S T U D I A G E O L O G I C A P O L O N I C A
Vol. 135, Kraków 2012, pp. 7–54.
Geology of the Pieniny Klippen Belt and the Tatra Mts, Carpathians
Edited by K. Birkenmajer
Part XXI

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Jurassic and Cretaceous strata in the Maruszyna IG-1 Deep Borehole (Pieniny Klippen Belt, Carpathians, Poland): lithostratigraphy, dinoflagellate cyst biostratigraphy, tectonics[2]

(Figs 1–26)

Abstract. The paper presents core description of the Maruszyna IG-1 Deep Borehole located in the southernmost part of the Pieniny Klippen Belt of Poland, at the Kraków–Zakopane geotraverse of the Polish Carpathians. In the borehole, two Laramian nappes have been recognized: the Pieniny Nappe, PN (0 down to 930–960 m below the surface), and the Branisko Nappe, BN (1225–4843 m below the surface). The rocks of the Branisko Nappe are unconformably covered by the Maastrichtian marine molasse (conglomerates with large olistoliths derived from this nappe) – the Jarmuta Formation, JmF (930–1190 m below the surface). The Laramian overthrust zone: PN over JnF (and BN) lies at 930–960 m below the surface. The Branisko Nappe is subdivided into three first-order (major) and numerous, second-order (minor) tectonic scales. 29 samples from the Middle Jurassic, Lower and Upper Cretaceous rocks have been analyzed for palynofacies and organic-walled dinoflagellate cysts. Biostratigraphic interpretation of dinoflagellate cyst assemblages generally confirms the ages of the earlier-distinguished Jurassic and Cretaceous lithostratigraphic units in this borehole. An Aalenian dinoflagellate cyst assemblage from rocks attributed to the Harcygrund Shale Formation, suggests a slightly wider time-range of this unit than hitherto assumed: Aalenian–Lower Bajocian.

Key words. Jurassic, Cretaceous, Pieniny Klippen Belt, Polish Carpathians, deep borehole, lithostratigraphy, dinoflagellate cyst biostratigraphy, palynofacies, tectonics

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A. GEOLOGY

by K. Birkenmajer

INTRODUCTION

The present paper describes core and discusses geological section of the Maruszyna IG-1 Deep Borehole against regional geological structure of the area, as presented in detailed geological map (1:10,000 scale), sheet Szaflary-Bór na Czerwonem (Birkenmajer, 1970). The borehole was located in the southernmost part of the Pieniny Klippen Belt (West Carpathians, Poland), immediately south of the road Szaflary–Maruszyna, on right slope of the Mały Rogoźnik (*vel* Skrzypny) Stream valley, south-west of the Ranysborg hill (738 m) – see Figs 1, 2 . The borehole project was prepared by (the late) Dr Wacław Sikora, head of the Carpathian Branch of the Polish Geological Institute (Kraków), as early as 1975. During drilling, it was supervised by geologists of this Institute, (the late) Prof. Julian Sokołowski and Dr Józef Chowaniec. The coring was performed repeatedly at ca 50-m distances. The 4843-m deep drilling, completed in 1981, was available to the present author's investigation in October 1981 and April 1983. His preliminary tectonic interpretation was presented to the members of the XIIIth Congress of the Carpatho-Balkan Geological Association in 1985 (see Birkenmajer, ed. *et al.*, 1985). The following tectonic units were distinguished (from the top downwards): the Pieniny Nappe; the Branisko Nappe with Maastrichtain molasse cover, subdivided into 2 tectonic scales; and the "Czorsztyn and transitional (?) units" at the bottom.

The present paper offers a detailed lithostratigraphic description and tectonic reinterpretation of the borehole section. Lithostratigraphic names used are those from lithostratigraphic standard of Birkenmajer (1977), with later supplements and modfications (see Birkenmajer & Jednorowska, 1983a, b, 1984, 1987a, b; Birkenmajer, 1987, 2008). Correlation of the borehole section with lithostratigraphic units distinguishable at the surface (see Birkenmajer, 1970) are given. New stratigraphic age evidence is being presented by P. Gedl (see part B of this paper), based on a dinoflagellate cyst study of samples from selected Jurassic and Cretaceous strata of the borehole.

The Maruszyna IG-1 Deep Borehole (Fig. 3)

Core description

(Note: Lithostratigraphic names are abbreviated. Borehole cored ca every 50 metres)

metres	units
Pieniny Nappe (PN):	
0–560	**Sromowce Fm.**: flysch sandstones and shales (at the surface dipping 30–50° SE – see Birkenmajer, 1970), refolded with red marls of the **Jaworki Fm.**;
560–564	**Jaworki Fm.**: marls, grey, green (Brynczkowa Mbr) and variegated (Skalski Mbr), slickensided;

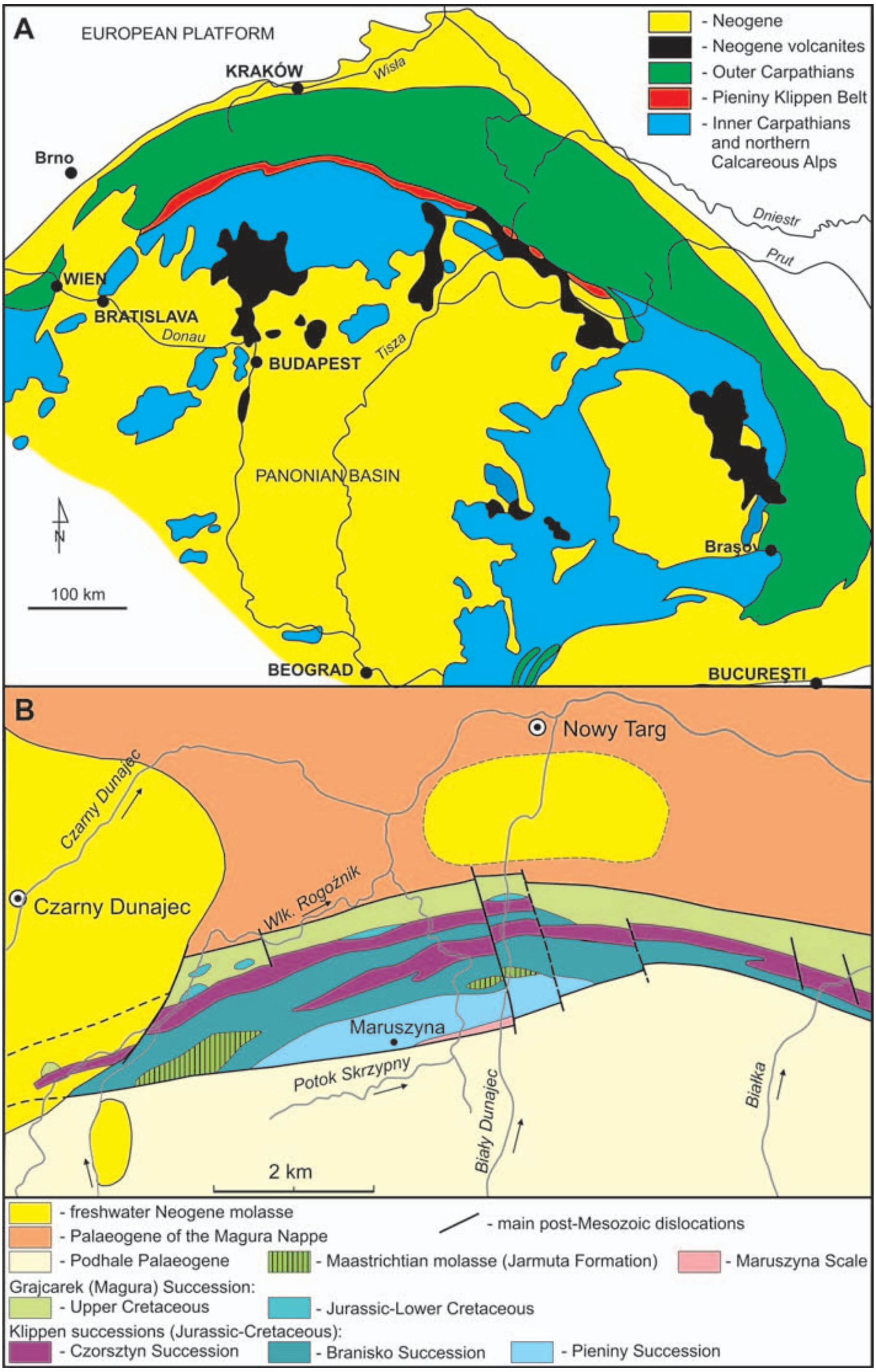


Fig. 1. **A.** Location of the investigated area in the Carpathians (arrowed). **B**. Pieniny Klippen Belt between Nowy Targ and Szaflary (from Birkenmajer & Jednorowska, 1983b, fig. 1)

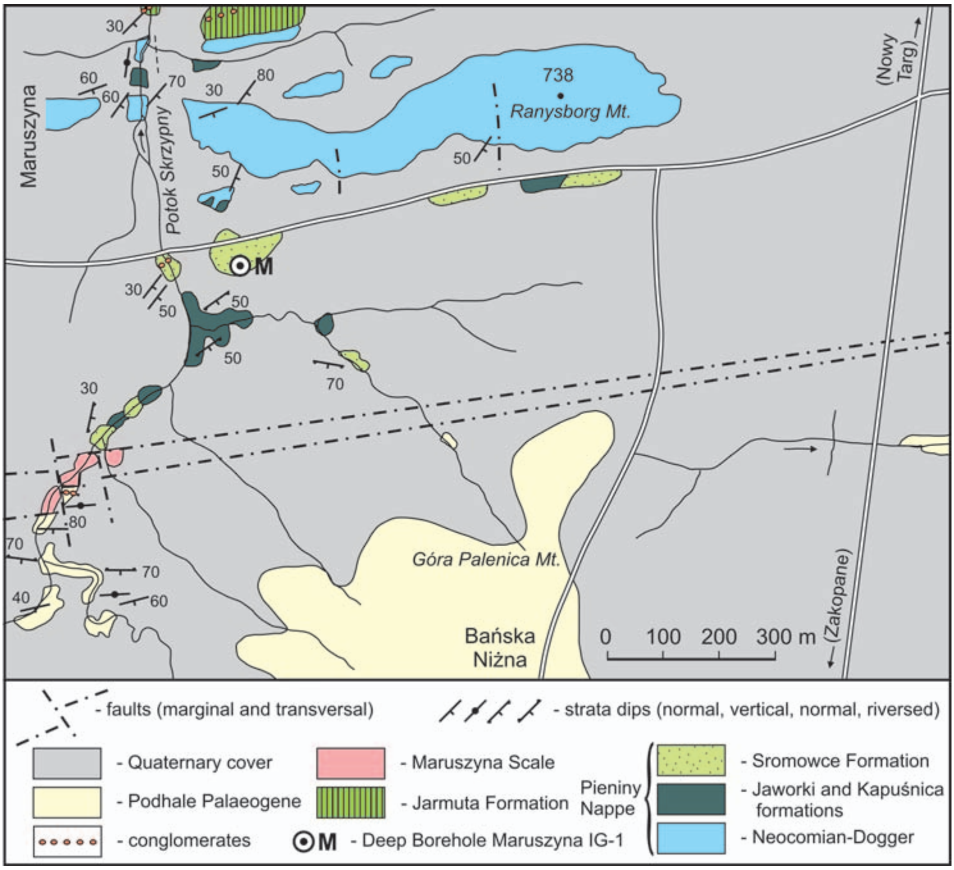


Fig. 2. Location of the Maruszyna IG-1 Deep Borehole at Maruszyna (geology after Birkenmajer, 1970, and Birkenmajer & Jednorowska, 1983b, fig. 2, simplified)

612–621.5 **Kapuśnica Fm.**: marly limestone, marly shale, black, grey and green, very strongly slickensided;

692–773.5 **Pieniny Fm.**: cherty limestone, cream-yellow to light grey with black cherts;

773.5–845 (coreless: radiolarite fragments from the **Czajakowa** and **?Sokolica fms**);

845–847 **Podzamcze Fm.** (upper part): limestones, slightly siliceous, grey, spotty, brown-grey, and marly shale, green;

847–957 (coreless: brownish limestone fragments: Podzamcze Fm.)

(930–960 *Overthrust zone PN/JmF*)

Older Klippen Mantle: Jarmuta Fm. (JmF):

930–960 Conglomerate, fine to medium, consisting, i.a., of light limestone (Jurassic: Pieniny Fm.), brownish dolostone (Middle Triassic: ?Gutenstein Fm.), green spilite etc. (*JmF/olistolith contact at ca 963 m)*;

1033.6–1151 **Olistolith**: block of the Branisko Succession consisting of: marly limestone grey to black (Kapuśnica Fm., Rudina Mbr: 1033.6–1035.6); marly shale, green, slickensided (Kapuśnica Fm., Rudina Mbr: 1096–1098.4); breccia

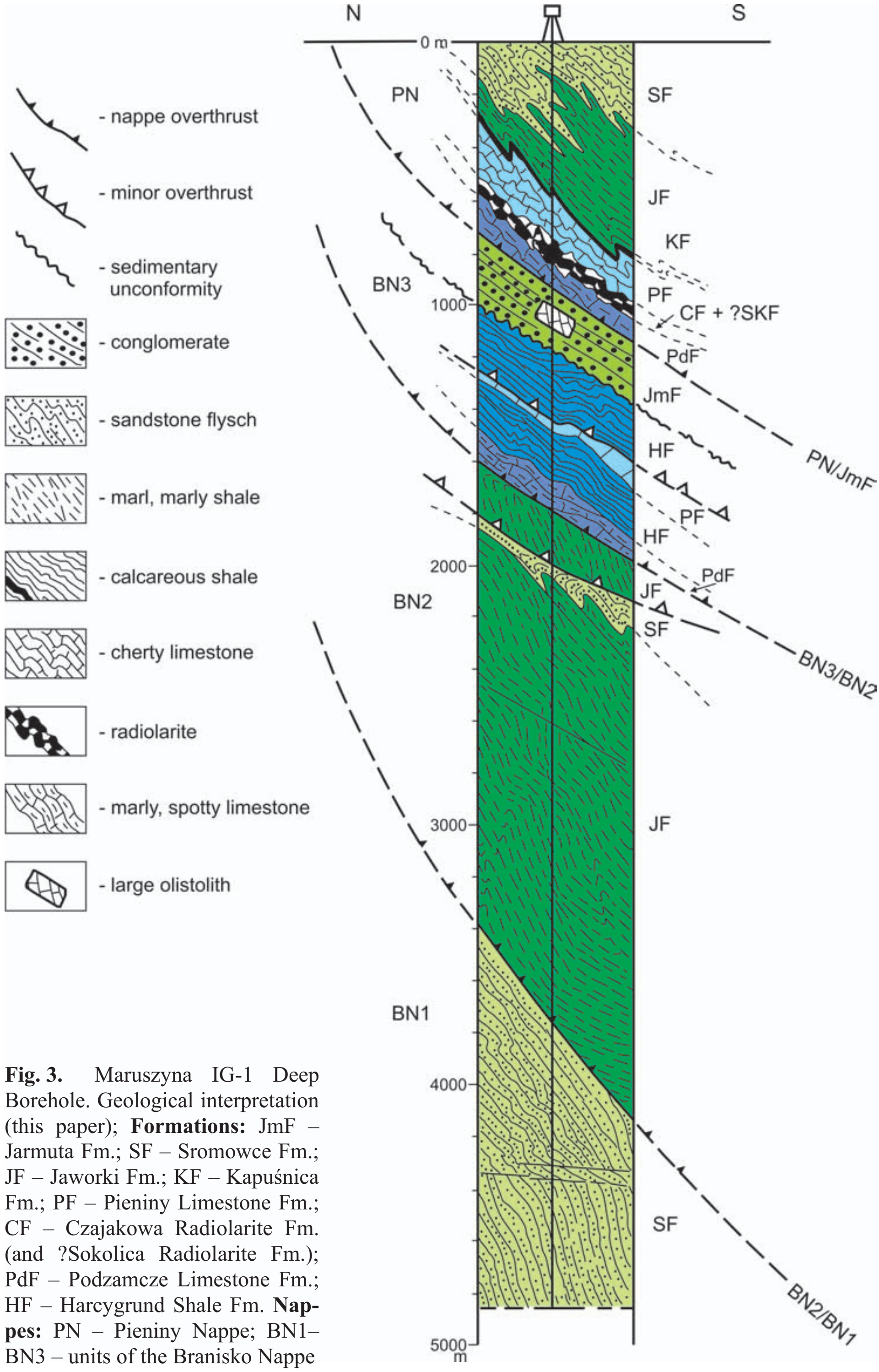


Fig. 3. Maruszyna IG-1 Deep Borehole. Geological interpretation (this paper); **Formations:** JmF – Jarmuta Fm.; SF – Sromowce Fm.; JF – Jaworki Fm.; KF – Kapuśnica Fm.; PF – Pieniny Limestone Fm.; CF – Czajakowa Radiolarite Fm. (and ?Sokolica Radiolarite Fm.); PdF – Podzamcze Limestone Fm.; HF – Harcygrund Shale Fm. **Nappes:** PN – Pieniny Nappe; BN1–BN3 – units of the Branisko Nappe

consisting of greyish cherty limestone and black shale (Kapuśnica Fm., Brodno Mbr: 1098–1151);

(?Overthrust: olistolith/conglomerate contact at ca 1151 m)

1151–1190 Conglomerate, medium, consisting of grey cherty limestone (Pieniny Fm.) pebbles;

(JmF/BN3 sedimentary unconformity at c. 1190 m)

Branisko Nappe, upper unit (BN3):

1225–1342.5 **Harcygrund Fm.**: claystone and siltstone, black to grey, slickensided and brecciated (1225–1226.5; 1288–1290; 1340.5–1342.5);

1407–1409 **Podzamcze Fm.**: limestone, shaly, black and dark-brown, and black shale, slickensided;

1458–1517 **Harcygrund Fm.**: shale, black, slickensided and brecciated (1458–1460; 1516–1517);

1630–1685 **Podzamcze Fm.**: limestone, brownish;

(1789 *Overthrust: BN3/BN2)*

Branisko Nappe, middle unit (BN2):

1789–1998 **Jaworki Fm:**

- 1789–1792 – Brynczkowa Mbr: marls, marly limestone, green, greenish-grey, veined with calcite (1789–1792; 1831–1833);
- 1926.5–1929 – Skalski Mbr: marls, grey and green to reddish;
- 1929.5–1998 – Macelowa Mbr – red marls with thin intercalations of fine-grained sandstone and mudstone;

(?Minor overthrust at c. 2160 m)

2160–2175.5 **Sromowce Fm.**: sandstone, fine-grained, calcareous, and marly shale, grey (Osice Mbr, bottom part);

2228–3800 **Jaworki Fm.:**

- 2228–2540 – Macelowa Mbr: marl, shaly, greenish to variegated and red with thin (1–10 mm) calcareous sandstone and siltstone bands (2228–2231; 2289–2291; 2346.5–2350; 2402–2405; 2453.5–2457; 2534–2536);
- 2602–2660.5 – Brynczkowa Mbr: marls and marly limestones, greenish-grey, spotty, dip 50°;
- 2736–2738 – Snežnica Mbr: marl and marly shale, greenish, with thin laminae of fine-grained sandstone, tectonically corrugated;
- 2780–2902.5 – Brynczkowa Mbr: marls and shaly marly limestone, spotty, dip vertical at top, dip 60° lower down, slickensided (2780–2790; 2839–2840; 2901–2902.5);
- 2977–3178 – Snežnica Mbr: marls, green and grey, with thin fine-grained sandstone laminae (0.5–1 cm), dip 55–60°, slickensided (2977–2979; 3046.5–3048.5; 3116–3118; 3176–3178);
- 3241.5–3243 – Skalski Mbr: marls, green and red with thin laminae of fine-grained sandstone, tectonically corrugated;
- 3311.5–3345.5 – Snežnica Mbr: marls, grey-green, slightly reddish, with thin (1–5 mm) sandstone laminae, dip 70° at top, 50° lower down (3311.5–3314; 3380–3381.5; 3443.5–3445.5);
- 3501–3503.5 – Upper half of core – Snežnica Mbr (fine flysch); middle part of core: Brynczkowa Mbr (green marls); lower part of core – Skalski Mbr/Snežnica Mbr (variegated marls with thin fine-grained sandstone laminae);

– 3568.5–3647.5 – Macelowa Mbr: marls, red, with greenish and grey siltstone laminae (1–2 cm), dip 60° at top, 10–30° lower down, veined with calcite (3568.5–3571; 3644.5–3647.5);
– 3705–3707.5 – Snežnica Mbr: marls, silty, and marly shales, grey-greenish, with thin fine-grained sandstone laminae;

(*Overthrust BN2/BN/1 at c. 3800 m)*

Branisko Nappe, lower unit (BN-1)

3801–4843 **Sromowce Fm.:**

– 3801–3803 – sandstone, fine-grained, grey;
– 3865.5–3915.5 – silty shales, grey-greenish, and thin fine-grained sandstone – poor core (3893–3895; 3914–3915.5);
– 3983–4562 – siltstone/fine-grained sandstone, and shale, grey (dip 50°): 3983–3985; 4020–4024; 4092–4099.5 (dip 45°); 4148.5–4151 (horizontal strata); 4202–4206.5 (dip 0–10°); 4255.5–4260.5 (dip 10°; strongly calcitized); 4297.5–4303; 4355–4358 (dip 70°); 4402–4403.5 (dip 70–80°); 4456–4458 (dip 80°); 4505–4505.5 (dip 80°); 4560–4562 (dip 80°);
– 4603–4606 – marl and marly siltstone, corrugated (4652–4653; 4695–4696; 4758–4759 (?Osice Mbr);
– 4759–4843 coreless (borehole end)

MARUSZYNA IG-1: TECTONIC UNITS

Two nappes have been recognized in the Maruszyna IG-1 Deep Borehole: the Pieniny Nappe and the Branisko Nappe. The latter is subdivided into several tectonic scales, easily correlatable with those distinguishable at the surface (see Birkenmajer, 1970).

