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Geology of the Pieniny Klippen Belt and the Tatra Mts, Carpathians
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Part XVIII

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Age of some deep-water marine Jurassic strata at Mt Hulina, Małe Pieniny Range (Grajcarek Unit, Pieniny Klippen Belt, West Carpathians, Poland), as based on dinocysts[3]

(Figs 1–6; Tabs 1, 2)

Abstract. A geological section on Mt Hulina at Szczawnica Niżna, the Małe Pieniny Range, exposes Jurassic through Cretaceous rocks of the Grajcarek Unit, the northernmost tectonic unit of the Pieniny Klippen Belt (West Carpathians, Poland). Dark marine shales of very similar lithology, but with different microfossil assemblages, occur twice in the section, representing the Middle Jurassic (Opaleniec Formation) and the Lower Cretaceous (Wronine Formation) units of the Magura (Grajcarek) Succession, respectively. This paper presents the results of dinocyst investigations from the Opaleniec Formatiom which indicate its Bathonian age, and the Sokolica Radiolarite Formation which point out to their Middle Oxfordian–?Lower Kimmeridgian age.

Key words: Jurassic strata, dinocyst ages, stratigraphy, Grajcarek Unit, Carpathians

A. GEOLOGICAL PART

by K. Birkenmajer

INTRODUCTION

The Małe Pieniny Range (Little Pieniny Range) extends along the Polish/Slovak frontier from Szczawnica Niżna in the west, to Jaworki-Biała Woda in the east. The range, part of the Pieniny Klippen Belt (West Carpathians), is bounded in the

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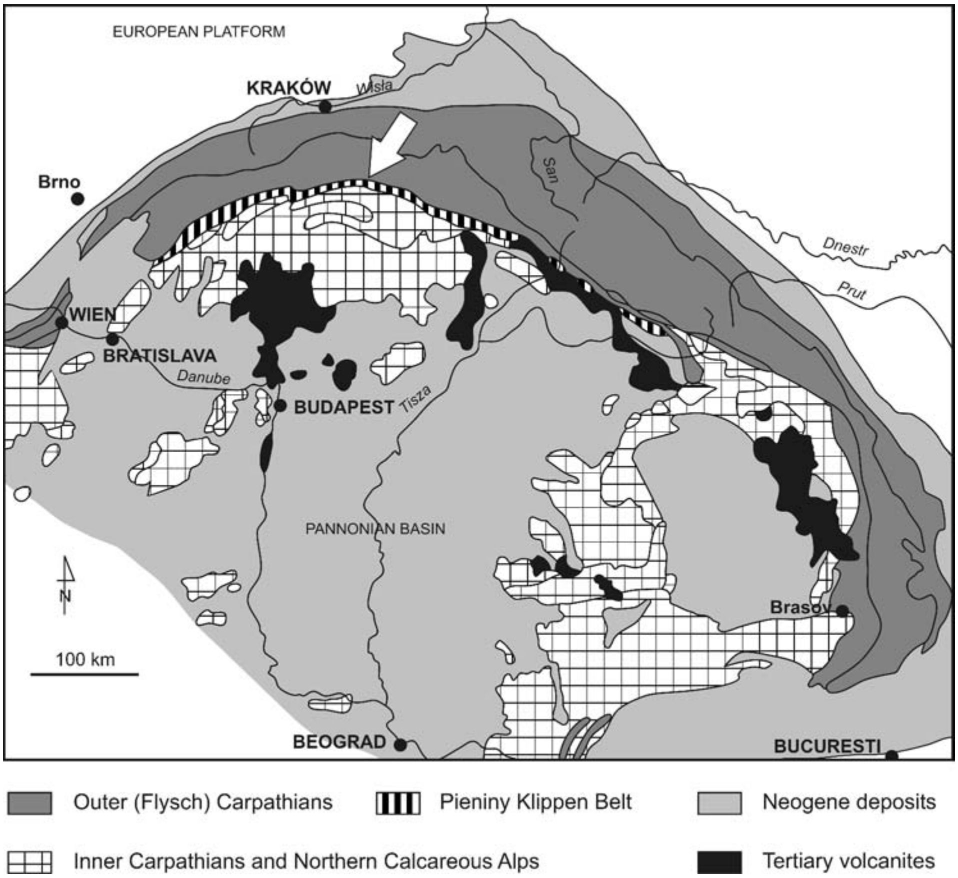


Fig. 1. West Carpathian foldbelt and position of the Pieniny Klippen Belt (adapted from Żytko, 1999). Arrowed – position of Fig. 2

north by the latitudinal Grajcarek River valley subsequent to the Belt structures. The valley runs along the northern boundary fault of the Pieniny Klippen Belt with the Magura Nappe, between Szczawnica Niżna in the west, and Biała Woda in the east (Figs 1, 2). This is the major area of occurrence of the Grajcarek Unit, the northernmost tectonic unit of the Pieniny Klippen Belt.

The Grajcarek Unit consists of deep-water marine deposits of Early Jurassic (Toarcian–Aalenian) through Late Cretaceous (Maastrichtian) ages. They were deposited in a southern part of the Magura Basin northwards from the Czorsztyn Ridge which, during the Jurassic and Cretaceous, divided the Klippen Basin from the Magura Basin (Birkenmajer, 1970, 1977, 1979, 1986a, b, 1988). These deposits were first folded during the Laramian orogeny, at the Cretaceous/Tertiary transition, as a result of subduction of the Magura oceanic crust and its thin Mesozoic cover under the Late Cretaceous Pieniny Klippen Belt orogen: the Grajcarek Unit

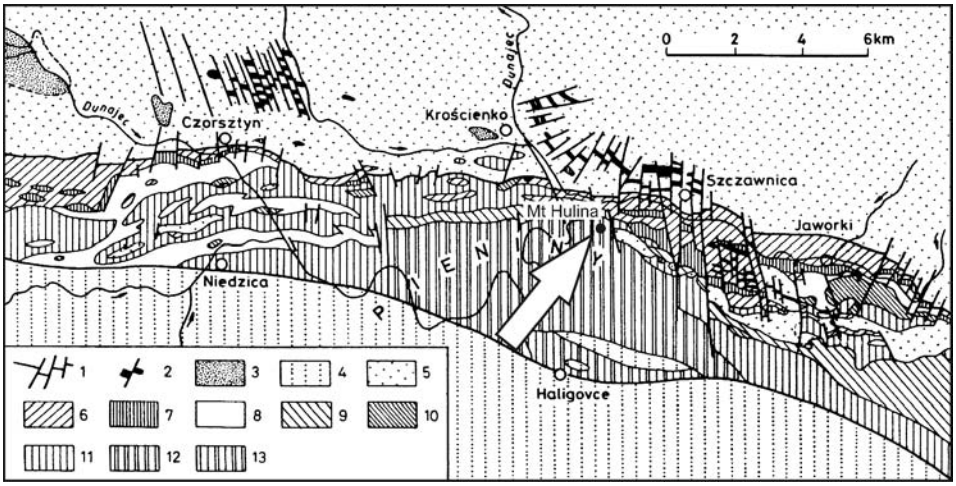


Fig. 2. Geological sketch of the Pieniny Klippen Belt (PKB), central sector (arrow marks location of Mt Hulina). *1* – Miocene faults; *2* – Miocene andesite intrusions; *3* – Neogene fresh-water deposits; *4* – Podhale Palaeogene (autochthonous); *5* – Magura Palaeogene (Magura Nappe and autochthonous Palaeogene in the PKB); *6* – Jarmuta Formation (Maastrichtian): Grajcarek Unit and autochthonous molasse in the PKB; *7* – Jurassic–Campanian deposits of the Grajcarek Unit; *8–13* – Klippen successions, Jurassic–Upper Cretaceous (*8* – Czorsztyn; *9* – Czertezik; *10* – Niedzica; *11* – Branisko; *12* – Pieniny; *13* – Haligovce)

had thus formed. Since Paleocene, this unit became attached to the northern margin of the Klippen Belt orogen (Birkenmajer, 1986a, b, 1988).

