prevailing lithology (sandstones with minor siltstone interbeds) allowed for assignment to the Ociesęki Formation (e.g., Cybulska 2017; Kozłowski *et al.* 2017).

More detailed measurements became possible in 2022–2023 when intense quarrying exposed over 50 m of the Cambrian succession. Observations included lithology, sedimentary structures, and basic recognition of ichnofossils (a more detailed analysis of the ichnofossils will be the subject of a separate contribution). These data have been used in the sedimentological analysis to distinguish and interpret the facies associations. Measurements were made on six subsections (I–VI in Text-fig. 3), which were subsequently combined into a composite lithological log (Text-fig. 4). Additionally, three palynologic samples were collected from the dark grey facies exposed in the northern part of the quarry floor (complex A in Text-fig. 3A, B). They were subject to classical palynologic maceration techniques (see e.g., Szczepanik and Żylińska 2016, 2021 for methodology). The palynologic slides are stored in the Holy Cross Branch of the Polish Geological Institute-National Research Institute in Kielce.

[1] International Phonetic Alphabet

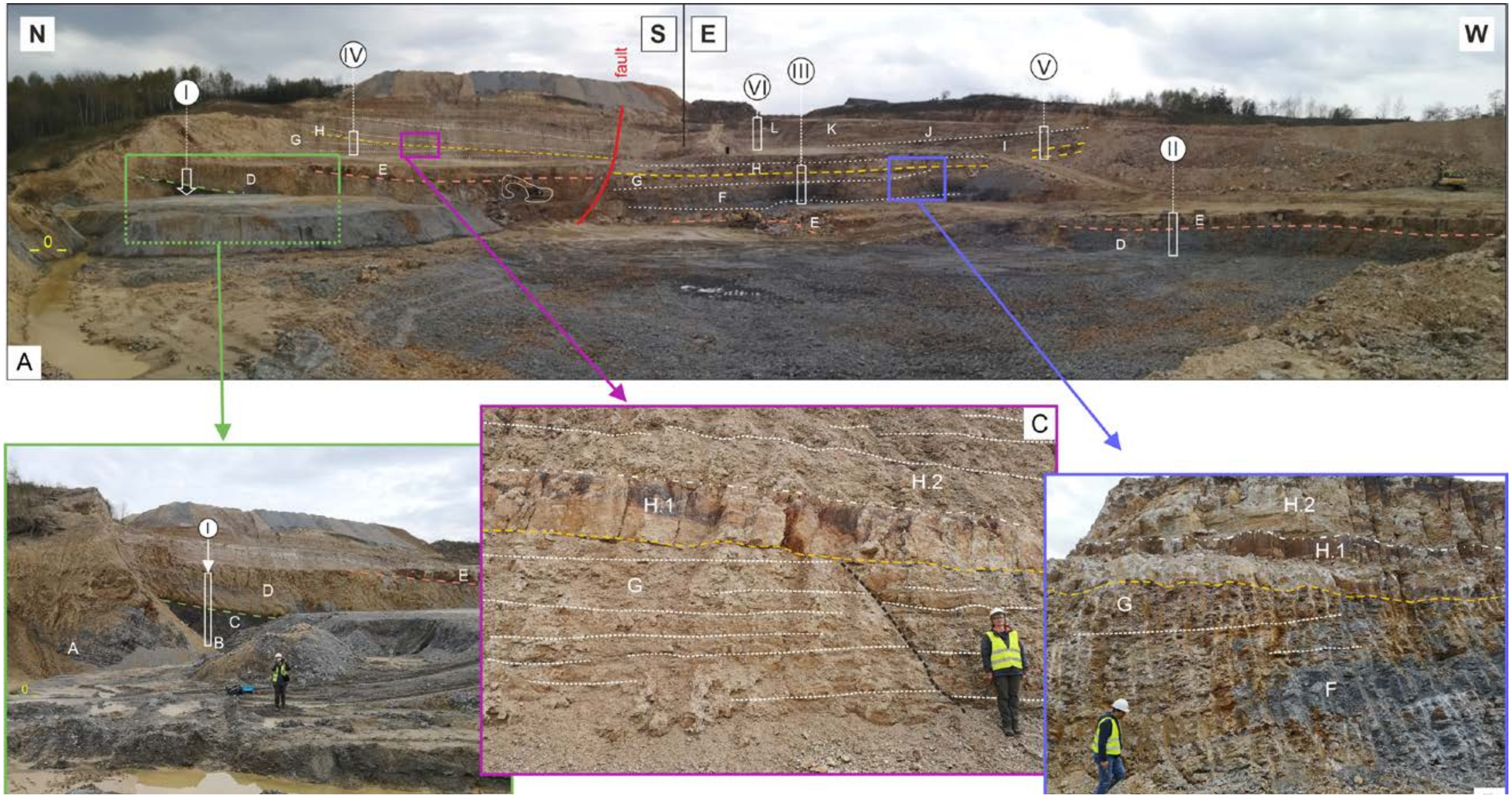
SEDIMENTOLOGY

Lithofacies Association 1

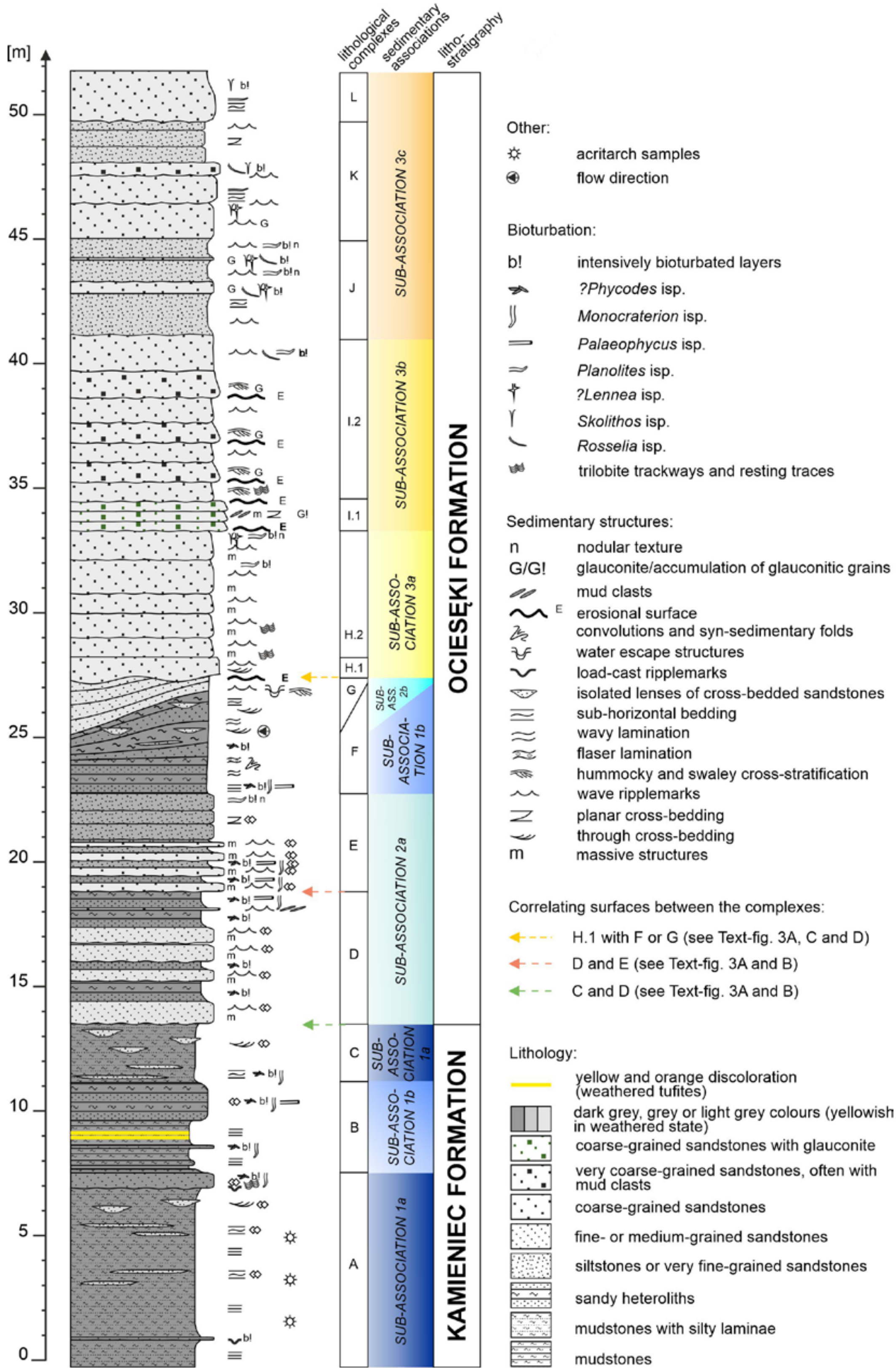
Association 1 is mainly represented by dark grey and grey fine-grained rhythmites, present in subsection I in the northern part of quarry, in subsection II within the lowermost floor of the quarry in its western part, and in subsection III in the southern wall of the quarry (Text-fig. 3A, B). In the dark muddy deposits subtle differences are recognisable between complexes A and C *vs*. B and F; a higher content of silty-sandy material and different sedimentary structures are clearly visible in complexes B and F. These differences were the basis for distinguishing parts ‘a’ (with complexes A and C) and ‘b’ (with complexes B and F) of association 1.

