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Coal-bearing submarine slump sediments from Oligocene–Miocene transition of the Eastern Outer Carpathians (Bieszczady Mountains, SE Poland)

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The paper presents a new finding of lustrous coal particles in the youngest flysch sediments of the Silesian Nappe, Eastern Outer Carpathians, outcropped in the Bieszczady Mountains. The coal material occurs in a 1 m thick submarine slump layer in the Kiczera Dydiowska Sandstones that belong to the youngest part of the Krosno Beds. Coal particles are numerous (up to 16%) in a massive sandstone of the slump layer. The siliciclastic particles in these sediments are classified as material derived from weathered rocks of a continental block or they have been recycled from post-orogenic sediments. Lustrous coal represents coaly, mostly homogeneous plant fragments representing macerals of the vitrinite group. The random vitrinite reflectance varies from 0.52 to 0.57%, which corresponds to high volatile bituminous rank. Some coal pebbles display a tree structure, typical of gelified xylites, due to impregnation of cell walls by resinite. Its occurrence in this material indicates terrestrial plants producing waxes and resins. Some of the gelified plant debris shows evidence of pyritisation that, in the absence of inertinite macerals in coal, may indicate dysoxic conditions during the first decomposition processes of organic matter under an aqueous environment. The coaly-bearing slump moved down most probably from the SE during Oligocene–Miocene transition time. This shows that an intrabasinal exotic massif, as an uplifted fragment of ?Precambrian craton, which supplied a large amount of siliciclastic material to the Silesian–Subsilesian basin during the Early–Middle Oligocene, still existed at the end of the Oligocene.

Key words: coal pebbles, submarine slump, foraminifera, Oligocene–Miocene transition, Eastern Outer Carpathians, Bieszczady Mts.

INTRODUCTION

Cretaceous through Paleogene flysch sediments of the Inner and Outer Carpathians contain numerous exotics of the Upper Carboniferous coal and thin layers or lenses of autochthonous lustrous coal (for summary see Kotlarczyk, 1979; Matl, 1991; Wagner, 1996). The Upper Carboniferous detrital material was supplied by gravitational flows mainly to the marginal parts of the Carpathian realm within the Silesian–Subsilesian and Skole–Tarčau basins. The coal exotics occur in various fractions of turbidites, showing variable petrographic and microfossil composition (e.g., Bukowy, 1957; Kotlarczyk and Śliwowa, 1963; Ladyzenski and Sawkiewicz, 1968; Turnau, 1970; Frankiewicz, 1974). They have been found in various lithostratigraphic units. Most of them belong to the Beriasian–Aptian strata in the Western Outer Carpathians, and Berriasian to the Maastrichtian–Oligocene turbidite sediments in the Eastern Outer Carpathians (Kotlarczyk, 1979). Supply of the allochthonous (exotic) coal was postulated based on microfloristic and petrographic studies. Most probably, this material was supplied as coal detritus to the Western Outer Carpathian basins from the Upper Silesia Coal Basin and its continuation to the south, and to their eastern part from other Upper Carboniferous basins, recently occurring under the nappes of the Eastern Outer Carpathians (Bukowy, 1957; Kotlarczyk and Śliwowa, 1963). According to Turnau (1970), both these areas may have formed a single Precarpathian Coal Basin near the southern margin of the European Platform. It is also possible that some of the so-called Upper Carboniferous coal layers occurring in the flysch successions could be an effect of carbonisation of much younger organic matter mixed with Carboniferous spores, as was documented from the Maastrichtian–Paleocene and Oligocene sections in the Skole Nappe of the Outer Carpathians by Kotlarczyk (1979), and from the so-called “black flysch” in the Pieniny Klippen Belt (Birkenmajer and Turnau, 1962), differently dated as Early Jurassic (e.g., Horwitz, 1937; Birkenmajer, 1957; Birkenmajer et

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al., 2008) or Early Cretaceous (Sikora, 1962; Książkiewicz, 1972; Oszczypko et al., 2004, 2012).

However, autochthonous detrital coal which has been described mainly from mudstones and claystones as coalified debris occurs also in various fractions of flysch sediments (Kotlarczyk, 1979; Matl, 1991; Wagner, 1980). Additionally, it may create lenses and thin layers, and co-occur with tree trunks or their fragmented stems (Zuber, 1918; Dżułyński and Ślączka, 1958; Kotlarczyk, 1979; Wagner, 1980). This coaly organic matter occurs mostly in the Oligocene turbidites of the Inner Carpathians (Podhale Flysch) and in the Eocene–Middle Miocene of the Eastern Outer Carpathians (Horwitz and Doktorowicz-Hrebnicki, 1932; Gołąb, 1959; Bąkowski, 1967; Frankiewicz, 1974; Kotlarczyk, 1979; Lipiarski and Peszat, 1984; Ladyzenski and Sawkiewicz, 1968; Zielińska, 2010; Wagner, 2011, 2013). It was also found in the Middle Miocene sediments of the Carpathian Foredeep and within intra-mountain depressions (Sarjusz-Makowski, 1947; Frankiewicz and Wagner, 1982; Szafran and Wagner, 1999). Coaly organic matter is characterized by variable coal rank from dull and bright brown coal to bituminous coal (Wagner, 1980, 1992, 1996, 2011, 2013; Lipiarski and Peszat, 1984; Zielińska, 2013). Higher rank coal is compared with ortho-lignite (Wagner, 2013).

Most of the Cretaceous–Eocene organic matter is the autochthonous coal derived from the northern margin of the Outer Carpathian basins, as was suggested based on flute casts of turbidite layers. A much rarer source of bituminous coal is related to emerged intra-basinal cordilleras from which it was transported by gravitational flows to more internal parts of the Outer Carpathian basins (e.g., Kotlarczyk, 1978; Zielińska, 2013).

This study presents a new finding of lustrous coal pebbles from the Oligocene–Miocene transition flysch sediments of the Silesian Nappe, Eastern Outer Carpathians, outcropped in the Bieszczady Mountains (Fig. 1). We discuss sedimentary and petrographic features of the coal-bearing layer, petrographic features of coal particles and stratigraphic position of sediments containing the coal-bearing layer.

GEOLOGICAL SETTING

The Silesian Nappe, one of tectonic units of the Outer Carpathians, consists of a succession of Upper Jurassic through Miocene flysch sediments. The coal-bearing sediments have been found in the southeastern part of the Silesian Nappe, outcropped in the Bieszczady Mountains. It is represented only by the youngest series, Oligocene–Miocene in age. These sediments, distinguished as the Krosno Beds, are composed of a 3.2 km thick flysch succession. In the Polish part of the Bieszczady Mountains, the Krosno Beds have been subdivided into three informal lithostratigraphic units (Fig. 2), named as the lower, middle and upper divisions (Żytko, 1968). Detailed geological mapping of the Bieszczady Mountains allowed recognition of sedimentary features and stratigraphy of this succession (Haczewski et al., 2007, 2015a, b). The lower division, up to 700 m thick, consists of medium- and thin-bedded sandstones and marlstones. The middle division, up to 1300 m thick, consists of thick (up to 80 m) packages of thick-bedded polymictic sandstones, the so-called Otryt Sandstones. The upper division, up to 1200 m thick, consists mostly of non-fissile marlstones with convolute- and cross-laminated, thin-bedded sandstones. The middle part of this division includes two horizons with coccolith limestone bands, the Jasło and the Zagórz limestones, which are widely used as isochronous regional markers within the Oligocene successions of the Outer Carpathians (e.g., Jucha, 1958, 1969; Koszarski and Żytko, 1961; Jucha and Kotlarczyk, 1961; Haczewski, 1984, 1989). The uppermost part of the upper division consists also of two lenticular packages (130 m and 25 m thick) of thick-bedded low- to medium-grained, massive, rarely cross- to parallel-laminated sandstones, classified as the Kiczera Dydiowska Sandstones (Haczewski et al., 2007).

LOCALITY OF THE COAL-BEARING LAYER

The outcrop of sediments containing lustrous coal pebbles and accompanying coal detritus lies in a local road crossing the village of Procisne, within the San River valley in the Bieszczady Mountains, Poland, close to the Polish/Ukrainian border (Fig. 1). Structurally, this sedimentary succession is located on the NE limb of the Dźwiniacz Górny Syncline (Haczewski et al., 2007, 2015a). With regard to the geology of the area, the coal-bearing layer occurs in a turbidite succession, ca. 550 m above the Zagórz Limestone (Fig. 2), a coccolith limestone, recognized in this area by Haczewski (1972). The sediments are part of the second package of the Kiczera Dydiowska Sandstones, which consists here of two types of thick-bedded sandstones (Fig. 3). The first of them consists of thin- to medium-grained sandstones with clayey-calcareous cement including coal pebbles and clayey/silty clasts. The second one is represented by fine-grained, parallel-, cross- and convolute-laminated micaceous sandstones with calcareous cement.

