Herr sekretær Tornøe
med hilsen
fra forf.

DET KONGELIGE DEPARTEMENT
FOR HANDEL, SJØFART, INDUSTRI, HÅNDVERK OG FISKERI

NORGES SVALBARD- OG ISHAVS-UNDERSØKELSER
LEDER: ADOLF HOEL

SKRIFTER OM SVALBARD OG ISHAVET

Nr. 57

ANDERS K. ORVIN

GEOLOGY OF THE KINGS BAY REGION, SPITSBERGEN

WITH SPECIAL REFERENCE TO THE COAL DEPOSITS

WITH 52 TEXT FIGURES, 4 MAPS AND 3 PLATES

OSLO
I KOMMISJON HOS JACOB DYBWAD
1934

Results of the Norwegian expeditions to Svalbard 1906—1926 published in other series. (See Nr. 1 of this series.)

The results of the Prince of Monaco's expeditions (Mission Isachsen) in 1906 and 1907 were published under the title of 'Exploration du Nord-Ouest du Spitsberg entreprise sous les auspices de S. A. S. le Prince de Monaco par la Mission Isachsen', in Résultats des Campagnes scientifiques, Albert I[er], Prince de Monaco, Fasc. XL—XLIV. Monaco.

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Bear Island. 1 : 10 000. (In six sheets). 1925. Kr. 30,00.

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Charts:

No. S. 1. Bear Island. 1 : 40 000. 1932. Kr. 4,00.
„ S. 2. Bear Island Waters. 1 : 350 000. 1931. Kr. 5,00.
„ S. 3. From Bellsound to Foreland Reef with the Icefjord. 1 : 200 000. 1932. Kr. 5,00.
„ S. 5. Norway—Svalbard, Northern Sheet. 1 : 750 000. 1933. Kr. 4,00.
„ S. 6. Norway—Svalbard, Southern Sheet. 1 : 750 000. 1933. Kr. 4,00.

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A. W. BRØGGERS BOKTRYKKERI A/S

Contents.

Illustrations.

Maps and Plates.

Preface.

This paper treats of the property of the Norwegian coal mining company, *Kings Bay Kul Comp. A/S*, which is situated at Kings Bay on the west coast of Spitsbergen.

The company was incorporated in 1916, and from 1917 almost continuous coal-minig operations were carried on until the summer of 1929, when the mines were closed down. The workings were constructed during a time of exceptionally high prices and were therefore very expensive. In 1920 the company had spent its capital and loan resources, and it then applied to the Norwegian Government for support. As the Spitsbergen coal mines were vitally important to Norway as a source of supply, the Government granted advances on coal deliveries to the State. Also in the following years such advances were given.

To attend to the interests of the State in the coal-mining industry of Spitsbergen the Government appointed two committees, the Spitsbergen Coal Committee in 1920 and a committee in 1927 to report upon the question of crude oil production from Kings Bay coals. Further, the Government granted means for an extensive and detailed geological examination of the coal field in 1922 and 1923, and for deep drilling in 1928.

In 1922 the Norwegian Government was authorized by the *Storting* to make a closer examination of the coal field, and the Department of Trade requested the office of the Norwegian State-supported Spitsbergen expedition to draw up a plan for the work. This plan was accepted by the Spitsbergen Coal Committee and the Department of Trade, and the above-mentioned office was entrusted with this work, which was executed in 1922 and 1923 by the author, who was also in charge of the drilling operations in 1928.

For the geological description of the property area I have worked out two maps on the scale of 1 : 100000, surveyed to the scale of 1 : 50000; and for the coal field two maps on the scale of 1 : 12500, surveyed to the scale of 1 : 5000. On the one copy of these maps, which is printed in colours, the geological observations from the surface have been inserted. However, as the surface is to a great degree covered, so that the real geological development of the solid rock cannot be plainly determined from the surface maps, I have also constructed maps on the same scale, in which all the superficial deposits have been removed. The geological features have been inserted as I think they really are. In places where I consider the border lines, the outcrops of coal seams, faults, etc., to be more or less doubtful, I have used dotted lines. For the construction of these maps I have also had the benefit of the results of mining work, deep-drilling, and the pit sections. For further explanation of the maps I have drawn up section plates. These are meant to be of a more schematic nature, and thus they do not claim to be absolutely correct, since I have lacked sufficient observations relating to the depth of the layers. Under the glaciers I have dotted the probable course of border lines, faults, etc.

