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The Middle Jurassic succession in the central sector of the Pieniny Klippen Belt (Sprzycne Creek): implications for the timing of the Czorsztyn Ridge development

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Abstract: In this study, we revisit the stratigraphic age and discuss sedimentary characteristics of the lower Middle Jurassic turbidite deposits ("black flysch") of the Szlachtowa Formation, as well as the under- and overlying members of the Sprzycne Creek section situated in the central sector of the Pieniny Klippen Belt (Poland). We show that the succession captures the lower Middle Jurassic marine sediments of the pre-Late Albian Magura Basin, located to the north of an ancient submarine swell (Czorsztyn Ridge). The turbidite deposits of the Szlachtowa Formation and marly shales of the Opaleniec Formation yield dinoflagellate cysts indicative of the latest Aalenian or learliest Bajocian to Early Bathonian. The character of these deposits, and their location below the overthrusted Subpieniny Nappe show that this succession does not belong to the successions of the Oravicum domain, located on the southern side of the Czorsztyn Ridge. The Szlachtowa Formation is underlain by the Skrzypny Formation, which is reported for the first time outside the Oravicum domain. It suggests that the pre-Late Albian Magura Basin came into existence not earlier than during the latest Aalenian, following the rising of the Czorsztyn Ridge. The marly shales assigned here to the Opaleniec Formation of Late Bajocian-Bathonian age and younger marly deposits of Cretaceous age were distinguished in the past as the so-called "Sprzycne beds" of Cretaceous age. However, the combination of these two rock units into a single lithostratigraphic unit is unsuitable because they represent two separated stratigraphical intervals and their contact is tectonic.

Key words: Middle Jurassic, Pieniny Klippen Belt, Magura Basin, "black flysch", stratigraphy, dinoflagellate cysts.

Introduction

During the Laramian movements, the sedimentary nappes which constitute the Pieniny Klippen Belt (PKB), a narrow and elongated tectonic zone situated on the northern flank of the Central Western Carpathians (a part of the Alpide belt) (Fig. 1), were stripped off from their basement and stacked at the front of the propagating thrust (Birkenmajer 1986). These structures were subsequently redeformed during the Miocene, when the turbiditic basins of the Outer Carpathians were closing and the original spatial arrangement of the depositional succession was distorted (see Jurewicz 2005). The intensity of the wrench tectonics led to the spatial complexity of the belt's structure, expressed in an apparently chaotic distribution of rigid rock complexes ("Klippen") within the crumpled, less rigid shaly sediments. Therefore, the sequences dominated by shales and marls (such as the one described in this paper) tend to be strongly disturbed and incomplete. However, the stratigraphy and paleogeographic position of marly sediments with turbidites is of high importance in assessing the structural evolution of the Pieniny Klippen Belt during the Mesozoic because they can be used to infer the timing of the major sea-floor differentiation in the PKB. Such is the case of a Middle Jurassic succession comprising the turbiditic Szlachtowa Formation, examined and discussed herein within a context of the Czorsztyn Ridge development.

The stratigraphic and structural position of the deposits of the Szlachtowa Formation (the so-called "black flysch"), represented by the black micaceous shales with intercalations of sandstones and allodapic crinoidal limestones, have been subject to controversial interpretations over the years. These deposits were stratigraphically attributed either to certain parts of the Early–early Middle Jurassic interval, namely the Upper Toarcian–lowermost Aalenian (Birkenmajer 1977), Upper Toarcian–Upper Bajocian (Gedl 2008a; including a hiatus spanning the uppermost Toarcian/Lower Aalenian to lower Upper Aalenian), Lower Bajocian (Barski et al. 2012; base and top of the formation unknown), ?Middle/Upper Toarcian–Middle Bathonian (Gedl & Józsa 2015), or, by contrast, to the middle Cretaceous (Albian–Cenomanian) (e.g. Sikora 1971c; Oszczypko et al. 2004, 2012). Due to tectonic perturbations, the base of the formation has remained enigmatic until now. On the other hand, the sedimentary area of the Szlachtowa Formation was assigned either to the Oravicum domain and pre-Late Albian Magura Basin/Grajcarek Succession (see e.g. Birkenmajer 2007; Birkenmajer et al. 2008; Gedl 2008a) or exclusively to the pre-Late Albian Magura Basin (e.g. Barski et al. 2012; Oszczypko et al. 2012), structurally located either below the overthrusted Pieniny-Subpieniny Nappes or in front of them (see e.g. Birkenmajer 2007; Birkenmajer et al. 2008; Barski et al. 2012; Oszczypko et al. 2012). Therefore, a critical analysis of the Szlachtowa Formation in carefully described sections is of high importance. Our analysis of similar deposits in central areas of the PKB (previously attributed to the Oravic domain successions, Birkenmajer 1977) shows

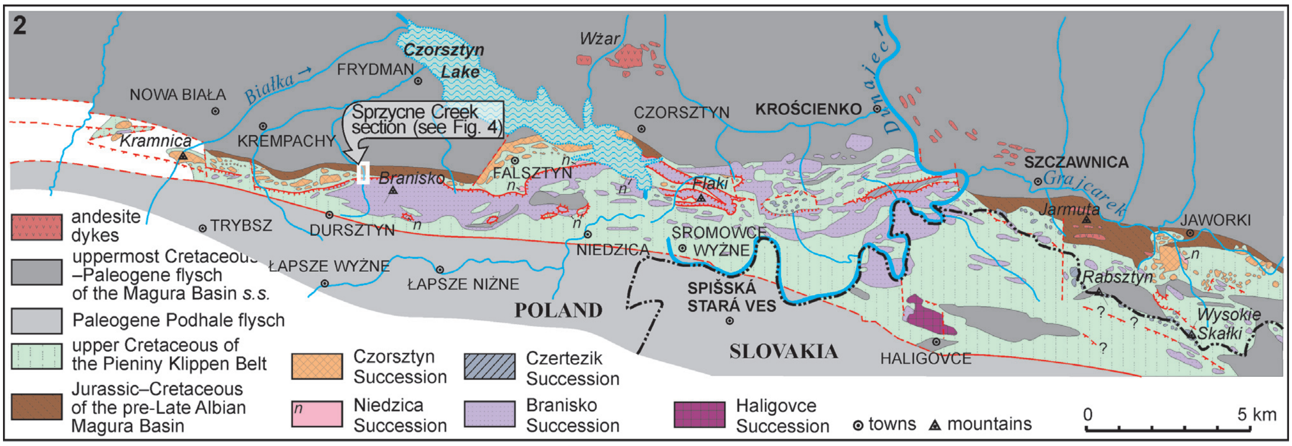

Fig. 1. Position of the Pieniny Klippen Belt and Sprzycne Creek section. **1** — sketch map with the position of the Pieniny Klippen Belt in the Carpathians, **2** — tectonic map of the central sector of the Pieniny Klippen Belt (modified from Książkiewicz 1972).

that the Bajocian deposits in the Podubocze section represent the lowermost tectonic unit of the Pieniny Klippen Belt of pre-Late Albian Magura Basin provenance (sensu Barski et al. 2012). In this study, we focus on a succession of the Szlachtowa Formation and younger deposits located at the Sprzycne Creek at Dursztyn in the central part of the Pieniny Klippen Belt in Poland (Fig. 1).

The dark turbiditic deposits cropping out along Sprzycne Creek were originally attributed to the "Flysch Aalenian" and placed in the Branisko Succession of the Pieniny Klippen Basin by Birkenmajer (1958). Sikora (1971a) recognized a thick succession of "black flysch" deposits with a well distinguished bed of micaceous sandstone, a few meters in thickness, in the upper part of this section. According to Sikora (1971a), these deposits were stratigraphically overlain by the Sprzycne beds which are developed as light-grey marly shales with intercalations of limestones and spotted siderites. Higher, the Cenomanian Key Horizon represented by green radiolarites is covered by variegated and green shales with Upper Cretaceous microfauna (Sikora 1971a,c; see Fig. 2 herein). Despite the lack of any biostratigraphic markers (except for the uppermost member), the whole succession exposed at the Sprzycne Creek was assigned to a late Early to Late Cretaceous age (Sikora 1971c) and attributed to the Hulina Succession (synonymous with the Grajcarek Succession). It is worth noting that the alleged equivalents of the deposits described here were subsequently recognized also in the eastern part of the Pieniny Klippen Belt in the Małe Pieniny Mts — in the Grajcarek Succession, where grey shales and marls of the Sprzycne Beds (Sikora 1971d; see also Oszczypko et al. 2012) of Cretaceous age were distinguished directly above the so called Sztolnia Beds (including the "black flysch" deposits). The Sprzycne Beds were then treated as corresponding to the Opaleniec Formation of Birkenmajer (1977), and were also called the Opaleniec (Sprzycne) Formation by Oszczypko et al. (2012, fig. 2). However, the age of the Opaleniec Formation remained controversial. It was of Bajocian age according to Birkenmajer et al. (2008) and of Albian–Cenomanian age according to Oszczypko et al. (2012).

The timing of the first stratigraphic appearance and the character of the deposits underlying the Szlachtowa Formation in the Pieniny Klippen Belt also remain enigmatic. The slaty, marly "sub-flysch beds" originally placed below the "black flysch" and assumed to be of Aalenian or Toarcian–Aalenian age (Birkenmajer 1953) turned out to be in most cases Cretaceous strata in tectonic contact with the former (Birkenmajer & Pazdro 1963). In the other cases (Birkenmajer & Pazdro 1963, fig. 5, bed 4c; Birkenmajer 1958), the "sub-flysch beds" yielded siderite nodules that are characteristic of the Skrzypny Formation (Birkenmajer 1977). The Sprzycne Creek section provides an extended record through both the base and top of the Szlachtowa Formation with a good biostratigraphic control.

Pieniny Klippen Belt

The Pieniny Klippen Belt predominantly consists of marine sediments of the Oravicum domain (Mahel' 1968) (corresponding to the Pieniny Klippen Basin *s.s.*), in which several bathymetric zones (successions or units) have been distinguished, including the shallowest Czorsztyn Succession, the transitional Niedzica and Czertezik successions, and the basinal Branisko-Kysuca and Pieniny successions (Birkenmajer 1965; see also Mišík 1997). The depositional environment was rather uniform across the basin during the deposition of the monotonous marls and shales of the Krempachy and Skrzypny formations during the Aalenian (Birkenmajer 1977). The succession types of the Oravicum domain acquired their identity during the latest Aalenian or earliest Bajocian when synsedimentary tectonics led to the origin of a submarine swell (Czorsztyn Ridge) (Fig. 3). The Lower Bajocian is represented in the Oravicum either by the deep-water Harcygrund and Podzamcze formations or hiatuses on the elevations and their slopes. The stratigraphy is well-constrained by the presence of ammonites in either case (Myczyński 1973; Krobicki & Wierzbowski 2004).

