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GEOLOGY OF A MIDDLE DEVONIAN CANNEL COAL FROM SPITSBERGEN

BY

THOROLF VOGT

PETROLOGY OF Á MIDDLE DEVONIAN CANNEL COAL FROM SPITSBERGEN

BY

GUNNAR HORN

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GEOLOGY OF A MIDDLE DEVONIAN CANNEL COAL FROM SPITSBERGEN

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WITH 3 FIGURES IN THE TEXT

Abstract: A synopsis is given of the stratigraphy of the Middle Devonian beds of Mimer Valley, Central Spitsbergen, and a description presented of an occurrence of cannel coal in this series. The coal occurs just below beds with Asterolepis, belonging to the upper part of Middle Devonian. Large tree-shaped Lepidophytes of this age are also found. The early appearance of this „Upper Devonian" flora element is discussed. It is pointed out that the Middle Devonian sediments consist of much more weathered mineral grains than the sediments of Lower Devonian. The possible influence of the immigrating woods of Middle Devonian on chemical weathering is mentioned.

On his expedition to Spitsbergen in 1928, the present author studied, *inter alia*, the Devonian formation of Mimer Valley (Mimerdalen), at Billen Bay (Billefjorden), on the north side of the Ice fjord. He discovered here, in Middle Devonian beds, a seam of coal, representing, from the investigations of Horn (1941), a cannel coal, which may be of interest especially on account of its old age. A description of the geology of this coal bed will be given. As regards the previous geological work on the Devonian formation of the Mimer Valley reference may be made to the papers of Nathorst (1884, 1894, 1910), and to the paper of Stensiö (1918).

Synopsis of the Middle Devonian Stratigraphy of the Mimer Valley Area; Eastern Development.

In order to place the coal seam in the series, a synopsis will be given of the Middle Devonian beds in question, based on my observations in 1925 and 1928.

The Devonian beds of the Mimer Valley may be divided into a Lower and a Middle Devonian series, separated by a break. The sedimentary rocks of the two series are strikingly different. The rock material of the lower series is not much weathered, the sandstones often containing fresh felspars in great quantity, whereas the rock material of the upper series is heavily weathered, the sandstones generally only with "kaolinized" remnants of felspars. The rocks of the lower series clearly represent a more or less rapidly transported and deposited material. The material of the upper series was, on the contrary, subjected to the weathering during a long space of time. Both series are generally of continental character.

A western and an eastern development is discernible for the lower as well as for the upper series. In the lower series, the red and green Porolepis Sandstones, beds *d* and *e* of Stensiö, are increasing considerably in thickness towards the west, as indicated by my observations in the Hugin Valley—Dickson Bay area. As to the upper series, the lower part of the western development includes several beds which are not found at all in the east. These beds are thought to represent a part of the lost interval in the east. This is in accordance with the fish fauna, as partly described by Heintz (1929), of the Huginaspis Pass (between the Munin and Hugin Valleys), which belongs to the western development. The occurrence of a Huginaspis, (*Huginaspis Vogti* Heintz), especially indicates a smaller paleontological break between the two series in the west than in the east. Also other diversities occur, e. g. the disappearance, as far as is known, of the black shales towards the west.

The fossils mentioned in the present paper are given from the papers of Stensiö, (1918 a, 1918 b) and Heintz (1929, 1935), and from personal communications by A. Heintz (the fishes), and O. Arbo Høeg (the plants).[1] It may perhaps be mentioned that the most important fossil finds on my expeditions in this area were the discovery of the Devonian flora at Plantekløften (Plant Ravine), by A. Heintz, F. Isachsen, and myself in 1925, and of the flora to the south of Fiskekløften (Fish Ravine), by O. Arbo Høeg, T. Strand, and myself in 1928.

The following succession represent the eastern development, as exposed at the Estheria Hill, at the Plant Ravine, and at the Fish Ravine (vide the map fig. 1). Above the green Porolepis Sandstone (bed e of Stensiö), of Lower Devonian age, follow:

1. Gray sandstone in thick beds, total thickness about 5 m in the profile on the east side of Estheria Hill. These beds are, pro-

[1] Tree-shaped Lepidophytes are mentioned also from my own diaries.

