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Depositional setting of the Oligocene sequence of the Western Carpathians in the Polish Spisz region – a reinterpretation based on integrated palynofacies and sedimentological analyses

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The research on the Oligocene succession of the Central Carpathian Paleogene Basin (CCPB) in the Kacwin region focused on sedimentological and palynofacies analyses. Observations were carried out in natural exposures along three streams flowing in the Polish Spisz: Kacwinianka, Łapszanka and Kacwiński. Three main groups of lithofacies have been distinguished: coarse-grained, mixed and sandy-grained, and fine-grained. The lithofacies are characterized by variable sedimentary structures, e.g. massive structure, horizontal lamination, ripple cross-lamination, hummocky cross-stratification, deformation structure. Sedimentological analyses showed that structures typical for turbidity currents and those characteristic of relatively shallow deposition (HCS, wave ripples) could coexist in the investigated succession interpreted as typical for turbidity currents influenced by storm waves. This indicates relatively shallow-water environments. The palynofacies analysis enabled identification of the following components: black wood, brown wood, cortex, resin, sporomorphs, cuticle, algae, dinoflagellates and AOM. A high proportion of black wood and low diversity of components point to an origin related to turbidity currents. Furthermore, results of the palynofacies analysis have allowed determining that, during the deposition of the CCPB sediments in the Polish Spisz area, the distance between the deposition area and the source area became relatively large. The biostratigraphic analysis of dinoflagellate cysts from the Podhale Basin (Szaflary, Zakopane, and lower Chochołów beds) indicates an Early Rupelian age. Moreover, kerogen analysis in the UV was applied for the first time to study the CCPB succession. As a result, reworking was documented, so far unrecognized by other methods, and the mutual verification of the obtained results was possible.

Key words: wind-influenced turbidites, palynofacies, Oligocene, Central Carpathian Paleogene Basin, Carpathians.

INTRODUCTION

The Central Carpathian Paleogene Basin (CCPB) deposits in the Podhale area are generally represented by sandstones, calcareous claystones, mudstones, shales and conglomerates. Previous research on the age of the flysch-like deposits from the study area was based on microfossils (e.g., foraminifers); it was initiated by Kuźniar (1910 *fide* Roniewicz, 1969) and continued by many authors (e.g., Bieda, 1946, 1948, 1959; Alexandrowicz and Geroch, 1963; Blaicher, 1973; Dudziak, 1983, 1984, 1986, 1993; Gedl, 1995, 1998, 1999, 2000; Olszewska and Wieczorek, 1998; Garecka, 2005). The stratigraphic position of the deposits from the Polish Spisz was interpreted by Gedl (1995, 1998, 1999, 2000), who analysed dinoflagellate cysts from exposures near the Łapszanka and Kacwinianka streams and concluded that they are Oligocene in age (Gedl, 1998, 2000; Fig. 1). Worth noting is the fact that Gedl's (1998, 2000) stratigraphic interpretation differs from that by other authors who based their conclusions on other groups of microfossils (e.g., Bieda, 1959; Garecka, 2005). In the adjoining Orava Basin (the Slovak part of the CCPB), many papers devoted to biostratigraphical microfossil-based studies were also published. The results showed unequivocally an Oligocene age of the formation of CCPB sediments (Soták, 1998a; Soták et al., 2007). However, all reports indicate different ages of the CCPB deposits from Podhale, which induced the need for a new biostratigraphic analysis using UV light. However, samples collected earlier in the Kacwin area were characterized by a small amount of organic matter and often by the lack of dinoflagellate cysts (Gedl, 2000). Parallel sedimentological studies were also conducted in the Podhale region (Grzybek and Halicki, 1958; Radomski, 1958, 1959; Gołąb, 1959; Marschalko and Radomski, 1960; Roniewicz, 1966; Marschalko, 1968; Roniewicz and Pieńkowski, 1977; Pieńkowski and Westwalewicz-Mogilska, 1986; Westwalewicz-Mogilska, 1986; Janočko et al., 1998; Janočko and Jacko, 1998; Soták and Janočko, 2001; Soták et al., 2001). Unfortunately, their range did not cover the area of the Polish Spisz, which was considered the innermost part of the northern zone of CCPB in the Paleogene

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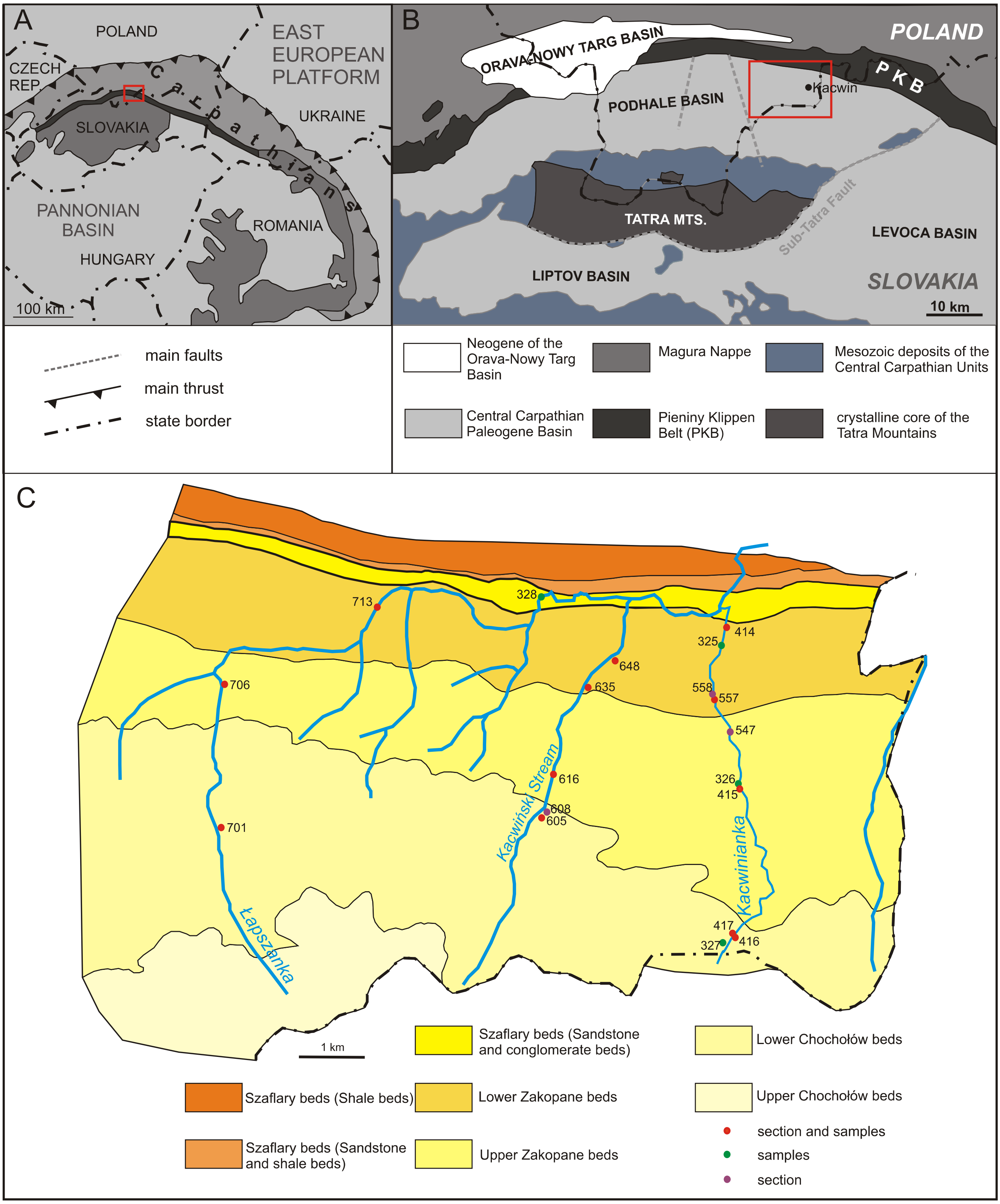

Fig. 1. Schematic map of the Carpathians in Central Europe (A) with location of the study area near the village of Kacwin (B) (after Lexa et al., 2000, modified); geological map of the study area with sampling sites marked (C) (Filipek, 2015, based on Watycha, 1975 and Kulka et al., 1987; modified)

(Marschalko and Radomski, 1960). Thus, our observations can complete the previous analysis of the CCPB deposition.

Interpretation of palynological studies of clastic rocks, especially of flysch-like type, is relatively difficult, because the phenomenon of redeposition should be considered. For this reason, three methods were applied herein: sedimentological analysis, palynofacies analysis, and UV excitation. Integration of palynofacies and sedimentological methods broadens the interpretations and allows verifying the obtained data. The investigations enhanced the determination of the palaeoenvironment, in which the CCPB turbidites were deposited, and resolved several controversial issues. Furthermore, UV excitation was used to document reworking, which was unrecognizable by other methods. In view of the controversies associated with the interpretation of age and sedimentary environment, the aim of this paper is to reconstruct the palaeoenvironmental conditions in the eastern Podhale region during the Paleogene. The investigations allow for a new approach to the knowledge on the CCPB with regard to stratigraphy, depositional palaeoenvironment, and changes during deposition.

GEOLOGICAL SETTING

The study area is located in Central Europe, at the Polish-Slovakian border within the Carpathians (Fig. 1A, B). In the Oligocene, the area belonged to the Podhale Basin, which was part of the immense Central Carpathian Paleogene Basin (CCPB). The CCPB included also the Liptov, Levoča, Orava, Rajec, Turiec and Žilina basins and the Poprad and Hornád depressions (Soták et al., 2001). Tari et al. (1993) and Kázmér et al. (2003) interpreted the Podhale Basin as a fore-arc basin composed of thick Oligocene flysch sediments, including those that originated due to gravity flows (Marschalko, 1968; Książkiewicz, 1972). Presently, the sediments of the Podhale Basin are preserved in the structural sub-basin, called by Mastella (1975) the Podhale Synclinorium (Fig. 1B).