At the same time, dark, micaceous, turbidite sequences of the Szlachtowa Formation were deposited in the basin located to the north of the Oravicum (see Barski et al. 2012). The paleogeographic position of this region between the Oravicum domain and the North European Platform during the early Middle Jurassic is of essential importance in the current study. We adopt here a term "pre-Late Albian Magura Basin" sensu Barski et al. (2012) for this region, referring to some extent to the Mesozoic basement of the Magura Basin of the Outer Carpathians. This term emphasizes the difference between the pre-Upper Albian (i.e. pre-orogenic) sequence and the uppermost Cretaceous–Paleogene flysch cover. Although some authors advocate the unity and continuity of the Jurassic–Lower Cretaceous succession of what is here called the pre-Late Albian Magura Basin and the flysch succession of the Magura Basin *s.s.* (Birkenmajer 1977; Oszczypko 2004; Uchman et al. 2006), we separate them as representing in fact two, completely different subsidence/sedimentary regimes: the older one, terminated with Scaglia Rossa-type redbeds, and the younger one, starting with syn-orogenic Jarmuta-type clastics (regardless of their continuous or discordant superposition).

We stress that the terms currently used for the sequences comprising the Szlachtowa Formation, such as the Grajcarek Succession (Birkenmajer 1977, 1986) or the Šariš Unit (Plašienka & Mikuš 2010) are not synonymous with the "pre-Late Albian Magura Basin", because they do not define the sedimentary basin as such, but rather refer to paleotectonic units or sequences of strata corresponding to certain parts of the basin.

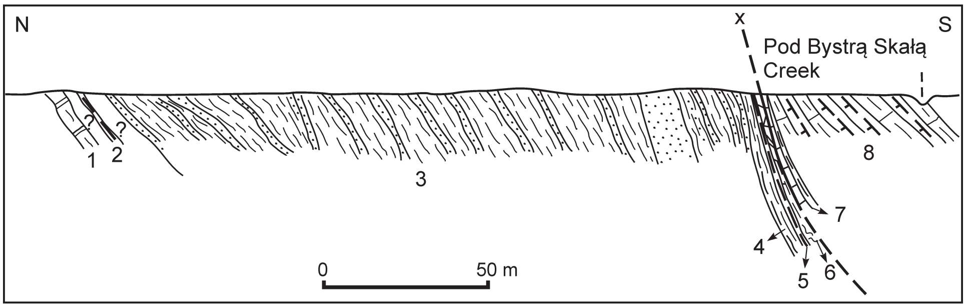

Fig. 2. Sikora's (1971a, fig. 40) original sketchy cross-section along middle Sprzycne Creek (see Fig. 4.1 for the approximate section line location); the original explanations given by Sikora 1971a, translated: **1** — cherty limestones — Jurassic–Neocomian, **2** — variegiated shales — Upper Cretaceous, **3** — Sztolnia Beds — Lower Cretaceous, **4** — Sprzycne Beds — Cenomanian, **5** — variegiated shales/Upper Cretaceous/+green shales with Mn-oxides coatings, **6** — tectonically brecciated black shales, **7** — Pomiedznik Beds — Lower Cretaceous, **8** — variegiated marls and marly limestones /"Puchov Marls"/. **x** — thrust of the Czorsztyn Unit.

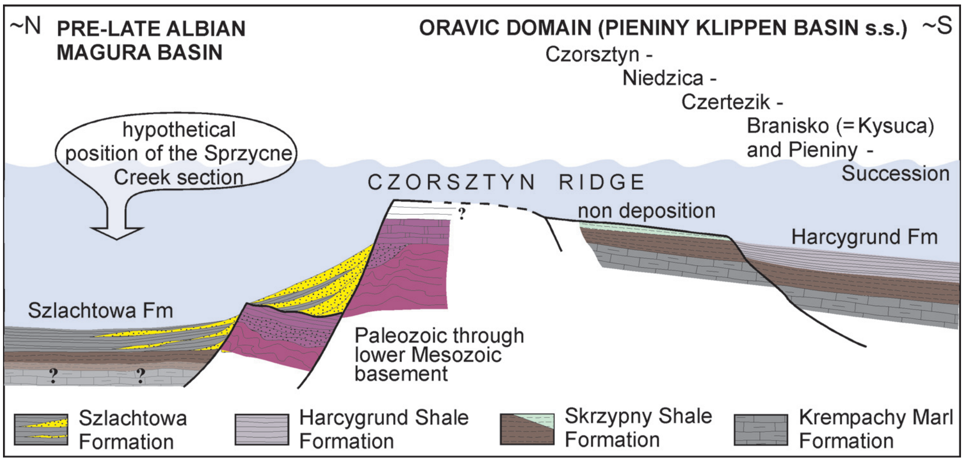

Fig. 3. Idealized arrangement of facies zones and corresponding lithostratigraphic units of the Oravicum domain and pre-Late Albian Magura Basin in the early Early Bajocian (modified from Barski et al. 2012).

Location and geological setting of the Sprzycne Creek section

The uppermost tectonic unit at Dursztyn is represented by the Pieniny Nappe, formed mainly by cherty maiolica-like limestones and radiolarites of the Branisko Succession (Fig. 4). The Jurassic/Lower Cretaceous klippen of the Czorsztyn Succession and their marly envelope occupy the adjacent zone to the north. The Sprzycne Creek section (analysed in this study) is located still further to the north and is thus tectonically below the Czorsztyn Succession; it represents the paleogeographical area lying north of the Czorsztyn zone. The northernmost chain of isolated rigid tectonic units formed by red radiolarites and maiolica limestones (the contact of the latter with the Kapuśnica Formation is visible north of the site in the Sprzycne Creek cutting) has an unknown structural affinity. It either represents a tectonic slice (or syn-thrusting olistoliths) of the Pieniny Nappe or a facies equivalent of the Branisko-Pieniny Succession in the pre-Late Albian Magura Basin. The thick sequence of clastics along the northern margin of the Klippen Belt (Jarmuta Formation) is a remnant of foreland sediments deposited during

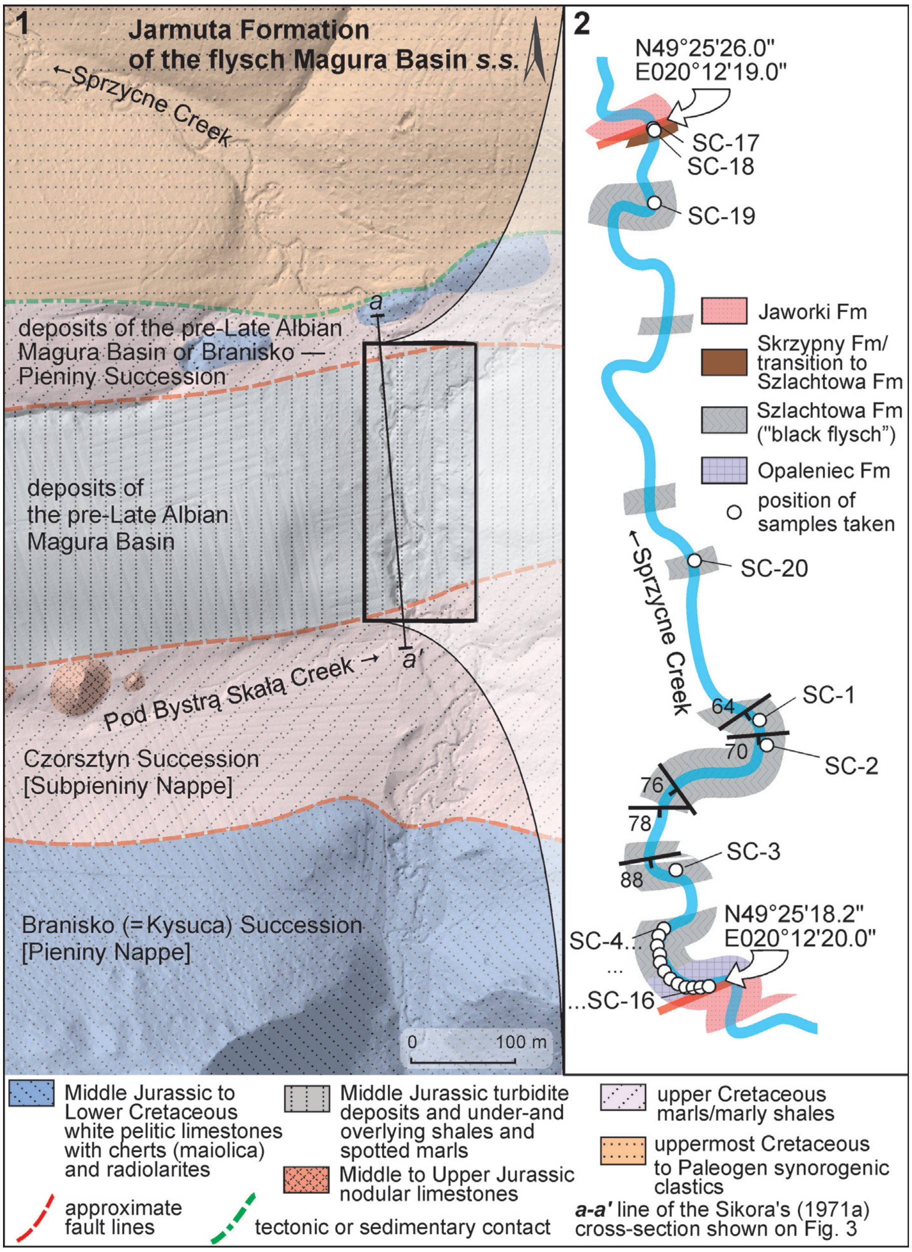

Fig. 4. Geological situation of the Sprzycne Creek section. **1** — simplified bedrock map of the area between Dursztyn and Frydman — see Fig. 1.2 for location, **2** — exposed intervals of strata with sample locations.

the Laramian thrusting of the Pieninic nappes (cf. Jurewicz 1997) and belongs to the flysch Magura Basin.

The Sprzycne Creek section is located geographically on the northern slope of the Pieniny Spiskie range, 1.5 km northeast of Dursztyn village (Figs. 1, 4). The deposits crop out along the Sprzycne Creek over a distance of about 240 m heading upstream. Coordinates of the beginning of the section are: N 49°25′26.0″, E 020°12′19.0″. The approximately 200 m-thick succession is exposed in the stream bed and the erosion escarpments. The lower half of the section is poorly exposed, whereas the upper part is more continuous. The beds are generally inclined steeply towards the south in the lower and middle parts of the sequence (60–80°) but become nearly vertical or even somewhat overturned in the upper part. The Middle Jurassic portion of the Sprzycne Creek section is mantled by variegiated Cretaceous red and grey marls, visible both at its base and top.

