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Tertiary coal from the Lions Cove Formation, King George Island, West Antarctica

ABSTRACT: Thin coal seams found in the Lions Cove Formation, Polonia Glacier Group (Middle Eocene, upper part) at King George Bay, King George Island (South Shetland Islands, West Antarctica), represent lustrous (vitrine) brown-coal metaphase. The coal from the lower seam represents carbonized wood, probably angiosperm, that from the upper ones originated due to accumulation of branches or larger wood fragments and leaf remains. These coals are slightly older than metaxylite brown coal previously described from Admiralty Bay on King George Island, and dated at Eocene-Oligocene boundary. Both coal occurrences are evidences for a warm climate which prevailed in the Antarctic Peninsula sector during the Arctowski Interglacial (ca 50—32 Ma).

Key words: Antarctic, Tertiary, brown coal.

Introduction

Occurrences of brown coal in West Antarctica are rare (Birkenmajer 1985), the best known localities are at Admiralty Bay, King George Island (Birkenmajer 1980; Birkenmajer and Lipiarski 1985), and at Seymour Island, western Weddell Sea (Fleming and Askin 1982).

The site at Admiralty Bay belongs to the Ezcurra Inlet Group (Arctowski Cove Formation, Petrified Forest Member). By a combination of K-Ar and palynological data (Birkenmajer *et. al.*, 1983; Stuchlik 1981) it is dated at the Eocene-Oligocene boundary, falling within the Arctowski Interglacial (Birkenmajer 1988, 1990; Birkenmajer and Zastawniak 1989a, b) — Tab. 1. The coal is represented by metaxylite densely intergrown with silica, passing into siliceous rocks with subordinate coal matter. The main coal component is collinite often cracked or intergrown with quartz veinlets. Small fragments of plant tissues (telinite) with cellulae filled with granular porigelinite or massive levigelinite may sometimes occur (Birkenmajer and Lipiarski 1985).

The site at Seymour Island is within the Cross Valley Formation dated as Late Paleocene (Askin and Fleming 1982; Fleming and Askin 1982; Askin 1988 a, b). It pre-dates the first Tertiary glaciation (Kraków Glaciation) in the Antarctic Peninsula sector (Table 1).

Another locality of Tertiary brown coal on King George Island is at Lions Rump, King George Bay (Birkenmajer 1981). This locality is here described in detail.

Geological setting

The geological relations at Lions Rump, King George Bay (Fig. 1) have been described in detail by Birkenmajer (1981). There occur Tertiary lavas alternating with pyroclastic deposits with petrified wood, and with coaly shale and thin brown-coal intercalations, belonging to the Lions Cove Formation,