The Grajcarek Unit was refolded together with the Laramian Pieniny Klippen Belt orogen during the Miocene. The Early Miocene compression/transpression (Savian phase), and the resultant lateral translation of tectonic units along the strike-slip northern boundary fault, had produced very complex tectonic structures. As a result, relatively competent beds such as radiolarites (Middle/Upper Jurassic), cherty limestones (Tithonian–Barremian), conglomerates and sandy flysch beds (Upper Cretaceous) became disintegrated into tectonic blocks squeezed into much softer, incompetent marls, shales and shaly flysch beds of Lower to Middle Jurassic, and Lower to Upper Cretaceous ages.

During post-Savian Middle Miocene relaxation of orogenic stress, the area adjoining the northern boundary fault of the Klippen Belt orogen (Birkenmajer, 1983), including the Grajcarek Unit and a southern part of the Miocene Magura Nappe, was densely intruded by the older (1st phase) andesite dykes and sills. The Middle Miocene transversal faults (strike-slip), directed NNE–SSW and NNW–SSE, displaced the Pieniny Klippen Belt, the Grajcarek Unit inclusively, and the Palaeogene flysch strata in southern part of the Magura Nappe. Locally, these transversal faults facilitated intrusion of the younger (2nd phase) andesites (Birkenmajer, 1983, 1986a, b, 2003; Birkenmajer & Pécskay, 1999, 2000).

OUTLINE OF JURASSIC SUCCESSION IN THE GRAJCAREK UNIT

The Jurassic sucession in the Grajcarek Unit includes nine formal lithostratigraphic units (Birkenmajer, 1977, 1979) – see below.

(1) The **Szlachtowa Formation** (Late Toarcian–Early Aalenian) is the oldest lithostratigraphic unit of the Grajcarek Succession. It consists of dark-grey to black (sometimes bluish or olive-greenish) flysch/flyschoid deposits ("black flysch"), mainly shales, with subordinate, usually thin, strongly micaceous turbidite sandstone intercalations. Thicker, coarser-grained sandstones are an exception. Siderite concretions, limonite lenses and pyrite aggregates occur in the shales (Birkenmajer, 1970, 1973a, 1976a, 1977; Krawczyk & Słomka, 1986; Krawczyk *et al.*, 1987). Thin allochthonous coal intercalations derived from reworked productive Carboniferous strata, sometimes occur in lower and upper parts of the unit (Birkenmajer & Turnau, 1962). The formation reaches up to 220 m in thickness.

The Late Toarcian–Early Aalenian age of the Szlachtowa Formation is based on:

Late Toarcian or Early Aalenian aptychi: *Cornaptychus* gr. A *lythensis* (Quenstedt) Trauth var. aff. *sigmopleura* Trauth, and *C.* sp. gr. A (Gąsiorowski, 1962) collected near the base of the formation;

Early Aalenian ammonites: *Leioceras opalinum* (Reinecke) and *L.* cf. *comptum* (Reinecke), preserved in a *Fleckenkalk*-type limestone intercalation, in an upper part of the Szlachtowa Formation (Birkenmajer & Myczyński, 1977; Birkenmajer, 1977);

Gryphaeid bivalves: *Gryphaea dewalquei* Rollier (Late Toarcian–Early Bajocian), *G. ferruginea-champigneullensis* Charles et Maubeuge (Early-Late Aalenian), *G. sublobata* Deshayes (Early Aalenian–Early Bajocian), *G. lampada* (Middle Aalenian–Early Bajocian) – see Pugaczewska (1971), Birkenmajer (1977), derived from the "Krzonowe Formation" (Birkenmajer, 1977), some 30 m thick. The latter has been interpreted as an intercalation of member rank in the Szlachtowa Formation (Birkenmajer & Tyszka, 1996);

Thin-shelled bivalves *Bositra buchi* (Roemer), and *Bositra*-filaments (Toarcian to Oxfordian) which occur throughout the Szlachtowa Formation (Birkenmajer & Pazdro, 1963a; Birkenmajer, 1977; Birkenmajer & Myczyński, 1977; Birkenmajer & Tyszka, 1996);

Belemnite rostra *Holcobelus blainvillei* (Voltz) and *H.* sp. (Krawczyk *et al.*, 1992); Ostracoda (Błaszyk, 1968), Crinoidea (Głuchowski *et al.*, 1983; Głuchowski, 1987); calcareous nannoplankton (Birkenmajer *et al.*, 1970; Dudziak, 1986); Foraminifera (Birkenmajer & Pazdro, 1968; Pazdro, 1979; Birkenmajer & Tyszka, 1996); and dinocysts (Gedl E. & Gedl P., 2001; Birkenmajer & Gedl P., 2004), indicating the Jurassic, mainly Toarcian–Aalenian, age of the Szlachtowa Formation (Birkenmajer *et al.*, 2007).

(2) The **Opaleniec Formation** (Bajocian) consists of soft shale and marly shale, blue-grey to greenish, sometimes slightly micaceous, with fucoidal burrows *Planolites* and *Chondrites* (Birkenmajer, 1977; Tyszka, 1995; Birkenmajer & Gedl P., 2004; Birkenmajer *et al.*, 2007). Aggregates and concretions of pyrite, moreover concretions, lenses and lenticular layers of blue-grey, spotty ferruginous dolostone and limestone up to 1 m thick occur in the shales. This is an impoverished *Fleckenmergel* facies, as best represented by the ammonite- and *Bositra*-bearing limestone intercalations (Tyszka, 1995, 2001). The background matrix consists of radiolarian-filament microfacies.

The formation is 16–18 m thick at its type locality (Birkenmajer, 1977). Being lithologically very similar to the Lower Cretaceous Wronine Formation, it has initially been included to that unit (Birkenmajer & Pazdro, 1963a). Further investigations of its microfossil content (Birkenmajer & Pazdro, 1968; Pazdro, 1979), as well as finds of ammonites and thin-shelled (*Bositra*) bivalves (Birkenmajer & Myczyński, 1977) corrected the age of the formation to the Bajocian.