Pieniny Nappe (PN)

The Pieniny Nappe is 930–960 m thick. It represents a normal sequence of strata, with the youngest Sromowce Fm. (flysch) at the top, and Middle Jurassic Podzamcze Fm. at the bottom.

Sromowce Formation, refolded with the **Jaworki Formation** (0–564 m). The Sromowce Formation, representing a flysch development (age: Upper Santonian, *Dicarinella asymmetrica* Zone through Early Campanian *Globotruncanita elevata* Zone – Birkenmajer & Jednorowska, 1987a) is refolded with red marls of the Jaworki Formation. The latter is represented by two members: the Brynczkowa Member (age: uppermost Albian *Rotalipora apenninica* Zone to Lower Cenomanian *R. brotzeni* Zone – Birkenmajer & Jednorowska, 1987a), and the Skalski Member (age: Lower Cenomanian *R. reicheli* Zone through Upper Cenomanian *R. cushmani* Zone – Birkenmajer & Jednorowska, 1987a). The successive Macelowa Member (deep-red marls, age: Lower Turonian *Praeglobotruncana helvetica* Zone through Upper Senonian *Dicarinella asymmetrica* Zone – Birkenmajer & Jednorowska, 1987a) is missing most probably due to tectonic causes. In a surficial exposure just north of the road Szaflary–Maruszyna, at right bank of the Mały Rogoźnik (*vel* Skrzypny) Stream, green marls (Brynczkowa Mbr) of the Jaworki Fm. are refolded with the Pieniny Limestone Fm. (Birkenmajer, 1970).

Kapuśnica Formation. This unit, which occurs at transition from the Pieniny Limestone Formation to the Jaworki Formation, is considerably well represented in the borehole. Its age in the Pieniny Nappe corresponds to the Aptian and Lower Albian (Birkenmajer, 1977).

Pieniny Limestone Formation. This lithostratigraphic unit (age: Lower Tithonian–Barremian – Birkenmajer, 1977) is well represented in the borehole (at 692–773 m). East of the borehole site, it builds southern and south-eastern slopes of the Ranysborg hill (738 m).

Czajakowa Radiolarite Formation (Oxfordian–Kimmeridgian) and the **Sokolica Radiolarite Formation** (Upper Bajocian–?Callovian) are well exposed on northern and western slopes of the Ranysborg hill (see Birkenmajer, 1970). Their presence in the borehole is signalled by small radiolarite fragments at 773–845 m. Due to their lithologic character and dense cleavage/brecciation, these radiolarites only very rarely are represented in borehole cores. Their stratigraphic ages are based on data from the Branisko Succession (see Birkenmajer, 1977, 2009)

Podzamcze Limestone Formation. This lithostratigraphic unit is here typically developed as spotty brownish limestones (Fleckenkalk facies). Its age corresponds to Middle Bajocian, as based on ammonite fauna from the Branisko Succession (Myczyński, 1973; Birkenmajer, 1977, 2009).

?Harcygrund Shale Formation (Middle Bajocian), the **?Skrzypny Shale Formation** (Aalenian–Middle Bajocian) and the **?Szopka Limestone Formation** (Pliensbachian–Domerian – Birkenmajer & Myczyński, 1994; Birkenmajer, 2008). These three lowest lithostratigraphic units of the Pieniny Succession (see Birkenmajer, 1977) have not been recognized in the borehole. However, they might, at least partly, fill the coreless gap from 847–957 m, and be present in the overthrust zone PN/JmF at 930–960 m (see Fig. 3).

Older Klippen Mantle: Jarmuta Formation (JmF)

The Jarmuta Formation (Maastrichtian): conglomerates with exotic pebbles, and pebbles and olistoliths derived from the Branisko Succession, have been described and illustrated from the Biały Dunajec River valley at Szaflary since 1958 (see Birkenmajer, 1958: II, 1970, 1977, 1979: figs 22–26, 1985). The formation represents synorogenic Laramian molasse, resting unconformably upon eroded Branisko Nappe (Birkenmajer, 1986a, b, 1988). Along northern margin of the Pieniny Klippen Belt, in the Grajcarek Unit (coarse to medium flysch of the Laramian accretionary prism), the Jarmuta Formation was dated by calcareous nannoplankton at Maastrichtian through Paleocene (Birkenmajer *et al.*, 1987; Birkenmajer & Dudziak, 1991).

The core, from 930–1190 m (930–960 and 1181–1190 m), presents a good example of the Jarmuta Formation conglomerates, with a large olistolith (1033.6–1180 m) in the middle of the formation. The olistolith consists of the Lower Cretaceous Kapuśnica Formation (Brodno and Rudina members). It most probably derived from a marine cliff abraded during Maastrichtian in front of the advancing Branisko Nappe.

Olistoliths, up to c. 100 m large, consisting of rocks of the Branisko Nappe: Pieniny Limestone Formation (Tithonian–Lower Cretaceous) and the Czajakowa Radiolarite Formation (Oxfordian–Kimmeridgian), are well recognizable in a 250–350-m wide belt of the Jarmuta Formation between the Biały Dunajec River in the east and the Mały Rogoźnik (Skrzypny) Stream in the west (see Birkenmajer, 1970).

Branisko Nappe: units BN1–BN3

Three tectonic scales built of the Branisko Nappe have been recognized in the borehole. They include Middle Jurassic (BN3) and Upper Cretaceous (BN2 and BN3) lithostratigraphic units thrust one over another.

The **Harcygrund Shale Formation** (Middle Bajocian) and the **Podzamcze Limestone Formation** (Middle Bajocian) are refolded. This was also recognized during mapping (Birkenmajer, 1970: geological map and cross-section).

The **Sokolica-Czajakowa-Pieniny-Kapuśnica** formations (Bathonian through Albian). These four formations have been distinguished in the map and cross-section (Birkenmajer, 1970), but have not been recognized in the borehole.

The **Jaworki** (Albian–Santonian) and the **Sromowce** (Santonian–Campanian) formations are well represented in the BN2 and BN3 tectonic scales. Four lithostratigraphis divisions of the Jaworki Formation: the Brynczkowa-, the Skalski-, the Snežnica- and the Macelowa members, have been recognized. Dense bed-parallel thrust faults cause multiple repetition of strata.

At the surface, the Sromowce and Jaworki formations (and their members) are poorly exposed between the BN3 (Kurnikowa Skała, Kurzak-Dział klippes) and the BN2 (Zwierzyniec klippes) tectonic scales of the Branisko Nappe (see Birkenmajer, 1970).

REMARKS ON GEOLOGICAL S–N TRANSECT MARUSZYNA–SZAFLARY

The S-to-N geological transect Maruszyna–Szaflary was presented for the first time over forty years ago (Birkenmajer, 1970: cross-section). Since then, closer elaboration of the Upper Cretaceous stratigraphy of the Branisko Nappe between the Pasieczny and Trawne streams west of the transect (e.g., Blaicher & Sikora, 1972; Gasiński, 1983, 1986; Birkenmajer, 1986c, 1987; Krawczyk & Słomka, 1986), and recognition of a new tectonic unit at the Pieniny Nappe/Podhale Palaeogene contact – a "suspect terrane" comparable with the Myjava Zone of West Slovakia (Alexandrowicz & Birkenmajer, 1978; Birkenmajer, 1979, 1985, 1986a, b; Birkenmajer & Jednorowska, 1983b, 1987b; Kostka, 1933), introduced new elements to this transect (Fig 4).

(1) The Podhale Palaeogene flysch (Oligocene) is separated by a major vertical fault (southern boundary fault) from the Pieniny Klippen Belt;

(2) The vertical Maruszyna Scale (Maastrichtian–Paleocene–Middle Eocene) is wedged at the Podhale Palaeogene/Pieniny Nappe contact;

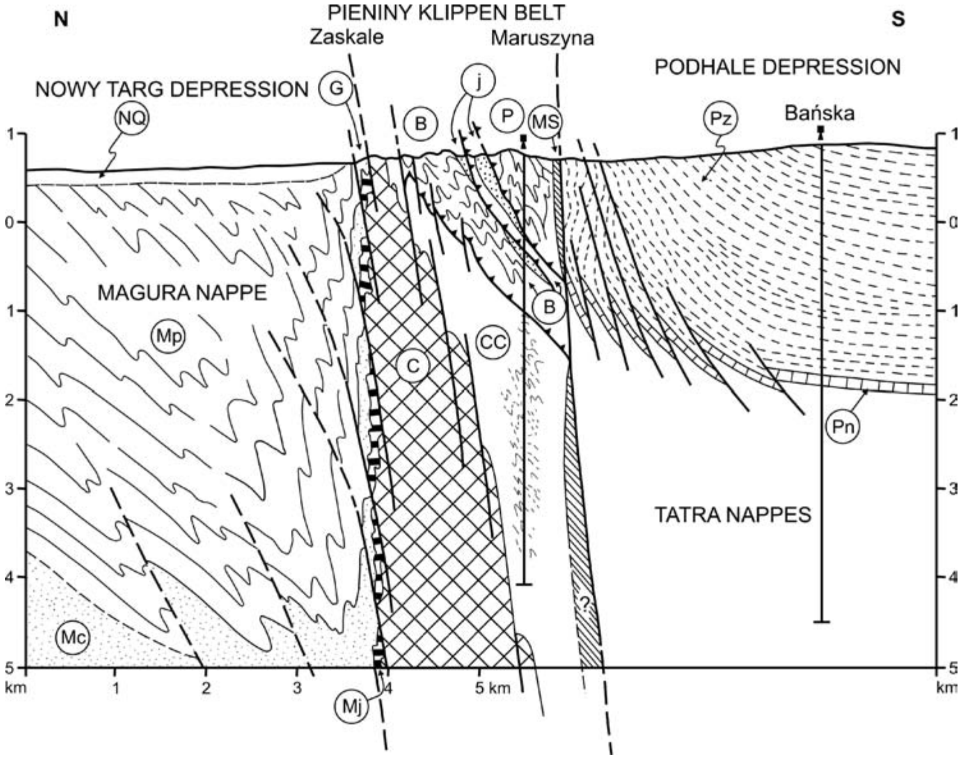


Fig. 4. A fragment of the N–S Geotraverse Kraków–Zakopane, Polish Carpathians (from Birkenmajer, 1986a, fig. 2, explanations slightly modified). **Magura Nappe:** Mj – Jurassic to Albian; Mc – Cenomanian to Maastrichtian; Mp – Palaeogene. **Pieniny Klippen Belt:** G – Grajcarek Unit (Laramian Magura Unit: Mj + Mc); C – Czorsztyn Unit: competent limestones (Jurassic–Lower Cretaceous) and soft marls (Upper Cretaceous); CC – Upper Cretaceous, incompetent rocks (= Branisko Nappe, lower tectonic scale – BN1); B – Branisko Nappe, middle (BN2) and upper (BN3) tectonic scales; P – Pieniny Nappe; j – Maastrichtian molasse and flysch – Jarmuta Fm.; MS – Maruszyna Scale; Pz – Podhale Palaeogene flysch (Central Carpathians): Pn – basal conglomerate and nummulitic limestone; barbed – Laramian overthrusts in the Pieniny Klippen Belt; Tertiary faults marked by heavy lines and dashes; deep boreholes marked at Bańska and Maruszyna

(3) The Pieniny Nappe (?Lower-Middle Jurassic–Lower Campanian), rather gentle folded, is thrust north at about 40 degrees over the Maastrichtian marine molasse (the Jarmuta Formation) which overlies the Branisko Nappe (Middle Jurassic to Lower Campanian). This overthrust is considered to be one of the best evidences for the post-, resp. syn-Jarmuta Formation age of the Laramian folding in the Pieniny Klippen Belt;

(4) The Branisko Nappe (Middle Jurassic to Lower Campanian), with its Jarmuta molasse cover (Maastrichtian), consists of several tectonic scales: BN3, BN2 and BN1. They are correlatable with the Kurzak-, Dział- and Zwierzyniec tectonic scales (see Birkenmajer, 1970: cross-section) which are thrust one over another in a northward direction;

(5) The northern tectonic scale of the Branisko Nappe (= the Zwierzyniec Scale) is thrust directly over brick-red Upper Cretaceous marls (Pustelnia Marl Mbr: Cenomanian–Lower Maastrichtian) of the Czorsztyn Unit (see Birkenmajer, 1970: cross-section);

(6) The faulted Czorsztyn Unit (Aalenian–Lower Maastrichtian) contacts in the north with a narrow zone of steeply dipping Jurassic and Cretaceous strata belonging to the Grajcarek Succession (Jurassic–Maastrichtian). Contrary to the earlier interpretation (Birkenmajer, 1970, cross-section), it does not seem to be thrust over the Pustelnia Marl Mbr of the Czorsztyn Unit.

B. PALYNOFACIES AND DINOFLAGELLATE CYST BIOSTRATIGRAPHY

by P. Gedl

INTRODUCTION

The Maruszyna IG-1 is the only deep borehole that drilled the structure of the Pieniny Klippen Belt to such a depth – 4840 m. Despite this, the unique material of this core has not been extensively examined so far. This refers especially to biostratigraphical studies. Lithostratigraphical division proposed by Birkenmajer (*in* Chowaniec & Sokołowski, 1985) was based on lithological criteria.

Organic-walled dinoflagellate cyst have been applied for biostratigraphical studies of Jurassic (e.g., Birkenmajer & Gedl, 2004, 2007; Bąk *et al*, 2005; P. Gedl, 2007a, 2008) and Cretaceous strata (Jamiński, 1995; Skupien, 2003; E. Gedl, 2007; P. Gedl, 2007a, b) of the Pieniny Klippen Belt. This microfossil group has been used in the Maruszyna IG-1 Deep Borehole to date its Jurassic and Cretaceous lithostratigraphic units.

MATERIAL

Twenty-nine samples have been collected from cores of the the Maruszyna IG-1 borehole for palynological studies. Their correlation with tectonic and lithostratigraphic units follows a scheme elaborated by K. Birkenmajer (*in* Chowaniec & Sokołowski, 1985; lithostratigraphic units after Birkenmajer, 1977). These are, in descending order.

Pieniny Nappe

1. sample 561 m – Jaworki Marl Formation (slightly calcareous hard, dark greyish mudstone);
2. sample 616.9 m – Kapuśnica Formation (slightly calcareous black, easily disintegrating shale);
3. sample 773.4 m – Pieniny Limestone Formation (light grey hard limestone with black clay intercalations);
4. sample 846 m – according to Birkenmajer (*in* Chowaniec & Sokołowski, 1985, and part A of this paper) interval 839–867 m represents the Czajakowa Radiolarite Formation (the Podmajerz Radiolarite Member) and the Podzamcze Limestone Formation; it is not certain which lithostratigraphic unit is represented by the studied sample (light greenish-grey moderately calcareous shale).

Jarmuta Formation

5. sample 957 m – conglomerate: dark grey matrix with intraclasts up to 2 cm in diameter.

Olistolith

6. sample 1097.4 m – Kapuśnica Formation (poorly calcareous light grey mudstone with fine intercalations of black clays);
7. sample 1225.5 m – Harcygrund Shale Formation (hard greyish marl with intercalations of disintegrable black shale);
8. sample 1341.8 m – Harcygrund Shale Formation (black, highly calcareous shale);
9. sample 1458.5 m – Harcygrund Shale Formation (dark grey hard limestone with black easily disintegrating shale).

Branisko Nappe

10. sample 1790.2 m – Podzamcze Limestone Formation: this sample was collected from a thin tectonic wedge (1789–1791 m) of Jurassic rocks that occur within the Cretaceous Jaworki Marl Formation at depth of 1772–2160 m (dark grey hard limestone with black easily disintegrating shale);
11. sample 2229.8 m – the Sromowce Formation (dark greyish-black moderately calcareous mudstone);
12–16. following samples represent the Jaworki Marl Formation:
12. sample 2402.5 m (red shale);
13. sample 2402.7 m (red shale);
14. sample 2534.8 m (red shale);
15. sample 2603.5 m (dark greyish-black moderately calcareous mudstone);
16. sample 2736.3 m (light grey disintegrable, moderately calcareous mudstone);
17–20. following samples represent the transitional part of the Jaworki Marl Formation to the Sromowce Formation:
17. sample 2839.3 m (dark grey-black poorly calcareous, disintegrable mudstone);
18. sample 2902 m (dark grey-black poorly calcareous, hard mudstone);
19. sample 3047 m (dark grey poorly calcareous, hard mudstone);
20. sample 3116.5 m (dark grey-black poorly calcareous, disintegrable mudstone with thin intercalations of hard dark grey mudstone);
21–23. following samples represent the Jaworki Marl Formation:
21. sample 3242.1 (black poorly calcareous, disintegrable shale with calcite veins);
22. sample 3444.8 m (very hard dark greyish, poorly calcareous marl with intercalations of black shale);
23. sample 3501.3 m (hard poorly calcareous, dark greyish-greenish to black mudstone);
24–29. following samples represent presumably the Snežnica Member of the Jaworki Marl Formation:
24. sample 3705.9 m (hard poorly calcareous, dark greyish-greenish to black mudstone);
25. sample 4022.5 m (hard poorly calcareous, dark greyish to black mudstone);
26. sample 4150.9 m (hard poorly calcareous, dark greyish to black mudstone);
27. sample 4402.6 m (hard poorly calcareous, dark greyish-greenish to black mudstone, strongly tectonized);
28. sample 4601.8 m (hard poorly calcareous black shale with calcite veins);
29. sample 4758.3 m (hard moderately calcareous, black mudstone).

METHODS

The samples were processed in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków. The applied standard palynological procedure included 38% hydrochloric-acid (HCl) treatment, 40% hydrofluoric-acid (HF) treatment, heavy-liquid ($ZnCl_2$+HCl; density 2.0 g·cm^{-3}) separation, ultrasound for 10–15 s and sieving at 10 µm on a nylon mesh. No nitric-acid (HNO_3) treatment was applied.

The quantity of rock processed was 30.0 g for each sample. Palynological slides were made from each sample using glycerine jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

RESULTS

All samples yielded palynological organic matter (POM) except of red shale samples (depths 2402.5 m, 2402.7 m and 2534.8 m): the majority of samples contain low amounts of it; the only exception is a sample from depth 616.9 m, which yielded very high amounts of POM. The lowest amounts of POM are in samples from depths 4402.6 m and 3242.1 m.

(1) Sample 561 m. Palynofacies consists in 90% of small-sized equidimensional black opaque phytoclasts. Subordinate dark brownish cuticle fragments and rare sporomorphs (Fig. 5P, Q) occur. Dinoflagellate cysts are very rare – below 1%. Their assemblage consists chiefly of small peridinioids assigned to *Alterbidinium* spp. (Fig. 5A, I–K, N, O); rare, poorly preserved specimens of *Palaeohystrichophora infusorioides* have been found (Fig. 5L, M). They are characterized by delicate wall structure and pale colouration. Single gonyaulacoids are darker coloured, and are slightly worse preserved: *Pterodinium cingulatum* (Fig. 5C, D), *Odontochitina operculata* (Fig. 5S), *Pseudoceratium*? sp. (Fig. 5G, H).

