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Geological Results of the Polish Spitsbergen Expeditions
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Part XVII

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Coals of the Calypsostranda Group (Palaeogene) at Bellsund, Spitsbergen[2]

(Figs 1–4)

Abstract. Numerous thin coal seams occur in terrestrial deposits of the Skilvika Formation, Calypsostranda Group (Late Palaeogene), at Bellsund, central Spitsbergen. According to coal-petrographic study, they mainly belong to the vitrinite-fusinite facies. At Calypsostranda (Tyvjobekken), Calypsobyen (abandoned coalmine) and Skilvika (coastal main section), they are represented mainly by telocollinite subfacies which developed in a wet forest swamp at high groundwater level condition (the "shale with coal streaks" subfacies) close to a delta distributary or main river channels. At Rensdyrbekken (NW Calypsostranda), an increased share of herbaceous swamp facies was recognized in coal formation: a sapropelic coal facies was generated there under condition of inner parts of interchannel lakes.

Key words: Spitsbergen, Bellsund, Palaeogene, coals, petrography, origin.

INTRODUCTION

The coal-bearing Palaeogene strata here described were investigated and sampled in the Bellsund area, central Spitsbergen (Svalbard archipelago), by the senior author, during a Polish expedition organized in 2002 by Dr Krzysztof P. Krajewski. Coal-petrographic investigation of the samples was performed by the junior author.

GEOLOGICAL SETTING

The Late Palaeogene coal-bearing terrestrial strata at Bellsund, central Spitsbergen, crop out along Calypsostranda, along western coast of Recherchefjorden, be-

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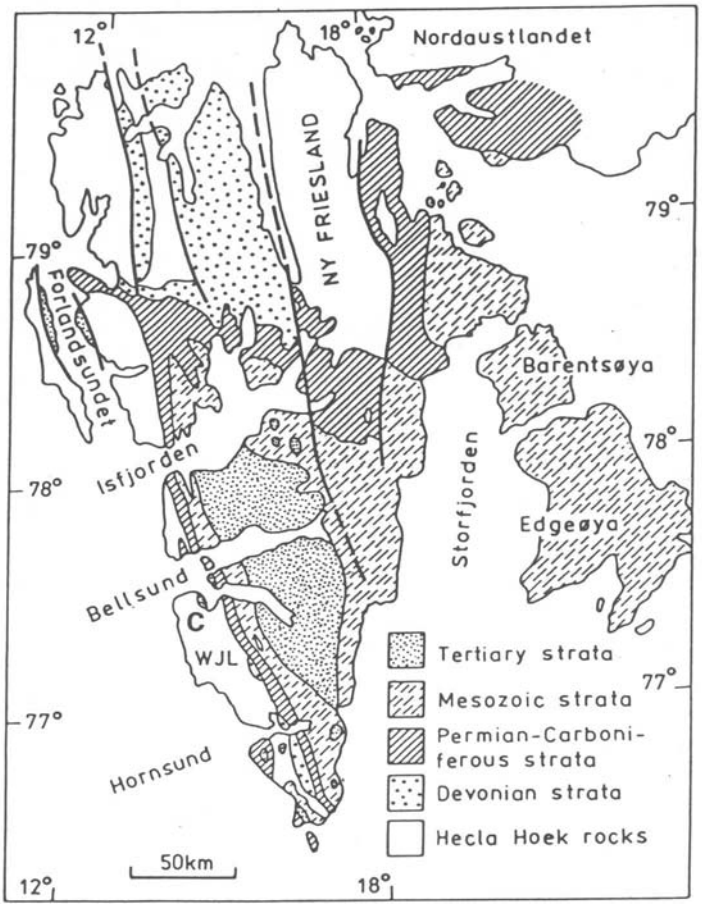

Fig. 1. Simplified geological map of the Svalbard archipelago (compiled from various sources). C – Calypsostranda; WJL – Wedel Jarlsberg Land

tween Skilvika and Renardodden in the north and Renardbreen in the south (Figs 1, 2). They infill the Calypsostranda Graben in western part of the Tertiary fold-and-thrust belt (see Dallmann, 1989; Dallmann *et al.*, 1990, 1993; Harland *et al.*, 1997; Dallmann ed., 1999; Birkenmajer, 2004, 2006; Birkenmajer & Zastawniak, 2005).