Material and methods

The chronostratigraphic position of each sample from the Sprzycne section was evaluated on the basis of the reference ranges of diagnostic dinoflagellate cysts, with notation of the chronozones as defined after the ammonite faunas according to Callomon (1995), with the exception of the Jaworki Formation that is barren of palynomorphs. This study was focused on the species most significant from a stratigraphic point of view, while the complete spectra of the dinoflagellate cyst assemblages will be published elsewhere. The first (FAD) and last appearance data (LAD) of selected dinoflagellate cyst species are extracted from several references, prioritized according to publication date and paleogeographic affinity with the northern Tethyan margin. Some differences between the ranges of dinoflagellate cysts in the Pieniny/pre-Late Albian Magura Basins, which belonged to the Tethys Realm, and the ranges recorded in epiplatform areas of Europe should be taken into account. The LAD-based chronostratigraphic inferences may also be affected by redeposition. Twenty samples were taken from the section: two samples represent the Skrzypny-Szlachtowa Formation transition, ten samples represent the typical Szlachtowa Formation and eight samples represent the Opaleniec Formation (Figs. 4, 5). Two other samples were taken from the basis of the section: the lowermost sample (SC-17) was picked from between two layers of siderite concretions, while the second sample (SC-18) came from above the micaceous sandstone bed, at a distance of about 0.8 m above the first (Fig. 6.1). The sampling frequency in the Szlachtowa Formation was higher in the topmost, artificially exposed part of the formation (the interval 54–62 m on Fig. 5), up to the contact with the overlying Opaleniec Formation. The lithologies of the samples consist

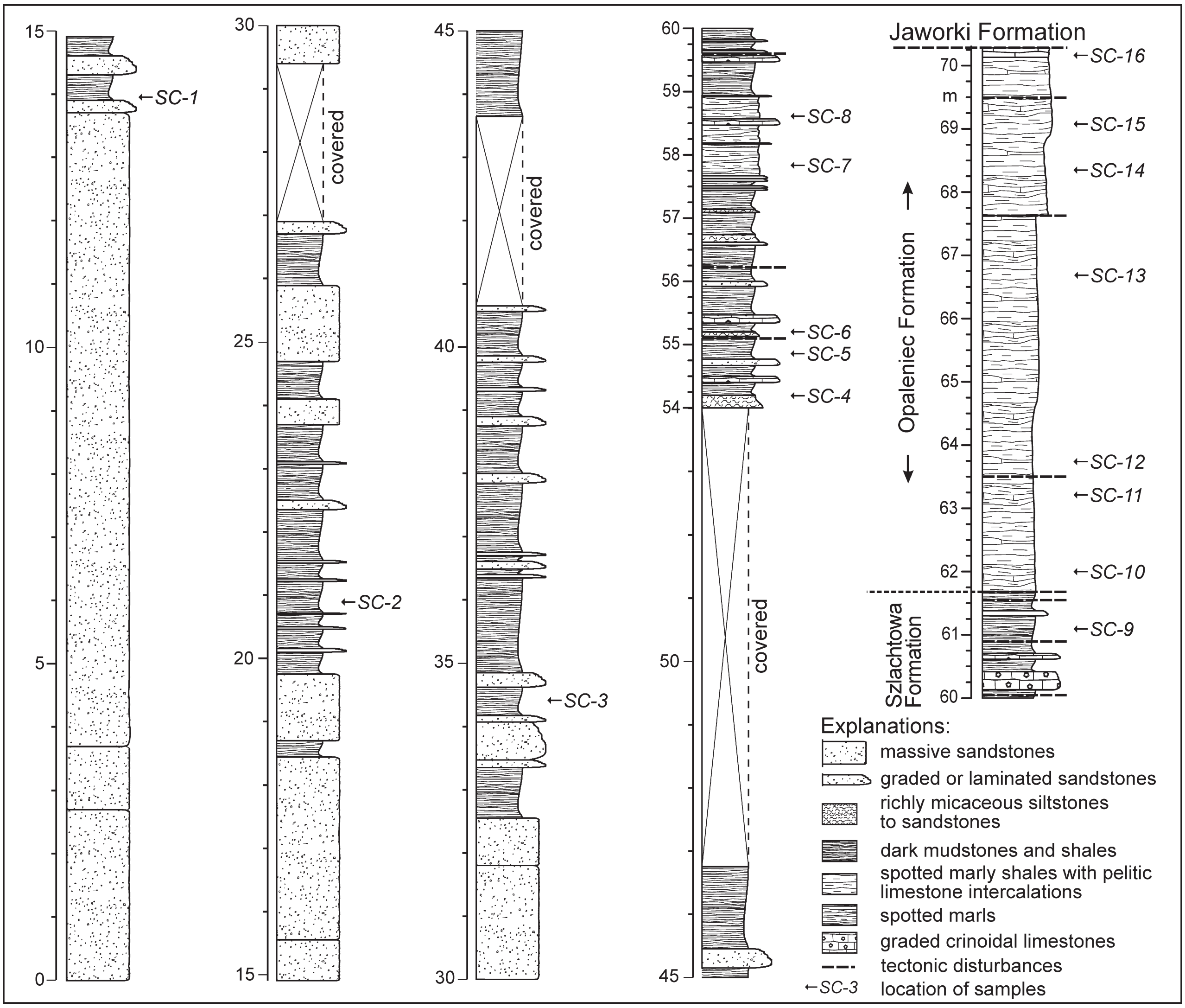

Fig. 5. Columnar lithological section of the upper part of the Szlachtowa Formation and the Opaleniec Formation in Sprzycne Creek at Dursztyn, Pieniny Klippen Belt, Poland.

of marls, shales and siltstones. The rock samples were processed in compliance with standard palynological procedure (Traverse 2007), which involved concentrated chloric and fluoric acid treatment, wet sieving through a 15 μm nylon mesh, and glycerin-jelly slide mounting. Thin-sections were prepared to distinguish lithologically similar marly intervals by means of microfacies. Planktonic foraminifera, which were found only in the sections representing the Jaworki Formation, provide some complementary stratigraphic data.

Results

Lithological succession and microfacies

The section starts with a few meters (not fully exposed) of crumpled, slightly lustrous black shales with tabular sideritic concretions up to ~20 cm in length (Fig. 6.1,3). This lithofacies corresponds best to the Skrzypny Formation (Birkenmajer 1977), with the exception of some beds a few cm-thick of turbiditic micaceous sandstones/siltstones. It is unclear whether such packets are of tectonic or sedimentary character; in the first case they could be the slices of the overlying Szlachtowa Formation, alternatively the described interval as a whole can represent a sedimentary transition from the topmost Skrzypny Formation into the Szlachtowa Formation. The second eventuality, in the light of the stratigraphic evidence (see below) seems to be reasonable and is accepted herein.

Dark shales and siltstones alternating with sandstone turbidites are characteristic of the central, thickest part of the section (Fig. 5). These deposits with the appearance of turbiditic beds, considering their lithological characteristics given below, belong to the Szlachtowa Formation (cf. Birkenmajer 1977). The proportion of shales and sandstones varies upwards. The patchily exposed lower part of the unit is mostly composed of shales with frequent but volumetrically subordinate, up to 20 cm-thick sandstone layers. The

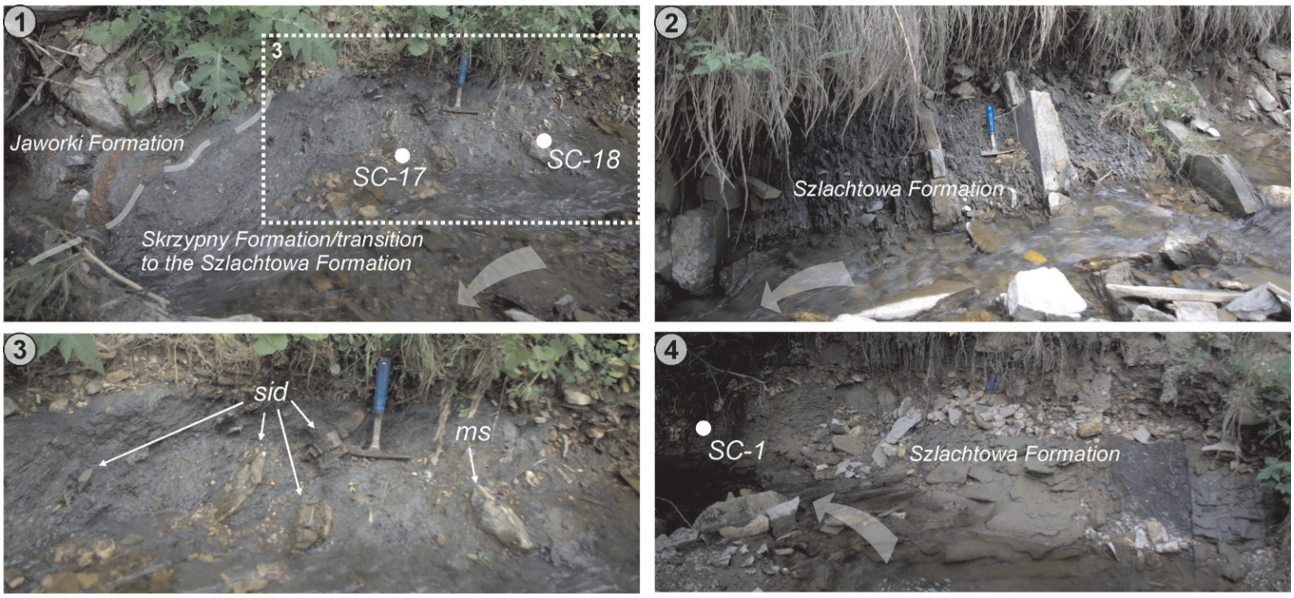

Fig. 6. Lower and middle part of the Sprzycne Creek section (2014). **1, 3** — tectonic contact of the Jaworki Formation with the Skrzypny Formation/transition to the Szlachtowa Formation (*sid* — siderite concretions, *ms* — micaceous sandstone bed); **2** — shale-dominated interval of the Szlachtowa Formation (~2 m above sample SC-3); **4** — brittle sandstone-dominated interval of the Szlachtowa Formation; white dots indicate sample locations.

first thicker (~1.3 m) bed of sandstone is exposed about half way up the section. The lower 20 m of the relatively well exposed topmost 60 m-thick interval of the Szlachtowa Formation consists of thick-bedded sandstones with rare shale interbeds (Figs. 5, 6.4), while the overlying 40 m-thick interval is generally shale-dominated (Figs. 5, 6.2), with sandstone beds not exceeding 0.4 m in thickness (except for the interval 24.7–34 m, where massive sandstones prevail). Graded, well-bedded sandstones to siltstones rich in mica flakes are typical of the thin hard layers and they testify, along with hieroglyphs (casts), that strata are not overturned. Thick sandstone beds are often coarse-grained, brittle, and poorly consolidated. They are weathered to almost the same degree as the shale interbeds. They are also internally homogeneous and often synsedimentarily disturbed in the form of large-scale bulbous load casts; they represent possible fluxoturbidites. Abundant mica flakes impart a lamination to the topmost parts of the sandstone-siltstone sets, and an admixture of crinoidal ossicles is common. The shales and mudstones are also usually micaceous, black or grey in colour, and they locally contain plant debris and thin coal laminae. A few beds of allodapic crinoidal limestones (up to 0.3 m in thickness) and an interval with yellowish-grey spotted marls occur in the artificially exposed uppermost eight meters of the Szlachtowa Formation (Figs. 5, 7.3).

The contact of the Szlachtowa Formation with younger deposits of the Opaleniec Formation is tectonic. It is marked by calcitic veins and by a strong deformation of the surrounding deposits. The top 8 m of the entire section consists mostly of spotted marls and marly shales with a few thin intercalations (0.01–0.1 m in thickness) of nodular spotted limestones (Figs. 5, 7.1,4). These deposits can be subdivided into two lithological types lying in a stratigraphic continuity: a 5.5 m-thick interval of grey or greenish brittle marls, and an about 2.5 m-thick interval of harder, slightly darker marly shales with yellowish-brownish Fe/Mn coating. Marly limestones show the microfacies dominated by filaments (*Bositra*) (Fig. 8.1). The whole interval of the Jurassic spotted marls in Sprzycne Creek thus represents the Opaleniec Formation in its typical development (cf. Birkenmajer 1977). The contact with the Cretaceous deposits is of tectonic character, marked by a well developed, nearly vertical tectonic zone which stretches approximately ENE–WSW along the stream (Fig. 7.2).