The Podhale Basin is bordered by the Pieniny Klippen Belt (PKB) from the north and by the Tatra Mountains from the south (Birkenmajer, 1958; Halicki, 1963; Plašienka et al., 2013; Fig. 1B). It extends from Spisz in the east to Orava in the west (Janočko et al., 2000; Lexa et al., 2000; Cieszkowski et al., 2009). The Pieniny Klippen Belt is a long, narrow and intensively tectonized structure composed of several successions of Jurassic to Paleogene rocks represented mainly by limestones, claystones and marls (Andrusov, 1958; Birkenmajer, 1960; Plašienka and Soták, 2015). The nature of the contact between the PKB and the Podhale Basin is tectonic (Birkenmajer, 1958; Plašienka et al., 2013). In the study area, the Podhale Basin is probably underlain by the Nummulitic Eocene (Kuźniar, 1910 *fide* Roniewicz, 1969), which is a transgressive deposit that remains in erosional and sedimentary contact with the nappes of the Tatra Mountains.

The Podhale Basin is an asymmetric structure consisting of several longitudinal tectonic zones (Mastella, 1975; Ludwiniak, 2010). The following zones have been distinguished in the study area: the tectonic contact between the flysch rocks and the PKB, the peri-Pieniny flexure, and the zone of gently dipping beds (Mastella, 1975). In most of the study area, the beds slightly dip towards the south. The dip values increase in the zone of the peri-Pieniny flexure and become steep near the PKB (Mastella and Rybak-Ostrowska, 2012).

The Podhale Basin is composed of thick series of clastic rocks referred traditionally to as the Podhale Flysch, which belong to the CCPB succession. These rocks have been subdivided into several informal lithostratigraphic members (Gołąb, 1959; Watycha, 1959; Małecka, 1982; Figs. 1C and 2). In the northern part of the described area, the oldest unit comprises the Szaflary beds (Szambronska Formation *sensu* Gross et al., 1984) occurring only in the northern part of the Podhale Basin. The Szaflary beds are composed of thick- to medium-bedded sandstones and conglomerates, interbedded with shales (Cieszkowski et al., 2009). They are characterized by a variable bed thickness and variable grain size, both laterally and vertically (Watycha, 1976). The overlying Zakopane beds (Huty Formation; Watycha, 1976) are finer-grained than the Szaflary beds. The lower unit (claystone member) of the Zakopane beds consists predominantly of thin-bedded mudstones and claystones with only a few intercalations of sandstones. Intercalations of ferruginous dolomites and calcareous conglomerates are also present (Kosiorek-Jaczynowska, 1959; Watycha, 1976; Cieszkowski et al., 2009). The upper unit (sandstone member) is represented by claystones and mudstones with more numerous sandstone intercalations than in the claystone member (Cieszkowski et al., 2009). The Chochołów beds (Zuberec Formation; Watycha, 1976) are characterized by numerous thick-bedded sandstones. The lower unit is a complex of thin- and medium-bedded sandstones, claystones and mudstones. The upper unit (known also as the Brzegi beds) comprises mudstones, calcareous shales and thin-bedded sandstones with organic detritus (Watycha, 1976; Małecka, 1982). Thin tuffite beds were also found in the Chochołów beds (Michalik and Wieser, 1959; Roniewicz and Westwalewicz-Mogilska, 1974). The boundaries between the particular lithostratigraphic units of the CCPB succession from the Podhale Basin are variably presented by different authors on the existing geological maps (Birkenmajer, 1958, 1960, 1968; Watycha, 1975; Małecka, 1982; Lexa et al., 2000).

METHODS

Field work was focused on drawing lithological-sedimentological logs for 42 exposures, photographic documentation, and bedding dip measurements along the three streams of Łapszanka, Kacwinianka and Kacwiński (Fig. 1C) in the north-eastern part of the Podhale Basin.

During field investigations, the lithological classification of the clastic rocks was based on macroscopic observations of the dominating grain size. In the case of coarse-grained rocks, grain-size, sorting, rounding and shape of clasts were examined, followed by matrix and clast packing analyses. The colour of particular units was also observed. Carbonate content was tested in the rocks using 10% HCl. Moreover, the thicknesses of particular beds were plotted; they may indicate depositional energy or cyclic changes in the sedimentary setting. Twenty-five samples were collected directly in the exposures, and they were ordered in the following stratigraphic succession: 8Ałł, 8Łm, 7Łp (Łapszanka section), 414a, 414b, 2Kcm, 1Kcp (Kacwinianka section), 713 (Łapszanka section), 648 (Kacwiński Stream section), 557pod, 557s, 557nad (Kacwinianka section), 635 (Kacwiński Stream section), 4Kcm, 3Kcp, 415 (Kacwinianka section), 706 (Łapszanka section), 616, 605 (Kacwiński Stream section), 417, 416a, 416b, 6Kcm, 5Kcp (Kacwinianka section), 701 (Łapszanka section) (Fig. 2).

Field observations were supported with microscopic analyses, including (1) micropalaeontological study of selected samples, and (2) UV excitation. Samples of ~50 to 150 grams were subject to standard palynological techniques following Poulsen et al. (1990), which included 37% HCl treatment, 40% HF treat-

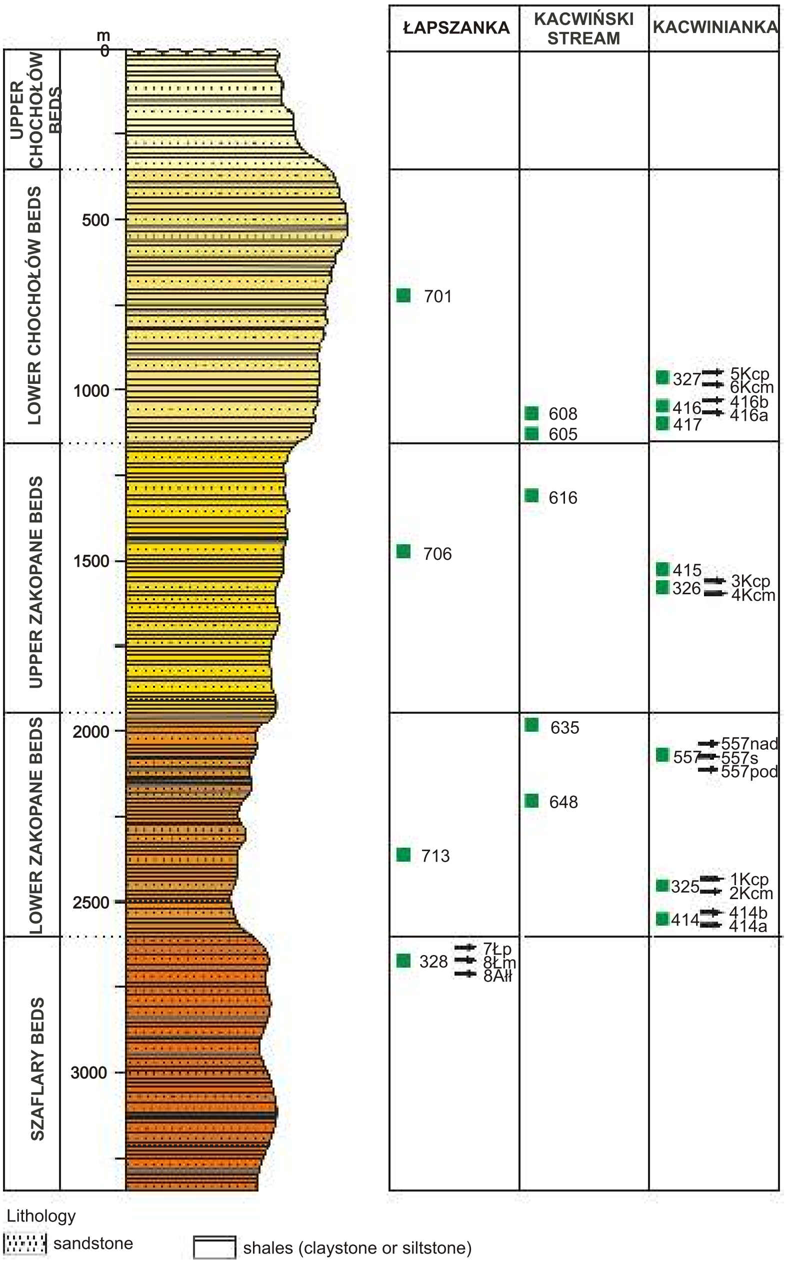

Fig. 2. Lithostratigraphic log of the Podhale Basin succession (Watycha, 1975; Głowacka, 2010, modified) and the sample distribution in the Łapszanka, Kacwinianka and Kacwiński Stream sections

ment, sieving through a 15 μm sieve, and heavy-liquid ($ZnCl_2$; density 2.0 g/cm^3) separation. Glycerol gelatine was used as the mounting medium. The rock samples and the palynological residues are stored at the Faculty of Geology, University of Warsaw. Not all samples have yielded organic-walled dinoflagellate cysts. Small amounts of cysts in some samples might have led to anomalous quantitative values. For this reason, the range chart is provided herein for qualitative purposes only.

Dinoflagellate cyst redeposition mainly takes the form of co-occurrence of taxa with discordant stratigraphic ranges. Furthermore, UV light excitation has also shown good results in this respect. Excitation is a technique that can be used for macerated palynological residues in either reflected or transmitted light.

Palynofacies analysis is based on the observation of organic material isolated from the rock using an optical microscope (Combaz, 1964). It permits performing statistical analysis using various organic constituents (Tyson, 2012). This method allows for the reconstruction of depositional environments, biostratigraphic correlation, determination of petroleum potential of the source rock, palaeogeographic reconstructions, and identification of the origin of organic matter (Batten, 1996; Słodkowska, 2003; Tyson, 2012). Components examined under transmitted light display a large diversity of colour, morphology, opacity and recognizable structures (Tyson, 2012).