The Calypsostranda Graben is a minimum 6 km long and more than 1.5 km wide. Its Palaeogene sediment pile probably exceeds 250 m in thickness. The graben is bounded from the southwest by the NW–SE-trending, vertical Calypsostranda Fault (Fig. 2), and from the southeast – by the NE–SW-trending vertical Josephbukta Fault. Northeastern and northern boundaries of the graben are concealed under sea level (Birkenmajer, 2004).

LITHOSTRATIGRAPHY

The Palaeogene strata of the Calypsostranda Graben were formally distinguished as the Calypsostranda Group (Dallmann ed., 1999). The Group is subdivided into the Skilvika Formation (lower unit) and the Renardodden Formation (upper unit) – Livšic (1967, 1974), Dallmann *et al.* (1990), Harland ed. (1997). A closer description of the strata has been presented by Dallmann (1989), Birkenmajer and Zastawniak (2005) and Birkenmajer (2006).

Skilvika Formation

The Skilvika Formation consists of terrestrial deposits, mainly grey, fine-grained, often laminated sandstones alternating with dark-grey to black shales and coalshales, with thin black coal seams. Red-weathered sideritic concretions and layers infrequently occur in the shales. Macrofloral remains, mostly angiosperm leaf imprints, have been found mainly in sandstone beds; conifer shoots were collected predominantly from siderite layers.

There are five groups of exposures of the Skilvika Formation at Calypsostranda, from south to north (Fig. 2):

(1) **Kjeftbekken creek** (Station 1). This is a poor exposure in a small creek. Black shale fragments from the Skilvika Formation are visible there in slope scree. No coal fragments were found. Probably, this is the southernmost site of Tertiary deposits at Calypsostranda;

(2) **Tyvjobekken creek** (Stations 8, 12–14). Basal beds of the Skilvika Formation are poorly exposed at Station 8. They are represented by fine-grained, platy sandstone with cementation concretions 2–3 cm in size, moreover by sedimentary breccia (pellet conglomerate), consisting of small pellets (0.1–1 cm in size) of green shale/phyllite derived from the Proterozoic basement. This part of the formation lies very close to the Calypsostranda Fault and to a small exposure of the Kapp Lyell diamictites (Kapp Lyell Formation, Upper Proterozoic – see Birkenmajer, 2010).

The best field section is available at Station 14, immediately east of Station 8. Eleven sedimentary units have been distinguished (see Fig. 3B). These are grey, medium- to fine-grained sandstones alternating with grey to black shale, with thin coalshale and coal seams (Birkenmajer & Zastawniak, 2005, p. 148).

At the entrance to the Tyvjobekken creek (Station 12), north of an old hut, traces of collapsed coal-mine shafts, and a dump heap with coal fragments are still visible.

(3) **Calypsobyen, abandoned coal-mine** (Station 22). This is the main site of the Calypsobyen coal mining, with six collapsed shafts still recognizable. Sandstone, shale and coal fragments are visible there in dump heaps.

(4) **Rensdyrbekken, stream valley** (Station 26). This is a poor exposure of grey fine-grained sandstones and coal-bearing shales, with a plant-bearing siderite intercalation (Fig. 3A).

(5) **Skilvika, main section** (Station 35). This is the most complete section of the Skilvika Formation (Fig. 2), well exposed in a high marine cliff. The Skilvika For-