The Cretaceous deposits are represented by variegated, locally spotty, grey-green and red marly shales with subordinate marly limestone intercalations (Scaglia Rossa-type deposits). They are characterized by slightly silicified radiolarian-foraminifera wackestone to mudstone microfacies (Fig. 8.2–4). These deposits can probably be attributed to the Jaworki Formation (of Birkenmajer 1977). They may correspond to those from which Sikora (1971 a) reported the foraminifer *Uvigerinammina jankoi* Majzon. They are in tectonic contact to the south with the deposits of the Czorsztyn Succession (Sikora 1971a; see Fig. 2 herein).

Biostratigraphy

Skrzypny Formation (topmost/transitional part)

The samples SC-17 and SC-18 contain very similar dinoflagellate cyst assemblages characterized by high abundance of *Adreedinium elongatum* (=*Phallocysta elongata*). Other stratigraphically meaningful species are represented by *Nannoceratopsis dictyambonis*, *Nannoceratopsis evae*, *Pareodinia ceratophora* and *Dissiliodinium lichenoides* (Figs. 9, 10). The lower stratigraphic limit of *P. ceratophora*

Fig. 7. Uppermost part of the Sprzycne Creek section (2013/2014). **1** — general view from the stream scarp to NW and the position of the 2, 3 and 4; **2** — tectonic contact of the Opaleniec and Jaworki formations in the stream bed; **3** — artificially exposed topmost part of the Szlachtowa Formation at the contact with the Opaleniec Formation; **4** — exposure of the Opaleniec Formation; panorama views 3 and 4 are somewhat distorted, white dots indicate sample locations, hashed lines indicate tectonic disturbances. *ct* — crinoidal turbidite beds.

according to Riding & Thomas (1992) spans the undifferentiated Middle Aalenian, but some detailed reports show its later appearance in the Late Aalenian (Feist-Burkhardt 1990; Riding et al. 1991) or earliest Bajocian (Riding 1987). This species occurs already in the Late Aalenian of the Pieniny Klippen Belt (Segit 2010). *D. lichenoides*, as well as *Evansia eschachensis* recognized in sample SC-17, also do not occur below the upper Middle Aalenian and Upper Aalenian, re-

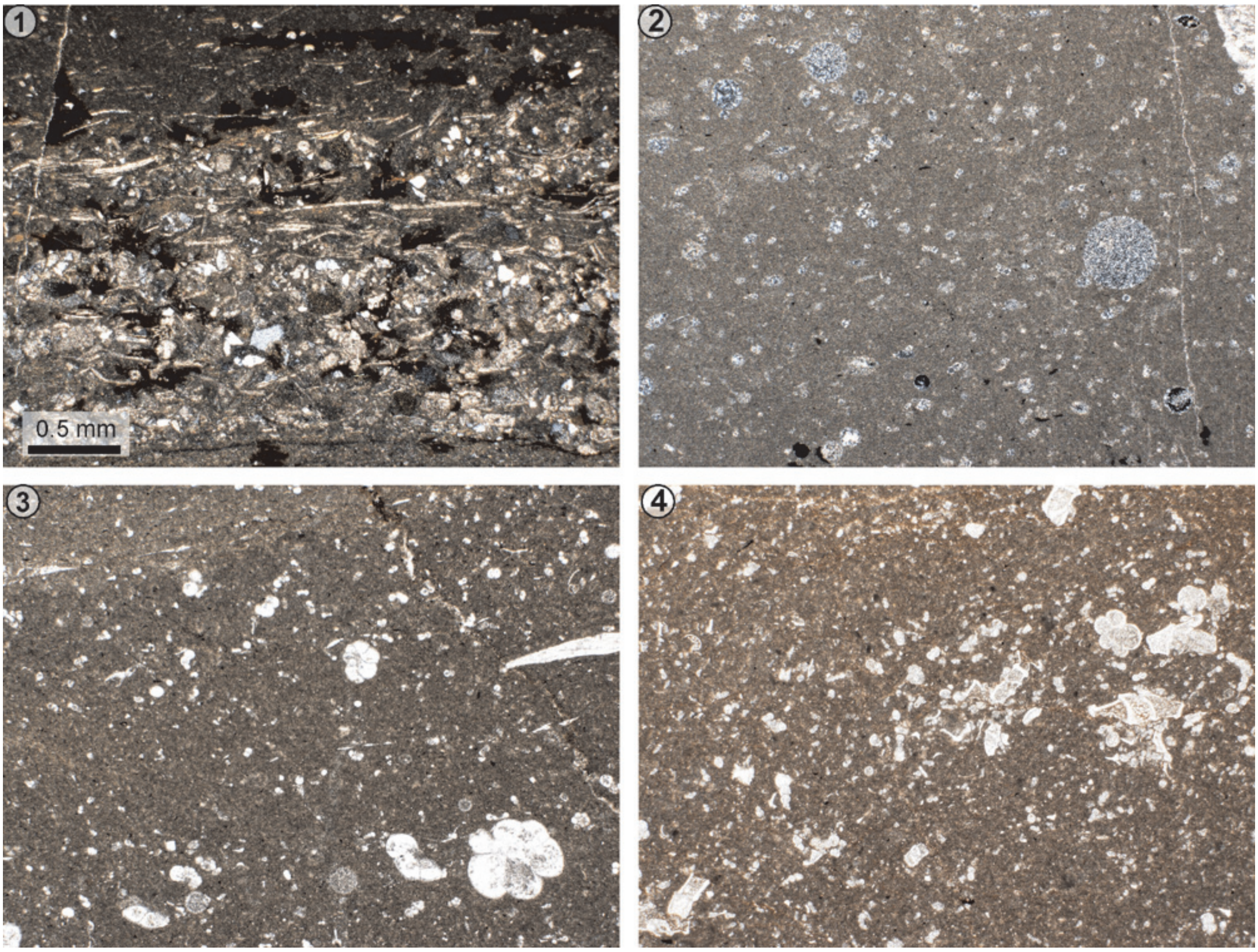

Fig. 8. Typical microfacies of the Middle Jurassic and Cretaceous marly deposits from the Sprzycne Creek section, Pieniny Klippen Belt, Poland. **1** — filamentous (Bositra) packstone with quartz admixture (thin hard limestone bed with Fe-Mn coatings, upper part of the Opaleniec Formation, Middle Jurassic); **2–4** — radiolarian/radiolarian-foraminifera wackstones, slightly silicified (Jaworki Formation, upper Cretaceous); fot. 1 and 2 — crossed nicols. Scale bar applies to all micrographs.

spectively, either in the PKB or elsewhere (Feist-Burkhardt & Monteil 2001). The upper stratigraphic limits of most of the species mentioned above lie in the Laeviuscula or Propinquans Zones of the Lower Bajocian; only the LAD of *N. evae* is restricted to the Discites Zone of the lowermost Bajocian (Prauss 1989). The absence of *Scriniocassis priscus* (common in lower Aalenian and ranging up to the Upper Aalenian in the PKB, Segit 2010), and *Dissiliodinium giganteum* and *Durotrigia daveyi* (typical of the upper Lower Bajocian, Fig. 9) is noteworthy. To conclude, the most probable age of the topmost part of the Skrzypny Formation is the latest Late Aalenian or the earliest Early Bajocian (late Concavum to Discites Zone).

Szlachtowa Formation

The sample SC-19 is almost the same as SC-17 and SC-18 with regard to its dinoflagellate cyst assemblage, with the exception of relative abundance of individual species. Despite the general paucity of marine palynomorphs, most samples of the Szlachtowa Formation from the Sprzycne Creek section contain stratigraphically diagnostic representatives of the *Durotrigia*, *Dissiliodinium* and *Aldorfia* (Figs. 9, 10). Earlier studies have revealed these genera are locally abundant at other sites exposing the Szlachtowa Formation (Segit 2010; Barski et al. 2012). *Dissiliodinium giganteum*, which is a marker species for the Discites/Laeviuscula–Propinquans zones of the Early Bajocian in south-west Germany (Feist-Burkhardt & Wille 1992; Feist-Burkhardt & Monteil 2001), occurs in samples SC-20, SC-1, SC-2, and SC-5. The presence of *Mancodinium semitabulatum* (providing its in-situ occurrence) restricts the top position of sample SC-6 to the Humphriesianum Zone. *Durotrigia daveyi*, with its lower limit in the Laeviuscula Zone and the top in the Niortense Zone of the Late Bajocian (Feist-Burkhardt & Wille 1992), occurs in samples SC-1, SC-2, SC-3 and SC-9, while the *Durotrigia* occurs in all samples except for SC-8 and SC-7. In the uppermost exposed beds of the Szlachtowa Formation, *D. daveyi* co-occurs with *Aldorfia aldorfensis* (sample SC-9). The topmost beds of the Szlachtowa Formation exposed in the Sprzycne Creek section thus can be attributed to the lowermost Upper Bajocian because