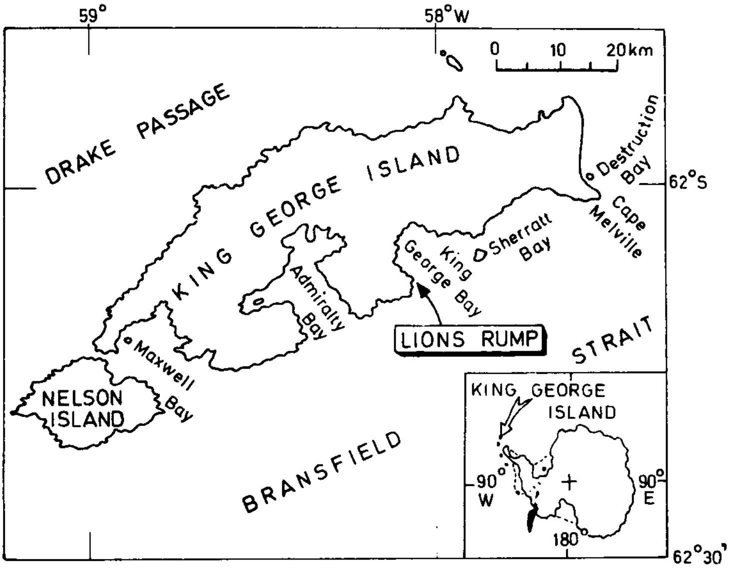
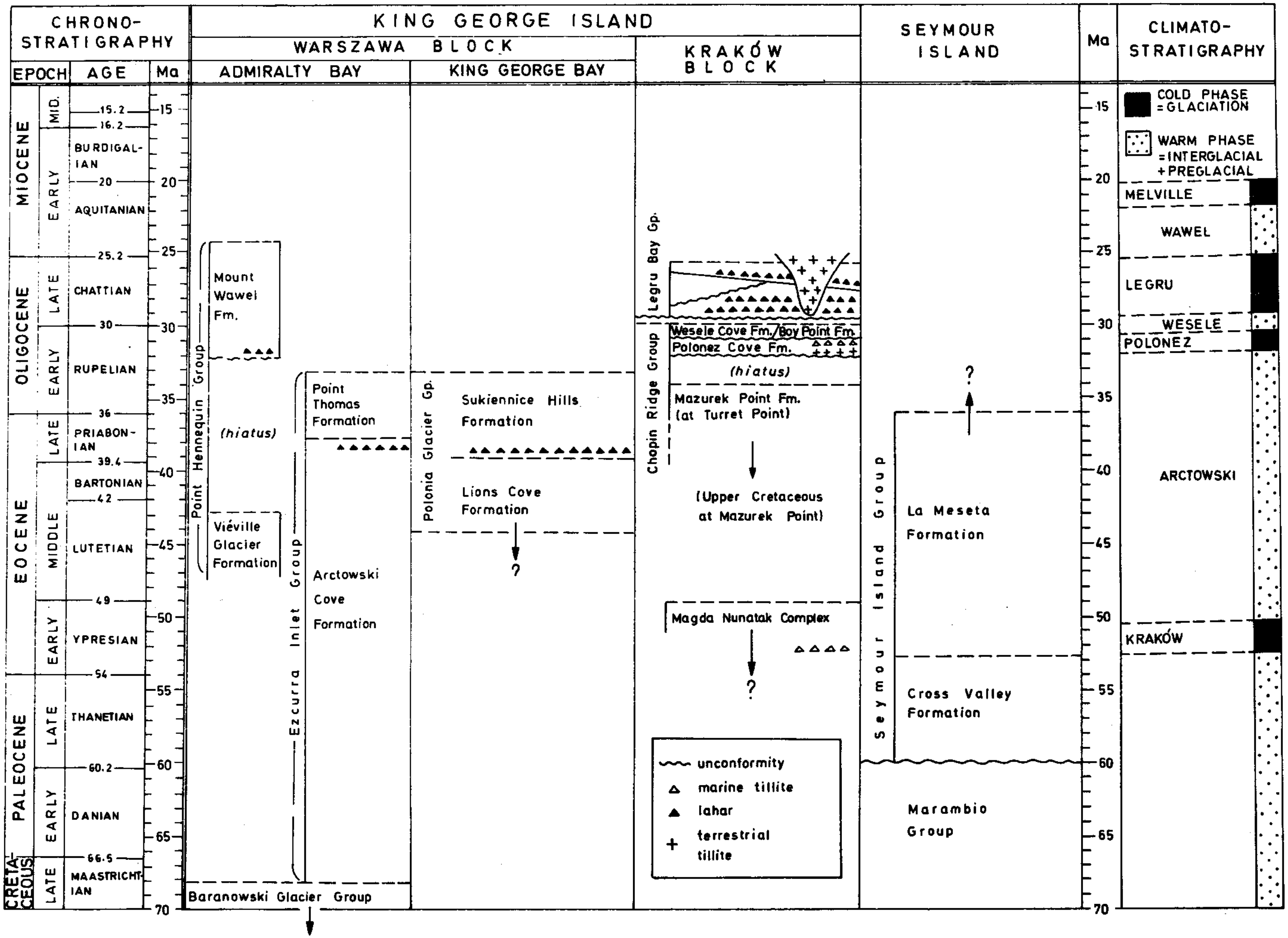


Fig. 1. Key maps to show location on Lions Rump on King George Island and in Antarctica (inset)

Table 1

Position of the Lions Cove Formation in lithostratigraphic and climatostratigraphic standards of King George Island. Seymour Island sequence given for comparison (*after* Birkenmajer 1988, 1990, modified). Chronostratigraphic scale *after* Haq *et al.* (1987)