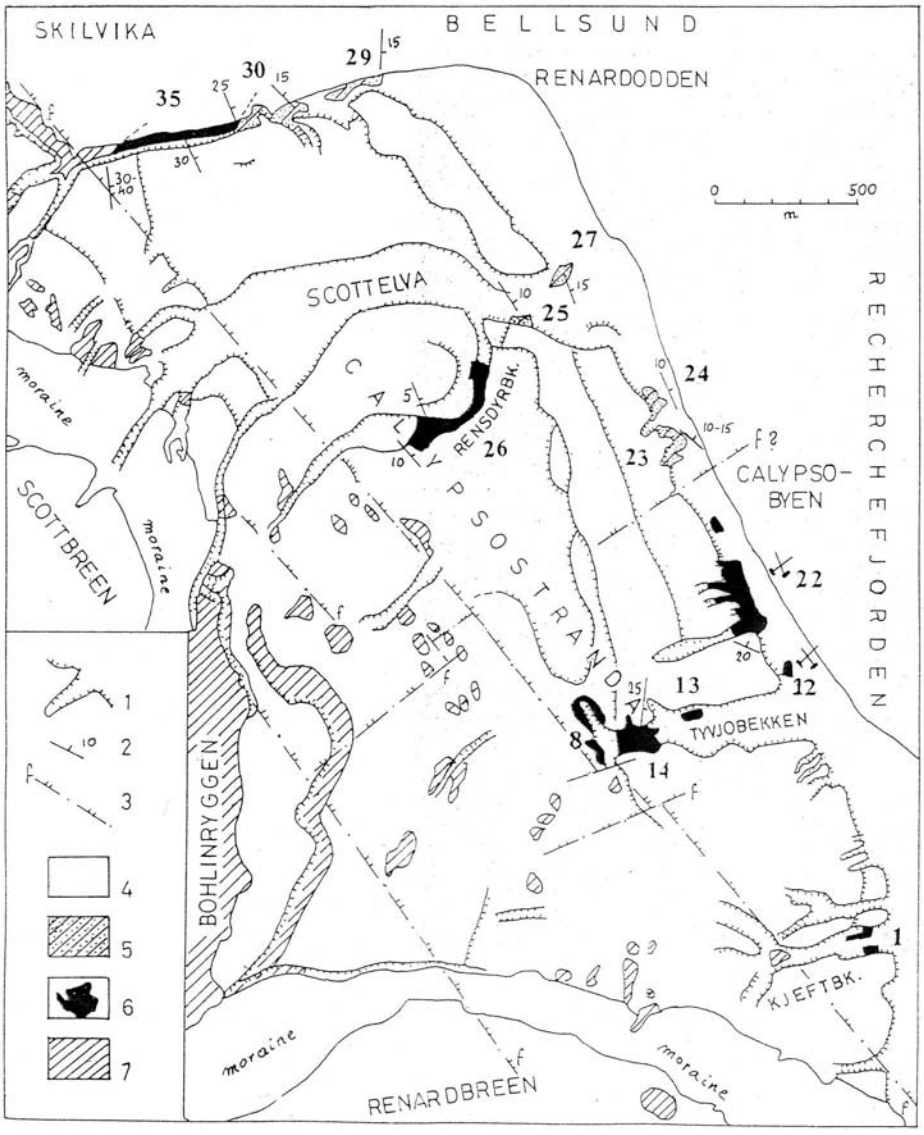

Fig. 2. Exposures of Palaeogene strata at Calypsostranda, between Skilvika and Renardbreen/Josephbukta (after Birkenmajer & Zastawniak, 2005, fig. 3, explanation numbers corrected). *1* – escarpments; *2* – strike and dip of strata; *3* – faults; *4* – Quaternary cover; *5* – Renardodden Fm. (Palaeogene); *6* – Skilvika Fm. (Palaeogene); *7* – Proterozoic metasediments (Kapp Lyell Fm.). Bold numbers denote field stations

mation consists there mainly of grey to black, fine-grained, laminated sandstone layers alternating with grey shale, clayshale and coalshale, with eleven thin horizons of black shaly coal. This section yielded plant fossils recorded by Thiedig *et al.* (1979, fig. 3) and Dallmann ed. (1999, figs 4–49).

