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A palaeoenvironmental reconstruction based on palynological analyses of Upper Triassic and Lower Jurassic sediments from the Holy Cross Mountains region

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ABSTRACT. The material for this study was taken from various sites in the Holy Cross Mountains: Studzianna, Huta OP-1 and Przysucha P-3 (bore cores), and Odrowąż (geological outcrop). Palynological and palynofacial analyses were used to reconstruct the Upper Triassic and Lower Jurassic vegetation and palaeoenvironment of that area.

Samples from all the sites are characterised by having majority of terrestrial particles. The slides were dominated by translucent phytoclasts and small opaque phytoclasts. Pollen grains and spores were also present. The presence of marine palynomorphs was not confirmed in the samples from any of the sites, dinoflagellate cysts did not occur, and there were no foraminiferal test linings.

The Sporomorph EcoGroup (SEG) model (Abbink 1998) was applied to characterise the ecological types of the plant assemblages. The most frequently occurring sporomorphs were assigned to Upland, Lowland and River SEGs. Stratigraphical changes in each of the SEGs indicate differences in climatic conditions.

The floristic composition of the Studzianna, Huta and Odrowąż localities inferred from sporomorphs differs somewhat from the composition reconstructed from macroremains.

KEYWORDS: spores, pollen grains, palynofacies, macroflora, Mesozoic, Poland

INTRODUCTION

Upper Triassic and Lower Jurassic sediments surround the Palaeozoic core of the Holy Cross Mountains (Góry Świętokrzyskie) to the north, west and south-west. Establishing the stratigraphy and reconstructing the palaeoenvironments of these sediments is made difficult by an insufficiency of age-diagnostic index fossils, which is due to the dominance of sediments of terrestrial origin there.

RESEARCH HISTORY

The Triassic sediments lie on an eroded Palaeozoic basement, and their development displays the clear influence of the morphology and structural composition of this basement. The diverse relief of the Palaeozoic bedding surface and its complex tectonic structure resulted in heterogeneous development of the Triassic sediments in the Holy Cross Mts.

Many researchers have investigated the Triassic sediments of the Holy Cross Mts. The Triassic formations were first recognised by Schneider (1829) and next described by Pusch (1836) and Zejszner (1868). Roemer (1866, 1868) was the first to confirm the presence of the Upper Buntsandstein in this area. Research was also done by Michalski (1884, 1888), Rydzewski (1924), and Kowalczewski (1926). The Rhaetian strata were first recognised by Siemieradzki (1887). The next geological investigations in this region were conducted by Czarnocki (1923, 1925, 1926, 1950, 1958), Samsonowicz (1929), Karaszewski (1947, 1949), Jurkiewiczowa (1947), and Senkowiczowa (1970).

Relatively few studies related to the Triassic macroflora of the Holy Cross Mts. area have been published so far. Roemer (1866) gave the first description of plant macroremains from that region, from a site in Mierzęcin. That material was later re-examined by Reymanówna & Barbacka (1981) and Barbacka (1991). Czarnocki (1925, 1931) and Bocheński (1957) made paleontological analyses of Upper Buntsandstein sediments of the Holy Cross Mts. Pacyna (2014) gave a review of the Triassic macroflora localities of Poland.

The Triassic-Jurassic boundary has drawn the attention of Polish researchers in recent years. Pieńkowski (2004, Pieńkowski et al. 2008, 2011) combined results from his sedimentological research with other geological, mineralogical, and palaeontological analyses to address issues connected with the Triassic-Jurassic boundary in Poland. Brański (2009a, b, 2011) did mineralogical research.

Lower Jurassic deposits surround the main Palaeozoic core of the Holy Cross Mts. to the north, west and south-west. Schneider gave the first information about these sediments in 1829 (Samsonowicz 1929). The lithology, stratigraphy, micro- and macroflora of the Lower Jurassic deposits have been examined by Pusch (1831–1836, 1837), Samsonowicz (1929, 1934), Karaszewski (1947, 1960, 1962), Jurkiewiczowa (1967), and Karaszewski & Kopik (1970). Pieńkowski (1983) studied the sedimentology of these deposits. The current classification of the Holy Cross Mts. Lower Jurassic deposits is based on sequence stratigraphy (Pieńkowski 2004).

The palaeontological research initiated by Pusch (1831–1836, 1837) has continued. Raciborski (1891, 1892) and Makarewiczówna (1928) described fossil flora. Since 1987 the plant macroremains from an outcrop in the village of Odrowąż, also known as Sołtyków, have been studied by Reymanówna (1987, 1991a, b, 1992, Reymanówna et al. 1987), Wcisło-Luraniec (1991a, 1992), and Barbacka et al. (2007, 2010). Marcinkiewicz (1957, 1971, Marcinkiewicz et al. 1960), Fuglewicz (1973, 1977, 1980), and Mamczar (1971) studied Triassic and Jurassic megaspores and their stratigraphical settings.

Rogalska (1954, 1956) was the first to analyse the microflora of Jurassic sediments in Poland, and also made the most detailed description of microspore species from boreholes in this area (Rogalska 1976). Later palynological research was done by Marcinkiewicz (1957, 1959, 1961, 1966), Pautsch (1958, 1971, 1973), Orłowska-Zwolińska (1960, 1983), Grabowska (1962), Fijałkowska (1988a, b, 1989a, b, 1991, 1992), Ziaja (1989, 1991, 1992, 2006), and Gedl & Ziaja (2004). Ziaja (2006) published results from palynological work in Odrowąż, in which she described 63 taxa of pollen grains and spores. Pacyna (2013) has described Lower Jurassic research in Poland in detail.

GEOLOGICAL SETTING

In the Triassic and Lower Jurassic, sedimentation in the Holy Cross Mts. region took place in the south-eastern zone of the epicontinental Polish Basin (Feist-Burkhardt et al. 2008, Pieńkowski et al. 2008). This region constituted the southern part of the axial zone of the Polish Basin, that is, the Mid-Polish Trough. In the Lower Triassic and Lower Jurassic, strong subsidence compensated by sedimentation resulted in thick siliciclastic deposits. In the Norian, dry and warm climate dominated. Sedimentation of pink, red or green-grey sandstones, green-grey dolomitic mudstones, and green, yellow or red claystones took place probably in the channels and on the fluvial plains of braided rivers (Czapowski & Romanek 1986).

Climate change from dry to wet is observed from the beginning of the Rhaetian, manifested in a change of sediment color from red to grey and in more abundant remains of flora (Deczkowski 1997). The Rhaetian basin in the Holy Cross Mts. margin was probably smaller in extent than the Norian one. Sediments are preserved only in the narrow zone connected with the axial part of the Mid-Polish Trough.

Sedimentation of Jurassic sediments in the epicontinental Polish Basin evidently was preceded by erosion. Due to very low sea level at the end of the Triassic and the beginning of the Jurassic, the basin area was exposed. As presented in Figure 1, the Upper Rhaetian strata have most often been eroded, and an erosion surface has been recognised at the Triassic-Jurassic boundary (Pieńkowski 2004).

The Lower Jurassic deposits in Poland are sediments of a vast inland basin. This basin communicated only with the epicontinental seas of Central and Western Europe (Dadlez 1964, 1969). Ammonite fauna remains were found only in Pliensbachian rock in the Pomerania region (Dadlez & Kopik 1972), hindering efforts to determine the ages of the Lower Jurassic sediments. At the beginning of the Jurassic, the Mid-Polish Trough again became active after a period lasting for most of the Middle and Late Triassic, during which subsidence was not significant.

The Zagaje Formation was deposited in an alluvial-lacustrine environment and is correlated with the initial phase of a transgression which entered the Polish Basin from the west (Pieńkowski 1991, 2004, Pieńkowski et al. 2008). The series reaches 150 m thickness in the southern part of this area. The lower part of the Zagaje Formation is predominated by varigrained sandstone beds formed in diverse fluvial environments. Deposits from braided and meandering rivers pass upwards into lacustrine-backswamp claystones and mudstones with abundant coalified flora remains, rhizoids, and coal levels (Karaszewski 1962, Karaszewski & Kopik 1970, Pieńkowski 1983, 2004, Pieńkowski & Gierliński 1987). The occurrence of freshwater ostracods has been confirmed in the upper parts of this series.

The Skłoby Formation, representing Middle Hettangian strata, is built mainly of shallow marine (nearshore and barrier/lagoon) sandstones. To the north-east are deltaic depositional system deposits. This formation reaches 30–100 m thickness. It contains marine fauna, including molluscs and foraminifers, and micro- and macrospores were also found.

In the Holy Cross Mts. the Upper Hettangian is represented by the Przysucha Ore-bearing Formation, which was deposited mainly in marginal-marine conditions. It is developed mostly in fine-grained facies deposited in an environment of brackish lagoons, coastal barriers, and deltas, and is composed of intercalated sandstones as well as limeless, grey, greenish-grey, brown, and variegated claystones and mudstones. They contain siderite intercalations, abundant plant remains, and in some regions plant roots. A distinctive feature of this formation is the occurrence of so-called ore horizons, that is, claystone/

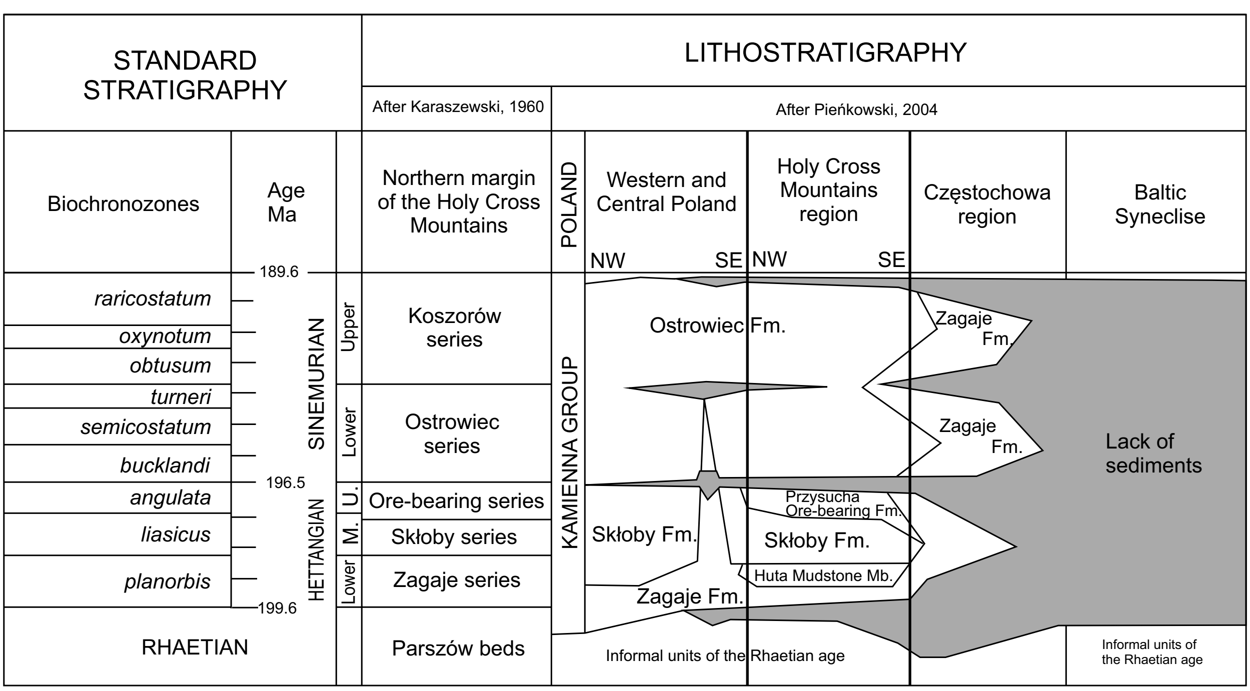

Fig. 1. Lithostratigraphical units of Early Jurassic deposits in Poland (after Pieńkowski 2004, modified, drawing by A. Sojka)

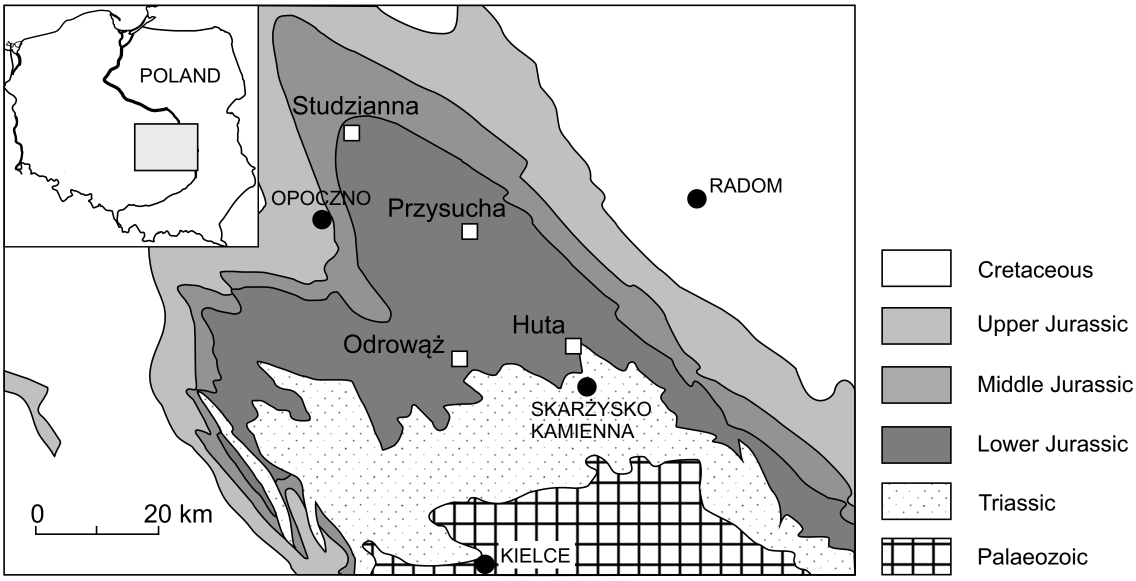

Fig. 2. Map of investigated localities: Studzianna, Huta OP-1, Przysucha P-3 boreholes and Odrowąż outcrop (after Brański 2009 a, b, modified, drawing by A. Sojka)

mudstone packets several metres in thickness containing siderites (Karaszewski 1962, Kozydra 1968). Whitish-gray or variegated clays of this formation were exploited as refractory and ceramic clays. This formation is between 40 m and 110 m thick.

The sediments of the Hettangian Formations (Zagaje, Skłoby and Przysucha Ore-bearing) together built the first depositional sequence of the Lower Jurassic (Pieńkowski 2004, Pieńkowski et al. 2008).

The Sinemurian is represented by the Ostrowiec Formation. The lower part of it consists of alluvial sandstone with intercalations of mudstone beds and abundant plant remains. The middle and upper parts are dominated by shallow brackish-marine sandstone and mudstone interbedded by lagoonal, barrier and deltaic deposits (Pieńkowski 2004).

MATERIALS AND METHODS

LOCALITIES

The material selected for this research comes from four sites in the Holy Cross Mts region. Triassic and Lower Jurassic material from three boreholes (Studzianna, Przysucha P-3, and Huta OP-1) were analysed. Lower Jurassic rocks from the Odrowąż outcrop were also sampled.

Studzianna

The Studzianna borehole at the northern margin of the Holy Cross Mts. is 60 km north-west of Skarżysko-Kamienna (Fig. 2).

The borehole section includes Triassic and Jurassic sediments which Karaszewski studied (see earlier citations); in that work he focused on sediments of the Rhaetian, the entire Lower Jurassic and the Lower Aalenian (Middle Jurassic). He described the profile of the Lower Jurassic part of the section in detail (Karaszewski 1962); from an analysis of the core he distinguished the nine series which became the basis for the formal stratigraphical division of the Lower Jurassic in the Holy Cross Mts region (Pieńkowski 2004).

Huta OP-1

The Huta OP-1 borehole is on the northern margin of the Holy Cross Mts., 12 km north-east of Skarżysko-Kamienna (Fig. 2). The core from this place incorporates sediments of the Upper Triassic and the Hettangian (Pieńkowski 2004).

Przysucha P-3

The Przysucha area comprises part of the Gielnów mega-anticline and the Opoczno syncline, which are on the border between the northern margin of the Holy Cross Mts. and the southern part of the Kujawy Anticlinorium (now called the Kujavian Swell) (Pożaryski 1974).