As commonly used by *Norges Svalbard- og Ishavs-undersøkelser* the geographical names are written in Norwegian, excepting some names of greater localities.

In preparing this paper I have, in addition to the earlier published papers, had the opportunity to use some former reports on the coal field. The most important of these were written by Herr Otto Wex, Bergassessor a. D. 1911, Dr. F. W. Voit 1913, and Mr. Adolf Hoel, of the University of Oslo, 1921.

During my work at Kings Bay I have also obtained information from Mr. B. A. Sherdahl, who was then manager of the mine. He has also measured a great part of the pit sections. Further, Mr. E. Slåtto, then mining engineer at Kings Bay, has given me useful information as well as maps of the mines with necessary figures of elevations in the section lines.

Sherdahl has also been good enough to read through the chapter concerning the history of coal mining and has, in addition, given me some of the figures concerning the number of hands employed and the inhabitants of Ny-Ålesund. The mining inspector of Svalbard, Mr. H. Merckoll, has also kindly furnished me with mining statistics for the period since 1926. I am also greatly indebted to Mr. Adolf Hoel, the leader of *Norges Svalbard- and Ishavs-undersøkelser*, who has given me valuable help and useful suggestions in the preparation of this paper.

Oslo, May 30, 1933. *Anders K. Orvin.*

Introductory.

The surroundings of Kings Bay and the occurrence of coal on the south side of the fjord are mentioned at an early date in the history of Spitsbergen. Thus, coal is mentioned as early as 1610 by the English Whaler Jonas Poole, who also describes the fjord and its environs for the first time. [Purchas (1610)]. The famous Scottish whaler and polar explorer W. Scoresby (1820) mentions the occurrence of coal and marble at Kings Bay, and he also publishes a list of minerals and rocks from this tract. Poole named the fjord Deere Sound. Later on several different names were used, e. g., Kars Sond, Engelsche Bay, Koninks Bay, and others. The name Kings Bay was introduced by Scoresby in 1820.

In 1837 the Swedish zoologist, Professor Sven Lovén, visited Kings Bay. He has not himself written about this visit, but K. Chydenius (1865) cites his diary notes from this expedition. There is, however, very little of geological interest in his account. In 1861 Spitsbergen was visited by a great Swedish expedition headed by Otto Torell. Some of the members of this expedition also worked at Kings Bay. One of the members, I. W. Kuylenstjerna, surveyed Blomstrandhamna (Blomstrand Harbour) and Kolhamna (Coal Harbour). The geologist of the expedition C. W. Blomstrand (1864), has given a good description of his geological investigations of the district around Kings Bay. He also drew up a geological sketch map of the eastern part of the coal field, on which he noticed a coal seam that lay uncovered in five different places in cuttings made by the brooks. According to this map it can not be doubted that it is the Ester Seam which he has observed in front of Lovénbre No. 1.

In 1892 a German expedition in the *S. S. Amely* visited Kings Bay. One of the members, Leo Cremer, who was the mining expert of the expedition, searched in vain for the coal seams found by Blomstrand (Zeppelin 1892).

In 1892 the Swedish professor Axel Hamberg (1894) went to Spitsbergen on board a Norwegian sealer. He worked on the south side of the fjord and made a sketch-map of the lower parts of the Lovén Glaciers, which were named by him. The chief object of his visit was to make observations on the glaciers.

Sir Martin Conway and E. J. Garwood visited Kings Bay in the summer of 1897. They made a sketch-map of the central part of Spitsbergen including also Kings Bay and studied the glaciers on a sledge excursion inland.

The first topographic map of the Kings Bay region was surveyed in 1906 and 1907 by the expeditions sent out and financed by the Prince of Monaco. These expeditions were led by Gunnar Isachsen, who mapped Brøggerhalvøya and surroundings in 1907. Arve Staxrud and Alfred Koller took part in the mapping north of Kings Bay. The map was printed on the scale of 1 : 100 000.