METHODS

In addition to field sedimentary observations, microscopic analyses have been made during this study, including: (1) micropalaeontological study of the coal-bearing succession, (2) mineralogy and petrography of the coal-bearing layer, and (3) petrography of coal.

Six samples were collected from the Procisne section for microfossil study. Microfossils were extracted by repeated heating up and drying in sodium carbonate solution. Residues were dried, and washed through 63 μm mesh sieves. Foraminiferal and diatom specimens were manually picked up from the fraction 0.063–1.5 mm.

The petrographic study of the coal-bearing sandstone layer was performed on three thin sections using a *NICON YM-EPI Eclipse E600POL* optical microscope. The modal mineralogy of the sediment was obtained by counting at least 700 points with a *ZEISS* automatic counter in each thin section. The framework composition (modal analysis) was quantified using the point-counter method described by Dickinson (1985). In contrast to the Gazzi-Dickinson method (Ingersoll et al., 1984), minerals >63 μm within lithoclasts were counted as rock-forming minerals of the lithoclast composition (Decker and Helmold, 1985).

The petrographic study of coal is based on three samples. The analyses were carried out on polished surfaces of lump samples including determination of maceral composition of coal using reflected white and fluorescent blue light, under magnification 400 . In order to determine the degree of organic matter coalification, random vitrinite reflectance was examined. All measurements were obtained in accordance with ICCP (International Committee for Coal and Organic Petrology) requirements.

The residual rock samples used in the petrographic studies and microfossil slides are housed at the Institute of Geography, Pedagogical University of Cracow (collection of K. Bąk).

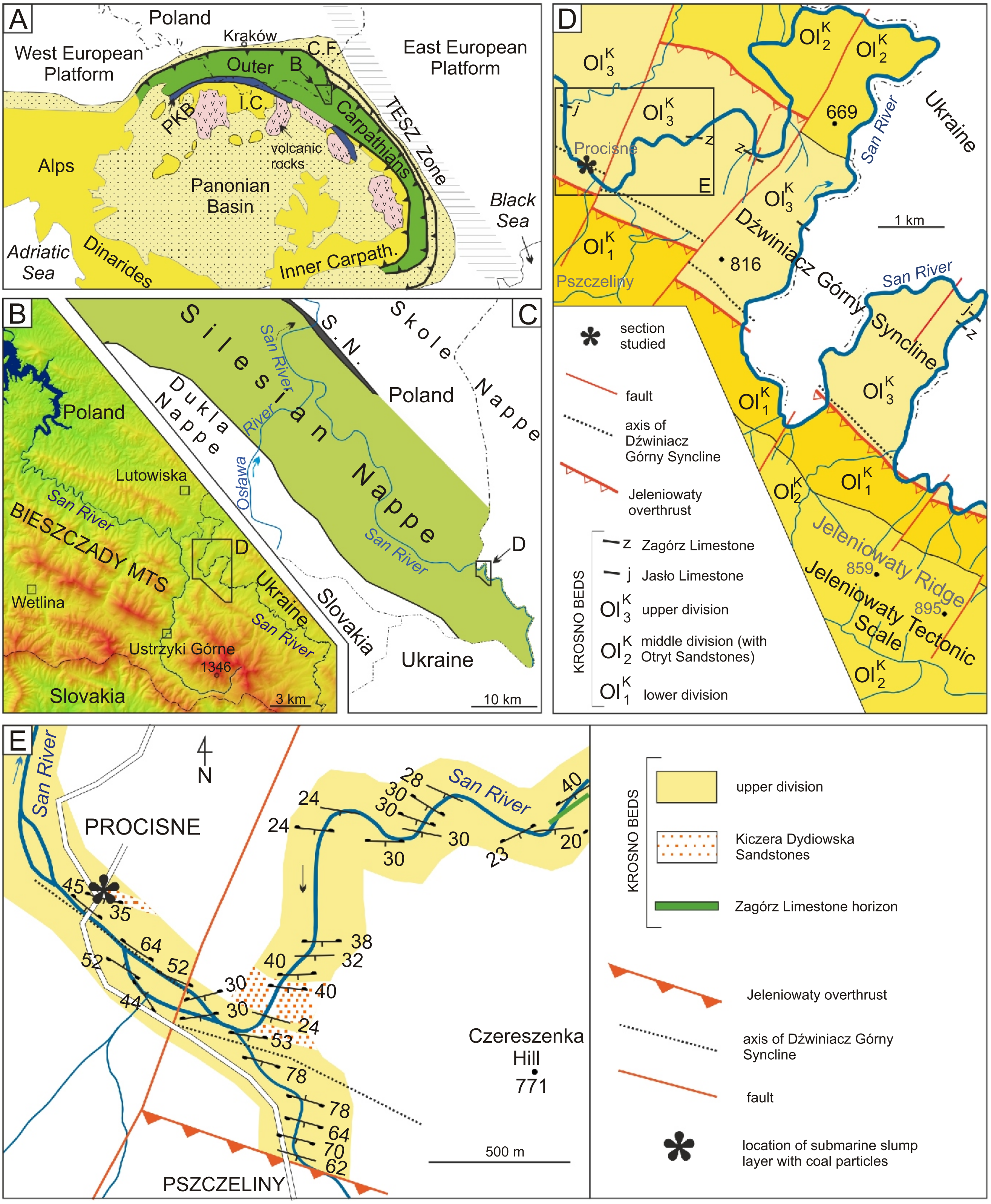


Fig. 1A – the Outer Carpathians on the background of simplified geological map of Alpine orogens and their foreland; B, C – position of the study area in relation to main morphological (B) and geological units (C) (after Oszczypko, 2004 and Bryndal, 2014); D, E – detailed geological maps of the Procisne region (after Haczewski, 1972; Haczewski et al., 2007, 2015a) with the location of study section

C.F. – Carpathian Foredeep, I.C. – Inner Carpathian, PKB – Pieniny Klippen Belt, S.N. – Subsilesian Nappe

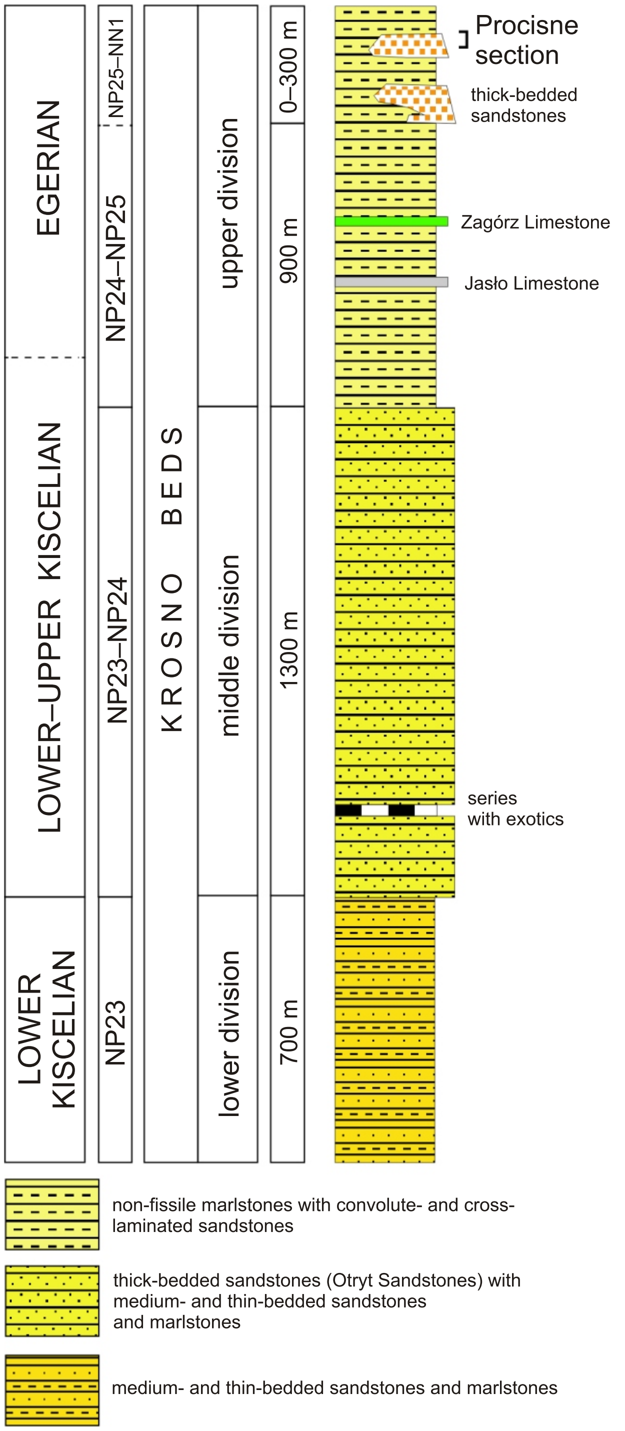


Fig. 2. Lithostratigraphic subdivision and lithologic log of the Silesian Nappe in the Bieszczady Mountains (Poland; after Bąk, 2005; Haczewski et al., 2015b)