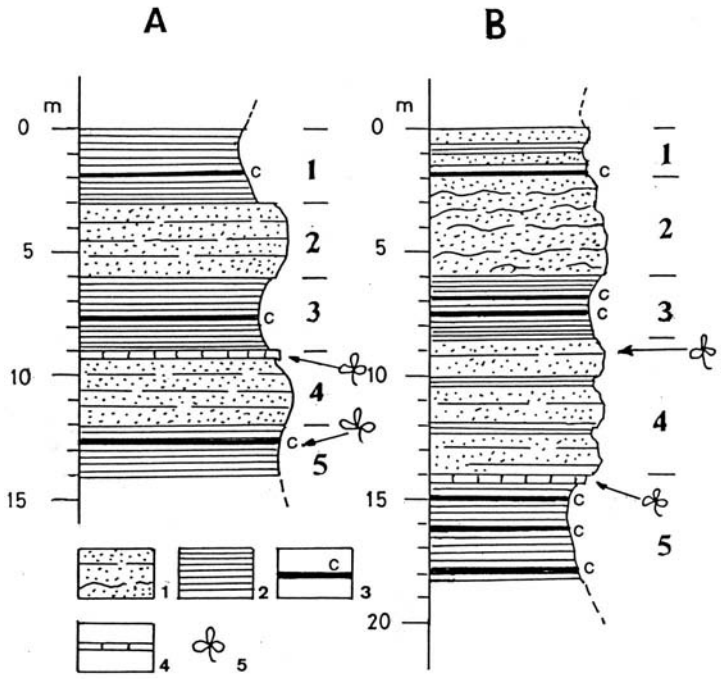

Fig. 3. Lithologic columns of the Skilvika Fm. (Palaeogene) at Calypsostranda (after Birkenmajer & Zastawniak, 2005, fig. 4). A – Rensdyrbekken (Station 26); B – Tyvjobekken (Station 14); *1* – sandstone; *2* – shale, coalshale; *3* – coal seam; *4* – siderite; *5* – macroflora

The section at Skilvika (Fig. 4) exposes the Precambrian metasedimentary substrate of the Tertiary beds, the terrestrial Skilvika Formation (c. 77 m thick), and the basal part (c. 16 m) of the marine Reinodden Formation (Birkenmajer & Zastawniak, 2005, pp. 147–148; Birkenmajer, 2006).

Lithostratigraphy/Lithology		Thickness (m)
Kapp Lyell Formation (Upper Proterozoic)		
1	Diamictite, quartzite-clast-supported, grey to rusty to yellow, strongly tectonized (folded and faulted), with thin intercalations of quartzite and quartzitic sandstone (see Birkenmajer, 2006, pp. 110–111, fig. 4). Exposed	over 15
Skilvika Formation (Upper Palaeogene)		total thickness 80.1
2	Basal breccia, rather chaotic ("Rochesterpynten Fm." of Harland *et al.* , 1993, p. 100; Harland ed., 1997, p. 180), probably a fossilized incipient slump of fragmented basal Tertiary strata, resting in a normal sedimentary contact directly upon weathered and planated Proterozoic substrate (Birkenmajer, 2006, p. 111, fig. 4): (2a) wedge-shaped basal breccia consisting of angular fragments (1–5 cm in size) of diamictite; (2b) breccia-like bed consisting of angular fragments (5–20 cm in size) of grey laminated sandstone in shaly-sandy matrix. 2a, b thickness	3
3	Sandstone, fine-grained, clayey, grey	1
4	Shale, grey	1