(2) Sample 616.9 m. The sample, contrary to the remaining ones, contains high amounts of POM. Palynofacies consists of structureless, yellowish-brown coloured particles (80%), and variously preserved woody debris (Fig. 6D). Structureless particles show rigid structure (they are not amorphous; Fig. 6A–C) with common small black grains of opaque material (pyrite?; e.g., Fig. 6A, B). They represent highly degraded higher plant remains (Fig. 6C, Fig. 7M). Woody particles represent a range of phytoclasts (Fig. 7L) from black opaque ones, through dark-brown and black phytoclasts with translucent edges (Fig. 7O), to hyalinous, translucent particles. Single, well preserved, rather pale-coloured sporomorphs occur (Fig. 7A, B, I). Dinoflagellate cysts are very rare; they are pale-coloured and well preserved, commonly they are coated by structureless organic cloaks (Fig. 7C–H, J, K) making their determination impossible. *Spiniferites* sp. (Fig. 7F, G, J, K) and *Pterodinium* spp. (Fig. 7D, H) have been recognized.

(3) Sample 773.4 m. Palynofacies is composed of small-sized equidimensional, black, opaque phytoclasts (over 80%), pale-coloured amorphous organic cloaks and dinoflagellate cysts (a few per cent). Rare sporomorphs (mainly spores) occur; they are rather well preserved, relatively pale-coloured. Dinoflagellate cysts are pale-coloured and poorly preserved; their cyst wall structure bears traces of crystallization, they are commonly wrinkled and torn-off: many specimens are indeter-

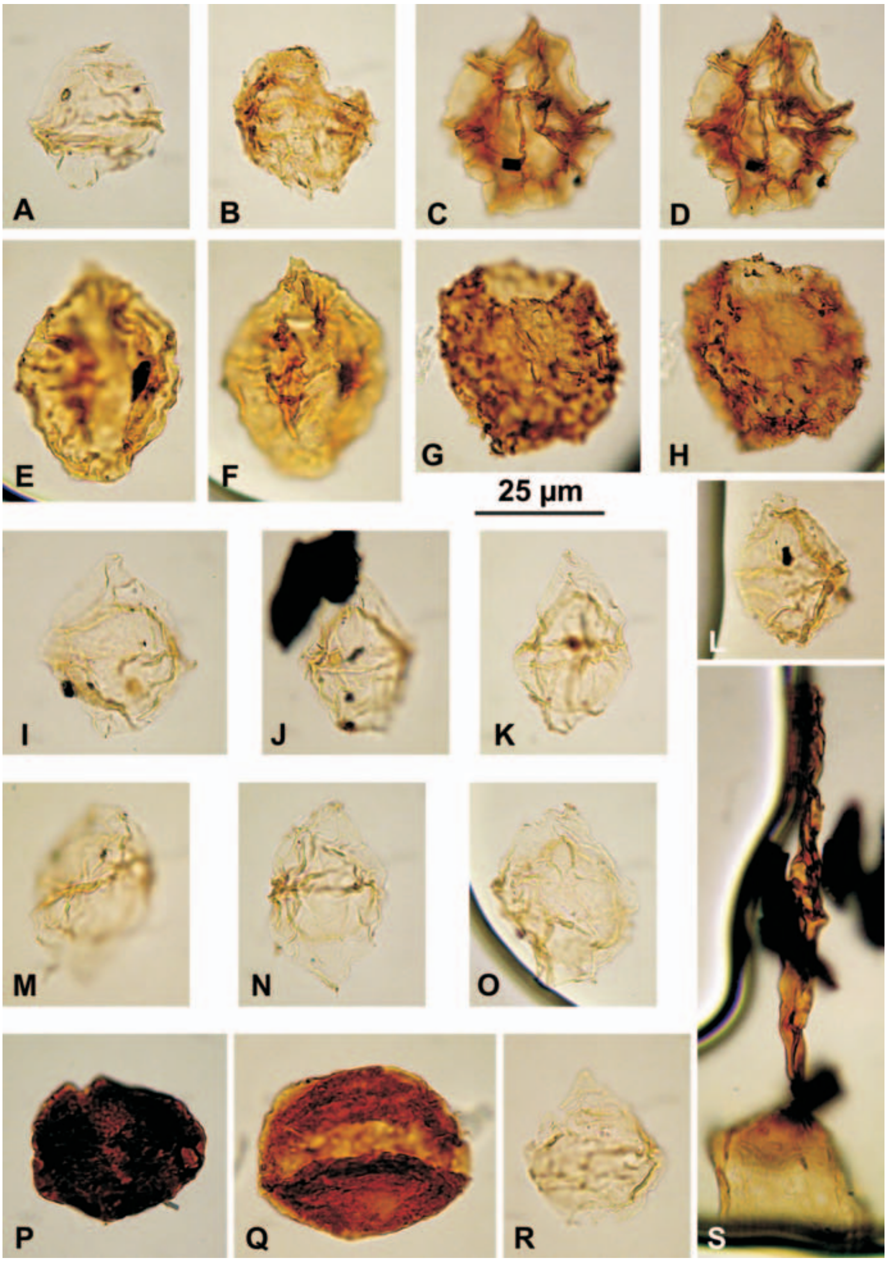


Fig. 5. Dinoflagellate cysts and sporomorphs from the Maruszyna IG-1 Deep Borehole; sample from depth 561 m. **A** – *Alterbidinium*? sp.; **B** – indeterminable dinoflagellate cyst; **C**, **D** – *Pterodinium cingulatum* (same specimen, various foci); **E**, **F** – undetermined dinoflagellate cyst (same specimen, various foci); **G**, **H** – *Pseudoceratium*? sp. (note dark colouration, especially in relation to peridinioids; same specimen, various foci), **I**–**K** – *Alterbidinium* spp.; **L**, **M** – poorly preserved specimens questionably assigned to *Palaeohystrichophora infusorioides*; **N**, **O** – *Alterbidinium* spp.; **P**, **Q** – dark coloured spores; **R** – incomplete peridinioid with 3I archaeopyle; **S** – operculum of *Odontochitina operculata*

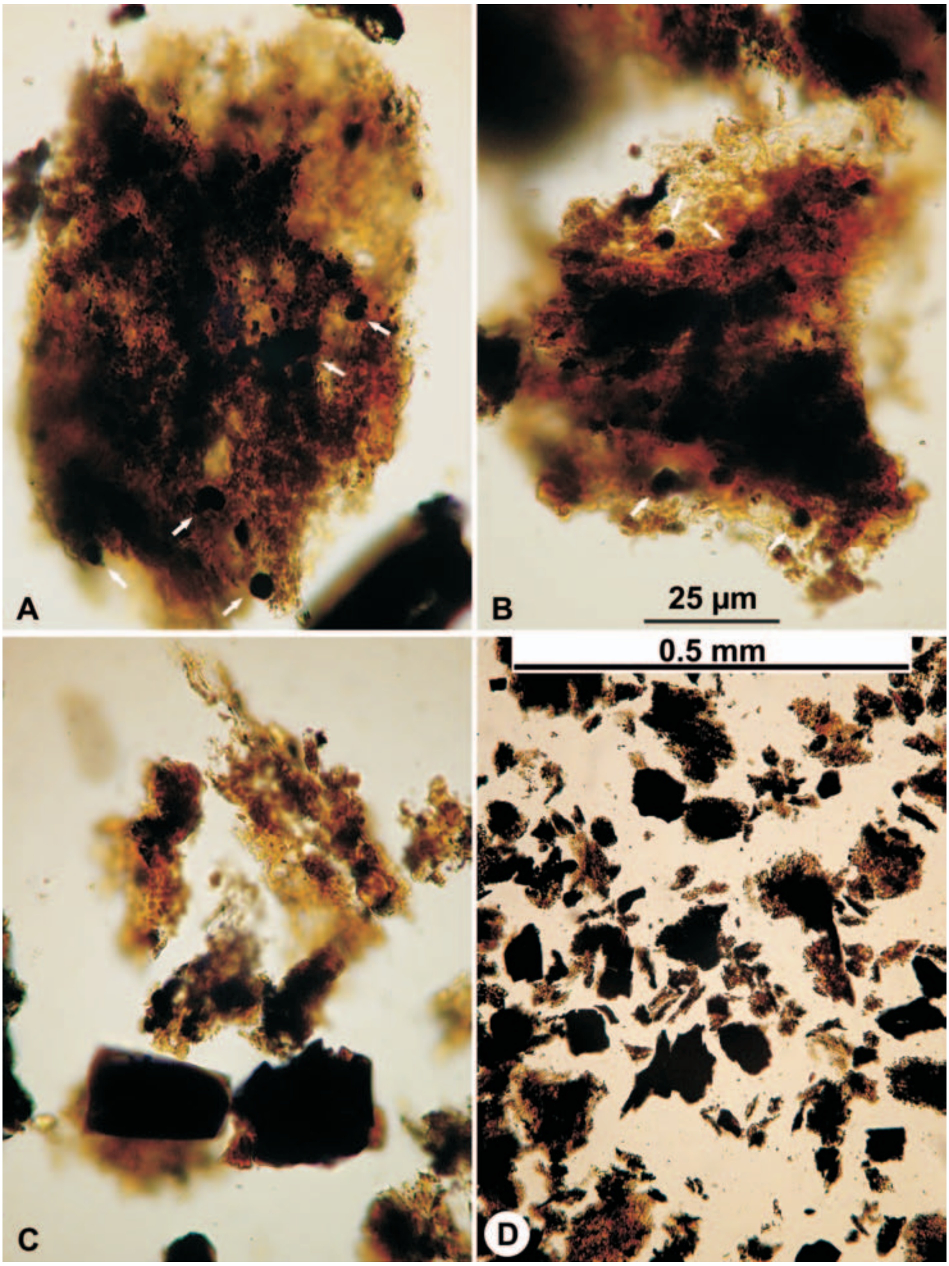
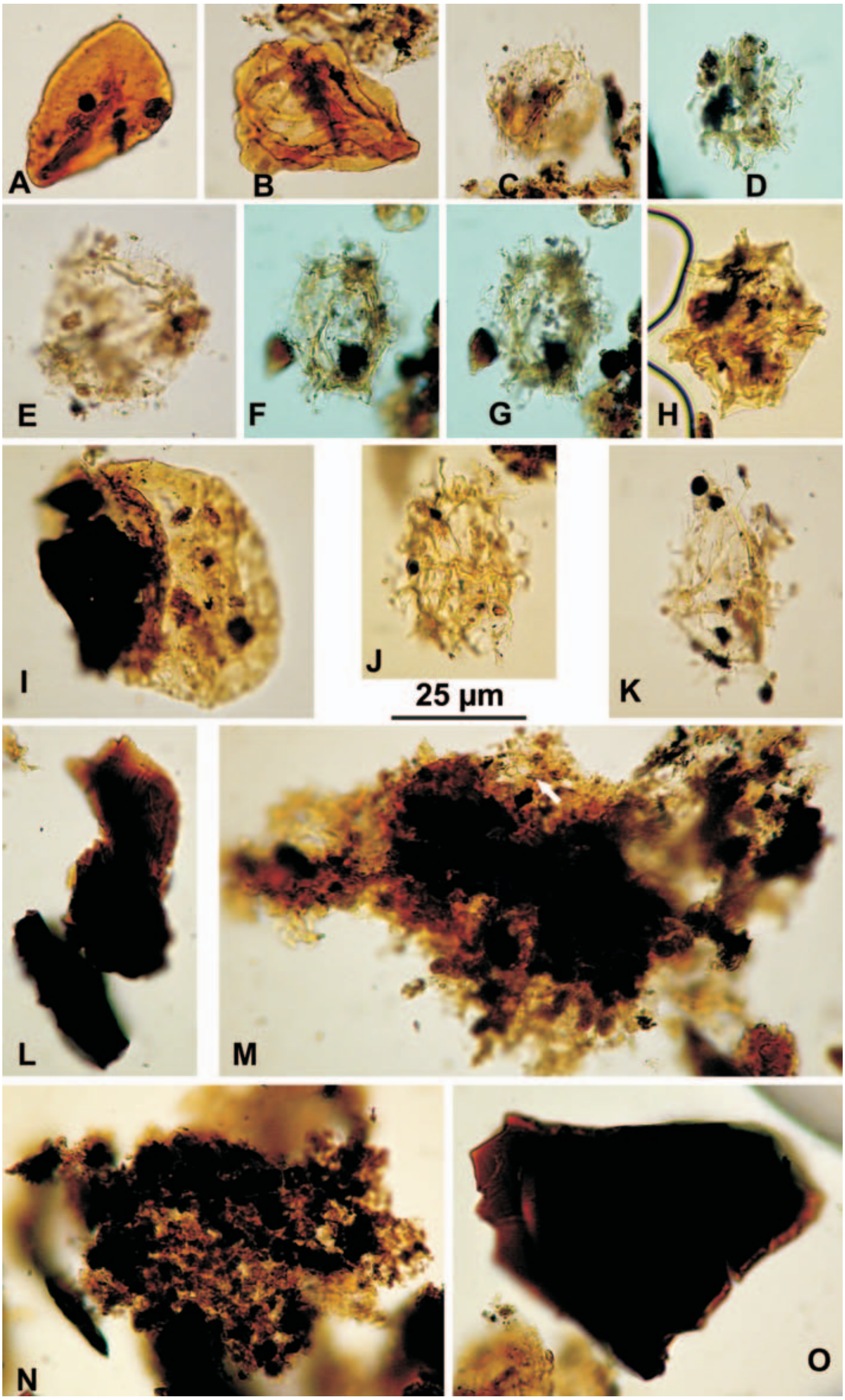


Fig. 6. Palynofacies and phytoclasts from the Maruszyna IG-1 Deep Borehole; sample from depth 616.9 m (25-µm scale bar in B refers also to A and C). **A**, **B** – structureless phytoclasts with opaque minerals (pyrite?; arrowed); **C** – highly degraded cuticular phytoclasts (upper part of photomicrograph) and black woody particles with dark brown, translucent edges (lower part of photomicrograph); **D** – palynofacies


A
B
C
D
E
F
G
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25 µm
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minable. Most frequent are specimens of *Nexosispinum vetusculum* (Fig. 8) and *Bourkidinium* spp. (Fig. 9). The following taxa have been determined (Figs 8–13): *Nexosispinum vetusculum*, *Bourkidinium* sp. 1 *sensu* Leereveld 1997, *Tanyosphaeridium salpinx*, *Bourkidinium* sp. A, *Wallodinium krutzschii*, *Tanyosphaeridium* sp. A, *Oligosphaeridium complex*, *Oligosphaeridium* sp., *Oligosphaeridium irregulare*, *Cymososphaeridium validum*, *Spiniferites* sp., *Pterodinium* ?*bab*, *Dingodinium cerviculum*, *Dingodinium albertii*, *Phoberocysta*? sp., *Odontochitina* sp., *Endoscrinium campanula*, *Diacanthum hollisteri*, *Muderongia* sp., *Circulodinium*? sp., *Cassiculosphaeridia*? sp., *Protoellipsodinium touile*, *Protoellipsodinium*? sp., *Kiokansium polypes*, *Protoellipsodinium* ?*clavulum*, *Circulodinium* sp., *Kiokansium*? sp., *Kiokansium unituberculatum*.

(4) Sample 846.2 m. Palynofacies consists of small-sized black opaque phytoclasts (30%), pale-coloured organic particles of uncertain origin (presumably land-plant debris and fragments of indeterminable aquatic palynomorphs; 50%), sporomorphs (spores and pollen grains) and dinoflagellate cysts (up to 10%). A characteristic feature of palynodebris is various preservation of their particles: majority is pale-coloured, poorly preserved, being torn-off and showing traces of crystallization. Other particles are well preserved. The same refers to dinoflagellate cysts, which include both wrinkled, usually incomplete specimens [mainly proximochorate and chorate specimens (Figs 14, 15)], and pale-coloured, fairly well preserved ones [e.g., *Ctenidodinium combazii* (Fig. 15C, F), *Chytroeisphaeridium chytroeides* (Fig. 14G, J), *Dingodinium minutum* (Fig. 15D, E)]. The dinoflagellate assemblage is dominated by specimens of *Lithodinia*-*Valensiella*-*Epiplosphaera* morphotype (Fig. 14). Less frequent are chorate, commonly poorly preserved specimens of *Adnatosphaeridium*-*Systematophora* morphotype (Fig. 15). Following dinoflagellate cyst species were found: *Systematophora*? sp., *Ctenidodinium combazii*, *Dingodinium minutum*, *Ctenidodinium ornatum*, *Endoscrinium asymmetricum*, *Cleistosphaeridium*? sp., *Adnatosphaeridium caulleryi*, *Systematophora valensii*, *Gonyaulacysta jurassica*, *Epiplosphaera* sp., *Polygonifera* sp., *Lithodinia* sp., *Chytroeisphaeridium chytroeides*, *Sentusidinium* sp., *Batiacasphaera* sp., *Lithodinia caytonensis*, *Ellipsoidictyum gochtii*.

(5) Sample 957 m. This sample (conglomerate) yielded very small amounts of palynological organic matter, which consists almost exclusively of black opaque phytoclasts. No palynomorphs have been found.

Fig. 7. Dinoflagellate cysts, sporomorphs and phytoclasts from the Maruszyna IG-1 Deep Borehole; sample from depth 616.9 m. **A**, **B** – spores (note well preserved structure and relative pale colouration); **C** – undetermined dinoflagellate cyst; **D** – *Pterodinium* sp.; **E** – undetermined dinoflagellate cyst; **F**, **G** – *Spiniferites* sp. (same specimen, various foci); **H** – *Pterodinium* sp.; **I** – pollen grain; **J**, **K** – *Spiniferites* spp.; **L** – woody particles: black opaque one (bottom of the photomicrograph), black with translucent edges (in the middle), hyalinous one at the top; **M** – structureless particle with partly preserved plant tissue structure (arrowed); **N** – structureless particle densely filled by tiny opaque particles (pyrite?); **O** – black phytoclast with translucent edges

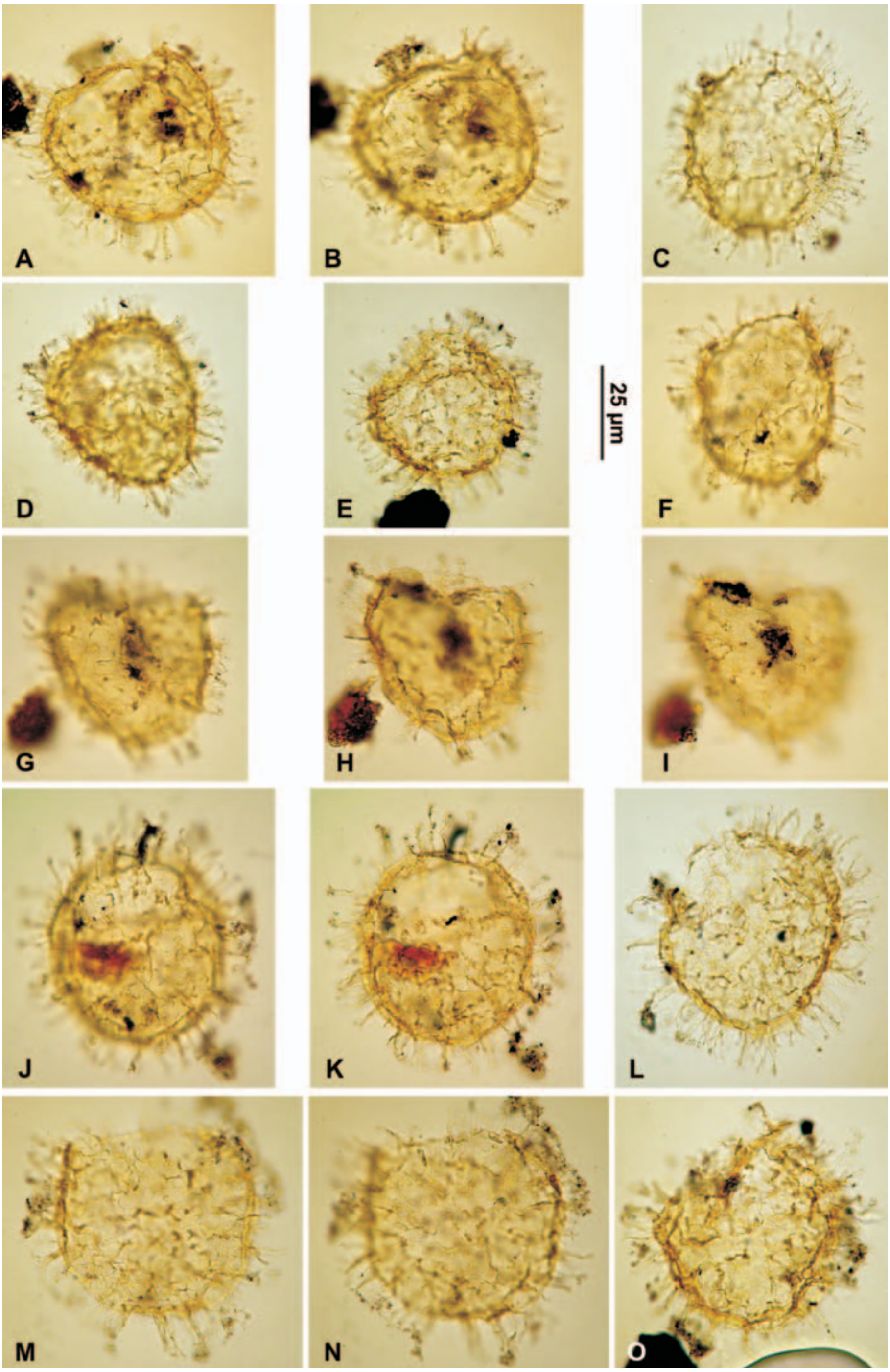


Fig. 8. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 773.4 m. **A**–**O** – *Nexosispinum vetusculum* (A, B: same specimen, various foci; G–I: same specimen, various foci; J, K: same specimen, various foci; M, N: same specimen, various foci)