The Przysucha P-3 borehole is ca 40 km west of Radom (Fig. 2). Karaszewski completed the profile of this borehole in 1971–72. It incorporates sediments of the lower part of the Lower Jurassic (Skłoby and Przysucha Ore-bearing formations – Hettangian).

Odrowąż

The Odrowąż site, also known as Sołtyków, located 25 km north of Kielce (Fig. 2), is an outcrop in a clay pit, in which Jurassic flora occurs. The outcrop was designated a geological reserve in 1997. According to Pieńkowski (2004) the sediments of the Odrowąż outcrop represent the Zagaje Formation, which is composed of sandstone, claystone, spherulitic siderites, and siderites with coal intercalations, and has been dated to the early Hettangian. This age was confirmed by assemblages of microspores (Ziaja 2006) and megaspores, in particular by the presence of the *Lycostrobus scotti* Nathorst megaspore, which is regarded as an age-diagnostic index fossil for the Lower Jurassic (Marcinkiewicz 1957, Marcinkiewicz et al. 1960). In the Early Jurassic the investigated area was part of a region containing numerous freshwater basins. The Odrowąż succession is interpreted as a sequence of meandering rivers deposits (Pieńkowski 1998).

Also described from this area are plant macroremains (Reymanówna 1987, 1991a, b, 1992, Reymanówna et al. 1987, Wcisło-Luraniec 1987, 1991a, b, 1992, Barbacka et al. 2010), dinosaur footprints (Pieńkowski & Gierliński 1987, Gierliński & Pieńkowski 1999), and insect remains (Węgierek & Zherikhin 1997).

MATERIAL

Fourteen samples from the Studzianna profile were collected (Tab. 1, Fig. 3), from which 70 microscope slides (5 slides per sample) were prepared for palynological and palynofacial analysis. To account for differences in data resulting from differences in research methods, another 40 slides were prepared from the Studzianna profile and compared with 40 slides that Ziaja made in 1987 from the same horizons without using nylon sieves.

Sixteen samples from the Huta OP-1 profile were collected (Tab. 2, Fig. 3), from which 80 microscope slides were prepared (5 preparations per sample).

Eight samples from the Przysucha P-3 profile were collected (Tab. 3, Fig 4), from which 40 microscope slides were prepared (5 preparations per sample).

This study also used 20 microscope slides from

Table 1. Samples taken from the Studzianna borehole for analysis

Sample No.	Depth [m]	Lithologic Description	Chronostratigraphy Lithostratigraphy (after Karaszewski 1962)
1/n	642	Sandstone: light grey, with mica on the clay intercalations. Mudstone: grey, thin-bedded, sandier toward bottom, with sandstone lenticles	Sinemurian Ostrowiec Formation
3/1	783	Mudstone: dark grey, sandier toward bottom, with sandstone lenses at bottom	
138/9	862	Sandstone: fine-grained, fissured almost vertically with fine mudstone drapes	Hettangian Przysucha Ore-bearing Formation
2/n	862.6		
4/1	978	Claystone: dark grey with black intercalations, root traces	Hettangian Zagaje Formation
2/1	980	Claystone: dark grey, in places finely laminated by mudstone containing flora, with siderite intercalations and concretions	
3/n	1011		
1/1	1013		
4/n	1048	Claystone: olive-grey, a little sideritic with spherulites of Ø 0.5–1 mm, with reddish-grey stains	
138/78	1058	Claystone: grey, containing flora, with sprays of fine galena crystals crushed into crevices	
5/n	1060		
6/n	1090	Dolomitic muddy sandstone: light greenish-grey, infrequent plant remains	Rhaetian
7/n	1145.8	Muddy sandstone: reddish-brown, with bright green stains	Norian
8/n	1175	Muddy dolomitic claystone: greenish, massive	

Table 2. Samples taken from the Huta OP-1 borehole for analysis

Sample No.	Depth [m]	Lithologic Description	Chronostratigraphy Lithostratigraphy (after Pieńkowski 2004)
1/2011	21.5	Claystone: grey, with dark grey intercalations, coalfield plant remains	Hettangian Skłoby Formation
139/255	36.8	Mudstone: olive grey, with cherry stains, rhizoids up to Ø 6 mm, sand lamination, flora	Hettangian Zagaje Formation
139/235	50.2	Claystone: ash grey, dark grey lower down, with flora and rhizoids that disappear in lower part, small siderite spherulites	
139/289	63	Mudstone: grey with violet tint, slightly sideritic, infrequent sandstone laminae traces of bedding. Abundant flora	
139/207	63.6		
139/293	73.1	Mudstone: grey, finely laminated with silted sandstone and Podozamites flora	
2/2011	85	Mudstone: olive grey, numerous rhizoids	
139/308	98.6	Mudstone: dark grey, containing decomposed plant remains, merges into black mudstone; rhizoids, intercalations of olive grey mudstone	
139/223	103.5	Mudstone: dark grey, with numerous rhizoids, merges into olive-grey mudstone	
139/205	131.7	Mudstone: grey, with intercalations of dark grey and black bituminous claystone, flora	
3/2011	142.5	Mudstone: grey with olive tint and numerous rhizoids	
4/2011	177	Claystone and mudstone: finely laminated with sandstone containing rhizoids	
5/2011	190	Sandstone: medium-grained, laminated with grey mudstone	Rhaetian
6/2011	197.8	Claystone and mudstone: finely laminated	Norian
7/2011	200	Mudstone: grey, with claystone intercalations	
8/2011	202.1	Mudstone: grey, massive	

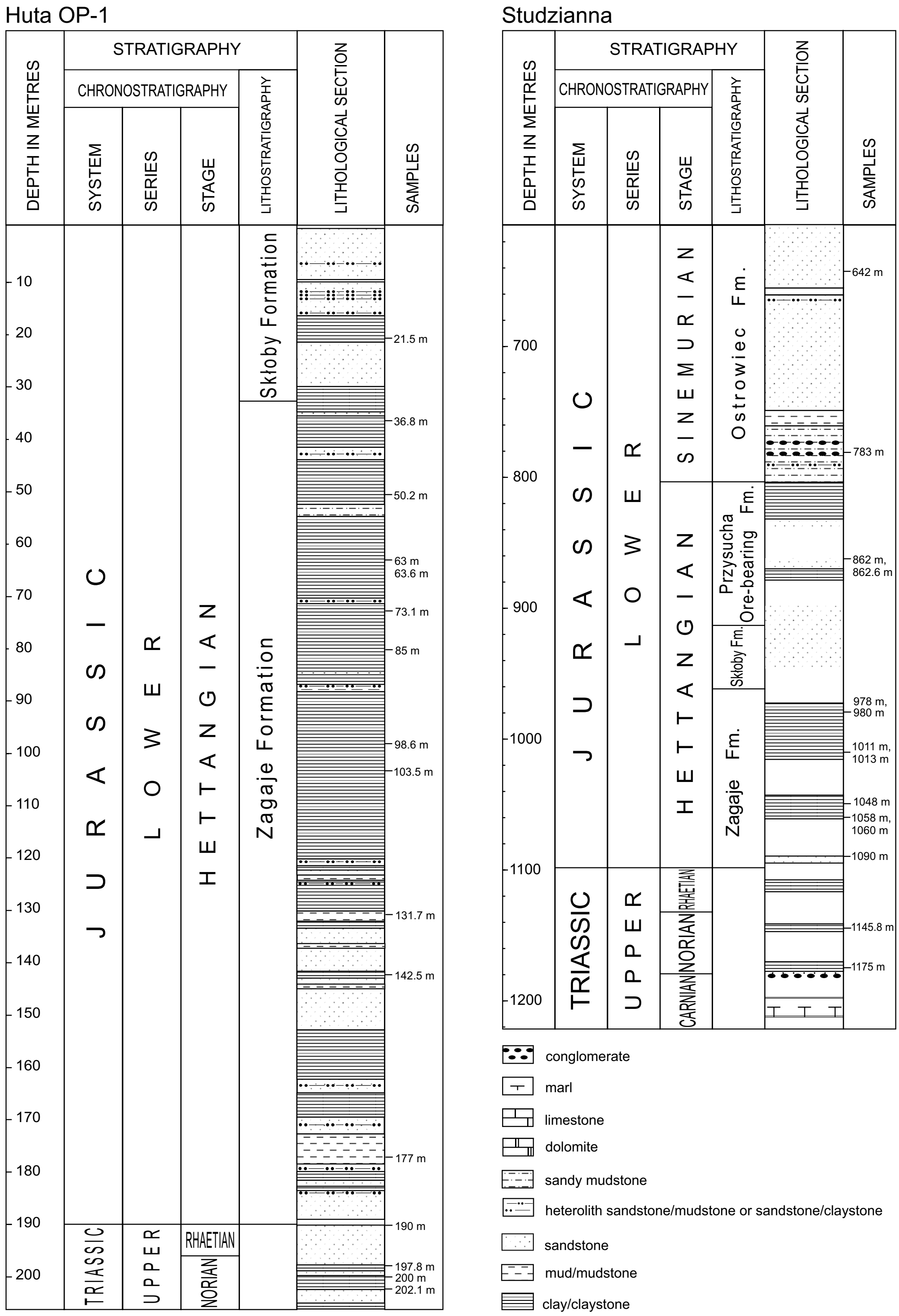

Fig. 3. Profiles of Studzianna borehole (stratigraphy after Karaszewski 1962) and Huta OP-1 borehole (stratigraphy after Pieńkowski 2004) (drawing by A. Feldman-Olszewska and A. Sojka)

4 samples taken from the Odrowąż outcrop, which Ziaja prepared in 1986, 1987 and 1990 by a method that did not employ nylon sieves.

METHODS

The samples were prepared for palynological and palynofacial investigations by three methods. The first method used HCl, HF, heavy liquid $ZnCl_2$ (D ca 2.1 g/cm^3) and a nylon 15 µm mesh sieve.

The second method used HCl, HF, KOH, Schulze's solution (HNO_3 + H_2O + $KClO_3$) and a nylon 15 µm mesh sieve. The third method used HCl, HF, Schulze's solution [equal amounts of 65% nitric acid (HNO_3) and distilled water with a small amount of potassium chlorate ($KClO_3$) added] and 10% KOH, without sieving.

The methods were applied to rock samples taken from different horizons of the Studzianna borehole. Five preparations were made for each horizon.

Table 3. Samples taken from the Przysucha P-3 borehole for analysis

Sample No.	Depth [m]	Lithologic Description	Horizon/ lithostratigraphy
140/19	29.5	Muddy clay: grey and dark grey, with flora and desiccation cracks	Hettangian Przysucha Ore-bearing Fm.
140/3	38	Sandstone: greyish white, medium-grained, with flora in places; mica	
140/8	62.5	Clay: grey, with fragments of olive brown siderite mudstone	
140/7	63	Mudstone: grey, laminated with sandstone, with abundant flora	
140/40	70	Mudstone: grey, finely laminated with sandstone, with fine mica on its bedding surfaces	
140/39	84	Muddy sandstone: laminated, with worm burrows, fragments of flora	
140/76	111.8	Mudstone: grey, laminated with sandstone containing worm burrows and flora	
140/45	138.5	Mudstone: grey, laminated with sandstone, containing flora	Hettangian/ Skłoby Fm.

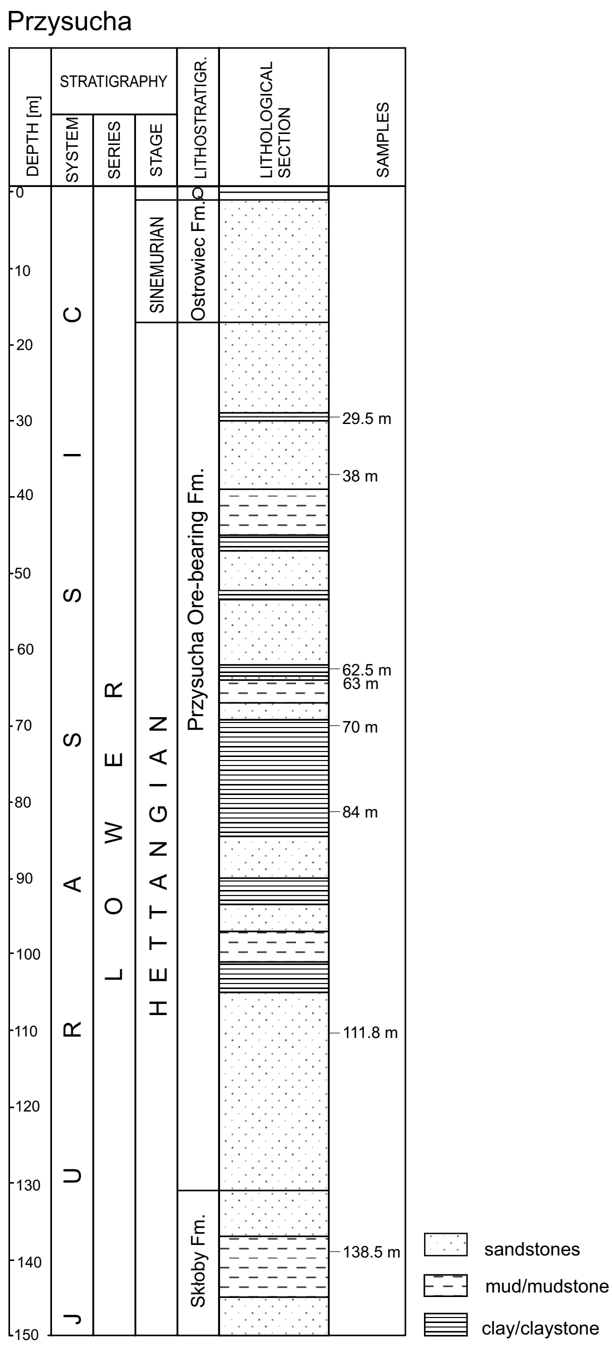

Fig. 4. Profile of Przysucha P-3 borehole (stratigraphy after Karaszewski (unpubl. data 1972), drawing by A. Sojka and A. Feldman-Olszewska)

Initial processing of the samples involved removal of all carbonates using 35–38% hydrochloric acid. The residue was treated by 40% hydrofluoric acid for 48 hours to remove any silicates. In methods 1 and 2 the sample was sieved to dispose of the finest fraction. The microscopy images of the samples differed between methods. There was no significant change in the mixing ratio of the palynofacies elements but the clarity of the slides and the state of preservation of the palynomorphs were markedly improved by the use of nylon sieves (Krupnik 2011).

As the sediment was composed of finer grains, heavy liquid flotation turned out in this case proved particularly important. Using precisely calibrated (15 µm) nylon micromeshes (NYTEX), organic and inorganic microparticles that had been resistant to previous treatments were removed. This facilitated the conversion analysis of palynofacies and improved the photographs of palynomorphs.

The analyses were aimed at reconstructing the local and regional palaeoenvironmental conditions. The palynofacial analyses determine the relative abundance and type of organic matter with grain size over 15 µm. Combined with pollen analyses, they give a picture of some components of the environment and sedimentation processes. The elements of palynological matter contained in the sediments are characteristic of specific palaeoenvironments. The relations between these elements may reflect palaeogeographic changes and so may assist in reconstructing them. Additional analyses employing the Sporomorph Eco-Group (SEG) model (Abbink 1998, Abbink et al. 2001, 2004), which assigns particular sporomorphs to plant groups, help determine their living environment. These sites have never before been subjected to palynofacies or SEG analyses.

Nikon Eclipse E400 and Nikon Eclipse E600 microscopes were used for the observations and analyses of all samples. In the palynofacial analyses, all the organic particles on each of the slides were counted (at least 500 particles per sample totalling up 5 slides for every sample). The organic matter categories follow Steffen & Gorin's (1993) classification. Numerical data for the palynofacial analysis graphs are given in Appendix 1. The material is stored in the palaeobotanical collection of KRAM-P, PM (Botany Museum, W. Szafer Institute of Botany, Polish Academy of Sciences).

PALYNOLOGY AND PALYNOSTRATIGRAPHY

The sporomorph assemblages in the Triassic and Rhaetian samples (Tab. 4) are similar to assemblages described for the Germanic Basin region (Orłowska-Zwolińska 1983).

The Triassic samples from the Studzianna and Huta OP-1 boreholes are dominated by *Classopollis* pollen grains (ca 50%). The sporomorph assemblage, typical of Rhaetian/Hettangian microfloras, is dominated by bisaccate pollen grains, fern spores, seed ferns, and *Classopollis* pollen grains. *Classopollis* belongs to coniferous plants from the extinct family Cheirolepidiaceae (Alvin 1982) and occurs in the samples as single grains and tetrads.