The Bajocian age of the Opaleniec Formation is based on:

The ammonites *Eurystomiceras polyhelictum* (Böckh), *?E. polyhelictum* (Böckh), *Dorsetensia* sp. and *?Pseudotoites* sp.: Bajocian, resp. Middle Bajocian (Birkenmajer & Myczyński, 1977);

The bivalve *Bositra buchi* (Roemer) shells: Toarcian–Oxfordian (Birkenmajer & Myczyński, 1977);

The benthic foraminiferal assemblages ranging in age from the uppermost Early Bajocian to Late Bathonian (Pazdro, 1979; Tyszka, 1999; Birkenmajer *et al.*, 2007);

The dinocyst assemblages: Late Bajocian, possibly ranging up to Late Bathonian–?Callovian (Birkenmajer & Gedl P., 2004).

(3) The **Harcygrund Formation** (Birkenmajer, 1977) consists of marly shales, silty marls and shaly marly limestones with *Bositra buchi* (Roemer). The formation occurs only locally in the Grajcarek Succession (Magura Basin), in the Homole-Jaworki area, Little Pieniny Range ("*Posidonia*-beds" of Birkenmajer, 1970), where it is about 30 m thick. There, south of the Petrylakowska Skała klippe it yielded Aalenian ammonites (Myczyński, 2004, p. 13). In the Branisko and Pieniny successions (Klippen Basin), this formation yielded ammonites of Early Bajocian age (Myczyński, 2004, p. 11).

(4) The **Stembrow Formation** (Birkenmajer, 1977) consists of green to greenish-yellow shale with thin intercalations of graded, blue-grey crinoidal limestone, and grey to brownish spotty marl rich in shells of *Bositra buchi* (Roemer). The formation is barely 5–8 m thick. In the Little Pieniny Range, the formation has been recognized at Mt Jarmuta only.

(5) The **Podzamcze Formation** (Birkenmajer, 1977). This is a *Fleckenkalk* facies, consisting of blue-grey (brownish-weathered) spotty limestone bands with subordinate shale intercalations. The formation typically occurs in the Branisko and the Pieniny successions of the Klippen Basin where it is of Lower Bajocian age (Myczyński, 2004). In the Magura (Grajcarek) Succession, it probably occurs in the Homole area, Little Pieniny Range ("supra-*Posidonia* beds" of Birkenmajer, 1977, p. 46).

(6) The **Sokolica Radiolarite Formation** (Birkenmajer, 1977) consists of thin-bedded (5–7 cm thick), spotty, grey-green, bluish or black radiolarian chert layers, sometimes slightly calcareous, alternating with dark-grey radiolaria-bearing shales (1–2 cm thick). The formation is best developed in the basinal Klippen successions (Pieniny and Branisko successions) where it may exceed 20 m in thickness. In the Magura (Grajcarek) Succession, the thickness of the formation does not exceed 2–4 m. The age of the formation probably correspods mainly to the Callovian (resp. ?Upper Bajocian–?Bathonian–Callovian–?Lower Oxfordian: see Birkenmajer, 1977, p. 56).

(7) The **Czajakowa Radiolarite Formation** (Birkenmajer, 1977) in the Magura (Grajcarek) Succession includes two members: the lower Podmajerz Radiola-

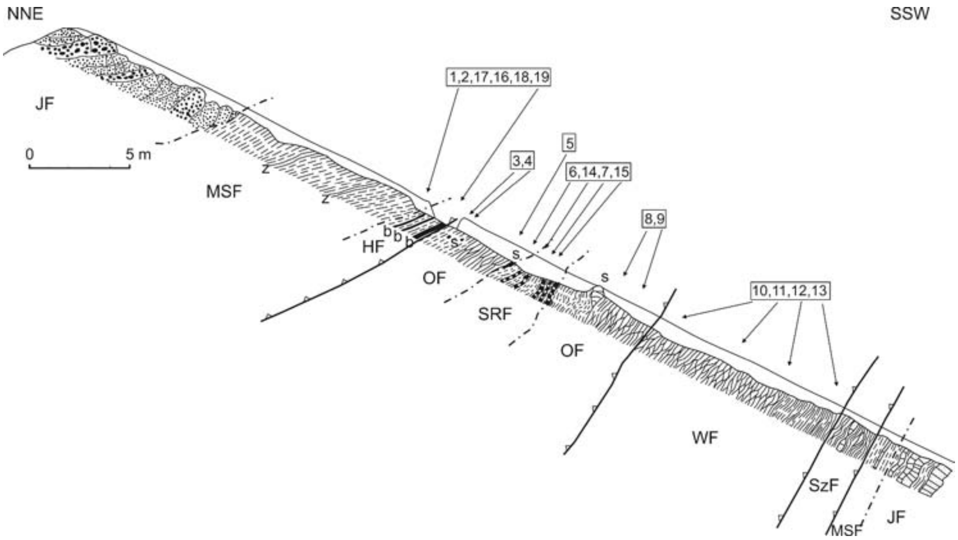


Fig. 3. Exposure on SW slope of Mt Hulina, Szczawnica Niżna, Grajcarek Unit, with location of samples. Geological cross-section reproduced from Birkenmajer (1973, fig. 172; 1976, fig. 172): lithostratigraphic attribution of beds after the present paper. Formations: JF – Jarmuta (sandstone and conglomerate); MSF – Malinowa Shale (red shale; z – green shale intercalations); HF – Hulina (b – bentonitic layers); WF – Wronine; SRF – Sokolica Radiolarite; OF – Opaleniec (s – siderite concretion); SzF – Szlachtowa; barbed – main tectonic contacts

rite Member (green radiolarites), 2–5 m thick, and the upper Buwałd Radiolarite Member (red radiolarites) 1–2 m thick. The age of the formation corresponds to the Oxfordian but, possibly, reaches up to Lower Kimmeridgian (Widz, 1991; Widz & De Wever, 1993; Birkenmajer & Widz, 1995).

(8) The **Czorsztyn Limestone Formation** (Birkenmajer, 1977) in the Magura (Grajcarek) Succession is developed as the Palenica Marl Member which is barely 0.2–0.5 m thick. It consists of red or variegated marls, marly limestones and shales with frequent aptychus shells which indicate a Kimmeridgian age of the member (lower part of the aptychus subzone VI_1 of Gąsiorowski – see Birkenmajer, 1965, 1977). According to Nowak (1971, 1973), its microorganisms indicate the presence of the Early Tithonian *Parastomiosphaera malmica* Zone.

(9) The **Pieniny Limestone Formation** (Birkenmajer, 1977) which is best developed in the Pieniny, Branisko and Czertezik successions, in the Magura (Grajcarek) Succession is condensed to 2–6 m. As compared with the basinal successions of the Pieniny Klippen Belt, its age corresponds to the Tithonian–Barremian time span.