Adolf Hoel took part in the expedition of 1907 as geologist and worked partly at Kings Bay. A topographical description was written by Isachsen and Hoel (1913). In this paper the authors deal with the topographical conditions on Brøggerhalvøya and its surroundings very closely, and, further, they give a detailed description of the glaciers and their movements. Hoel (1913) has also published a geological paper of the different formations around the fjord, in which, besides giving the new observations, he summarizes what was previously known. His geological observations relate to the Quaternary in particular.

In 1909 and 1910 Kings Bay was again visited by the expeditions of Isachsen. Both these expeditions had the financial support of the Norwegian State. The hydrographers of these expeditions, A. Hermansen and J. Pettersen-Hansen (Jørgen), surveyed Kings Bay on the scale of 1 : 200 000. Olaf Holtedahl, of the university of Oslo, and Hoel were geological members of these expeditions. Holtedahl, in particular, worked in the Kings Bay region.

In 1910 the German Arctic Zeppelin expedition also visited Kings Bay and made a detailed survey of Zeppelinhamna.

In 1911 an expedition conducted by Hoel and Staxrud worked in Spitsbergen. Also this expedition had the support of the Norwegian State. Holtedahl took part also in this expedition, and geological work was done on a sledge journey from the interior of Kings Bay and on Brøggerhalvøya.

On the expeditions in 1909 and 1910 Holtedahl made a detailed examination of the Upper and Middle Carboniferous strata, in which he established the presence of a Middle Carboniferous division belonging to the Russian Moscovian. In a paper published in 1911 he gives a detailed paleontological description of the rich fauna found in this division. In 1911 he continued the work at Kings Bay, and in a paper published the following year he deals amongst other localities also with the Kings Bay region including also Brøggerhalvøya. In this paper he has given a geological description of the formations found at Kings Bay and has included the first geological map of Brøggerhalvøya on the scale of 1 : 100 000. Another geological map on the scale of 1 : 200 000 shows the geological conditions from Kings Bay to the Ice Fjord.

Holtedahl (1912) observed the Hecla Hoek rocks resting upon younger formations, and pointed out the thrust plane forming the border between the Hecla Hoek rocks and the younger rocks from Forlandsundet eastwards. At that time there was no coal mining at Kings Bay and a detailed examination of the Tertiary field was therefore not made.

From 1906 Kings Bay was visited yearly by expeditions sent out by companies interested in the examination or working of the coal field. Of the scientific work done in the first years of this period we shall mention the examination of the coal field in 1911 by the German mining director, Otto Wex, the topographical mapping of the coal field in 1913 by Mr. Karl Bay on a scale of 1 : 10 000, and the geological examination by the German geologist, Dr. F. W. Voit in the same year. In 1914 Adolf Hoel made a preliminary examination and geological mapping of the coal field. As his basis he used the map surveyed in 1913 by Bay. In 1915 the Russian mining engineer Maliavkin also examined the coal deposits.

Since coal mining began some of the Norwegian State-supported expeditions under the leadership of Hoel did various work and paid short visits to Kings Bay in different years.

In 1921 the *Kings Bay Kul Comp. A/S* requested the Norwegian State — supported Spitsbergen expeditions under the leadership of Hoel to map the coal field on the scale of 1 : 1000. The mapping was executed in the autumn by Alfred Koller and Wilhelm Solheim. The stereophotogrammetric method was used, and the mapped area was 11 sq. kilometres.

As already mentioned, the Government made grants for the geological examination of the coal field and its surroundings in 1922 and 1923.

In 1922 the western part of Brøggerhalvøya and the coal field were mapped. As the topographical basis for the mapping of the peninsula I used the map surveyed in 1906 and 1907. For the coal field I used the map surveyed by Mr. Karl Bay in 1913. The results were presented to the Department of Trade in a report of March 1923.