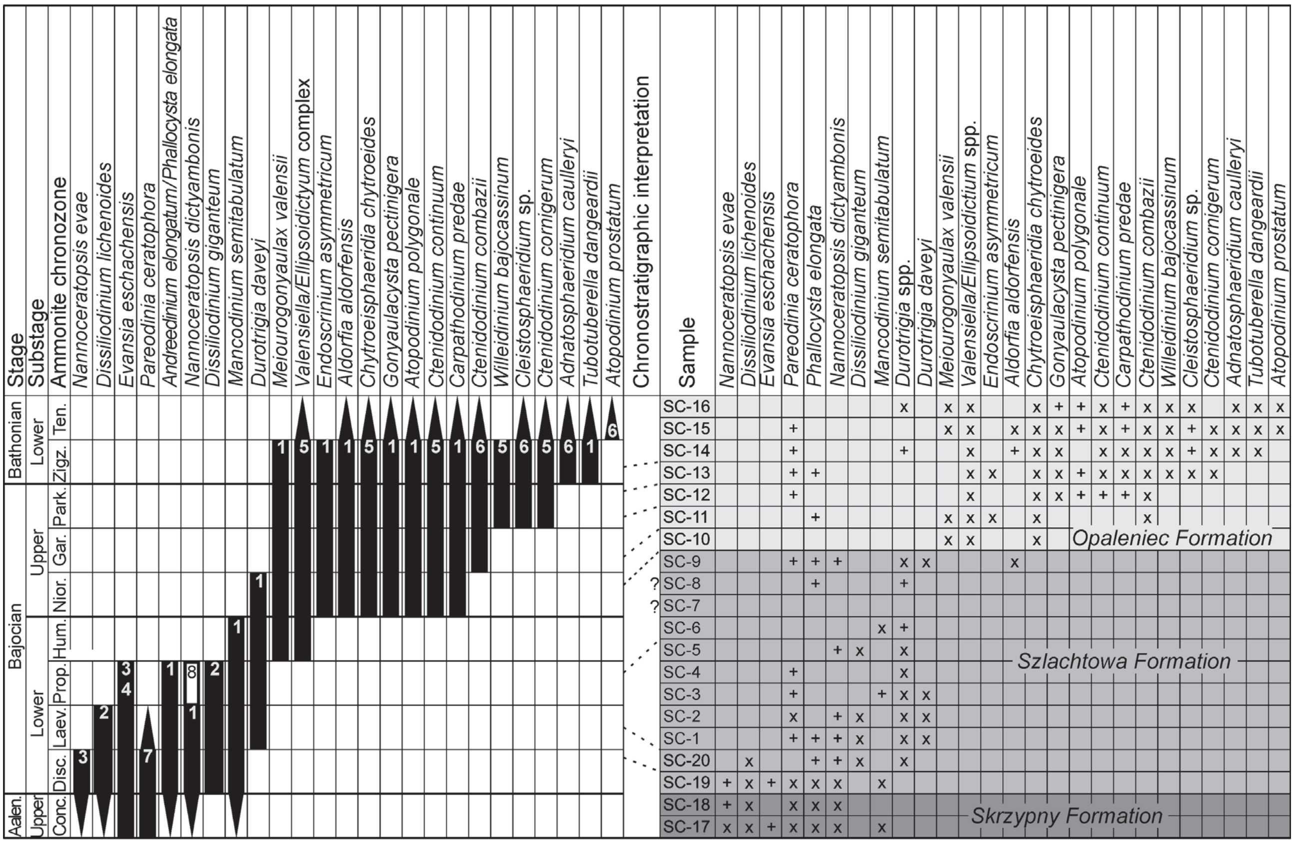

Fig. 9. Stratigraphic range chart compiled from: **1** — Feist-Burkhardt & Wille (1992), **2** — Feist-Burkhardt & Monteil (2001), **3** — Prauss (1989), **4** — Burkhalter et al. 1997, **5** — Feist-Burkhardt & Monteil (1997), **6** — Riding & Thomas (1992), **7** — Feist-Burkhardt (1990), **8** — extended ranges observed in the PKB (Segit 2010), and distribution of the selected dinoflagellate cysts in the Sprzycne Creek section. Approximate stratigraphic positions of samples are given (see also Fig. 13) (**x** — common to rare occurrence, **+** — very rare or single occurence, some specimens may be redeposited).

the FAD of *A. aldorfensis* is located in the Niortense Zone (Feist-Burkhardt & Wille 1992).

Sample SC-7 contains a species and specimen-poor assemblage of exclusively long-ranging or stratigraphically non-diagnostic taxa (such as *Nannoceratopsis gracilis*, *Kallosphaeridium praussii* and *Batiacasphaera* sp.), while sample SC-8 also contains *Andreedinium elongatum* (=*Phallocysta elongata*) and rare *Scriniocassis priscus*. These two latter species, otherwise abundant in the ammonite-constrained Aalenian strata of the Skrzypny Formation in the Pieniny Klippen Belt (Segit 2010) and, in the case of *A. elongatum*, also common in the lowermost samples SC-17, SC-18 and SC-19 of the Sprzycne section, could span the Early Bajocian (Riding & Thomas 1992; Feist-Burkhardt & Wille 1992). Assuming that the strata are tectonically not duplicated, the superposition of sample SC-8 above sample SC-7 shows that both are in fact not older than the late Early Bajocian (Fig. 9). This inference is also supported by the occurrence of rare *Durotrigia* sp. in sample SC-8. The Triassic cysts of *Rhaetogonyaulax rhaetica* consistently present throughout the section suggest that some Toarcian–Aalenian sediments (where these cysts are encountered commonly) were affected by synsedimentary redeposition and thus enriched the Bajocian strata with older cysts.

Dinocyst stratigraphy indicates that the sample SC-19 taken from the lowermost part of the Szlachtowa Formation *s.s.* (above the transition from the topmost Skrzypny Formation; see Fig. 4.2), represents the upper Concavum Zone of the Late Aalenian or the Discites Zone of the earliest Bajocian. The interval between the samples SC-20 and SC-5 probably represents the Laeviuscula and/or Propinquans zones of the Early Bajocian, the dinocyst-poor sample SC-6 could reach up to the Humphriesianum Zone, and the sample SC-9 corresponds to the Niortense Zone of the Late Bajocian (Figs. 9, 13). Due to the paucity of dinoflagellate cysts and dominance of long-ranging taxa, samples SC-7 and SC-8 can be assigned to Laeviuscula–Niortense zones.

Opaleniec Formation

The dinoflagellate cyst assemblages in the lowermost part of the Opaleniec Formation (Figs. 9, 11, 12) differ distinctly from the underlying beds of the Szlachtowa Formation, following a slight tectonic displacement at the contact of the units (Figs. 5, 7.4). The stratigraphically diagnostic species that were encountered in sample SC-10 are *Meiourogonyaulax valensii* (dominant in the assemblage) and the *Valensiella/Ellipsoidictyum* plexus, both having their FAD

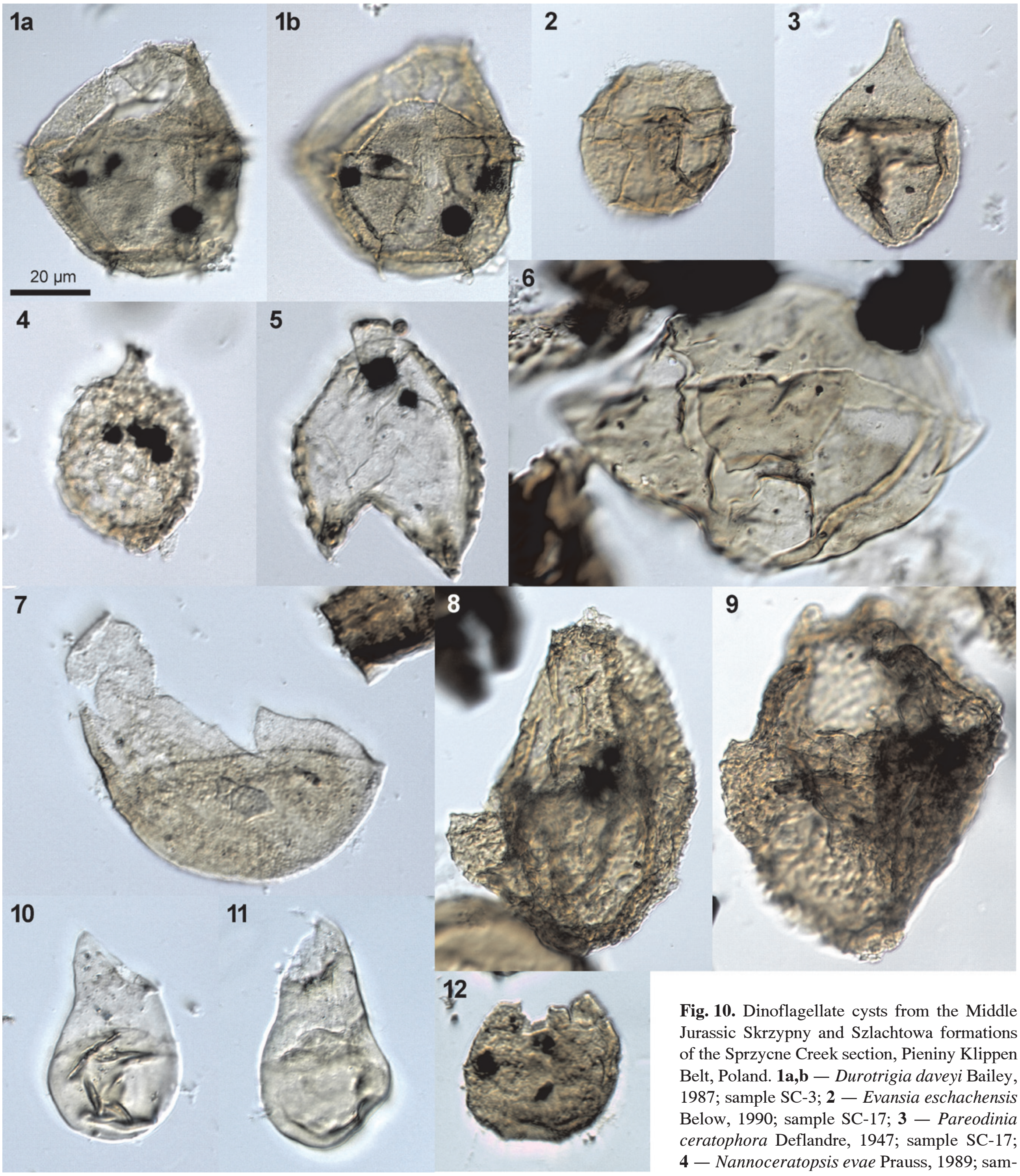

Fig. 10. Dinoflagellate cysts from the Middle Jurassic Skrzypny and Szlachtowa formations of the Sprzycne Creek section, Pieniny Klippen Belt, Poland. **1a,b** — *Durotrigia daveyi* Bailey, 1987; sample SC-3; **2** — *Evansia eschachensis* Below, 1990; sample SC-17; **3** — *Pareodinia ceratophora* Deflandre, 1947; sample SC-17; **4** — *Nannoceratopsis evae* Prauss, 1989; sample SC-17; **5** — *Nannoceratopsis dictyambonis* Riding, 1984a; sample SC-17; **6** — *Dissiliodinium giganteum* Feist-Burkhardt, 1990; sample SC-1; **7** — *Dissiliodinium lichenoides* Feist-Burkhardt & Monteil, 2001; sample SC-17; **8, 9** — *Aldorfia aldorfensis* (Gocht, 1970) Stover & Evitt 1978; sample SC-9; **10**, **11** — *Anreedinium elongatum* (Beju, 1971) Feist-Burkhardt & Monteil in Feist-Burkhardt 1990; sample SC-17; **12** — *Mancodinium semitabulatum* Morgenroth, 1970; sample SC-3. Scale bar applies to all photographs.

in the upper Humphriesianum Zone of the Early Bajocian. *Chytroeisphaeridia chytroeides* has its FAD in the Niortense Zone of the Late Bajocian (Feist-Burkhardt & Wille 1992; Feist-Burkhardt & Monteil 1997). Early *Meiourogonyaulax* species (of which *M. valensii* is a representative) were reported to be very common below the Early-Late Bajocian boundary in southwest Germany (Feist-Burkhardt & Wille 1992). Sample SC-11 also yielded *Endoscrinium asymmet-*