AGE DETERMINATION

Biostratigraphic analyses based on organic dinoflagellate cysts were conducted recently in the study area by Gedl (1995, 1998, 1999, 2000). However, the samples collected in the area of Kacwin were characterized by a small amount of organic material and often by the lack of dinoflagellate cysts (Gedl, 2000). This has prompted the authors to repeat the analyses and collect samples from the Kacwiński Stream, not reported by Gedl (2000) in his studies.

Stratigraphic ranges of the key dinoflagellate cysts used in the biostratigraphical analysis are based on the synthetic works of Williams (1978), Powell (1992), Gradstein et al. (2004), Köthe and Piesker (2008). The age assignment of the chosen samples is summarized in Figure 3. The remaining samples were characterized by lack of Dinoflagellata or abundance of destroyed cysts, which suggest that organic material is redeposited, e.g. *Tityrosphaeridium* sp. (Fig. 4G). That is why they were omitted in the biostratigraphic analysis. Selected taxa are photographically documented on the Figure 4.

Twenty-five samples have been analysed, with dinoflagellate cysts recovered in 18 samples. Because of low abundance of the cysts, only qualitative results are presented herein (Table 1). The best state of preservation and the largest amounts of dinoflagellate cysts are observed in samples from the Łapszanka section. The identified dinoflagellate cysts have allowed for the stratigraphic interpretation of the following samples:

Sample 8Ałł (Szaflary beds, Łapszanka section), collected from shales, has yielded a low-diversity dinoflagellate cyst assemblage. It consists of 22 species of dinoflagellate cysts with ranges within the Early Rupelian. Stratigraphically significant taxa include *Wetzeliella symmetrica* (Fig. 4A), *W. articulata* (Fig. 4C) and *W. gochti*.

Sample 8Łm (Szaflary beds, Łapszanka section) was collected in the same exposure as Sample 8Ałł and confirms the obtained results. Only four species of dinoflagellate cysts were recognized in sample 8Łm, but two of them (*Wetzeliella symmetrica* and *W. articulata*) range within the Early Rupelian (Fig. 3).

Table 1

Qualitative distribution of dinoflagellate cysts in the studied samples

	Sample																								
	701	5Kcp	6Kcm	416b	416a	417	605	616	706	415	3Kcp	4Kcm	635	557nad	557s	557pod	648	713	1kcp	2Kcm	414a	414b	7Łp	8Łm	8AŁ
Achilleodinium sp.																+									
Achomoshaera sp.	+																					+			+
Amphoroshaeidium sp.																									
Caligodinium amiculum	+								+																+
Caligodinium sp.													+			+		+						+	
Caligodinium sp. B	+																								+
Charlesdowniea sp.	+																								
Chiropteridium galea										+							+								
Chiropteridium lobospinosum																	+				+				
Chiropteridium sp.	+																+				+				
Cordosphaeridium inodes																					+				
Cordosphaeridium sp.																									+
Ctenidodinium sp.			+																						
Deflandrea phosporitica	+			+		+			+	+				+	+	+				+	+	+			
Distatodinium ellipticum									+																
Dracodinium laszczynskii	+					+			+																
Eneadocysta pectiniformis																					+				
Eneadocysta sp.																						+			
Fibrocysta sp.	+													+							+	+			+
Glaphyrocysta sp.													+		+										
Homotryblium abbreviatum								+																	
Homotryblium plectilum																									
Homotryblium sp.					+													+			+	+			
Homotryblium tenuispinosum									+									+							
Hystrichokolpoma rigaudie									+							+									
Impletoshperidium sp.	+								+						+	+					+				
Lejeunecysta sp.																									+
Melitasphaeridium sp.																					+				
Nannoceratopsis sp.																					+				
Operculodinium centrocarpum																	+					+			
Operculodnium microtriainum																					+				
Operculodnium sp.	+												+												
Polysphearidium sp.																+									
Pyxidnopsis sp.																								+	
Reticulatosphera actinocoronata	+																								
Rhombodinium freienwaldense																+		+							
Rhombodinium longimanum																+									
Rhombodinium sp.	+								+				+			+									
Rhombodinium sp. B																+									
Spiniferites pseudofurcatus																+									
Spiniferites ramosus									+				+			+						+			+
Thalassiphora pelagica	+															+									
Tityrosphaeridium sp.																					+				
Wetzeliella articulata	+								+					+		+					+			+	+
Wetzeliella gochti										+				+						+	+				+
Wetzeliella sp.										+						+					+				
Wetzeliella sp. A									+																
Wetzeliella symmetrica	+								+						+				+				+	+	

Sample 414a (lower Zakopane beds, Kacwinianka section) is characterized by the co-occurrence of *Cordosphaeridium inodes*, *Deflandrea phosporitica, Wetzeliella articulata* and *W. gochti* (Fig. 4D). The coexistence of these taxa has allowed defining the age of the lower Zakopane beds at the Early Rupelian (Fig. 3).

Three samples were collected from section 557 (lower Zakopane beds, Kacwinianka section), of which two were con-

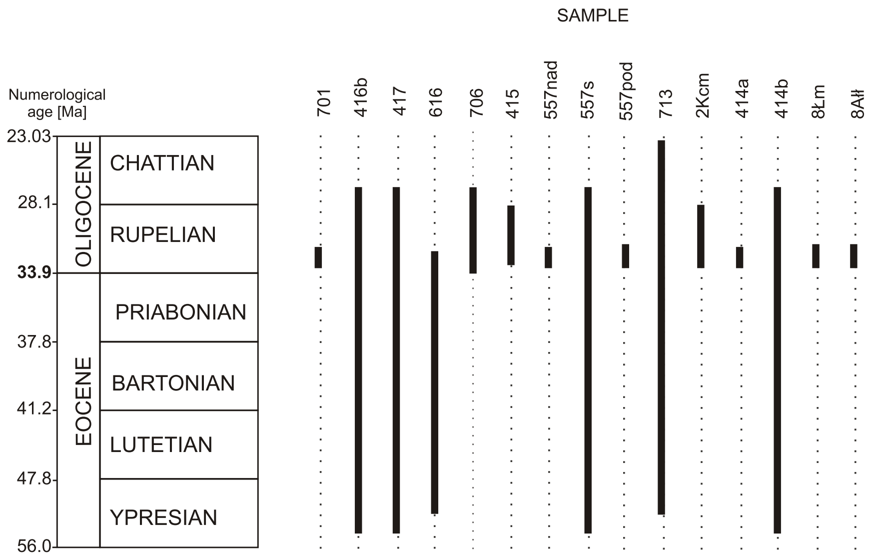

Fig. 3. Stratigraphic assignment of particular samples

Stratigraphic range based on Gradstein et al. (2004)

sidered as stratigraphically significant (557pod and 557nad). The following dinoflagellate cysts were found in slide 557pod: *Deflandrea phosporitica, Hystrichokolpoma rigaudie, Rhombodinium longimanum, R.* sp. B of Gedl (Fig. 4B), *Spiniferites pseudofurcatus, Thalassiphora pelagica, Wetzeliella articulata* and *W. symmetrica*. Their co-occurrence assigns this sample to the Early Rupelian. Sample 557nad gives the same results (Fig. 3).

Sample 701 (lower Chochołów beds, Łapszanka section) contains the following stratigraphically significant taxa: *Deflandrea phosporitica* (Fig. 4E), *Reticulatosphera actinocoronata*, *Thalassiphora pelagica* (Fig. 4H), *Wetzeliella articulata* and *W. gochti*. Their co-occurrence allows interpreting the age of the lower Chochołów beds as the Early Rupelian (Fig. 3).

All samples yielding dinoflagellate cysts confirm that the Podhale Flysch was deposited during the Paleogene. Furthermore, samples 8Ałł, 8Łm, 414a, 557pod, 557nad and 701 have allowed to narrow the age of the Szaflary beds, Zakopane beds and the lower Chochołów beds to the Early Rupelian, based on *Wetzeliella articulata* (Powell, 1992; Köthe and Piesker, 2008). Strangely enough, Gedl (2000) also identifies this taxon, but does not apply it in his biostratigraphic analysis. The recognized assemblage of dinoflagellate cysts has aided in estimating the sedimentation rate for the Podhale Flysch (excluding the upper Chochołów beds) at 1.6 mm/year (Fig. 3).

The obtained results significantly supplement the biostratigraphic reports by Gedl (1998, 2000) with data on the Zakopane and Chochołów beds from the Kacwinianka region, and on the Szaflary beds from the Łapszanka section.

PALYNOLOGICAL INDICATORS OF SEDIMENTARY ENVIRONMENT

DINOFLAGELLATE ASSEMBLAGES

During the identification of dinoflagellate cysts, worth emphasizing is the vast majority of species from different environmental groups as designated by Gedl (2000): *Wetzeliella*, *Deflandrea-Caligodinium* and *Spiniferites* (Fig. 4). These groups are distinguished by the palaeoenvironmental preferences of particular species.

The *Wetzeliella* group in the analysed material is represented by the taxa of *Wetzeliella* and *Rhombodinium*, and rarely by *Dracodinium* and *Charlesdowniea*. These genera indicate mainly coastal and shallow-water environments characterized by reduced salinity (Gedl, 2000). The second group, *Deflandrea-Caligodinium*, which includes the species of *Deflandrea*, *Caligodinium* and *Lejeunocysta*, occupies a similar palaeoenvironmental niche as the *Wetzeliella* group. Representatives of the two groups are classified as heterotrophic dinoflagellates using organic ingredients, e.g. nutrients, or are predators preying on phytoplankton. A high abundance of these taxa testifies for a nutrient-rich environment interpreted as river mouths or upwelling zones (Harland, 1988 in: Gedl, 2000). Species of the *Wetzeliella* and *Deflandrea-Caligodinium* groups have never been found in deep-water environments (Gedl, 2000).

Another relatively frequently appearing group is the *Spiniferites* group represented by *Spiniferites* (mainly *S. ramosus*; Fig. 4F) and *Achomosphaera*. This group does not have any palaeoenvironmental preferences, although it is regarded mainly as comprising neritic forms that inhabit coastal shelf areas, and its common appearance in deep-sea successions is probably associated with redeposition (Edwards and Andrle, 1992; Gedl, 2000).