The topographical basis used for the geological mapping of the coal field in 1922 was not so detailed that all geological observations could be included. In 1923 I therefore made an exact geological mapping of the coal field on the scale of 1 : 5000. As my basis I used a photographic reduction of the map drawn to the scale of 1 : 1000 on the Norwegian State-supported Spitsbergen expedition in 1921. A new report was presented to the Department of Trade in May 1924.

On Hoel's expedition 1923 the waters surrounding the harbour at Ny-Ålesund were sounded by A. Hermansen and L. Hagerup, and the expedition put up a beacon on Brandalspynten.

In 1924 Hoel's expedition surveyed the danger line from Kvadehuken southwards and Kings Bay inside Lovénøyane and between Kap

Guissez and Blomstrandhalvøya. Hydrographers were: R. von Krogh, A. Hermansen and K. Thorkelsen.

Hoel paid short visits to Kings Bay in the years 1922 to 1925 for geological purposes. In 1925 the author, too, measured some sections in the mines.

As we have heard, the Government granted funds for deep drilling in 1928 with a view to finding out more about the value and the potentialities of the coal field. The drilling was planned and executed by *Norges Svalbard- og Ishavs-undersøkelser*, who hired two machines from *Norsk Diamantborings A/S*. As leader of this work I had again the opportunity to check the geological maps, and also to proceed with the geological mapping of the Hecla Hoek on the property area of the company. That summer the topographers B. Luncke and W. Solheim from *Norges Svalbard- og Ishavs-undersøkelser* made corrections and additions to the maps around Kings Bay.

Also an Italian expedition sent out by the Italian Navy in 1928 in connection with the expedition of Umberto Nobile did scientific work at Kings Bay, including detailed soundings along the shore at Ny-Ålesund and on the north side of the fjord, and also made an accurate determination of latitude and longitude, and gravity determinations on Blomstrandhalvøya.

In addition to the above-mentioned scientific exploration, the coal company has done considerable exploration work on the coal field, under the leadership of Sherdahl. As I am dealing with the history of coal mining in a special chapter I shall only summarize a few facts here.

The first claim was staked in 1901, and in the following eighteen years Kings Bay was visited by a series of expeditions, which partly undertook exploring work on the coal field. The results are available only as geological and technical reports. *Kings Bay Kul Comp. A/S* was constituted in the autumn of 1916, and later on continuous working of the coal seams was carried on until the summer of 1929, when the mines were closed down.

Geography.

Situation.

The area belonging to *Kings Bay Kul Comp. A/S* is situated around Kings Bay in the northwestern part of Spitsbergen in about 79° N. Lat. and 12° Long. E. of Gr., and is thus the northernmost coal field ever worked on a technical and economic basis.

The exact description of the border line in: Report of the Svalbard Commissioner concerning Claims to Land in Svalbard (Svalbard Commissioner (1927)) runs as follows: "The area is limited by the following boundary lines: From point No. 195 at the north coast of Kongsfjorden, about 2 kilometres northwest of Tønsneset, latitude 79° 01′ 25″ longitude 11° 55′ 40″, a straight line to point No. 196, the summit of Olssønfjellet, 912 metres above sea-level, latitude 79° 03′ 35″ longitude 12° 01′ 20″. Thence a straight line across Blomstrandbreen to point No. 197, the summit of Skreifjellet, 1,030 metres above sea-level, latitude 79° 02′ 25″ longitude 12° 20′ 40″. Thence a straight line to point 198, a summit 822 metres above sea-level, latitude 79° 01′ 45″ longitude 12° 27′ 40″. Thence a straight line to point No. 199 on the summit of the westernmost of Stemmeknausane, 368 metres above sea-level, latitude 78° 58′ 35″ longitude 12° 39′ 20″. Thence a straight line across Kongsbreen to point No. 200 on Colletthøgda, latitude 78° 53′ 55″ longitude 12° 37′ 40″ Thence a straight line across Kongsvegen to point No. 201, the summit of Nielsenfjellet, 844 metres above sea-level, latitude 78° 51′ 55″ longitude 12° 21′ 40″. Thence a straight line to point No. 202 on a summit of Bogegga, 894 metres above sea-level, latitude 78° 50′ 50″ longitude 12° 13′ 20. Thence a straight line to point No. 203 at the north coast of Engelskbukta, at its inner end, latitude 78° 50′ 00″ longitude 12° 55′ 20″. Thence the boundary follows the coast-line of Engelskbukta and Forlandsundet, via Kvadehuken, around Brøggerhalvøya, further the coastline of the east and north side of Kongsfjorden to point No. 33 at the left lateral moraine of Blomstrandbreen, latitude 78° 59′ 50″ longitude 12° 17′ 40″. Thence a straight line to point No. 32 at the coast of the southeastern shore of Blomstrandhamna, latitude 78° 59′ 35″ longitude 12° 07′ 20″. Thence the boundary follows the coast-line around the bottom of Blomstrandhamna, then past Tønsneset back to the starting point No. 195. (Points Nos. 33 and 32 are also boundary points of the area No. 2 of the *Northern Exploration Co. Ltd.*). To the area also belong Prins Heinrichs Øy and the islets a little to the east of it. Area (including Prins Heinrichs Øy and the islets east of it): 114.1 sq. miles or 73 000 acres or 295 sq. kilometres".