OVERLYING CRETACEOUS FORMATIONS

The Pieniny Limestone Formation is succeeded by Lower and Upper Cretaceous marine strata (Birkenmajer, 1977): (10) the Kapuśnica Formation (Aptian–

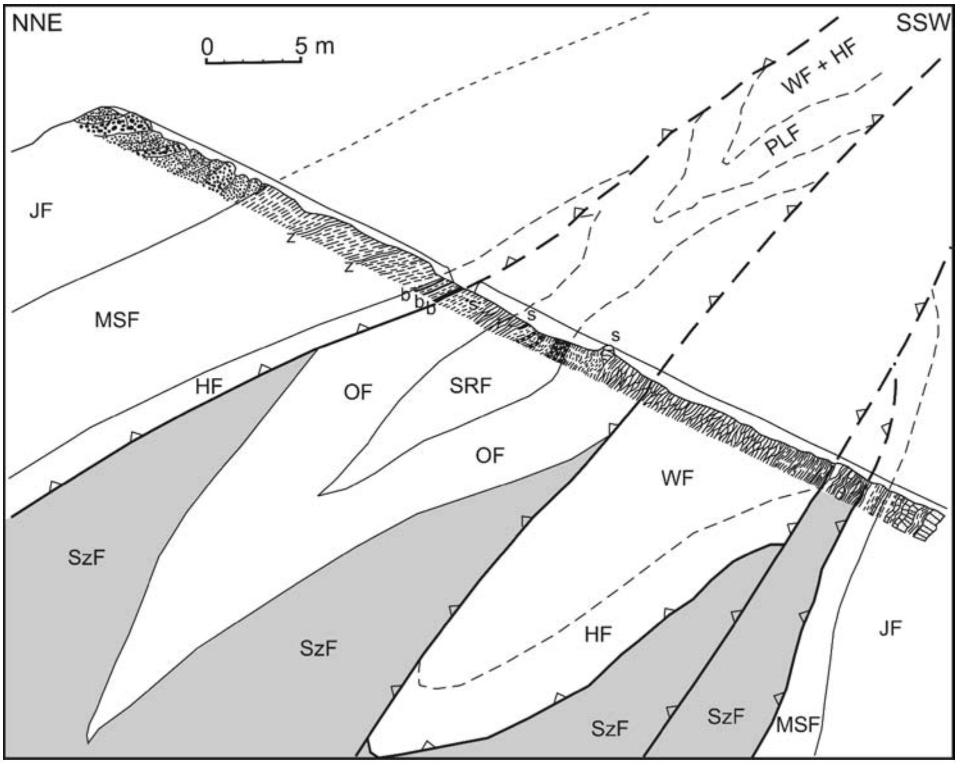


Fig. 4. New tectonic interpretation of geological section on SW slope of Mt Hulina, Szczawnica Niżna. Grajcarek Unit, formations: JF – Jarmuta; MSF – Malinowa Shale; HF – Hulina; WF – Wronine; e; PLF – Pieniny Limestone; SRF – Sokolica Radiolarite; OF – Opaleniec; SzF – Szlachtowa; barbed – main tectonic contacts; for other abbreviations – see Fig. 3

Albian); (11) the Wronine Formation (?Lower Albian); (12) the Hulina Formation (Albian–Cenomanian); (13) the Malinowa Shale Formation (Upper Cenomanian–Campanian); (14) the Hałuszowa Formation (probably Campanian); and (15) the Jarmuta Formation (?higher Campanian–Maastrichtian to Paleocene–Lower Eocene).

THE SECTION AT MT HULINA

The section on south-west slope of Mt Hulina at Szczawnica Niżna (Figs 3, 4; Tab. 1) exposes Jurassic and Cretaceous rocks of the Grajcarek Unit (see Birkenmajer, 1973, fig. 172; 1976, fig. 172). In 2000, the present authors, in the company of Dr Elżbieta Gedl, collected there samples for dinocyst examination. The results of these allowed to revise the age and lithostratigraphic attribution of some strata. The results based on Jurassic dinocysts are given in part B of this paper, those based on Cretaceous dinocysts are presented separately by E. Gedl (2007).

B. MICROPALAEONTOLOGICAL PART

by P. Gedl

Premininary results of a palynological study of Jurassic deposits exposed on south-west slope of Mt Hulina (see Birkenmajer, 1973, fig. 172; 1976, fig. 172), were given by E. Gedl and P. Gedl (2001). In the present paper, a detailed analysis of Jurassic dinocyst assemblages from this section is presented. Cretaceous dinocysts from this section are being published separately (E. Gedl, 2007).

MATERIAL

Nineteen samples collected in 2000 were examined (Fig. 3; Tab. 1):

Samples Hln1, 2, and 18, were taken from soft greenish shales just below red shales of the Malinowa Shale Formation;

Samples Hln16, 17 and 19 – from black, finely laminated bentonitic shales (*sensu* Birkenmajer, 1973, fig. 172; 1976, fig. 172);

Samples Hln3–15 – from greenish, often dark-spotted shales exposed lower down the section, below bentonitic shales;

Samples Hln14, 15 – from shales alternating with dark-green cherts (radiolarites).

METHODS

All samples were processed by the author in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Cracow Research Centre.

The following procedure was applied: 20–30 G of cleaned and crushed rock was treated with 38% HCl to remove carbonates, sieved on 15 μm sieve (with ultrasonic treatment), treated with 40% HF to remove silicates, neautralized and sieved again on 15 μm sieve (with ultrasonic treatment). Organic matter was separated from undissolved or insoluble particles with heavy liquid ($ZnCl_2$+HCl; s.g. = 2.0 G/cm$^{3)}$, sieved on 15 μm nylon sieve and transferred into glycerine water for storing. Glycerine-gelatine jelly was used as a mounting medium; two slides were made from each sample.

The slides were examined under transmitted light microscope CARL ZEISS Axiolab. Microphotographs were taken with the use of CARL ZEISS Axiolab micrfoscope, SONY DSC-S75 camera and ZEISS Plan-NEOFLUAR 100x/1.30 Oil Pol objective.

The rock samples, palynological residuum and slides are stored in the collection of the Institute of Geological Sciences (Cracow Research Centre), Polish Academy of Sciences, Senacka 1, 31-002 Kraków.

RESULTS OF PALYNOMORPH INVESTIGATIONS

All investigated samples contained palynological material. Its composition (palynofacies) shows a pronounced differentation relative to position of the sample in the studied section, and to its lithology (Fig. 4; Tab. 1). Dinocysts, present in the majority of samples, are rather poorly preserved: in some samples only a small percentage of these are determinable (Tab. 2).

Opaleniec Formation. This unit is represented by: (1) olive-green shales (samples Hln3, 4) and greyish non-calcareous shale (sample Hln5) which occur above

Table 1

Lithological description of studied samples from Mt. Hulina section

Sample number	Simplified lithology	HCl	Lithostratigraphy (this study and E. Gedl, 2007)	Previous stratigraphic attribution (Birkenmajer, 1973, 1976)
Hln1	dark-grey soft mudstone	++	Hulina Formation	"Cenomanian correlation horizon"
Hln2	greenish very soft claystone	=		
Hln17	black mudstone	++		
Hln18	greenish soft claystone	++		
Hln16	black mudstone with white lamina	++		
Hln19	black mudstone with white lamina	+		
Hln3	olive-greenish very soft claystone with black spots	(+)	OpaleniecFormation	
Hln4	olive-greenish very soft claystone with black spots	(+)		
Hln5	greenish-grey hard silicified shale with cubic fissility	=		
Hln6	greenish-grey hard silicified shale with cubic fissility	=	SokolicaFormation	"Albian radiolarites"
Hln14	dark-greyish silicified limestone	++		
Hln7	dark-greenish-grey hard silicified shale with cubic fissility	=		
Hln15	dark-greyish silicified spotty limestone	++		
Hln8	greenish spotty, soft claystone	=	OpaleniecFormation	"Wroninebeds"
Hln9	dark-greenish hard claystone	=		
Hln10	olive-green soft claystone with black lamina	+	WronineFormation	
Hln11	greenish-grey very soft claystone with black spots	(+)		
Hln12	greenish-grey very soft claystone	(+)		
Hln13	greenish-grey claystone	=		

"HCl" refers to crushed sample reaction with 28% chloric acid (HCl): = – no reaction (non-calcareous sample); (+) – very weak reaction; + – weak reaction; ++ – rapid reaction (highly calcareous sample)

the Radiolaria-bearing unit (Sokolica Radiolarite Formation, Hnl6, 7, 14, 15); and (2) by soft or hard greenish claystones (Hnl8, 9) which crop out below the Sokolica Radiolarite Formation (Figs 3, 4; Tab. 1).