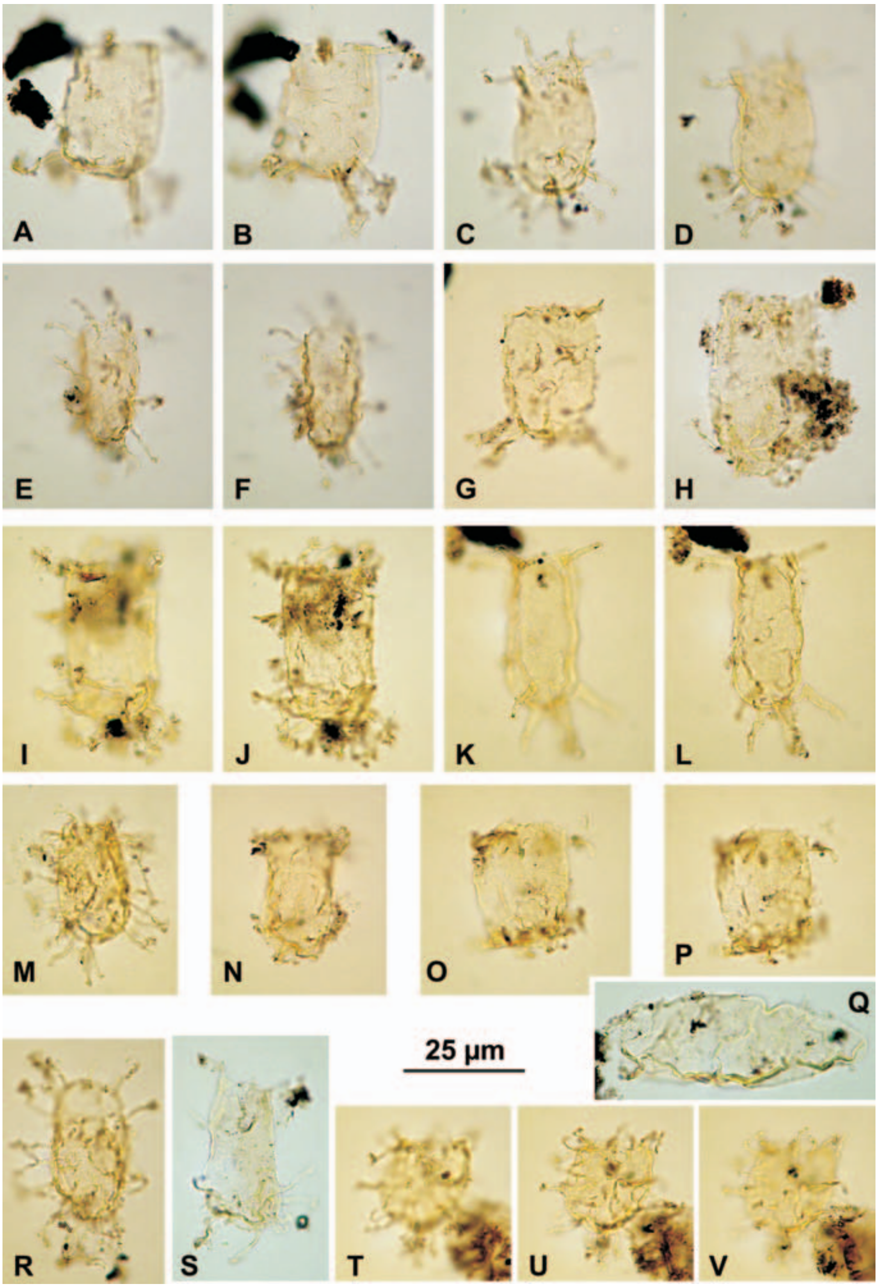


Fig. 9. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 773.4 m. **A**–**D** – *Bourkidinium* sp. 1 *sensu* Leereveld 1997 (A, B: same specimen, various foci; C, D: same specimen, various foci); **E**, **F** – *Tanyosphaeridium salpinx* (same specimen, various foci); **G**–**L** – *Bourkidinium* sp. 1 *sensu* Leereveld 1997 (I, J: same specimen, various foci; K, L: same specimen, various foci); **M** – *Tanyosphaeridium salpinx*; **N**–**P** – *Bourkidinium* sp. A (O, P: same specimen, various foci); **Q** – *Wallodinium krutzschii*; **R** – *Tanyosphaeridium salpinx*; **S** – *Bourkidinium* sp. 1 *sensu* Leereveld 1997; **T**–**V** – *Tanyosphaeridium* sp. A (same specimen, various foci)

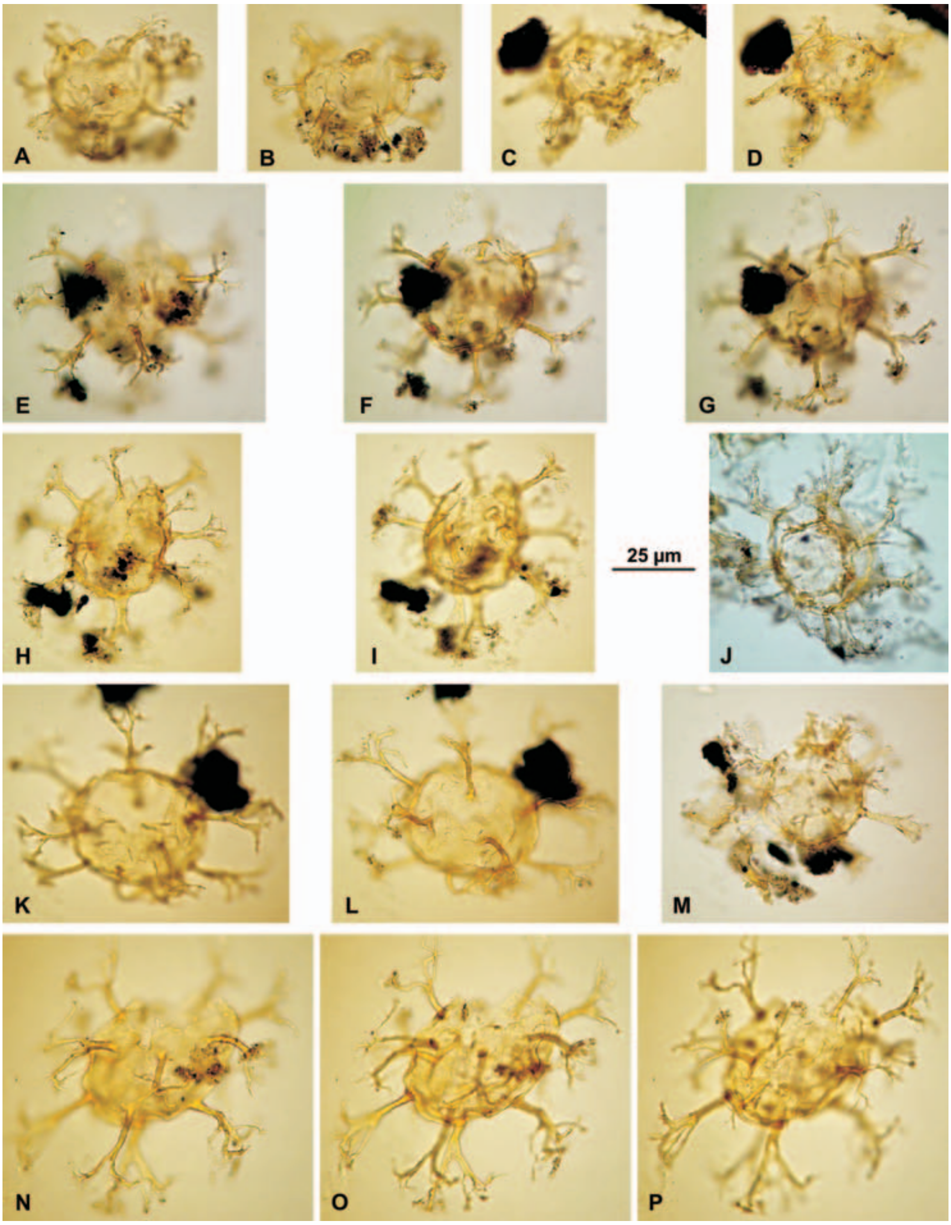


Fig. 10. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 773.4 m. **A**, **B** – *Oligosphaeridium complex* (same specimen, various foci); **C**, **D** – *Oligosphaeridium* sp. (same specimen, various foci); **E**–**G** – *Cymososphaeridium validum* (same specimen, various foci); **H**–**J** – *Oligosphaeridium irregulare* (H, I: same specimen, various foci); **K**, **L** – *Cymososphaeridium validum* (same specimen, various foci); **M** – *Oligosphaeridium irregulare*; **N**–**P** – *Cymososphaeridium validum* (same specimen, various foci)

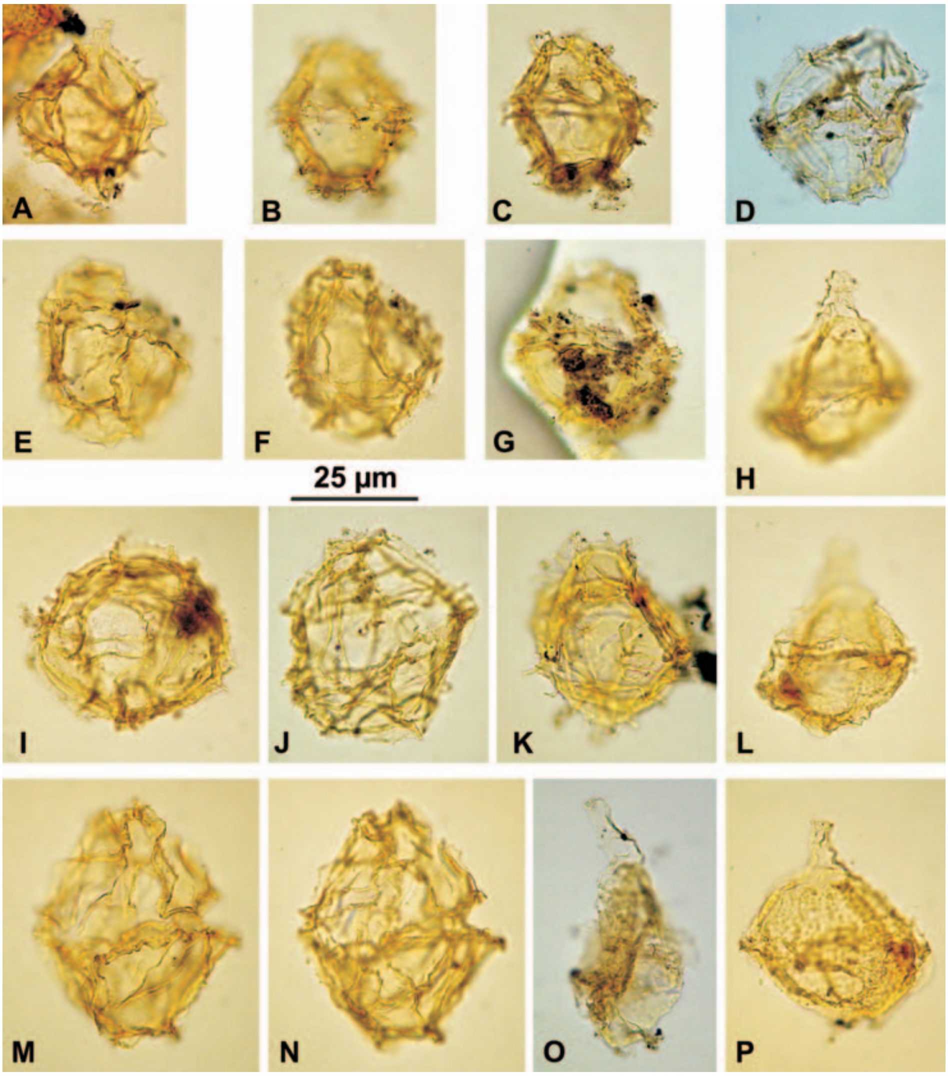


Fig. 11. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 773.4 m. **A–C** – *Spiniferites* sp. (B, C: same specimen, various foci); **D–G** – *Pterodinium* ?*bab* (E, F: same specimen, various foci); **H, L** – *Dingodinium albertii* (same specimen, various foci); **I, J** – *Pterodinium* ?*bab*; **K** – *Spiniferites* sp.; **M, N** – *Pterodinium* ?*bab* (same specimen, various foci); **O** – *Dingodinium cerviculum*; **P** – *Dingodinium albertii*

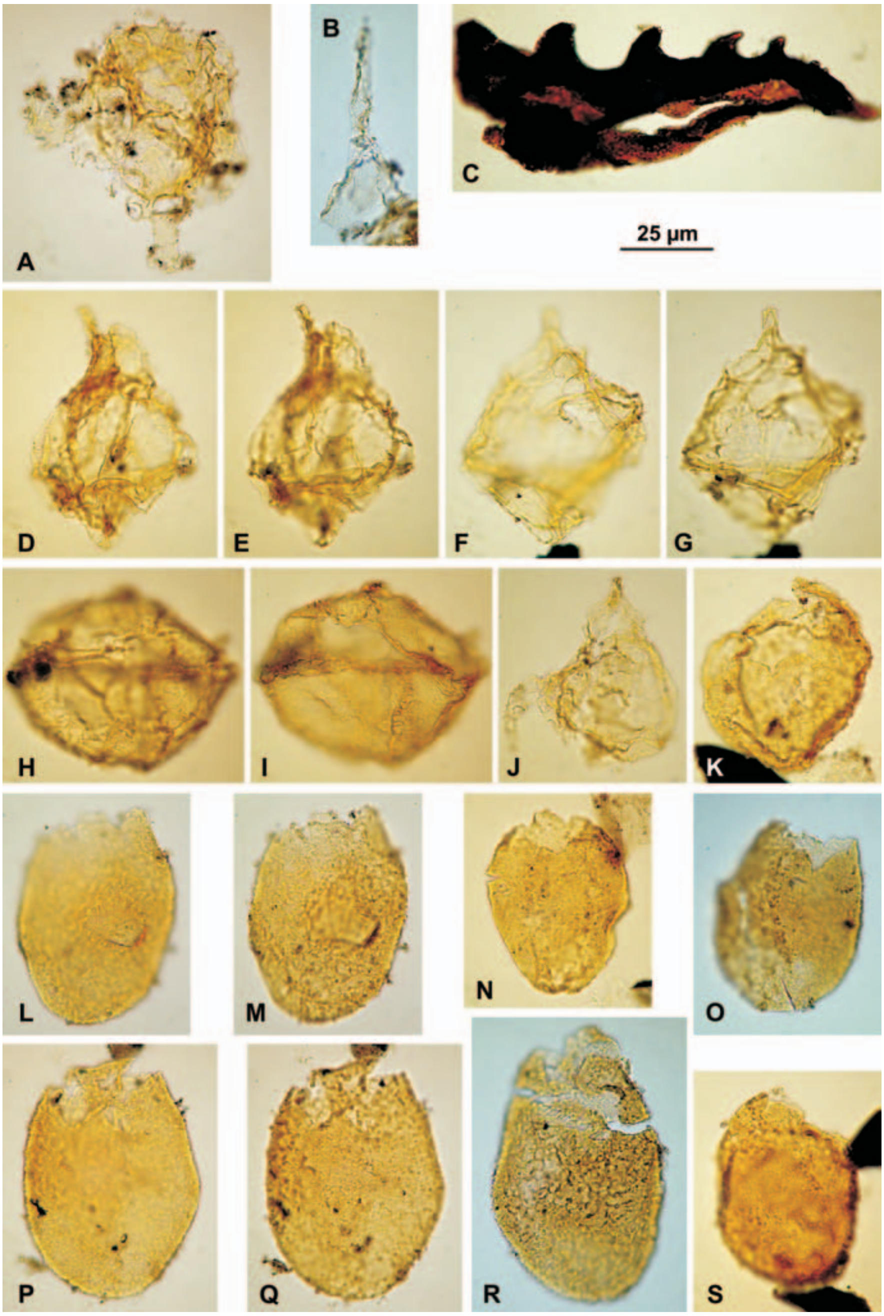


Fig. 12. Dinoflagellate cysts and a scolecodont from the Maruszyna IG-1 Deep Borehole; sample from depth 773.4 m. **A** – *Phoberocysta*? sp.; **B** – *Odontochitina* sp.; **C** – scolecodont; **D**–**G** – *Endoscrinium campanula* (D, E: same specimen, various foci; F, G: same specimen, various foci); **H**, **I** – *Diacanthum hollisteri* (same specimen, various foci); **J** – *Muderongia* sp.; **K** – undetermined dinoflagellate cyst (*Circulodinium*? sp.); **L**–**S** – *Cassiculosphaeridia*? sp. (L, M: same specimen, various foci; P, Q: same specimen, various foci)

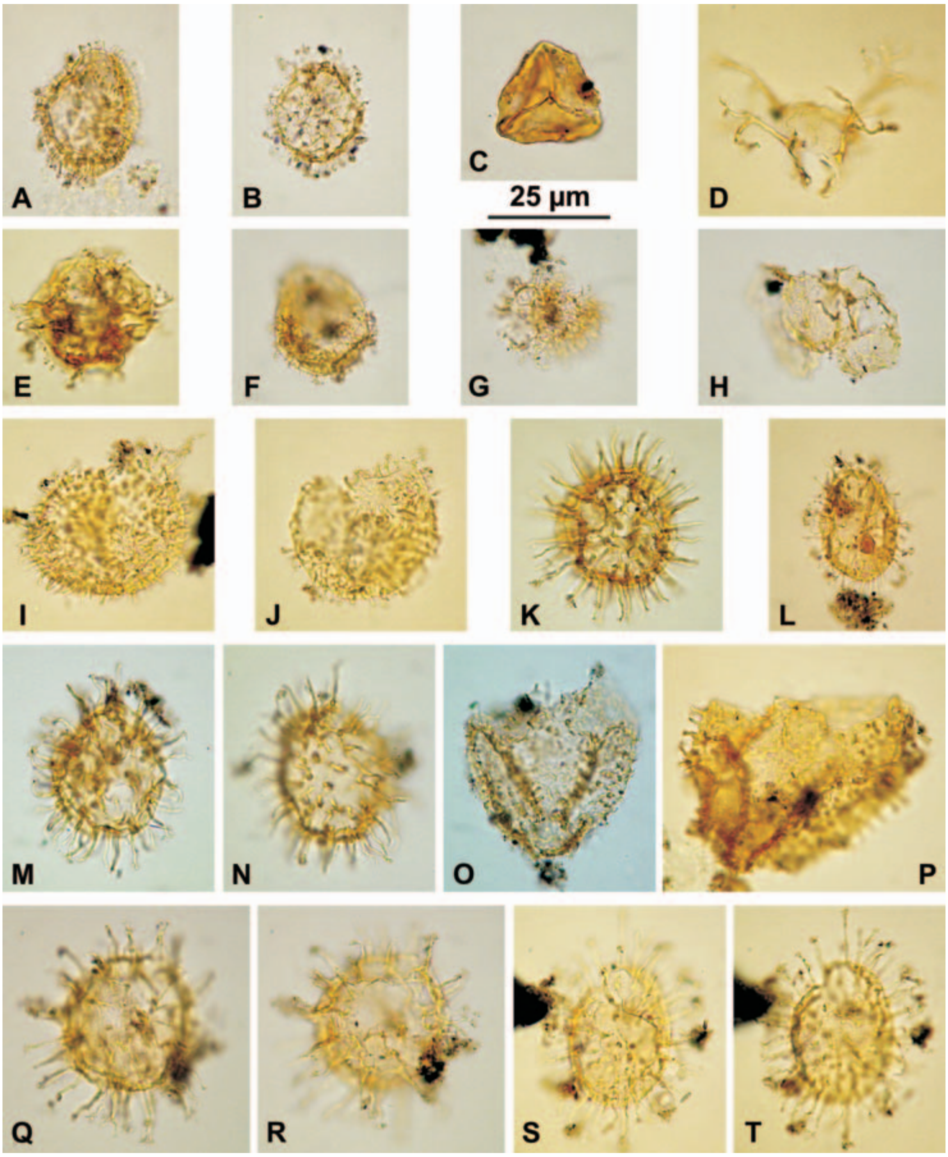


Fig. 13. Dinoflagellate cysts and sporomorphs from the Maruszyna IG-1 Deep Borehole; sample from depth 773.4 m. **A**, **B** – *Protoellipsodinium touile*; **C** – spore; **D** – operculum of *Cymososphaeridium validum*; **E** – *Spiniferites* sp.; **F**, **G** – spiny dinoflagellate cysts, presumably *Protoellipsodinium* sp.; **H** – pollen grain; **I**, **J** – *Protoellipsodinium*? sp.; **K** – *Kiokansium polypes*; **L** – *Protoellipsodinium ?clavulum*; **M**, **N** – *Kiokansium polypes*; **O**, **P** – *Circulodinium* sp.; **Q**, **R** – *Kiokansium*? sp. (same specimen, various foci); **S**, **T** – *Kiokansium unituberculatum* (same specimen, various foci)