Sub-association 1a

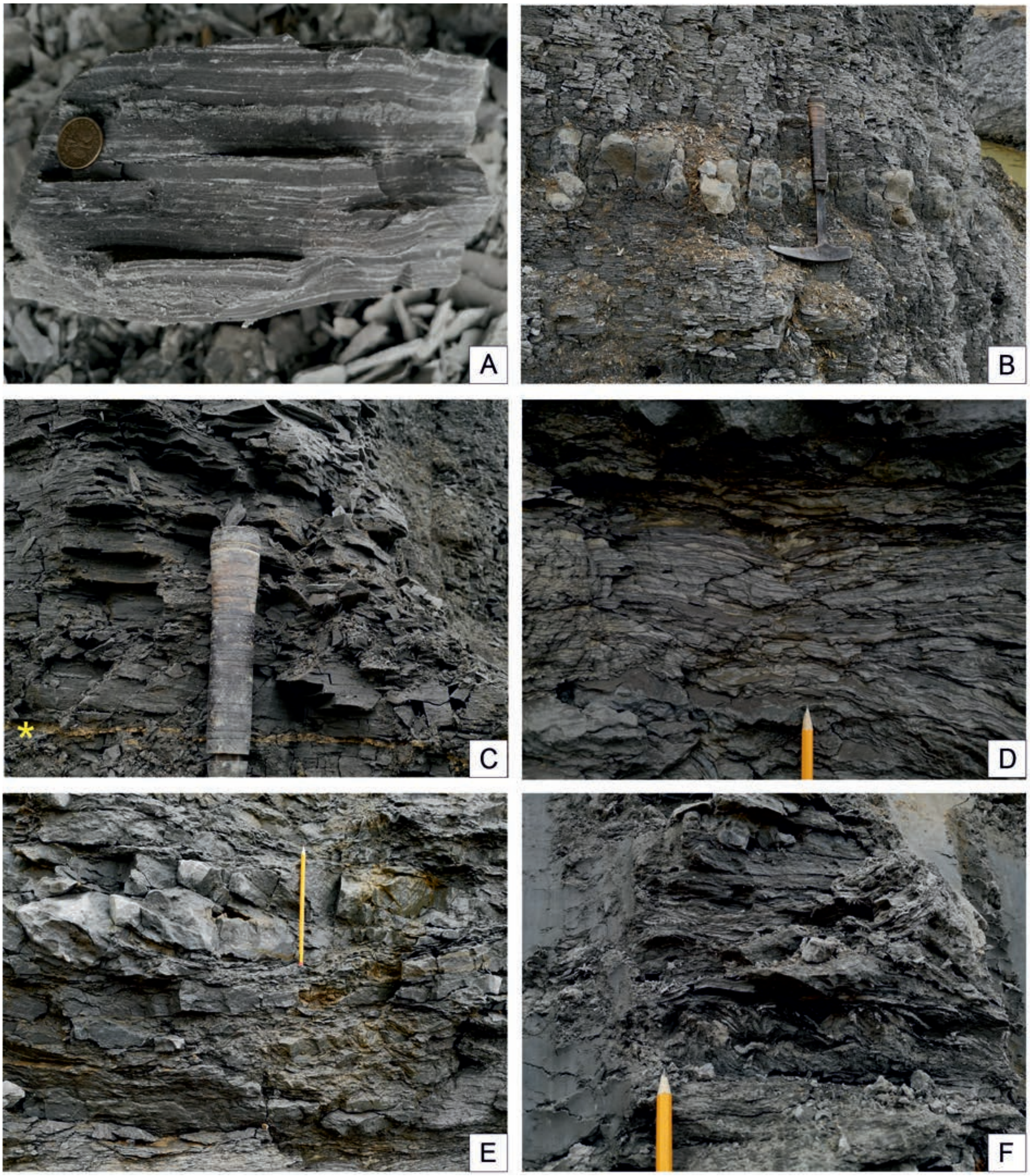
In the lower part of association 1 (complexes A and C; Text-figs 3 and 4), sub-association 1a is domi-



Text-fig. 3. Geometry of lithological complexes exposed in Dziewiątle Quarry. A – General view of the quarry with marker sand beds used for correlation (highlighted by colour dashed lines), general bedding (marked by white dotted lines), and the measured subsections I–VI (in stratigraphic order; marked with white rectangles); 0 marks the base on the composite sedimentological log (Text-fig. 4); B – Close-up of subsection I showing the geometry of complex A and complex B observed in the eastern quarry wall, 0 marks the base on the composite sedimentological log (Text-fig. 4); C – Disconformity in the base of complex H.1 (between complexes G and H.1; yellow dashed line) at the 27 m mark of the composite log in Text-fig. 4; white dashdotted line marks the contact between complexes H.1 and H.2; D – Disconformity (yellow dashed line) in the base of complex H.1 (between complexes G and H.1 in the left side of the photograph, and between complexes F and H.1 in the right side of the photograph); white dashdotted line marks the contact between complexes H.1 and H.2.

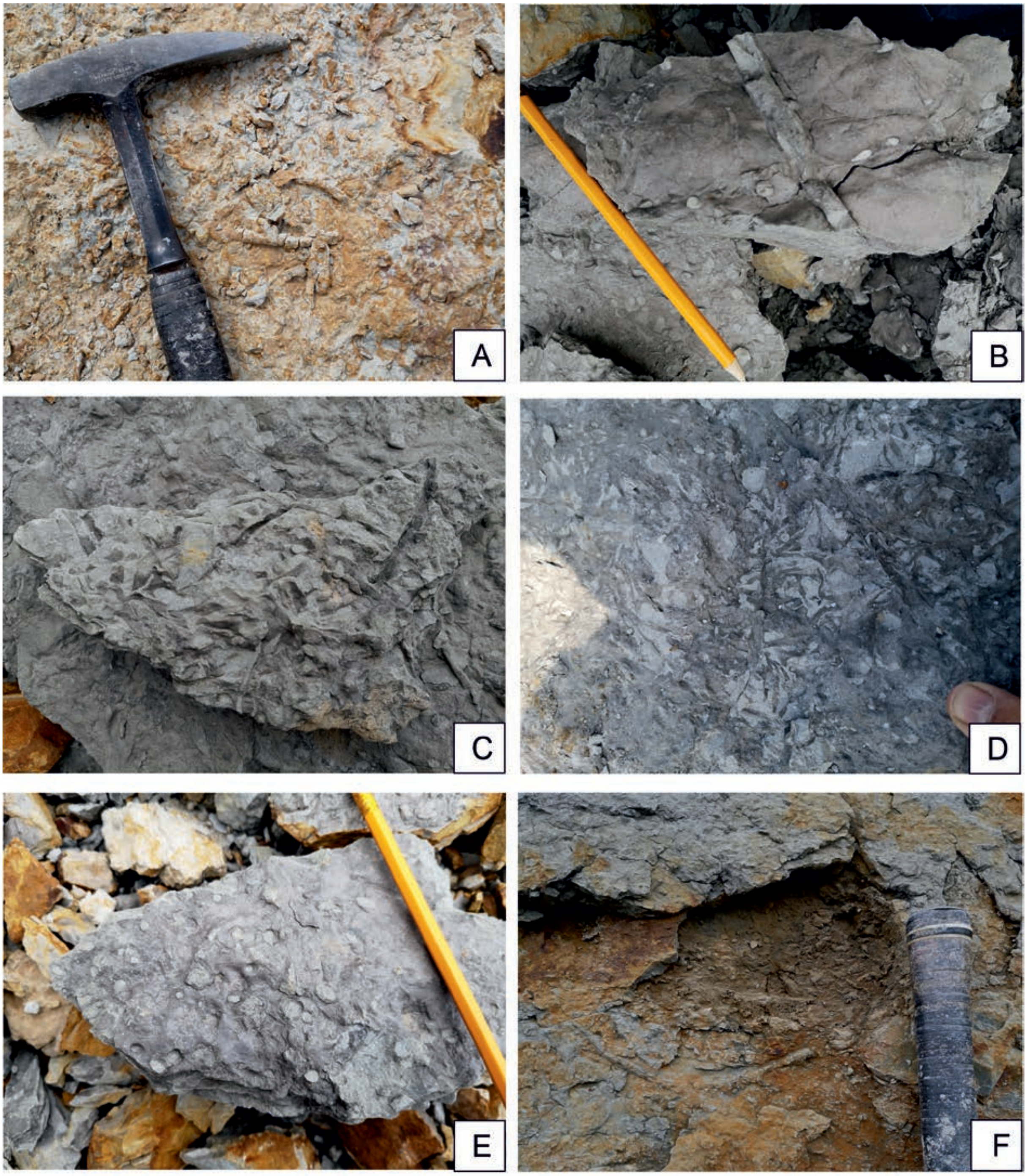


Text-fig. 4. Composite sedimentological log of Cambrian strata exposed in Dziewiątle Quarry, composed on the basis of observations of lithology, sedimentary structures and ichnofossils, and documented in subsections I–VI.