The taxa on the slides from the Rhaetian sediments of the Huta OP-1 borehole correspond to the 7th group of sporomorphs (Fijałkowska 1992). The following taxa occur abundantly in the samples: *Cyathidites minor* Couper 1953, *Concavisporites toralis* (Leschik 1955) Nilsson 1958, *Todisporites minor* Couper 1958, *Lycopodiumsporites* sp., *Pinuspollenites nitidus* Pautsch 1971, and *Monosulcites minimus* Cookson 1947 ex Couper 1953. The 7th group corresponds to a *Riccisporites tuberculatus* (Orłowska-Zwolińska 1985)/*Rhaetipollis germanicus* (Kürschner & Herngreen 2010) Zone (Tab. 5). The samples also contain a large share of *Alisporites* spp. There are numerous bisaccate pollen grains but their state of preservation is not good enough for the taxa to be determined.

Within the Zagaje Formation (from Huta OP-1, Studzianna and Odrowąż) there are noticeable changes in the frequency of spores and pollen grains in individual strata, perhaps indicating climatic changes or changes in distance from land.

The high percentage of bisaccate pollen grains of coniferous plants indicates that the investigated assemblages were dominated by

Table 4. Occurrence of the most important sporomorphs in the investigated samples

Taxon	Studzianna	Huta OP-1	Przysucha P-3	Odrowąż
***Cyathidites minor* Couper 1953**	x	x	x	x
***Concavisporites toralis* (Leschik 1955) Nilsson 1958**	x	x	x	x
***Deltoidospora* sp.**	x	x	x	x
Plicifera delicata (Bolch. 1953) Bolch. 1967	x	x		x
Calamospora tener (Leschik 1955) Madler 1964	x	x		x
Rogalskaisporites sp.	x			x
***Todisporites minor* Couper 1958**	x	x	x	x
Conbaculatisporites mesozoicus Klaus 1960	x			x
***Uvaesporites argenteaeformis* (Bolch. 1953) Schulz 1967**	x	x	x	x
Leptolepidites sp.	x	x	x	
***Lycopodiumsporites* sp.**	x	x	x	x
***Matonisporites* sp.**	x	x	x	x
Cingutriletes sp.	x			
Foveotriletes sp.	x			x
Marattisporites sp.	x	x	x	
Aratrisporites minimus Schulz 1967	x	x		x
***Alisporites thomasii* (Couper 1958) Nilsson 1958**	x	x	x	x
***Vitreisporites pallidus* (Reissinger 1950) Nilsson 1958**	x	x	x	x
Cerebropollenites sp.	x			
***Pinuspollenites nitidus* Pautsch 1971**	x	x	x	x
Pinuspollenites minimus (Couper) Kemp	x	x	x	x
Inaperturopollenites sp.			x	x
Araucariacites sp.	x			x
Spheripollenites sp.	x			x
***Perinopollenites elatoides* Couper 1958**	x	x	x	x
Chasmatosporites major (Nilsson 1958) Pocock & Jansonius 1969				x
***Chasmatosporites apertus* (Rogalska 1954) Nilsson 1958**	x	x	x	x
Chasmatosporites cf. *elegans* Nilsson 1958			x	x
Chasmatosporites hians Nilsson 1958	x			x
***Monosulcites minimus* Cookson 1947 ex Couper 1953**	x	x	x	x
Monosulcites subgranulosus Couper 1958	x	x		x
***Classopollis torosus* (Reissinger 1950) Couper 1958**	x	x	x	x

Table 5. Miospore zonations of the Middle and Late Triassic in Poland (after: Orłowska-Zwolińska 1985), correlated with Central and NW Europe zonation (Kürschner & Herngreen 2010, modified)

<table>
<tr><th colspan="2">Stratigraphy</th><th>Orłowska-Zwolińska (1985)</th><th>Kürschner-Herngreen (2010)</th></tr>
<tr><td rowspan="7">T R I A S S I C</td><td>RHAETIAN</td><td>Ricciisporites tuberculatus</td><td>Rhaetipollis germanicus</td></tr>
<tr><td>NORIAN</td><td rowspan="2">Corollina meyeriana</td><td rowspan="2">Granuloperculatipollis rudis</td></tr>
<tr><td rowspan="2">CARNIAN</td></tr>
<tr><td>Aulisporites astigmosus
Porcelispora longdonensis</td><td>Camerosporites secatus</td></tr>
<tr><td>LADINIAN</td><td>Heliosaccus dimorphus</td><td>Heliosaccus dimorphus</td></tr>
<tr><td rowspan="2">ANISIAN</td><td>Tsugaepollenites oriens</td><td rowspan="2">Stellapollenites thiergartii</td></tr>
<tr><td>Perotrilites minor</td></tr>
</table>

wind-dispersed sporomorphs, mainly from pteridosperms and conifers of the order Coniferales, which formed the regional vegetation. The most frequently encountered sporomorphs, occurring in almost all the samples, are *Deltoidospora* sp., *Todisporites minor* Couper, *Monosulcites* sp., *Classopollis* sp. and *Perinopollenites elatoides* Couper. Spores of Pteridophyta are most frequent in these sediments.

Representatives of the following groups occur in the flora determined from the Lower Jurassic at the studied sites:

Bryophyta – *Stereisporites steroides* (Potonié & Venitz) Thomson & Pflug and *Stereisporites* sp.;

Equisetales – *Calamospora* sp., *Calamospora tener* (Leschik 1955) de Jersey 1962;

Lycopodiales – *Lycopodiacidites* sp., Selaginellales – *Uvaesporites* spp.;

Ferns of the families Matoniaceae – *Matonisporites* spp., Cyatheaceae or Dicksoniaceae – *Cyathidites minor* Couper and *Cyathidites* sp.;

Pteridospermophyta of the order Caytoniales – *Vitreisporites pallidus* (Reissinger) Nilsson, Ginkgoales or Cycadales or Bennettitales – *Chasmatosporites* sp., *Chasmatosporites apertus* (Rogalska) Nilsson, *Monosulcites* sp. and *Monosulcites minimus* Cookson;

Coniferales of the family Taxodiaceae – *Perinopollenites elatoides* Couper;

Pinaceae – *Pinuspollenites minimus* (Couper) Kemp;

Araucariaceae – *Araucariacites* sp.;

Cheirolepidiaceae – *Classopollis* spp.

Ziaja (2006) gave precise descriptions of the sporomorphs from the Odrowąż outcrop.

The sediments of the Skłoby Formation are represented by two samples (Huta OP-1, 22.5 m; Przysucha, 140 m). Pollen grains dominate the sporomorphs. Spores comprise only 20–30%. *Classopollis* sp. and *Alisporites thomasi* (Couper) Nilsson pollen appear in both samples, and *Cyathidites minor* and *Calamospora* spores also appear. *Cyathidites minor* most probably is a fern of the Cyatheaceae or Dicksoniaceae families (Couper 1958).

The slides of sediments from the Przysucha Ore-bearing Formation (Przysucha P-3) are dominated by bisaccate pollen grains adapted for long-range wind transport, of the genera *Alisporites* and *Vitreisporites*. The bisaccate *Alisporites* sp. pollen grains may represent seed ferns. Similar pollen grains are also produced by coniferous plants of the families Pinaceae and Podocarpaceae (Balme 1995).

The Zagaje, Skłoby and Przysucha Ore-bearing formations are of Hettangian age. The sporomorph composition of the samples taken from these sediments is similar to that of the *Pinuspollenites-Trachysporites* Zone (Lund 1977), but these samples are dominated by *Classopollis* spp. pollen (ca 70%). Spores also form a high share but they are not dominant.

Pinuspollenites minimus pollen grains are not abundant.

Microspore zonations for the Lower Jurassic (Tab. 6) have been presented by Schulz (1967), Lund (1977), Dybkjær (1988), and Koppelhus & Batten (1996), among others.

The *Cerebropollenites macroverrucosus* Zone (Dybkjær 1988) is similar in sporomorph composition to the zone from the Hettangian age but has been defined on the basis of the distinctive first appearance of *Cerebropollenites macroverrucosus* pollen grains. The upper boundary of this zone is marked by a rise in the number of *Spheripollenites* pollen grains and the appearance of the genus *Leptolepidites* (Dybkjær 1988).

Samples taken from the sediments of the Ostrowiec Formation at Studzianna, which represents the Sinemurian (Fig. 3, Tab. 1), were not assigned to a miospore zonation. The sporomorph composition resembles that of the lowermost formations but the poor state of preservation of *Cerebropollenites* spp. made it impossible to confirm them as *Cerebropollenites macroverrucosus* and thus to assign the sporomorphs of those samples to the *Cerebropollenites macroverrucosus* Zone (Dybkjær 1988).

SPOROMORPH GROUPS

Every attempt to classify plant communities in the Mesozoic is hampered by uncertainty about the botanical affinity of numerically important sporomorphs and the ecological preferences of extinct parent plants. However, habitats can be characterised based on the presence of taxa with very similar ecological preferences. Ecological community types are the basis for the Sporomorph Ecogroup conceptual model.

Despite the effect of processes related to preservation state, transport and sedimentation, accumulations of sporomorphs reflect the composition of terrestrial plant communities (Chaloner & Muir 1968, Traverse 1988, Abbink 1998). They are most useful for the Quaternary, which is distinctive for the similarity of the plant communities to those that grow today. Reconstructions of this sort can also be done from Pre-Quaternary sediments. Abbink (1998) proposed the Sporomorph Eco-Group Model (SEG) method. This model is based on a division of sporomorph groups (Sporomorph EcoGroups) that reflects the composition of the corresponding plant communities: Upland, Lowland, River, Pioneer, Coastal, and Tidally-influenced SEGs (Tab. 7). Changes in the quantitative composition of SEGs can be employed to reconstruct climatic changes.

A nutrient shortage or reduced availability of freshwater in upland areas may lead to environmental stress. Periodic submersion and riverbank erosion will force plants to adopt ruderal strategies. Ruderal strategies will also be used by first colonisers or pioneer plants. Plants in lowlands will also exhibit competitive strategies adapted to that habitat (Abbink et al. 2001). Plants' tolerance to environmental stress and disturbances is not completely understood. Plants can develop in several environments, for example both in lowlands and along rivers (Abbink et al. 2004). Abbink (1998) noted that spores belonging to Schizaeaceae, Cyatheaceae, Dicksoniaceae, Dipteridaceae, and Pteridaceae may be characteristic of Lowland or River SEGs. Bryophyte spores may also be in River or Lowland SEGs. *Vitreisporites* pollen grains of the order Caytoniales were also included by Abbink in the River SEG, but the parent plant can also grow under canopy, so these grains should be assigned to the Coastal SEG, as Zatoń et al. (2006) suggest.

The Sporomorph EcoGroup model was initially established for the Upper Jurassic/Lower Cretaceous in the North Sea region. The climatic conditions that prevailed in that period differed from those at the Triassic-Jurassic boundary. The warmer/cooler and more humid trends described by Abbink do not apply to sporomorphs from the Triassic-Jurassic boundary, because the climate at the end of the Jurassic and the beginning of the Cretaceous was much more humid. The parent plants of many sporomorphs from the Mesozoic are still unknown. The SEG model is therefore incomplete (Ruckwied et al. 2008). A number of

Table 6. Miospore zonations of the North European Lower Jurassic (after Koppelhus & Batten 1996, modified)

Stratigraphy			Koppelhus & Batten (1996)
JURASSIC	Lower	Toarcian	*Callialisporites-Perinopollenites*
		Pliensbachian	*Cerebropollenites macroverrucosus*
		Sinemurian	
		Hettangian	*Pinuspollenites-Trachysporites*

Table 7. Affinity of sporomorphs to different Sporomorph EcoGroups, based on Abbink et al. (2001)

SEG	SPECIES	AFFINITY
UPLAND	Alete bisaccate pollen grains	Pteridosperms and Conifers
	Quadraeculina anellaeformis	Podocarpaceae
LOWLAND	*Calamospora* spp.	(*mesozoica*) Equisetales
	Chasmatosporites spp.	?Cycadales
	Cicatricosisporites spp.	Schizaeaceae
	Clavatipollenites spp.	?Angiospermae
	Concavisporites spp.	Matoniaceae
	Concavissimisporites spp.	?Dicksoniaceae/Cyatheaceae
	Contignisporites spp.	Pteridaceae
	Cycadopites spp.	
	Deltoidospora / Dictyophyllidites / Cyathidites spp.	Dicksoniaceae, Cyatheaceae, Dipteridaceae, Matoniaceae
	Eucommiidites troedsonii	Cycadales
	Exesipollenites spp.	Bennettitales
	Gleicheniidites spp.	Gleicheniaceae
	Impardecispora apiverrucata	?Dicksoniaceae
	Ischyosporites spp.	Schizaeaceae
	Matonispories spp.	Matoniaceae
	Monosulcites minimus	Ginkgoales
	Monosulcites spp.	Cycadales, Bennettitales
	Osmundacidites (Baculatisporites) spp.	Osmundaceae
	Perinopollenites spp.	Taxodiaceae
	Plicatella spp.	Schizaeaceae
	Punctatisporites / Todisporites spp.	Osmundaceae
	Trilobosporites spp.	?Dicksoniaceae
	Varirugosisporites spp.	?Schizaeaceae, Lygodium-type
RIVER	*Leptolepidites* spp.	Lycopodiales
	Lycopodiacidites spp.	Lycopodiales
	Neoraistrickia spp.	Lycopodiales
	Sestrosporites pseudoalveolatus	?Lycopodiales
	Staplinisporites spp.	Bryophyta and Lycopodiaceae
	Stereisporites spp.	Bryophyta
	Uvaesporites spp.	Selaginellaceae
	Vitreisporites palliadus	Caytoniales (Pteridosperms)
PIONEER	*Cerebropollenites* spp.	?Taxodiaceae
COASTAL	*Araucariacites* spp.	Araucariaceae
	Callialasporites spp.	Araucariaceae
	Corollina spp.	Cheirolepidiaceae
	Exesipollenites spp.	Bennettitales
TIDALLY-INFLUENCED	*Alisporites thomasi*	Pteridosperms
	Densoisporites spp.	Lycopodiaceae
	Retitriletes spp.	Lycopodiaceae
UNATTRIB-UTED	*Eucommiidites minor*	
	Spheripollenites spp.	Inner bodies of pollen grains from Taxodiaceae or Cheirolepidiaceae
COMMENTS	Ferns from the LOWLAND SEG may also belong to the RIVER SEG Mosses from the RIVER SEG may also belong to the LOWLAND SEG	

authors, including Ruckwied et al. (2008), Götz et al. (2009, 2011), and Kustatscher et al. (2010) have determined individual sporomorph groups by verifying their definitions and applying the Sporomorph EcoGroup model to the Triassic and Early Jurassic. In this study we also regrouped some sporomorphs on the basis of the conditions prevailing at the Triassic-Jurassic boundary (Tab. 8).

The Upland SEG is represented by bisaccate pollen grains from seed ferns and coniferous trees (Pinaceae and Podocarpaceae) and Cheirolepidiaceae. The Lowland SEG contains spores belonging to Equisetales, Lycophyta, and Pteridophyta, and pollen grains from Cycadales, Bennettitales, and Ginkgoales, as well as Coniferales (Taxodiaceae). The River SEG is comprised of Bryophyta, Lycophyta,

Table 8. Affinity of sporomorphs appearing in the investigated samples to corresponding groups in the Sporomorph EcoGroup model

SEG	SPECIES
UPLAND	*Perinopollenites elatoides* Bisaccate pollen grains *Classopollis* spp.
LOWLAND (warmer)	*Concavisporites* spp. *Cyathidites minor* *Cyathidites* spp. *Deltoidospora* spp. *Cycadopites* spp. *Eucommiidites minor* *Monosulcites* sp. *Todisporites minor*
LOWLAND (cooler)	*Concavisporites* sp. *Cyathidites* spp. *Deltoidospora* sp. *Cycadopites* sp. *Eucommiidites minor* *Monosulcites* spp.
LOWLAND (more humid)	*Chasmatosporites* sp. *Concavisporites* sp. *Cyathidites* sp. *Cycadopites* sp. *Deltoidospora* sp. *Eucommiidites minor* *Monosulcites* sp. *Perinopollenites* sp. *Todisporites minor*
RIVER	*Concavisporites* spp. *Cyathidites* sp. *Deltoidospora* sp. *Sestrosporites* sp. *Stereisporites* sp. *Todisporites minor* *Uvaesporites* sp. *Vitreisporites pallidus* *Classopollis* spp.
PIONEER	*Cerebropollenites* spp.
COASTAL	*Araucariacites* spp.
TIDALLY-INFLUENCED	*Alisporites thomasi* *Densoisporites* sp.