A relatively large quantity of forms from the three groups does not clearly explain the conditions of the Podhale Flysch deposition, in which the dinoflagellate cysts have been found (Pross and Brinkhuis, 2005). However, the presence of the *Wetzeliella* and *Deflandrea-Caligodinium* groups indicates their origin in a coastal area near river mouths or in open-marine areas, which were rich in nutrients, e.g. upwelling zones. This would confirm the existing concepts recognizing the Podhale Basin succession as deep-marine sediments.

PALYNOFACIES ANALYSIS

Kacwinianka. The analysed samples indicate differences in the individual elements of the recognized palynofacies within particular sections and between them (Fig. 5). Samples from exposures along the Kacwinianka Stream are characterized by an evident dominance of phytoclasts (Fig. 6A–C). At the top of the section, a clear decline in the diversity of palynological material is observed. In the lower part of the section occur such

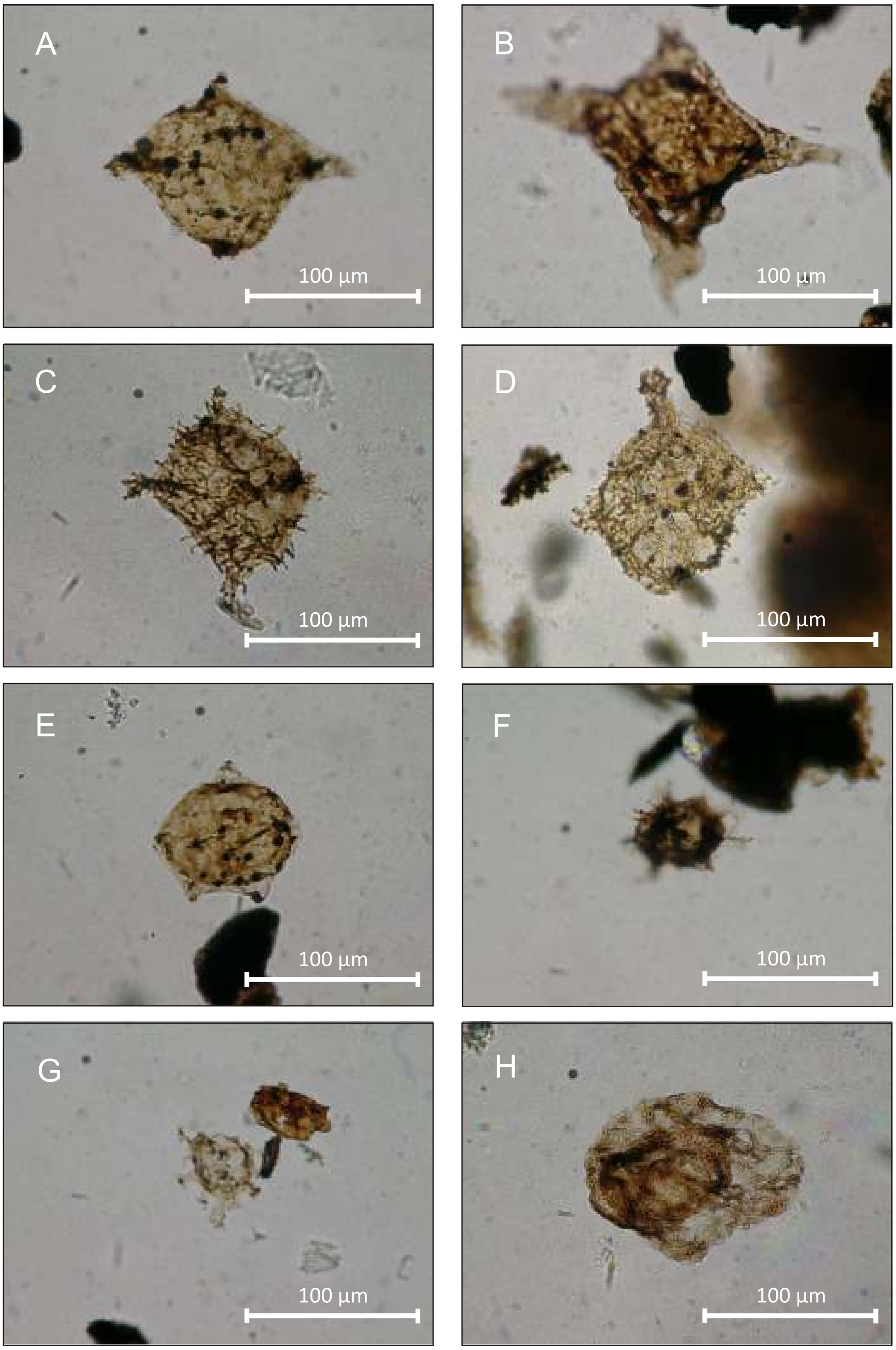

Fig. 4. Photographs of specimens of selected dinoflagellate cysts from the studied samples

A – *Wetzeliella symmetrica* Weiler (sample 8AłŁ, Łapszanka section), 1956; **B** – *Rhombodinium* sp. B of Gedl (2000) (sample 557pod, Kacwinianka section); **C** – *W. articulata* Eisenack, 1938 (sample 8AłŁ, Łapszanka section); **D** – *W. gochti* Costa and Downie, 1976 (sample 414 a, Kacwinianka section); **E** – *Deflandrea phosporitica* Eisenack, 1938 (sample 701, Łapszanka section); **F** – *Spiniferites ramosus* Mantell, 1854 (sample 8AłŁ, Łapszanka section); **G** – *Tityrosphaeridium* sp. (sample 414a, Kacwinianka section); **H** – *Thalassiphora pelagica* Eisenack and Gocht, 1960 (sample 701, Łapszanka section)

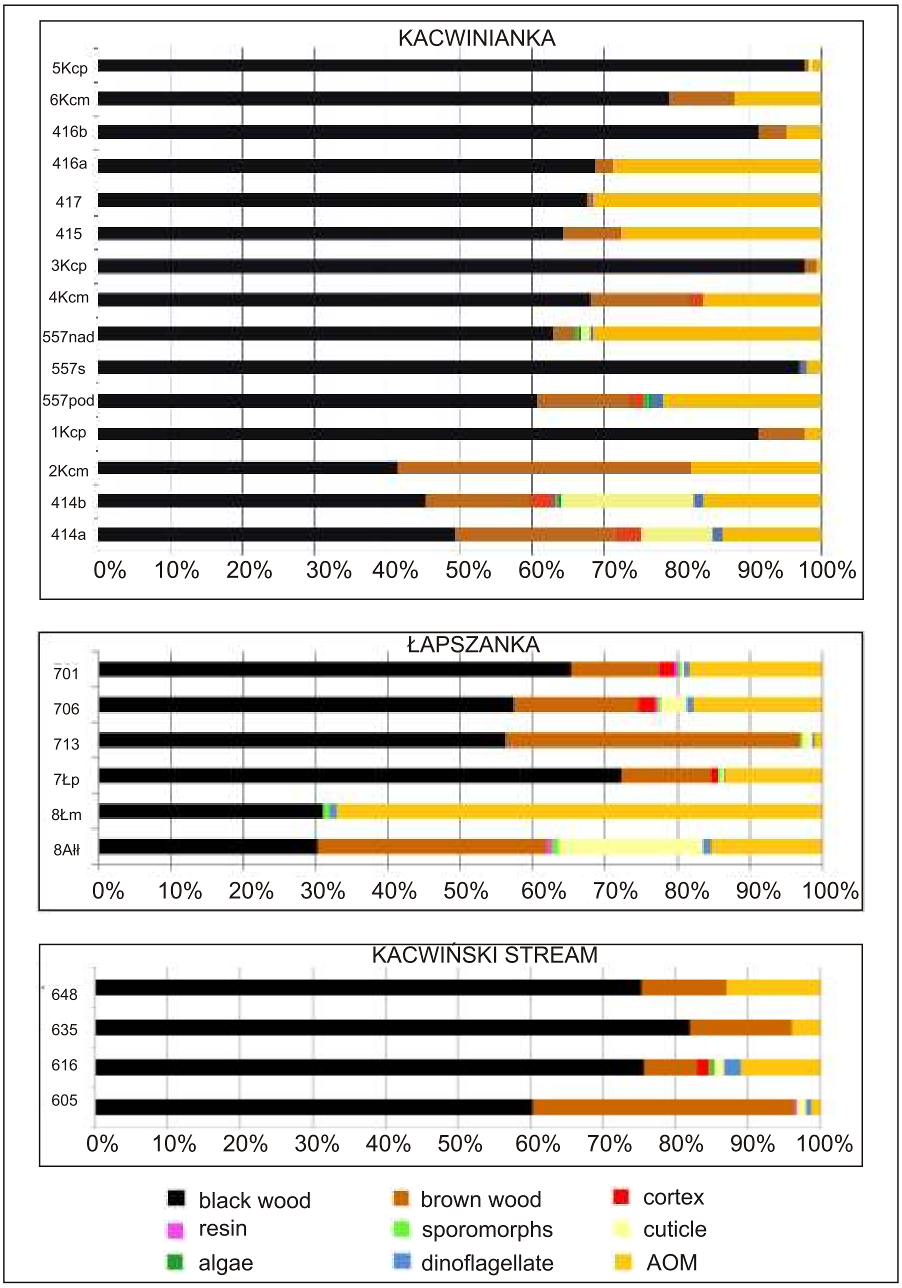

Fig. 5. Graphs showing the percentage of palynofacies in the Kacwinianka, Łapszanka and Kacwiński Stream sections

components as black wood, brown wood, AOM, cuticle, sporomorphs, cortex, dinoflagellate cysts, and resin. In turn, the upper part of the section contains only black wood, brown wood and AOM. Characteristic for the mudstone samples (414b, 2Kcm, 557pod, 557nad, 415, 417, 416a and 6Kcm) is the gradual up-section increase in black wood (from 45.3% in sample 414b to 79% in sample 6Kcm) with slight fluctuations in samples 414a, 4Kcm, and 416b. It can also be noticed that some of the samples (5Kcp, 3Kcp, 557s and 1Kcp) deviate from the trend of gradual increase of the proportion of black wood and are characterized by an overwhelming dominance of this component (97.7, 97.7, 97 and 91.3%, respectively; Fig. 5). Samples were collected from different rock types: samples 5Kcp, 3Kcp, 1Kcp from sandstones, and sample 557s from ankerite. Two samples can be clearly distinguished: 414a and 414b, which show a much higher content of cuticle (10 and 18.3%, respectively; Fig. 5).