Text-fig. 5. Sedimentological features of offshore deposits exposed in Dziewiątle Quarry. A – Dark grey horizontally laminated silty mudstones of complex A (sub-association 1a) with intercalations of bioturbated sandy beds; B – Discrete irregular thin laminae of silt in the horizontally laminated mudstones of complex A (sub-association 1a); C – Dark grey horizontally laminated mudstones of complex B (sub-association 1b); yellow star indicates yellow tuffite lamina; D – Grey heteroliths of complex F (sub-association 1b) with flaser and wavy lamination; pencil points to post-depositional convolutions; E – Grey heteroliths of complex F (sub-association 1b) with cross-bedded sandy lenses (length of pencil 18 cm); F – Convoluted beds of grey heteroliths of complex F (sub-association 1b).

nated by mudstones with thin silty laminae with horizontal or sub-horizontal lamination (Text-fig. 5A). Upwards, the thin, millimetre-thick siltstone laminae become thicker, reaching up to several centimetres.



Text-fig. 6. Examples of ichnofossils from the middle shoreface (A), lower shoreface (B–E) and offshore (F) deposits of Dziewiątle Quarry. A – *Planolites* isp. (sub-association 3a, complex H.2); B – *Palaeophycus* isp. (sub-association 2a, complex E); C, D – ?*Phycodes* isp. (sub-association 2a, complex D); E – *Monocraterion* isp. (sub-association 2a, complex E); F – ?*Syringomorpha* isp. (sub-association 1b, complex B).

Towards the top, the increase in thickness is coupled with coarsening of grain size in the silty-sandy layers. Only the sandy and silty deposits are intensively bioturbated (Text-fig. 5B), and the abundance of trace fossils results in characteristic weathered layers with a nodular texture (thin layers in complexes A and C, see Text-fig. 4). Sandy lenses with cross-bedding were noted in the topmost part of complex A and in the entire complex C (Text-fig. 4).

Sub-association 1a is characterised by a poverty of trace fossils. Only a few thin silty layers in complexes A and C, and the topmost sandy bed of complex C, are intensively bioturbated. A high frequency of ?*Phycodes* isp. and *Monocraterion* isp. was documented. Sporadically trilobite/arthropod trace fossils were also noted, represented mainly by *Cruziana* isp.

Sub-association 1b

This sub-association is composed mainly of mixed, muddy-sandy deposits of complexes B and F (Text-fig. 4). In the lowermost part (complex B) the sandy-silty material appears in the form of thin layers. Toward the top of sub-association 1b, coarser, sandy material dominates. Silty-muddy heteroliths with sub-horizontal and flaser lamination were observed in the upper part of sub-association 1b (complex F; Text-figs 4 and 5D). The heterolithic beds (complex F; Text-fig. 5D, E) contain post-depositional convolutions and load-cast ripple marks (Text-fig. 5F). Syn-sedimentary small-scale faults and folds were also observed in the heterolithic succession. Two very thin tuffite layers were recognised in complex B (Text-figs 4 and 5C).

Sub-association 1b is characterised by a moderately diversified suite of ichnofossils, generally comprising repichnia and domichnia, with subordinate cubichnia. The heterolithic beds usually contain horizontal traces, such as *Planolites* isp. and *Palaeophycus* isp., which were probably produced by worm-like organisms. The coarser, mainly silty and subordinately heterolithic beds are dominated by ?*Phycodes* isp. Their abundance coupled with *Planolites* isp. results in characteristic nodular beds in the silty/heterolithic deposits. Vertical burrows assigned to *Monocraterion* isp. were observed only in the silty/heterolithic beds. Trace fossils attributed to ?*Syringomorpha* isp. were also noted (Text-fig. 6F). The general frequency of the bioturbated beds is low and restricted mainly to the heterolithic beds.

Interpretation

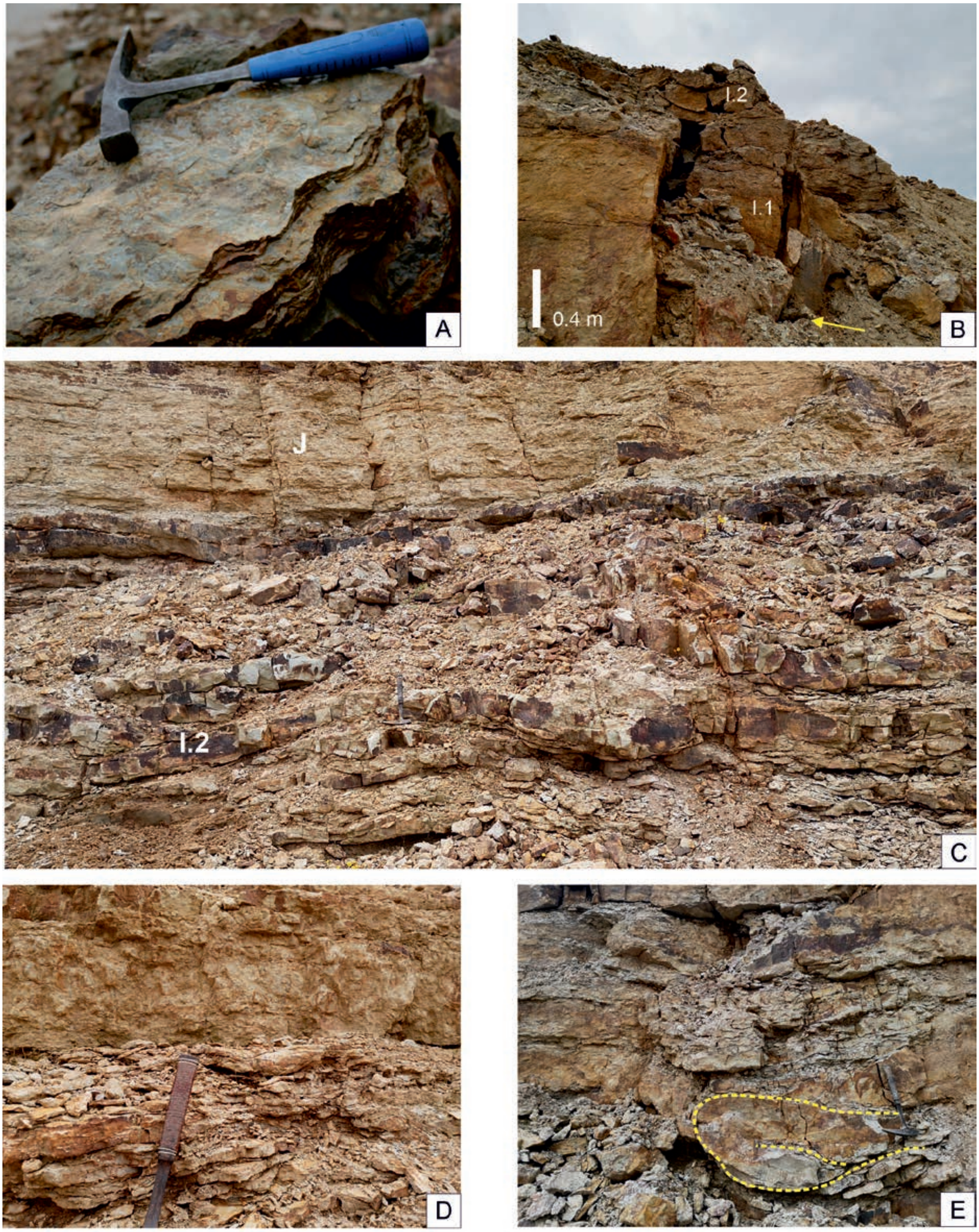
Lithofacies association 1 documents deposition from suspension in an offshore environment, below the storm wave base, in a relatively low-energy setting. Similar silty deposits appearing in the muddy succession as irregular, thin laminae (rhythmites) can be interpreted as typical distal tempestite deposits as in the model by Dott and Bourgeois (1982, p. 677). The silty laminae in the mudstones of sub-association 1a, in the lower part only a few millimetres thick, become thicker, coarser, more regular and more intensively bioturbated upwards (see complexes B and F in Text-fig. 4). This testifies to the increasing proximity of storm processes and reflects a gradual transition from a deeper to a shallower, higher energy part of the shore environment. A vertical pattern of lithofacies similar to association 1 is characteristic of offshore to shoreface conditions (see Boyd *et al.* 1992). Proximity to the coastal zone and therefore a higher terrigenous supply also suggests a higher sedimentation rate. This could be responsible for the occurrence of the heterolithic facies in sub-association 1b. Numerous post-depositional structures, as well as load-cast ripple marks, convolutions, syn-sedimentary folds and faults confirm deposition influenced by an increasing sedimentation rate. The ichnofossil assemblage recognised in sub-association 1b is characteristic of the offshore/shoreface transition, similar to the *Cruziana* ichnofacies as defined by Seilacher (1967). Following the detailed description by Pemberton *et al.* (2012) of the relation between the sedimentary setting and ichnofossil suites, and taking into account the lithology and sedimentary structures of the described deposits, the assemblage of horizontal traces of sub-association 1b may be considered as typical of the upper offshore environment. Most of the traces, as well as *Cruziana* isp., *Planolites* isp. and *Palaeophycus* isp. are produced only by opportunistic deposit and carnivore feeders. On the other hand, the occurrence of intensively bioturbated silty/heterolithic beds with ?*Phycodes* isp., indicates better oxygenated conditions in a setting inhabited by organisms that could penetrate the sea bed deeper. Moreover, the common *Phycodes* isp. in Palaeozoic rocks has been documented mainly in offshore to lower shoreface successions (Hanken *et al.* 2016).