Samples Hln3, 4. Palynofacies of samples Hln3, 4 is characterized by frequent dinocysts, which are the most numerous palynomorphs, and by black opaque phytoclasts; sporomorphs and small cuticle remains are relatively rare. Dinocysts are generally poorly preserved.

Sample Hln3 contains a poorly taxonomically diversified dinocyst assemblage dominated by *Lithodinia jurassica*, associated with relatively frequent specimens of *Chytroeisphaeridium chytroeides, Endoscrinium asymmetricum, Ctenodidinium combazii* and *C. ornatum*. A single, very poorly preserved specimen of a chorate dinocyst (*Systematophora?* sp.) was found.

Lithodinia jurassica is the most frequent species also in sample Hln4 which, however, contains a more diversified dinocyst assemblage than that of sample Hln3, with proximochorate forms belonging to the genus *Epiplosphaera* (*E. gochtii*, *E. reticulata* and *E. areolata*) and poorly preserved

Table 2

Distribution of dinocysts in samples from Jurassic deposits exposed on south-western slope of Mt. Hulina, Grajcarek Unit, Pieniny Klipen Belt. Lithostratigraphic unit abbreviations: OF – Opaleniec Formation; SRF – Sokolica Radiolarite Formation

Lithostratigraphy	OF			SRF				OF	
Taxon (in alphabetical order) / Sample	Hln3	Hln4	Hln5	Hln6	Hln14	Hln7	Hln15	Hln8	Hln9
Adnatosphaeridium caulleryi				x					
Apteodinium sp.		x							
Atopodinium prostatum		x			x				
Atopodinium sp.									x
Bradleyella? sp.			x					x	x
Cassiculosphaeridium pygmae					x				
Chlamydophorella spp.				x	x	x	x		
Chytroeisphaeridium chytroeides	x	x	x	x	x	x	x	x	x
Cleistosphaeridium sp.		x	x						
Compositosphaeridium polonicum				x	x	x	x		
Ctenidodinium combazii	x	x						x	x
Ctenidodinium continuum	x								
Ctenidodinium ornatum	x	x						x	x
Dichadogonyaulax selwoodii	x	x		x	x	x	x	x	x
Dichadogonyaulax sp.			x						
Dingodinium minutum		x	x						
Endoscrinium asymmetricum	x	x	x						
Endoscrinium luridum	x	x						x	x
Epiplosphaera areolata		x		x	x	x			
Epiplosphaera gochtii		x				x	x	x	
Epiplosphaera reticulata	x	x	x			x			
Epiplosphaera spp.	x	x		x	x		x		x
Escharisphaeridia psilata					x				
Gongylodinium spp.		x	x						x
Gonyaulacysta eisenackii		x							
Gonyaulacysta fastigiata					x	x		x	
Gonyaulacysta jurassica			x		x	x			
Gonyaulacysta pectinigera	x								
Gonyaulacysta sp.				x					
Impletosphaeridium sp.		x							
Korystocysta gochtii		x							
Lithodinia spp.	x	x	x		x				x
Nannoceratopsis pellucida	x	x			x	x			
Nannoceratopsis spiculata		x						x	
Nannoceratopsis sp.									x
Pareodinia ceratophora					x				
Pareodinia aff. *prolongata*	x								
Pareodinia sp.	x		x						x
Rhynchodiniopsis cladophora			x						
Scriniodinium inritibile							x		
Sentusidinium spp.	x								
Systematophora areolata				x	x		x		
Systematophora orbifera							x		
Systematophora spp.		x	x	x	x	x	x		x
Taeniophora iunctispina							x		
Tubotuberella apatela	x					x			
Tubotuberella dangeardii?								x	
Tubotuberella dentata				x		x			

chorate forms of the *Systematophora-Surculosphaeridium* morphotype. *Ctenidodinium* sp. is here much less frequent than in sample Hln3.

Sample Hln5. Its palynofacies is dominated by black opaque woody particles, dinocysts (moderately well preserved) and sporomorphs (less frequent). *Epiplosphaera* sp. is the most frequent taxon, *Lithodinia* sp. occurs subordinately, *Endoscrinium asymmetricum* and *Systematophora* sp. (poorly preserved) have also been found.

Samples Hln8, 9. Dinocysts from sample Hln8 (in contrast to samples Hln3, 4) are relatively well preserved, dominated by *Ctenidodinium combazii/ornatum* morphotype. A similar dinocyst assemblage from sample Hln9 shows a higher frequency of mostly poorly preserved specimens.

Sokolica Radiolarite Formation. This unit is developed as Radiolaria-bearing strata, mainly shales (Hln6, 7), with thin silicified limestone intercalations (Hln14, 15). Their palynofacies is dominated by undeterminable or very poorly preserved dinocysts and black phytoclasts. Plant tissue remains and sporomorphs have also been found.

Samples Hln6, 7, 14, 15. Morphotypes of *Epiplosphaera* and *Systematophora* are the most common specimens in the shales (Hln6, 7). In silicified limestones (HLn14, 15) dinocysts are frequent, but poorly preserved.

Epiplosphaera spp. are the most common, *Dichadogonyaulax sellwoodii*, *Systematophora* spp. and *Chlamydophorella* spp. are very frequent. Specimens of small proximate genera *Chlamydophorella*, *Escharisphaeridia* and *Chytroeisphaeridia* are rather well preserved (especially so in silicified limestones), while large specimens of the chorate genera *Systematophora* and *Compositosphaeridium* are considerably damaged.

AGE OF THE JURASSIC DINOCYST ASSEMBLAGES

The dinocysts determined from the deposits exposed at Mt Hulina represent both the Jurassic (Hln3–9, 14–15) and the Cretaceous (Hln1, 10, 11, 13, 16–19: see E. Gedl. 2007) assemblages. Two assemblages (I and II) of different Jurassic ages have been recognized (Figs 5, 6; Tab. 2). The dinocysts are very frequent, dominating in some samples, however, they are generally poorly preserved.

Ist Dinocyst Assemblage: ?Middle-Late Bathonian

Characteristics. This assemblage has been recognized in samples Hln3–4 and Hln8,9. It is typified by numerous specimens of the genus *Ctenidodinium* (*C. combazii, C. continuum* and *C. ornatum*). Other, stratigraphically important dinocyst species include: *Atopodinium prostatum, Dichadogonyaulax sellwoodii, Endoscrinium asymmetricum, E. luridum, Nannoceratopsis pellucida, Pareodinia prolongata, Rhynchodiniopsis cladophora* and *Tubotuberella apatela*.