As will be seen from this description and the geological map, Blomstrandhalvøya and Lovénøyane do not belong to the company. These areas were the property of the *Northern Exploration Co. Ltd.*, London, and now belong to the Norwegian State.

The coal field and the mining camp of Ny-Ålesund, are situated on the south side of the fjord in the middle part of the northeastern coast of Brøggerhalvøya.

The distance from Ny-Ålesund to Tromsø in Northern Norway is about 590 nautical miles, or about two and a half days' voyage by collier.

Climate.

Continuous meteorological observations have not been made at Kings Bay, and thus we do not know the monthly and weekly average temperatures. However, such observations are available from Green Harbour, lying in 78° 2′ N. Lat. and 14° 14′ Long E. of Gr., since 1912. The temperatures at Kings Bay differ but little from those at Green Harbour. The mean temperature at Green Harbour from 1912 to 1926 is calculated by the Meteorological Institute of Oslo.

Mean temperatures from 1912 till 1926 in C°.

Month	Degrees
January	— 16.1
February	— 19.1
March	— 18.5
April	— 13.5
May	— 4.8
June	2.0
July	5.4
August	4.6
September	0.1
October	— 5.8
November	— 11.8
December	— 14.3
Yearly average	— 7.6

This table shows that the mean temperature of Green Harbour is — 7.6 degrees Celcius. Probably the temperature at Kings Bay is somewhat lower, perhaps about — 8°. The snow lies from the middle of September to the middle of June with some variation in the different years. The precipitation is unknown, but, as in other places in Spitsbergen, it is not very high.

The fjord usually freezes up in the latter half of October. The ice, which may break up several times in the winter, finally disappears in the month of June. Shipping may commence in the middle of June and be carried on till the middle of October, about four months.

The drift-ice hampers shipping but rarely. Some years the drift-ice, which float northward along the coast of Spitsbergen, may extend as far as Kings Bay, but usually the ice is melted in the warm branch of the Gulf Stream flowing along this coast. The ice north of Spitsbergen is brought to the west towards Greenland with the current, and does not drift southwards along the coast of Spitsbergen. Ice from the glaciers in the interior of the fjord floats out to the sea throughout the summer, but never in such great quantities as to impede shipping.

At Kings Bay there is midnight sun from April 17 to August 27, and a season of obscuration from October 23 to February 19.

Topography.

From the map it will be seen that the area belonging to the company in respect of the topography is not a connected whole. The great

Fig. 1. Kings Bay coal field seen from Gerdøya.
To the left Sherdahlfjellet, in the middle Zeppelinfjellet, to the right Scheteligfjellet.
L. J. Orvin phot. 6/8 1922.

glaciers debouching into the interior of the fjord divide the area into several detached parts. The most prominent of these is Brøggerhalvøya including the coal field. It is also the only part containing geological formations younger than Hecla Hoek. On the east and north sides of the fjord there are three different areas, namely, the surroundings of Ossian Sarsfjellet, Feiringfjellet with adjacent land, and the mountains west of Blomstrandbreen.