Lithofacies Association 2

Detailed documentation of the lithology and sedimentary structures of association 2 was prepared in subsections II, III and IV (Text-fig. 3A, C and D). This association is mainly composed of cyclic sandy-heterolithic or sandy-silty successions (complexes D, E and G in Text-fig. 4). Two sub-associations, referred to as 2a (complexes D and E) and 2b (complex G) are recognised.

Sub-association 2a

Each cycle observed in complexes D and E comprises medium- or fine-grained sandstones with massive structure and minor-scale but distinct erosional



Text-fig. 7. Sedimentological features of lower shoreface (A) and middle shoreface (B–E) deposits of Dziewiątle Quarry. A – Sandstones with symmetrical ripple marks of complex E (sub-association 2a); B – Massive sandstones of complex I.1 (sub-association 3b) and sandstones with HCS of complex I.2 (sub-association 3b); yellow arrow marks the basal erosional surface of complex I.1; C – Sandstones with HCS of complex I.2 (sub-association 3b), gradually passing into sandstones with wave ripple marks, overlain by silty sandstones with wave ripple marks of complex J (sub-association 3c); D – Sandy beds with small scale wave ripple marks of complex J (sub-association 3c); E – Syn-sedimentary fold in sandstones with HCS of complex I.2 (sub-association 3b).

surfaces at the base. The massive sandy beds are 0.15 to 1.0 m thick. Toward the top of the cycles, the massive beds pass gradually into micaceous and very fine-grained sandstones or siltstones with small- and medium-scale symmetric wave ripple marks (Text-fig. 7A). The wave-rippled sandstones are in turn overlain by heteroliths with poorly developed sub-horizontal lamination or intensively bioturbated beds with a conspicuous nodular texture. In the upper part of sub-association 2a are also seen grey, very fine-grained sandstones and siltstones with planar cross-bedding and asymmetrical wave ripple marks (topmost part of complex E in Text-fig. 4). Generally, towards the top of sub-association 2a, a gradual decrease in heterolith frequency and increase of sandy lithofacies can be observed in the cycles. Moreover, the thickness of the sandy beds increases upwards and the erosional nature of their bases becomes more obvious (complex E in Text-fig. 4).

The ichnofossil assemblage is overall similar to the one in association 1, but it occurs only in sub-association 2a. It comprises mainly *Palaeophycus* isp. (Text-fig. 6B), *Planolites* isp., and *Monocraterion* isp. (Text-fig. 6E), which appear in the heterolithic lithofacies. ?*Phycodes* isp. has also been recognised (Text-fig. 6C, D), similarly to association 1, and is associated with complex D and the lower part of complex E.

Sub-association 2b

This sub-association, noted only in the eastern quarry wall in subsections III and IV (complex G in Text-fig. 3A, C and D), consists of cyclic, finely bedded silty-sandy deposits with irregular medium-scale wave ripple marks, in part constituting fragments of discontinuous lenses with hummocky cross-bedding (starved hummocks). The characteristic wedge-shape of this sandy-silty body occurs in subsection IV (Text-fig. 3D). The beds of complex G originally had a low-angle inclination to the north (as deduced after the removal of structural tilt and re-rotation of the bedding dips to the position as they were during time of deposition). The complex shows syn-depositional deformations, i.e., syn-sedimentary faults, water-escape structures, interrupted beds, and load-casts. In the north-eastern part of the quarry, complex G is disconformably truncated by the erosive base of complex H.1 (Text-fig. 3C), whereas in the south-eastern part of the quarry, sandstones of complex G are eroded away and complex F is directly overlain by complex H.1 (Text-fig. 3D).

No ichnofossils have been recovered from sub-association 2b so far.

Interpretation

Lithofacies association 2 records distal to proximal lower shoreface environments. According to Dott and Bourgeois (1982) and Boyd *et al.* (1992), the transition from the offshore to the lower shoreface environment is mainly indicated by: a) the more frequent occurrence of coarser, sandy lithofacies, especially with wave ripple marks and hummocky cross-stratification (HCS), and b) an increase of thickness of sandy and silty beds. In sub-association 2a, changes in lithology and structures are clearly seen; the increasing upward contribution of the sandy lithofacies and the occurrence of relatively thick complexes of sandstones with wave ripple marks are significant indicators of the proximity of the wave base and an increasing contribution of shallow-water deposits in the succession. The ichnological suite of sub-association 2a is equally significant; the lithological changes are correlated with an increasing abundance of bioturbated beds but also with decreasing taxonomic diversity (Eckdale 1985; Pemberton *et al.* 2012). Moreover, the increasing number of bioturbated beds is additional proof of the shallowing trend of the sedimentary environment.

The irregular starved hummocks and wave ripple marks observed in sub-association 2b point to deposition in a lower shoreface environment. Low-angle inclined bedding developed on the shore slope by downwelling storm currents. The occurrence of syn-sedimentary deformation coupled with lack of bioturbation are interpreted as being caused by rapid deposition. These features coupled with the observed geometry and position below the prominent erosive surface (see Text-fig. 3C) suggest that complex G constitutes a fast prograding (northwards – according to the inferred bedding inclination) wedge-shaped subaqueous fan, formed as the effect of intensive redeposition of a cannibalised strand plain during falling sea level conditions (*sensu* Hunt and Tucker 1992).

Lithofacies Association 3

Association 3 was observed at the upper quarry level in subsections III, IV, V, and VI (Text-fig. 3A). Generally, it comprises sandy-silty deposits, representing complexes H.1 to L (Text-fig. 4), with some differences in the sedimentary structures recognisable between complexes H, I and J–L. Three sub-associations are recognised, referred to as ‘a’ (complexes H.1 and H.2), ‘b’ (complexes I.1 and I.2), and ‘c’ (complexes J to L).

A major erosional surface, occurring at the base of association 3 (base of complex H.1), can be traced across the quarry; the disconformity truncates the underlying strata (complexes F or G; Text-fig. 3A, B, yellow dashed line).

Sub-association 3a

This sub-association begins with about 1 m of thick medium-grained sandstones with planar cross-bedding. It is overlain by sandy cycles with a massive structure in the bottom part and wave ripple marks in the upper part of each bed. The thickness of each cycle is c. 30 to 70 cm.

The ichnofossil assemblage includes *Cruziana* isp. and *Rusophycus* isp. (Text-fig. 8E), which appear rarely and usually along the lithological contact between the muddy and sandy beds. *Skolithos* isp. and ?*Lennea* isp. burrows were noted in the topmost intensively bioturbated sandy horizon; *Planolites* isp. is relatively common (Text-fig. 6A).

Sub-association 3b

The lowermost part of sub-association 3b begins with a few, irregular, coarse-grained sandstones with abundant glauconite, gradually passing into wave-rippled sandstones (complex I.1; Text-fig. 4). This sandy complex, about 1 m thick in total, is underlain by an erosional surface, visible all along the southern quarry wall (Text-fig. 7B). The basal sand is overlain by several cyclic complexes composed of medium- to coarse-grained sandstones with large- or medium-scale HCS and swaley cross-stratification in the lowermost part, and fine- to medium-grained sandstones with medium-scale wave ripple marks in the upper part (complex I.2; Text-figs 4, 7C). The hummocky beds are amalgamated and contorted. In the bottom part of complex I.2, syn-sedimentary folds can be observed (Text-fig. 7E). Each cycle has an erosional base and an average thickness of 1.7–2.5 m. The upper part of sub-association 3b (complex I.2) is intensively bioturbated (Text-fig. 9A). It is overlain by the siltstones and fine-grained sandstones of sub-association 3c.