Stratigraphic age. The age of the above dinocyst assemblage is Bathonian, presumably even Middle to Late Bathonian, as compared with dinocyst age ranges of Upper Bajocian to Callovian deposits of Central Poland (see Poulsen, 1998). This is based on the presence of *Atopodinium prostatum* and *Tubotuberella apatela*, which have the lowest occurrences (LOs) in Middle Bathonian or younger strata, and on *Endoscrinium asymmetricum* and *Gonyaulacysta eisenackii* found by Poulsen exclusively in the Bathonian deposits. *Ctenidodinium combazii*, found in the first assemblage only, has its highest occurrence (HO) in Central Poland in Late Batho-

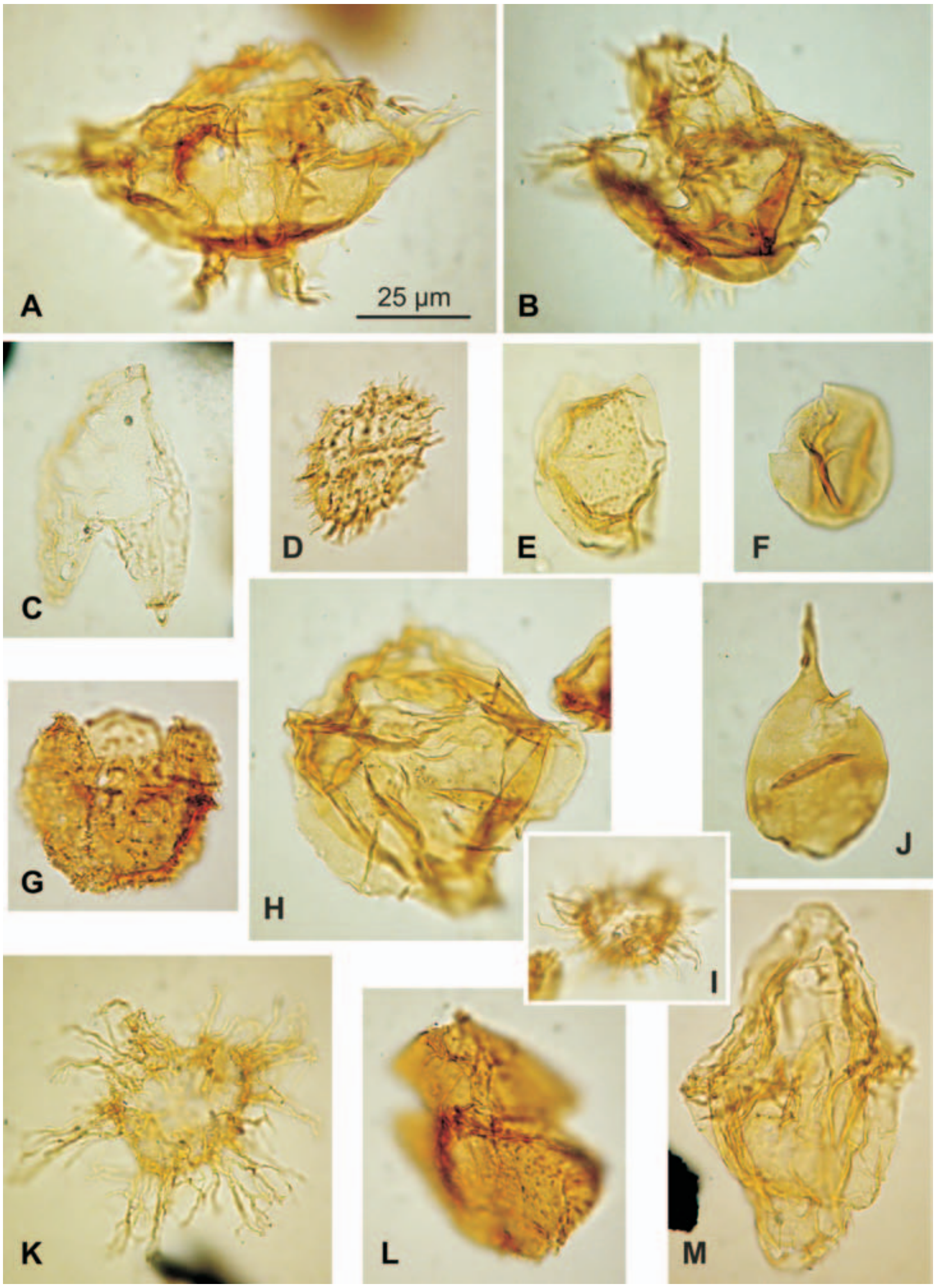


Fig. 5. Dinocysts from Jurassic deposits exposed at south-western slope of Mt Hulina: Opaleniec Formation (Grajcarek Unit, Pieniny Klippen Belt). **A** – *Ctenidodinium combazii* (Hln3); **B** – *Ctenidodinium combazii* (Hln3); **C** – *Nannoceratopsis pellucida* (Hln3); **D** – *Epiplosphaera gochtii* (Hln3); **E** – *Dingodinium minutum* (Hln5); **F** – *Chytroeisphaeridia chytroeides* (Hln3); **G** – *Lithodinia* sp. (Hln3); **H** – *Endoscrinium asymmetricum* (Hln3); **I** – *Cleistosphaeridium* sp. (Hln4); **J** – *Pareodinia* sp. (Hln3); **K** – *Systematophora* sp. (Hln5); **L** – *Korystocysta gochtii* (Hln4); **M** – *Endoscrinium asymmetricum* (Hln5). Scale bar refers to all microphotographs

nian. Other taxa, such as *Dichadogonyaulax sellwoodii*, found in both assemblages (I and II), and *Ctenidodinium continuum*, found in the Ist assemblage only, range in Central Poland from Bajocian to Lower Callovian inclusively (Poulsen, 1998).