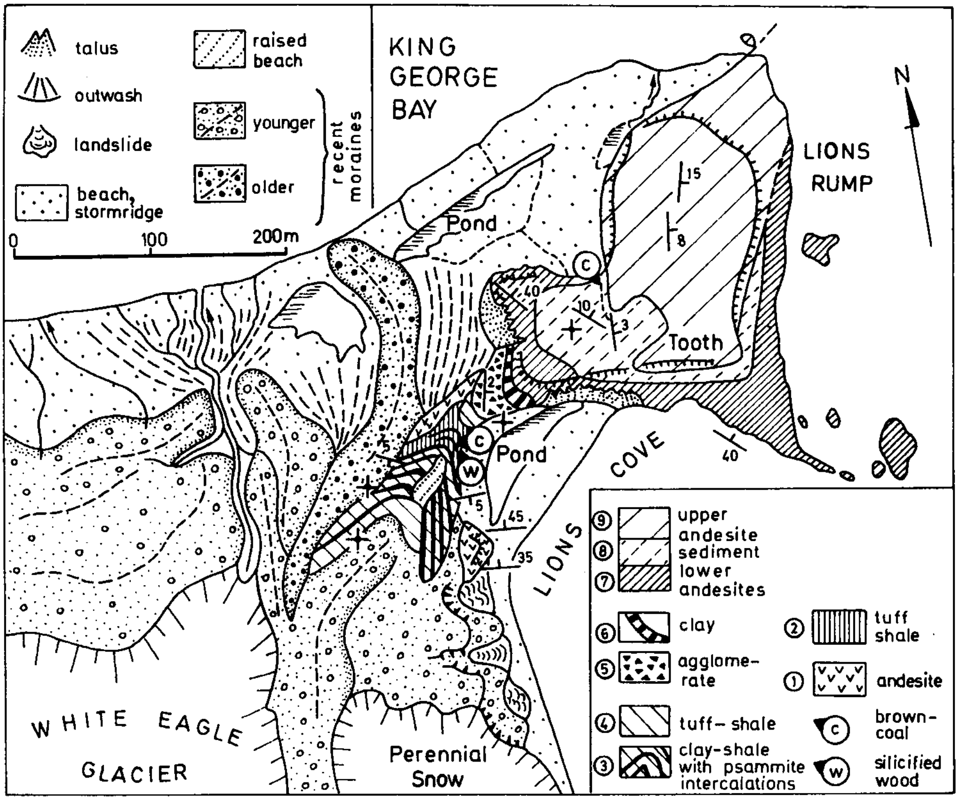


Fig. 2. Geological map of Lions Rump (*after* Birkenmajer 1981). Circled numbers correspond to those in Figs 3, 4 and Table 2

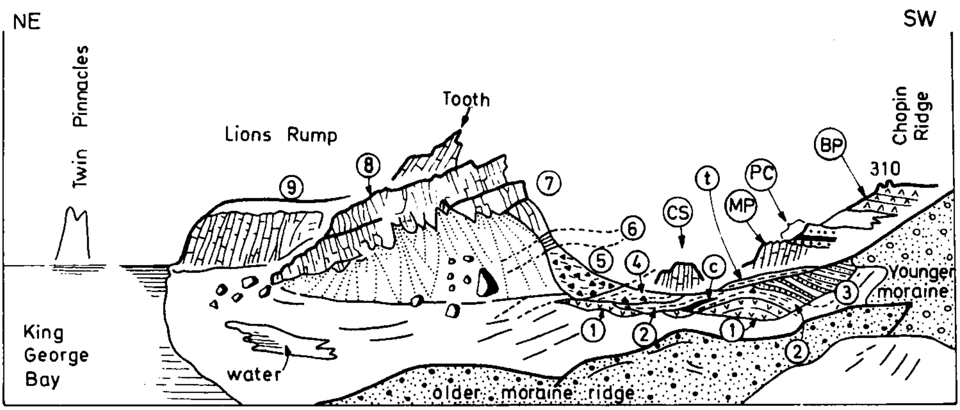


Fig. 3. Perspective view of Lions Rump; Chopin Ridge in the background (*after* Birkenmajer 1981). Lions Cove Formation: 1—9 *see* Figs 2, 4, Tab. 2; c — coal seams. Chopin Ridge Group: MP — Mazurek Point Formation; PC — Polonez Cove Formation; BP — Boy Point Formation; CS — Cape Syrezol Group (olivine basalt plug). Quaternary cover: t — raised marine gravel (at 10—20 m a.s.l.)