In the lowermost part of the sub-association, repichnia of large arthropods, representing either *Rusophycus dispar* (Linnarsson, 1871) or *Rusophycus magnus* (Orłowski, 1992) (Text-fig. 8F), were observed. The general frequency of the bioturbated horizons in sub-association 3b is low.

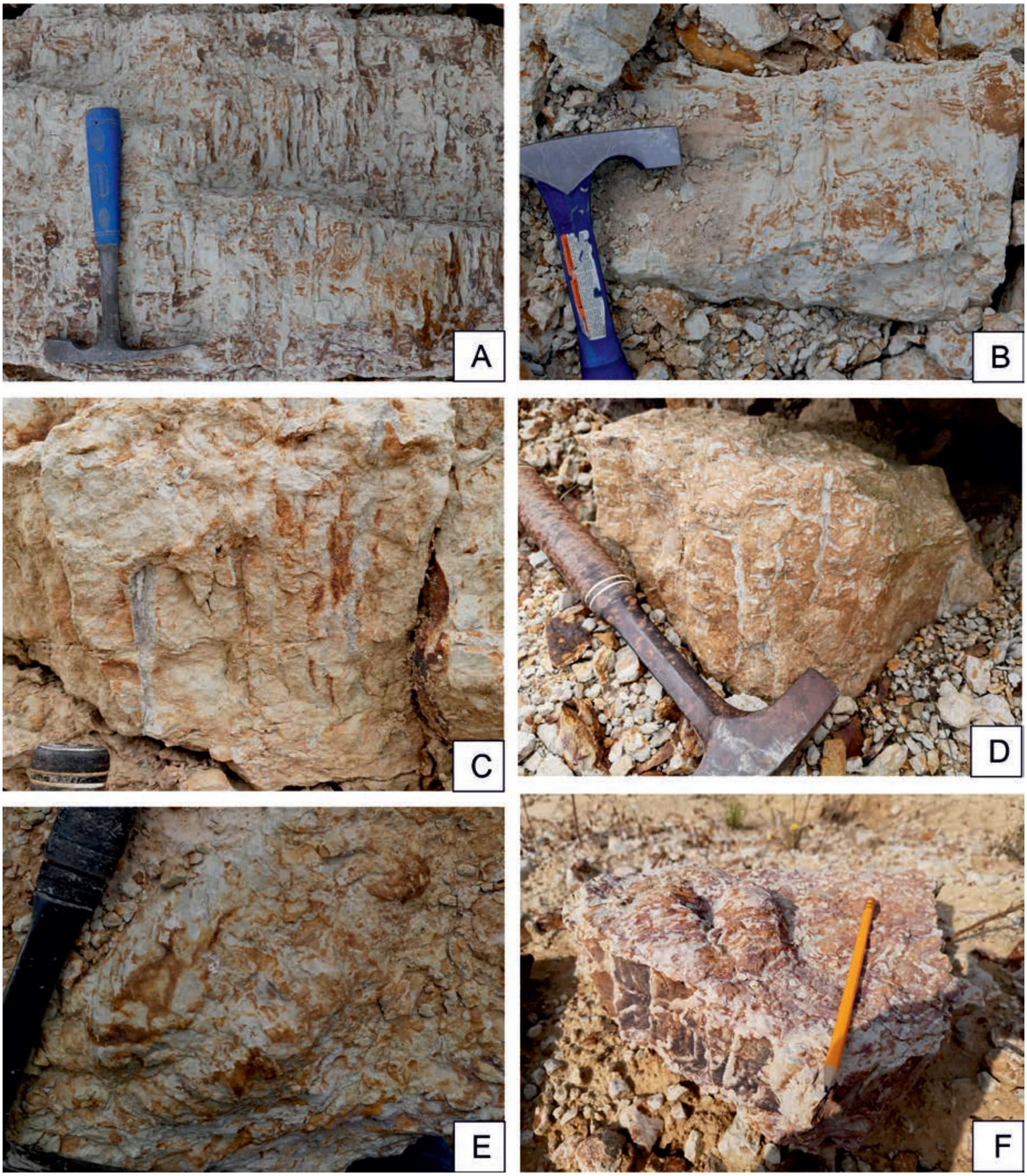
Sub-association 3c

This sub-association is represented by complex J, consisting of fine-grained sandstones and siltstones with symmetrical ripple marks, and complex K, comprising sandstones with planar cross-bedding, sub-horizontal bedding and wave ripple marks (Text-figs 4 and 9B). Some of the sandy beds are intensively bioturbated (see nodular horizons in complexes J and K; Text-fig. 4). In the topmost part of this sub-association are seen fine-grained sandstones and siltstones with small-scale asymmetrical wave ripple marks and sub-horizontal bedding, allocated to complex L. This unit contains vertical burrows, about 20–30 cm long (Text-fig. 9B). Sub-association 3c begins with a planar base that truncates sub-association 3b containing HCS (Text-figs 7C and 9A).

The ichnological assemblage of sub-association 3c is somewhat different from those in the other sub-associations. The sandstones are mottled mainly by filter feeders and vertical burrow dwellers; the suite is generally represented by numerous *Skolithos* isp., *Diplocraterion* isp., ?*Lennea* isp., and sporadic *Rosselia* isp. (Text-fig. 8A, B, D). Intensively bioturbated horizons are common in all complexes of sub-association 3c.