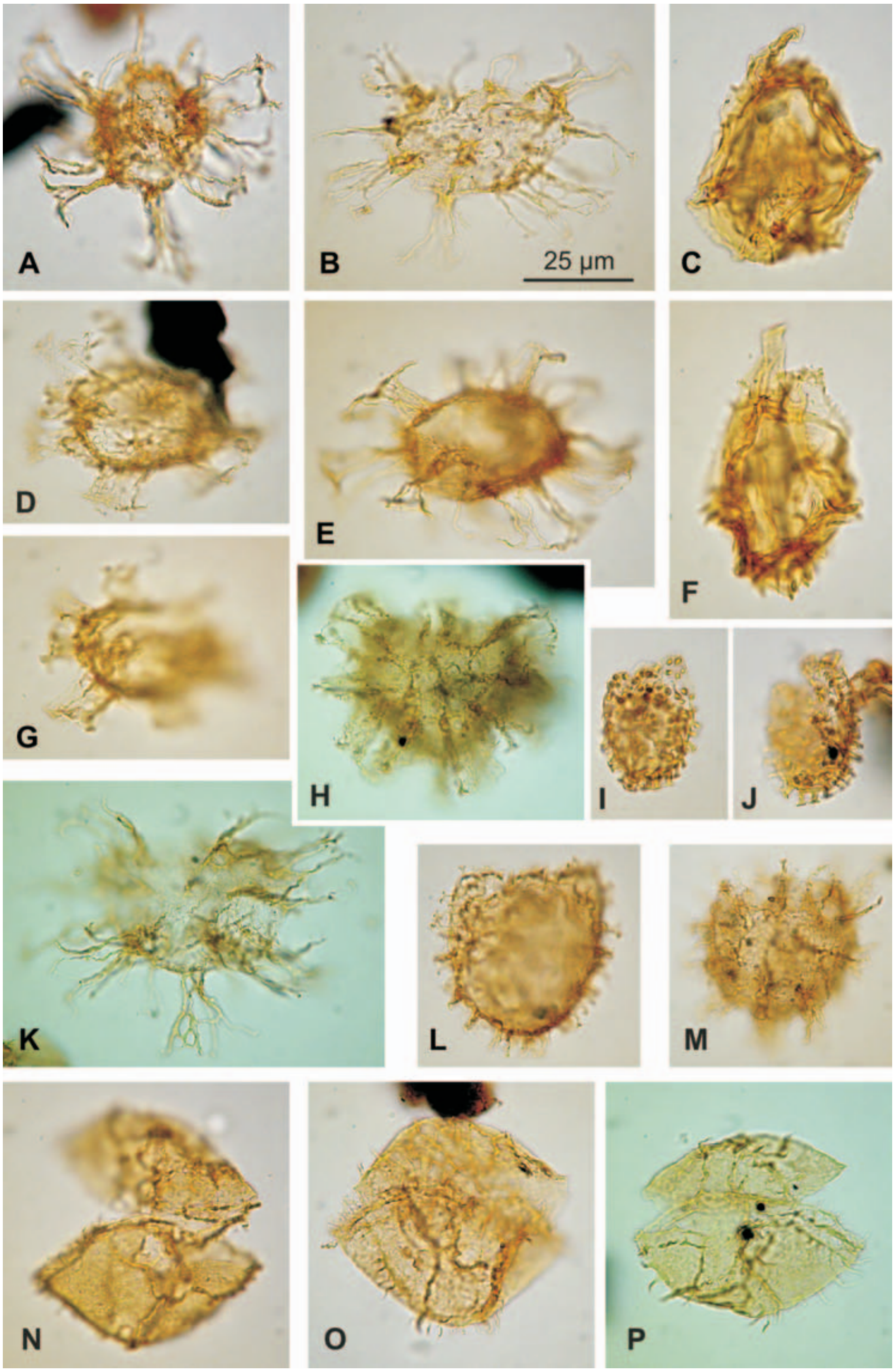
Poulsen (1998) has recognized an important change in dinocyst assemblages within Bathonian and Callovian deposits of Central Poland. The Bathonian assemblages are dominated by ctenidodinioids (i.e., representatives of the genera *Ctenidodinium* and *Dichadogonyaulax*), wheareas the Early Callovian ones are dominated by proximate species with apical archeopyle, such as *Sentusidinium* spp., *Lithodinia caytonensis* and *Epiplosphaera gochtii*. Such difference resembles that between our Ist, ctenidodinioid-dominated assemblage, and the IInd one, in which proximate taxa with apical archeopyle, like the genera *Epiplosphaera*, *Lithodinia* and *Chlamydophorella*, occur in significant numbers.

The dinocysts from the Ist assemblage are most similar to those from the Middle-Late Bathonian DSJ16 Dinoflagellate Cyst Zone of Poulsen (1998). This zone is correlated by him with the *morrisi* to a part of the *orbis-discus* Ammonite Zones. A ?Middle-Late Bathonian through Early Callovian age could be attributed to the Ist assemblage, as compared with dinocyst distribution in Middle Jurassic strata of the NW-German Basin (Prauss, 1989). Several dinocyst taxa found in this assemblage, have their LOs in Late Bathonian (Middle Bathonian is missing in the NW-German Basin – see Prauss, 1989), ranging upwards into post-Callovian strata. This is also true of such taxa as *Atopodinium prostatum*, *Dichadogonyaulax sellwoodii* and *Tubotuberella apatela*. The HO of *Ctenidodinium combazii* is in Early Callovian *calloviense* Ammonite Zone (Prauss, 1989): this delimits the upper age boundary of the Ist dinocyst assemblage at Mt Hulina.

A Middle Jurassic age of the Ist Assemblage is also based on comparison with stratigraphic distribution of Middle Jurassic dinocyst taxa in North Bulgaria presented by Dodekova (1990). *Endoscrinium* (determined by her as *Scriniodinium*) *asymmetricum* and *Dichadogonyaulax* (determined by her as *Ctenidodinium*) *sellwoodii* have their LOs in Middle Bathonian, whereas *Atopodinium prostatum* and *Ctenidodinium ornatum* have their lowest occurrences in Upper Bathonian strata.

Co-occurrence of *Nannoceratopsis spiculata*, *Endoscrinium asymmetricum*, *Pareodinia* aff. *prolongata* and *Ctenidodinium ornatum* allows to correlate the first assemblage with the Late Bathonian part of the *Ctenidodinium sellwoodii* Interval Biozone (ammonite zones: *hodsoni-discus*) of Riding and Thomas (1992).

Attribution to lithostratigraphic unit. The first dinocyst assemblage from Mt Hulina shows a similarity to that described from the stratotype section of the Opaleniec Formation at Sztolnia Creek (Birkenmajer & Gedl, 2004). Some samples from the latter exposure do also contain frequent specimens of *Ctenidodinium* and *Epiplosphaera*. Moreover, several dinocyst taxa recognized in the Ist assemblage from Mt Hulina, correspond to the one from the Sztolnia Creek section, which yielded: *Atopodinium prostatum, Dingodinium minutum* and a *Systematophora*-morphotype. Middle Bathonian and younger ranges of these taxa suggest that we deal here with the Middle Bathonian (or slightly younger) strata.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IInd Dinocyst Assemblage: Oxfordian–?Kimmeridgian

Characteristics. This dinocyst assemblage was recognized in samples Hln5–7 and Hln14, 15. It includes *Compositosphaeridium polonicum* but is devoid of specimens of the genus *Ctenidodinium*. Other dinocysts of this assemblage include *Adnatosphaeridium caulleryii*, *Dichadogonyaulax sellwoodii*, *Gonyaulacysta jurassica*, *Systematophora areolata*, *S. orbifera*, *Taeniophora iunctispina* and *Tubotuberella apatela* (see Tab. 2).

Stratigraphic age. Based on comparison of stratigraphic ranges of these taxa in Boreal and Sub-Boreal realms, which are present exclusively in the IInd assemblage, i.e. *Compositosphaeridium polonicum, Systematophora areolata, S. orbifera* and *Taeniophora iunctispina*, a post-Middle Bathonian age of this assemblage is postulated.

Riding (1982) reported LO of *Compositosphaeridium polonicum* from Middle Callovian (*coronatum* Ammonite Zone, *obductum* Subzone) of SE England. LO of this species was reported by Huault (1999) from strata of the same age (*macrocephalus* Amonite Zone) in the Paris Basin. Other taxa characteristic of the IInd assemblage occur in the Paris Basin in Callovian or younger strata (Huault, 1999): *Taeniophora iunctispina* (Callovian–Early Oxfordian: *macrocephalus-cordatum* Ammonite Zones), *Systematophora areolata* and *Endoscrinium galeritum* (Late Callovian–Oxfordian), *Systematophora orbifera* (latest Callovian *lamberti* Ammonite Zone), and *Scriniodinium inritibile* (Oxfordian).