A gradual increase in black wood upwards in the Kacwinianka section may indicate a relative increase of the distance between the study area and the source zone. Black wood has the highest mechanical resistance and its considerable proportion proves long-term transport. According to Tyson (1984 *fide* Tyson, 1993), a large percentage of phytoclasts in samples may be linked with the activity of turbidity currents.

The higher content of cuticle in samples 414a and 414b indicates a shorter distance from the land during the deposition of primary rocks (Rich, 1989 *fide* Tyson, 1993). This is due to the origin of cuticle from leaves. Cuticle cannot be current-transported, because it is prone to mechanical degradation. Its presence proves also a relatively low-velocity current, which trans-

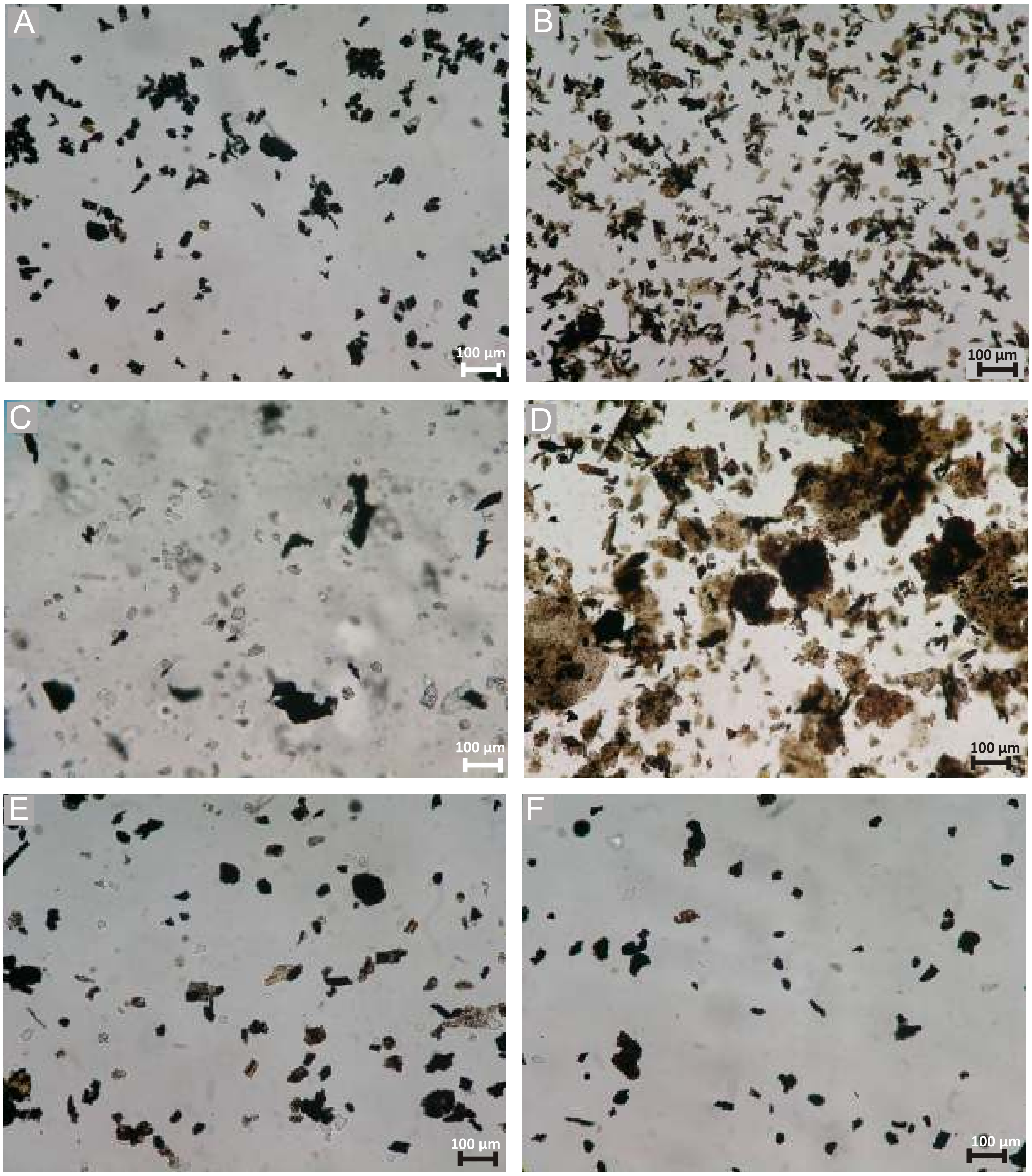

Fig. 6. Palynofacies from selected samples

A – organic material characterized by dominance of phytoclasts, 416b (Kacwinianka section); **B** – palynological material characterized by dominance of phytoclasts, 414b (Kacwinianka section); **C** – organic material characterized by a small amount of organic matter and evident dominance of phytoclasts, 3Kcp (Kacwinanka section); **D** – organic matter characterized by dominance of AOM, 8Łm (Łapszanka section); **E** – organic material with dominance of black wood, 701 (Łapszanka section); **F** – palynological material characterized by low diversity of components, 605 (Kacwiński Stream section)

ported the leaves, or a low energy environment, in which the rocks were formed (Dance, 1981 *fide* Tyson, 1993). Tyson (2012) suggested that the presence of cuticle may be related to the deposition of the proximal parts of a submarine fan. Only two samples from the Kacwinianka section can be assigned to the plant tissue palynofacies distinguished by Gedl (2000). Other samples can be assigned to the black wood palynofacies (Gedl, 2000).

The dominance of black wood in sandstone and ankerite shows a clear relationship of organic matter to the type of lithology and the rate of deposition. Reyre (1973 *fide* Tyson, 1993) suggested that the percentage of phytoclasts can often be correlated with the content of coarse silt or sand.

Sandstone samples with a high percentage of phytoclasts (1Kcp, 3Kcp, 5Kcp) are characterized by a small amount of organic matter in the entire slide (Fig. 6C). We associate the low content of organic matter with a fast deposition rate resulting from sedimentation due to the activity of turbidity currents. However, similar observations have also been made in one sample of mudstone (6Kcm). We assume that, also in this case, the small proportion of organic matter and the dominance of phytoclats is associated with reworking and an origin related to turbidity currents.

Łapszanka. Samples from the Łapszanka section are characterized by a greater diversity than those from the Kacwinianka section. All samples contained dinoflagellate cysts (0.3–1.0%) and sporomorphs (0.3–1.0%). These features distinguish the Łapszanka section from the other sections. Cuticle was found in five samples (0.3–20%), while resin in three samples (0.3–0.7%). It is worth noting that AOM clearly dominates (67%) in sample 8Łm (Figs. 5 and 6D).

The content of black wood gradually increases in mudstones (8Ał, 8Łm, 713, 706 and 701) from the Łapszanka section (Fig. 6D, E). This may indicate a relative increase of the distance between the study area and the source zone. In the Łapszanka section, the amount of black wood is lower than in the Kacwinianka section. This fact and the abundance of cuticle in almost all samples prove that the Łapszanka area was closer to the source area in Rupelian times than the Kacwinianka area.

Sandstones from the Łapszanka Stream are characterized by the dominance of black wood (7Łp – 73%). Noteworthy is the fact that black wood dominates (even up to 40.7%) in two samples (713 from Łapszanka and 2Kcm from Kacwinianka). Both samples were taken from the lower Zakopane beds. It appears that the material was transported over a shorter distance than the material from the samples containing much black wood. Moreover, sample 713 contains more cuticle than sample 2Kcm, which proves that the Łapszanka area was closer to the source zone than the Kacwinianka area.

Kacwiński Stream. Like the previously described two sections, the Kacwiński Stream section is also characterized by a gradual up-section increase in black wood (from 60.3 to 82%). A lower diversity of the components in the upper part of the section than in the lower part can be observed (8 components in sample 635 compared with 3 components in samples 605 and 616; Fig. 6F). These results confirm previous observations and indicate a relative increase of distance to the source area during the deposition of the Podhale Basin succession (Fig. 5).

REDEPOSITION AND MIXING

In view of the origin of the analysed rocks and the co-occurrence of two groups of differently preserved dinoflagellate cysts, samples 8Łm (Łapszanka section), 557pod (Kacwinianka section), 557s (Kacwinianka section) and 557nad (Kacwinianka section) were examined by fluorescence microscopy to detect cyst reworking (Barski et al., 2012). The analysis has confirmed the presence of variably preserved assemblages.

Samples 557pod, 557s and 557nad were taken from the same exposure. Individual slides show a variable number of dinoflagellate cysts and differently preserved kerogen. Samples 557pod and 557nad are characterized by a good preservation state of the cysts in contrast to sample 557s, where the cysts are destroyed and contain pyrite inclusions (Fig. 7A–D). Presence of pyrite framboids is commonplace in the Menilite Shales, being related to a sulphidic water column (Wilkin et al., 1997; Soták, 2010).