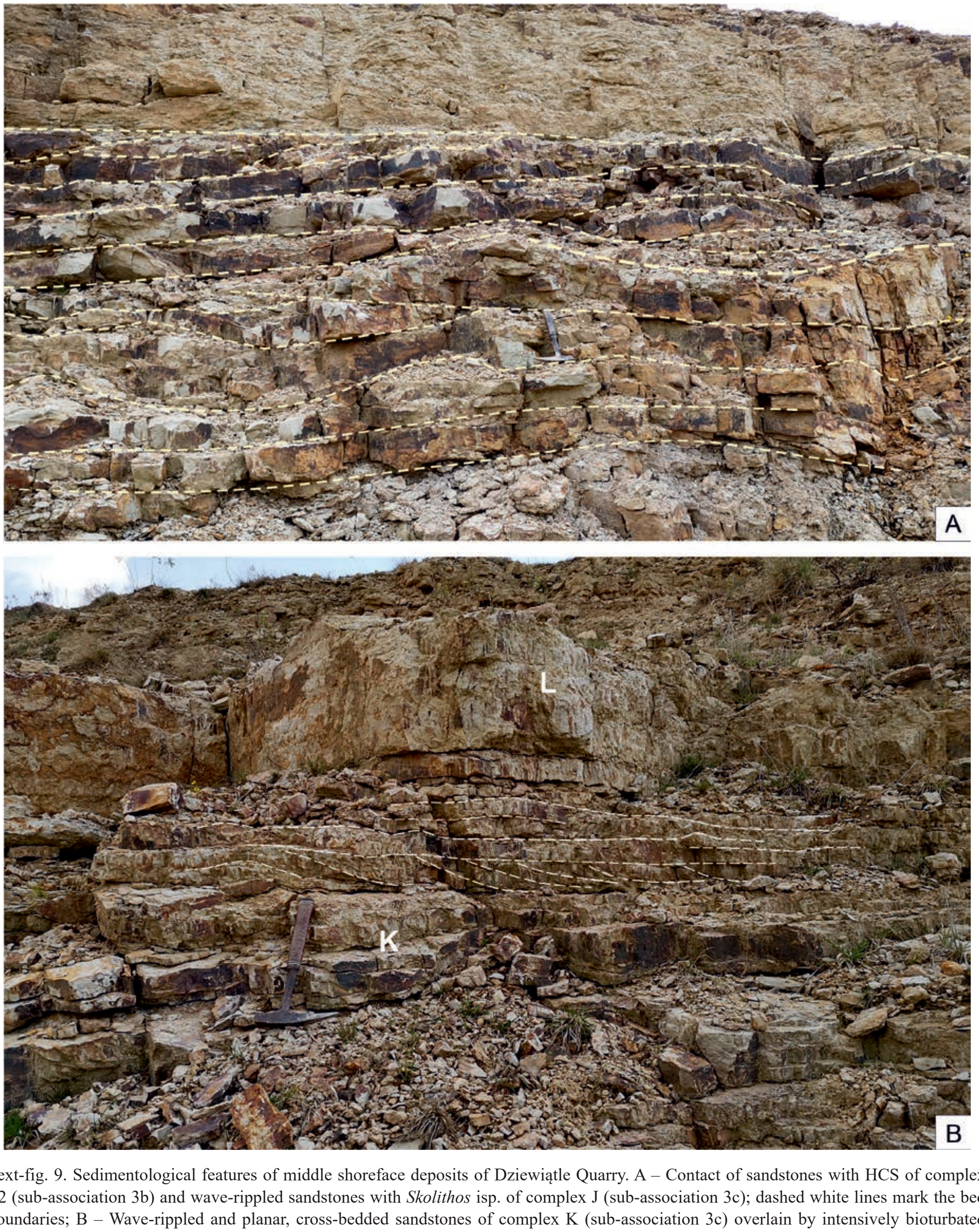
Interpretation

Lithofacies association 3, which is mainly composed of HCS and wave-rippled sandstones, is 7 m thick in total. It contains numerous internal erosional surfaces, and has all the characteristic features of storm sediments formed in a shallow, middle shoreface zone. Deposition in this environment began with the sandy deposits of sub-association 3a. The wave-rippled sandstone reflects deposition in fair-weather conditions in the lowermost part of the middle shoreface. The cyclic complexes of the overlying sub-association 3b are similar to those described by Dott and Bourgeois (1982, p. 665) as an “idealized hummocky sequence.” According to these authors, such a sequence is composed of HCS sandstones that pass upwards into flat laminated sandstones, followed by wave-rippled sandy beds, and finally mudstones, often intensively burrowed. Typical HCS sequences are known from many modern and ancient successions, and are interpreted as being formed by storm processes in the shoreface zone, between the fair-weather and storm wave bases (Dott and Bourgeois 1982; Duke 1985; Boyd *et al.* 1992). Although the scientific debate on the main sedimentary mechanisms forming sandy hummocks is still ongoing, it is generally agreed that HCS is an indicator of deposition associated with storms (Allen 1985; Duke 1985; Swift and Nummedal 1987; Duke *et al.* 1991; Boyd *et al.* 1992; Cheel and Leckie 1993; Dumas *et al.* 2005;



Text-fig. 8. Examples of ichnofossils from the middle shoreface deposits of Dziewiątle Quarry. A – *Skolithos* isp. from complex K (sub-association 3c); B – *Diplocraterion* isp. from complex K (sub-association 3c); C – *Rosselia* isp. from complex I.2 (sub-association 3b); D – ?*Lennea* isp. from complex J (sub-association 3c); E – *Rusophycus* isp. from complex H.1 (sub-association 3a); F – *Rusophycus dispar* (Linnarsson, 1871) from complex I.1 (sub-association 3b).

Dumas and Arnott 2006). The cyclic complexes of association 3, poor in burrowed mudstone interbeds, are represented by relatively thick, amalgamated and contorted HCS sandy beds, which is suggestive of the middle shoreface zone with high energy conditions. However, the ichnofossil suite of sub-association 3c, represented by *Skolithos* isp., *Diplocraterion* isp., ?*Lennea* isp., and with rare *Rosselia* isp., suggests on



Text-fig. 9. Sedimentological features of middle shoreface deposits of Dziewiątle Quarry. A – Contact of sandstones with HCS of complex I.2 (sub-association 3b) and wave-rippled sandstones with *Skolithos* isp. of complex J (sub-association 3c); dashed white lines mark the bed boundaries; B – Wave-rippled and planar, cross-bedded sandstones of complex K (sub-association 3c) overlain by intensively bioturbated sandstones of complex L (sub-association 3c); the sandy beds are dominated by *Skolithos* isp.

the other hand an even shallower part of the shoreface, representing the typical *Skolithos* ichnofacies (*sensu* Seilacher 1967), produced by suspension feeders and vertical tube dwellers, and even encompassing the transition to the upper shoreface. According to Eckdale (1985), Frey (1990), and Pemberton *et al.*

(2012), dominant suspension-feeder behaviour should correspond to high-energy, middle (to upper?) shoreface environmental conditions.

BIOSTRATIGRAPHY

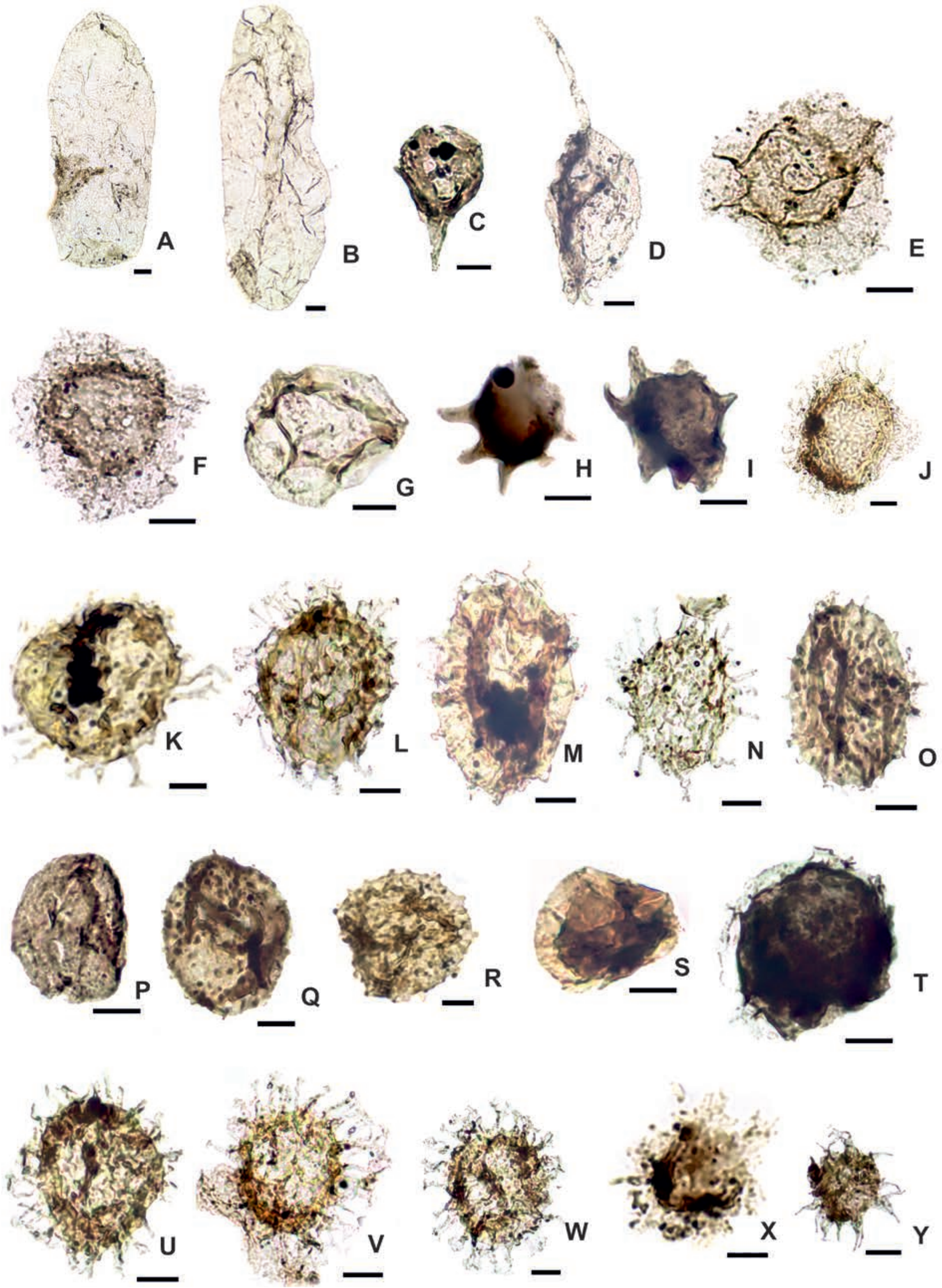
Despite intense search body fossils were not recovered from the analysed succession. Instead, additional sampling for acritarch analysis was performed in the dark grey rocks from the northern part of the quarry, assigned to sub-association 1a and representing the Kamieniec Formation (complex A; Text-figs 3 and 4). The three samples contained a moderately abundant and fairly well-preserved acritarch microflora. Individual specimens were relatively dark (Text-fig. 10), ranging from light-brown to black depending on the wall thickness. Compared to other acritarch assemblages of the HCM from an approximately similar stratigraphic interval (Szczepanik 2009; Żylińska and Szczepanik 2009), the Dziewiątle assemblage shows a much higher degree of thermal maturity, which might have been caused by local tectonic phenomena. All of the fossiliferous samples are similar in their palynomorph content and they are therefore discussed jointly below.