The total area is 295 sq. kilometres, of which 124 sq. kilometres or 42 per cent. is covered with ice.

Brøggerhalvøya is a wild and ragged alpine land with many glaciers lying in cirques, divided by narrow crests and ragged peaks up to 900 metres high, which may be quite inaccessible. The watershed is well defined and runs in a zigzag line. The glaciers do not reach the sea. Their terminal fronts are situated at the inner edge of the great plain of marine denudation, which borders the peninsula. This plain, which for the greater part is covered by terraces made up of marine gravel and clay, is from one to two kilometres broad; at Kvadehuken the width extends up to five kilometres.

The area of the peninsula is about 180 sq. kilometres, of which one-fourth, or 46 sq. kilometres, is covered by glaciers. More than 50 sq. kilometres are covered by marine clay and gravel and river deposits. Of the remaining 70 sq. kilometres the greater part is covered by talus, débris, and earth slided by solifluction. Thus only on a smaller part the solid rock can be seen on the surface.

Of the whole property area, about 104 sq. kilometres or 35 per cent. is lying below the 100-meter level, 168 sq. kilometres or 57 per cent. between 100 and 500 metres above sea-level, and 23 sq. kilometres or about 8 per cent., above 500 metres.

On Brøggerhalvøya, 71 sq. kilometres or 39.5 per cent. is lying below 100 metres, 97 sq. kilometres or 54 per cent. between 100 and 500 metres, and 12 sq. kilometres or 6.5 per cent. above 500 metres.

The area between Kongsvegen and Kongsbreen, which is occupied by Ossian Sarsfjellet, is of a somewhat different shape. The mountain is made up of rocks belonging to the Hecla Hoek system, mica schists, quartzites, and limestones, which have been scoured and striated by the ice from the east, and thus has more rounded forms. The greatest elevation is here only 364 metres above sea-level. At the base of Ossian Sarsfjellet there is no coastal plain.

Between Kongsbreen and Blomstrandbreen there is a steep mountain, which reaches the height of 1070 metres in the summit of Feiringfjellet. This mountain, as well as the sharp crest of Skreifjellet farther west, is built up by quartzite and mica schist. The steep slopes are covered with rocks and débris. In the lower part of the slope on the south side of Feiringfjellet are a large number of granite blocks, which must have been brought thither by Kongsbreen, once when this glacier was thicker and had a far more advanced situation than at present. The coastal plain is here narrow and covered with great blocks of rock down to the shore.

To the west of Blomstrandbreen, the northern part of Olssønfjellet and Nordvågfjellet, a name I have attached to the isolated mountain above Nordvågen in Blomstrandhamna, are made up of the same limestones as are found in Blomstrandhalvøya, where attempts have been made to quarry them for building purposes.

On this northwestern part the coastal plain is up to one kilometre broad.

We will now look a little closer at the conditions in the Tertiary area. This area, containing the coal seams, is of a very limited extent.

It is situated on the low-lying ground between Scheteligfjellet to the west, Kings Bay to the northwest, Brøggerbreen and Zeppelinfjellet to the south and southwest, and to the east it wedges out somewhere under Lovénbre No. 2 close to the north of Sherdahlfjellet. This mountain was originally named Kolfjellet by Blomstrand. As, however, this name is used for a mountain at Bell Sound, I have named the mountain after Sherdahl, who was manager of the mine from 1917 to 1929.

The southern part of the field is covered by Brøggerbreen, and thus the width can not be exactly established here. The Tertiary field