Pteridophyta, seed ferns, and Cheirolepidiaceae. The Pioneer SEG probably represents coniferous trees of the family Taxodiaceae, while the Coastal SEG is composed of coniferous trees of the family Araucariaceae. The Tidally-influenced SEG incorporates Lycophyta (Sellaginellaceae) and seed ferns.

When determining Sporomorph EcoGroups we omitted the presence of *Classopollis* pollen grains from the graphs because on most of the slides these grains were several times more abundant than the other sporomorphs (50–70% of all sporomorphs per sample), making it difficult to graphically depict the differences in results together. The numerical data for the Sporomorph EcoGroup graphs are given in Appendix 2.

STUDZIANNA (Fig. 5)

Groups belonging to the Upland SEG and Lowland SEG appear, but also those belonging to River and Coastal SEGs. The pollen grains most frequently appearing in these sediments are of the family Araucariaceae (*Araucariacites* sp.), which, if they occur at high frequency, are usually associated with a warm climate without wide seasonal amplitudes (Mohr 1989, Abbink 1998). Also occurring are ferns of the families Osmundaceae, Cyatheaceae, Dicksoniaceae, Schizaeaceae, and Matoniaceae, which also grow well in warm climate (Abbink 1998).

HUTA OP-1 (Fig. 6)

Groups belonging to the Upland SEG and Lowland SEG appear, but also those belonging to River and Coastal SEGs. The group of sporomorphs representing Rhaetian sediments in samples from the Huta OP-1 borehole are bisaccate pollen grains, with marked dominance of *Alisporites* spp.

The sediments of the lower Zagaje Formation are represented by the following groups of sporomorphs: *Matonisporites* sp., *Cyathidites* sp., *Vitreisporites palliadus*, *Uvaesporites* sp., and *Calamospora tener*. The upper part of the Zagaje Formation is abundant in the following sporomorphs: *Matonisporites* spp., *Monosulcites minimus*, *Chasmatosporites* sp. *Chasmatosporites apertus*, *Classopollis* sp., and *Perinopollenites elatoides*. The Skłoby Formation contains a large share of *Alisporites thomasi* pollen grains.

PRZYSUCHA P-3 (Fig. 7)

The samples taken from the Przysucha P-3 borehole present diverse environments. Groups belonging to the Upland SEG and Lowland SEG appear, but also groups belonging to River and Coastal SEGs. The shares of taxa from Coastal and Tidally-influenced SEGs are significant. The Przysucha Ore-bearing Formation, represented by the majority of the samples from the Przysucha P-3 borehole, is associated with sediments of broad bays or lakes, separated by river or delta deposits.

The Odrowąż site is represented by microflora assemblages of the kind described from the Zagaje Formation samples from the

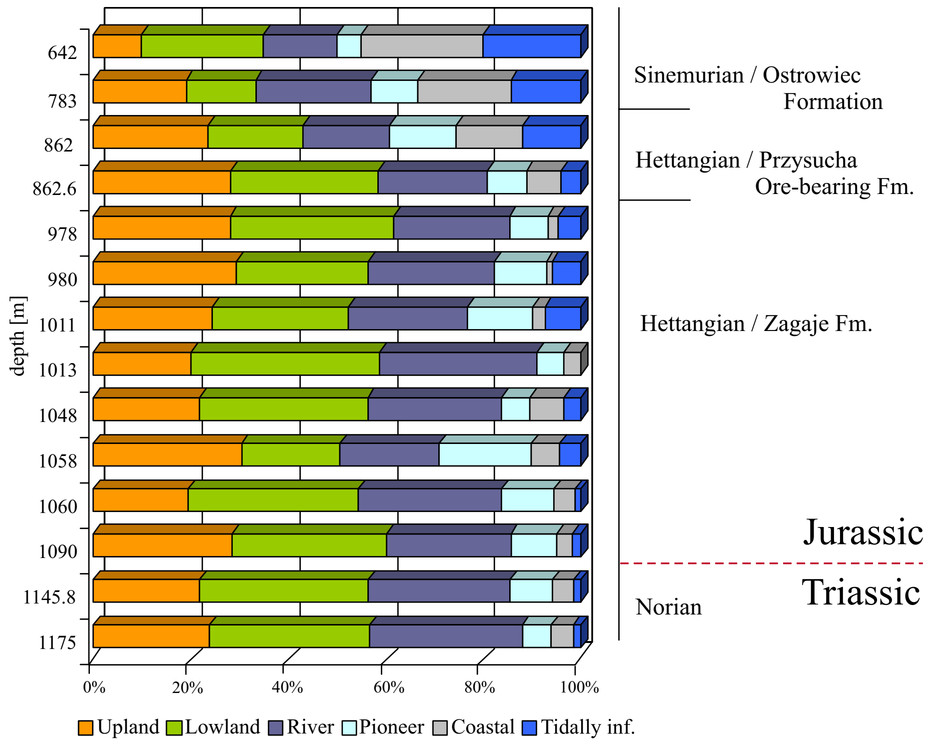

Fig. 5. Sporomorph EcoGroup analysis of samples from the Studzianna borehole

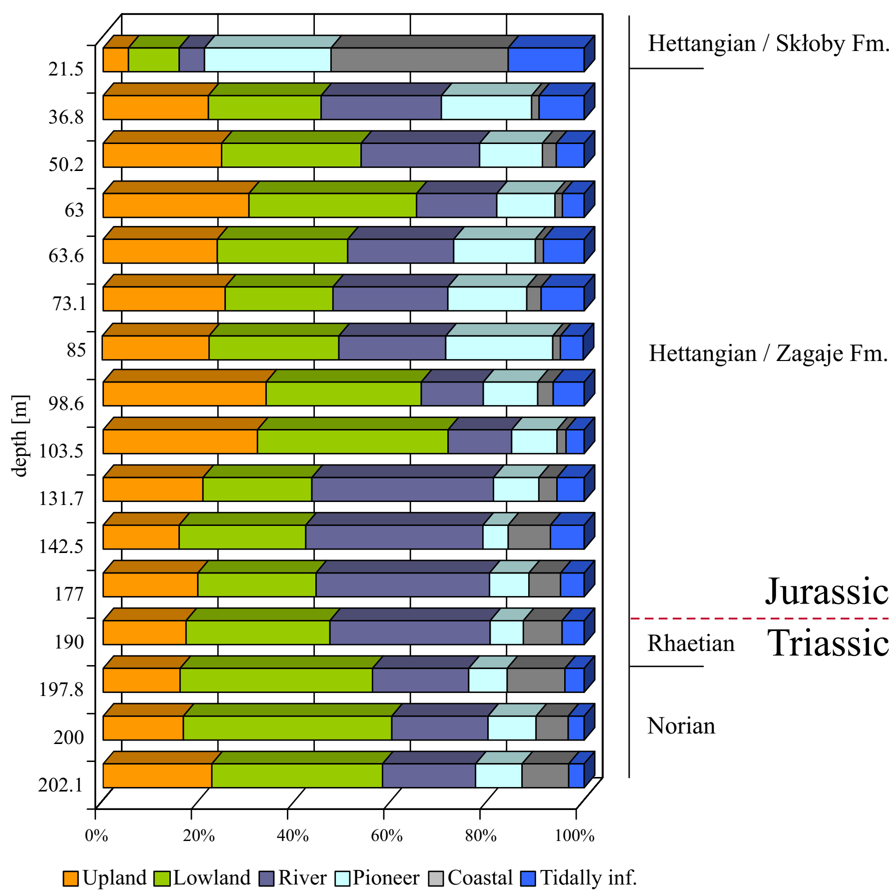

Fig. 6. Sporomorph EcoGroup analysis of samples from the Huta OP-1 borehole

Studzianna and Huta OP-1 boreholes. The number of specimens indicating given types of environment in the samples is low. They represent different types of environment (*sensu* Abbink) that existed during the Jurassic: Upland, Lowland, and River SEGs.

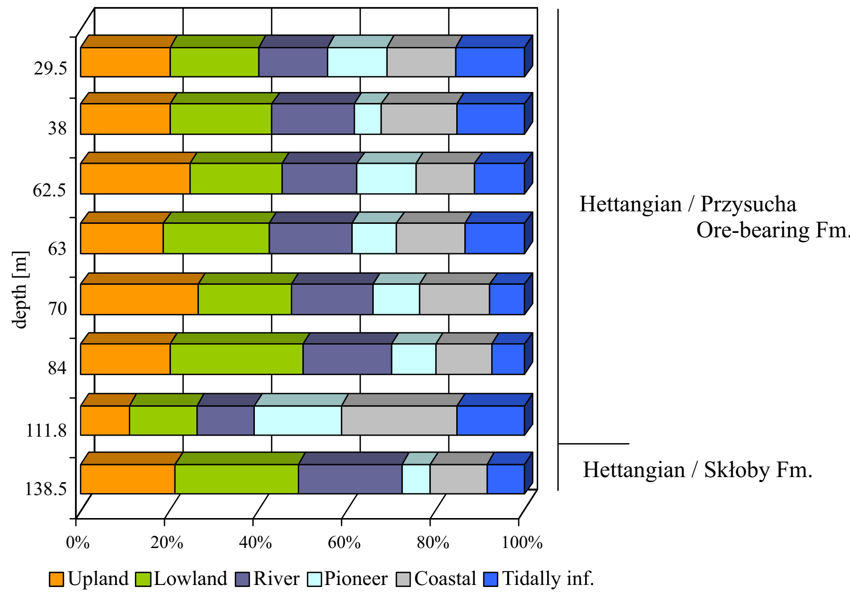

Fig. 7. Sporomorph EcoGroup analysis of samples from the Przysucha P-3 borehole

PALYNOFACIES

STUDZIANNA

In the studied samples the main assemblage comprises phytoclasts that are translucent or small and opaque (Fig. 8, Pl. 1, fig. 6). The preparations from the Studzianna profile are notable for their large shares of bisaccate pollen grains of seed ferns or coniferous plants (Fig. 9, Pl. 2).

The Przysucha Ore-bearing Formation palynofacies is rich in semi-translucent and translucent phytoclasts (Pl. 2, fig. 3), the cuticles are very well preserved, and sporomorphs are abundant (Pl. 1, fig. 5). It is built of deposits of wide shallow bays or lagoons.

The Ostrowiec Formation (Pl.1, fig. 6) shows strong terrestrial influences (Barbacka et al. 2009).

Our analysis of the material from Studzianna (Fig. 8) generally confirmed Karaszewski's (1962) conclusion that the Lower Jurassic sediments of the Holy Cross Mountains region are mainly terrestrial in nature. He identified limnic-marshy and local fluvial facies in the lowermost Jurassic sediments.

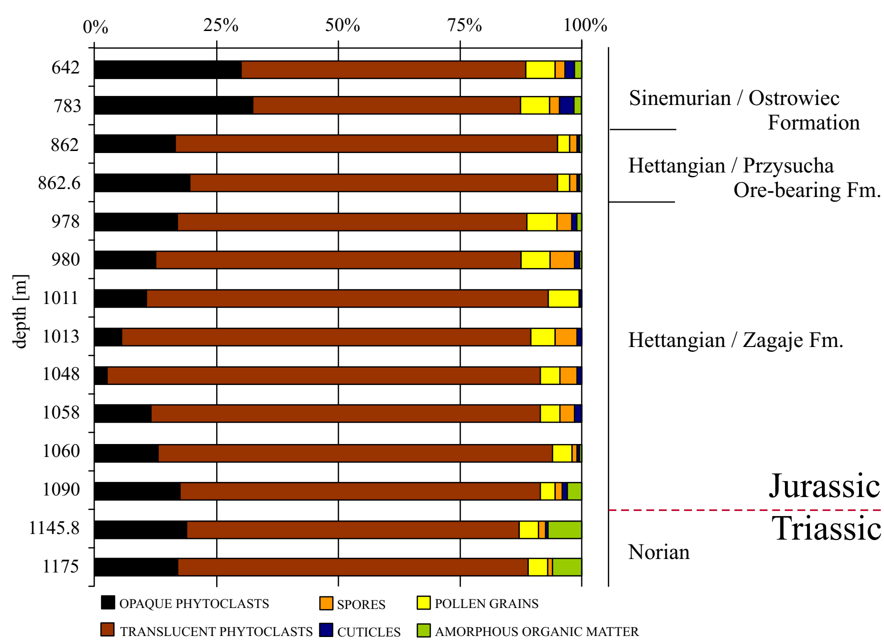

Fig. 8. Palynofacial analysis of sediments from the Studzianna borehole

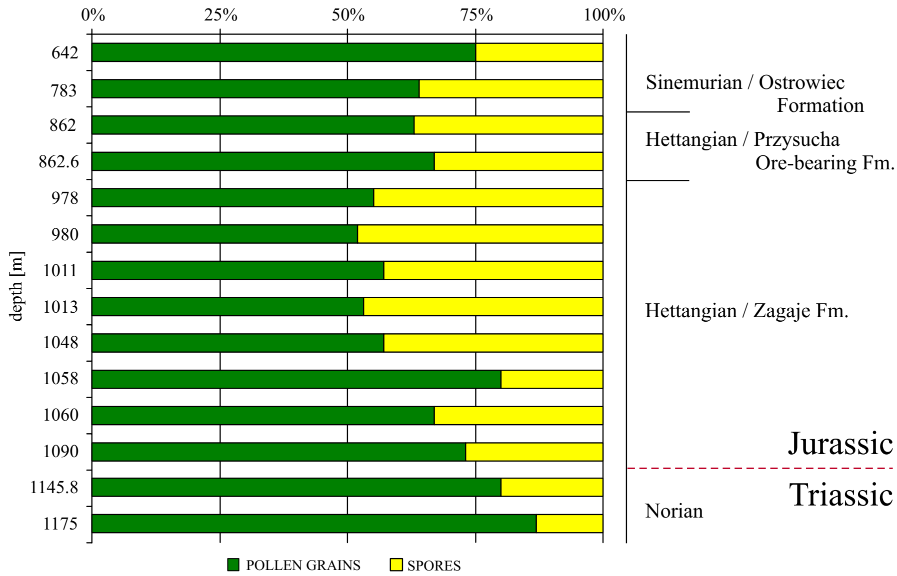

Fig. 9. Comparison of sporomorph shares in samples from the Studzianna borehole

HUTA OP-1

In the sediments from the Huta OP-1 borehole we distinguished several different palynofacies reflecting slightly differing sedimentation conditions (Fig. 10). In the samples the palynofacies are dominated by terrestrial particles. Sixteen samples taken from the borehole were used for palynofacial analyses.

Three of the samples (202.6–197 m) come from Triassic sediments. The slides from these levels contain only opaque and translucent phytoclasts, and amorphous organic matter. Sporomorphs comprise only a few percent of the total particles in those samples. These are mainly bisaccate pollen grains, including *Alisporites* sp. seed ferns (Fig. 11).