The first group of organic cysts (poorly preserved) is characterized by orange (dark yellow) fluorescence and consists of stratigraphically older species and species with long stratigraphic ranges, e.g. *Deflandrea phosporitica*. Gedl (2000) distinguishes palynofacies with *Deflandrea* blooms (Fig. 7G, H). Such high abundance of *Deflandrea* is rather related to the redeposition of this taxon, which may cause erroneous environmental interpretations. The second assemblage (well-preserved) contains species with bright yellow fluorescence colours, e.g. *Rhombodinium*. All three samples contain *Rhombodinium* specimens showing various preservation states in the individual samples (Fig. 7A–D). However, examination in UV light has shown that each representative of *Rhombodinium* shone with bright fluorescence, which proves that the specimens were not reworked repeatedly and can be used for biostratigraphic interpretations. Sample 577pod yielded representatives of *Deflandrea phosporitica* in two states of preservation (Fig. 7E–H). This proves active redeposition during sedimentation of the Podhale Flysch and indicates that only species with short stratigraphic ranges can be used for stratigraphic analysis. Partial reworking of taxa may lead to erroneous interpretations of the age and depositional environment.

Sample 8Łm (Łapszanka section) was selected for further analysis in UV, because it has a high proportion of AOM among the palynofacies components. Analysis in transmitted and UV light has revealed variable types of fluorescence, which indicates the presence of two, differently preserved AOM types (Fig. 8). The first type of structureless material is characterized by bright fluorescence. This group of AOM is composed of planktic organisms. The second group is distinguished by dark colours in both transmitted and UV light, and its origin cannot be determined. The presence of two types of AOM may be associated with their different resistance to destruction, resulting from their mechanical or biological destruction and oxidation. It is also possible that various types of structureless material come from different rocks, or the AOM, characterized by dark colours, is reworked from primary rocks.

Moreover, noteworthy are also samples 416b (Kacwinianka section) and 701 (Łapszanka section), which are characterized by the mixing of organic matter of different states of preservation. This is a further proof of possible redeposition during the formation of the CCPB sediments. Both samples were taken from the lower Chochołów beds. It seems that increased redeposition took place during the formation of these strata.

LITHOFACIES

To extend environmental interpretation based on the palynological investigations, the lithology and sedimentary structures were characterized in detail for each section (Figs. 1C and 9). They have allowed distinguishing 13 lithofacies, whose description and interpretation are presented in Table 2. The lithofacies coding is based on Miall (2006). Interpretations of particular lithofacies are conducted according to the following reports: Reineck and Singh (1973), Bridge (1978), Gradziński et al. (1986), Miall (2000), and Nichols (2001).

The studied sections are dominated by fine-grained lithofacies (fl) interbedded with sand lithofacies (Gng, Sng, Sm, Sr, Srl, Srf, Sk, Sds, Sh and Shcs) characterized by variable sedimentary structures. Coarse-grained lithofacies (Gm) are subordinate (Fig. 9 and Table 2). The presence of sedimentary structures characteristic of the Bouma sequence (graded bedding, horizontal lamination, lenticular bedding, flaser bedding, convolute bedding, and hemipelagic sediments) has been observed in the sections (Fig. 10). This indicates deposition from the water column during calm periods, as well as sedimentation during turbidite activity and a small contribution of other mass move-

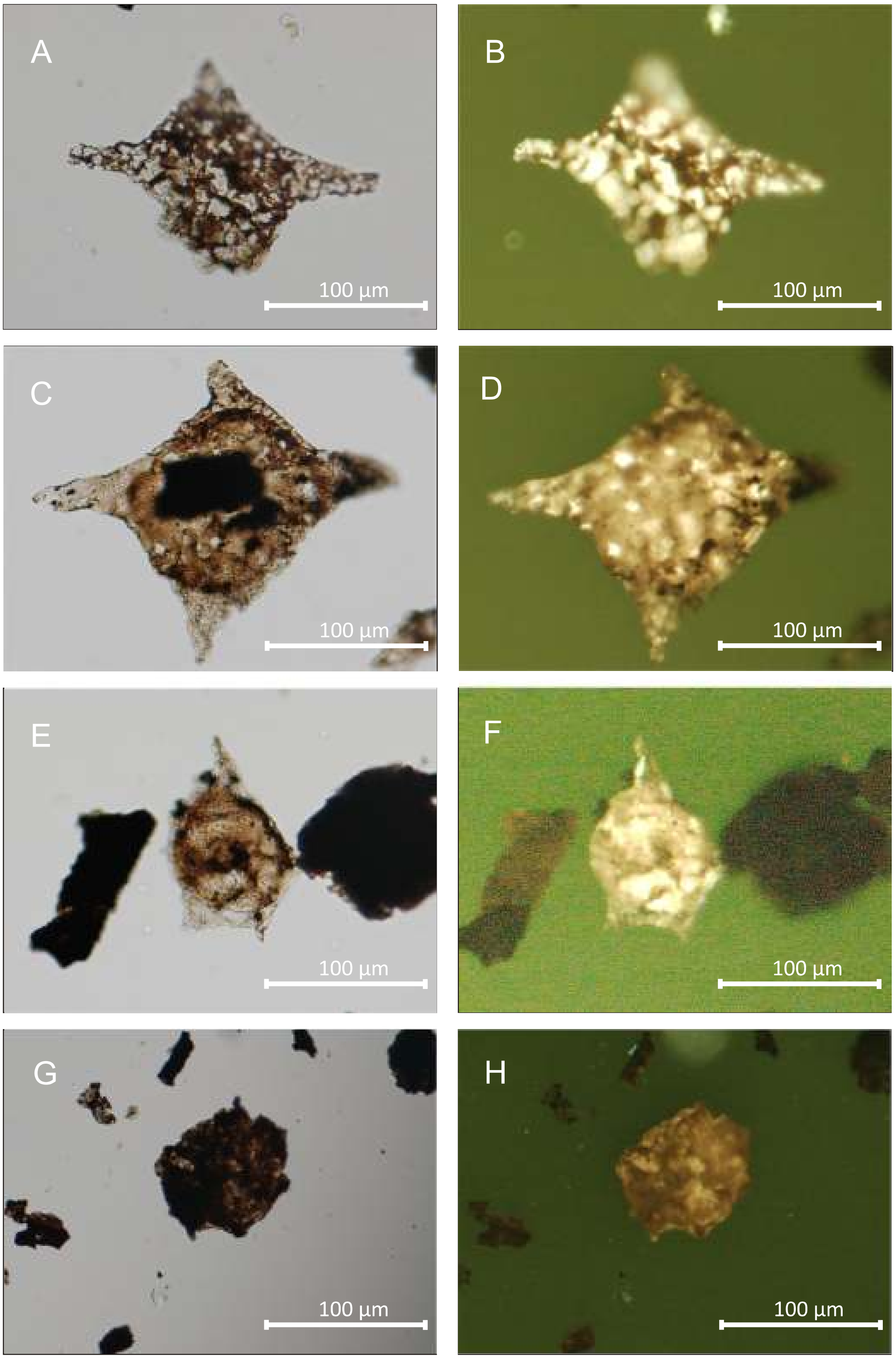

Fig. 7. Specimens of selected dinoflagellate cysts from the studied samples in transmitted (A, C, E, G) and UV light (B, D, F, H); A, B, C, D – *Rhombodinium* sp.; E, F, G, H – *Deflandrea phosporitica* Eisenack, 1938

A, B – 557s (Kacwinianka section); B, C – 557nad (Kacwinianka section); E, F, G, H – 557pod (Kacwinianka section)

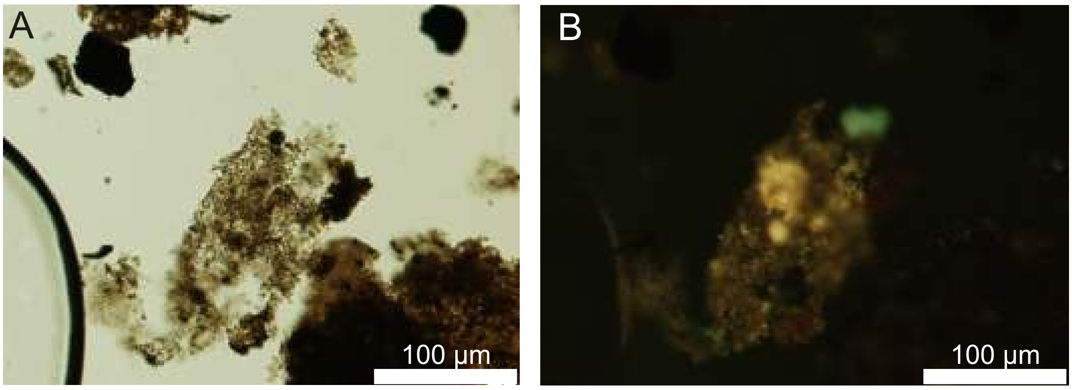

Fig. 8. Amorphous organic matter (AOM) from sample 8AŁł (Łapszanka section) in transmitted (A) and UV light (B)

ments, such as debris flows. The predominance of fine lithofacies indicates either deposition of the CCPB sediments in the distal part of the basin or a small proportion of the coarse fraction in the source material.

In the past, there was a strong conviction that deposits of turbidity currents can form only in deep-marine settings. At present, there are numerous reports on ancient flysch deposits both from deep and shallow settings (Contero et al., 2012). Therefore, of large significance is the occurrence of the Shcs lithofacies in the studied sections. The presence of hummocky cross stratification indicates that the described rocks of the CCPB were formed above the storm wave base. Likewise, the presence of symmetric ripples, interpreted as wave ripples, points to deposition in a shallow setting, in which wave action reached the sea bottom. The sediment deposited by turbidity currents must have been subject to wave action from the normal and storm wave base (Lamb et al., 2008).

The described lithofacies indicate the formation of the CCPB succession from the Polish Spisz either in a shallow setting in the distal part of the basin, or at a low supply of coarse material. An important feature of the Oligocene basin was its inclined bottom, which allowed triggering of turbidity currents. Stevenson et al. (2015) considered that bottom inclination is indispensable for turbidite formation. The currents could be formed due to numerous triggering phenomena, such as exceeding the natural angle of repose of the sediment, earthquakes, or the presence of storms.