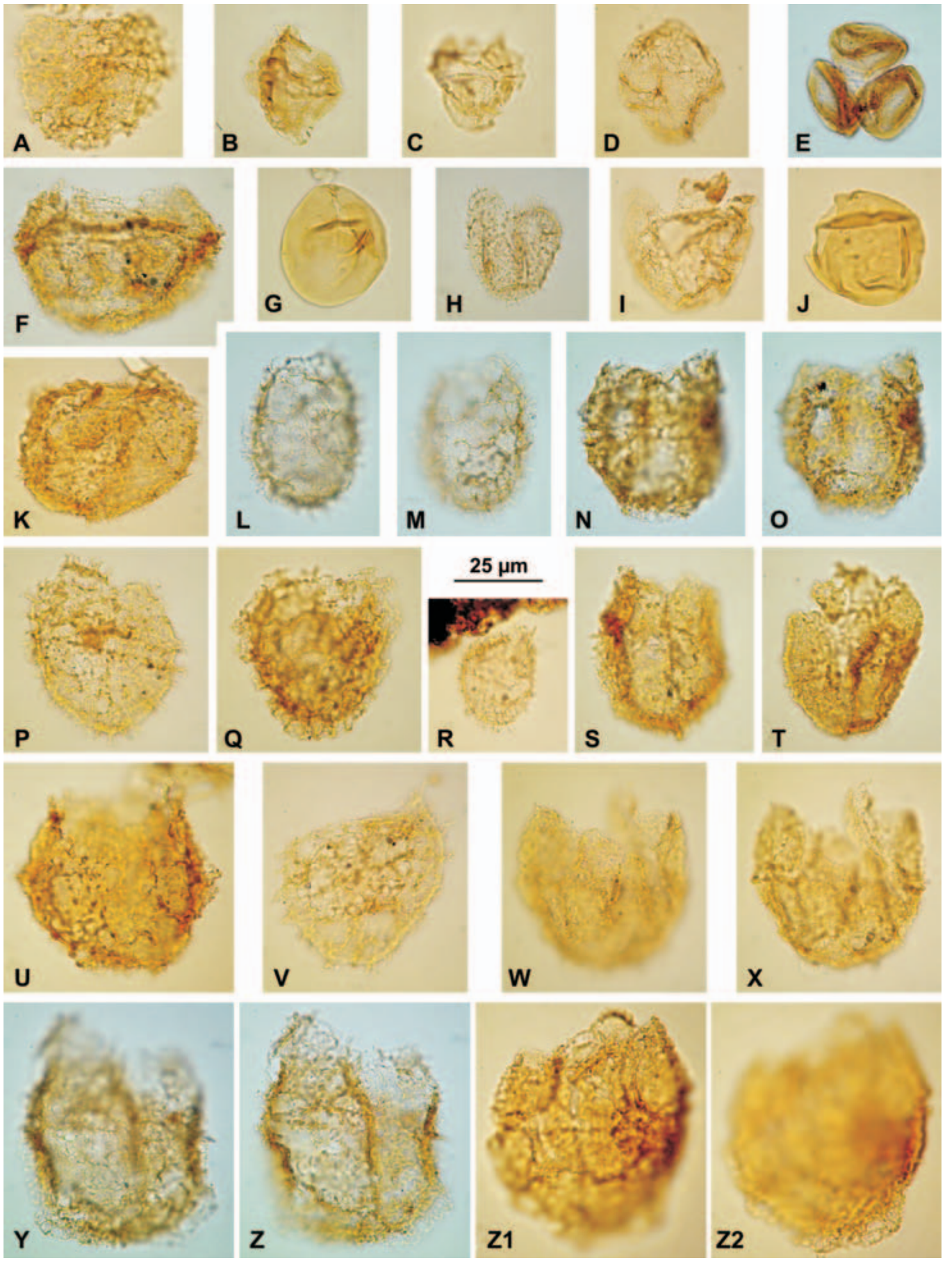


Fig. 14. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 846 m. **A** – *Epiplosphaera* sp.; **B**, **C** – *Polygonifera* sp.; **D** – undetermined dinoflagellate cyst; **E** – sporomorphs; **F** – *Lithodinia* sp.; **G** – *Chytroeisphaeridium chytroeides*; **H** – *Sentusidinium* sp.; **I** – *Batiacasphaera* sp.; **J** – *Chytroeisphaeridium chytroeides*; **K** – *Lithodinia* sp.; **L**, **M** – *Epiplosphaera* sp. (same specimen, various foci); **N**, **O** – *Lithodinia caytonensis* (same specimen, various foci); **P** – *Ellipsoidictyum gochtii*; **Q** – *Epiplosphaera* sp.; **R** – *Sentusidinium* sp.; **S**–**U** – *Lithodinia* spp.; **V** – *Ellipsoidictyum gochtii*; **W**, **X** – *Lithodinia* sp. (same specimen, various foci); **Y**–**Z2** – *Lithodinia caytonensis* (Y, Z: same specimen, various foci; Z1, Z2: same specimen, various foci)

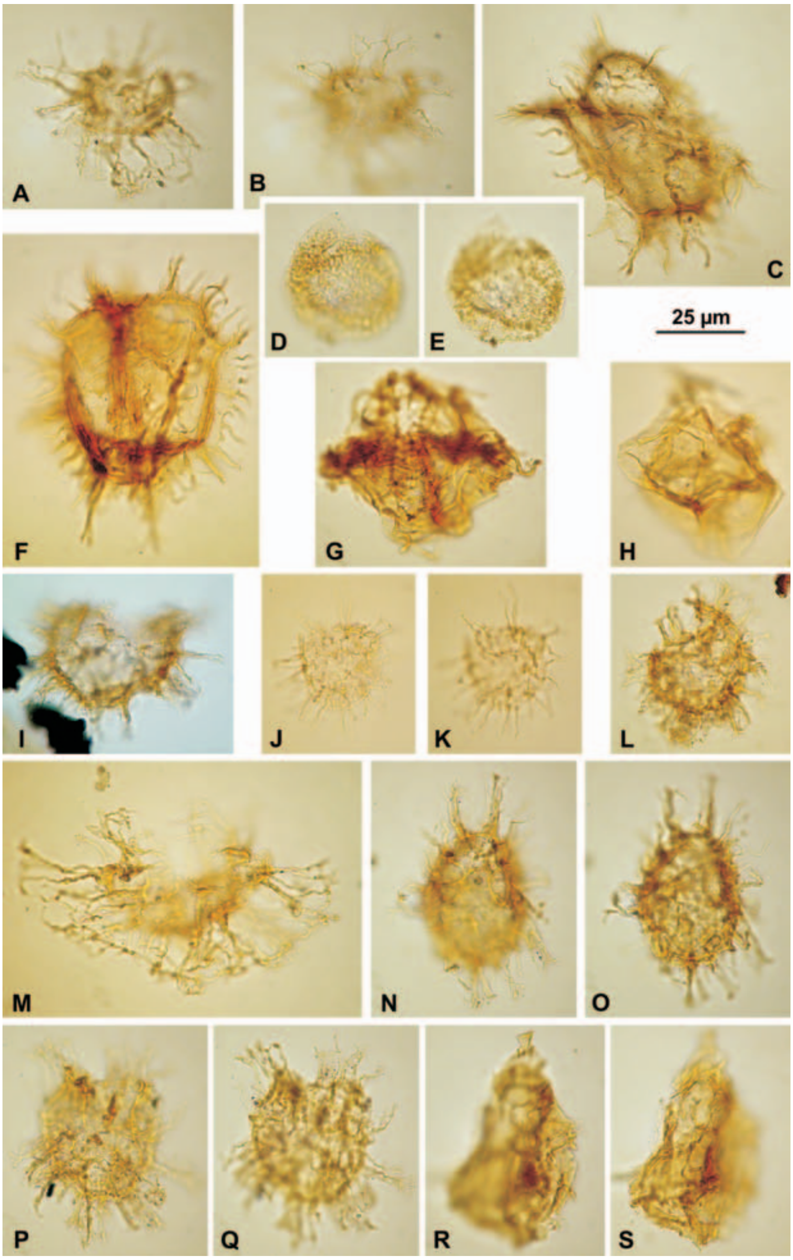
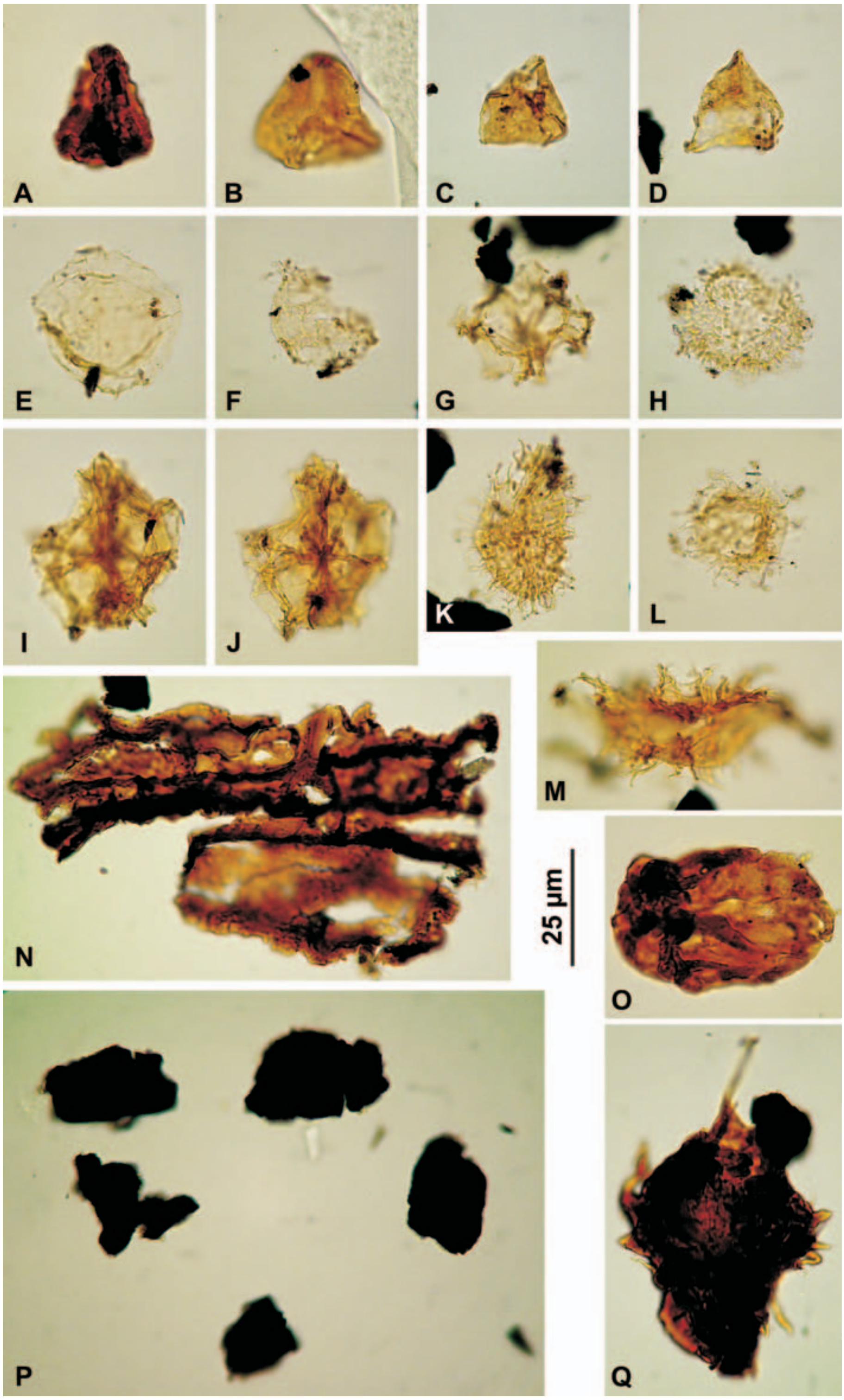


Fig. 15. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 846 m. **A**, **B** – Systematophora? sp. (same specimen, various foci); **C** –*Ctenidodinium combazii*; **D**, **E** – *Dingodinium minutum* (same specimen, various foci); **F** – *Ctenidodinium combazii*; **G** – *Ctenidodinium ornatum*; **H** – *Endoscrinium asymmetricum*; **I** – undetermined chorate species with apical archaeopyle; **J**, **K** – *Cleistosphaeridium*? sp. (same specimen, various foci); **L** – undetermined chorate species; **M** – *Adnatosphaeridium caulleryi*; **N**, **O** – undetermined chorate species (same specimen, various foci); **P**, **Q** – *Systematophora valensii* (same specimen, various foci); **R**, **S** – *Gonyaulacysta jurassica* (same specimen, various foci)


A
B
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25 µm
O
P
Q

(6) Sample 1097.4 m. Palynofacies is composed of small-sized, easily disintegrating black opaque equidimensional phytoclasts (Fig. 16P). Rare dark-brown highly degraded cuticles occur (Fig. 16N). Palynomorphs are represented by sporomorphs (spores – well preserved and moderately dark-coloured; Fig. 16A–D, O) and dinoflagellate cysts. The latter show bimodal state of preservation: majority is pale-coloured, and despite a delicate thin-walled nature relatively well preserved, although commonly wrinkled (e.g., Fig. 16E, H, I, J, M). Others are dark coloured, degraded, indeterminable (Fig. 16Q). The following dinoflagellate cyst taxa have been identified: *Spiniferites* sp. (Fig. 16L), *Impletosphaeridium*? sp. (Fig. 16K), *Palaeohystrichophora*? sp. (Fig. 16F), *Pterodinium cingulatum* (Fig. 16I, J).

(7) Sample 1225.5 m. Dinoflagellate cysts are frequent palynofacies elements in this sample. However, they occur commonly as torn-off fragments of thin-walled proximate specimens. The latter are represented by *Kallospahaeridium* and *Dissiliodinium* species (Fig. 17). Specimens of *Phallocysta* (Fig. 18) are common whereas *Nannoceratopsis* is subordinate (Fig. 19A–J). Aquatic palynomorphs are additionally represented by rare acritarchs (small spherical spiny morphotypes; Fig. 20B, C, E, F, H, K) and organic linings of foraminifera (Figs 19K; 20L, Q); a single specimen of thick-walled *Tasmanites* has been found (Fig. 19L, M). Terrestrial palynofacies elements consist of small-sized equidimensional, black, opaque phytoclasts, small-sized woody particles, and sporomorphs represented by spores (Fig. 20A, C, D, I, J, R). Palynomorphs are rather pale-coloured, well-preserved. The latter feature refers to wall structure of majority specimens; delicate proximate forms (*Kallosphaeridium*) are commonly wrinkled and/or torn-off. Some specimens of thicker-walled *Nannoceratopsis* (mainly *N. gracilis*) have wall structure slightly damaged by crystal growth, presumably of pyrite (e.g., Fig. 20B, I, J – specimens with opaque crystals, and Fig. 20D, F – specimens with empty crystal cavities). Comparison of palynomorph colouration is shown on Figure 20Q, R. The following dinoflagellate cysts were found: *Phallocysta* spp., *Valvaeodinium* sp. A, *Nannoceratopsis deflandrei senex*, *Nannoceratopsis gracilis*, *Nannoceratopsis raunsgardii*, *Nannoceratopsis* sp., *Nannoceratopsis dictyambonis*, *Nannoceratopsis ?gracilis* (large specimen), *Dissiliodinium* sp., *Kallosphaeridium praussii*, *Kallosphaeridium capulatum*, *Dissiliodinium lichenoides*, *Kallosphaeridium* sp., *Atopodinium* sp.

(8) Sample 1341.8 m. Palynofacies consists of small-sized particles represented by black opaque phytoclasts (both equidimensional and elongated; up to 40%), dark brown phytoclasts and cuticle remains (30%), sporomorphs (20%), and

←

Fig. 16. Sporomorphs, dinoflagellate cysts and phytoclasts from the Maruszyna IG-1 Deep Borehole; sample from depth 1097.4 m. **A**–**D** – spores; **E** – peridinioid cyst; **F** – incomplete specimen, presumably *Palaeohystrichophora* sp.; **G** – incomplete specimen; **H** – small spiny specimen; **I**, **J** – *Pterodinium cingulatum* (same specimen, various foci); **K** – *Impletosphaeridium*? sp.; **L** – *Spiniferites* sp.; **M** – wrinkled undetermined specimen; **N** – dark coloured cuticle; **O** – sporomorphs; **P** – main component of palynofacies: black opaque phytoclasts; **Q** – dark coloured undeterminable chorate dinoflagellate cyst

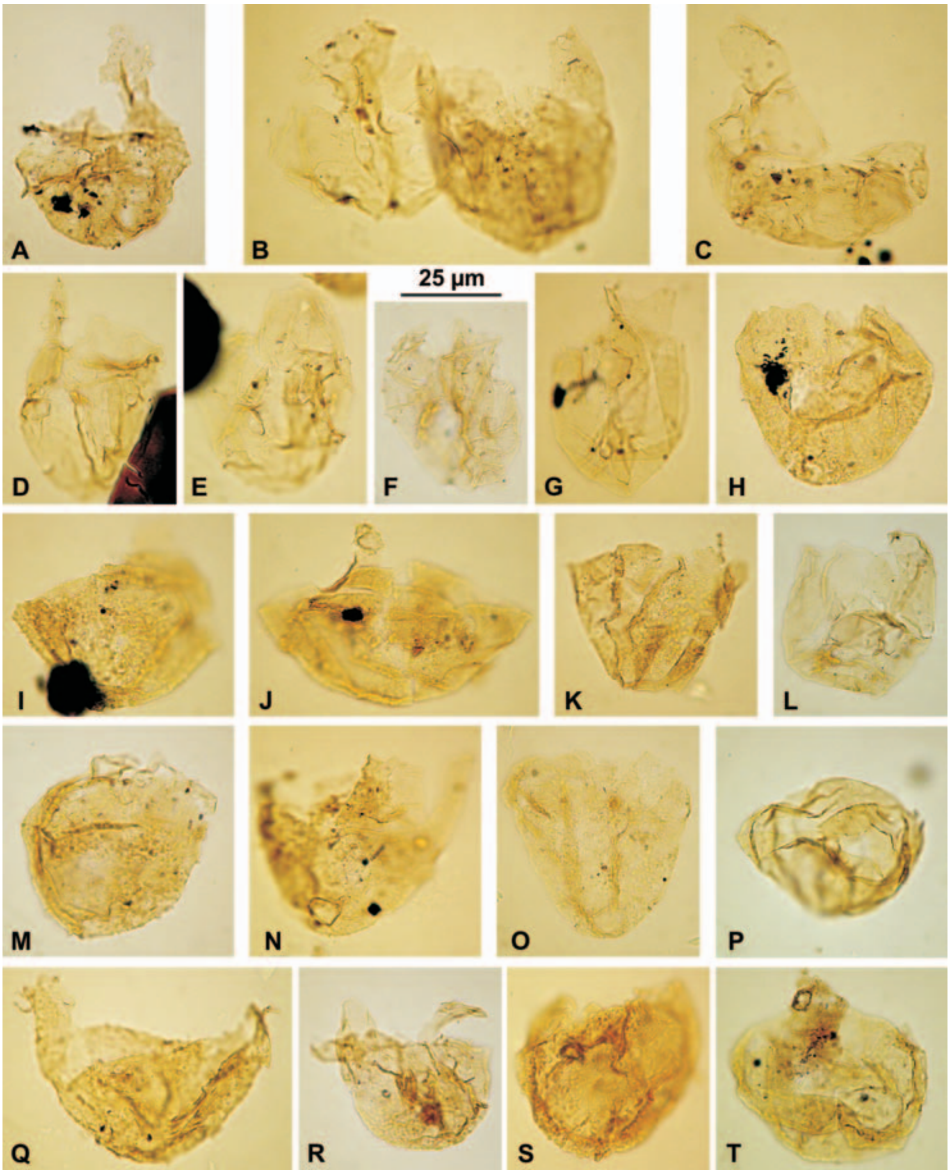

Fig. 17. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 1225.5 m. **A**, **B** – *Kallosphaeridium praussii*; **C** – *Dissiliodinium* sp.; **D**–**G** – *Kallosphaeridium praussii*; **H** – *Kallosphaeridium capulatum*; **I**, **J** – *Dissiliodinium lichenoides*; **K** – *Kallosphaeridium capulatum*; **L –** *Kallosphaeridium praussii*; **M**–**O** – *Kallosphaeridium capulatum*; **P** – *Dissiliodinium* sp.; **Q** – *Dissiliodinium lichenoides*; **R**, **S** – *Kallosphaeridium capulatum*; **T** – *Dissiliodinium lichenoides*