The palynofacies in the four samples taken from 190–131.7 m depth (190 m – Rhaetian–Hettangian boundary; 177 m, 142.5 m, 131.7 m – Zagaje Formation, Hettangian) comprise semi-translucent phytoclasts, opaque phytoclasts, and sporomorphs, with predominance of spores from cryptogams (Pl.1, figs 1, 3). These samples

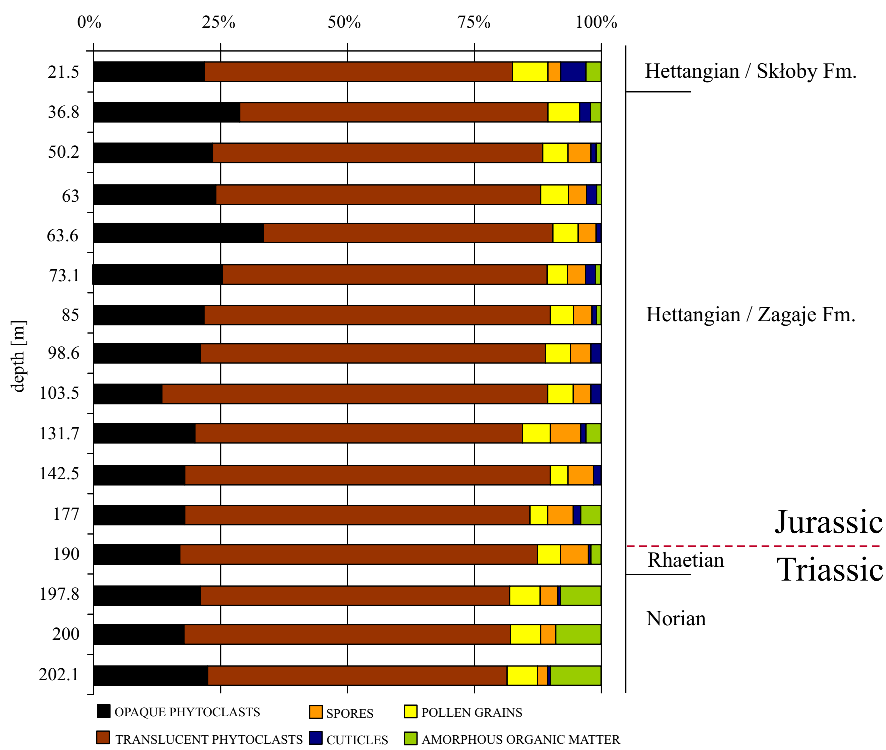

Fig. 10. Palynofacial analysis of sediments from the Huta OP-1 borehole

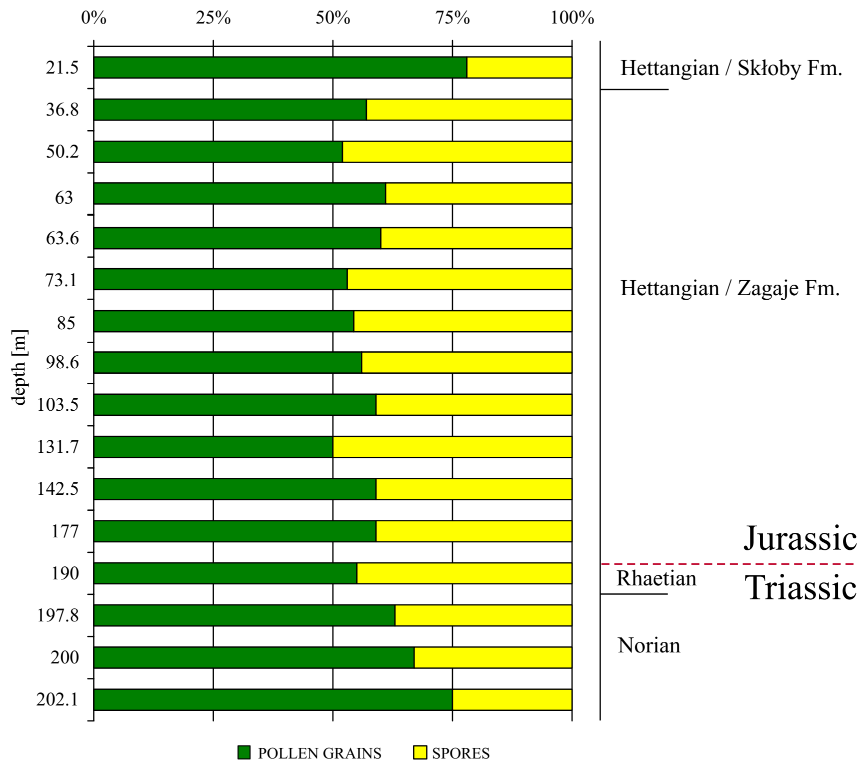

Fig. 11. Comparison of sporomorph shares in samples from the Huta OP-1 borehole

do not contain many elements but the preserved palynofacies point to a fluvial environment, in accordance with findings by Pieńkowski (2004).

In the next eight samples, from 103.5–36.8 m depth (Zagaje Formation, Hettangian), we noted translucent phytoclasts and numerous accumulated sporomorphs from ferns of the Matoniaceae family (*Matonisporites* sp.) (Pl. 1, fig. 2). Copious amounts of pollen grains from conifers are present but their diversity is low (large amount of *Classopollis* pollen grains only).

The sample from 21.5 m depth (Skłoby Formation, Hettangian) is rich in translucent phytoclasts, well-preserved cuticles and numerous sporomorphs, with predominance of bisaccate pollen grains (Fig. 11), pointing to a sedimentation environment possibly associated with a lagoon.

In the Huta OP-1 borehole sediments we distinguished several different palynofacies reflecting slightly differing sedimentation conditions (Fig. 10). In all those samples the palynofacies are dominated by terrestrial particles.

PRZYSUCHA P-3

The slides are dominated by translucent phytoclasts and also small opaque phytoclasts (Fig. 12). In all samples the frequency of sporomorphs is low, ranging from a few to a dozen or so per slide (Fig. 13, Pl. 1, fig. 4). The composition of the palynological matter from Przysucha P-3 indicates a terrestrial environment of sediment deposition.

ODROWĄŻ

The palynological organic matter contained in all the investigated samples from Odrowąż is composed mainly of terrestrial particles (Fig. 14). The manner of development of the palynofacies may indicate intensive supply of organic matter by a fluvial system from adjacent land. There are numerous pollen grains of *Classopollis* sp (Fig. 15).

COMPARISON WITH MACROFLORA

Macroflora remains were described from the Odrowąż outcrop (Reymanówna 1991a, b, 1992, Wcisło-Luraniec 1991a, 1992, Barbacka et al. 2007, 2010) and recently studied from two of the boreholes introduced in the present paper, Studzianna and Huta OP-1.

The floristic composition of these three localities based on sporomorphs differs somewhat from the composition reconstructed using macroremains. Certain groups whose occurrence was confirmed or suggested by the presence of

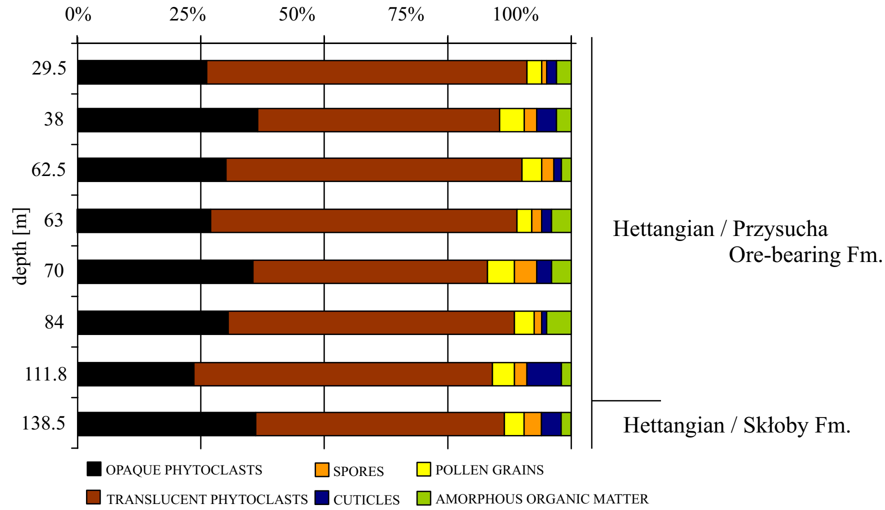

Fig. 12. Palynofacial analysis of sediments from the Przysucha P-3 borehole

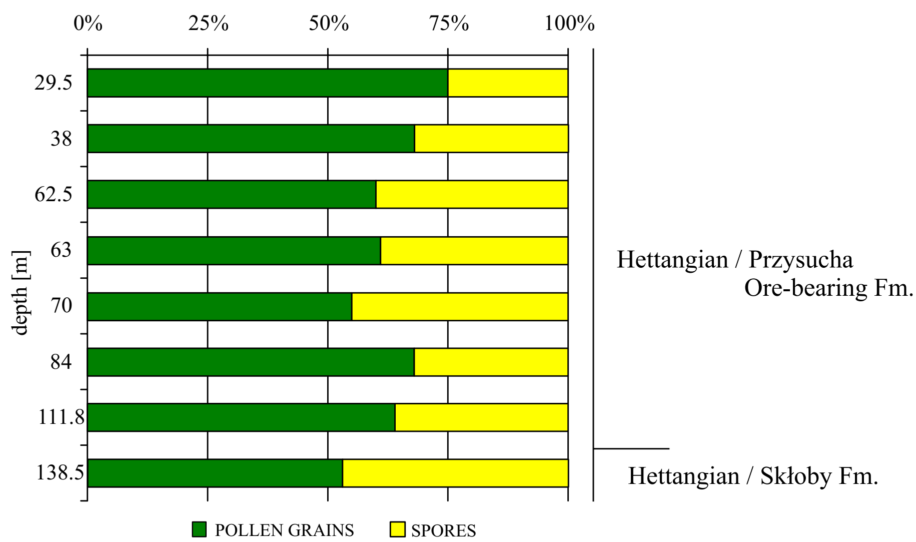

Fig. 13. Comparison of sporomorph shares in samples from the Przysucha P-3 borehole

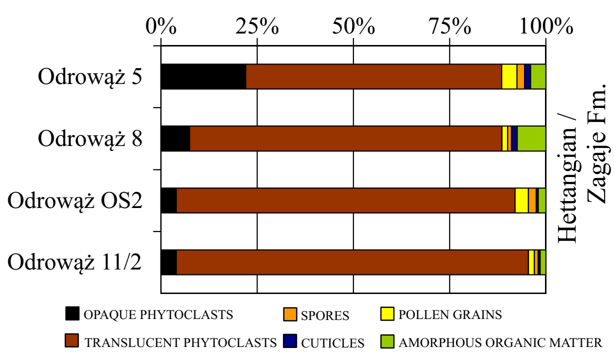

Fig. 14. Palynofacial analysis of sediments from the Odrowąż outcrop

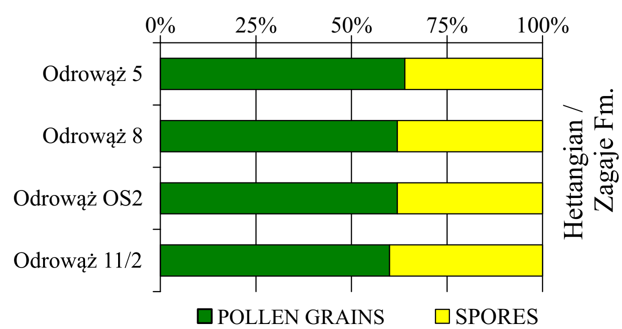

Fig. 15. Comparison of sporomorph shares in samples from the Odrowąż outcrop

spores or pollen grains were not represented by fossilised plant organs.

Generally, more taxa were indicated by pollen or spores than by macroremains (Tab. 9). Lycophyta, although videly represented in spore assemblages, were detected as macroremains only in Odrowąż, and from Selaginellaceae only spores were noted. Spores of diverse fern taxa were abundant but frond fragments were infrequent. This disparity was most conspicuous in Studzianna, where only one small fragment of *Cladophlebis* was found in the samples. Ferns were most diverse in Odrowąż, and the same was true for cycadophytes. Pollen grains

Table 9. Co-occurrence of major groups of sporomorphs and macroflora remains (+ – occurrence of sporomorphs where corresponding macroremains were absent)

Sporomorphs	Macrofossils	Studzianna borehole	Huta OP-1 borehole	Odrowąż outcrop
Sphenophyta	Sphenophyta	*Neocalamites merianii* (Brongniart) Halle *Neocalamites* sp.	*Neocalamites lehmannianus* (Goeppert) Weber *Neocalamites merianii*	*Neocalamites lehmannianus* (Goeppert) Weber *Neocalamites* sp.
Lycophyta	Lycopodiales?			*Odrolepis liassica* Barbacka and Ziaja
Osmundaceae	Osmundaceae	*Cladophlebis* sp.	*Todites princeps* (Presl) Gothan *Cladophlebis nebbensis* (Brongniart) Nathorst	*Todites princeps* (Presl) Gothan
Dipteridaceae	Dipteridaceae	+	*Thaumatopteris* sp.	*Thaumatopteris brauniana* Popp *Dictyophyllum* sp. *Goepertella microloba* (Schenk) Oishi and Yamasita
Matoniaceae	Matoniaceae	+	*Phlebopteris angustiloba* (Presl) Gothan	*Phlebopteris angustiloba* (Presl) Gothan
Dicksoniaceae	Dicksoniaceae	+	*Coniopteris hymenophylloides* (Brongniart) Seward	
Cyathaceae (possibly)	+	+	+	+
Selaginellaceae	+	+	+	+
Marattiaceae (possibly)	+	+	+	+
Pteridospermopsida	Pteridospermopsida	*Pachypteris* sp.	+	*Pachypteris lanceolata* Brongniart
Caytoniales	+	+	+	+
Cycadopsida	Cycadopsida	+	+	*Otozamites brevifolius* Braun *Pterophyllum alinae* Barbacka *Paracycas minuta* Barbacka
Ginkgophyta	Ginkgophyta	*Pseudotorellia nordenskioeldii* (Nathorst) Florin *Ginkgoites marginatus* (Nathorst) Florin *Ginkgophytes indet.* *Phoenicopsis insolita* Nosova et Kiritchkova *Czekanowskia hartzii* Harris *Czekanowskia rigida* Heer	*Baiera furcata* (Lindley and Hutton) Braun *Baiera* sp. *Pseudotorellia* sp. *Ixostrobus groenlandicus* Harris	*Schmeissneria microstachys* (Presl) Kirchner and van Konijnenburg- van Cittert
	Gnetopsida			*Piroconites kuespertii* Gothan
Coniferophyta	Coniferophyta	+	*Podozamites distans* (Presl) Braun *Brachyphyllum* sp.	*Podozamites schenkii* Heer *Podozamites* sp. *Swedenborgia* sp. *Hirmeriella muensteri* (Schenk) Jung
	Coniferophyta *incertae sedis*		*Desmiophyllum* sp. nov.	

of this group were noted from all localities but leaf fragments were found only in material from Odrowąż. *Vitreisporites pallidus*, indicating the presence of Caytoniales, is common in material from all localities but macrofossils from this group are entirely lacking.

Pollen grains belonging to coniferophytes are very abundant, particularly those of the genus *Classopollis*, but specimens of *Hirmeriella muensteri* are known only from Odrowąż.

The disparity between sporomorph diversity and macroremains diversity may be explained by differences in preservation and in the dispersal pathways between sporomorphs and macroremains. Sporomorphs are produced in huge amounts and are more resistant in sediments. They are dispersed differently and can be transported over much longer distances.

Plant organs fossilise in a narrower range of circumstances than sporomorphs are. Sometimes they are not preserved because of their fine structure (e.g. Selaginellaceae or fine ferns). Sometimes their environment does not promote fossilisation and their presence in a given territory will be detected only by their spores or pollen grains. Sporomorphs, on the other hand, can be transported by water and wind far from their natural sites, so their presence is not absolute proof of the plant composition of a locality.

DISCUSSION AND CONCLUSIONS

The palynofacies from the Upper Triassic in the investigated area are terrestrial in nature. Some sporomorph habitats representing the Lowland SEG are associated with vegetation that may have overgrown riverbanks (River SEG). The determined sporomorph types indicate a warm environment. At the end of this period the climate changed, becoming more humid.

The palynofacies of the Lower Jurassic sediments are also terrestrial in nature. The spores and pollen grains represent various plant groups: Bryophyta, Sphenophyta, Lycophyta, Pteridophyta, Pteridospermophyta, Cycadophyta or Ginkgophyta, and Coniferophyta. They correspond to the different types of environment (*sensu* Abbink 1998) that existed during the Jurassic, and they were associated with upland terrain as well as lowland terrain with a developed river network (Upland SEG, Lowland SEG, River SEG). The occurrence of spores representing the fern families Matoniaceae and Schizaeaceae suggests a warm and rather humid climate.

The lower part of the Zagaje Formation is associated with an environment of river valleys covered with low- and high-growing vegetation. The upper part of this formation represents a deltaic environment.

The Skłoby Formation (Lower–Middle Hettangian) has a palynofacies rich in semi-translucent phytoclasts, well-preserved cuticles, and abundant sporomorphs, with bisaccate pollen grains dominant.

The Przysucha Ore-bearing Formation has a palynofacies of shallow sediments and broad bays or lagoons divided by sandy deposits of deltas, barriers, and rivers. Translucent phytoclasts clearly predominate but are clumped in agglomerates together with black phytoclasts; this is typical of sediments subject to variable irrigation.