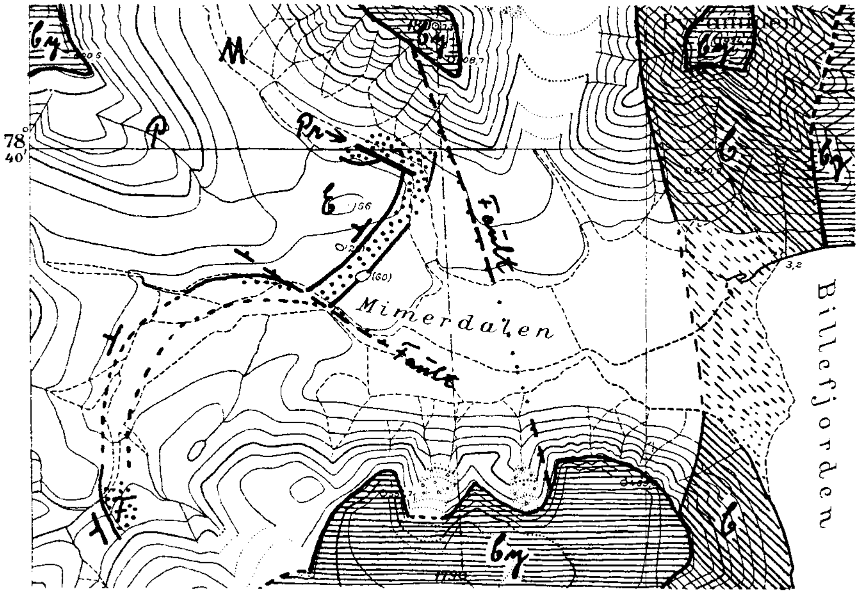

Fig. 1. The central part of Mimer Valley. Scale 1 : 75000. The dotted area between the two lines represents the Middle Devonian beds 1—6. Otherwise the Devonian beds are left unmarked. C = Culm beds. Cy = Cyathophyllum Limestone. M = Munin River. P = Plant Ravine (Plantekløften). E = Estheria Hill. F = Fish Ravine (Fiskekløften). Pr = the profile fig. 2. Topography from map 23 published in: Report of the Svalbard Commissioner concerning the Claims to Land in Svalbard. Part I. B. Oslo 1927.

visionally, interpreted as the basement beds of the Middle Devonian Series.

2. Black shale I with concretions of clay ironstone (bed Sk. I of Stensiö). This bed is exposed on the east and south side of Estheria Hill, in the latter locality with a thickness of about 20 m. From this bed are reported *Psammosteus* (*Psammolepis?*) *spinosus* n. sp., fragments of great Crossopterygii, and jaws of Coccosteids (?).

3. Yellowish gray sandstone, about 2 m and 1.5 m thick, respectively on the east and south side of Estheria Hill (bed f_1 of Stensiö).

4. Black shale II, (bed Sk. II of Stensiö). This brownish black shale, with concretions of clay ironstone, is exposed on the east side, to the northeastern corner, and on the south side of Estheria Hill. In the latter locality the thickness was about 30 m.

5. Yellowish gray, rather coarse sandstones, disclosed on the north and south side of Estheria Hill, with a thickness of about

60—70 m, respectively 30 m, near the Fish Ravine etc. (bed f_2 of Stensiö). These sandstones contained the first smaller tree-shaped Lepidophytes, and the bed of cannel coal described in the next section.

6. Black shale III (Fish Ravine Shale, and beds Sk. III and IV of Stensiö). A brownish black shale with concretions of clay ironstone, representing the bed extremely rich in fish fossils at the Fish Ravine, discovered by Nathorst in 1882. The thickness of this shale was about 15—20 m at the Fish Ravine and on the south side of Estheria Hill (Sk. III), and about 30 m on the north side. On the south side of the Estheria Hill, this bed appears twice in the profile (Sk. III and Sk. IV of Stensiö), owing to a fault. The western exposure contains *Estheria nathorsti* R. Jones, in great quantity in a relatively thin layer in the shale itself, whereas the eastern exposure has yielded *Asterolepis scabra* (A. S. Woodward), *Psammolepis undulata* etc. from concretions of clay ironstone. From the bed of the Fish Ravine itself, the following fish remains are reported: *Asterolepis scabra* (A. S. Woodward 1891), *Psammolepis undulata*, *Onchys arcticus* A. S. Woodward, *Dictyonosteus arcticus* Stensiö, *Holonema cf. radiatum* (Obručev), Rhizodontide scales, Dendrodont teeth, Glyptolepis scales (?), Coccosteide jaws, etc. Nathorst further reports on tree-shaped Lepidophytes.