RESULTS

LITHOLOGY AND STRUCTURE OF THE COAL-BEARING SUBMARINE SLUMP

The second package of the Kiczera Dydiowska Sandstones exposed at the village of Procisne contains a 22 m thick turbidite succession, including a 1 m thick deformed layer, which resembles a submarine slump (Figs. 3 and 4). A three metres long exposure of this layer displays its specific internal structure. The layer is composed of wedge- and ball-shaped bodies of coherently to semicoherently folded alternating sandstone, mudstone and thin claystone beds showing folded or tilted internal bedding (Fig. 4). Macroscopically, the wedge- and ball-shaped bodies consist of poorly cemented fine- to medium-grained massive sandstones, grey-yellow on weathered surfaces due to ferrous compounds in clayey-calcareous matrix. They contain contorted lenses of laminated very fine- and fine-grained sandstones and mudstones, and slubs of shales or claystones. Claystones and shales in this layer are calcareous and grey in colour, occurring as thin beds within folds and as rip-up clasts of various dimensions in massive sandstone within wedge-shaped bodies. The shales also form small irregular lenses containing small rounded, ball-shaped laminated sandstones and mudstones (Fig. 3). In addition to claystone clasts, numerous scattered lustrous black coal particles, from pebbles to detritus in shape, are present in the wedge-shaped sandstone bodies of the slump layer (Fig. 5). The dimensions of coal pebbles vary between 1 and 3 cm (middle axis).

Slump folds are isoclinal. Internal bedding of laminated sandstone and mudstone pieces is discordant, resembling imbricated slabs. The bottom of the slump layer is sharp, and the top is mounded to flat.

PETROGRAPHY OF COAL-BEARING SLUMP SANDSTONES

The coal-bearing massive sandstones from the slump layer in the Procisne section represent fine- to medium-grained (0.21–0.063 mm and 0.63–0.21 mm) subarcoses/sublitharenites using Folk's classification (Q–F–RF diagram; Fig. 6). Most of mineral and lithoclast grains range from 0.2 to 0.5 mm in size, occasionally to 0.9 mm. The framework grains are rounded and subrounded according to the terminology after Pettijohn (1975). The sandstones are moderately to well-sorted. Quartz is the dominant mineral in these sediments (Table 1 and Fig. 7), with its a content varying between 48 and 61%. It commonly occurs as "mosaic" and undulose grains (up to 50%; Fig. 8A). Coal particles are the second major component of the sandstones (up to 16%). Numerous grains are represented by feldspar accounting for 9%. The majority of feldspar grains (4.5%) are strongly altered (seritised, kaolinised). Among the unaltered feldspars, K-feldspars (as orthoclase perthite; Fig. 8B), microcline (Fig. 8C) and plagioclases (Fig. 8D) occur. Fragments of phyllosilicate flakes occur in subordinate amounts, including white mica (Fig. 8A; up to 7%) and biotite (up to 3%). Biotite is often altered showing different stages of the chloritisation process (Fig. 8B). Small chlorite flakes are also observed. The sandstones contain also heavy minerals, up to 0.2%. Transparent heavy minerals are represented by very stable minerals,

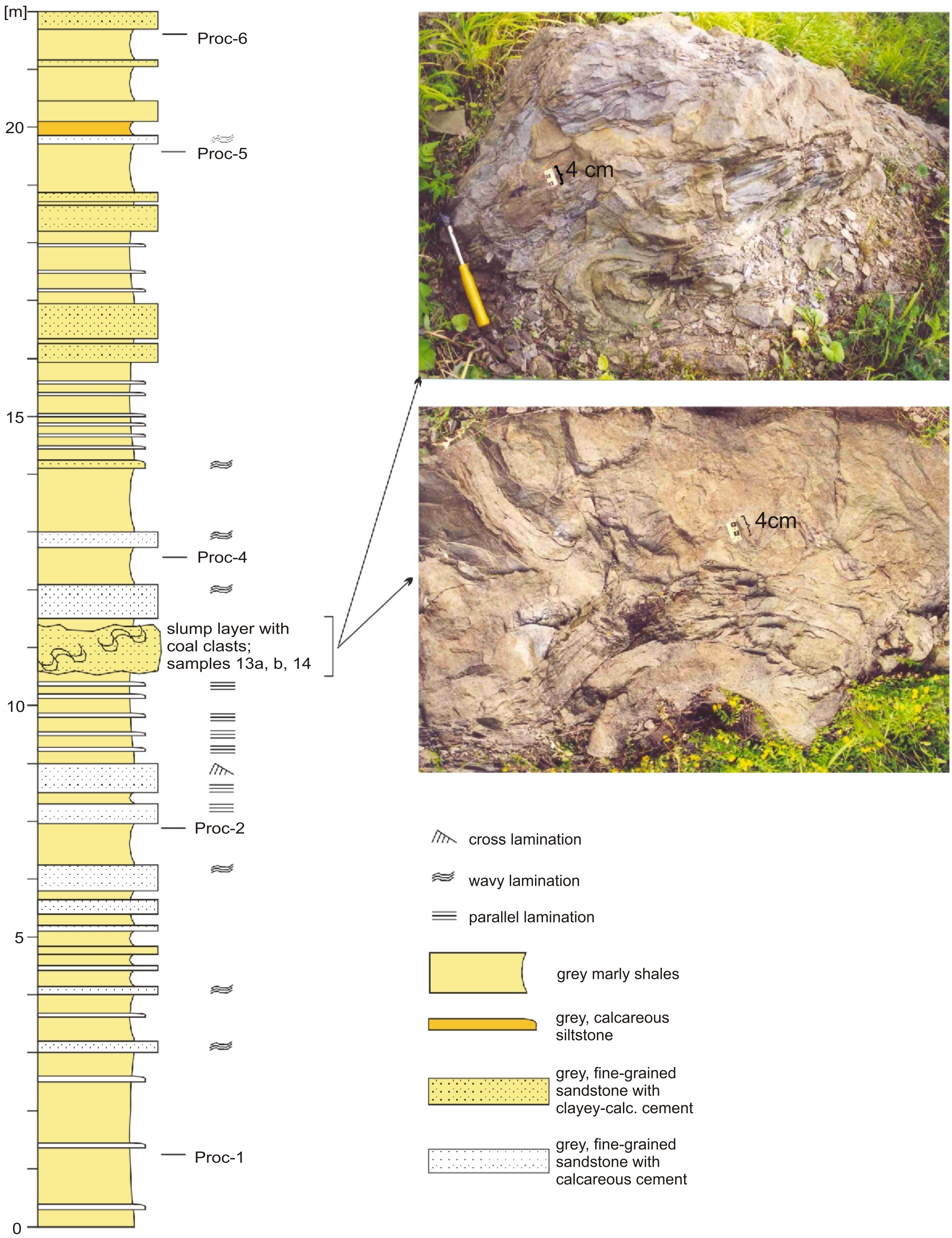


Fig. 3. Detailed lithological log of the upper division of the Krosno Beds at Prosisne (Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains) with the position of samples and photographs of submarine slump layer

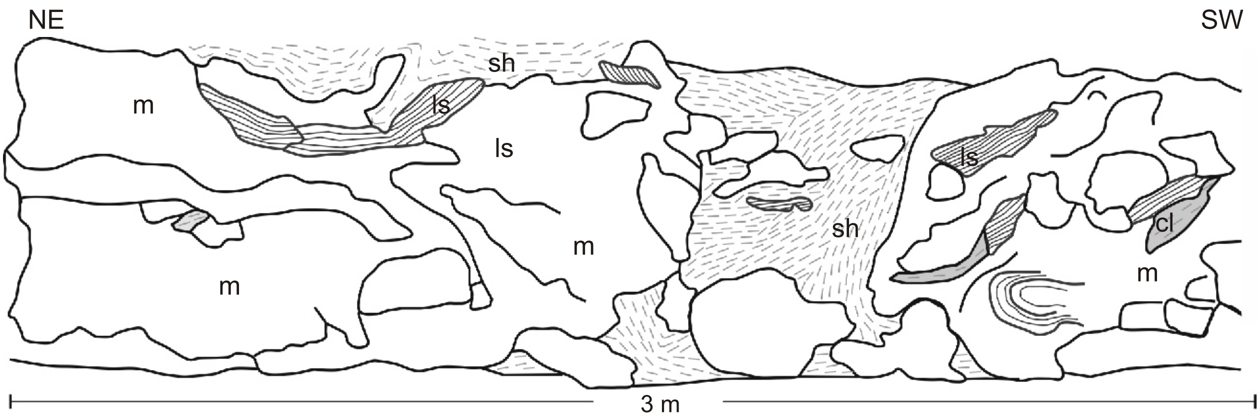


Fig. 4. Slump layer exposed along a road at Procisne, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

cl – calcareous claystone, ls – laminated fine-grained sandstone and mudstone, m – massive fine- to medium-grained sandstone, sh – calcareous shale