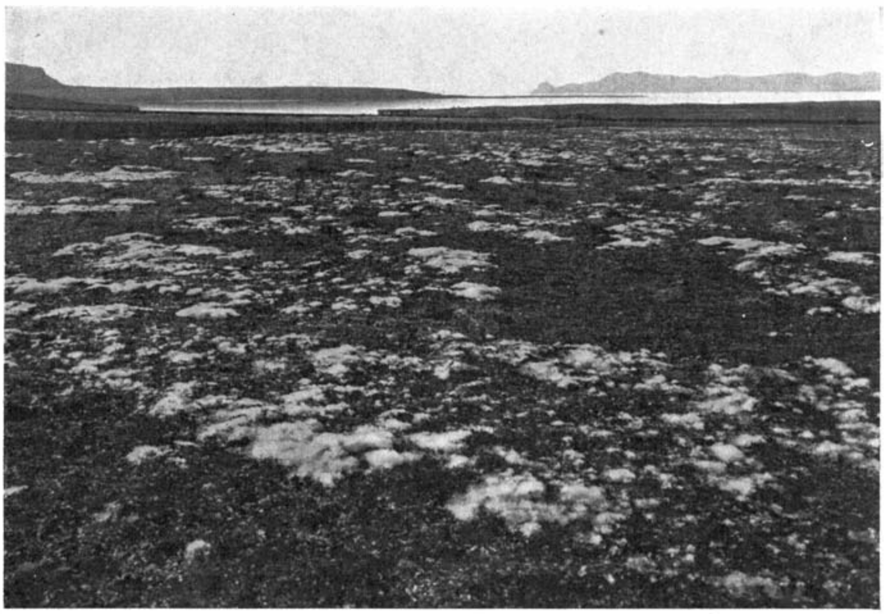

Fig. 2. *Salix polaris* on the plain at Ny-Ålesund.
A. K. Orvin phot. 26/8 1922.

does not reach the sea anywhere. The shore area is made up of Upper Carboniferous rocks.

The total length of the coal field is between six and seven kilometres; the width varies considerably. Easternmost it wedges out, in the central parts it is from 400 to 700 metres, and at Brøggerbreen the greatest width is thought to be between 1000 and 1100 metres. The total area is about 4.5 sq. kilometres.

The surface of the solid rock on and around the coal field belongs to the old strandflat and rises fairly smooth from the shore up to the base of the mountains. However, south of Kolhamna the cyathophyllum limestone forms a ridge along the shore. Only the harder rocks are cropping out here and there. The greater part is covered by loose material composed of marine terraces of clay and gravel, partly old moraines, washed out by the sea during a period with a more elevated sea-level, partly river gravel and fluvioglacial sand, beach sand and recent moraines, talus and earth slided by solifluction at the base of the mountain, as well as gravel and fragments of the outcropping bedrock. At points where the latter condition prevails one may draw a conclusion as to the bedrock; where, however, the ground, is covered by gravel and other material transported from other places, it is quite impossible to draw such a conclusion.

Within great areas of the coal field one will thus have to conclude from observations made in brook cuttings, pits, and boreholes. From the geological map will be seen to what extent the coal field is covered.

The greater part of the area is occupied by Quaternary terraces, which are firm and dry and partly as smooth as a carpet. Arriving at Ny-Ålesund one might almost think that the ground had been levelled and filled up with shingle and gravel.

Great areas are also covered with moraines partly lying far ahead of the present glacier fronts. These are remnants of older lateral and terminal moraines from Brøggerbreen, once when this glacier was far more advanced than at present. The depression between the present terminal front and the ridge at the outlet of Bayelva, as well as the depression of Tvillingvatnet, have been worked out by erosion of the glacier. The fact that these moraines are composed of rocks from all the prevailing formations renders the mapping rather difficult of execution. Thus I have found rocks belonging to the Hecla Hoek system far up the slope of Zeppelinfjellet, where they have been laid up by the ancient lateral moraines. As all these old moraines have later on been washed out partly by the sea and partly by flowing water, it is now difficult to fix their extent. In some places the moraine ridges may contain practically only one kind of rock. Such a moraine ridge east of Tvillingvatnet thus contains mainly sandstone from the lower part of the Tertiary strata, and on my first visit I really believed that the sandstone was to be found in solid rock here. Later on I came to the result that the whole sandstone ridge is situated on Permo-Carboniferous chert. On closer examination I also found rocks from the Devonian and Hecla Hoek layers in the moraine ridge, and I also observed chert in solid rock in some places around it.

That remnants of old moraines are now found on the top of the small hills can only be explained by these moraines being older than the last submersion of the land. The lower part of the moraines has then been washed out, and the material has been deposited as marine terraces.