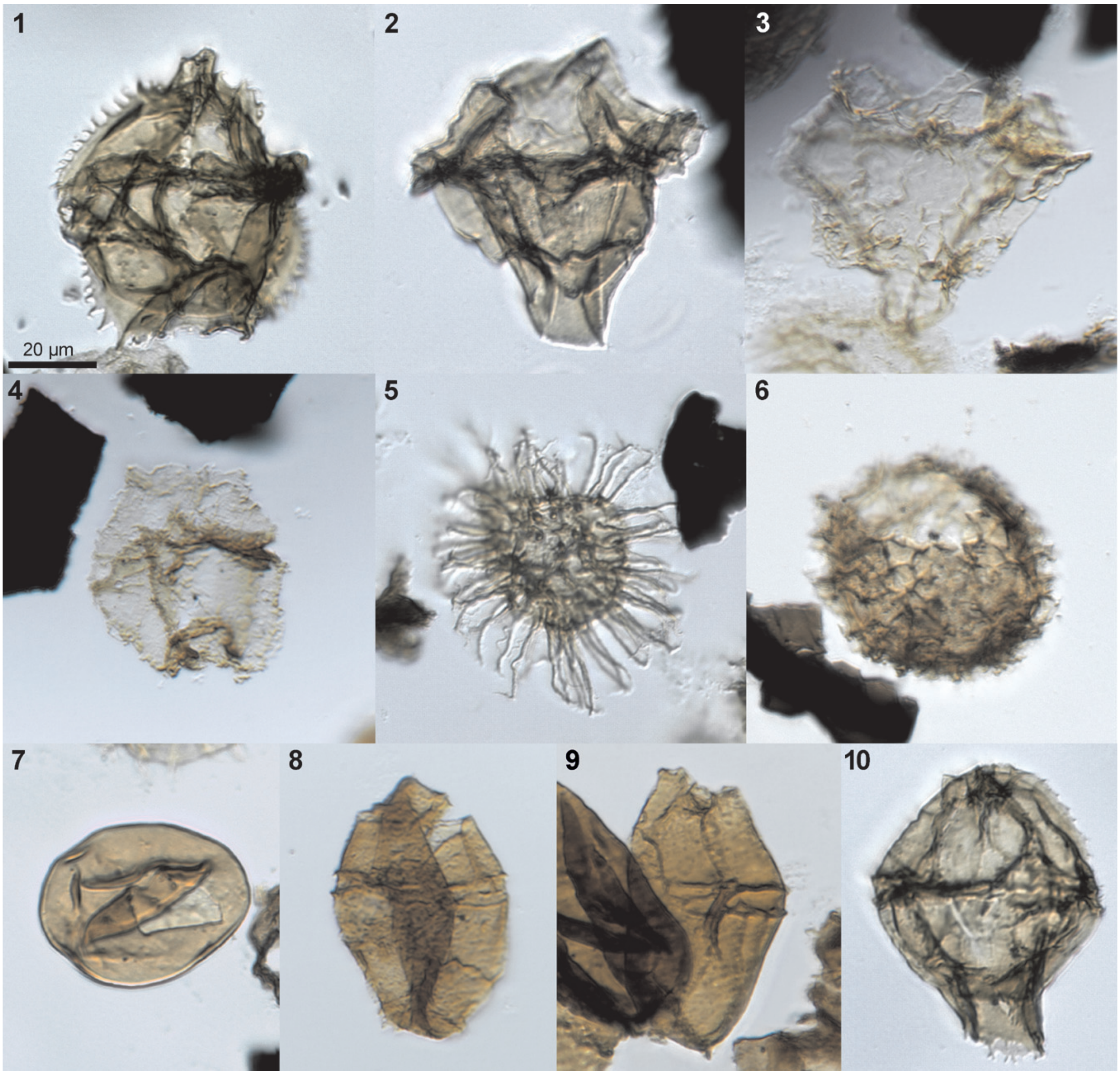

Fig. 11. Dinoflagellate cysts from the Middle Jurassic Opaleniec Formation of the Sprzycne Creek section, Pieniny Klippen Belt, Poland. **1** — *Gonyaulacysta pectinigera* (Gocht, 1970) Fensome 1979; sample SC-13; **2** — *Endoscrinium asymmetricum* Riding, 1987; sample SC-13; **3** — *Atopodinium polygonale* (Beju, 1983) Masure 1991; sample SC-15; **4** — *Atopodinium* cf. *prostatum* (Drugg, 1978) Masure 1991; sample SC-15; **5** — *Cleistosphaeridium* sp.; sample SC-15; **6** — *Valensiella* cf. *ovulum* (Deflandre, 1947) Eisenack 1963; sample SC-15; **7** — *Chytroeisphaeridia chytroeides* (Sarjeant, 1962) Davey 1979; sample SC-15; **8, 9** — *Carpathodinium predae* (Beju, 1971) Drugg 1978; sample SC-15; **10** — *Tubotuberella dangeardii* (Sarjeant, 1968) Sarjeant 1982; sample SC-14. Scale bar applies to all photographs.

ricum (with its FAD in the Niortense Zone), and *Ctenidodinium combazii*, which has its lower limit in the Garantiana Zone (Riding & Thomas 1992) or even the uppermost Parkinsoni Zone of the Late Bajocian (Feist-Burkhardt & Wille 1992). Species appearing at the base of the Upper Bajocian, namely *Ctenidodinium continuum*, *Carpathodinium predae*, *Gonyaulacysta pectinigera* and *Atopodinium polygonale*, occur in sample SC-12. *Cleistosphaeridium* sp. and *Willeidinium bajocassinum* (with FAD recorded in the Parkinsoni Zone) occur in the section from sample SC-13 upwards. *Ctenidodinium cornigerum*, also recognized in that sample, has not been observed yet below the uppermost part of the Parkinsoni Zone (Feist-Burkhardt & Monteil 1997) or even Zigzag Zone (Riding & Thomas 1992; Poulsen 1998) of the Upper Bajocian, while *E. asymmetricum*, on the other hand, declined in the Zigzag Zone (Feist-Burkhardt & Wille 1992). Sample SC-14 yielded specimens of *Adnatosphaeridium caulleryi* and *Tubotuberella dangeardii,* with FAD diagnostic of the Zigzag Zone (Riding & Thomas 1992; Feist-Burkhardt & Wille 1992) or Tenuiplicatus Zone

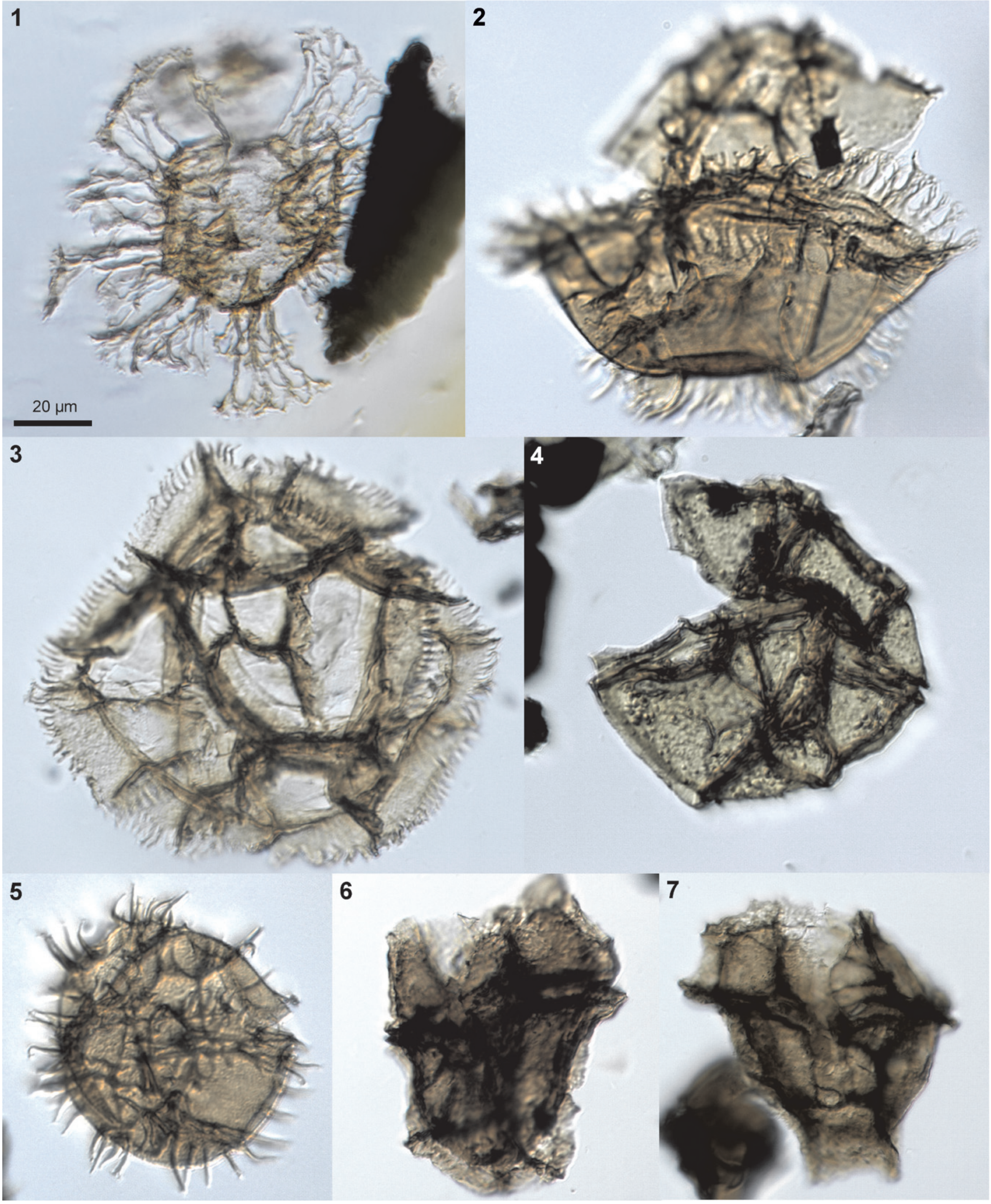

Fig. 12. Dinoflagellate cysts from the Middle Jurassic Opaleniec Formation of the Sprzycne Creek section, Pieniny Klippen Belt, Poland. **1** — *Adnatosphaeridium caulleryi* (Deflandre, 1939) Williams & Downie 1969; sample SC-16; **2** — *Ctenidodinium combazii* Dupin, 1968; sample SC-14; **3** — *Ctenidodinium continuum* Gocht, 1970; sample SC-14; **4** — *Willeidinium bajocassinum* Feist-Burkhardt, 1995; sample SC-14; **5** — *Ctenidodinium cornigerum* (Valensi, 1953) Jan du Chęne et al. 1985; sample SC-14; **6, 7** — *Meiourogonyaulax valensii* Sarjeant, 1966b; sample SC-10. Scale bar applies to all photographs.

of the Early Bathonian (in the case of *A. caulleryi* in Feist-Burkhardt & Wille 1992). The stratigraphy of samples SC-15 and SC-16 is based on the co-occurrence of *Carpathodinium predae*, *Atopodinium prostatum* and *Willeidinium bajocassinum*. The upper limit of *Carpathodinium predae* usually spans the Middle Bathonian Progracilis Zone (Riding & Thomas 1992) or Morrisi Zone (Feist-Burkhardt & Wille 1992). Although the FAD of *A. prostatum* was recorded in the Tenuiplicatus Zone (Riding & Thomas 1992), while *W. bajocassinum*, according to Feist-Burkhardt (1995) and Feist-Burkhardt & Monteil (1997), has its LAD in the Zigzag Zone, both species were listed by Poulsen (1998, fig. 3 therein) from the Tenuiplicatus Zone in the Ore Bearing Częstochowa Clay Formation in southern Poland (although *W. bajocassinum* is very rare and was not illustrated). *M. valensii* with its LAD in the Zigzag Zone implies that the sample SC-14 still belongs to the lower Lower Bathonian.

The stratigraphy of the Opaleniec Formation is deduced mainly on the basis of FADs; only a few species went extinct in the Early Bathonian. To conclude, the diagnostic species appear in the section of the Opaleniec Formation in a general stratigraphic order that corresponds to the successive zones of the Late Bajocian and Early Bathonian. Tectonics affects the stratigraphic continuity of the transition from the Szlachtowa Formation to the Opaleniec Formation only weakly, leaving probably a stratigraphic gap that spans only a part of the Niortense Zone. The samples can thus be assigned to the interval from the Niortense Zone of the Late Bajocian up to the Zigzag or Tenuiplicatus Zones of the Early Bathonian (Figs. 9, 13).