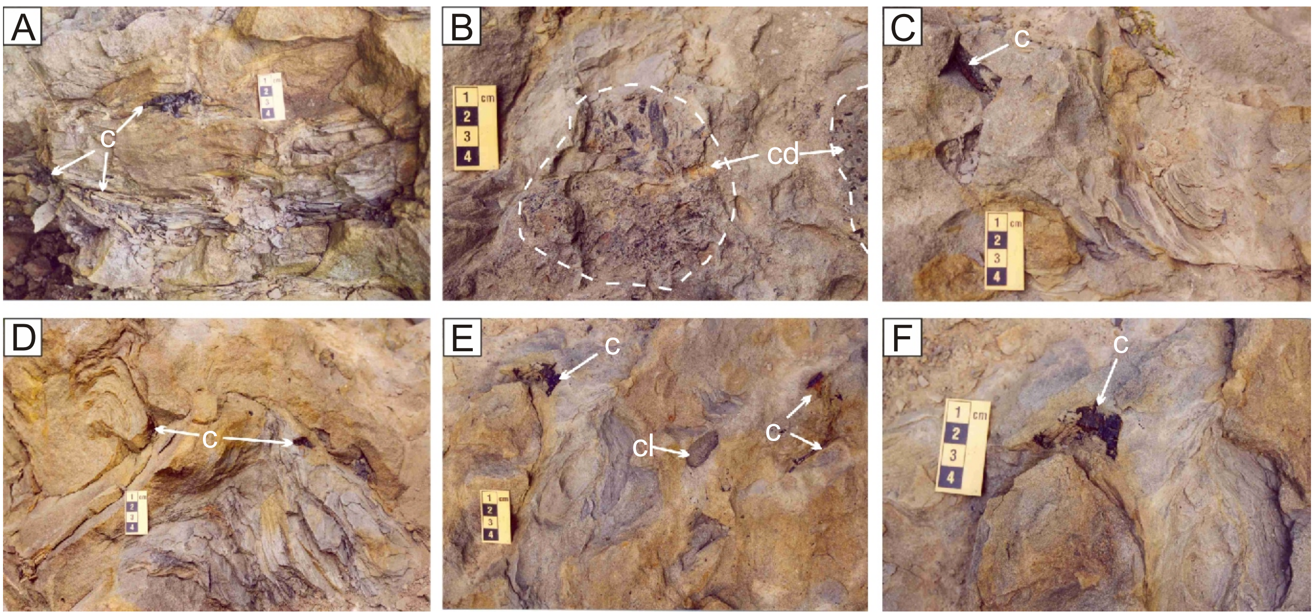


Fig. 5. Coal particles (c), clay clast (cl) and coal detritus (cd) in sandstone from slump layer at Procisne, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

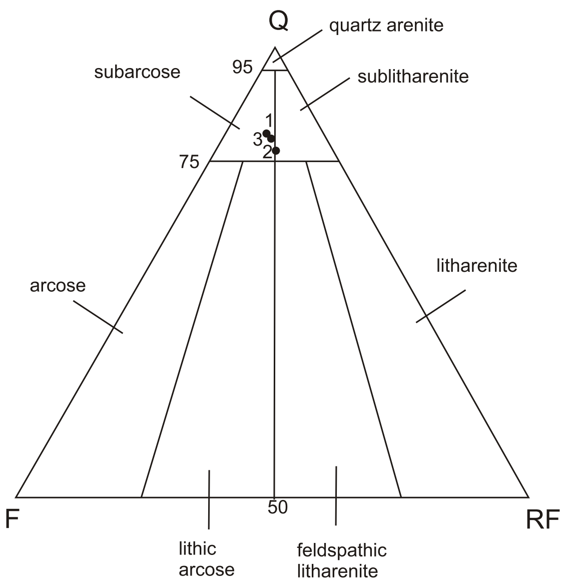


Fig. 6. Quartz–Feldspars–Rock fragments (Q–F–RF) discrimination diagram (after Folk, 1974) of massive sandstone from slump layer at Procisne, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

Samples: 1 – Proc-13a, 2 – Proc-13b, 3 – Proc-14

Table 1

Modal mineralogy of massive sandstone from the slump coal-bearing layer in the Procisne section, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

		Samples		
		Proc-13a	Proc-13b	Proc-14b
		subarcose*	sub-litharenite*	subarcose*
		%		
Quartz	"mosaic" grains	49.5	35.4	44.8
	undulose grain	1.1	2.0	2.9
	non-undulose grain	10.8	10.3	13.1
Feldspars	plagioclases	2.0	2.0	2.7
	K-feldspars	2.5	0.9	2.4
	strongly altered feldspars	4.5	4.2	2.9
Other minerals	withe mica	4.4	6.9	4.0
	biotite/altered biotite	2.1	2.9	2.4
	chlorite	1.3	1.9	1.0
	transparent heavy minerals	0	0.1	0.2
	non transparent heavy minerals	1.1	1.7	1.3
Lithoclasts	gneisses	1.8	1.6	1.9
	granitic gneisses/granites	1.7	1.4	1.8
	schists	1.6	1.4	0.2
	slates/phyllites	0	1.0	0.6
	siliceous rocks/chert	0.2	0.6	0.9
	brown carbonates	0.7	0.9	0.8
	mudstones	0.1	0	0
	volcanic rocks	0	0.4	1.0
Bioclasts	coal macerals	8.2	15.8	1.1
Cement	carbonates + clay minerals	6.4	8.6	14.0
Total content		100.0	100.0	100.0

* – names of the rocks after the classification of Folk (1974)

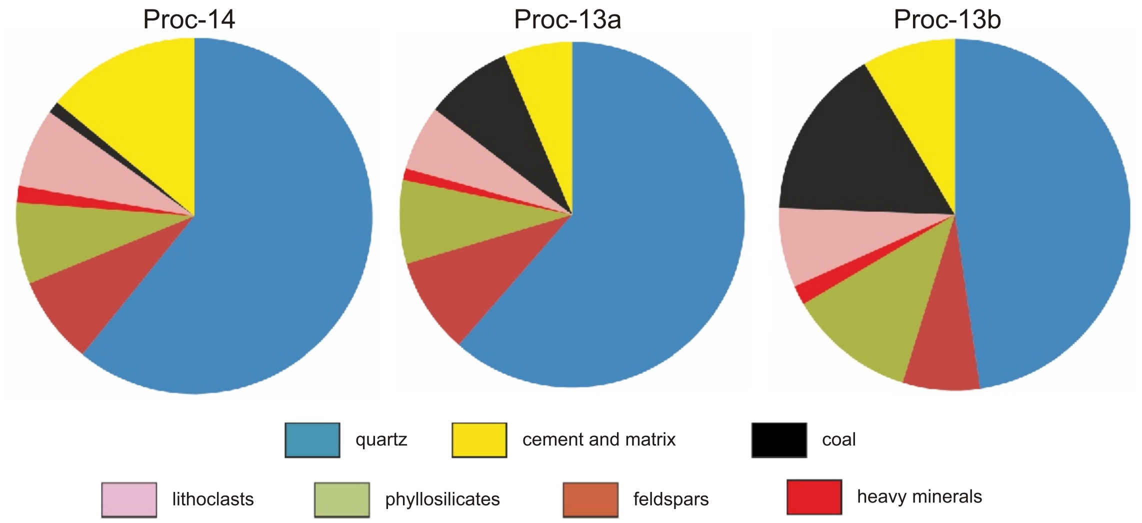


Fig. 7. Pie charts of modal composition of massive sandstone from slump layer at Procisne, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