The assemblage is dominated by *Skiagia* spp. (Text-fig. 10K–O). Due to rather poor preservation (crushed processes and effaced fine elements of the sculpture), most specimens can be identified only at genus level. A relatively well-preserved and abundant form is *Skiagia* cf. *brevispinosa* Downie, 1982 (Text-fig. 10O). Additionally, *Lophosphaeridium* sp. (Text-fig. 10P–R), *Pterospermella* sp. (Text-fig. 10E, T) and *Heliosphaeridium* sp. are also present. A characteristic element of the microflora, which very rarely occurs in other assemblages, is *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas and Kiryanov in Volkova *et al*., 1979 (Text-fig. 10V, W). Overall, the composition of the assemblage is typical for the *Heliosphaeridium–Skiagia* and *Volkovia–Liepaina* microfloral zones (Moczydłowska 1991), corresponding to the Vergale and Rausve regional Baltic stages (Volkova *et al.* 1983). The analysed samples also contain abundant *Leiovalia tenera* Kiryanov, 1974 (Text-fig. 10A), which coupled with the presence of *S.* cf. *brevispinosa*, recall the assemblages from the stratotype section of the Kamieniec Formation in Kamieniec (Żylińska and Szczepanik 2009). Similarly as in the Kamieniec Formation, the Dziewiątle assemblage contains also a few specimens of *Eliasum llaniscum* Fombella, 1977. Although this species is considered an index taxon of the Miaolingian (Wuliuan) *Eliasum–Cristallinum* Zone, it was also noted in the uppermost Cambrian Series 2 strata (Volkova *et al.* 1979; Hagenfeldt 1989). In the stratigraphic scheme of Jankauskas and Lendzion (1992, 1994), *E. llaniscum* ranges from the Rausve Regional Stage upwards. Its co-occurrence in Dziewiątle with *M. dendroideum* (Text-fig. 10V, W) may indicate the eponymous zone in the scheme of Jankauskas and Lendzion (1992, 1994), correlated with the upper part of the Rausve Regional Stage, a stratigraphic position that is further supported by the presence of *Volkovia* sp. (Text-fig. 10C), ?*Deunffia* sp. (Text-fig. 10D), *Retisphaeridium* sp., and *Celtiberium* sp. (Text-fig. 10H, I, U). In the biostratigraphic scheme for the HCM, the *Volkovia–Liepaina* acritarch Zone correlates with the *Protolenus–Issafeniella* trilobite Zone (cf. Żylińska and Szczepanik 2009).

DISCUSSION

Sedimentary environment

The over 50 m thick Cambrian Series 2 succession exposed in Dziewiątle Quarry documents a transition from lower offshore, through upper offshore, lower and middle shoreface, to the upper(?) shoreface. The vertically increasing frequency and thickness of the beds with HCS, correlated with the upward decrease of interlayered mudstone beds, the generally coarsening upward trend, and changing trace fossil assemblages of the *Cruziana* to *Skolithos* ichnofacies, all constitute significant evidence of an increasing intensity of storm processes, and a shallowing trend during the deposition of the analysed succession. A similar sedimentary pattern of lithofacies and depositional model was documented from the Eocene Lower Coaledo Formation in the USA (Dott 1966; Dott and Bourgeois 1982). It was interpreted as a prograding wave-dominated shoreface clastic succession developed near the delta front. Sandy deposition near active distributaries produced strand plain environments. The development of storm-dominated sandy coastlines usually takes place when rivers supply huge amounts of terrigenous material during a relative sea level fall. Wave action and storms redistribute the delta-related clastic material which results in the development of a coarsening-upward regressive succession. Probably, deposition of the shallow-marine Cambrian Series 2 sandy succession of Dziewiątle Quarry was also associated with a high rate of supply in sediment, delivered by rivers from the eroded land of the Małopolska Fold-Thrust Belt (see Text-fig. 1)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and subsequently reworked by waves and currents along the Baltica shorelines. The scanty sedimentary observations in the region which have been published document a 4 m-thick sandy complex of Cambrian Series 2 strata, representing a storm-cut channel infill in the Rybnica section near Gieraszowice, located about 20 km to the south-east of Dziewiątle Quarry (Mizerski *et al.* 1999). This sandy succession also provides evidence of high-energy processes that could have taken place in the offshore/shoreface zone, near the storm wave base, although in the original interpretation of Mizerski *et al.* (1999), the storm processes were supposed to have been induced by (presumably local) submarine seismic shocks. The shoreface sedimentary setting is in line with the fact that the past attempt to retrieve recognisable palynomorphs from the Ociesęki Formation was unsuccessful (Żylińska and Szczepanik 2009). Similarly in Dziewiątle, the only palynomorph material recognised from mudstone intercalations within the Ociesęki Formation was carbonized organic matter, probably of microbial or algal origin (ZS unpublished data).

The previously available data for the sedimentary environment of the Ociesęki Sandstones were assumed to indicate a clear shallowing-upward trend of the Cambrian Series 2 succession (Mizerski *et al.* 1986; Studencki 1988). Furthermore, based on observations from the central part of the Palaeozoic inlier, Orłowski and Mizerski (1996) and Stachacz (2010) suggested a lower shoreface environment and the *Cruziana* ichnofacies for the lower part of the Ociesęki Formation representing the *Holmia–Schmidtiellus* Zone, and a middle shoreface setting and the *Skolithos* ichnofacies for its upper part attributed to the *Protolenus–Issafeniella* Zone. Our studies in the eastern part of the inlier (Dziewiątle Quarry) show that both of these ichnofacies and environments occur in strata correlatable with the upper part of the *Protolenus–Issafeniella* Zone (see Żylińska and Szczepanik 2009), which suggests that the previous assumptions, although correct for the small exposures investigated, were oversimplified.

Lithostratigraphy

The Ociesęki Sandstone Formation was established by Orłowski (1975b) to encompass grey to olive in colour, fine-grained, thin- to medium-bedded sandstones, with interbeds of siltstones and shales, characterised by rich ichnofossil assemblages (Orłowski *et al.* 1970; Orłowski 1989, 1992; Orłowski and Żylińska 2002; Stachacz 2010, 2012, 2013, 2016). Rocks of this formation are exposed in many places throughout the Kielce Region, from the western part of the Zgórsko Range in the south-west and west, to the Gieraszowice area in the south-east (over a distance of c. 80 km; e.g., Orłowski 1975b; Kowalczewski 1990; Żylińska 2013, her text-fig. 1), and constitute some of the most prominent (although meagre in altitude above sea level) elevations of the southern HCM.

Most of the succession exposed in Dziewiątle Quarry undoubtedly represents the Ociesęki Formation; the rocks are dominated by light-grey to olive in colour, thin-to medium bedded sandstones and sandy heteroliths, and with siltstone interbeds, contain numerous shallow-marine sedimentary structures, and display a rich array of ichnofossils. However, on the original map showing the distribution of lithostratigraphic units in the HCM (Orłowski 1975b, his fig. 2), the Ociesęki Formation is in the central part of the area occupied by the Kamieniec Formation, with the boundary between the two units established along the Łagowica River valley. Later, this boundary was correlated with the dip-slip Łagowica Fault (Mizerski and Orłowski 1993), and accordingly, directly to the east of the Łagowica valley, no exposures of the Ociesęki Sandstones were expected up to the area of Klimontów (located c. 20 km east of Dziewiątle Quarry; e.g., Orłowski and Mizerski 1995). Furthermore, the Kamieniec Formation was considered an age equivalent of the upper (but not uppermost) Ociesęki Formation (Orłowski 1975b, fig. 1; Kowalczewski *et al.* 2006; Żylińska and Szczepanik 2009).

The Dziewiątle exposure provides new data that allows these interpretations to be re-evaluated.

← Text-fig. 10. Acritarchs from the Kamieniec Formation (sub-association 1a) of Dziewiątle Quarry. Symbols in parentheses refer to number of slide and location of specimen according to England Finder. A – *Leiovalia tenera* Kiryanov, 1974 (1800a5-T52/3); B – *Eliasum llaniscum* Fombella, 1977 (1800a5-D34/2); C – *Volkovia* sp. (1800b5-U36/3); D – ?*Deunffia* sp. (1800a5-T41/3); E – *Pterospermella velata* Moczydłowska, 1988 (1800b5-R22/2); F – *Granomarginata squamacea* Volkova, 1968 (1800b5-P22/1); G – ?*Retisphaeridium* sp. (1800a5-P50/3); H, I – *Celtiberium* sp. (H – 1800a5-E30/3; I – 1800b5-K36); J – *Comasphaeridium* sp. (1800a5-T50/4); K – *Skiagia orbiculare* (Volkova) Downie, 1982 (17799a1-L56); L – *Skiagia ornata* (Volkova) Downie, 1982 (1800a5-L35/1); M – *Skiagia ciliosa* (Volkova) Downie, 1982 (1800a5-N44/4); N – *Skiagia compressa* (Volkova) Downie, 1982 (1800b5-O51/3); O – *Skiagia* cf. *brevispinosa* Downie, 1982 (1800a5-H46/2); P – *Lophosphaeridium tentativum* Volkova, 1968 (1800a5-P33/1); Q, R – *Lophosphaeridium truncatum* Volkova, 1968 (Q – 1800a5-45/2); R – 1800b5-V44/2); S – *Cymatiosphaera* sp. (17798a-Z54/4); T – *Pterospermella* cf. *vitalis* Jankauskas in Volkova *et al*., 1979 (1800a5-O45/2); U – ?*Celtiberium* sp. (17798a-G47/2); V, W – *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas and Kiryanov in Volkova *et al*., 1979 (V – 1800a5-N45; W – 1800b5-F28/2); X – *Parmasphaeridium implicatum* (Fririchsone) Jachowicz-Zdanowska, 2013 (1800b5-L52/2); Y – *Ammonidium notatum* (Volkova) Jachowicz-Zdanowska, 2013 (1800a5-N27/4). Scale bars equal 10 μm.