7. Then follows a very characteristic division of green argillaceous sandstone (bed h of Stensiö), about or somewhat more than 100 m thick. It contains *Asterolepis cf. scabra* (A. S. Woodward), *Psammolepis undulata*, and of plants *Psygmophyllum* (or *Platyphyllum*) *williamsoni* Nathorst, and the first great Lepidophytes in Bergeria preservation.

8. The next division (bed i of Stensiö), consisting principally of sandstones with subordinate beds of shales and conglomerates, may probably be more than 400 m thick. It begins with 8 a: the lower Svalbardia Sandstone, a yellow sandstone, well exposed in the canyon to the south of the Fish Ravine, at this locality about 20 m thick, and rich in plants. Here occur a great tree-shaped Lepidophyte, with stems about 10 cm across, viz. *Bergeria mimerae* Høeg, and further a *Svalbardia* n. g. Høeg, displaying similarities to Kiltorkensia. This sandstone is superimposed by 8 b: a green shale, about 10 m thick, followed by 8 c: a violet sandstone. The succeeding beds are not present in this canyon, and were only poorly exposed in the profiles. I have studied them across the Estheria Hill to the Plant Ravine.

Above the frequently dark violet sandstone follow yellow sandstones, dark green sandstones, and conglomerates, with pebbles of quartz and quartzites, but also of non-metamorphic sandstones, possibly of Devonian age. Beds of green shales seem to be present in the series, to judge from disintegrated débris among the covering morainic drift.

Near the top, beds rich in plants again occur, the Upper Svalbardia Sandstone, viz. a yellowish green sandstone with well preserved plant remains: the same species of Lepidophyte, *Bergeria mimerae* Arbo Høeg, and the same new species of Kiltorkensia as in the lower bed. Further, a *Psygmophyllum* (or *Platyphyllum*) sp., a new genus named *Enigmophyton* Høeg with the aspect of a great Psygmophyllum, *Hyenia Vogti* Høeg, and a small Lepidophyte, *Protolepidodendropsis pulchra* Høeg.

9. The following division, the Plant Ravine Conglomerate, (bed m of Stensiö), represents a very peculiar conglomerate, as it seems with a thickness of more than 100 m, well exposed at the Plant Ravine, and also farther to the north. The well rounded conglomerate stones, up to about 35 cm in diameter, are lying close together in a dark and very friable sandstone matrix, and consisting almost exclusively of a gray, non-metamorphic sandstone, possibly of Devonian age. It contains thin layers of friable dark sandstone, dark shale with concretions of clay ironstone, and also coarse yellow sandstone. In the latter, indeterminable plant remains are found. This conglomerate includes the youngest known beds of the Devonian formations of the Mimer Valley area and of Spitsbergen.

The Coal Seam at Estheria Hill.

Along the Munin River, on the north side of Estheria Hill, a section through Middle Devonian beds is exposed. The eastern termination of the profile corresponds with the acute northeastern corner of the Estheria Hill area, where the river turns sharply to the south. To the west, the rocks are increasingly covered with morainic drift. The designation of the beds follows the stratigraphical members of the previous section. From ESE to WNW the following beds are exposed (vide fig. 2):

4. Brownish black shale, with yellowish brown streak, representing the upper about 10 m of the Black shale II. To the south of the corner, the river runs for a distance almost parallel to the strike of this bed.