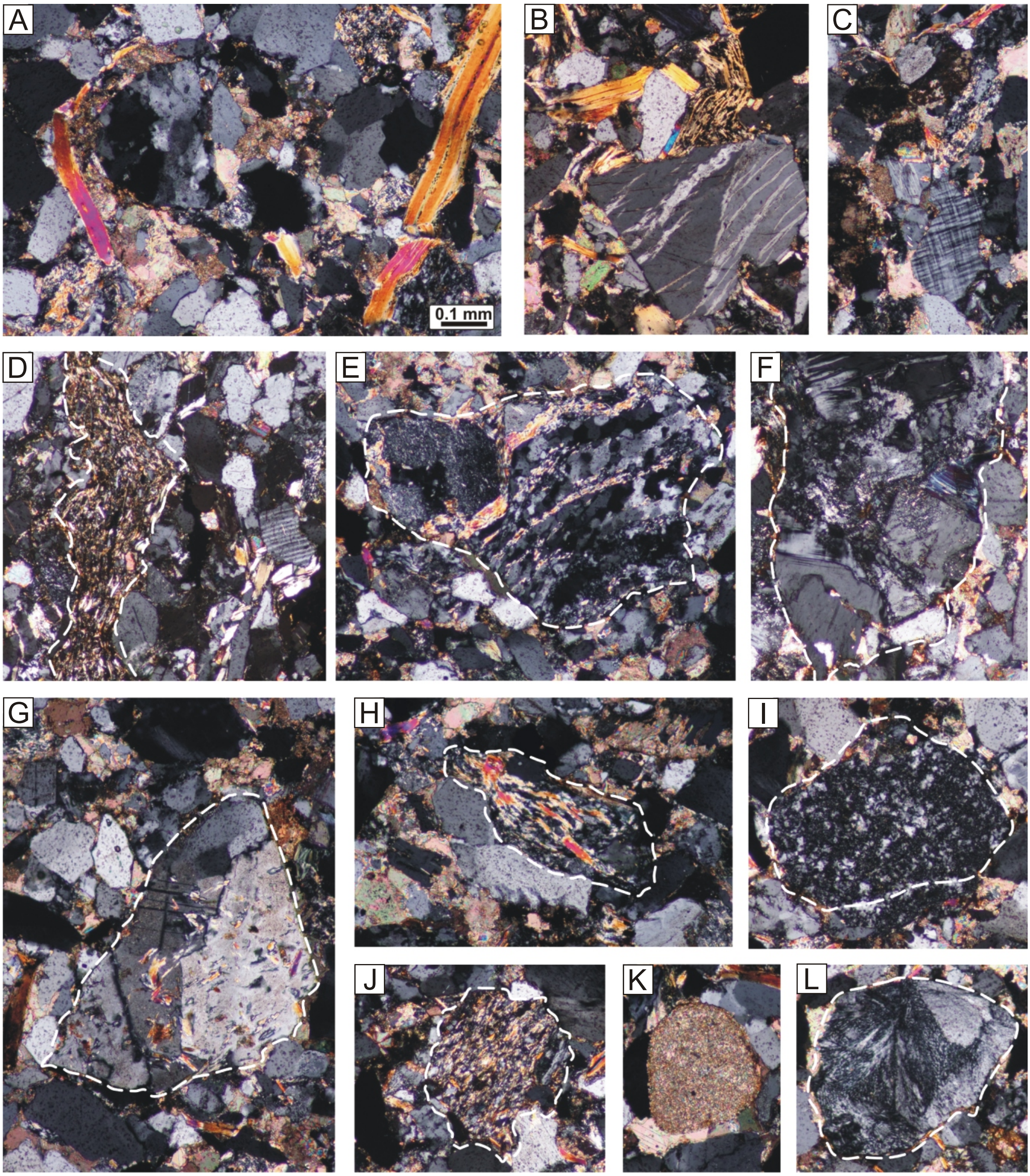


Fig. 8. Microphotographs of grains and lithoclasts in sandstone from slump layer at Procisne, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

A – "mosaic" quartz grain and white mica flake (left), sample Proc-14b; **B** – pertithic orthoclase grain and altered biotite flake (above), sample Proc-13a; **C** – microcline grain with characteristic tartan-type twinning, sample Proc-14b; **D** – plagioclase grain (right) showing multiple lamellar albite twinning, and mudstone lithoclast (left), sample Proc-13a; **E** – augen gneiss lithoclast, sample Proc-14b; **F** – granitic gneiss lithoclast, sample Proc-14b; **G** – granite lithoclast, sample Proc-14b; **H** – schist lithoclast, sample Proc-14b; **I** – siliceous rock lithoclast, sample Proc-14b; **J** – slate/phyllite lithoclast, sample Proc-14b; **K** – siderite lithoclast, sample Proc-14b; **L** – volcanic rock lithoclast (pumice-rich tuff ?), sample Proc-14b; all photographs under crossed polars; scale bar for all photographs is shown in A such as tourmaline, rutile, zircon, and opaque minerals (2%) – anhydrous and hydrated iron oxides.

The total content of rock fragment grains varies between 6 and 7%. The content of lithoclasts of metamorphic rocks is variable (Table 1). They are represented mainly by rocks of low- and medium-grade regional metamorphism, such as gneisses (Fig. 8E), granitic gneisses (Fig. 8F), granites (Fig. 8G), schists (Fig. 8H), and slates/phyllites (Fig. 8I). Other grains, including siliceous rocks (Fig. 8J), siderites (Fig. 8K), volcanic rocks (Fig. 8L) and mudstones (Fig. 8D), are less common (Table 1). The slump layer sandstones contain predominantly the contact-porous type of carbonate cement (6–14%) with a mixture of clay material. Some parts of the sandstones also contain a matrix (up to 5%).

MICROFOSSILS FROM THE KICZERA DYDIOWSKA SANDSTONES

Six samples of calcareous shales from the Procisne section (Fig. 3) reveal a poorly diversified foraminiferal assemblage (Table 2) and undeterminable radiolarian and diatom moulds. Among planktonic foraminifers, four species have been determined, including *Globigerina praebulloides* (Fig. 9B–D), *Tenuitella munda* (Fig. 9A), *T. liverovskae* and *Tenuitellinata angustiumbilicata* (Fig. 9E, F). The assemblages of benthic foraminifers consist of well-preserved, partly pyritised, originally calcareous, smooth-walled hyaline forms. Most numerous are *Virgulinella chalkophila* (Fig. 9H) and *Nonionella liebusi* (Fig. 9L), accompanied by *Virgulinella karagiensis* (Fig. 9I), *Chilostomela ovoidea* (Fig. 9K), *Fursenkoina mustoni* (Fig. 9G), *Praeglobobulimina pyrula*, *P. bathyalis* (Fig. 9J), *Ammonia beccari*, *Cibicidoides lopjanicus*, *Stilostomella* sp. and agglutinated forms, such as *Bathysiphon* sp. and *Saccammina* sp.

Large pyritised diatoms are a significant component in these sediments (Table 2). Most of them are gonioid diatoms, angular in outline, represented by triangular specimens of *Triceratium* sp. (Fig. 9O) and elliptical frustules of *Odontella*? sp. (Fig. 9P). There are also discoid diatoms (Fig. 9M, N) and specimens with long linear-elliptical valves (*Pyxilia*? sp.; Fig. 9R). Many spherical micronodules, overgrown by large pyrite crystals resembling radiolarian moulds, are a subordinate component in the microfossil assemblages.

PETROGRAPHY OF COAL PEBBLES

Coal pebbles from the Procisne section occur as vitrain particules. Random vitrinite reflectance measurements display a range from 0.52 to 0.57%, indicating the rank of high volatile bituminous coal (Taylor et al., 1998).

Organic matter is represented mostly by the vitrinite group. Collotelinite, which is dominant among the main macerals, forms very thin lenses (1–3 mm) attaining a length of 8–10 mm (Fig. 10A, B). The lenses are distributed parallel to each other

Table 2

Microfossils in rock samples from the Procisne section, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mts.