Jaworki Formation

No dinoflagellate cysts were found in the marly deposits of the Jaworki Formation. The analyses of planktonic foraminifera carried out on thin sections (Dr. Zofia Dubicka, pers. comm.) revealed some Upper Albian taxa in the grey-greenish spotted marl samples taken from immediately above the contact with the Opaleniec Formation and Turonian taxa in the red marl samples taken a few meters above the former (possible tectonic gaps occur between the sampling points).

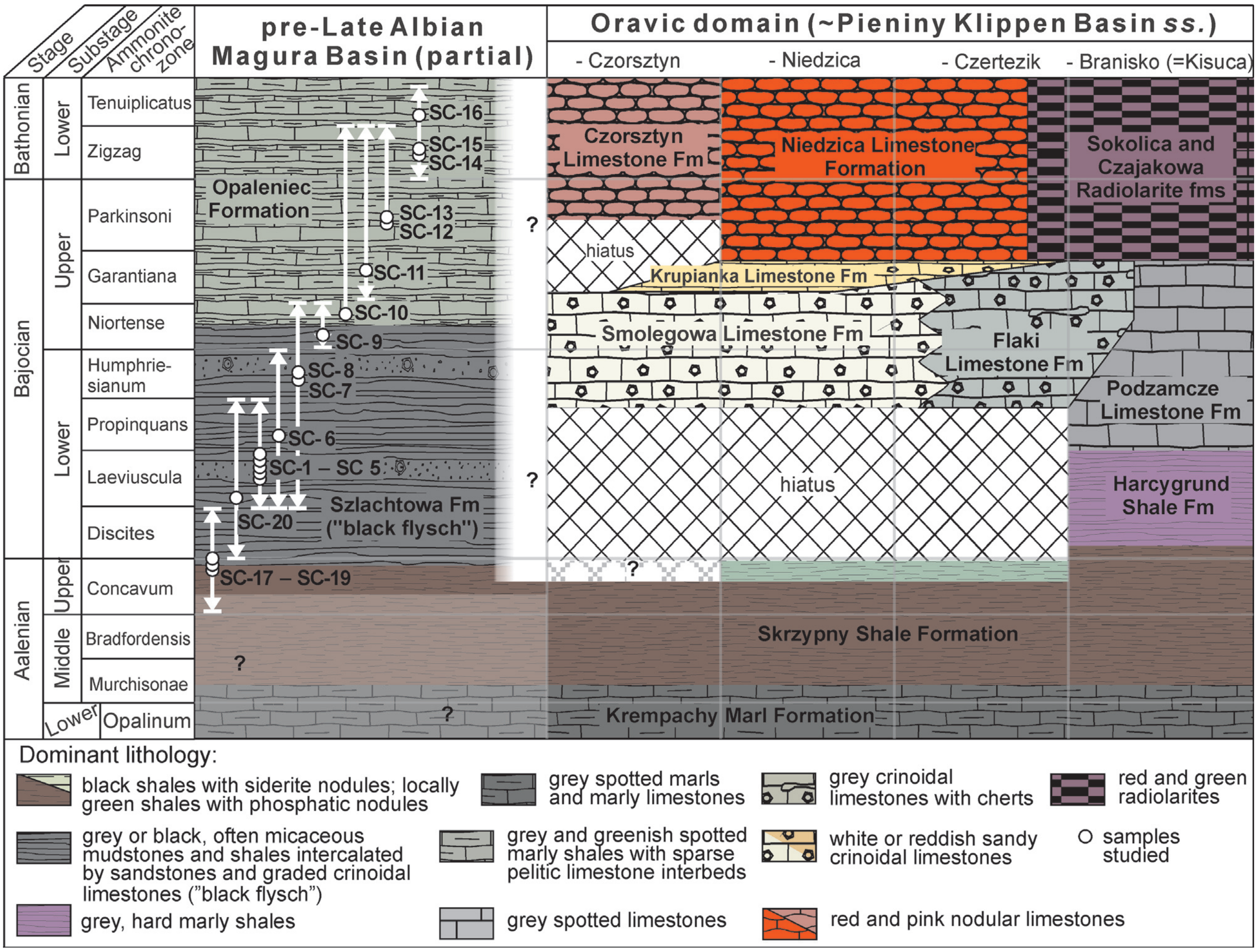

Fig. 13. Lithostratigraphic scheme of the Aalenian–Lower Bathonian (Middle Jurassic) of the Pieniny Klippen Belt (after Wierzbowski et al. 2004; Segit 2010, modified). Stratigraphic positions of samples studied from the Sprzycne Creek section are shown; the arrowed intervals indicate maximum possible range based on dinoflagellate cyst co-occurrences and superposition.

Discussion

Stratigraphy of the turbidite succession (Szlachtowa Formation)

The deposits of the Szlachtowa Formation of Sprzycne Creek contain dinoflagellate cyst assemblages characteristic of the Late Aalenian or Early Bajocian to early Late Bajocian age. The upper portion of the Szlachtowa Formation is practically of the same age as in sections studied previously at Podubocze and Hałuszowa near Czorsztyn in the Pieniny Klippen Belt (Barski et al. 2012) and consistent with some of the stratigraphic assessments given by Gedl (2008a,b). However, the onset of turbidite sedimentation in the pre-Late Albian Magura Basin and the character of the underlying strata remains controversial.

The Lower Aalenian ammonites *Leioceras opalinum* and *Leioceras* cf. *comptum* were described from the Szlachtowa Formation in the Sztolnia creek section south of Szlachtowa village (Birkenmajer & Myczyński 1977). Notwithstanding the very poor state of preservation of this assemblage, as well as the marked tectonic disturbance of the section and the untypical lithology of the host rock (spotted limestones resembling the Krempachy or Opaleniec formations rather than the Szlachtowa Formation), the assumption about the existence of Upper Toarcian–Lower Aalenian strata within the Szlachtowa Formation deposits persisted (Birkenmajer 1977). Such a view suggesting that the deposition of the Szlachtowa Formation started during the Toarcian was repeated also by Gedl (2008a, 2013) and Gedl & Józsa (2015).

According to Gedl (2008a, fig. 165), in addition to the upper Upper Aalenian and Bajocian, also the lower Upper Toarcian is represented in the Szlachtowa Formation, whereas the uppermost Toarcian to lower Upper Aalenian interval is spanned by sedimentary hiatus. The Toarcian cyst-based ages, however, were based on mostly poorly-preserved assemblages consisting mostly of long-ranging and weakly-specific representatives of *Nannoceratopsis* spp. and *Kallosphaeridium* spp., to a total absence of taxa restricted to the Toarcian. There are also no sedimentary indices of non-deposition in the middle, or in any other parts of the Szlachtowa Formation. The Toarcian age of the deposits of the Szlachtowa Formation in the Podubocze section as proposed by Gedl (2008a) was questioned by Barski et al. (2012), who proved the Bajocian age of these strata based upon superposition. However, Gedl (2013) recognized the presence of the Upper, Middle and Lower Aalenian/?Upper Toarcian in the Szlachtowa Formation at the Szczawnica–Zabaniszcze section.

None of the dinoflagellate cyst taxa listed by Gedl (2013) from the Szczawnica–Zabaniszcze section are stratigraphically restricted to the Toarcian or Aalenian, whereas *Pareodinia* sp. and *Korystocysta* sp. as reported by him from the lowermost sample studied (allegedly representing the ?Upper Toarcian/Lower Aalenian; see Gedl 2013, fig. 14), have not been reported elsewhere below the Middle Aalenian and the Upper Bajocian, respectively (e.g. Riding & Thomas 1992). Considering the evident redeposition of Triassic palynomorphs in the Bajocian strata of the Szlachtowa Formation, as shown here and in some previous studies (eg. Segit 2010; Barski et al. 2012), the possible presence of dinoflagellate cysts common in/or restricted to the Toarcian/Aalenian should also be interpreted with caution.

The Middle–Late Toarcian age of a part of the Szlachtowa Formation was recently postulated by Gedl & Józsa (2015), who studied outcrops and a tectonically sliced borehole section (Jar-1) at Jarabina and Kamienka in Eastern Slovakia. The stratigraphic inferences of Gedl & Józsa (2015) are partly based on the absence of some stratigraphically-diagnostis species, namely the lack of dinoflagellate cysts which were considered by them as Late Toarcian/Aalenian indices, such as *Nannoceratopsis dictyambonis*, *Phallocysta elongata*, *Dissiliodinium* spp. and *Kallosphaeridium–Dissiliodinium* plexus, in otherwise low-diversity assemblages composed of *Nannoceratopsis* spp. (*N. gracilis*, *N. raunsgaardii*, *N. deflandrei*, *N. ambonis*) and *Kallosphaeridium* spp. (Gedl & Józsa 2015, pages 111–113). In our opinion, *Nannoceratopsis deflandrei*, which was used as the only Toarcian marker species in their study, can hardly be approved as a key species in stratigraphy due to two reasons. Firstly, its separation from morphologically diverse *N. gracilis* is disputable (Evitt 1962; Prauss 1989; see also Bucefalo-Palliani & Riding 1997, fig. 9, table 1) and even if assumed, its distinctive feature is subtle (i.e. fine ornamentation of the wall) and can be obliterated to varying extents depending on preservation conditions. Secondly, the global upper stratigraphic limit of *Nannoceratopsis deflandrei* s.l. does not correspond to the Toarcian, but to the Callovian (*N. deflandrei* subs. *senex* — see Bucefalo-Palliani & Riding 1997; Upper Bajocian/Bathonian in the case of *N. deflandrei* subs. *deflandrei* — see Mantle & Riding 2012). In addition, the range base of the *Kallosphaeridium–Dissiliodinium* combination (referred to thin-walled, undeterminable representatives of these two genera) was extended down to the Upper Toarcian by Gedl & Józsa (2015, page 111), but FAD of *Dissiliodinium* sp. in fact corresponds to the upper Middle Aalenian (Feist-Burkhardt & Monteil 2001). The Middle Toarcian substage, according to Gedl & Józsa (2015), is represented by only one sample recovered from borehole Jar-1 at a depth of 61.9 m, where some poorly preserved, broken specimens of foraminifer *Lenticulina* cf. *chicheryi* were identified. Apart from the inconclusive taxonomic determination implying uncertain stratigraphic position of the sample, the core interval 61–79.5 m is devoid of the sandstone intercalations typical of the Szlachtowa Formation (see Birkenmajer 1977). Gedl & Józsa (2015) also sampled a large exposure of the Szlachtowa Formation at Riečka Stream near Kamienka and ascribed it to the Lower Bajocian (as also shown by Segit 2010 and Barski et al. 2012). However, the overlying strata (their normal stratigraphic position is ascertained by graded crinoidal calciturbidites — Segit 2010), cropping out down the creek in the dip direction and represented by samples Kmn4–8, were surprisingly attributed to the Upper Toarcian and upper Middle–Upper Aalenian (Gedl & Józsa 2015, page 111, fig. 17). Therefore, the above-mentioned doubts and objections seem to invalidate the position of the lower stratigraphic limit of the Szlachtowa Formation as suggested by Gedl & Józsa (2015). Considering preservational, sedimentological and ecological variables controlling occurrence of particular dinoflagellate cyst species, as well as the unknown relationship between species richness and number of specimens and the discontinuity of studied sections, stratigraphic assessments based on the absence of diagnostic dinoflagellate cyst species, rather than on co-occurrence of found species, are not reliable.