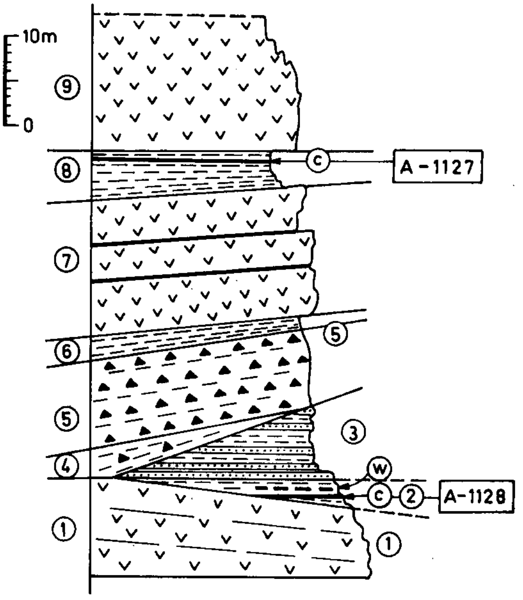


Fig. 4. Lithostratigraphic column of the Lions Cove Formation at Lions Cove — Lions Rump (*after* Birkenmajer 1981), with position of coals investigated shown (samples A-1127, A-1128). For explanations — see Figs 2, 3 and Tab. 2

Polonia Glacier Group (Figs 2—4, Table 2). Two coal samples have been investigated:

S a m p l e A-1128 derived from yellow tuff-shale containing carbonized wood, and silicified wood fragments 10—15 cm thick, at the base of the section (Bed No 2 — *see* Fig. 4; Table 2);

S a m p l e A-1127 derived from a coal seam up to 10 cm thick present in tuff shale between two andesite lava flows (Bed No 8 — *see* Fig. 4; Table 2). The geological cross-section is as follows (Fig. 5):

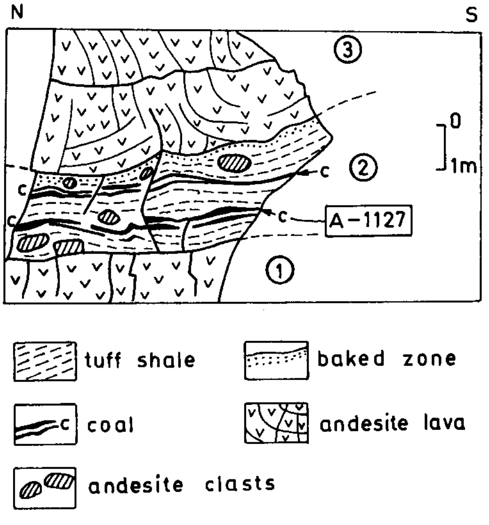


Fig. 5. Upper coal horizons in the Lions Cove Formation at Lions Rump. 1—3 — *see* the text

3 — andesite lava (4th flow), partly weathered, 5—15 m thick;

2 — tuff-shale, greenish to yellowish-rusty, with single andesite fragments 10—30 cm in diameter, with two thin black, shaly coal seams (maximum 10 cm thick), splitting into parallel bands and lenses. Sample A-1127 was taken from the lower seam. The tuff-shale is baked at the top just below the andesite lava, becoming yellow-coloured;

1 — andesite lava (3rd flow), strongly weathered at the top below coal-bearing tuff-shale.

Age of coal-bearing strata

The age of the coal-bearing Lions Cove Formation is Lower Tertiary as based on K-Ar dating of andesite lavas: 42±1 Ma (Smellie *et al.*, 1984, Table XVIII, Sample P.438.1 Lions Rump; taken probably from the upper part of the Lions Cove Formation, detailed localization not given). This date corresponds with an upper part of Middle Eocene and suggests that the Polonia Glacier Group correlates, at least in part (Lions Cove Formation), with an upper part of the Arctowski Cove Formation, Ezcurra Inlet Group, and with a middle part of the Point Hennequin Group (Table 1).