	Pr-1	Pr-2	Pr-4	Pr-5	Pr-6	Pr-7
Bathysiphon sp.						1
Saccammina sp.		1		1		
Stilostomella sp.					1	
Globigerina praebulloides Blow				3		3
Tenuitella liverovskae (Bykova)			1			
Tenuitella munda (Jenkins)				2	4	
Tenuitella sp.				3		
Tenuitellinata angustiumbilicata (Bolli)				2		2
Praeglobobulimina bathyalis (Reiser)		2				
Praeglobobulimina pyrula (d'Orbigny)			2			1
Fursenkoina mustoni (Andreae)	2					
Virgulinella chalkophila (Hagn)		20				4
Virgulinella karagiensis Mikhailova		4	1			1
Virgulinella sp.						7
Nonionella liebusi Hagn			7			1
Chilostomella ovoidea Reuss					3	1
Ammonia beccari (Linne)			1			
Cibicidoides lopjanicus (Myatlyuk)			1			
Cibicidoides sp.			1	1		
Diatomae – *Triceratium* sp.		2				5
Diatomae – discoid morphotype		8				5
Diatomae – ?*Odontella* sp.		17				
Diatomae – ?*Pyxilia* sp.		3				
Spherical pyritysed moulds of ?radiolarians		5	1			8
Echinoid spines			3		1	1

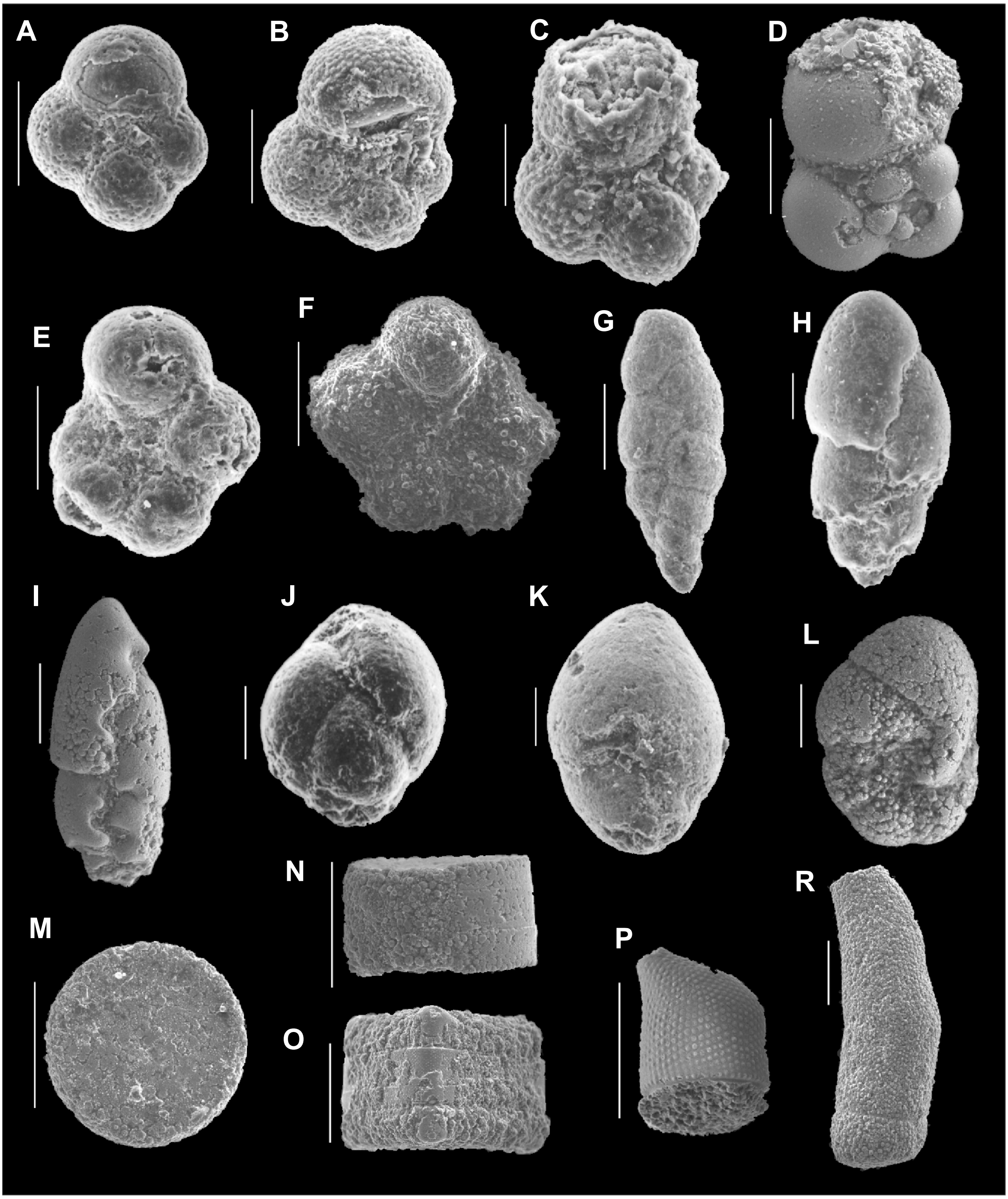
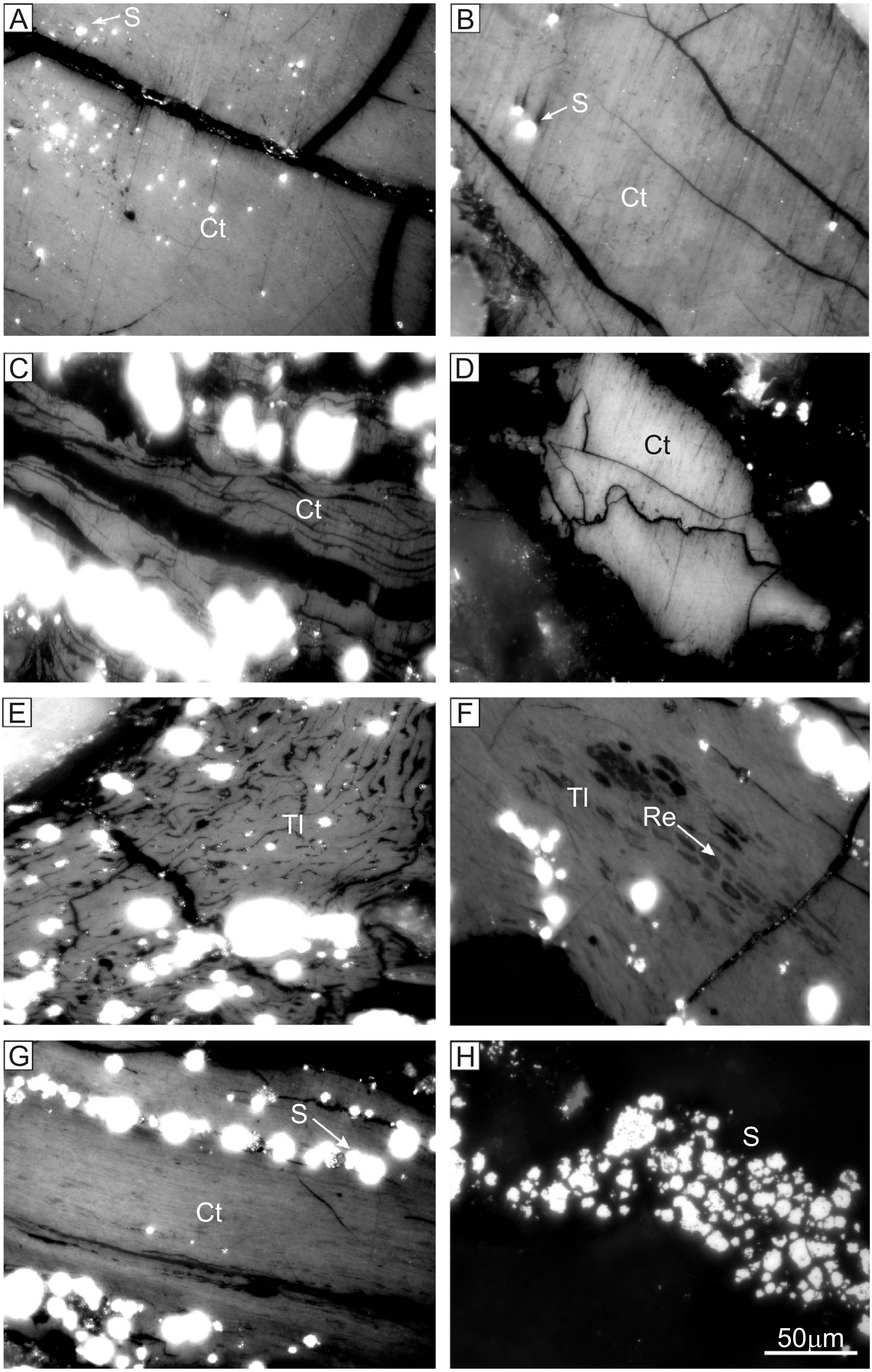


Fig. 9. SEM photomicrographs of foraminifers and diatoms from the Procisne section, Kiczera Dydiowska Sandstones of the Krosno Beds, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

A – *Tenuitella munda* (Jenkins), sample Proc-6; **B**–**D** – *Globigerina praebulloides* Blow: B – sample Proc-6, C, D – sample Proc-5; **E** – *Tenuitellinata angustiumbilicata* (Bolli), sample Proc-5; **F** – *Tenuitellinata* cf. *angustiumbilicata* (Bolli), sample Proc-5; **G** – *Fursenkoina mustoni* (Andreae), sample Proc-1; **H** – *Virgulinella chalkophila* (Hagn), sample Proc-2; **I** – *Virgulinella karagiensis* Mikhailova, sample Proc-2; **J** – *Praeglobobulimina bathyalis* (Reiser), sample Proc-2; **K** – *Chilostomella ovoidea* Reuss, sample Proc-6; **L** – *Nonionella liebusi* Hagn, sample Proc-4; **M, N** – Diatomae indet gen sp., sample Proc-2; **O** – *Triceratium* sp., sample Proc-7; **P** – *Odontella* sp., sample Proc-2; **R** – diatomae indet gen sp., sample Proc-2; scale bar is 100 µm


A
S
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B
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S
50μm

(Fig. 10C). Colotellinite is also visible as dispersed remains around vitrain lenses (Fig. 10D). The second component of the vitrinite group is tellinite, both with empty window cells (Fig. 10E) and impregnated with resinite (Fig. 10F). In wide vitrain lenses, a gradual transition from tellinite (occurring in the central part) to colotellinite (in the marginal part) is visible. The second maceral group of the coal pebbles is the liptinite group represented by resinite characterized by orange colour under blue fluorescent light.