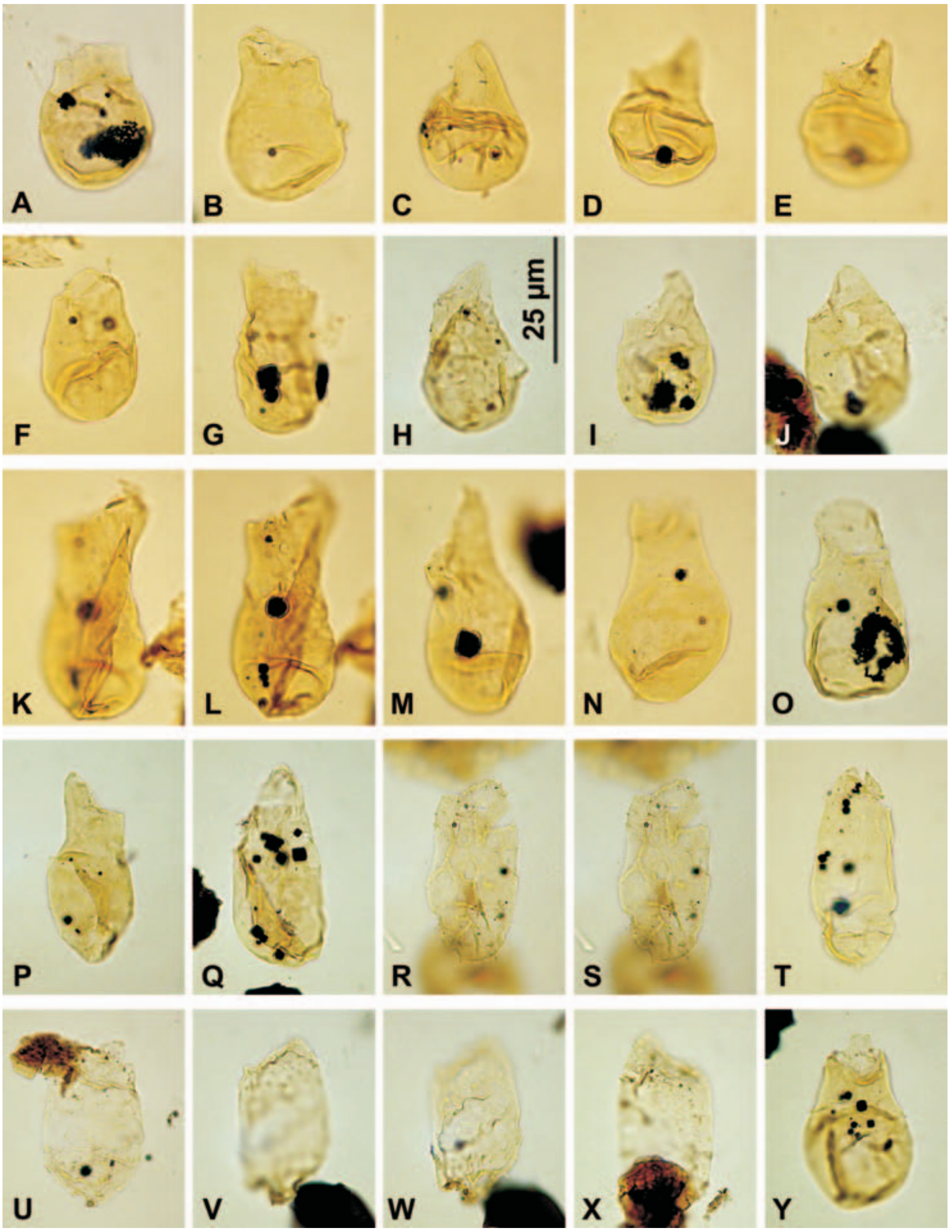

Fig. 18. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 1225.5 m (scale bar in H refers to all other photomicrographs). **A**–**Q** – *Phallocysta* spp.; **R**–**X** – *Valvaeodinium* sp. A; **Y** – *Phallocysta* sp.

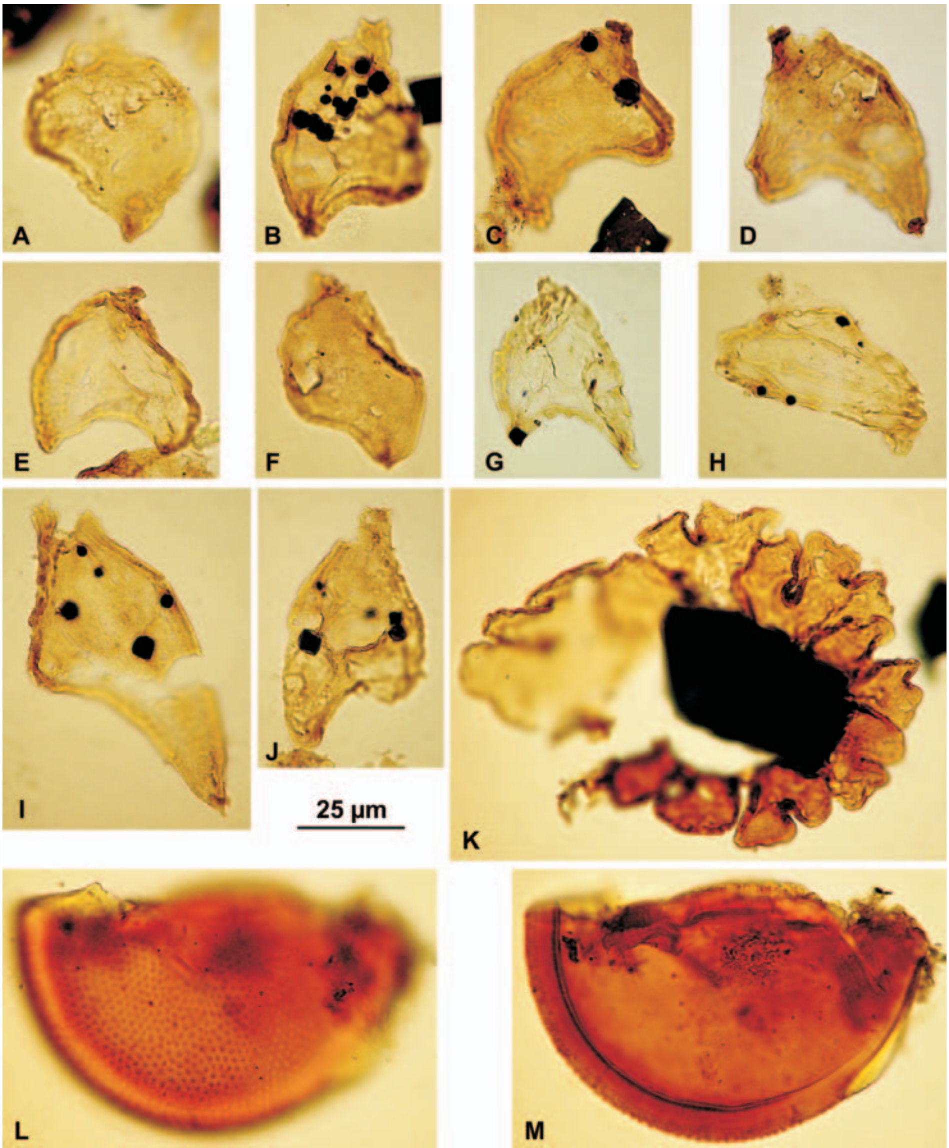

Fig. 19. Palynomorphs from the Maruszyna IG-1 Deep Borehole; sample from depth 1225.5 m. **A** – *Nannoceratopsis deflandrei senex*; **B**–**D** – *Nannoceratopsis gracilis*; **E** – *Nannoceratopsis raunsgardii*; **F** – *Nannoceratopsis* sp.; **G**, **H** – *Nannoceratopsis dictyambonis*; **I** – *Nannoceratopsis* ?*gracilis* (large specimen); **J** – *Nannoceratopsis gracilis*; **K** – Foraminifera's organic lining; **L**, **M** – *Tasmanites* sp. (same specimen, various foci)

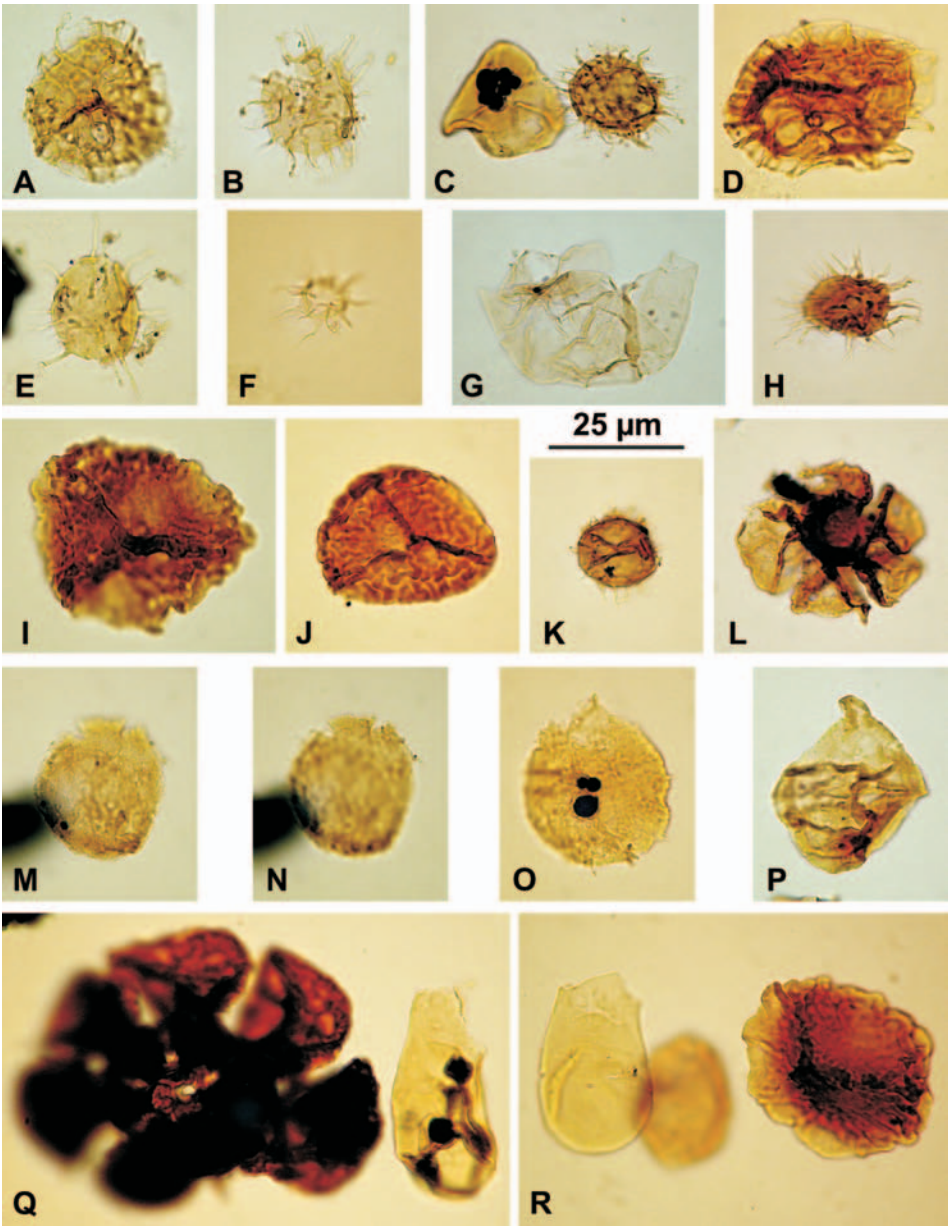

Fig. 20. Palynomorphs from the Maruszyna IG-1 Deep Borehole; sample from depth 1225.5 m. **A** – spore; **B** – acritarch; **C** – spore (right) and acritarch (left); **D** – spore; **E**, **F** – acritarchs; **G** – thin-walled dinoflagellate cyst *Kallosphaeridium* sp.; **H** – acritarch; **I**, **J** – spores; **K** – acritarch; **L** – Foraminifera's organic lining; **M**, **N** – dinoflagellate cyst sp. B (same specimen, various foci); **O** – palynomorph of uncertain taxonomy; **P** – dinoflagellate cyst sp. C; **Q** – Foraminifera's organic lining (left) and dinoflagellate cyst *Phallocysta* sp. (right); **R** – dinoflagellate cyst *Phallocysta* sp. (left) and spore (right)

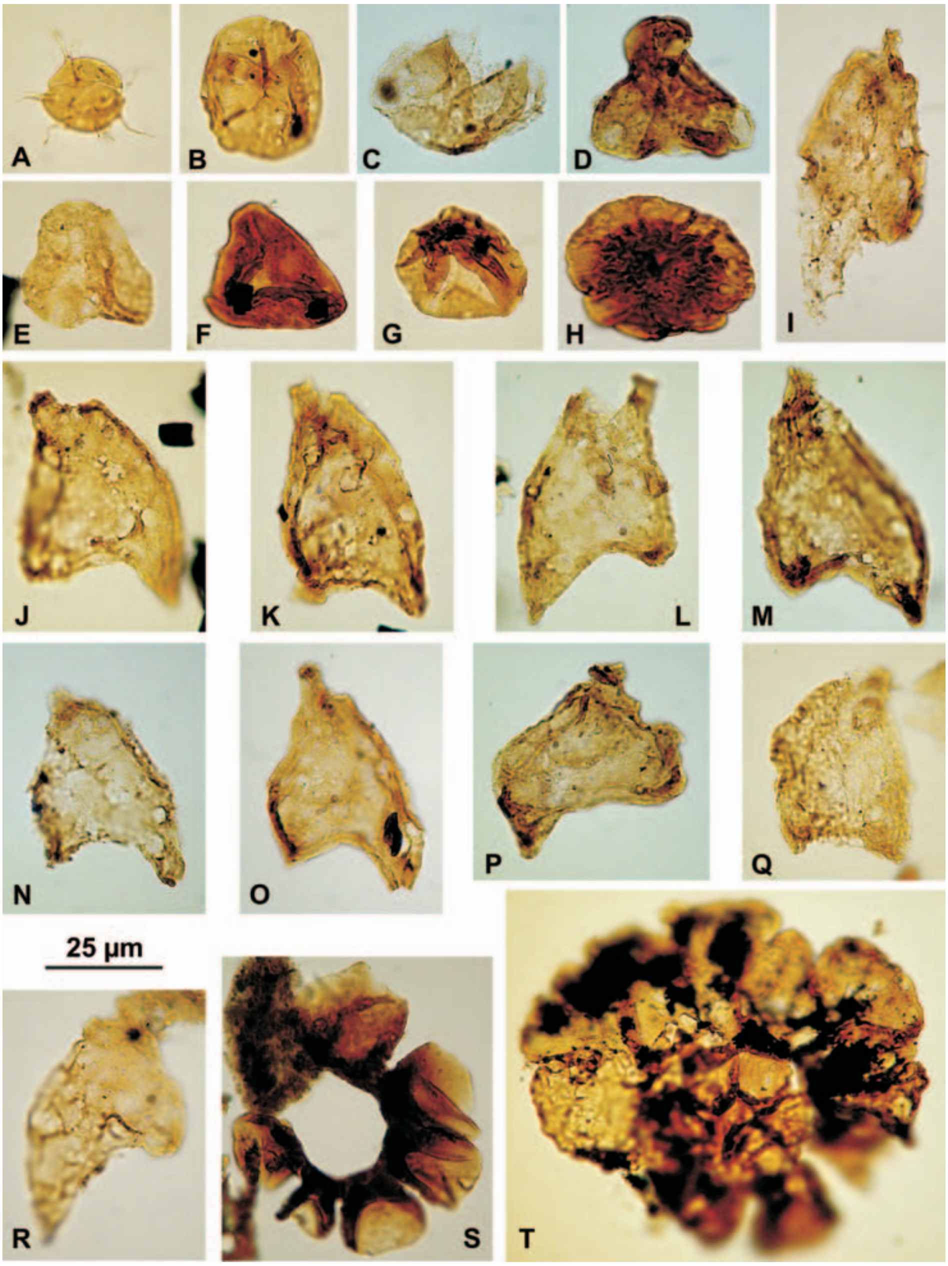

Fig. 21. Palynomorphs from the Maruszyna IG-1 Deep Borehole; sample from depth 1341.8 m. **A** – acritarch; **B**–**H** – spores; **I** – *Nannoceratopsis ?gracilis* (large specimen); **J**, **K** – *Nannoceratopsis gracilis*; **L** – *Nannoceratopsis ridingii*; **M** – *Nannoceratopsis spiculata*; **N** – *Nannoceratopsis ?dictyambonis*; **O**, **P** – *Nannoceratopsis gracilis*; **Q** – *Nannoceratopsis evae*; **R** – *Nannoceratopsis gracilis*; **S**, **T** – Foraminifera's organic linings

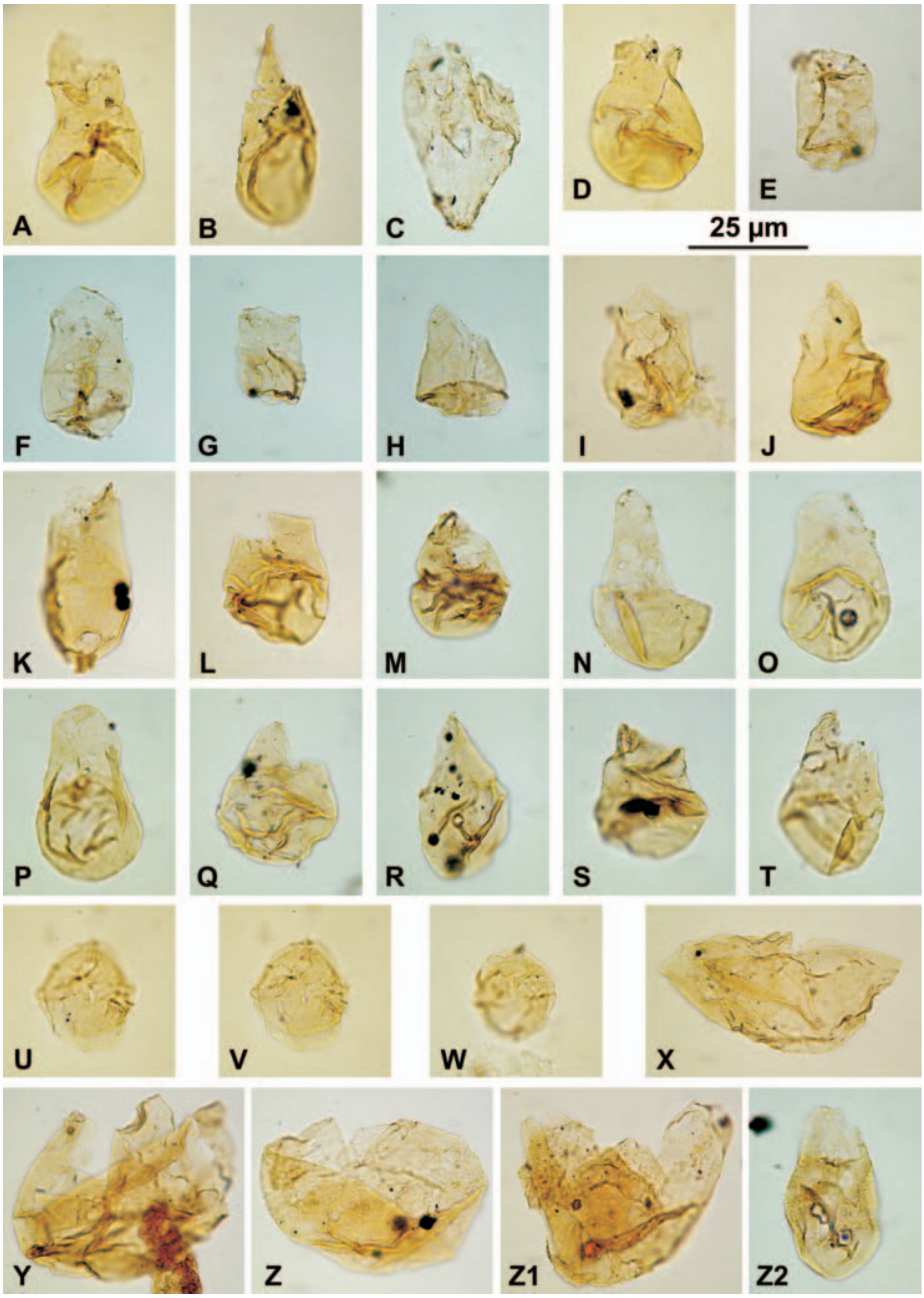

Fig. 22. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 1341.8 m. **A**, **B** – *Phallocysta elongata*; **C** – *Kallosphaeridium hypornatum*; **D** – *Phallocysta elongata*; **E** – *Valvaeodinium* sp. A; **F**–**T** – *Phallocysta* sp.; **U**–**W** – dinoflagellate cyst sp. A (U, V: same specimen, various foci); **X**–**Z1** – *Dissiliodinium* sp.; **Z2** – *Phallocysta* sp. A

aquatic palynomorphs, including dinoflagellate cysts and some thin-walled forms of uncertain origin, possibly fragments of dinoflagellate cysts. Rare acritarchs (Fig. 21A) and organic linings of foraminifera (Fig. 21S, T) occur. Sporomorphs are well preserved, yellowish-brown (Fig. 21B–H). The dinoflagellate cyst assemblage consists of thin-walled, pale-coloured forms with intact wall structure (*Phallocysta* spp., *Dissiliodinium* sp., *Kallosphaeridium* sp.; Fig. 22) and, less frequent, darker coloured, slightly worse preserved specimens of *Nannoceratopsis* with moderately degraded cyst wall (Fig. 21I–R). The following dinoflagellate cyst species were found: *Nannoceratopsis ?gracilis*, *Nannoceratopsis gracilis*, *Nannoceratopsis ridingii*, *Nannoceratopsis spiculata*, *Nannoceratopsis ?dictyambonis*, *Nannoceratopsis evae*, *Nannoceratopsis* sp., *Valvaeodinium* sp. A, *Phallocysta elongata*, *Kallosphaeridium hypornatum*, *Kallosphaeridium* sp., *Phallocysta* sp., dinoflagellate cyst sp. A, *Dissiliodinium* sp., *Phallocysta* sp. A.