Firstly, the sandstones of the Ocieseki Formation obviously occur directly east of the Łagowica valley, and most probably continue eastwards into the Wygiełzów Syncline, the youngest rocks of which are the coarse-grained sandstones attributed to the Słowiec Sandstone Formation. This means that the map of Mizerski *et al.* (1986, their fig. 8) and the map and schemes of Orłowski and Mizerski (1995, their figs 2–4) should be adjusted to accommodate the Ocieseki Formation, although the character of the boundary between these two formations remains unclear, to the extent that even an angular unconformity cannot be excluded.

Secondly, the quarrying exposed grey mudstones and heteroliths in the lowermost level of the northern part of the quarry; they constitute part of the succession assigned to complexes A to C (sub-association 1a and lower occurrence of sub-association 1b; Text-figs 3B and 4). Comparison with rocks exposed in Kamieniec and drilled also in the Zaręby 2 well (Żylińska and Szczepanik 2009; Szczepanik 2019) shows that they can be attributed to the Kamieniec Formation. Hence, in the quarry, the Kamieniec Formation (complexes A to C) underlies (and not overlies) the Ocieseki Formation (complexes D to L) and is probably also a lateral equivalent of this unit (see above for age assignment). The lithostratigraphic scheme of Orłowski (1975b) works well in identifying lithologies typically characteristic of each unit, but the boundaries between particular units are not defined precisely. In fact, in most cases the boundaries between the units are not exposed (see original paper of Orłowski 1975b). In the present case, the observations in Dziewiątle Quarry for the first time give the opportunity to document the boundary between two lithostratigraphic units of formation rank. The base of the Ocieseki Formation and thus the boundary between the Kamieniec and Ocieseki formations, is defined in the quarry at the first occurrence of distinct layers of fine- and medium-grained sandstones marked by a green dashed line in Text-fig. 3B and a green arrow on the lithological log in Text-fig. 4. This boundary coincides also with a change of rock colour from dark grey to light grey (yellowish in a weathered state), which is related to improvement of the environmental conditions to more oxygenated ones (see above).

Chronostratigraphy

The age of the Dziewiątle Quarry succession is constrained by bio- and lithostratigraphic data. The oldest unit exposed in the quarry is sub-association 1a, attributed to the Kamieniec Formation. As discussed above, these mudstones represent the *Volkovia–Liepaina* acritarch Zone, corresponding to the top part of the Rausve Regional Stage (upper part of Cambrian Series 2). Eastwards, the Dziewiątle Quarry succession is overlain by the youngest strata of the Wygiełzów Syncline. These coarse-grained sandstones represent the Słowiec Sandstone Formation and are exposed c. 15 km further to the east e.g., in Konary, where findings of trilobites indicate the *Acadoparadoxides samsonowiczi–Acadoparadoxides kozlowskii* Zone which spans the Cambrian Series 2-Miaolingian boundary interval (Orłowski 1971; Żylińska and Szczepanik 2009; Nowicki and Żylińska 2019, 2021). This assemblage most probably correlates with the Kibartian Regional Stage (cf. Nielsen and Schovsbo 2011, 2015). Therefore, the Dziewiątle succession spans the upper part of Cambrian Series 2, and is not older than the late Rausvian and not younger than the early Kibartian regional stages.

Sequence stratigraphy

The succession exposed in the quarry represents a regressive-transgressive event and the major disconformity at the base of complex H.1 (base of Lithofacies Association 3) is interpreted as a sequence boundary. This surface truncates the top of complex G (sub-association 2b), which is regarded herein as a wedge-shaped subaqueous fan, formed by redeposition of a cannibalised strand plain during falling sea level conditions (*sensu* Hunt and Tucker 1992).

The abundant glauconite noted in complex I.1 points to a rapid opening of the accommodation space probably caused by a rapid and pronounced sea level rise (initiation of transgressive conditions – initial flooding surface). Moreover, the 1st order scale of the observed regressive-transgressive event may be inferred from the impressive thickness (7 m!) of the overlying continuous succession of HCS (complex I.2) recording a prominent increase of accommodation space balanced by ample sedimentary supply.

The biostratigraphic (latest Rausvian acritarchs below) and lithostratigraphic (late Kibartian Słowiec Formation above) position of the analysed succession (discussed above) allows a correlation of the observed 1st order sequence boundary with the base of sequence LC2-5 (När Lowstand) of Nielsen and Schovsbo (2011, 2015), suggesting that the sea level changes were eustatic in nature. The sequence has been so far recognised in successions representing the distal margins of the Baltica palaeocontinent (Yoldia, Digermul, Łebsko Formation in N Poland; Nielsen and Schovsbo 2011, 2015).

Regional context

Marginal marine and coastline sandstones of Cambrian Epoch 2 have been documented from southern Norway, southern Sweden, Bornholm, as well as Podlasie in eastern Poland, and further to the east (Jensen 1997; Nielsen and Schovsbo 2011, 2015; Clemmensen *et al.* 2017; Wendorff 2019). The location of Baltica within a major ocean (cf. Cocks and Torsvik 2005) suggests a high energy coastline affected by strong waves and storm activity. This sedimentary setting was commented on by Hamberg (1991) in the context of the deposition of the Hardeberga Formation of southern Scania (Sweden), where that sandy succession was considered to represent sandy barrier islands formed during winter storms. Moreover, in agreement with this setting, Clemmensen *et al.* (2017) suggested that a sandy coast developed in the Bornholm area during Cambrian Epoch 2. The vast sand deposition was the effect of long-term processes of strong wave or storm activity. Sequences of offshore to shoreface transition were also documented by Wendorff (2019) from the Cambrian Series 2 Kaplonosy and Radzyń formations documented in the boreholes of NE Poland. In this context, the Dziewiątle area, as well as the southern part of the HCM, represents a broad zone of clastic deposition along the Baltica coastline (Text-fig. 1A), affected by strong storms and modified by eustatic sea level changes.

CONCLUSIONS

1. The succession in Dziewiątle Quarry in the eastern part of the Holy Cross Mountains of Poland represents a transition from the lower offshore to the middle (or even the upper) shoreface of a wave-dominated siliciclastic shoreline at very shallow water depths and very high supply of clastic material in the topmost part of the exposed succession.

2. The facies succession in Dziewiątle Quarry records a regressive-transgressive event separated by a 1st order sequence boundary, with well-developed: a) shallowing-upward offshore deposits (high sea level); b) rapidly prograding wedge-shaped subaqueous fan (falling stage); c) distinct erosional surface/disconformity (sequence boundary); d) initial flooding surface with common glauconite (onset of transgressive conditions); e) pronounced increase of the accommodation space accompanied by high clastic influx, resulting in deposition of a 7-m thick succession of hummocky and swaley cross-stratified sandstones (further sea level rise); and f) shallowing trend of ichnofossil assemblages in the topmost part of the analysed succession (beginning of highstand conditions).

3. The age of the Dziewiątle Quarry succession is bracketed by the acritarch assemblages of the *Volkovia–Liepaina* Zone below and by the transition into the Cambrian Series 2/Miaolingian Słowiec Formation above.

4. Age constraints of the analysed succession allow a correlation of the sequence boundary in Dziewiątle Quarry with the base of sequence LC2-5 (uppermost part of Cambrian Series 2; När Lowstand) of Nielsen and Schovsbo (2011, 2015).

5. The siliciclastic succession exposed in Dziewiątle Quarry for the first time allows a documentation of the lithostratigraphic boundary between the Kamieniec and Ociesęki formations. The presence of the Ociesęki Formation directly east of the Łagowica River Valley requires revision of the geological mapping in the area. The spatial relationships between Cambrian lithostratigraphic units in the Holy Cross Mountains are more complex than in the commonly accepted scheme.

6. With regard to its sedimentary structures and trace-fossil content, the Ociesęki Sandstone Formation is comparable to other shallow-water (but older), epicontinental siltstones and sandstones of Baltica, such as the Hardeberga and Mickwitzia sandstones.

Acknowledgements

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