Another characteristic mineral component in coal is pyrite occurring around organic remains and filling the intergranular space. The pyrite is also observed as framboids that are distributed in collotelinite (Fig. 10G) and scattered in the mineral fraction of massive sandstone (Fig. 10H).

DISCUSSION

STRATIGRAPHY OF THE SUCCESSION WITH COAL-BEARING SLUMP LAYER

Biostratigraphy of the Oligocene in the Outer Carpathians renders some problems. Planktonic foraminiferal species, usually poorly preserved, occur as single specimens, or they are absent (e.g., Olszewska, 1984a, b, 1997, 1998; Bąk, 1999, 2005).

Planktonic forms from the studied section are typical of the Oligocene in the Outer Carpathians, but they do not constrain the age of these sediments. Consequently, the stratigraphic position of the sediments is here suggested based on a comparison with sections from the area located a few kilometres to the SE of Procisne in the same tectonic unit, the Dźwiniacz Górny Syncline. Biostratigraphy of these sediments has been studied in both the syncline limbs by Bąk (2005). They represent the upper part of the *Tenuitella munda* and *Globigerinoides primordius* planktonic foraminiferal zones there, corresponding to the upper part of the NP24 through NN1 calcareous nannoplankton zones (Garecka in Haczewski et al., 2015b). Due to the position of the coal-bearing slump layer within the uppermost part of the Kiczera Dydiowska Sandstones, its stratigraphic position may roughly correspond to the Oligocene–Miocene transition.

PARENT ROCKS OF MINERAL GRAINS IN SLUMP LAYER

The ratios of feldspars, quartz and lithic grains, presented for the sandstones in ternary diagrams (Fig. 11), indicate that their minerals could originate from rocks of a continental block or they have been recycled from post-orogenic sediments (Dickinson, 1985). Such origin may be confirmed by a low content of feldspars and volcanic rocks within the mineral assemblages (cf. Dickinson and Suczek, 1979). The occurrence of undulose and "mosaic" quartz grains in unstructured sandstones within the slump layer implies their origin from low- and medium-grade metamorphic rocks, such as slates, granitic gneisses, gneisses or schists. On the other hand, the presence of subrounded and rounded grains, and the occurrence of very stable heavy miner-

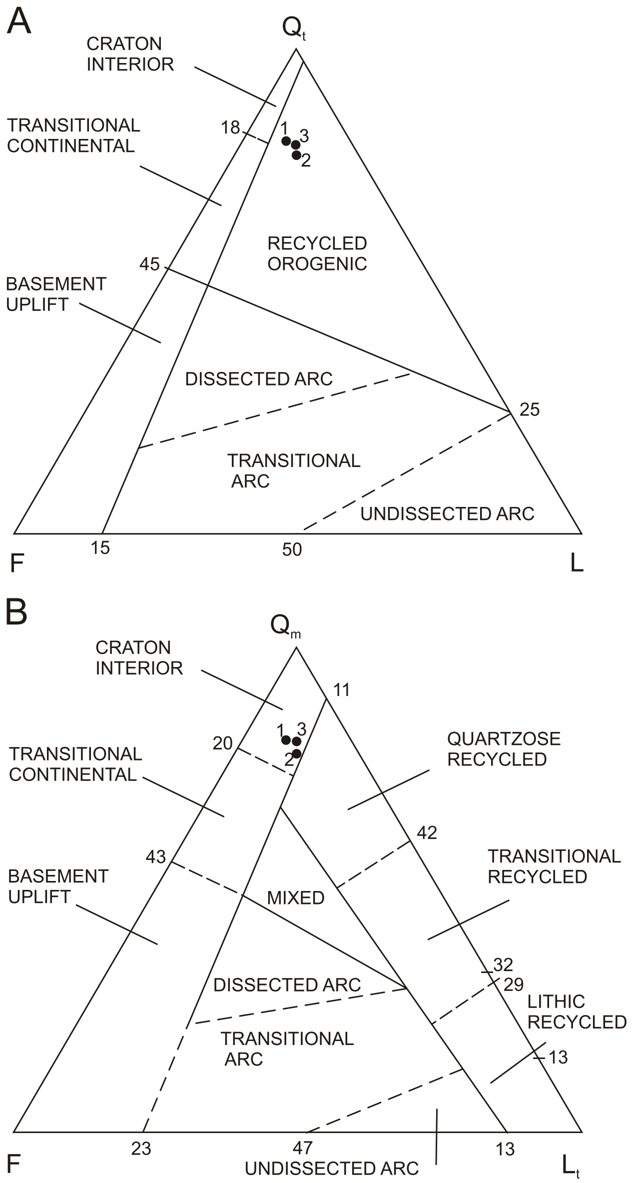

Fig. 11. F–Q_t–L (A) and F–Q_m–L_t (B) ternary discrimination diagrams of sandstone from slump layer at Procisne, related to different tectonic provenances (after Dickinson et al., 1983)

F – total feldspar, L – total lithic fragments including extrabasinal carbonate lithic fragments, L_t – total lithic fragments including extrabasinal carbonate lithic fragments plus polycrystalline quartz, Q_m – monocrystalline quartz, Q_t – total monocrystalline and polycrystalline chert; samples: 1 – Proc-13a, 2 – Proc-13b, 3 – Proc-14

◄

Fig. 10. Microphotographs of coaly organic matter from slump layer at Procisne, Silesian Nappe, Polish Outer Carpathians, Bieszczady Mountains

A, B – typical collotelinite (ct) impregnated with pyrite (S); **C** – collotelinite lenses parallel to each other; **D** – idspersed remains of collotelinite; **E** – telinite (Tl) with empty window cells; **F** – telinite impregnated with resinite (Re); **G** – collotelinite impregnated with pyrite (S); **H** – pyrite framboids in mineral setting; all photographs under reflected light, with oil immersion, and at the same scale (Figure H) als (rutile, tourmaline, zircon) within the sandstones show, long recycling processes of the primary rocks.

ORIGIN OF COAL MATERIAL

Lustrous coal particles found in the slump layer do not represent an exotic Carboniferous material. Laminar structure characteristic of the exotic Carboniferous coal pebbles has not been detected in coal of the studied material. Numerous coaly plant fragments found in these sediments are the result of post-diagenetic processes of land-derived organic matter, which was semi-contemporaneous with the slump layer. Petrographic components of coaly organic matter are mostly homogeneous and belong to the vitrinite group. Vitrinisation of organic matter occurred within the sediment after final deposition at the basin floor. It is confirmed by intermediate values of vitrinite reflectance (ca. 0.5%) with their low range suggesting similar diagenetic and catagenetic changes of organic matter particles.

The origin of organic matter is related to the composition of tissue plant components differing in the gelification and fragmentation extent. The plant fragments with well-preserved cellular structure, which is reflected in the presence of telinite, and completely gelified plant fragments indicate various plant resistance levels to biochemical decomposition due to both microorganism activity and mechanical disintegration, including dragging and friction. Part of the coaly material with gradual transition from tellinite (in the central part) to colotellinite (in the marginal part) in wide vitrain lenses is evidence of setback gelification processes after burial within the sediment.

Some coal pebbles display well-preserved tree structure, typical of gelified xylites, due to impregnation of cell walls by resinite. Furthermore, the occurrence of resinite in this material indicates a specific type of terrestrial plants producing waxes and resins.

The occurrence of pyrite framboids in coaly organic matter, which is produced during decomposition of plant material by bacteria under specific redox conditions (e.g., Canfield, 1989; Wilkin et al., 1996; Wilkin and Barnes, 1997), in the absence of inertinite macerals in the coal pebbles, which in turn may indicate oxidising conditions in the primary environment, suggests that the first decomposition of organic matter with its gelification took place in a water environment under dysoxic conditions. Most of the gelified plant debris do not show evidence of pyritisation. It means that they had stayed for a long time in a water column before they were buried in the sediment.