Gedl 2013 (fig. 15b) and Gedl & Józsa 2015 (fig. 4k) presented the same field photograph of the fragmented ammonite *Brasilia* (*Brasilia*) sp. found in the Szlachtowa Formation in Eastern Slovakia (Jarabina). Although this ammonite clearly supports the presence of at least Upper Aalenian strata in the Szlachtowa Formation, we consider that this small and flattened cast does not show ribbing features (on the basis of personal observation) that would be clear enough to distinguish Middle from Upper Aalenian graphoceratid fauna with confidence (i.e. *Brasilia* sp. vs. *Graphoceras* sp.).

Although strongly deformed by tectonics, the lower part of the Sprzycne Creek section provides unique insights into the character of the strata underlying the Szlachtowa Formation which can be attributed to the Skrzypny Formation or the transitional beds. The siderite-bearing shales and the basal part of turbidite sequence (represented by samples SC-17–SC-19) are palynologically very similar and stratigraphically very close to each other. Therefore, such similarity points to the original sedimentary or just slightly disturbed position of the strata of the Upper Aalenian and/or lowermost Lower Bajocian.

The superposition of the Skrzypny and Szlachtowa formations is reported for the first time in our study. Such superposition, although usually not immediately evident due to tectonic complications, seems to be relatively common. We observed it and examined it palynologically in the Hałuszowa Stream section (just above the site described in Barski et al. 2012), in the road cut north of the Chotuč Pass at Vršatské Podhradie (Segit 2010), in the stream escarpment south of the large exposure of the Skrzypny Formation at Zázrivá in Western Slovakia (see Aubrecht et al. 2004; Segit 2010) and in the road cut near Udol (Ujak) in Eastern Slovakia (see "sideritic limestone" and "marly shales and sandstones" erroneously ascribed to the Cretaceous by Oszczypko et al. 2004, fig. 4). If the sedimentary nature of these contacts between formations is substantiated, the structural and paleogeographic position of each particular site and their surroundings will change significantly.

Early Czorsztyn Ridge development

Major facies change took place in the shallower successions of the Oravicum domain at the Aalenian/Bajocian boundary, when black shales with sideritic concretions were replaced by black to pale green shales with phosphatic nodules (Segit 2010) prior to the period of nondeposition spanning most of the Early Bajocian (Krobicki & Wierzbowski 2004). Therefore, the simultaneous facies turnover in the Oravicum domain and pre-Late Albian Magura Basin can be accounted for by an uplift of the asymmetrical submarine swell (Czorsztyn Ridge). This uplift was probably spatially complex, thus the start and termination of turbiditic facies could have been diachronic in different parts of the basin; although unequivocal stratigraphic evidence for such diachronity have not been presented so far. The southern slope of the Czorsztyn Ridge was probably gentle (as indicated by gradual downslope facies transition and by absence of turbidites) while the northern slope was probably steeper, exposing bedrock to a great depth and thus sourcing turbidites of the Szlachtowa Formation (Barski et al. 2012; see also Birkenmajer 2007; Segit 2013). However, some crinoidal turbidites also occur in the Oravicum domain in some portions of the western sectors of the PKB in Western Slovakia (Segit 2010, 2013; see also Aubrecht & Ožvoldová 1994). The total lack of data on depositional settings, sea-floor topography or distance from the opposite (i.e. northern) margin of the pre-Late Albian Magura Basin led to us leaving this area out of consideration for our simplified and coherent depositional model (see Fig. 3). However, tilt-block extension generating some bedrock-exposing, submarine scarps at the southern margin of the basin (as presumed in the model) match up well to synchronous synsedimentary tectonics that brought about hiatuses, clastic admixture and variability in the thickness of Bajocian crinoidal limestones in the adjacent Czorsztyn facies zone. Furthermore, the stratigraphic occurrence of crinoidal turbidites in the Szlachtowa Formation is congruent with the timing of crinoid proliferation in the Oravicum domain (Wierzbowski et al. 2004; Krobicki & Wierzbowski 2004).

The deposits of the Opaleniec Formation in Sprzycne Creek yielded abundant markers of the Upper Bajocian to Lower Bathonian interval. The disappearance of dark turbiditic lithofacies, and the appearance of the non-turbiditic deposits of the Opaleniec Formation in the Late Bajocian corresponds well to the general subsidence of the Czorsztyn Ridge, and the onset of the pelagic deposition in the Oravicum domain (Wierzbowski et al. 1999; Gedl 2008a; see also Fig. 13 herein).

From a broader paleogeographic perspective, we stress that facies changes at the Aalenian/Bajocian and Early/Late Bajocian boundaries, associated with early tectonic evolution of the Czorsztyn Ridge, coincide with episodes of the 'mid-Cimmerian tectonic event' represented by unconformities, hiatuses and facies changeover in the Tethyan/north Peri-Tethyan realms and adjoining boreal areas, for example, in the Iberian Basin (García-Frank et al. 2008), Paris Basin (Jacquin et al. 1998), North Sea (Underhill & Partington 1994), basins of the Caucasus (Saintot et al. 2006), Alborz & Kopet-Dagh (Fürsich et al. 2009).

Structural position of deposits representing the pre-Late Albian Magura Basin

The Szlachtowa Formation and overlying deposits of Sprzycne Creek, as well as similar deposits occurring about 1.3 km towards the west in Żłobny Creek on the Sosnowa Skała klippe, have been interpreted as belonging to the Grajcarek Succession appearing below the overthrusted deposits of the Czorsztyn Succession (Sikora 1971b,c,d). It should be remembered that the Szlachtowa Formation deposits of Sprzycne Creek, Żłobne Creek, as well as some other localities at Dursztyn, were originally placed in the Branisko Succession of the Oravicum domain by Birkenmajer (1958). This interpretation is incorrect because the stratigraphic position of these and the directly overlying deposits, such as the Opaleniec Formation, excludes their attribution to the Branisko Succession, where the same stratigraphic interval is represented by another lithofacies, attributed to the Harcygrund, Podzamcze, Flaki, Smolegowa, Czorsztyn and Sokolica formations (Fig. 13; cf. also Barski et al. 2012). The Szlachtowa Formation and the overlying deposits of Sprzycne Creek as well as the other deposits mentioned above (Żłobny Creek), similar to those at Podubocze and other sections described previously (Barski et al. 2012), are comparable to those of the Grajcarek Succession in the eastern part of the Pieniny Klippen Belt in Poland. Gedl (2008a, fig. 46) interpreted the deposits of Kręty Creek near Dursztyn in a similar way. The attribution of the Szlachtowa Formation as well as the overlying deposits to the Grajcarek Succession changes markedly the tectonic interpretation of this region. The deposits of this succession appear below the overthrusted deposits of the Czorsztyn Succession in several tectonic windows between Sprzycne Creek and Kręty Creek near Dursztyn and Krempachy.

The structural and paleogeographic interpretation of these deposits is consistent with the results of Jurewicz (1997), Oszczypko et al. (2010), Plašienka & Mikuš (2010) and Plašienka (2012) in the eastern part of the Pieniny Klippen Belt. These authors recognized that the Pieniny Nappe (including the Pieniny and Branisko/Kysuca successions) and the Subpieniny Nappe (including the Czertezik, Niedzica, and Czorsztyn successions) of Oravicum domain provenance are thrust over the deposits of the Grajcarek Succession, corresponding to the pre-Late Albian Magura Basin. The latter has been renamed as the Faklovka or the Šariš unit due to its newly proposed tectonic interpretation.

Interpretation of the "Sprzycne beds"

The Sprzycne beds according to the original definition of Sikora (1971a,b,c,d) corresponded to the light grey marly shales with intercalations of limestones and spotted siderites overlying the "black flysch" deposits (Sztolnia beds), and occurring below the "Cenomanian Key Horizon" in Sprzycne Creek. These deposits were attributed to the Albian–Cenomanian and correlated with the Opaleniec Formation by Oszczypko et al. (2012). We show, however, that the "Sprzycne beds" occurring at Sprzycne Creek (i.e. its type locality) actually represent a set of deposits composed of fragments of different lithostratigraphic units placed in tectonic contact and of different ages: the marly shales of the Upper Bajocian/Bathonian age corresponding to the Opaleniec Formation, and the marly shales with marly limestone intercalations (Jaworki Formation). Therefore the term "Sprzycne beds" should not be used as it is misleading in stratigraphic correlations.

Some details of the Sprzycne section as described herein differ from those given by Sikora (1971a) — e.g. lack of the "Cenomanian Key Horizon" which corresponds to the radiolarite Hulina Formation of Birkenmajer (1977) of Albian–Cenomanian age. These differences may be easily explained, however, by the local appearance or disappearance of tectonically reduced units due to changes in the flow of Sprzycne Creek during the long period of time in observations from early 1970's up to 2014.

Conclusions

The Jurassic succession of Sprzycne Creek consists of (1) the topmost part of the Skrzypny Formation or transitional beds from Skrzypny Formation to the Szlachtowa Formation representing the Upper Aalenian or the lowermost Bajocian, (2) the Szlachtowa Formation ("black flysch") representing the Upper Aalenian or the lowermost Bajocian to lowermost Upper Bajocian, and (3) the Opaleniec Formation representing the Upper Bajocian and the Lower Bathonian. The Cretaceous variegated marls are in tectonic contact with the latter. Thus, the "Sprzycne beds" as originally distinguished in their type section consist of at least two tectonically amalgamated units of Middle Jurassic and Cretaceous age. This study provides further evidence that the dark turbiditic deposits in the Pieniny Klippen Belt, with very high mica content and crinoidal debris admixture, is of Jurassic and not Cretaceous age. The dinoflagellate cyst assemblages in the Sprzycne Creek section is indicative of several successive zones of the ?latest Aalenian/Bajocian and Lower Bathonian, with a total absence of Cretaceous species. Therefore, the composition of dinoflagellate cyst assemblages contradicts the suggestion of redeposited Jurassic palynomorphs in allegedly Cretaceous "black flysch" deposits. In addition, the suggestion of the pre-Late Aalenian age of the Szlachtowa Formation seems unsubstantiated as well. We propose that the "sub-flysch beds", which referred to the strata underlying the Szlachtowa Formation, is a redundant synonym of the Skrzypny Formation. Our results, as well as reinterpreted earlier data, suggest uniform depositional conditions of the Skrzypny Formation both in the Oravicum domain and in the area to the north prior the Late Aalenian. The pre-Late Albian Magura Basin evolved separately from the Oravicum domain after the uplift of the Czorsztyn Ridge, as subsequently witnessed by the onset of turbidite sedimentation restricted to the northern foot of the ridge and the remarkable facies dissimilarity in the adjacent basins. Thus the section in the Sprzycne Creek represents pre-Late Albian Magura Basin deposits. These deposits are overthrust by the Subpieniny and Pieniny Nappes consisting of the Czorsztyn and Branisko successions, which resulted in the inferior tectonic position of the pre-Late Albian Magura Basin within the structure of the Pieniny Klippen Belt.

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