(9) Sample 1458.5 m. Palynofacies is dominated by small-sized palynodebris consisting of black opaque phytoclasts, dark-brown translucent phytoclasts, and tiny particles of uncertain origin. Cuticles and palynomorphs are subordinate. The latter are represented by sporomorphs (Fig. 23A, C) and rare dinoflagellate cysts (Fig. 23D–H); a single acritarch was found (Fig. 23B). Organic particles in this sample show various preservation: cuticles are generally dark-brown and degraded (Fig. 23I), whereas sporomorphs are dark-coloured and relatively well preserved (dark colouration may partly be a result of thick-walled nature of examined specimens; Fig. 23A, C). Dinoflagellate cysts are rather well preserved, but some specimens of *Nannoceratopsis gracilis* are brownish, their cyst wall is moderately degraded, showing traces of crystallization (Fig. 23D, G). This contrasts with lighter-coloured (yellow-brownish) thin-walled specimens of *Dissiliodinium*/*Kallosphaeridium* whose wall structure is almost intact (Fig. 23E, F, H). The following dinoflagellate cysts were found: *Nannoceratopsis* sp., *Dissiliodinium giganteum*, *Kallosphaeridium*? sp., *Nannoceratopsis gracilis*, *Dissiliodinium*? sp.

(10) Sample 1790.2 m. Palynofacies consists of black to dark-brown woody phytoclasts, which are black in central, thickest parts, and become brownish and translucent at the edges (60%; Fig. 24N). Some of them show preserved cellular structures (Fig. 24E). Black opaque phytoclasts represent up to 30%; in majority, they are equidimensional, partly elongated (Fig. 24L). Cuticular fragments are rather rare; they are characterized by dark-brown colouration and high degree of degradation of the tissue structure (Fig. 24O). Palynomorphs are very rare (sporomorphs and dinoflagellate cysts represent less than 1%), single organic linings of foraminifera (Fig. 24H) and a scolecodont (Fig. 24M) were found. Palynomorphs show highly corroded structure (sporomorphs: Fig. 24G, I, K; dinoflagellate cysts: Fig. 24A–D, F, J?); this, in most cases, makes their taxonomic determination impossible. An exception is a single specimen of foraminifera organic lining, which is fairly well preserved (Fig. 24H). Among highly degraded dinoflagellate cysts, only a few specimens of *Nannoceratopsis gracilis* have been distinguished (due to their characteristic shape). Some forms presumably represent *Dissiliodinium* sp. (Fig. 24F).

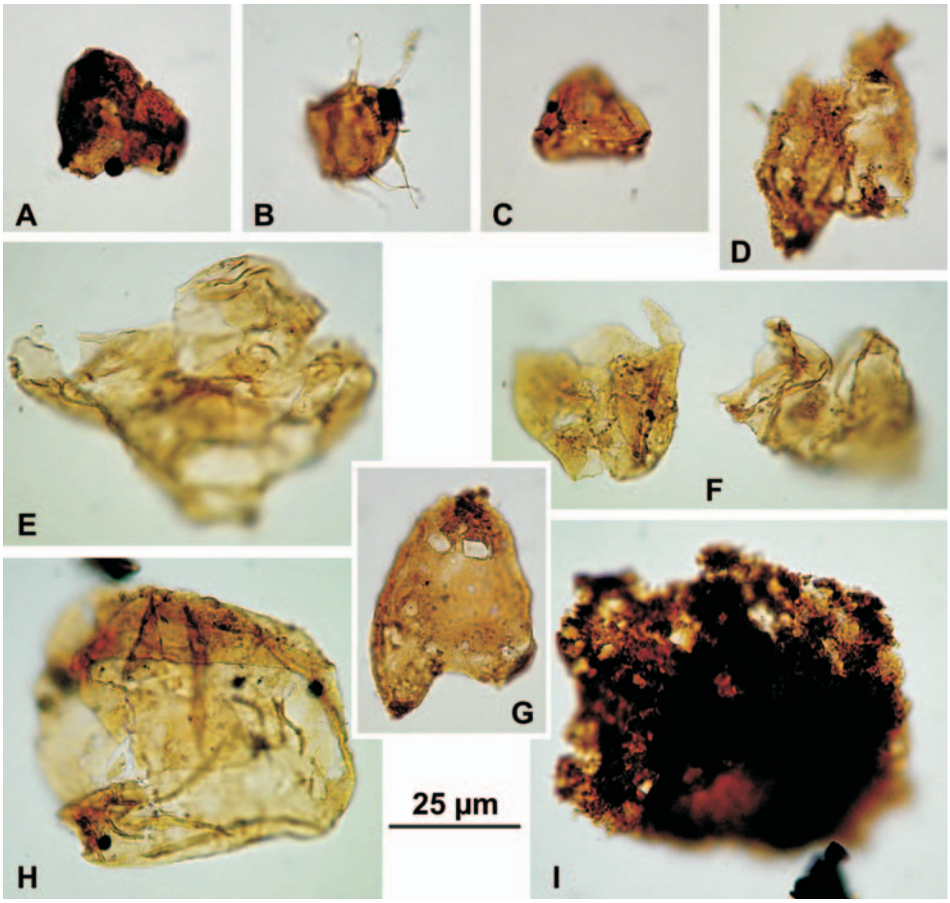

Fig. 23. Dinoflagellate cysts from the Maruszyna IG-1 Deep Borehole; sample from depth 1458.5 m. **A** – sporomorph; **B** – acritarch; **C** – sporomorph; **D** – poorly preserved *Nannoceratopsis* sp.; **E** – *Dissiliodinium giganteum*; **F** – two specimens of proximate, thin-walled dinoflagellate cysts (*Kallosphaeridium*? sp.); **G** – *Nannoceratopsis gracilis* (specimen with traces of crystal growth – empty cavities); **H** – *Dissiliodinium*? sp.; **I** – highly degraded cuticle

(11) Sample 2229.8 m. Palynofacies consists of black opaque equidimensional phytoclasts. Single dark-coloured dinoflagellate cysts occur: an incomplete, brownish peridinioid (Fig. 25A), and poorly preserved *Spiniferites*? (Fig. 25B).

(15) Sample 2603.5 m. Palynofacies: black opaque equidimensional phytoclasts (99%). Rare, poorly preserved dark-brown phytoclasts (Fig. 25I, J) and palynomorphs, mainly sporomorphs (Fig. 25C–E, G, H), occur. One palynomorph may represent a highly degraded dinoflagellate cyst (Fig. 25F).

(16) Sample 2736.3 m. Palynofacies is composed of black opaque, equidimensional phytoclasts (Fig. 25K). Very rare, poorly preserved dark-brown phytoclasts occur (Fig. 25M, N), some might be highly corroded dinoflagellate cysts. A single specimen of dinoflagellate cyst was found: it is dark-brown, however its wall structure is intact (Fig. 25L). It represents presumably a spiny peridinoid *Spinidinium* sp.

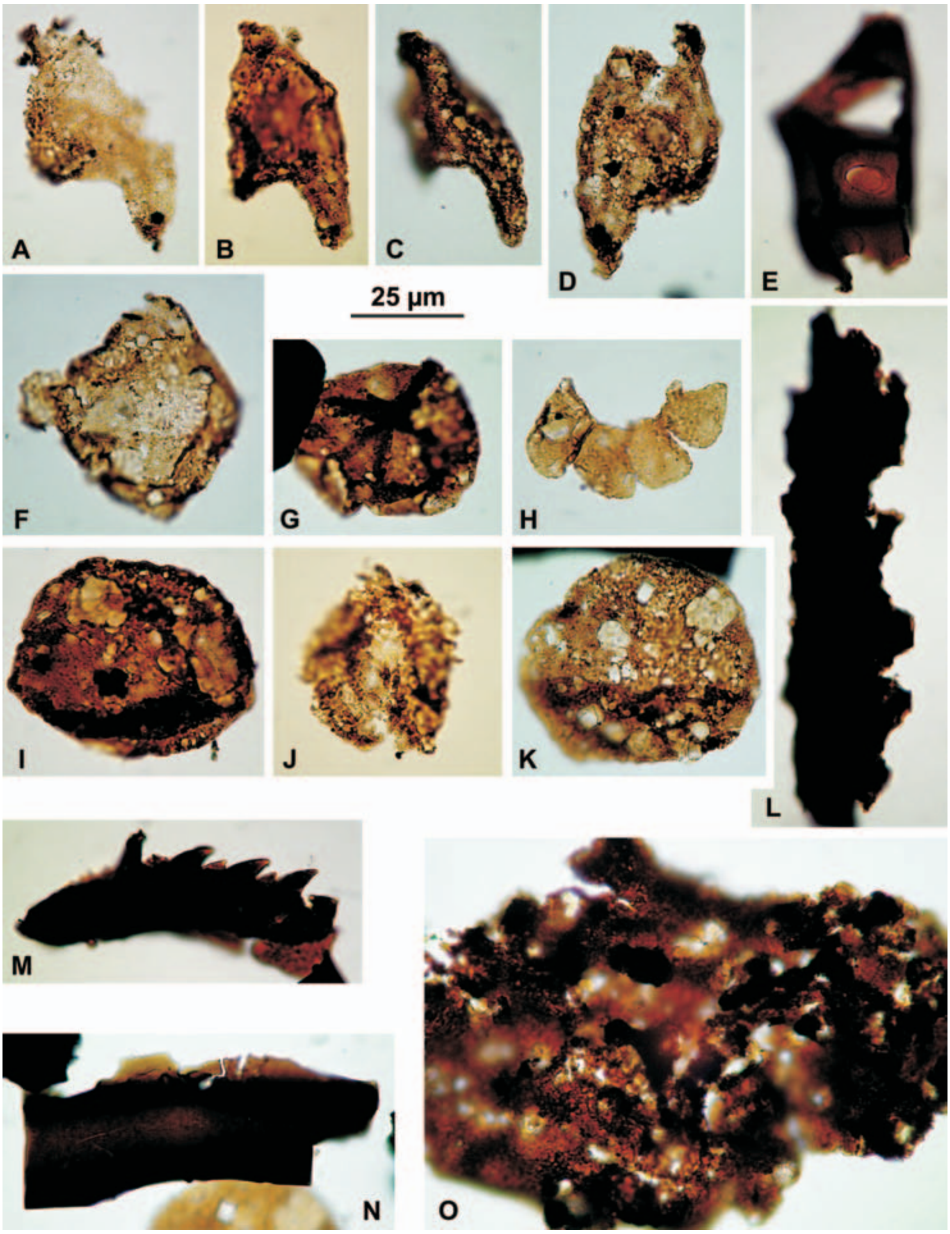

Fig. 24. Palynomorphs and phytoclasts from the Maruszyna IG-1 Deep Borehole; sample from depth 1790.2 m. **A** – *Nannoceratopsis gracilis*; **B**, **C** – *Nannoceratopsis* sp.; **D** – *Nannoceratopsis gracilis*; **E** – woody particle with tissue structures; **F** – indeterminable dinoflagellate cyst, presumably representing a proximate *Dissiliodinium* morphotype; **G** – sporomorphs; **H** – Foraminifera's organic lining; **I** – sporomorph; **J** – undetermined palynomorph, presumably a dinoflagellate cyst; **K** – sporomorph; **L** – elongated black phytoclast; **M** – scolecodont; **N** – cuticle

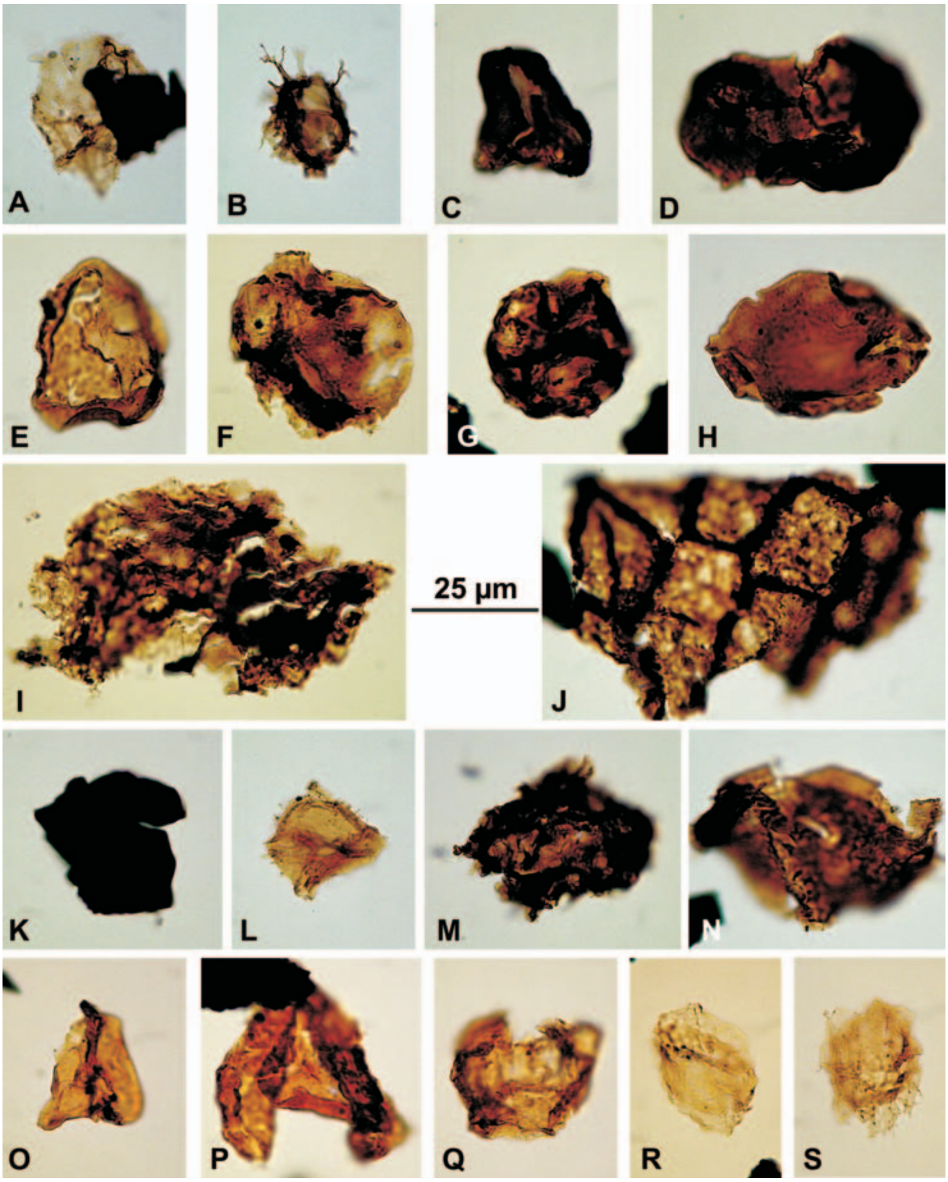

Fig. 25. Palynomorphs and phytoclasts from the Maruszyna IG-1 Deep Borehole; samples from depth interval 2229.8–2902 m (A, B: sample 2229.8 m; C–J: sample 2603.5 m; K–N: sample 2736.3 m; O–Q: sample 2839.3 m; R, S: sample 2902 m). **A** – incomplete peridinioid; **B** – *Spiniferites*? sp.; **C**, **D**, **E** – sporomorphs; **F** – palynomorph of uncertain origin, possibly a dinoflagellate cyst; **G**, **H** – sporomorphs; **I**, **J** – highly degraded cuticles; **K** – black opaque, equidimensional phytoclast; **L** – well preserved, pale-coloured peridinioid, *Spinidinium*? sp.; **M**, **N** – palynomorphs; **O**, **P** – sporomorphs; **Q** – dinoflagellate cyst?; **R** – pale-coloured peridinioid; **S** – pale-coloured incomplete specimen of presumably *Palaeohystrichophora infusorioides*

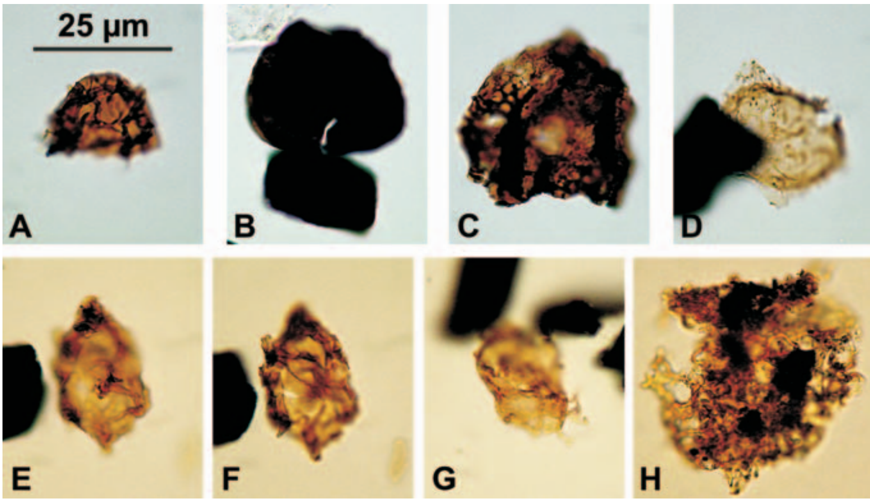

Fig. 26. Palynomorphs and phytoclasts from the Maruszyna IG-1 Deep Borehole; samples from depth interval 3116–3705 m (A–D: sample 3116 m; E–G: sample 3444 m; H: sample 3705 m). **A** – incomplete spore; **B** – black opaque phytoclast (below) and black phytoclast with translucent edges (above); **C** – highly degraded palynomorph; **D** – well preserved brownish dinoflagellate cyst (*Spinidinium*? sp.); **E**–**G** – incomplete dinoflagellate cysts (E, F: same specimen, various foci); **H** – highly degraded palynomorph, presumably pollen grain

(17) Sample 2839.3 m. Intermediate amounts of POM – 99.8% small-sized equidimensional black phytoclasts. Majority of phytoclasts are opaque, some of them have slightly transparent edges – dark brownish-yellow. Single torn-off spores occur; they are dark brownish-yellow (Fig. 25O, P). A single palynomorph was found, which might be an incomplete dinoflagellate cyst (Fig. 25Q).