5	**Coalshale**, black, with a 20-cm thick **coal** seam (sample 35/5)	0.2
6	Sandstone, medium-grained, poorly cemented, grey, passing to conglomeratic sandstone with streaks of coaly matter	2.5
7	Shale, soft, grey	1.5
8	**Coalshale** and **coal** seam, black (sample 35/8)	0.3
9	Sandstone, fine-grained, laminated, grey	2.5
10	Sandstone, shaly, grey	2.5
11	Shale, grey	10
12	**Coalshale**, black	0.1
13	Sandstone, fine-grained, grey	0.5
14	Shale, grey	1.5
15	**Coal**, shaly, black (sample 35/15)	0.1–0.5
16	Shale, grey	3
17	**Coal**, black (sample 35/17)	0.2
18	Shale, grey, with thin sandstone intercalations	3
19	Sandstone, large-scale cross-bedded, grey	1
20	Shale grey	2.2
21	Sandstone, fine-grained, hard, grey	0.6
22	Shale, silty, grey, with 3–4 grey, fine-grained sandstone intercalations	2.3
23	Sandstone lens, coarse-grained, yellowish-grey, with black coal clasts (1–3 cm in size)	0.5
24	Shale, silty, grey	1.5
25	Sandstone, fine-grained, hard, grey	0.4
26	Shale, silty, grey	4.3
27	Sandstone, cross-laminated, shaly, grey	0.5
28	Shale, grey	3.5
29	Sandstone, fissile, grey	0.5
30	**Coal**, black (sample 35/30)	0.05
31	Shale, grey	0.2
32	**Coal**, black	0.05
33	Shale, grey	1.5
34	Sandstone, grey	0.4
35	Shale, grey	3
36	Sandstone, fine-grained, laminated, grey	0.3
37	Shale, grey	3
38	**Coal**, black	0.05
39	Shale, grey	0.7
40	Sandstone, cross-laminated, grey, in layers 0.3–0.5 m thick, alternating with grey shale 0.5–0.7 m thick	4
41	**Coal**, black	0.05
42	Shale, grey	3.5
43	Sandstone, grey, in layers 0.1–0.3 m thick, alternating with grey shale, 0.5–1.5 m thick	8.5
44	Sandstone, cross-bedded, lenticular, with coal streaks, with small sandstone concretions	0.5–1
45	Sandstone, grey-greenish, in layers 0.1–0.2 m thick, alternating with grey shale	1.5
46	**Coal**, black (sample 35/46)	0.2

47	Shale, grey, with soft shaly sandstone intercalations	1
48	**Coal**, shaly, black (sample 35/48)	0.2–0.3
49	Sandstone, soft, greenish, in layers 2–5 cm thick	0.2
Renardodden Formation (Upper Palaeogene). Incomplete thickness		15.7
50	Sandstone with coal-accentuated cross-bedded at bottom, well-cemented, with vertical *Scolithos*-type burrows	1–2
51	**Coal** (redeposited), a thin intercalation between hard, well-cemented sandstone layers (Nos 50 and 52)	0.01–0.03
52	Sandstone, medium-grained well cemented, massive, with cross-bedding accentuated by coal detritus, with vertical *Scolithos*-type burrows	1.5–3
53	Sandstone, medium-grained, well cemented, alternating with grey shale	3.5
54	Gravelly conglomerate, with coarse-sand matrix, with streaks of sandstone, grey. Pebbles, mainly quartzite, well rounded, spindle-like to isometric. Admixture of small pebbles (1–3 cm) of black coal	1.5
55	Sandstone, as beds Nos 50 & 52	2.0

Comments

The **Skilvika Formation** at the Skilvika section is represented by terrestrial strata which were deposited in a deltaic environment with stagnant pools and marshes where thin coal beds have formed.

The **Renardodden Formation** exposed at this section formed in a shallow-marine environment. Its basal beds with vertical *Scolithos*-type burrows, with reworked coal fragments derived from the underlying Skilvika Formation, and with intercalations of gravelly conglomerates with well rounded quartzite pebbles, correspond to stormridge and marine beach sedimentary facies.

Smaller, discontinuous coastal outcrops of the Renardodden Formations are to be found to the east of Skilvika: Stations 30 and 29 at Renardodden, and Stations 27, 25–23 north of Calypsobyen (Fig. 2). They expose a higher part of the formation: bluish-grey to grey, banded, often concretionary, rather soft, fine-grained sandstones in layers 10–50 cm thick, with thin intercalations of medium- to coarse-grained sandstone. The beds are locally rich in trace fossils *Ophiomorpha* (resp. *Thalassinoides*-type crab burrows). In the sandstones, there occur well-rounded quartz and quartzite pebbles (0.5–3 cm, occasionally up to 10 cm in size) and angular, sometimes rounded, fragments (0.5–3 cm across) of black stone coal, probably derived from simultaneously eroded coal-bearing Lower Cretaceous strata. Plant detritus is frequent in the sandstones (Birkenmajer & Zastawniak, 2005, pp. 149–150). These beds formed in a sublittoral marine environment. Total thickness of the Renardodden Formation has been calculated at over 150 m (see Dallmann, 1990, fig. 4–49).