Table 2

Stratigraphic succesion in the Polonia Glacier Group (*after* Birkenmajer 1981)

GROUP	FORMATION		(MEMBERS/BEDS)	Thickness (m)
POLONIA GLACIER 210m+	SUKIENNICE HILLS 150m+		basaltic lava flows and tuffs	100+
POLONIA GLACIER 210m+	SUKIENNICE HILLS 150m+		agglomerate	50+
POLONIA GLACIER 210m+	LIONS COVE 60m+	9	(upper) hypersthene-augite-andesite	15+
POLONIA GLACIER 210m+	LIONS COVE 60m+	8	agglomerate & shale with coal	2–6
POLONIA GLACIER 210m+	LIONS COVE 60m+	7	(lower) augite-andesite (3 flows)	15
POLONIA GLACIER 210m+	LIONS COVE 60m+	4–6	tuff agglomerate and clay	8–9
POLONIA GLACIER 210m+	LIONS COVE 60m+	2–3	tuff-shale with feldspar-rich sand and conglomerate intercalations with coal and petrified wood in the lower part	6–8
POLONIA GLACIER 210m+	LIONS COVE 60m+	1	vesicular andesite	10+

(substratum unknown)

Coal petrography

Methods

Coal fragments from tuffogenic shale of Sample A-1127 were recovered by mechanical separation followed by enrichment in CCl_4 of 1250 kg/m^3 density. Coal fragments from Sample A-1128 did not need enrichment. The investigations included macroscopic description, as well as specialist petrographic and chemical studies:

— optical microscopic studies in transmitted and reflected light, with the use of Axioplan Opton microscope;

— measurement of reflectance coefficient of coal with the use of photometer MPM 200, Opton;

— construction of infrared absorption curve, with the use of Specord IR-75 Zeiss-Iena and pressed KBr pills;

— technological-chemical investigations aimed at determination of coal purity and its carbonization degree, based on Polish Normatives (Table 3);

— thermal investigations of coal, as a control of the above, with the use of derivatograph Q-1500 D (Hungarian production).

Petrography

Both coal samples show similar physical features. They are black in colour, with intense glassy-pitchy lustre which is visible at freshly broken surfaces only. On older broken surfaces, the lustre is much lower (dull) and the surface is covered with light-brownish films (scales) of Fe-oxides. The powdered coal is dark-brown.

Even slight pressure causes disintegration of coal into an aggregate of isometric grains 2—3 mm in diameter. This results from internal network of cracks in vitrinite and from dense schistosity parallel to bedding. Both discontinuites are being accentuated during weathering. The crack surfaces are uneven, needle-shaped or shelly. The surfaces of schistosity are uneven, orbicular (ring-like), consisting of concentric rings often developed incompletely (Fig. 6), from a fraction of mm to ca 12 mm in diameter (3—4 mm in diameter as a mean). In transversal section, they resemble flat cones with cut-off terminations (Fig. 7). Thin vertical pipes cutting through the whole thickness of caol seams (lenses) are visible. These pipes had probably formed already during semiplastic coaly gel stage, before development of contraction craks, and are traces of gas and vapour escape caused by warming-up the sediment by hot andesite lavas.

The coal consists almost entirely of vitrinite (98% vol.). Phlobaphenite (0.8% vol.) and mineral admixture (goethite at disintegration surfaces, pyrite and clay minerals as crack fills) are subordinate (1.2% vol.).

Collinite predominates among vitrinite macerals. It forms metrix for less common telinite and other admixtures. Collinite is optically not uniform, it reveals a district strain anisotropy, and includes microareas of unclear micrinite