PROVENANCE OF SUBMARINE SLUMP

Axes of the largest slump folds are oriented SW–NE with the vergence indicating the slump moved down to the NW. The trend of axes of small-scale folds is irregular. On the other hand, palaeocurrent data from turbidite sandstone layers of the Kiczera Dydiowska Sandstones (Haczewski et al., 2007, 2015b) suggest that turbidity currents flowed from the NW, most likely from the southern slope of the European Platform. Taking into account the orientation of fold structures, we can carefully suggest that the slump moved down from the SE (Fig. 12).

The lithology of the slump layer, which contains fragmented layers of fine-rhythmic cross- and wavy-laminated fine-grained sandstones and mudstones, shows that these packages are more likely to have been deposited from turbidity currents on a basin floor rather than on a slope, and after their partial

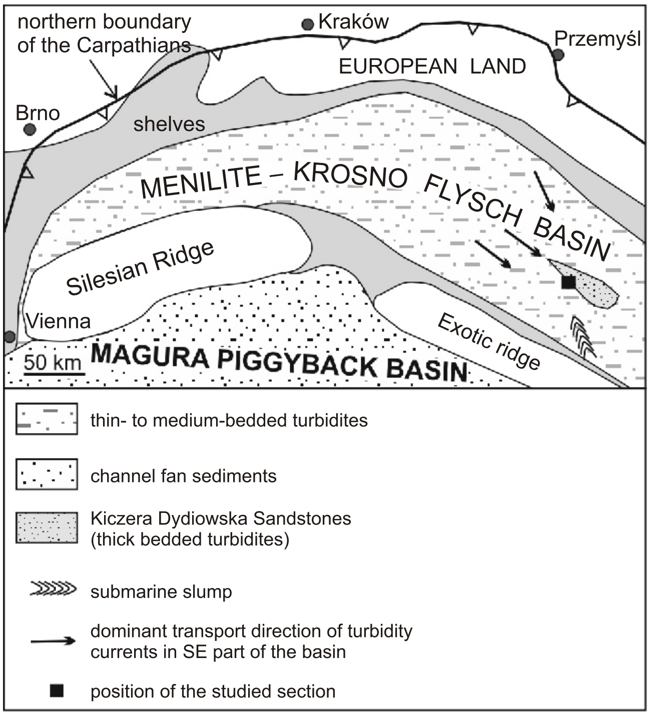

Fig. 12. Location of the exotic ridge as a source of organic particles supplied within the slump sediments to the Silesian Basin (a part of the Menilite–Krosno Basin) during Oligocene–Miocene transition time, based on simplified palaeogeographic map after Oszczypko and Oszczypko-Clowes (2006, supplemented)

lithification they have been involved into the slump. On the other hand, the petrography of medium-sized mineral grains, including lustrous coal particles of various sizes, which are components of massive sandstones, points to material derived from a shallow part of the basin. Hence, the initial stage of slumping could represent a motion of a muddy-silty flow from the upper part of the slope. Whereas, during the subsequent stages of movement, erosion with disruption and folding of the partially consolidated turbidites took place. Such a slumping mechanism was also suggested by Dżułyński and Ślączka (1958) for other submarine slumping layers from the ancient Silesian Basin. These authors presented the examples of similar inconsistences between transport directions of turbidites alternating the slump layers within the Oligocene succession of the Krosno Beds, and the vergencies of folds within those slumps. The fine-rhythmic turbidites originated from various directions corresponding mostly to the longitudinal extension of the Silesian Basin, whereas material of the slump layers and coarse-grained turbidites (including the Otryt Sandstones) came from the S and SE.

PALAEOGEOGRAPHIC IMPLICATIONS

During the Oligocene, a synorogenic basin (as part of the Central Paratethys Sea) was formed and filled with a thick turbidite series of the organic-rich Menilitic Shales followed by micaceous calcareous sandstones with grey marlstones, known as the Krosno Beds in the Western and Eastern Carpathian realm (e.g., Opolski, 1933; Książkiewicz, 1962). The studied slump sediments of the Kiczera Dydiowska Sandstones represent the youngest part of the Krosno Beds, corresponding to the Oligocene–Miocene transition. Their recent tectonic position in the Silesian Nappe (within the Dźwiniacz Górny Syncline) points to an almost central position within the Silesian–Subsilesian basin during the Late Oligocene–Early Miocene. The central part of this subbasin was a main depocentrum of turbidite sedimentation at that time, dominated at the beginning by deposition of fine-rhythmic micaceous turbidites and followed by thick-bedded sandstones with variable mineral composition, containing numerous muscovite, weathered feldspar grains and limestone clasts (Opolski, 1933; Żytko, 1968). The latter sediments are classified as the sandstones of the Lesko facies, including among others the Kiczera Dydiowska Sandstones. The change in type of material transported to the basin floor was related to changes in their source areas. During the Late Oligocene, turbidity currents flowed from the NW along the basin axis, most probably from the marginal part of the European Platform (Dżułyński and Ślączka, 1958; Haczewski et al., 2007). Later, other sources were of greater importance. Flute casts on soles of thick-bedded sandstones indicate variable transport directions from the north-west, north and south (Opolski, 1933; Dżułyński and Ślączka, 1958; Haczewski et al., 2015b). The latter directions were dominant during the Early–Middle Oligocene in this area, when the thick succession of thick-bedded Otryt Sandstones was deposited there (Haczewski et al., 2007). The petrographic composition of massive sandstone from the slump layer, characterized by a variable content of quartz grains (mainly "mosaic" metamorphic quartz) and numerous lithoclasts of metamorphic rocks is similar to that from the Otryt Sandstones, which additionally contain olistostromes including diversified metamorphic rocks (e.g., Ślączka and Wieser, 1962; Tokarski, 1975; Ziemianin and Wolska, 2014). It may suggest that a part of an intrabasinal massif, as the uplifted fragment of ?Precambrian craton, still existed at the end of the Oligocene. It supplied a large amount of siliciclastic material to the southern part of the Silesian–Subsilesian basin during the Early–Middle Oligocene. According to Ślączka (1963), Bąk et al. (2001) and Haczewski et al. (2007), this intrabasinal massif could represent a NW extension of the Marmarosh or Rachov massifs. In another palaeogeographic interpretation proposed by Oszczypko and Oszczypko-Clowes (2006), there occur an unnamed intrabasinal ridge between the Magura piggyback basin and the Silesian–Subsilesian–Skole Basin, lying in the same basinal position as the Silesian Ridge (Fig. 12). Irrespective of the name assigned, the authors accept the latter interpretation which takes into account the presence of a submerged source of terrestrial organic material, located to the south of the Silesian–Subsilesian–Skole Basin during the latest Oligocene–earliest Miocene.

CONCLUSIONS

Coaly organic matter commonly occurs in the Cretaceous–Neogene flysch sediments of the Carpathians. It is characterized by variable coal rank from dull and bright brown coal to bituminous coal. The present paper contains data on coal particles from the youngest turbidite sediments of the Silesian Nappe (Polish Outer Carpathians), latest Oligocene–earliest Miocene in age, based on planktonic foraminiferal data, where lustrous coal particles occur in sandstones of the submarine slump layer. Such occurrence of coal offers an opportunity for interpretation of the features of the source area of organic matter and siliciclastic material supplied to the deep basin floor from other directions than most of turbidites in the same area. This is suggested based on the vergence of folds within the studied slump layer, which is different than the transport directions interpreted from flute casts of the surrounding turbidite beds.

If the direction of slump movement is correctly interpreted (from SE to NW), the source areas of terrestrial material preserved in the slump layer could represent an intrabasinal cordillera (ridge) between the Magura piggyback basin to the south and the Menilite–Krosno Basin to the north, which was variably active (uplifted) during the whole Oligocene. Taking into account the mineral composition of the slump layer sandstones, this ridge was built mainly of metamorphic rocks associated by calcareous sedimentary strata. It seems that these sedimentary rocks were strongly eroded earlier, i.e. during the Early–Middle Oligocene, and transported by gravity currents (including olistostromes) to the Silesian–Subsilesian Basin.

Lustrous coal pebbles from the slump layer represent coalified organic matter of Late Oligocene–Early Miocene vegetation. Their features indicate the existence of coastal plains or lagoons within the shelf zone of an intrabasinal ridge. Terrestrial organic matter, including plants that produced waxes, could be partly degraded there under oxic/dysoxic conditions without burial, where it was subject to quick gelification. Nonetheless, most of the organic material underwent the gelification process at the deep basin floor after transport and burial, partly under dysoxic conditions, which is interpreted from the occurrence of pyrite framboids in organic particles.

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