PLANT ASSEMBLAGE AND GEOLOGICAL AGE OF THE SKILVIKA FORMATION

The plant fossil assemblage of the Skilvika Formation, recently described from Calypsostranda (Birkenmajer & Zastawniak 2005), is dominated by remains of co-

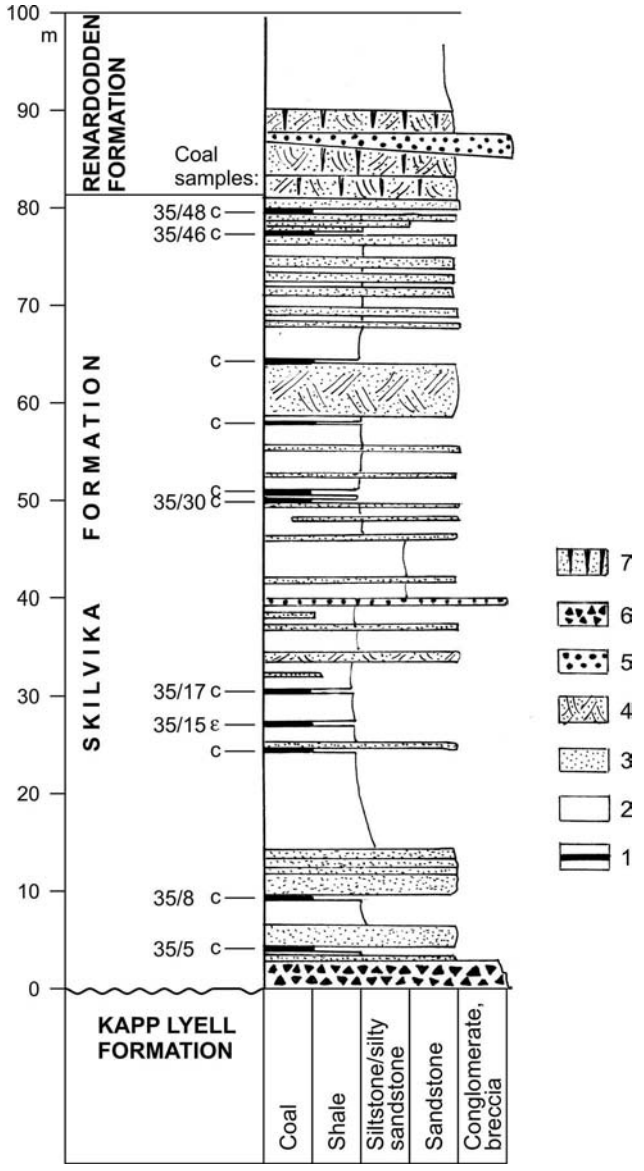

Fig. 4. Lithologic/stratigraphic log of the Callypsostranda Group at Skilvika (Station 25). See the text for detailed description. *1* – coal; *2* – shale; *3* – sandstone; *4* – cross-bedded sandstone; *5* – conglomerate; *6* – sedimentary breccia; *7* – cross-bedded sandstone with *Scolithos* burrows

niferous *Metasequoia* (Taxodiaceae) and leaf impressions of the morphogenus *Trochodendroides* (Trochodendraceae *vel* Cercidiphyllaceae). Other plant impressions include leaves of several Angiosperm taxons: the morphogenera of *Platanites* (Platanaceae), *Corylites* (Betulaceae), *?Ushia* (?Fagaceae), *Vitiphyllum* (?Vita-

ceae), "*Acer*" (Sapindaceae) and *Aesculus longipedunculata* (Hippocastanaceae), numerous leaf fragments of Dicotyledones gen. et sp. indet., and Monocotyledones (Liliopsida gen. et sp. indet.). Fruit fragments of two species of the genus *Nyssidium* (Cercidiphyllaceae) have also been found. The Sphenophyta are represented by stem fragments of the genus *Equisetum*. This macroflora represents the so-called Polar broad-leaved deciduous forest, as defined by Wolfe (1985). It correlates best with the Late Eocene/Oligocene plant assemblage from the Tertiary of Brøggerhalvøya, Northwest Spitsbergen.