The top age-range of the IInd assemblage may be based on HO of *Compositosphaeridium polonicum* which occurs in Central Poland close to the Middle/Upper Oxfordian boundary (*transversarium* Ammonite Zone – Poulsen, 1992, 1994).

A Middle Oxfordian age of the IInd assemblage may be based on comparison with stratigraphic ranges of dinocysts from NW Germany. Kunz (1987) reported co-occurrence of *C. polonicum* and *Systematophora areolata* in Middle Oxfordian (*plicatilis* Amonite Zone) strata.

Co-occurrence of the above two taxa in our samples, allows to correlate the IInd assemblage with the *Liesbergia scarburghensis* Interval Biozone and Sub-biozone *a* of the *Scriniodinium crystallinum* Interval Biozone in zonation scheme proposed by Riding and Thomas (1992; *cordatum-glosense* Ammonite Zones). A similar age (*cordatum-glosense* Ammonite Zone) may be accepted on comparison with the data of Fauconnier (1995).

Fig. 6. Dinocysts from Jurassic deposits exposed at south-western slope of Mt Hulina: Sokolica Radiolarite Formation (Grajcarek Unit, Pieniny Klippen Belt). **A**, **B**, **E**, **K** – *Systematophora* spp. (A, B, E: Hln7; K: Hln15); **C**, **F** – *Gonyaulacysta jurassica* (both specimens: Hln7); **D**, **G**, **H**, **M** – *Compositosphaeridium polonicum* (D, G: Hln7; H, M: Hln15); **I**, **J** – *Chlamydophorella* sp. (both specimens: Hln15); **L** – *Epiplosphaera gochtii* (Hln15); **N-P** – *Dichadogonyaulax sellwoodii* (all specimens: Hln15). Scale bar refers to all microphotographs

Much less dinocyst stratigraphic range data is available from Jurassic strata of the Tethyan Realm. Jan du Chêne *et al.* (1998) presented Middle Oxfordian–Early Kimmeridgian dinocyst stratigraphic ranges from the Vocontian Trough (SE France): according to their data, the HO of *Compositosphaeridium polonicum* should be placed at the top of the *transversarium* Ammonite Zone. This limits the upper stratigraphic range of the second assemblage to the top of Middle Oxfordian. More precise dating may be obtained if compared with dinocyst ranges from SW Germany, mainly from the Swabian Alb (Feist-Burkhardt & Willie, 1992). Co-occurrence of *C. polonicum*, *Systematophora areolata* and *Taeniophora iunctispina* suggests also a Middle Oxfordian age (*transversarium* Ammonite Zone) of the radiolaria-bearing complex.

Different, younger, ranges of dinocyst taxa from the second assemblage are indicated on comparison with North Bulgaria (see Dodekova, 1992). According to her, *Taeniophora iunctispina* appears for the first time during Middle Oxfordian, *Systematophora orbifera* – during Late Oxfordian, and *Scriniodinium inritibile* has its LO in Early Kimmeridgian. Early Kimmeridgian HOs of several other taxa (e.g., *Compositosphaeridium polonicum*) given by Dodekova (1992) suggest a Middle Oxfordian–Early Kimmeridgian age of the second dinocyst assemblage at Mt Hulina.

Attribution to lithostratigraphic unit. Occurrence of a Jurassic (Middle Oxfordian–Early Kimmeridgian) dinocyst assemblage in the radiolaria-bearing strata in question, indicates that we deal here with equivalents to the Sokolica Radiolarite Formation and the Czajakowa Radiolarite Formation, and not with the Lower Cretaceous (probably Albian) Groń Radiolarite Member of the Hulina Formation.

More information is needed on the age of the Sokolica Radiolarite Formation. This formation yielded so far only a poorly preserved dinocyst assemblage with *Compositosphaeridium polonicum* (P. Gedl, unpublished) from a well exposed site at Flaki, belonging to the Branisko Succession (for location – see Birkenmajer, 1985, p. 136).

APPENDIX

An alphabetical listing of dinocyst taxa found in the Mt. Hulina section is provided below. Taxonomic citations are given in Williams *et al*. (1998).

Adnatosphaeridium caulleryi (Deflandre 1939) Williams et Downie 1969
Apteodinium sp.
Atopodinium prostatum Drugg 1978
Atopodinium sp.
Bradleyella? sp.
Cassiculosphaeridium pygmae Stevens 1987
Chlamydophorella spp. (Fig. 6I, J)
Chytroeisphaeridium chytroeides (Sarjeant 1962) Downie et Sarjeant 1965 (Fig. 5I)
Cleistosphaeridium sp.
Compositosphaeridium polonicum (Górka 1965) Lentin et Williams 1981 (Fig. 6D, G, H, M)
Ctenidodinium combazii Dupin 1968 (Fig. 5A, B)

Ctenidodinium continuum Gocht 1970
Ctenidodinium ornatum (Eisenack 1935) Deflandre 1938
Dichadogonyaulax sellwoodii Sarjeant 1975 (Fig. 6N, O, P)
Dichadogonyaulax sp.
Dingodinium minutum Dodekova 1975 (Fig. 5E)
Endoscrinium asymmetricum Riding 1987 (Fig. 5H, M)
Endoscrinium galeritum (Deflandre 1938) Vozzhennikova 1967
Endoscrinium luridum (Deflandre 1938) Gocht 1970
Epiplosphaera areolata Klement 1960
Epiplosphaera gochtii (Fensome 1979) Brenner 1988 (Figs 5D, 6L)
Epiplosphaera reticulata (Valensi, 1953) Courtinat, 1989
Epiplosphaera spp.
Escharisphaeridia psilata Kumar 1986
Gongylodinium spp.
Gonyaulacysta eisenackii (Deflandre 1938) Górka 1965
Gonyaulacysta fastigiata Duxbury 1977
Gonyaulacysta jurassica (Deflandre 1938) Norris et Sarjeant 1965 (Fig. 6C, F)
Gonyaulacysta pectinigera (Gocht, 1970) Fensome 1979
Gonyaulacysta sp.
Impletosphaeridium sp.
Korystocysta gochtii (Sarjeant 1976) Woolam 1983 (Fig. 5L)
Lithodinia spp. (Fig. 5J)
Nannoceratopsis pellucida Deflandre 1939 (Fig. 5C)
Nannoceratopsis spiculata Stover 1966
Nannoceratopsis sp.
Pareodinia ceratophora Deflandre 1947
Pareodinia aff. *prolongata* Sarjeant 1959
Pareodinia sp.
Rhynchodiniopsis cladophora (Deflandre 1938) Below 1981
Scriniodinium inritibile Riley 1980
Sentusidinium spp.
Systematophora areolata Klement 1960
Systematophora orbifera Klement 1960
Systematophora spp. (Figs 5K, 6A, B, E, K)
Taeniophora iunctispina Klement 1960
Tubotuberella apatela (Cookson et Eisenack 1960) Ioannides et al. 1977
Tubotuberella dangeardii? (Sarjeant 1968) Stover et Evitt 1978
Tubotuberella dentata Raynaud 1978

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