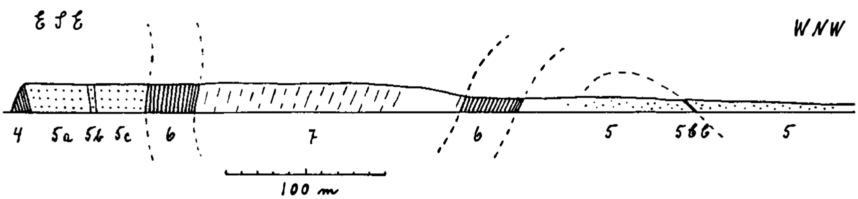

Fig. 2. Profile from the north side of Estheria Hill, along the Munin River. 4 = Black shale II. 5, 5a, 5c = Yellowish sandstone, with dark sandstone (5b), and seams of cannel coal (5CC). 6 = Black shale III (the Fish Ravine Shale). 7 = Green argillaceous Asterolepis Sandstone

5a. Yellowish gray sandstone with a yellowish coat of weathering, consisting prinicpally of quartz grains, with „kaolinized“ felspars in minor quantity. Thickness about 35 m.

5b. Dark, at least partly olive-green, sandstone. Thickness about 4 m.

5c. Yellowish gray sandstone like 5a, thickness about 30 m. The beds 5a and 5c contain fairly large, undeterminable plant remains, as do also the corresponding beds on the south side of Estheria Hill. The latter sandstones are similarly partly yellowish gray with a yellow coating, but also partly dark gray with a whitish coating.

6. A brownish black shale with numerous concretions of clay ironstone, representing the Black shale III (the Fish Ravine Shale) in inverted position. Thickness about 30 m.

7. Then follows, in the central part of the syncline, the distinctive green argillaceous Asterolepis Sandstone, to the east in inverted position. The strike of the western part of these beds, and of the beds further to the west, cross the profile intersection at a more or less acute angle. The green argillaceous sandstones are exposed over a length of about 130 m; then to the west follows a covered part of about 35—40 m with numerous blocks of this sandstone.

6. A black shale, probably representing the Black shale III, poorly exposed over a length of about 35 m, after which about 25 m wholly covered ground follows.

5. A yellowish sandstone, very poorly exposed, in many places only evidenced by numerous angular blocks, over a length of more than 150 m.

5 CC. The seam of cannel coal, exposed about 85 m from the first appearance of the numerous sandstone blocks, and about 110 m

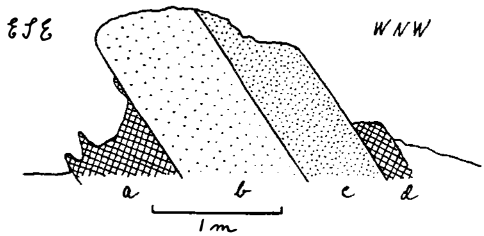

Fig. 3. The cannel coal exposure of the profile fig. 2. a and d = pure coal. b = dark sandstone. c = sandstone containing coal.

from the last exposure of the black shale. The strike of the coal seam is SSW, the dip about 55° to WNW.

From below follow (vide fig. 3):

a. 0.65—0.70 m pure coal
b. 0.80 m dark sandstone
c. 0.50 m sandstone containing coal
d. 0.20 m pure coal

The ground immediately below and above these beds was covered with drift.

The coal was wholly massive, without visible stratification, and rather strong and firm. In the sandstone near the coal layers was found a small tree-shaped Lepidophyte. It is possible that the coals and the accompanying dark sandstones correspond to the dark sandstone 5b farther to the east.

General Remarks. On The Early Appearance of the tree-shaped Lepidophytes.

The age of the fish fauna of the Fiskekløften Shale (Fish Ravine Shale = Black shale III) has been much discussed. The fauna was formerly considered to belong to the Upper Devonian by Nathorst (1910), Stensiö (1918a, 1918b), and Heintz (1935), whereas it is now referred to the upper part of Middle Devonian by Säve-Söderberg (1932, 1934, 1937 a and b), Heintz (1937), and Stensiö (Stensiö and Säve-Söderberg 1938). My own paper (1928 p. 112), where the Middle Devonian affinities of the fauna and flora of these and superimposed beds are pointed out, may, perhaps, also be mentioned. Based on the large *Asterolepis scabra* (A. S. Woodward), Säve-Söderberg (1937 b p. 30—34) refers the present zone to the Old Red Asterolepis beds, including the Nairn beds of Moray Firth, the John o'Groats Sandstones of Caithness, the Eday Sandstone of the Orkneys, the Brindister Flags of Shetland, and Dm_4 and Dm_5 of the Baltic states. This age determination refers to the Fish Ravine shale (6) and to the superposing green argillaceous Asterolepis sandstone (7).