DEPOSITIONAL ENVIRONMENTS – DISCUSSION

So far, there are no reports indicating the specific depth of the Podhale Basin. Prevailing views refer to the deep-marine origin of the Podhale Basin and other basins of the CCPB (Cieszkowski et al., 2009). Only Watycha (1959) pointed out that the flysch could be originated in a shallow setting. However, he did not provide conclusive evidence to support this. According to Gedl (2000), the sea was the shallowest during the sedimentation of the Szaflary beds, deepened during the sedimentation of the Zakopane beds, and reached the maximum depth during the sedimentation of the Chochołów beds, after which the sea level dropped. Soták et al. (2001) indicated that the highest sea level occurred at 32 Ma.

Furthermore, many different models of deposition in the Podhale Basin were created in the past. Westwalewicz-Mogilska (1986) presented models of submarine fans that formed in the Orava-Podhale Basin in different times. However, distribution of facies, location of channels, and unconfirmed transport of sediments from the south ruled out this proposition. Wieczorek (1989) partially agreed with Westwalewicz-Mogilska (1986) and proposed a model of a ramp, which was supplied by material from many sources during deposition of the Szaflary beds. Jankowski (2015) suggested that the Zakopane beds were the equivalent of the Menilite beds, deposited in the same jointed depositional system, which was varied in space and between depositional zones. Moreover, Jankowski et al. (2015) and Jankowski (2015) interpreted that shallow marine sedimentation predominated in Early Rupelian time in the area occupied by the present-day Carpathians. Soták (1998b, 2010) referred the deposition in the Podhale Basin with menilite facies, but he suggested that the deposition was related to a deep-water turbidity system.

Results of the palynofacies analysis have allowed determining that the distance between the deposition area and the source area became relatively larger during deposition of the CCPB sediments in the Polish Spisz area. This is indicated by the increase of the percentage of black wood, which also proves that these deposits were deposited by turbidity currents. Moreover, the presence of cuticle in some slides points to short distance from the source area. Additional investigations conducted on samples from the Łapszanka and Kacwiński Stream sections have confirmed that the western part of the present-day Polish Spisz was relatively close to the source area in the Oligocene. Based on the biostratigraphic analysis using dinoflagellate cysts, the age of the deposits (Szaflary beds, Zakopane beds, lower Chochołów beds) from the Kacwinianka, Łapszanka and Kacwiński Stream exposures can be determined at the Early Rupelian. The presented results are completely different from the previous biostratigraphic determinations. Based on these results, the deposition rate could be determined at 1600 m/My during the formation of the turbiditic deposits. The presence of some taxa (e.g., *Nannocertopsis* sp.) indicates that the material was reworked from older rocks. This conclusion was confirmed by investigations in UV light, which showed the presence of two cyst assemblages characterized by different fluorescence colours. Light coloured (yellow) dinoflagellate cysts are considered *in situ* components, e.g. *Rhombodinium* sp. In turn, dark coloured (orange) dinoflagellate cysts are thought to be redeposited specimens. Individuals with different fluorescence colours have also been found among the representatives of *Deflandrea phosporitica*, which indicates that some of them have been subject to reworking, owing to the long stratigraphic range of this taxon. Partial redeposition of a taxon may lead to erroneous stratigraphic and

Table 2

Lithofacies in the Podhale Basin succession, including their key features and interpretation

	LITHOFACIES	DESCRIPTION	INTERPRETATION
Coarse-grained	Massive conglomerates (Gm) (Fig. 10A)	Bed thickness up to 35 cm; grain- to matrix supported; medium-grained conglomerates; dense/chaotic clast packing	Sediment-gravity flow deposits: high-density gravity flows (debris-flow type)
Mixed and sandy grained	Normally graded sandstones and conglomerates (Gng, Sng) (Fig. 10B)	Bed thickness up to 40 cm; usually beginning with medium- or fine-grained conglomerates; variable clast rounding; usually chaotic clast distribution; presence of few clay clasts; begins with erosional boundary	Sediment-gravity flow deposits: high-density gravity flows (debris-flow type) or Ta division of the Bouma sequence
	Massive sandstones (Sm)	Bed thickness up to 1 m; presence of beds characterized by variable thickness; very fine-grained, fine-grained and coarse-grained sandstones; presence of mechanic hieroglyphs on bed soles; presence of sandstone lithoclasts	Sediment-gravity flow deposits: deposition caused by waning of a high-density current (Lowe, 1982)
	Ripple cross-laminated sandstones (Sr) (Fig. 10C)	Bed thickness up to 30 cm; fine-grained sandstones; presence of wave and current ripples	Current ripples: bottom forms that originated due to traction transport; by low to medium-concentration turbidity currents (*sensu* Lowe, 1982) or Tc division of the Bouma sequence, Wave ripples: bottom forms that originated due to traction transport above the normal wave base
	Sandstones with lenticular bedding (Srl)	Bed thickness up to 30 cm; presence of packets with mud distinctly prevailing above sand, which results in the presence of cross-laminated sets in the form of lenses, often isolated	Domination of deposition of fine-grained material from suspension during calm periods with periodical sedimentation of coarse material due to the activity of currents or Tc division of the Bouma sequence
	Sandstones with flaser bedding (Srf)	Bed thickness up to 75 cm; packets composed of sand grains with low mud admixture, which separates particular sets of cross-laminated sediment	Sedimentation of coarser terrigenous material during current activity and deposition of fine-grained material from suspension during calm periods or Tc division of the Bouma sequence
	Sandstones with cross bedding (Sc) (Fig. 10D)	Bed thickness up to 5 cm; fine-grained sandstones; presence of multi-directional cross-lamination	Individually, the lithofacies is not diagnostic; transport of sand material above the bottom in the upper range of lower flow regime
	Sandstones with load structures (Sk) (Fig. 10E)	Bed thickness up to 8 cm; fine-grained sandstones; load structures visible in the lower parts of the sandstone beds; sandy fragments are 'drowned' in the mud below; convolute bedding	Unstable density bedding or Tc division of the Bouma sequence
	Sandstones with deformation structures (Sds)	Bed thickness up to 65 cm; fine-grained sandstones, occasionally with admixture of medium-sandstone size grains; presence of synsedimentary deformation folds, flow structures, load casts, water escape structures, buried ripples	Ambiguous; transport of unlithified sediment above a gently inclined bottom; may be formed due to grain-flow type deposition, sediment liquefaction, rapid deposition
	Laminated sandstones (Sh) (Fig. 10F)	Bed thickness up to 40 cm; very fine-grained and fine-grained sandstones; occasionally beginning with an erosional boundary	Formed in the first plane-bed transport by traction currents in the lower flow regime or due to deposition from suspension or Tb or Td division of the Bouma sequence
	Sandstones with hummocky cross stratification (Shcs) (Fig. 10G, H)	Thickness up to 45 cm; very fine-grained or fine-grained sandstones; attaining the form of circular sandy hummocks up to several centimetres high; presence of lowered and elevated fragments in every direction; presence of low-angle bedding (values lower than the natural angle of repose); occasionally large-scale ripples covered by a set of low-angle multi-directional hummocky cross-stratification or convolute bedding formed due to the sucking force of the flowing current was covered by HCS	Formed due to traction transport on the bottom in an aqueous setting during the storm, below the normal wave base
Fine-grained	Laminated siltstones and mudstones (Fl)	Thickness up to 175 cm; single presence of coaly shales	Formed in the first plane-bed transport by traction currents in the lower flow regime or due to deposition from suspension or Te division of the Bouma sequence
	Ankerite (A)	Thickness up to 58 cm; usually as single lenses, rarely horizons	Formed due to diagenetic processes

environmental interpretations. During the identification of dinoflagellate cysts, attention was drawn on the significant prevalence of species from the *Wetzeliella*, *Deflandrea-Caligodinium* and *Spiniferites* groups in relation to other groups of dinoflagellate cysts. Based on the characteristic features of these groups, it has been assumed that the large number of individuals of these groups in relation to representatives of other taxa does not explicitly explain the depositional conditions of the sediments with the dinoflagellate cysts. However, the presence of the *Wetzeliella* group may indicate their formation either in the coastal zone at a small distance from river mouths or in open-marine zones rich in nutrients, e.g. upwelling zones, which would confirm the existing concepts of the CCPB formation as deep-marine rocks. Following the results of UV investi-