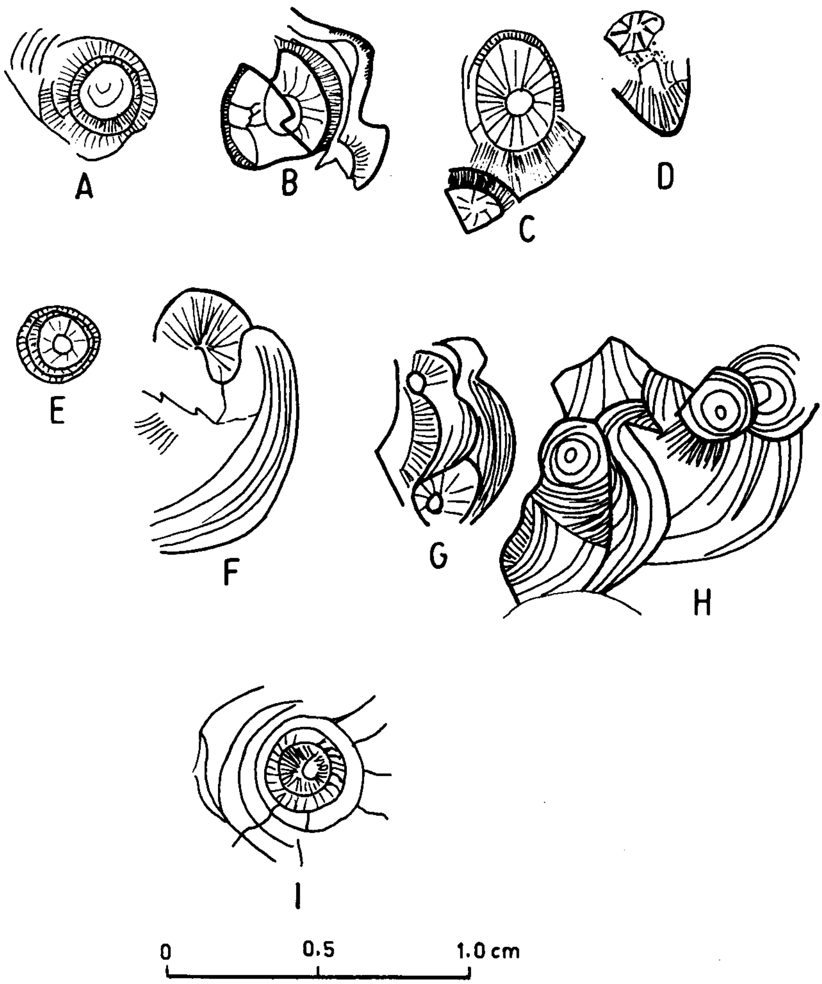


Fig. 6. Orbicular structures as seen on stratification surfaces in brown coal from the Lions Cove Formation

characteristics. This, together with other physical features, indicates the occurrence of brown-coal metaphase. Collinite in most cases is represented by telocollinite.

Telinite forms stripes and lenses of indistinct contours, up to 0.1 mm thick, in collinite and shows gradual passages to the latter. Concentration of telinite stripes showing characteristic disturbed structures, is visible in some parts of the rock. It evidences displacements at feebly-consolidated coal stage under pressure from overburden; at that stage, telinite was more rigid than gel of collinite medium. In some fragments, telinite contains phlobaphenite as fills of cells.

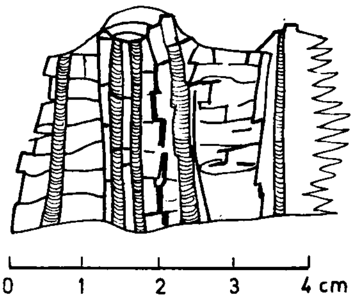


Fig. 7. Orbicular structures in brown coal from the Lions Cove Formation, transverse section

No fluorescence of vitrinite was observed in the coal (telinite) investigated. It confirms the suggestion that we deal here with brown coal (metaphase). This is also indicated by reflectance coefficient measurements of collinite (so-called telocollinite B): the values of R^o_m vary between 0.35 and 0.55 per cent (Fig. 8), with mean value of 0.44%, and standard deviation s = 0.04%. Such parametres are typical of brown coal (metaphase), *i.e.* for lustrous variety of hard brown coal. Feeble weathering of coal does not change the reflectance coefficient.

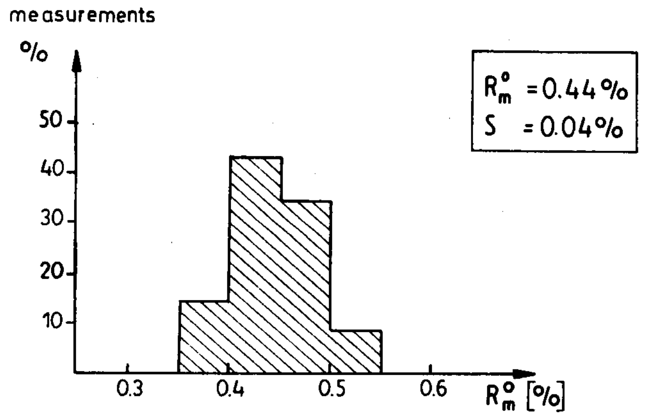


Fig. 8. Reflectogramme of coal sample A-1128, Lions Cove Formation

Chemistry

The chemical characteristics obtained indicate the presence of caustobiolite in medium-stage of carbonization. Analytical moisture of the coal, comparable with hygroscopic moisture (*i.e.* water content at equilibrium with moisture of the surrounding air) is 7.1 to 8.8 wt % (Table 3). Incineration of our coal is low, typical for vitrine (glossy) coal: 5.3 to 8.6 wt %.