The coal bed and the first tree-shaped Lepidophytes are found in the yellowish sandstone (5) below the Fish Ravine shale. According to Horn (1941) the coal principally represents a spore coal, laid down in more or less stagnant waters. These stagnant waters indicate marked continental conditions, with dry land in the immediate neighbourhood. The coal further indicates a rather dense vegetation at this time, consisting, at least partly, of smaller tree-shaped Lepidophytes. The first real, great tree-shaped Lepidophytes are found in beds, which, from the fish fauna are estimated to belong unquestionably to Middle Devonian, viz. the green Asterolepis Sandstone (7).

The beds above the green Asterolepis Sandstone do not contain determinable fish remains, the age being therefore more uncertain. According to information given by Arbo Høeg, Hyenia represents a typical Middle Devonian flora element, whereas *Svalbardia*, and still more the great Lepidophyte (*Bergeria Mimerae*) and *Protolepidodendropsis pulchra,* represent Upper Devonian flora elements. These beds may belong to the transition beds between Middle and Upper Devonian, as suggested by me before (1928). Or they may, and this is perhaps the most natural, belong to the upper part of Middle Devonian (the Asterolepis beds).

Even leaving the latter plants out of the discussion, it is a remarkable fact that so important an Upper Devonian flora element as the tree-shaped Lepidophytes (Lycopodiales), appears as early in Spitsbergen as in ascertained Asterolepis beds, or in upper part of Middle Devonian.

In Europe proper, similar "Upper Devonian" flora elements have, in appearance, not been found in Middle Devonian beds. This may give a slight indication as to a more proximate position of these northern areas to the centres of evolution of the mentioned flora elements than the more southern areas. The extremely rich development of the real Upper Devonian flora at Bear Island, also with coal beds, may perhaps give a hint in the same direction.

On the American side, another "Upper Devonian" flora element is found in beds now classed as Middle Devonian. The famous tree-stumps of Eospermatopteris at Gilboa, Schoharie Valley, New York, formerly considered Upper Devonian, belong, from the recent investigations of C. Arthur Cooper (1933—34, vide also Størmer 1934) to the upper part of Middle Devonian (Windom member of the Moscow formation, Hamilton group).

The development of the Devonian floras may have been connected with the rising lands of, largely or partly, late pre-Devonian mountain chains, the Old Red beds being regarded as postorogenic sediments from the new-formed mountains and hills. One may assume the existence of such a mountain chain from Spitsbergen, along the East coast of Greenland to Newfoundland and the Appalachians. It seems at present, in my opinion, to be possible that the mentioned land-belt may have played a prominent rôle in the development of the Upper Devonian floras.

Another feature, probably concerning the old vegetations of Spitsbergen, may be pointed out. As mentioned above, the mineral grains of the sediments, especially the sandstones, of the Lower Devonian series, were not much affected by chemical weathering, the felspars generally being preserved fresh and unaltered. This fact may be ascribed to a rapid transportation and sedimentation of the sands and muds, leaving the atmospherical factors only a comparatively short time to act on the mineral grains. This rapid transportation agrees well with the conception of semi-desert conditions which may have prevailed in Lower Devonian time, not by reason of shortness in precipitation, but owing to the existence of only sparse vegetation. Reference may be made to an earlier discussion by me on this topic, as to pre-Cambrian land surfaces without vegetation (1924 pp. 328—29, 369—70).

In contrast to the conditions of the lower series, the mineral grains of the Middle Devonian sediments are heavily weathered, the sandstones generally only containing decomposed remnants of felspars. The sands of these rocks were clearly subjected to chemical weathering during a long space of time. This marked change in external conditions from Lower to Upper Middle Devonian may have various causes. The Lower Devonian sediments were generally of postorogenic character, the basins of sedimentation being surrounded by relatively steep mountains, giving a rapid transport of the sands. In the course of time, these mountains were, however, denuded, giving a slower transport of the detritus. The climate may also have changed in the direction of greater warmth and humidity. It may, however, be pointed out that a more continuous cover of vegetation will also involve a slower transportation of the débris and an intensified chemical action on the mineral grains. Indirectly, the immigration of woods would also suggest some change of the climate. I have a strong impression from my field work of the generally great contrast between the quantity and type of vegetation in the Lower, and the quantity and type of vegetation in the Middle Devonian in these areas, and I would also in this connection stress the importance of the cover of vegetation.