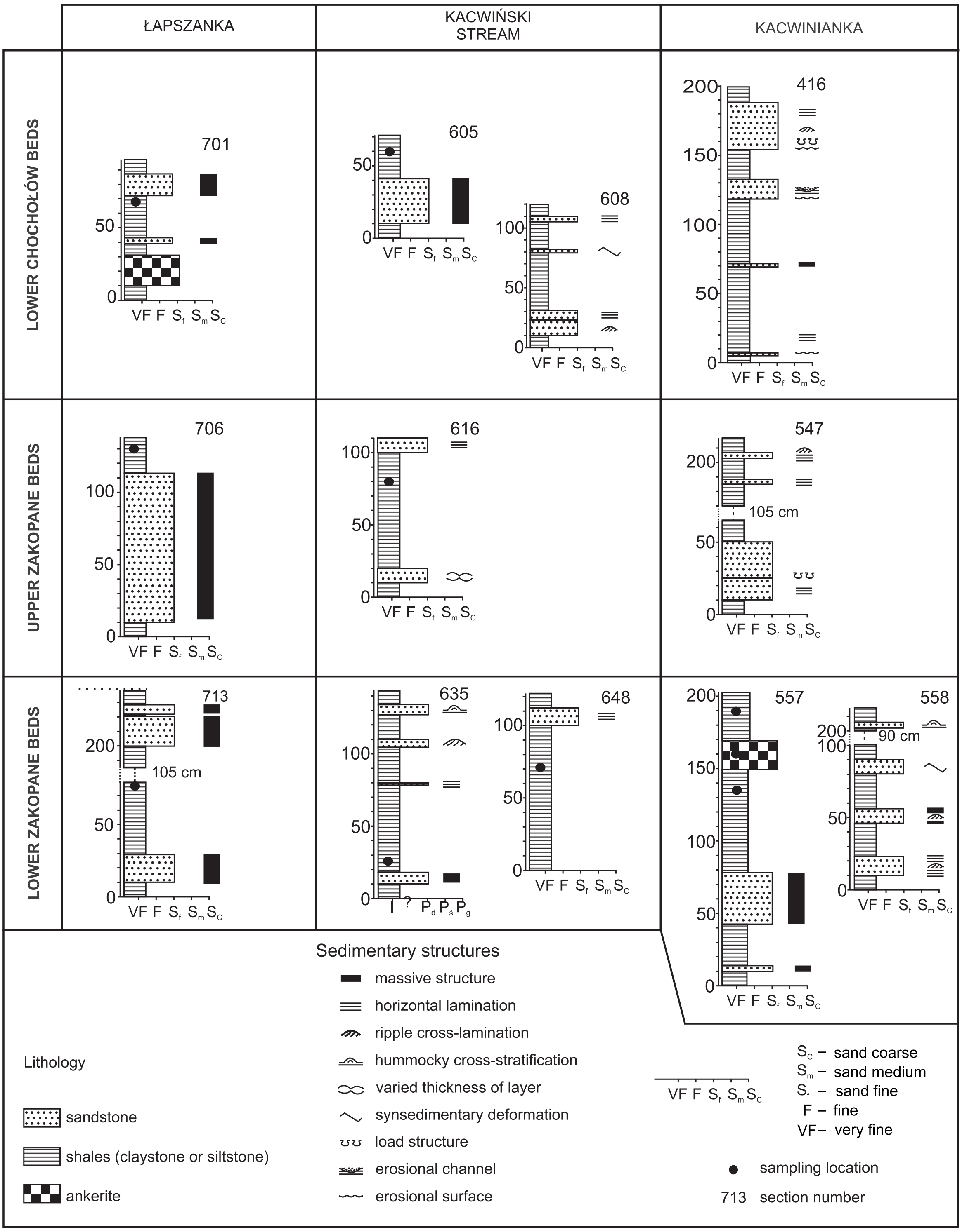

Fig. 9. Selected logs of the Kacwinianka, Kacwiński and Łapszanka sections

gations, conclusions drawn from the presence of the *Deflandrea-Caligodinium* group have been omitted from the environmental discussions.

Lithological logs of the exposures located along the escarpments of all three streams are dominated by fine-grained sediments interbedded with deposits of submarine gravitational flows, mainly turbidity currents, and subordinate high-density flows such as debris flows (Table 2, Figs. 9 and 10). This is confirmed by the presence of sedimentary structures, such as particular divisions of the Bouma sequence, typical of such settings in the study area. Moreover, hummocky cross-stratification (HCS) was also observed; this structure, typical of storm processes, indicates deposition in a relatively shallow setting (at depths oscillating near the storm wave base; Fig. 10G, H). The co-occurrence of gravitational flows, mainly turbidity currents, commonly associated with a

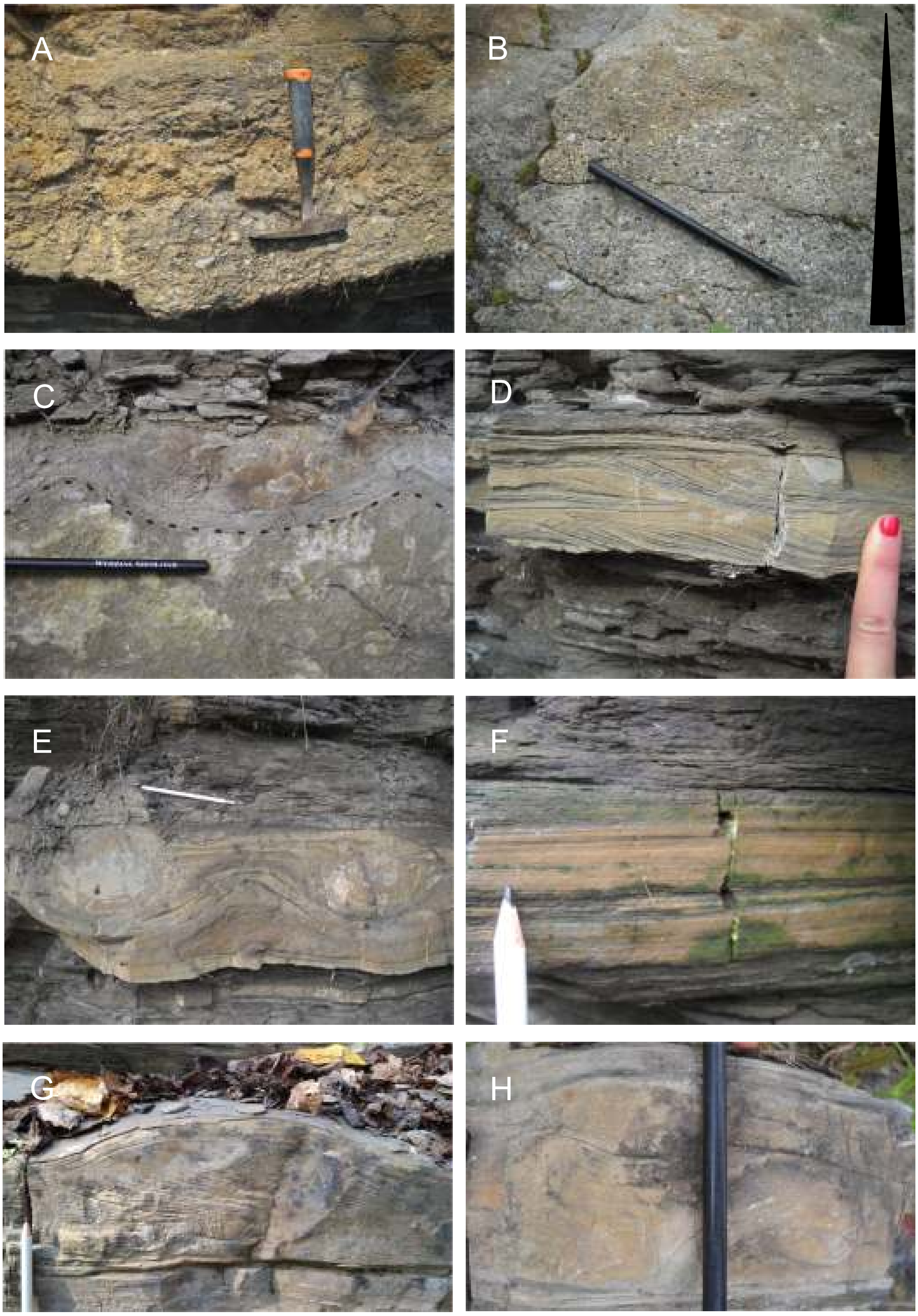

Fig. 10. Selected sedimentary structures typical for the clastic succession of the Podhale Basin

A – massive conglomerates, grain- to matrix-supported; dense/chaotic clast packing, beginning with an erosional surface (594, Kacwinianka section); **B** – normally graded sandstones and conglomerates (579, Kacwinianka section); **C** – ripple cross-laminated sandstones characterized by wave ripples (588, Kacwinianka section); **D** – ripple cross-laminated sandstones characterized by climbing ripples (537, Kacwinianka section); **E** – sandstones with convolute bedding (516, Kacwinianka section); **F** – laminated sandstone (525, Kacwinianka section); **G, H** – sandstones with hummocky cross-stratification, lowered and elevated fragments in every direction, and low-angle bedding (525, 579, Kacwinianka section) deep-marine setting, and HCS as well as wave ripples seem to exclude unequivocal interpretation of the sedimentary setting. However, turbidity currents can also form in a relatively shallow environment, assuming an inclined sea bottom and the existence of triggering mechanisms, such as storms or earthquakes (Lamb et al., 2008; Stevenson et al., 2015).

Genera of dinoflagellate cysts identified in the palynological slides, elements of palynofacies analysis (cuticle), and sedimentary structures (HCS) indicate a relatively shallow-marine setting in the study area during the Early Rupelian, at a subsequent activity of gravitational flows during deposition from turbidity currents.

CONCLUSIONS

Biostratigraphic analysis of dinoflagellate cysts from the Podhale Basin (Szaflary, Zakopane and lower Chochołów beds) in the study area indicates an Early Rupelian age. These results have allowed estimating the sedimentation rate of the rocks at 1.6 mm per year.

Results of palynofacies analysis indicate a gradual increase of black wood proportion in the Kacwinianka, Łapszanka and Kacwiński Stream sections. The upper parts of the sections show lower diversity of the components than their lower parts. These observations prove that, the study area was relatively far away from the source area during the deposition of the Podhale Basin clastic succession. A high proportion of black wood points to an origin related to turbidity currents.

The presence of cuticle confirms a short distance from the source area.

Differences between the Kacwinianka and Łapszanka sections suggest that, in the Early Rupelian, the Łapszanka area was closer to the source area than the Kacwinianka area.

The assemblage of dinoflagellate cysts provides evidence for reworking of organic material from older rocks. This is confirmed by investigations in UV light, which indicated the co-occurrence of two differently preserved groups of dinoflagellate cysts, characterized by different fluorescence colours. Reworking may cause erroneous biostratigraphic interpretations; accordingly, the samples were controlled in UV light.

Three groups of cysts dominated within the dinoflagellate cyst assemblages: *Wetzelliela, Deflandrea-Caligodinium* and *Spiniferites*. The large number of individuals within these groups points to deposition in the coastal part of the reservoir, near a river mouth or in an upwelling zone.

The described sections are dominated by fine-grained deposits that represent either the terminal division of the Bouma sequence (Te) or pelagic sedimentation.

Structures typical for turbidity currents and those typical for relatively shallow-marine deposition (HCS, wave ripples) coexist in the studied sections.

Sandstone event beds from the shale-dominated sections were deposited from turbidity currents influenced by storm waves.

The assemblages of dinoflagellate cysts, elements of palynofacies analysis, and sedimentary structures (wave ripples and HCS) indicate deposition in a relatively shallow-marine setting.

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