The burning energy released corresponds to 26,000 kJ/kg (ca 6,300 kcal/kg), while warming coefficient at moisture stage (as above) is high — ca 22,700 kJ/kg (5,450 kcal/kg).

The content of volatiles is typical of highly-carbonized brown coal: 34.0—35.2 wt %. On the other hand, effectiveness of the so-called „bitumina" (ethanol-benzene extractions) is low: 0.6—0.7 wt % (Table 3). The coal does not possess coke qualities (slow expansion coefficient, and Roga Number equal to 0), but shows contraction of the order of several per cent, mainly due to release of volatiles.

Table 3

Chemical analyses of coals from the Lions Cove Formation M — moisture (wt %); A — incineration (wt %); Q_s — burning energy (kJ/kg and kcal/kg); V — volatiles; B — bitumina efficiency (wt %); IS — slow expansion coefficient; LR — Roga Number; C, H, S — content of elements (wt %); d — dry state; d.a.f. — dry and non-ash state; a — analytic state

Sample No	M^a	A^d	$Q_s^{d.a.f.}$	$V^{d.a.f.}$	B^d	IS^a	LR^a	$C^{d.a.f.}$	$H^{d.a.f.}$	$S_t^{d.a.f.}$
A-1128	8.8	5.3	26,485 (6,326)	35.2	0.7	0	0	61.8	5.20	0.58
A-1127	7.1	8.6	26,786 (6,398)	34.0	0.5	0	0	62.5	5.11	1.17

The elementary carbon content is low and atypical, C = 61.8—62.5 wt %; this indicates advanced weathering process in the coal. Hydrogen content is of the order of 5.2 wt %, and total sulfur content — 0.58—1.117 wt %. The coal sample taken from coaly tuffogenic shale (A-1127) was richer in sulfur.

Basic infrared spectrum shows a high degree of carbonization within brown-coal rank. The level of radiation absorption is high, close to that of low-carbonized stone coal. However, its brown-coal character is confirmed by carboxyl acids (humine) peaks: ca 1700; 1440; and 670 cm^{-1}, moreover by symmetric and asymmetric oscillations of cycloalkanes (3120—3020 cm^{-1}) and aliphatic ketons (1270; 550 cm^{-1}), and by numerous stripes of oscillations of the CH_2 group (Fig. 9). A high degree of carbonization, comparable with low-carbonized stone coal, is also indicated by oscillations of aromatic skeleton (*e.g.*, 1620; 1510; ca 700 cm^{-1}), the absence of OCH_3 group oscillations, and of significant oscillations of the CH_3 group.

Based on infrared examinations, the coal from the Lions Cove Formation represents a macro-unit with well developed aromatic core which accounts for about 60% of its volume. This core is surrounded by aliphatic chains, in part showing a character of organic acids, ketons and cycloalkanes.

A similar „mixed" character is shown by the DTA curve (Fig. 10). The measurements were taken in oxydizing atmosphere acting selectively on groups of chemical compounds of similar structure (as based on a multiyear laboratory experience). Two main exothermal maxima are visible, at 430 and 490°C, respectively. The first one reflects occurrence (thermal destruction) of organic compounds containing oxygen, usually cyclic in structure. A faint bend of the