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GUNNAR HORN

WITH 1 PLATE

In 1928 the Norwegian geologist Th. Vogt discovered a seam of coal in Middle Devonian beds in Mimer Valley at Billen Bay (Billefjorden) on the north side of Ice Fjord, Spitsbergen. The geology of this area and the geological position of the coal have been exhaustively dealt with by Vogt himself (1941) to whose paper on the subject I beg to refer. Samples of the coal were handed to me for description.

The macroscopic appearance of the samples indicates coals of the same general character. They are homogeneous and with a more or less even fracture. The colour is dull blackish with a brownish shade, and the streak is distinctly brown. Tiny specks and streaks of shining coal are common. The coals are compact and tough, rather hard, traversed by a few joints, and much slickensided, so that the coal usually breaks into lumps limited by such features. The joints and slickensides are often stained brown from iron oxides. The specific gravity of a piece appearing to represent the average was determined at 1.316, i. e. the same as for bituminous coals. The brown streak might suggest that our coals were of the brown coal rank[1], but neither boiling with a potassium hydroxide solution (N. KOH) nor with diluted nitric acid (10 per cent. HNO_3) produced any brown or yellow colouring of the fluid, so that our coals are of the rank of true coal (*Steinkohle*). They can be kindled by the application of a match.

As the coals are compact and tough, polished and thin sections were easy to make. When viewed in polished section and reflected light (Pl., Fig. 1) the coal is seen to consist of fine-grained organic constituents with some grains of quartz (having a marked relief).

[1] *Rank* defines the position of the fuel in the series peat-anthracite. It shows the degree of metamorphism. The *type* of a coal is determined by the kind of plant material from which it originated.

Streaks of vitrinite (from fragments of woody matter) and some megaspores are also seen. It is, however, only in thin section that the true botanical nature of the coal is readily recognized. It consists almost entirely of the flattened spores of plants, and thus differs markedly from ordinary coal. Photomicrograph Fig. 2 (Pl.) shows a thin section of this spore coal, and Fig. 3 the same when viewed under a high magnification. The spores have commonly a length of 0.02 to 0.1 mm, and they have a more or less subparallel arrangement. They are compressed and partly interlocked, and humic matter is apparently distributed throughout the mass. The toughness of the coal is thereby easily explained. Some yellow bodies of bitumen also occur. Dark streaks and patches probably represent substance high in ash. Between crossed nicols the many grains of semi-angular quartz become conspicuous, and minute flakes of muscovite are also present. These mineral constituents occur scattered throughout the coal mass.

A powdered sample was oxidised for a week with Schulze's solution (conc. nitric acid + potassium chlorate). The coals were easy to macerate. The residue was washed in water and treated with ammonia, whereby the oxidised material was dissolved leaving a residue consisting almost exclusively of small spores and their fragments. In addition to these were some indistinct fragments of cuticle (?), and grains of quartz and some muscovite. On one spore were seen the triradiate ridges, these being the imprint of the three other spores of the tetrad.

From the above it is clear that the Mimer Valley coal is a *cannel,* although it has not quite its typical macroscopic appearance. The typical cannel has a marked conchoidal fracture and a dull, somewhat greasy or satiny lustre; but a high ash content would make this appearance less characteristic. A cannel coal is, above all, fine-grained, and in thin section is seen to consist of spores and subordinate other plant remains such as cuticle, resinous substance, fragments of woody matter. With this our coal agrees well. As will appear from the analyses below, the chemical composition is also typical cannel: extremely high content of volatiles and hydrogen, and a very high yield of tar[1]. The cannel coal from Mimer Valley was

[1] Boghead coals have also an extremely high yield of volatiles and tar, but are microscopically different from the cannels. They consist chiefly of "yellow bodies" ("algal bodies"). Cf. Horn (1931), Bode (1932), and Skilling (1938). Some cannels also contain subordinate amounts of these "algæ".

analysed by Mr. Ole A. Løkke of the Norwegian State Railway's Chemical Laboratory:

Proximate:

			On moisture-and ash-free basis	
Moisture	0.9	per cent.		
Ash	21.2	—		
Fixed Carbon (Coke less ash)	29.7	—	38.1	per cent.
Volatile Matter	48.2	—	61.9	—
	100.0		100.0	

Ultimate:

Moisture	0.9	per cent.		
Ash	21.2	—		
C	63.6	—	81.5	per cent.
H	5.7	—	7.3	—
O+N+S	8.6	—	11.2	—
	100.0		100.0	
Gross calorific value	6773 Cals. (12191 B. t. u.)		8694 Cals. (15649 B. t. u.)	
Net — —	6461 Cals. (11630 B. t. u.)		8300 Cals. (14940 B. t. u.)	

The coke was intumescent and silver grey. The ash is greyish. This coking propensity distinguishes our coals from the usual cannels, which are generally considered as non-caking (pulverulent coke); but it should be borne in mind that by progressive coalification (*Inkohlung*) the cannel coke also commences to swell.

A sample has been assayed (by me) for yield of tar and low-temperature coke. For this purpose 25 gm. were placed in the aluminium distillation apparatus of Fischer-Schrader, and the temperature was gradually increased to 520° C. The result was:

Semi-coke	59.4	per cent.
Tar	28.3	—
Water	4.5	—
Gas and loss	7.8	—

The semi-coke was well sintered and rather firm. The water had an alkaline reaction. Referred to dry, ash-less coal the tar yield is 35 per cent. The yield of various cannels is given by Fischer and Schrader (1920) as 20—30 per cent. Our coals have thus a very high yield of tar. The Tertiary coals of the Kings Bay Field in Spitsbergen are also distinguished by being high in volatiles, averaging abt. 47 per cent (dry, ash-less basis) and the content of hydrogen is abt. 7 per cent. Their yield of tar by low-temperature distillation is abt. 20 per cent. Although these chemical data would suggest a cannel, they are nevertheless *not* cannels (Horn 1928, pp. 37—38), which have *physical* characteristics that the Kings Bay coals do not possess. The latter are macroscopically and in thin section very similar to ordinary Long Flame coals. The reason why the Kings Bay coals and some coals from the Central Tertiary Basin of Spitsbergen are so high in tar is not quite clear. In some way it must be connected with the presence of material with a high content of resinous and fatty substances.

A study of the position of our coals in the classification schemes shows that they fit in well as cannels. The classification of Grout (1907) is based on fixed carbon for coals above bituminous, and on fixed carbon and total carbon for bituminous coals and those of lower rank. According to this classification, cannel coals are those with a fixed carbon content of 35—48 per cent., and a total carbon of 76.2—88 per cent. Our coals with 38.1 per cent of fixed carbon and 81.5 per cent of total carbon thus fit well into this scheme. The Kings Bay coals have on the average a fixed carbon content of 53 per cent and 82.5 per cent of total carbon (Horn *loc. cit.*, p. 37). In this classification they would thus not come within the cannel class, but be classed as bituminous coal. Seyler (1928) uses on his carbon-hydrogen diagram lines of equal calorific value (isocals) and of equal volatile content (isovols). Cannels are here in the area above the line of 15 734 B. t. u. and of the line of vol. 47. The volatiles of our coals bring them well into the cannel class, but the cals. only to the border. The Kings Bay coals with an average of 47 per cent of volatiles and 14 913 B. t. u. are, however, below the cannel border in this classification. Bode (1931) has emphasized the need for *combining* the microscopic and chemical data when classifying the bituminous coals. In his cannel group (including the bogheads) the cannels proper have a ratio of carbon to hydrogen of 10—14 and a fuel ratio (Fixed Carbon to Volatile Matter) of 0.65—2.50. These figures for our coals are 11.2 and 0.62, and for the Kings Bay coals 11.8 and 1.13. A consideration of these chemical data alone, then, would lead one to believe that the coals were practically identical, but a microscopic study of them shows that they are quite different, the Kings Bay coals belonging to the group of banded bituminous coals. When classifying a coal it is thus essential to consider the chemical *and* the microscopic criteria.