Based on terrestrial plant remains, the Calypsostranda Group was dated at Oligocene (see Manum, 1962; Livšic, 1967, 1974; Schweitzer, 1974; Lehmann *et al.*, 1978; Thiedig *et al.*, 1979). The dinocysts indicate its Late Eocene–Early Oligocene age (Head, 1984; Manum & Throndsen, 1986).

COAL-PETROGRAPHIC DESCRIPTION

Sampling

Block samples for petrographic analysis of coals have been collected from the Calypsostranda Group at four sites (Fig. 2).

(1) **Calypsostranda, Tyvjobekken creek** (Station 14: Fig. 3B), Skilvika Formation, samples:
14/1 – a 5–10 cm thick seam of banded bright coal forming intercalation in black and dark-grey sandstone;
14/3 – bright coal streaks 1–2 cm thick in grey to black shale;
14/5 – bright coal streaks 2–5 cm thick in grey to black shale.
(2) **Calypsobyen, abandoned coalmine, dump heap** (Station 22: Fig. 3A), Skilvika Formation, samples:
22/1 – banded bright coal;
22/2, 22/3 (coaly shale).
(3) **Rensdyrbekken** (Station 26: Fig. 3A), Skilvika Formation, samples:
26/1, 26/2, 26/3 – coal interbeddings in grey shale.
(4) **Skilvika** (Station 35 – Fig. 4), Skilvika Formation, samples:
35/5 – black coal seam (20 cm);
35/8 – black coal and coalshale (30 cm);
35/15 – black shaly coal (10–30 cm);
35/17 – black coal seam (20 cm);
35/30 – black coal seam (5 cm);
35/46 – black coal seam (20 cm);
35/48 – black shaly coal (20 cm).

Methods applied

All block samples were disintegrated to fraction of 0.75–1.00 mm, and grain polished sections (briquettes) were prepared according to the standard methodology developed by the International Committee for Coal and Organic Petrology (ICCP). Maceral composition of the samples was determined by point counting (500 points on each sample), using a reflected light microscope (Axioscop-Zeiss) equipped with a monochromator and a photometer MP-200. The reflectance measurements were carried out on telocollinite grains. The terminology used for

maceral identification was adopted from Stach *et al.* (1982) and Taylor *et al.* (1998). Ash content was determined according to the Polish standards PN 80/G-O4512.

In facies analysis of the coal seams examined, methods based on maceral composition of coals (Diessel, 1986, 1992) were applied. For construction of facies diagram, two indices were followed: the Tissue Preservation Index (TPI), and the Gelification Index (GI): TPI = telovitrinite + telointertinite/detro-+gelovitrinite + detro-+gelointertinite + sclerotinite; GI = vitrinite + gelointertinite/telointertinite + detrointertinite + sclerotinite. Increased TPI values indicate dominance of woody-type plants in a primary palaeopeatbog. The peatbog groups considered were: clastic marsh, herbaceous swamp, wet forest swamp, dry forest swamp, fen, and dry fen.

In determining conditions of a peatbog, the facies indices introduced by Calder *et al.* (1991) were used: VI -Vegetation Index, and GWI - Groundwater Index; VI = telovitrinite + telointertinite/detro-+gelovitrinite + detrointertinite + sclerotinite + sporinite + cutinite; GWI = detro- + gelovitrinite + mineral matter/telovitrinite.

The mire types are the hydrological ones: swamp, fen and bog, with vegetational subtypes of swamp forest and bog forest. Peat-forming environments prone to clastic inundation produce impure coal types (shaly coal, coaly shale). The terms "inundated marsh" and "inundated forest" were thus introduced by Calder *et al.* (1991) for such environments.