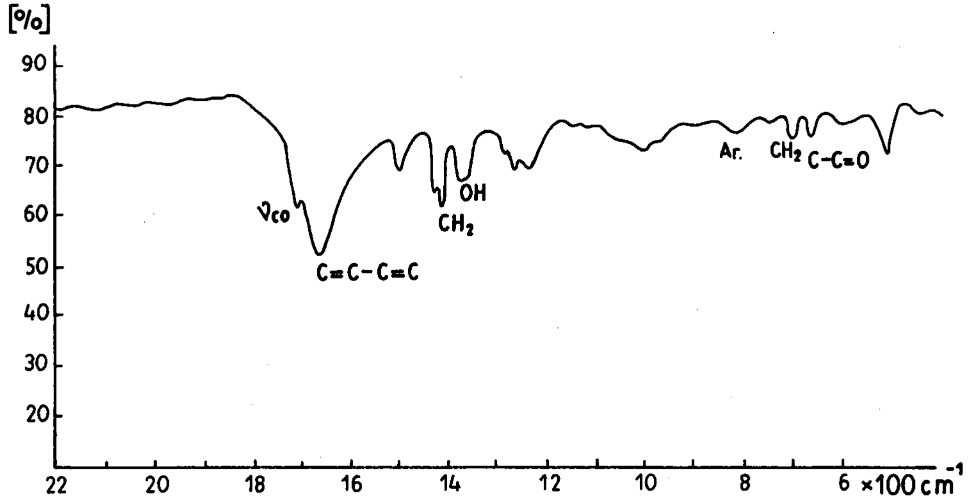


Fig. 9. Spectrogramme IR of coal from the Lions Cove Formation

peak at about 320°C indicates the presence of oxygen-containing compounds less stable than the terocyclic compounds. The other exothermal peak indicates thermal destruction of aromatic ring compounds which formed as a result of thermal transformation of oxygen-containing compounds.

A comparable intensity of both peaks is generally typical for brown coals (xylite coals) which, besides humines, contain also a significant amount of transformed lignine, sometimes also cellulose. However, slightly higher temperatures of both peaks compared with xylite coal, may be interpreted as an effect of thermal transformations of highly-carbonized brown coal (metaphase)

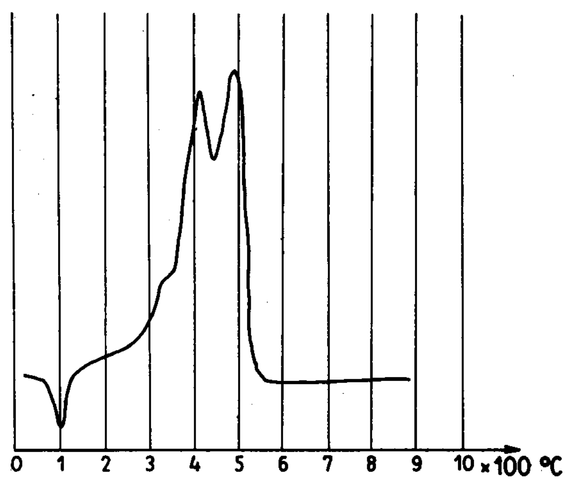


Fig. 10. Derivatogramme of coal from the Lions Cove Formation

altered by exogenic processes (weathering). The weathering of coal consists in initial phase mainly of oxydation of aliphatic compounds of peripheral zone of structural carbon unit, und at the same time in apparent increase of its aromatic character (Wagner 1981). Thus, besides acidic, realatively strong aromatic tendency is observable in such brown coals; this is shown by the DTA curve, and by chemical analyses which indicate low amount of C and low value of burning energy. Slight weathering of our coal is also indicated by its physical features, such as lack of lustre on older surfaces and a tendency to disintegrate.

Conclusions

The coals from the Lions Cove Formation represent lustrous (vitrine) brown coals (metaphase). The coal of Sample A-1128 from the lower part of the formation is a carbonized wood, probably angiosperm (lack of resinite and suberinite). The coal from Sample A-1127 from the upper part of the formation had formed by accumulation of fragments of branches or larger wood fragments, and of leaf remains; this is suggested by cutinite remains in coaly shale.

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Streszczenie

Zbadano węgiel pochodzący z dwóch poziomów w obrębie formacji Lions Cove (fm), grupy Polonia Glacier (gr) na Wyspie Króla Jerzego w Szetlandach Południowych (Antarktyka Zachodnia). Węgiel ten występuje we wkładkach skał osadowych wulkanogenicznych wśród lawowego kompleksu andezytowego wieku środkowoeoceńskiego. Węgiel z wkładki niższej przedstawia uwęglony pień drzewa, z wkładki wyższej — powstał wskutek akumulacji gałęzi lub większych fragmentów pnia oraz liści. Obydwa węgle należą do kategorii węgli brunatnych metafazy.