How were our coals formed? As stated above, they consist of a uniform mass of spores with rather abundant mineral constituents. It is reasonable to assume that they were formed through deposition of vegetable mud in lakes and stagnant waters, too deep for subaerial vegetation, in the forests, and they are consequently in a way allochthonous, and not the product of normal peat accumulation. The base of the lowest coal layer has not been uncovered, but I think no under-clay representing an ancient soil upon which the plants grew would be found below it.

The spores were blown into the lakes and deposited and mixed with mineral matter and some plant débris washed into the collecting basins. This mode of origin makes it probable that the beds of cannel have only a limited extension and are more or less lenticular. But in the same sequence similar deposits may well occur elsewhere.

It is interesting to note that in Bear Island we have coals which may have a similar mode of origin. One of the Upper Devonian coal seams has in its lower part a peculiar dull, graphite-black, and massive coal having the appearance of the so-called "pseudo-cannels" (cannels changed by metamorphism). Its texture and appearance has led me to believe that it represents plant débris which has drifted into stagnant waters and deposited here along with mineral matter (Horn *loc. cit.*, p. 18). The mode of origin should then be similar to that of the Spitsbergen cannel, but the Bear Island pseudo-cannels seem to have a wider extension. In Bear Island, however, the coalification has progressed much further (as indicated by the low content of volatiles and the physical character of the coal), resulting in a deep black somewhat lustrous coal in which it is impossible or, at all events, difficult to recognize the botanical constituents. Spores could not be identified in this altered coal, which seems to consist chiefly of humic matter. The texture, however, is granular, making it probable that when the coal was of a lower rank (less metamorphosed) it had the appearance of a true cannel in spite of the probable (?) absence of spores.

A progressive coalification of the Mimer Valley cannel would, perhaps, produce a coal with a similar appearance.

The occurrence of beds of true cannel in the Upper Middle Devonian of Spitsbergen is of considerable interest, since they are, to the best of my knowledge, the oldest known cannels in the world.

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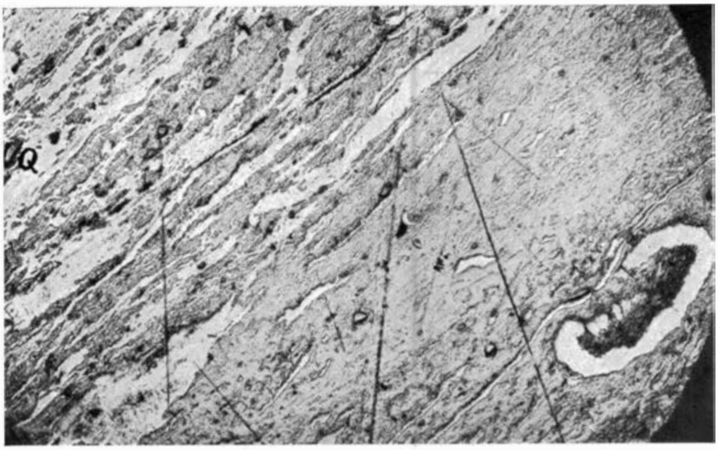
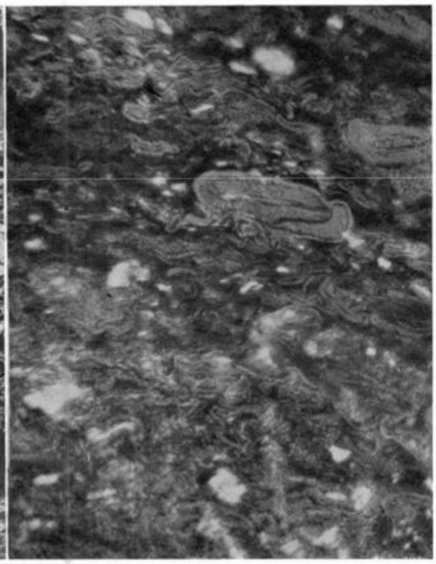


Fig. 1. Cannel coal. Fine-grained texture. Megaspore and streaks of vitrinite. Q = Quartz. Polished section. × 45.

2.



3.

Fig. 2. Showing the coal to consist chiefly of spores. Thin section. × 75.
Fig. 3. A more highly magnified view of the coal shown in Fig. 2. Subparallel arrangement of the spores. Light spots are quartz. Thin section. × 200.

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