(18) Sample 2902 m. Small-sized equidimensional black phytoclasts represent 99.9%. The majority of phytoclasts are opaque, some of them have slightly transparent edges – dark brownish-yellow. Some phytoclasts are dark-brown, with preserved cuticle structures. Brownish palynomorphs are rare. Two dinoflagellate cysts have been found (Fig. 25R, S): both are thin-walled peridinoids (one of them is presumably *Palaeohystrichophora infusorioides*: Fig. 25S), with relatively well preserved and rather pale-coloured (yellowish-brown) cyst wall.

(19) Sample 3047 m. Palynofacies: black opaque equidimensional phytoclasts.

(20 Sample 3116.5 m. Palynofacies: black opaque equidimensional phytoclasts (Fig. 26B). Rare dark-brown, usually highly degraded palynomorphs occur (Fig. 26C). A single dark-coloured spore was found (Fig. 26A). Single dark-brown, relatively well preserved dinoflagellate cysts occur: a single peridinioid (*Spinidinium*?; Fig. 26D) was recognized.

(21) Sample 3242 m. Very small amounts of POM consists of small-sized, equidimensional black opaque phytoclasts with irregular margins.

(22) Sample 3444.8 m. Palynofacies: black opaque equidimensional phytoclasts. Very rare brown incomplete dinoflagellate cysts (Fig. 26E–G) occur.

(23) Sample 3501.3 m. Palynofacies: black opaque equidimensional phytoclasts.

(24) Sample 3705.9 m. Palynofacies: black opaque equidimensional phytoclasts. A single, dark-brown, highly corroded palynomorph (pollen grain?) was found.

(25) Sample 4022.5 m. Palynofacies: 100% black, small-sized, equidimensional black phytoclasts. Single dark brown phytoclasts.

(26) Sample 4150.9 m. Palynofacies: 100% black, small-sized, equidimensional black phytoclasts.

(27) Sample 4402.6 m. Very small amounts of POM. 100% black, small-sized, equidimensional black phytoclasts.

(28) Sample 4601 m. Relatively high amounts of POM – 100% thick black phytoclasts with irregular margins. They are opaque; when thin at margins, they are dark brownish and transparent.

(29) Sample 4758.3 m. Very small amounts of POM. 100% black, small-sized, equidimensional black phytoclasts.

INTERPRETATION OF DINOFLAGELLATE CYST BIOSTRATIGRAPHY

Pieniny Nappe

(1), (2) Two uppermost samples (depths 561 m and 616.9 m) yielded impoverished dinoflagellate cyst assemblages, which do not allow precise datation. Presence of *Odontochitina operculata* and a specimen questionably assigned to *Palaeohystrichophora infusorioides* in sample at 561 m, suggests a Late Cretaceous, latest Albian–earliest Maastrichtian age (stratigraphic range of *P. infusorioides*: latest Albian–earliest Maastrichtian; the last appearance of *O. operculata*: earliest Maastrichtian; e.g., Stover *et al.*, 996). This age interpretation agrees with Birkenmajer's attribution of these strata to the Jaworki Marl Formation (Cenomanian to Coniacian, sometimes Cenomanian to Maastrichtian – Birkenmajer, 1977). Comparable dinoflagellate cyst assemblages were described from the Malinowa Shale Formation (Pieniny Klippen Belt, Grajcarek Succession) exposed at Potok Trawne (Gedl, 2007b). They consist of well preserved peridnioids (mainly *Alterbidinium* sp. and *Palaeohystrichophora infusorioides*); additionally *Pterodinium cingulatum*, *Spiniferites ramosus* and *Odontochitina operculata* occur. The age of this lithostratigraphic unit is Upper Cenomanian–Campanian (Birkenmajer, 1977; see also Jednorowska, 1980; Bąk *et al.*, 2000). Other similar Late Cretaceous dinoflagellate cyst assemblages were found in the Hałuszowa Formation at Hałuszowa (samples HlsS1 and HlsS2; Gedl, 2007a), and in the upper course of the Sztolnia Creek (sample Szt34; Birkenmajer & Gedl, 2004). In both cases, they are dominated by small peridinioids (including *P. infusorioides*), associated with rare specimens of *Pterodinium cingulatum*, *Spiniferites ramosus* and *Odontochitina operculata*.

Less precise, Cretaceous age can be suggested for a sample from depth 616.9 m. Although no age-diagnostic species has been found, its strongly impoverished assemblage with *Pterodinium* seems to be indicative for offshore assemblages of Cretaceous age. Noteworthy is a characteristic palynofacies of this sample, which consists of structureless organic matter occurring in high amount. This feature is typical for rocks deposited in anoxic conditions. Structureless organic matter was identified in Cretaceous strata of the Pieniny Klippen Belt in the Kapuśnica Formation exposed at Szczawnica (E. Gedl, 2007) and Biały Potok (P. Gedl, unpublished). This agrees with Birkenmajer's age attribution of the strata from depth 612–691 m to the Kapuśnica Formation.

(3) An older, Lower Cretaceous age, is suggested for sample from depth 773.4 m. Co-occurrence of *Cymososphaeridium validum* and *Bourkidinium* sp. 1 *sensu* Leereveld 1997 indicates the Upper Valanginian–lowermost Hauterivian age (e.g., Leereveld, 1997). Hauterivian age of this sample is supported by the presence of *Pterodinium* ?*bab*, a species described by Below (1981) from Hauterivian of Morocco [note: the specimens questionably attributed to this species have finely perforated crests; they presumably represent a variation of *Pterodinium bab* characterized by relatively smooth, almost imperforated crests (Below, 1981, p. 113, fig. 73c)]. This age interpretation agrees well with Birkenmajer's correlation of strata from this depth with the Pieniny Limestone Formation (Kimmeridgian/Tithonian–Barremian; Birkenmajer, 1977). Skupien (2003) and E. Gedl (2007) described dinoflagellate cysts from this lithostratigraphic unit. Among the Skupien's assemblages from the Rochovica section (Slovakia), the one from sample R341.1 is most similar to the assemblage from sample 773.4 m. Although impoverished, it contains *Bourkidinium* sp. and, according to Skupien (2003), it comes from an interval dated by calcareous nannoplankton and aptychi on uppermost Lower Hauterivian–Upper Hauterivian.

E. Gedl (2007) studied dinoflagellate cysts from two exposures of the Pieniny Limestone Formation of the Grajcarek Unit in the Polish part of the Pieniny Klippen Belt: upper course of the Sztolnia Creek, and at Szczawnica. Among dinoflagellate cyst assemblages from the first site, the one from sample Szt41 resembles the Maruszyna's assemblage. It contains *Cymososphaeridium validum* and *Bourkidinium* spp., and it was dated as not younger than Hauterivian (two other samples from this site were dated at Lower Barremian; E. Gedl, 2007). Two samples from topmost part of the Pieniny Limestone Formation exposed at Szczawnica yielded various assemblages, although both representing a Late Barremian age (E. Gedl, 2007). Interestingly, the sample Rzeźnia-I contains similar taxa (e.g., *Cymososphaeridium validum*, *Bourkidinium* spp.), but co-occurrence of younger species suggested E. Gedl (2007) that they are reworked.

(4) Sample from depth 846 m yielded dinoflagellate cyst assemblage, which is similar to the ones described from the Upper Bathonian of the Grajcarek Unit and Branisko Nappe (Gedl, 2008). It consists of common specimens of *Lithodinia*-*Valensiella*-*Epiplosphaera* morphotype and less frequent chorate specimens of *Adnatosphaeridium*-*Systematophora* morphotype; rare specimens of *Ctenidodi-*

nium combazii occur. Similar assemblages with frequent *Epiplosphaera*, *Lithodinia*, associated by *Ctenidodinium* and *Systematophora*, were described from the upper part of the Opaleniec Formation (Grajcarek Unit: Sztolnia Creek, samples Szt28–30; Hulina Mt., Hln4, Hln5; Krupianka Creek, Krp20) and lower part of the Sokolica Radiolarite Formation (Grajcarek Unit: Krupianka Creek, sample Krp21).

The Sokolica Radiolarite Formation from the Branisko Nappe (Wapiennik, samples Wpn1, Wpn2) yielded an assemblage with *Epiplosphaera* and *Lithodinia* spp., rare *Ctenidodinium* sp., but devoid of chorate species with apical archaeopyle (Gedl, 2008). The age of these assemblages was established as Bathonian and correlated with local dinoflagellate cyst zone *Ctenidodinium combazii* (Gedl, 2008). The studied sample from depth 846 m represents presumably a similar age (occurrence of e.g., *Dingodinium minutum*); younger, Callovian age is rather excluded (lack of Callovian species like *Compositospaheridium polonicum*). This assumption makes that this sample cannot be correlated with the Podzamcze Limestone Formation (Lower Bajocian according to Myczyński, 2004), which occurs in interval 839–867 m of the Maruszyna IG-1borehole. The age of the second lithostratigraphic unit from this interval, the Podmajerz Radiolarite Member of the Czajakowa Radiolarite Formation, is poorly documented palaeontologically: on the base of aptychi (Birkenmajer & Gąsiorowski, 1960, 1961a, b; Gąsiorowski, 1962) and radiolarians (Widz, 1991, 1992; see also Birkenmajer & Widz, 1995) Middle Callovian–Lower Tithonian is proposed (see also Birkenmajer, 1977). Therefore, studied sample may represent a different lithostratigraphic unit not distinguished by Birkenmajer (*in* Chowaniec & Sokołowski, 1985), e.g., the Sokolica Radiolarite Formation, or the age of the Czajakowa Radiolarite Formation spans also the Bathonian.

Dinoflagellate cysts from Jurassic of the Pieniny Nappe have not been found so far; thus, this is their first record from this basinal succession. Gedl (2008) examined samples from the Podzamcze Limestone Formation and the Sokolica Radiolarite Formation exposed at Sokolica but they all appeared to be barren (the same refers to samples from other Jurassic lithostratigraphic units of the Pieniny Succession).

Jarmuta Formation

(5) Conglomerate from the depth 957 m attributed by Birkenmajer (*in* Chowaniec & Sokołowski, 1985) to the Jarmuta Formation yielded no dinoflagellate cysts.

Olistolith

(6) Sample from depth 1097.4 m yielded a very impoverished dinoflagellate cyst assemblage composed of rare specimens of *Spiniferites* sp., *Pterodinium cingulatum*, incomplete specimens determined as *Impletosphaeridium*? sp. and *Palaeohystrichophora*? sp., and indeterminable forms. Precise determination of such an assemblage is not possible – the presence of *Palaeohystrichophora*? (presumably *P. infusorioides* – stratigraphic range: latest Albian–earliest Maastrich-

tian; Stover *et al.*, 1996) may only suggest a Late Cretaceous age (for comparison with Late Cretaceous dinoflagellate cyst assemblages from the Pieniny Klippen Belt – see sample from depth 561 m). A comparable impoverished assemblage was found in sample from depth 616.9 m, which represents the Kapuśnica Formation of the Pieniny Nappe (Birkenmajer *in* Chowaniec & Sokołowski, 1985; part A of this paper). It differs, however, by a palynofacies composed of black opaque phytoclasts – sample from depth 616.9 m contains mainly structureless organic matter typical for the Kapuśnica Formation (see E. Gedl, 2007). The age of the top of this lithostratigraphic unit is Barremian (Alexandrowicz *et al.*, 1968; see also Birkenmajer, 1977). This age was confirmed by E. Gedl (2007) who studied dinoflagellate cysts from transitional interval between these two units at Szczawnica: samples from the topmost part of the Pieniny Limestone Formation contain Late Barremian species, whereas samples from basal part of the Kapuśnica Formation yielded dinoflagellate cysts typical for Late Barremian–Early Aptian, and structureless organic matter characteristic for anoxic sedimentary conditions (E. Gedl, 2007).

(7) The age of dinoflagellate cyst assemblage from sample 1225.5 m (the Harcygrund Shale Formation according to Birkenmajer *in* Chowaniec & Sokołowski, 1985) is presumably Late Aalenian. This is based on the presence of *Dissiliodinium lichenoides* associated with other typical Aalenian species (e.g., *Nannoceratopsis evae*), and lack of earliest Bajocian *Dissiliodinium giganteum*. Such an assemblage allows correlation of the studied sample with local dinoflagellate cyst zone *Dissiliodinium lichenoides sensu* Gedl (2008). Former studies of dinoflagellate cysts from the Harcygrund Shale Formation showed that this lithostratigraphic unit represents in the Branisko Succession the Lower Bajocian *Dissiliodinium giganteum* dinoflagellate cyst zone (sections: Hałuszowa–Pustki, Harcygrund, Wapiennik; Gedl, 2008). Only one section, at Hałuszowa–Groń, yielded an assemblage which lacked *D. giganteum*; it was, questionably, due to very poor preservation of dinoflagellate cysts, correlated with Upper Aalenian (e.g., a single specimen of poorly preserved *Phallocysta*? sp. was found).

In the light of the Maruszyna IG-1 borehole data, the age of the Harcygrund Shale Formation in the Branisko Succession may be extended to at least Upper Aalenian; the sample from depth 1225.5 m can be correlated with exposures at Hałuszowa–Groń. In the 1225.5 m-sample a thick-walled *Tasmanites* was found (Fig. 19L, M); the same species was also found in the Aalenian Krzonowe Formation (Gedl, 2008, fig. 138F, G).

(8) A similar, Aalenian age can be suggested for another sample of the Harcygrund Shale Formation – from the depth of 1341.8 m. This is based on the presence of several species, including *Nannoceratopsis evae*, and the lack of *Dissiliodinium giganteum*. Dinoflagellate cyst assemblage from this sample may be compared with those from the *Nannoceratopsis evae* and/or *Dissiliodinium lichenoides* dinoflagellate cyst zones *sensu* Gedl (2008). This interpretation shows that deposition of the Hałuszowa Shale Formation in the Branisko Succession started earlier than it was suggested on the base of ammonites (Horwitz, 1937a, b; Myczyński, 1973, 2004; Birkenmajer & Myczyński, 2000). According to Myczyń-

ski (2004), this lithostratigraphic unit spans the Lower Bajocian *Sonninia sowerbyi*, *Otoites sauzei* and the lowest part of *Stephanoceras humphriesianum* ammonite zones.

(9) The sample from depth 1458.5 m (Podzamcze Limestone Formation according to Birkenmajer *in* Chowaniec & Sokołowski, 1985; Harcygrund Shale Formation – this paper, part A) yielded a dinoflagellate cyst assemblage, which contains *Dissiliodinium giganteum*. Its presence allows correlation of this sample with the Lower Bajocian *Dissiliodinium giganteum* dinoflagellate zone *sensu* Gedl (2008). The same zone was recognized in the Podzamcze Limestone Formation of the Branisko Succession at Hałuszowa–Groń and Wapiennik (Gedl, 2008). Its age, based on the stratigraphic range of *D. giganteum*, is Lower Bajocian (e.g., Feist-Burkhardt & Monteil, 1997). This age agrees with results of earlier ammonite datings of this lithostratigraphic unit by Myczyński (2004), who suggested a similar time-span (the *Stephanoceras humphriesianum* Ammonite Zone).

Branisko Nappe

(10) The sample from 1790.2 m contains highly degraded, almost indeterminable dinoflagellate cysts. Beside *Nannoceratopsis* specimens, a few specimens presumably representing *Dissiliodinium* sp. (Fig. 24F) have been identified. This assemblage does not allow precise datation of the sample; presence of *Nannoceratopsis* sp. and *Dissiliodinium*? sp. suggests an Early Bajocian age of this assemblage comparable with those from the Harcygrund Shale Formation and the Podzamcze Limestone Formation. According to Birkenmajer (*in* Chowaniec & Sokołowski, 1985), this sample belongs to a tectonic wedge of the Podzamcze Limestone Formation (at 1789–1791 m) thrust over the Cretaceous Jaworki Marl Formation (at 1772–2160 m).

(11–29) Samples from lower depths (2229.8–4758.3 m) contain a similar palynofacies characterized by dominance of black opaque phytoclasts, and absence, or very rare occurrence, of dinoflagellate cysts (all samples contain very low amounts of palynological organic matter). The latter are represented by single specimens of *Spiniferites*? sp. (2229.8 m), *Spinidinium*? sp. (2736.3 m and 3116.5 m) and *Palaeohystrichophora*? *infusorioides* (2902 m). These rare, poorly preserved specimens may represent Late Cretaceous. Similar "assemblages" occur in Upper Cretaceous samples of the Maruszyna IG-1 borehole in the Pieniny Succession (561 m) and the olistolith (1097.4 m). Samples from the depth 3242 m downwards contain no dinoflagellate cysts.

FINAL REMARKS

(1) Biostratigraphic interpretation of the dinoflagellate cyst assemblages correlates well with dating of lithostratigraphic units during previous studies.

(2) Aalenian dinoflagellate cyst assemblage found in the Harcygrund Shale Formation of the Branisko Nappe indicate its age to be slightly wider-ranged: Aalenian–Lower Bajocian.

(3) The topmost Pieniny Nappe and the underlying Branisko Nappe contain relatively well preserved forms. It contrasts with highly degraded dinoflagellate cysts from tectonic wedge of the Jurassic Podzamcze Limestone Formation (1789–1791 m), whereas dinoflagellate cysts from deeper strata (Upper Cretaceous lithostratigraphic units) yielded very rare but commonly well preserved specimens. This indicates that factors responsible for degradation of organic matter (pressure? temperature?) are not related to the present-day burial depth but they influenced studied deposits prior to their overthrusting.

(4) A set of open-nomenclature dinoflagellate cyst species is described: *Bourkidinium* sp. A, *Phallocysta* sp. A, *Tanyosphaeridium* sp. A, and *Valvaeodinium* sp. A.

SELECTED TAXONOMY

Bourkidinium sp. A

(Fig. 9N–P)

Material. Two specimens were found in a sample from depth 773.4 m (Pieniny Limestone Formation of the Pieniny Succession; age: Upper Valanginian–lowermost Hauterivian).

Description. Cyst with elongate ellipsoidal body and very short, hollow, tubular processes grouped on apical and antapical areas only. Cyst wall smooth, no indication of paratabulation except of archaeopyle margin. Archaeopyle apical, type tA.

Comparison. This species differs from all previously described *Bourkidinium* species by very short processes. *B.*? *cylindricum*, *B. elegans*, *B. granulatum*, *B. psilatum*, and species sp. 1 of Leereveld (1997) have long processes, which length varies usually from 1/2 to 3/4 of the central body length.

Phallocysta sp. A

(Fig. 22Z2)

Material. A single specimen was found in sample from depth 1341 m (Harcygrund Shale Formation of the Branisko Succession; age: Aalenian, Upper? Aalenian).

Description. Elongated cyst typical for the genus, with rounded hypocyst and conical epicyst. Cyst wall, except of hypocystal part where smooth, covered with densely distributed tiny granulae.

Tanyosphaeridium sp. A

(Fig. 9T–V)

Material. A single specimen was found in sample from depth 773.4 m (Pieniny Limestone Formation of the Pieniny Succession; age: Upper Valanginian–lowermost Hauterivian).

Description. Cyst with ellipsoidal short body and hollow, tubular processes; their length is less than 1/2 of the central body diameter. Processes smooth, hollow, tubular, distally open, with finely denticulate margins. Processes occur all over the cyst, being grouped in apical, postcingular, cingular and precingular series (apical processes have not been observed due to missing apical opercular paraplates). Archaeopyle apical, type (tA).

Comparison. All previously described species of *Tanyosphaeridium* have strongly elongated central body (*T. boletus*, *T. isocalamum*, *T. jurassicum*, *T. magneticum*, *T. regulare*, *T. salpinx*, *T. singulare*, *T. variecalamum*, *T. xanthiopyxides*). *Tanyosphaeridium* sp. A has short, relatively wide body; its length (without operculum) only slightly exceeds its width.

Valvaeodinium sp. A

(Fig. 18R–X, Fig. 22E)

2008 *Comparodinium* cf. *koessianum* Gedl, p. 159, fig. 139, fig. 140Q

Material. Rare specimens occur in samples from the depths 1225.5 m and 1341 m (the Harcygrund Shale Formation of the Branisko Succession; age: Aalenian, Upper? Aalenian).

Description. Elongated proximate cyst with cylindroidal shape. Tiny nontabular spikes grouped at apical and antapical areas only, whereas equatorial area remains free of processes. Archaeopyle intercalary, number of paraplates involved uncertain. Operculum free; in one case opercular paraplates attached (Fig. 18T).

Dinoflagellate cyst sp. A

(Fig. 22U–W)

Material. A few specimens were found in sample from depth 1341 m (the Harcygrund Shale Formation of the Branisko Succession; age: Aalenian, Upper? Aalenian).

Description. Small circumcavate cyst with oval epicyst and nearly ovoidal pericyst. The latter forms a small apical horn; antapical part of pericyst rounded. Paracingulum well visible, delimited by two parallel smooth ridges. Parasulcus indicated by a faint depression.

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