The samples from the Ostrowiec Formation (Sinemurian) taken from the Studzianna borehole are rich in fine dispersed organic particles. The sporomorphs are abundant but poorly preserved. There are similar shares of Sporomorph EcoGroups representing all the habitats.

The data from palynological analyses of the early Jurassic samples show dominance of plants of the orders Cycadales and Coniferales. These plants apparently constituted the upper stories of forest. The ferns and tree ferns having sporomorphs in the sediments probably were elements of the forest undergrowth, as they are in modern subtropical forests.

In the Zagaje Formation, *Classopollis* sp. pollen grains are the dominant element in all of the samples, appearing in huge amounts (ca 70% of all sporomorphs per sample). These grains were produced by, for example, *Hirmeriella*, an extinct plant of the order Coniferales, family Cheirolepidiaceae. Among modern plants there is no equivalent of the kind of pollen grain construction found in *Classopollis*. Its small size suggests anemophily, but the retention of grains in tetrads may also have some connection with entomophily (Alvin 1982). The *Classopollis* pollen grains we studied belong to the River SEG, because *Hirmeriella* may have formed humid dense forest along the river bank (Barbacka et. al. 2007, 2010), or to the Upland SEG. Since their manner of dispersal has not been clarified, it is not possible to determine what percentage of the *Classopollis* pollen grains in our samples correspond to vegetation growing at the investigated sites. However, the presence of these pollen grains in every sample suggests that Cheirolepidiaceae formed one of the main components of the flora of the investigated periods, especially the Lower Jurassic.

The appearance of *Classopollis* pollen in the Rhaetian sediments indicates relatively moderate climate (Vakhrameev 1981, Barrón et al. 2006). An increase in the number of trilete spores at the Triassic-Jurassic boundary is interpreted as indicating a rise in humidity. This accords with geochemical evidence for a rise in humidity occurring at the Triassic-Jurassic boundary (Cohen & Coe 2002, 2007, Götz et al. 2009).

The drill cores (Studzianna, Huta OP-1) are incomplete in the transition sediments (there is a gap), and the sampling distances were large. Our analyses showed little difference in the sporomorph composition of the collected samples. The only notable feature is an increase in *Classopollis* pollen grain content in the samples from Zagaje Formation sediments, characteristic of the transition period. The sporomorphs from the Lower Jurassic sediments (Zagaje, Skłoby and Przysucha Ore-bearing formations) are similar in composition to the kind of sporomorphs described for the *Pinuspollenites-Trachysporites* Zone by Dybkjær (1988) and by Koppelhus and Batten (1996) between the Triassic and Jurassic.

We applied the Sporomorph EcoGroup (SEG) model (Abbink 1998) to characterise the ecological plant assemblages. The most frequently occurring sporomorphs were assigned to Upland, Lowland and River SEGs. Stratigraphical changes in each of the SEGs indicate differences in climatic conditions.

The floristic composition of the Studzianna, Huta and Odroważ localities based on sporomorphs differs somewhat from the composition reconstructed from macroremains, probably due to differences in dispersal pathways and preservation.

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REFERENCES

ABBINK O.A. 1998. Palynological investigations in the Jurassic of the North Sea region. LPP Contrib. Ser., 8: 1–192.

ABBINK O.A., TARGARONA J., BRINKHUIS H. & VISSCHER H. 2001. Late Jurassic to earliest Cretaceous palaeoclimatic evolution of the Southern North Sea. Global Planet. Change, 30: 231–256.

ABBINK O.A., van KONIJNENBURG-van CITTERT J.H.A., van der ZWAN C.J. & VISSCHER H. 2004. Application of a Sporomorph Ecogroup Model to an Example from the Northwest European Upper Jurassic. Neth. J. Geosci., 83: 17–38.

ALVIN K.L. 1982. Cheirolepidiaceae: Biology, structure and palaeoecology. Rev. Palaeobot. Palynol., 37(1): 71–98.

BALME B.E. 1995. Fossil *in situ* spores and pollen grains: an annotated catalogue. Rev. Palaeobot. Palynol., 87(2–4): 81–323.

BARBACKA M., ZIAJA J. & WCISŁO-LURANIEC E. 2010. Taxonomy and palaeoecology of the Early Jurassic macroflora from Odrowąż, central Poland. Acta Geol. Pol., 60(3): 373–392.

BARBACKA M., ZIAJA J., WCISŁO-LURANIEC E. & REYMANÓWNA M. 2007. *Hirmeriella muensteri* (Schenk) Jung from Odrowąż (Poland), with female and male cones and *in situ Classopollis* pollen grains. Acta Palaeobot., 47(2): 339–357.

BARBACKA M., FELDMAN-OLSZEWSKA A., JARZYNKA A., KRUPNIK J., OCIEPA A.M., WCISŁO-LURANIEC E. & ZIAJA J. 2009. Wstępne wyniki badań paleobotanicznych wiercenia Studzianna (trias-jura) z północnego obrzeżenia Gór Świętokrzyskich. Geologia, Kwartalnik Akademii Górniczo-Hutniczej w Krakowie, 35(3/1): 17–19.

BARRÓN E., GÓMEZ J.J., GOY A. & PIEREN A.P. 2006. The Triassic–Jurassic boundary in Asturias (northern Spain): Palynological characterisation and facies. Rev. Palaeobot. Palynol., 138: 187–208.

BATTEN D.J. 1973. Use of palynologic assemblage-types in Wealden correlation. Palaeontology, 16: 1–40.

BATTEN D.J. 1982. Palynofacies, palaeoenvironment and petroleum. J. Micropaleontol., 1: 107–114.

BATTEN D.J. 1996. Palynofacies and palaeoenvironmental interpretation: 1011–1064. In: Jansonius J. & McGregor D.C. (eds), Palynology: principles and applications, vol. 3. American Association of Stratigraphic Palynologists Foundation, Salt Lake City.

BOCHEŃSKI T. 1957. Tymczasowa wiadomość o występowaniu formy roślinnej typu *Glossopteris*: *Glossopteridium J. Czarnockii* n. sp. – w pstrym piaskowcu w otworze Radoszyce 3. In: Łotocka Z. (ed.), Wyniki wiercenia Radoszyce 3. Biul. Inst. Geol., 124: 181–184.

BRAŃSKI P. 2009a. Epizody intensywnego wietrzenia chemicznego zapisane w profilach hetangu z obrzeżenia Gór Świętokrzyskich (wyniki nowych badań). Geologia, Kwartalnik Akademii Górniczo-Hutniczej w Krakowie, 35(3/1): 21–30.

BRAŃSKI P. 2009b. Influence of palaeoclimate conditions and greenhouse effect on the Hettangian clay mineral assemblages (Holy Cross Mts area, Polish Basin). Geol. Quart., 53(3): 363–368.

BRAŃSKI P. 2011. Skład minerałów ilastych w osadach triasu i jury basenu polskiego – zapis zmian paleoklimatu i paleośrodowiska (summary: Clay mineral composition in the Triassic and Jurassic deposits from the Polish Basin – a record of palaeoclimatic and palaeoenvironmental changes). Biul. Państw. Inst. Geol., 444: 15–32.

CHALONER W.G. & MUIR M. 1968. Spores and Floras: 127–146. In: Murchinson D.G. (ed.), Coal and Coal-bearing strata. Oliver and Boyd, Edinburgh.

COHEN A.S. & COE A.L. 2002. New geochemical evidence for the onset of volcanism in the Central Atlantic magmatic province and environmental change at the Triassic-Jurassic boundary. Geology, 30: 267–270.

COHEN A.S. & COE A.L. 2007. The impact of the Central Atlantic Magmatic Province on climate and on the Sr- and Os-isotope evolution of seawater. Palaeogeogr., Palaeoclim., Palaeoecol., 244: 374–390.

COOKSON I.C. 1947. Plant fossils from the lignites of the Kerguelen Archipelago. British, Australian and New Zealand Antarctic Research Expedition (1929–31) report, A2: 129–142.

COUPER R.A. 1953. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. New Zealand Geol. Surv., Paleontol. Bull., 22: 1–77.

COUPER R.A. 1958. British Mesozoic microspores and pollen grains. A systematic and stratigraphic study. Palaeontographica, B, 103: 75–179.

CZAPOWSKI G. & ROMANEK A. 1986. Litostratygrafia i środowisko sedymentacji osadów górnego triasu w rejonie Chmielnika. Prz. Geol., 11: 635–643.

CZARNOCKI J. 1923. Cechsztyn w Górach Świętokrzyskich. Spraw. Państw. Inst. Geol., 2 (1, 2): 151–191.

CZARNOCKI J. 1925. Wyniki badań geologicznych dokonanych w r. 1924 na obszarze mezozoicznym zachodniej części Gór Świętokrzyskich. Posiedz. Nauk. Państw. Inst. Geol., 11: 11–14.

CZARNOCKI J. 1926. Wyniki badań geologicznych w południowo-zachodniej części Gór Świętokrzyskich. Posiedz. Nauk. Państw. Inst. Geol., 15: 31–37.

CZARNOCKI J. 1950. Wyniki poszukiwań barytu w Strawczynku Nowym w Górach Świętokrzyskich w 1937 r. Biul. Inst. Geol., 9: 23–36.

CZARNOCKI J. 1958. Prace geologiczne. Surowce mineralne w Górach Świętokrzyskich z. 3. Surowce Skalne t. 5. Prace Inst. Geol., 21: 21–159.

DADLEZ R. 1964. Zarys stratygrafii liasu w Polsce Zachodniej i jego korelacje z liasem Polski środkowej. Kwart. Geol., 8(1): 122–144.

DADLEZ R. 1969. Stratygrafia liasu w Polsce zachodniej. Pr. Inst. Geol, 57: 1–92.

DADLEZ R. & KOPIK J. 1972. Wybrane problemy stratygrafii i sedymentacji liasu między Świnoujściem a Gryficami. Kwart. Geol., 16(3): 620–636.

DECZKOWSKI Z. 1997. Noryk i retyk. Sedymentacja, paleogeografia i paleotektonika: 187–194. In: Marek S. & Pajchlowa M. (eds), Epikontynentalny perm i mezozoik w Polsce (summary: The Epicontinental Permian and Mesozoic in Poland). Pr. Inst. Geol., 153.

DYBKJÆR K. 1988. Palynological zonation and stratigraphy of the Jurassic section in the Gassum No. 1-borehole, Denmark. Danm. Geol. Undersøg. Serie A, 21: 1–73.

FEIST-BURKHARDT S., GÖTZ A.E., SZULC J., BORKHATARIA R., GELUK M., HAAS J., HORNUNG J., JORDAN P., KEMPF O., MICHALIK J., NAWROCKI J., REINHARDT L., RICKEN W., RÖHLING H.G., RÜFFER T., TÖRÖK A. & ZÜHLKE R. 2008. Triassic: 749–821. In: McCann T. (ed.), The Geology of Central Europe. Geological Society, London.

FIJAŁKOWSKA A. 1988a. Wyniki badań sporowo-pyłkowych w profilu wiertniczym Mniszków IG 1. Kwart. Geol., 32(3, 4): 751.

FIJAŁKOWSKA A. 1988b. Wyniki badań sporowo-pyłkowych w profilu wiertniczym Studzianna IG 2. Kwart. Geol., 32(3, 4): 757–758.

FIJAŁKOWSKA A. 1989a. Badania sporowo-pyłkowe osadów dolnego liasu w profilu Skarżysko-Kamienna IG 1. Kwart. Geol., 33(2): 199–208.

FIJAŁKOWSKA A. 1989b. Nowe dane o palinostratygrafii osadów górnego triasu w północno-zachodniej części Gór Świętokrzyskich. Prz. Geol., 5: 252–256.

FIJAŁKOWSKA A. 1991. Występowanie mikroflory w profilu wiertniczym Nieświń PIG 1 (północno-zachodnie obrzeżenie Gór Świętokrzyskich). Kwart. Geol., 35(4): 521–522.

FIJAŁKOWSKA A. 1992. Palynostratigraphy of the Keuper and Rhaetic in north-western margin of the Holy Cross Mts. Kwart. Geol., 36(2): 199–220.

FUGLEWICZ R. 1973. Megaspores of Polish Buntersandstein and their stratigraphical significance. Acta Palaeont. Pol., 18: 401–453.

FUGLEWICZ R. 1977. New species of megaspores from the Triassic of Poland. Acta Palaeont. Pol., 22(4): 405–431.

FUGLEWICZ R. 1980. Stratigraphy and palaeogeography of Lower Triassic in Poland on the basis of megaspores. Acta Geol. Pol., 30: 417–470.

GEDL P. & ZIAJA J. 2004. Wstępne wyniki badań palinologicznych górnojurajskich utworów z florą z Wólki Bałtowskiej (NE obrzeżenie Gór Świętokrzyskich, Polska). Tomy Jurajskie, 2: 49–59.

GIERLIŃSKI G. & PIEŃKOWSKI G. 1999. Dinosaur track assemblages from the Hettangian of Poland. Kwart. Geol., 43: 329–346.

GÖTZ A.E., RUCKWIED K. & BARBACKA M. 2011. Palaeoenvironment of the Late Triassic (Rhaetian) and Early Jurassic (Hettangian) Mecsek Coal Formation (south Hungary): implications from macro- and microfloral assemblages. Palaeobio. Palaeoenv., 91(2): 75–88.

GÖTZ A.E., RUCKWIED K., PÁLFY J. & HAAS J. 2009. Palynological evidence of synchronous changes within the terrestrial and marine realm at the Triassic/Jurassic boundary (Csővár section, Hungary). Rev. Palaeobot. Palynol., 156(3, 4): 401–409.

GRABOWSKA I. 1962. (unpubl.) Opracowanie liasowej flory makroskopowej z rejonu Rozwad oraz z dwóch innych miejscowości z pn. obrzeżenia Gór

Świętokrzyskich (Rząd Ginkgoales). Archives of the Polish Geological Institute, Warszawa.

HOPKINS J.A. & MCCARTHY F.M.G. 2002. Post-depositional palynomorph degradation in Quaternary shelf sediments: a laboratory experiment studying the effects of progressive oxidation. Palynology, 26: 167–184.

JURKIEWICZOWA I. 1947. Uwagi na temat budowy geologicznej Majkowa, na wschód od Skarżyska-Kamiennej (summary: Remarks on the geological structure of the Majków region, east of Skarżysko-Kamienna, central Poland). Biul. Państw. Inst. Geol., 31: 92–103.

JURKIEWICZOWA I. 1967. Lias zachodniego obrzeżenia Gór Świętokrzyskich i jego paralelizacja z liasem Wyżyny Krakowsko-Częstochowskiej. Biul. Państw. Inst. Geol., 200: 5–132.

KARASZEWSKI W. 1947. Sprawozdanie z badań nad utworami retyko-liasu w rejonie na zachód od Skarżyska w 1946r. (summary: Report on Rhaetico-Lias deposits in the region west of Skarżysko (Central Poland) in 1946). Biul. Państw. Inst. Geol., 31: 70–89.

KARASZEWSKI W. 1949. Sprawozdanie z badań geologicznych na wschód od Skarżyska-Kamiennej w lecie 1947r. Biul. Państw. Inst. Geol., 54.

KARASZEWSKI W. 1960. Nowy podział liasu świętokrzyskiego (summary: New division of the Święty Krzyż Lias). Kwart. Geol., 4(4): 899–920.

KARASZEWSKI W. 1962. Stratygrafia liasu w północnym obrzeżeniu Gór Świętokrzyskich (summary: The stratigraphy of the Lias in the northern Mesozoic zone surrounding the Święty Krzyż Mountains (Central Poland). Pr. Inst. Geol., 30(3): 333–416.

KARASZEWSKI W. & KOPIK J. 1970. Jura dolna (summary: Lower Jurassic). In: The Stratigraphy of the Mesozoic in the margin of the Góry Świętokrzyskie. Pr. Państw. Inst. Geol., 56: 65–98.

KEMP E.M. 1970. Aptian and Albian miospores from southern England. Paleontographica, B, 131(1–4): 73–143.

KOPPELHUS E.B. & BATTEN D.J. 1996. Applications of a palynomorph zonation to a series of short borehole sections, Lower to Middle Jurassic, Øresund, Denmark: 779–793. In: Jansonius J. & McGregor D.C. (eds), Palynology: principles and applications, vol. 2. American Association of Stratigraphic Palynologists Foundation, Salt Lake City.

KOWALCZEWSKI B. 1926. O wapieniu muszlowym na zboczu południowym Gór Świętokrzyskim między rz. Łośnią a Czarną Nidą (summary: Sur le Muschelkalk du versant méridional du Massif de Święty Krzyż entre la Łośnia et la Czarna Nida). Spraw. Państw. Inst. Geol., 3(3, 4): 468–492.