In our study, we also used indices Va/Vb and Sf/F of Kalkrteuth and Leckie (1989) and V/I index of Harvey and Dillon (1985). The Va/Vb ratio is the quotient of structural vitrinite (telinite, collotelinite) to matrix-forming vitrinite (vitrinite B or collodetrinite and vitrodetrinite); it can be considered as an indication of the original contribution to the coal of preserved woody tissues versus detrital woody matter. High contents of vitrinite B or collodetrinite may also indicate some transportation of organic material prior to final deposition. The Sf/F ratio is calculated from semifusinite and fusinite macerals contained in the samples, and can be considered as a relative measure of the degree of oxidation which had taken place in the ancient peat swamp. The V/I index exhibits the vitrinite/intertinite ratio calculated on a fine micrinite and mineral-matter free basis. This index exhibits a general pattern in the vicinity of a channel. The high value of the V/I ratio indicates deposition of organic mater in a zone immediately adjacent to a channel.

Finally, Strehlau coal facies (Strehlau, 1991) were used for determination of different depositional sites within the swamps.

RESULTS

(1) In coals form the Skilvika Formation (Calypsostranda Group), the collotelinite reflectance Ro ranges from 0.48 to 0.54. All coals investigated belong to Sub-Bituminous Coal C according to the ASTM, and represent the 31rd technological type according to the Polish classification of bituminous coals.

(2) Petrographic analysis of our coals generally indicates a similar maceral groups composition.A diferent relation between structural and detrital macerals of vitrinite group was noted only in samples from Reinsdyrbekken.

(3) Vitrinite, dominated by its tellovitrinite subgroup (over 50% of vitrinite), is the most abundant maceral group of the coal seams and coal interlayers within grey and black shales from Tyvjobekken. Collotelinite and telinite occur mainly as thicker bands. Intertinite is present mostly as intertodetrinite finely distributed together with sporinite as thin laminae within vitrinite groundmass (detrovitrinite) between tellovitrinite bands. Fusinite and semifusinite are rare; they occur as irregular bodies inside vitrinite groundmass.

(4) Petrographic composition of coal and coaly shale from Calypsobyen (old coalmine dump heap), is similar to that of samples from Tyvjobekken. Vitrinite is there the dominant maceral group, telinite and collotelinite are second in frequency, intertinite and liptinite occur in minor amounts.

(5) The samples from Reinsdyrbekken are poorer in vitrtinite group macerals. Coal intercalations which occur in coalshales are dominated by detrital macerals: vitro- and intertodetrinite. The vitrinite group is represented mainly by collodetrinite. Intertodetrinite prevails in intertinite group. In the liptinite macerals group, sporinite is the most frequent.

(6) In the main section at Skilvika, coal seams and coal interbeddings are exceedingly rich in structural vitrinite macerals. Collotelinite is dominant, representing nearly 95% of total vitrinite. Telinite is rare, it occurs mainly as thicker bands within detrovitrinite. Intertinite and liptinite are represented mainly as intertodetrinite and sporinite dispersed in detrovitrinite.

(7) Optically determined mineral matter content is high (up to 50% in samples of shale with coal streaks). Clay minerals and quartz grains make up the bulk of the mineral matter. Ash content is quite variable, ranging from 15% in coal bands to 85% in samples from coalshales.

(8) Our coal seams are represented mainly by the vitrinite-fusinite facies. The coal seams from Calypsostranda, Calypsobyen and Skilvika (main section) are represented mainly by telocollinite subfacies: they originated in wet forest swamps with high groundwater condition. A wet forest swamp is characterized by a high degree of flooding and by gelification of organic material, with arborescent-type plants predominating. The coalshales from these sites represent the “shale with streaks of coal” subfacies. Their high content of mineral matter indicates that, during development of these coals and coalshales, the phytogenic deposits derived mostly from a wet forest swamp which grew close to a delta distributary or main river channels.

(9) A contribution of herbaceous swamp facies to coal formation was recognized in coals from Reinsdyrbekken. Coal streaks in coalshale from this site represent a cannel coal type of sapropelic coal facies, generated in inner parts of interchannel area lakes.

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