KOZYDRA Z. 1968. Złoża dolnojurajskich iłów ogniotrwałych na tle budowy geologicznej północnego obrzeżenia Gór Świętokrzyskich. Biul. Inst. Geol., 216: 5–94.

KRUPNIK J. 2011. Porównanie metod przygotowania próbek do analiz palinologicznych (mezozoik): 24. In: Jarzynka A., Jurochnik A., Krupnik J. & Olejniczak P. (eds), III Konferencja Naukowa Młodzi w Paleontologii, 13–14.05.2011, Kraków.

KRUPNIK J., ZIAJA J. & FELDMAN-OLSZEWSKA A. 2011. Wstępne wyniki badań palinologicznych wiercenia Huta OP-1 (trias-jura) z północnego obrzeżenia Gór Świętokrzyskich: 110–111. In: Matyja B.A., Wierzbowski A. & Ziółkowski P. (eds), Jurassica IX, Materiały konferencyjne, Abstrakty, Małogoszcz, 06–08.09.2011. Polskie Towarzystwo Geologiczne, Polska Grupa Robocza Systemu Jurajskiego.

KUSTATSCHER E., Van KONIJNENBURG-Van CITTERT J.H.A. & ROGHI G. 2010. Macrofloras and palynomorphs as possible proxies for palaeoclimatic and palaeoecological studies: A case study from the Pelsonian (Middle Triassic) of Kühwiesenkopf/ Monte Prà della Vacca (Olang Dolomites, N-Italy). Palaeogeogr., Palaeoclim., Palaeoecol., 290: 71–80.

KÜRSCHNER W.M. & HERNGREEN W.G.F. 2010. Triassic palynology of central and northwestern Europe: a review of palynofloral diversity patterns and biostratigraphic subdivisions: 263–283. In: Lucas S.G. (ed.) The Triassic Timescale. Geological Society, Special Publications: 334, London.

LESCHIK G. 1955. Die Keuperflora von Neuewelt bei Basel. II. Die Iso- und Mikrosporen. Schw. Palaeontol. Abh., 72: 1–70.

LUND J. 1977. Rhaetic to Lower Liassic palynology of the onshore south-eastern North Sea Basin. Danm. Geol. Undersøg. II. Række, 109: 129.

MAKAREWICZÓWNA A. 1928. Flora dolno-liasowa okolic Ostrowca (summary: Étude sur la flore fos sile du lias inférieur des environs d'Ostrowiec). Prace Towarzystwa Przyjaciół Nauk w Wilnie, Wydział Nauk Matematycznych i Przyrodniczych, Prace Zakładu Geologicznego Uniwersytetu St. Batorego w Wilnie (Travaux de la Société des Science et des Letters de Wilno, Travaux de L'Institut de Géologie de l'Université de Wilno), 4(3): 1–49.

MAMCZAR J. 1971. Importance of Megaspores in Stratigraphy of Epicontinental Rhaetic and Liassic Deposits in Poland. Memories, BRGM Colloque du Jurassique (Luxemburg, 1967), (75): 193–198.

MARCINKIEWICZ T. 1957. Liasowe megaspory z Praszki, Zawiercia i Gór Świętokrzyskich (summary: Megaspores of the Lias from Praszka, Zawiercie and the Święty Krzyż Mountains). Kwart. Geol., 1(2): 299–302.

MARCINKIEWICZ T. 1959 (unpubl.) Badania metodą analizy megasporowej osadów liasu z obszaru koneckiego. Archives of the Polish Geological Institute, Warszawa.

MARCINKIEWICZ T. 1961. Wyniki badań megasporowych liasu w otworze wiertniczym Gorzów Wielkopolski. Kwart. Geol., 4(3): 938–939.

MARCINKIEWICZ T. 1966 (unpubl.) Stratygrafia retyku i liasu w Polsce (z wyjątkiem Karpat) na podstawie badań megasporowych. Archives of the Polish Geological Institute, Warszawa.

MARCINKIEWICZ T. 1971. The stratigraphy of the Rhaetian and Lias in Poland based on megaspore investigations. Pr. Państw. Inst. Geol., 65: 1–58.

MARCINKIEWICZ T., ORŁOWSKA T. & ROGALSKA M. 1960. Wiek warstw helenowskich górnych (lias) w przekroju geologicznym Gorzów Śląski-Praszka w świetle badań mega- i mikrosporowych (summary: Age of upper Helenów beds (Lias) in view of mega- and microspore investigations geological section Gorzów Śląski-Praszka). Kwart. Geol., 4(2): 386–398.

MICHALSKI A. 1884. Badania geologiczne, dokonane w 1883 roku w północno-zachodniej części Guberni radomskiej i kieleckiej. Pam. Fizjogr., 4.

MICHALSKI A. 1888. Sprawozdanie przedwstępne z badań dokonanych w południowej części Guberni radomskiej. Pam. Fizyjogr., 8.

MOHR B.A.R. 1989. New palynological information on the age and environment of the Late Jurassic and Early Cretaceous vertebrate localities of the Iberian Peninsula (eastern Spain and Portugal). Berliner Geowiss. Abh., 106: 291–301.

NILSSON T. 1958. Über das Vorkommen eines mesozoischen Sapropelgesteins in Schonen. Publ. Inst. Mineral., Palaeont. Quatern. Geol., Univ. Lund, 53: 1–112.

ORŁOWSKA-ZWOLIŃSKA T. 1960. (unpubl.). Wiek serii zagajskiej (dolna jura) w północnym obrzeżeniu Gór Świętokrzyskich w świetle badań sporowo-pyłkowych. Archives of the Polish Geological Institute, Warszawa.

ORŁOWSKA-ZWOLIŃSKA T. 1962. Granica między retykiem a liasem w świetle dotychczasowych badań mikroflorystycznych. Kwart. Geol., 6(4): 729–730.

ORŁOWSKA-ZWOLIŃSKA T. 1983. Palinostratygrafia epikontynentalnych osadów wyższego triasu w Polsce (summary: Palynostratigraphy of the upper part of Triassic epicontinental sediments in Poland). Pr. Inst. Geol., 104: 1–89.

ORŁOWSKA-ZWOLIŃSKA T. 1985. Palynological zones of the Polish epicontinental Triassic. Bull. Pol. Acad. Sci., Earth Sci., 33(3, 4): 107–117.

PACYNA G. 2013. Critical review of research on the Lower Jurassic flora of Poland. Acta Palaeobot., 53(2): 141–163.

PACYNA G. 2014. Plant remains from the Polish Triassic. Present knowledge and future prospects. Acta Palaeobot., 54(1): 3–33.

PAUTSCH M.E. 1958. Keuper sporomorphs from Świerczyna, Poland. Microplaeont., 4(3): 321–325.

PAUTSCH M.E. 1971. Sporomorphs of the Upper Triassic from a borehole at Trzciana near Mielec (S Poland) (summary: Sporomorfy górnego triasu z wiercenia w Trzcianie koło Mielca). Acta Palaeobot., 12(1): 1–59.

PAUTSCH M.E. 1973. Upper Triassic spores and pollen from the Polish Carpathian Foreland. Micropaleont., 19(2): 129–149.

PIEŃKOWSKI G. 1983. Środowiska sedymentacyjne dolnego liasu północnego obrzeżenia Gór Świętokrzyskich (summary: Early Lias sedimentary environments at northern margin of the Holy Cross Mts). Prz. Geol., 31(4): 223–230.

PIEŃKOWSKI G. 1991. Eustatically-controlled sedimentation in the Hettangian-Sinemurian (Early Jurassic) of Poland and Sweden. Sedimentology, 38: 503–518.

PIEŃKOWSKI G. 1998. Dinosaur nesting ground from the Early Jurassic fluvial deposits, the Holy Cross Mountains (Poland). Kwart. Geol., 42(4): 461–476.

PIEŃKOWSKI G. 2004. The epicontinental Lower Jurassic of Poland. Pol. Geol. Inst. Special Papers, 12: 1–154.

PIEŃKOWSKI G. & GIERLIŃSKI G. 1987. New finds of dinosaur footprints in Liassic of the Holy Cross Mountains and its palaeoenvironmental background. Przegl. Geol., 35(4): 199–205.

PIEŃKOWSKI G., NIEDŹWIEDZKI G. & WAKSMUNDZKA M. 2011. Sedimentological, palynological and geochemical studies of the terrestrial Triassic-Jurassic boundary in north-western Poland. Geol. Magazine, 149: 308–332.

PIEŃKOWSKI G., SCHUDACK M.E., BOSAK P., ENAY R., FELDMAN-OLSZEWSKA A., GOLONKA J., GUTOWSKI J., HERNGREEN G.F.W., JORDAN P., KROBICKI M., LATHUILIERE B., LEINFELDER R.R., MICHALIK J., MONNING E., NOE-NYGAARDN., PALFY J., PINT A., RASSER W., REISDORF A.G., SCHMID D.U., SCHWEIGERT G., SURLYK F., WETZEL A. & WONG T.E. 2008. Jurassic: 823–922. In: McCann T. (ed.), The Geology of Central Europe, vol 2. Geol. Soc., London.

POŻARYSKI W. 1974. Budowa geologiczna Polski. T. IV, cz.1, Niż Polski. Wyd. Geol. Warszawa.

PUSCH G.G. 1831–1836. Geognostische Beschreibung von Polen so wie der übrigen Nordkarpathen-Ländern. I (1831), II (1836). J. G. Cotta Buchh., Stuttgart u. Tübingen.

PUSCH G.G. 1836. Geognostische Beschreibung von Polen. T. II. J. G. Cotta Buchh., Stuttgart u. Tübingen.

PUSCH G.G. 1837. Polens Palaontologie oder Abbildung und Beschreibung der vorzuglichsten und noch unbeschriebenen Petrefakten aus der Gebirgsformation in Polen, Volhynien und den Karpathen. E. Schweizerbart's Verlagshandlung, Stuttgart.

RACIBORSKI M. 1891. Flora retycka północnego stoku Gór Świętokrzyskich. Rozpr. Wydz. Mat.-Przyr. Akad. Umiej., 23: 292–326.

RACIBORSKI M. 1892. Przyczynek do flory retyckiej Polski. Rozpr. Wydz. Mat.-Przyr. Akad. Umiej., 22: 345–360.

REISSINGER A. 1950. Die „Pollenanalyse" ausgedehnt auf alle Sedimentgesteine der geologischen Vergangenheit. Zweiter Teil. Palaeontographica B, 90 (4, 5, 6): 99–126.

REYMANÓWNA M. 1987. Plants of the Lower Liassic forest from Odrowąż and their fructifications: Part I. Conifers. Abstracts of the General Lectures, Symposium Papers and Posters, 14 International Botanical Congress, Berlin: 403.

REYMANÓWNA M. 1991a. Are developing ovules and seeds of Mesozoic gymnosperms protected against the environment? Fifth Symposium on Mesozoic Terrestrial Ecosystems and Biota. Extended Abstracts. Contributions from the Palaeontological Museum University of Oslo, 364: 53–54.

REYMANÓWNA M. 1991b. Two conifers from the Liassic flora from Odrowąż in Poland. Pan-European Palaeobotanical Conference, Abstract – Volume, Natural History Museum Vienna: 33.

REYMANÓWNA M. 1992. Two conifers from the Liassic flora of Odrowąż in Poland: 307–310. In: Kovar-Eder J. (ed.), Palaeovegetational development in Europe and regions relevant to its palaeofloristic evolution. Proceedings of the Pan-European Palaeobotanical Conference, Vienna. Museum of Natural History, Vienna.

REYMANÓWNA M., WCISŁO-LURANIEC E. & ICHAS--ZIAJA J. 1987. The Liassic flora of the Holy Cross Mts. Guide to excursion No 24. From the Jurassic to the Holocene, 14 International Botanical Congress, Berlin: 46–54.

ROEMER F. 1866. Geognostische Beobachtungen im Polnischen Mittelgebirge. Z. Deutch. Geol. Ges., 18, Berlin.

ROEMER F. 1868. Notiz über das Vorkommen von Mastodonsaurus Jaegeri H. v. Meyer bei Odrowąż am Nordabhange des Polnischen Mittelgebrige. Z. Deutsch. Geol. Ges. 20, Berlin.

ROGALSKA M. 1954. Analiza sporowo-pyłkowa liasowego węgla blanowickiego z Górnego Śląska (summary: Spore and pollen analysis of the Brown coal of the region of the so-called Blanowice coal in Upper Silesia). Biul. Inst. Geol., 89: 1–46.

ROGALSKA M. 1956. Analiza sporowo-pyłkowa liasowych osadów obszaru Mroczków-Rozwady w powiecie opoczyńskim (summary: Spore and pollen analysis of the Liassic deposits of the Mroczków-Rozwady area in the Opoczno district). Biul. Inst. Geol., 104: 1–89.

ROGALSKA M. 1976. Stratygrafia jury dolnej i środkowej na obszarze Niżu Polskiego na podstawie badań sporowo-pyłkowych (summary: Stratigraphy of the Lower and Middle Jurassic in the Polish Lowlands on the basis of spore and pollen analysis). Pr. Państw. Inst. Geol., 78: 1–61.

RYDZEWSKI B. 1924. Wapień muszlowy nad Kamienną. Pr. Tow. Przyj. Nauk., T. 1., Wilno.

RUCKWIED K., GÖTZ A.E., PÁLFY J. & TÖRÖK Á. 2008. Palynology of a terrestrial coal-bearing series across the Triassic/Jurassic boundary (Mecsek Mts, Hungary). Centr. Eur. Geol., 51: 1–15.

SAMSONOWICZ J. 1929. Cechsztyn, trias i lias na północnym zboczu Łysogór (summary: Les Zechstein, le Trias et le Liasique sur le versant nord du Massif de S-te Croix). Spraw. Pol. Inst. Geol., 5(1–2): 1–281.

SAMSONOWICZ J. 1934. Objaśnienia arkusza Opatów ogólnej mapy geologicznej w skali 1:100 000. Państw. Inst. Geol. Warszawa.

SCHNEIDER A. 1829. Über die Struktur- und Lagerungs-Verhältnisse der Gebirgs am nördlichen Abhange des Sandomirer Gebirges, im desen östlichen Gegenden. Arch. Bergb. Hüttenw., 19: 450–498.

SCHULZ E. 1967. Sporenpalaontologische Untersuchungen ratoliassischer Schichten im Zentralteil des Germanischen Beckens. Palaeont. Abh. B, 2(3): 541–633.

SENKOWICZOWA H. 1970. Trias. In: Rühle W. (ed.), Stratygrafia mezozoiku obrzeżenia Gór Świętokrzyskich. Prace Inst. Geol., 56: 7–48.

STEFFEN D. & GORIN G.E. 1993. Palynofacies of the Upper Tithonian-Berriasian deep-sea carbonates in the Vocontian Trough (SE France). Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine, 17: 235–247.

TRAVERSE A. 1988. Paleopalynology. Unwin Hyman, Boston.

WCISŁO-LURANIEC E. 1987. Plants of the Lower Liassic conifer forest from Odrowąż and their fructifications: Part II. Pteridophytes and remaining gymnosperms. Abstracts of the General Lectures, Symposium Papers and Posters, 14 International Botanical Congress, Berlin: 403.

WCISŁO-LURANIEC E. 1991a. The Lower Liassic flora from Odrowąż in Poland and its ecosystem. Fifth Symposium on Mesozoic Terrestrial Ecosystems and Biota. Extended Abstracts. Contrib. Paleont. Mus. Univ. Oslo, 364: 69–70.

WCISŁO-LURANIEC E. 1991b. The flora from Odrowąż in Poland – a typical Lower Liassic European flora. Abstract – Volume, Pan-European Palaeobotanical Conference, Natural History Museum Vienna: 45.

WCISŁO-LURANIEC E. 1992. Flora from Odrowąż in Poland – a typical Lower Liassic European flora: 331–335. In: Kovar-Eder J. (ed.), Palaeovegetational development in Europe and regions relevant to its palaeofloristic evolution. Proceedings of the Pan-European Palaeobotanical Conference, Vienna. Museum of Natural History, Vienna.

WĘGIEREK P. & ZHERIKHIN V.V. 1997. An Early Jurassic insect fauna in the Holy Cross Mountains. Acta Palaeont. Pol., 42: 539–543.

VAKHRAMEEV V.A. 1981. Pollen *Classopollis*: indicator of Jurassic and Cretaceous climates. The Palaeobotanist, 28-29: 301–307.

ZATOŃ M., BARBACKA M., MARYNOWSKI L. & KRZYSTANEK J. 2006. *Sagenopteris* (Caytoniales) with its possible preserved biomarkers from the Bathonian of the Polish Jura, south-central Poland. N. Jb. Geol. Paläont. Mh., 7: 385–402.

ZEJSZNER L. 1868. Über die eigentümliche Entwicklung der triasischen Formationen zwischen

Brzeziny und Pierzchnica am sudwestlichen Abhange des palaozoischen Gebirges zwischen Sandomierz und Chęciny. Z. Deutsch. Geol. Ges., 20. Berlin.

ZIAJA J. 1989. The Lower Liassic flora from Odrowąż in Poland: Preliminary comparision of microflora with megaflora. II European Palaeobotanical Conference, Madrid, September 1989. Abstracts of contributed papers and poster sessions: 12.

ZIAJA J. 1991. The Lower Liassic microflora from Odrowąż in Poland.: Pan-European Palaeobotanical Conference, Abstract – Volume, Natural History Museum Vienna: 47.

ZIAJA J. 1992. The Lower Liassic microflora from Odrowąż in Poland: 337–340. In: Kovar-Eder J. (ed.), Palaeovegetational development in Europe and regions relevant to its palaeofloristic evolution. Proceedings of the Pan-European Palaeobotanical Conference, Museum of Natural History, Vienna.

ZIAJA J. 2006. Lower Jurassic spores and pollen grains from Odrowąż, Mesozoic margin of the Holy Cross Mountains, Poland. Acta Palaeobot., 46(1): 3–83.

PLATES

Plate 1

Palynofacies

1. Huta OP-1, 190 m, 5/2011, Rhaetian, numerous phytoclasts, sporomorphs, opaque and translucent phytoclasts
2. Huta OP-1, 36.8 m, 139/255, Zagaje Fm., Hettangian, numerous phytoclasts, sporomorphs
3. Huta OP-1, 142.5 m, 2/2011, Zagaje Fm., Hettangian, bisaccate pollen grains
4. Przysucha P-3, 138.5 m, 140/45, Skłoby Fm., Hettangian, translucent and opaque phytoclasts, spore
5. Studzianna 862 m, 138/9, Przysucha Ore-bearing Fm., Hettangian, translucent and numerous opaque phytoclasts, trilete spore
6. Studzianna, 783 m, 138/9, Ostrowiec Fm., Sinemurian, numerous phytoclasts, degraded pollen grains and dispersed organic matter

Scale bar 10 μm

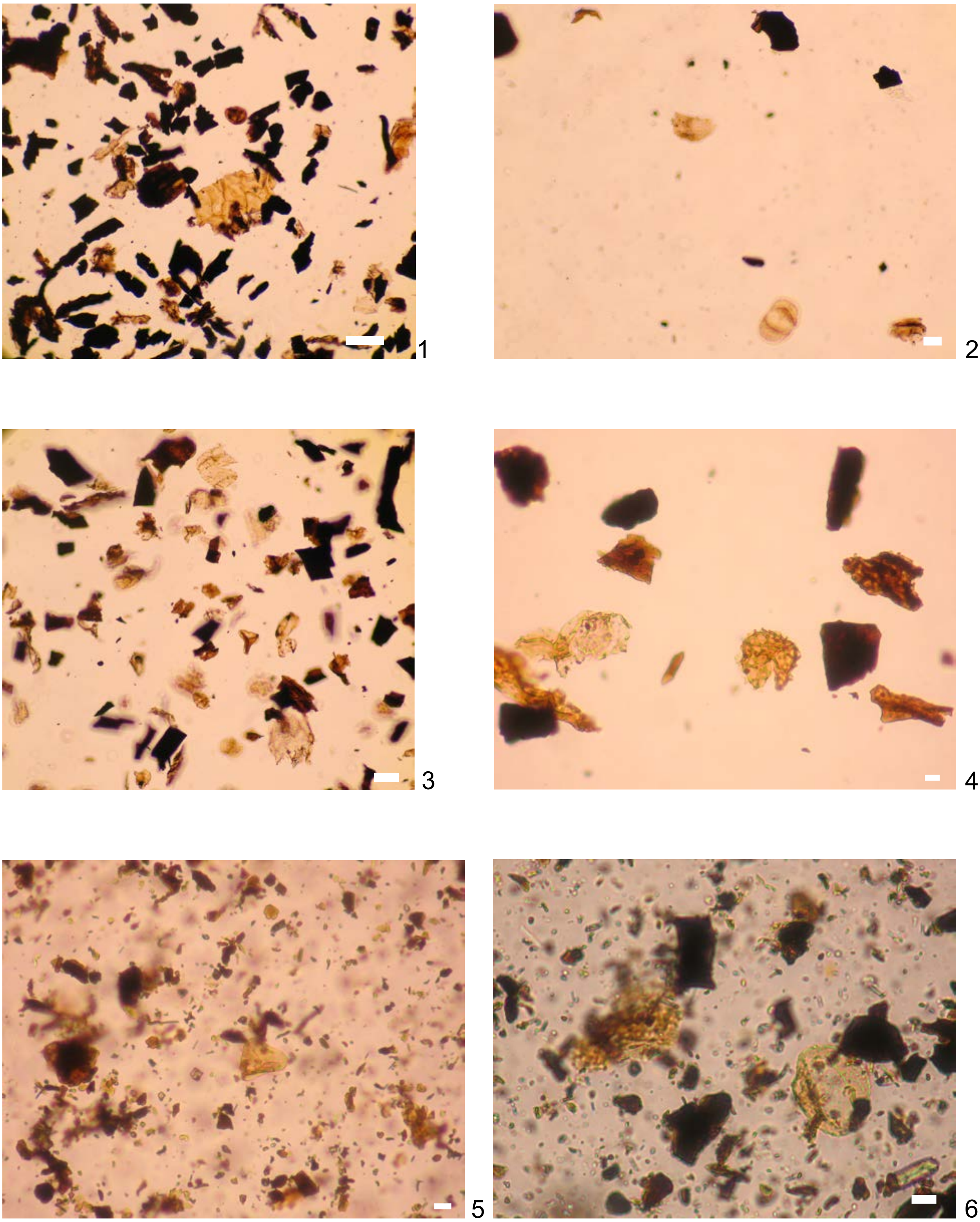
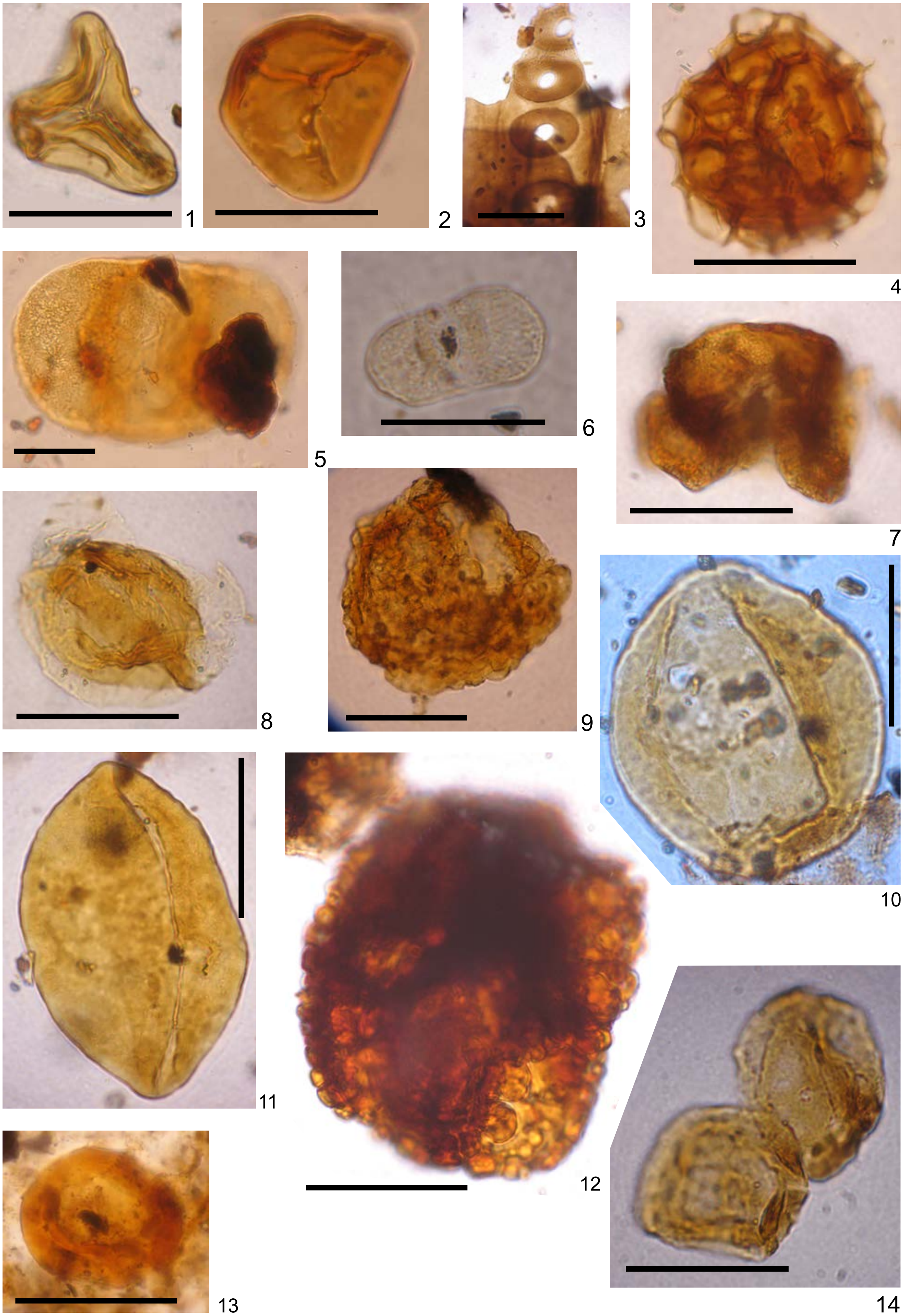


Plate 2

Upper Triassic and Lower Jurassic sporomorphs

1. *Cyathidites* sp., Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
2. *Todisporites minor* Couper, Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
3. Translucent phytoclast, Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
4. *Lycopodiumsporites clavatoides* (Couper) Tralau, Studzianna, 4/1, 978 m, Zagaje Fm., Hettangian
5. *Alisporites robustus* Nilsson, Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
6. *Vitreisporites pallidus* (Reissinger) Nilsson, Studzianna, 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
7. *Pinuspollenites minimus* (Couper) Kemp, Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
8. *Perinopollenites elatoides* Couper, Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
9. *Cerebropollenites* sp., Huta OP-1, 139/225, 36.8 m., Zagaje Fm., Hettangian
10. *Chasmatosporites apertus* (Rogalska) Nilsson, Studzianna, 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
11. *Cycadopites/Monosulcites* sp., Studzianna, 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
12. *Riccisporites tuberculatus* Lundblad, Huta OP-1, 5/2011, 190 m, Rhaetian
13. *Classopollis* sp., Studzianna 138/9, 862 m, Przysucha Ore-bearing Fm., Hettangian
14. *Classopollis* sp., Huta OP-1, 139/205, 131.7 m, Zagaje Fm., Hettangian

Scale bar 30 µm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APPENDIX

Appendix no. 1

Numerical data for the palynofacial analysis graphs

Abbreviations:

OP. PHYT. – opaque phytoclasts, TR. PHYT. – translucent phytoclasts, POLL. GR. – pollen grains, SP – spores, CUT – cuticles, AOM – amorphous organic matter

STUDZIANNA depth [m]	OP. PHYT.	TR. PHYT.	POLL. GR.	SP	CUT	AOM	SUM
642	1816	3657	375	125	125	94	6192
783	994	1683	184	61	92	46	3060
862	2650	12606	401	241	82	78	16058
862.6	1249	4834	160	96	32	32	6403
978	958	4210	348	174	57	59	5806
980	486	2914	233	194	39	19	3885
1011	748	5837	449	411	38	–	7483
1013	513	7836	466	420	93	–	9328
1048	181	6421	289	253	72	–	7216
1058	1016	7067	353	265	133	–	8834
1060	1613	10051	496	124	64	60	12408
1090	1966	8313	337	169	112	337	11234
1145.8	1384	4951	291	109	36	509	7280
1175	1719	7283	405	101	–	607	10115

HUTA OP-1 depth [m]	OP. PHYT.	TR. PHYT.	POLL. GR.	SP	CUT	AOM	SUM
21.5	1148	3184	365	104	261	156	5218
36.8	284	601	62	47	22	18	1034
50.2	219	604	46	42	10	8	929
63	1303	3474	298	190	108	55	5428
63.6	2346	3992	350	245	70	–	7003
73.1	2326	5839	365	319	183	91	9123
85	1508	4083	314	251	62	65	6283
98.6	1728	5597	412	329	165	–	8231
103.5	705	3969	261	183	104	–	5222
131.7	461	1486	133	132	23	69	2304
142.5	590	2362	164	115	49	–	3280
177	1414	5341	393	275	118	314	7855
190	338	1404	110	91	9	40	1992
197.8	155	451	45	26	4	59	740
200	217	770	72	36	–	108	1203
202.1	223	584	59	20	4	99	989

PRZYSUCHA P-3 depth [m]	OP. PHYT.	TR. PHYT.	POLL. GR.	SP	CUT	AOM	SUM
29.5	319	799	40	13	25	37	1233
38	368	494	52	25	40	30	1009
62.5	538	1235	60	39	40	79	1991
63	331	662	44	28	17	22	1104
70	575	770	89	73	48	65	1620
84	606	1152	75	35	19	99	1986
111.8	327	841	63	35	97	28	1391
138.5	529	744	59	52	58	30	1472

ODROWĄŻ	OP. PHYT.	TR. PHYT.	POLL. GR.	SP	CUT	AOM	SUM
Odrowąż 5	3784	11435	692	344	258	677	17190
Odrowąż 8	1761	18971	352	234	352	1748	23418
Odrowąż OS2	156	3443	137	77	20	78	3911
Odrowąż 11/2	716	16382	269	179	89	269	17904

Appendix no. 2

Numerical data for the Sporomorph EcoGroup graphs

STUDZIANNA depth [m]	Upland SEG	Lowland SEG	River SEG	Pioneer SEG	Coastal SEG	Tidally inf. SEG	SUM
642	2	5	3	1	5	4	20
783	4	3	5	2	4	3	21
862	12	10	9	7	7	6	51
862.6	28	30	22	8	7	4	99
978	25	30	21	7	2	4	89
980	25	23	22	9	1	5	85
1011	20	23	20	11	2	6	82
1013	18	35	29	5	3	0	90
1048	19	30	24	5	6	3	87
1058	21	14	14	13	4	3	69
1060	18	32	27	10	4	1	92
1090	18	20	16	6	2	1	63
1145.8	15	24	20	6	3	1	69
1175	16	22	21	4	3	1	67

HUTA OP-1 depth [m]	Upland SEG	Lowland SEG	River SEG	Pioneer SEG	Coastal SEG	Tidally inf. SEG	SUM
21.5	1	2	1	5	7	3	19
36.8	14	15	16	12	1	6	64
50.2	17	20	17	9	2	4	69
63	20	23	11	8	1	3	66
63.6	14	16	13	10	1	5	59
73.1	17	15	16	11	2	6	67
85	14	17	14	14	1	3	63
98.6	21	20	8	7	2	4	62
103.5	17	21	7	5	1	2	53
131.7	11	12	20	5	2	3	53
142.5	9	15	21	3	5	4	57
177	12	15	22	5	4	3	61
190	15	26	29	6	7	4	87
197.8	4	10	5	2	3	1	25
200	5	13	6	3	2	1	30
202.1	7	11	6	3	3	1	31

PRZYSUCHA P-3 depth [m]	Upland SEG	Lowland SEG	River SEG	Pioneer SEG	Coastal SEG	Tidally inf. SEG	SUM
29.5	9	9	7	6	7	7	45
38	13	15	12	4	11	10	65
62.5	13	11	9	7	7	6	53
63	11	14	11	6	9	8	59
70	10	8	7	4	6	3	38
84	8	12	8	4	5	3	40
111.8	5	7	6	9	12	7	46
138.5	10	13	11	3	6	4	47