Mountains.

Only the northwestern half of Brøggerhalvøya is made up of rocks younger than Hecla Hoek. The mountains here consist quite exclusively of upper Carboniferous limestone and chert, whereas the older rocks only here and there crop out in the crests. A more or less horizontal position of the layers is seen only in Scheteligfjellet, the height of which is 717 metres, and the northwestern part of Kiærfjellet which reaches to 589 metres above sea-level. Accordingly, plateau or mesa type is found only in these two mountains. But also here the erosion has proceeded so far that the upper plateau-formed parts are of very limited extent. In the northern part of Scheteligfjellet, facing the fjord, is a great plateau lying 200—250 metres above sea-level. This must evidently have been formed by marine denudation during an old period, when the sea-level was relatively much higher than at present. Towards the sea and the coastal plain it is bordered by a steep cliff, which must certainly have been formed by the sea in the same way as the present cliff around the coast.

Farther to the southeast the younger strata have been folded, so we find all inclinations, vertical and overtilted attitudes of the layers, and accordingly the mountains here are of another type. In Brøggerfjellet, the highest peak of which is 714 metres, and in Zeppelinfjellet, reaching 548 metres above sea-level, the upper crests and peaks are almost inaccessible, as the alternating harder and softer layers have given them quite a serrated appearance.

All the other mountains farther to the southeast of the peninsula are made up of phyllites, mica schists, and quartzites. These mountains form sharp crests and peaks between the glacial cirques, and it is very difficult and fatiguing to walk on the barren ground here. The crests are, without exaggeration, so narrow that in many places one may sit down with one leg on either side of them. During my trips here I was several times compelled to turn back because I could not proceed any farther. Everywhere the mountain slopes are covered with talus and alluvial cones creeping downhill, and the lower part of the slope facing the coastal plain also with earth slides.

Glaciers.

The glaciers at Kings Bay may be divided into three different types: The great glaciers coming from extended ice areas in the interior of the land and debouching into the sea with high terminal fronts or glacier walls, and the small cirque glaciers, and valley glaciers of alpine typus, having such small areas of precipitation that they do not reach the sea, but are lying with their terminal front on land.

Belonging to the first type are Kongsvegen, Kongsbreen, and Blomstrandbreen. These glaciers are all flowing from great ice areas, but only the lower parts are situated within the property of the company. They are flowing with a relatively great velocity down to the sea, and carry down great supplies of ice and moraine material. Throughout the summer the calving of the glaciers may be heard, and the inner part of the fjord is never free from this glacier-ice. These glaciers are in their lower part highly crevassed and almost impassable.

When Lovén visited Kings Bay in 1837 there was about 1000 feet of water between a moraine islet and the front of Kongsbreen. During the visit of Nordenskiöld in 1861 and the visit of Conway in 1897 the glacier front stretched almost right round this islet. The glacier had thus advanced about 350 metres. At present the islet is again situated far from the glacier-front.

To the other types belong all the glaciers on Brøggerhalvøya. They are small glaciers, nearly all of which have their source in cirques or corries between the narrow crests. Because of the small area of precipitation, they receive a very limited supply of snow, and for this reason they are moving very slowly. The greater part of the melting evidently takes place on the glacier surface, but this process must take place also in the bottom part of the ice sheet. This I could observe in the summers of 1922 and 1923 at an ice cave in the front of Brøggerbreen. This ice cave was in 1922 high and regular (fig. 3). In 1923 it had sunk down to form an irregular hole in the terminal front. One could recognise the different ice-bands in the sides of the cave, but in 1923 they were thinned out owing to melting and flowing of the ice towards the cavern.

In warm summers the melting is so strong, that the new snow and part of the ice will dissappear, also, in the névé basin of the glacier. The result is that the glacier diminishes. This has to a great extent been the case in recent years. These small glaciers did not, however, vary in length from 1922 to 1928, but they diminished in thickness, so that the ridges of surface moraines seemed relatively far greater, and the terminal fronts, which in 1922 were steep and inaccessible, were in 1928 rounded with a slope which could be climbed almost anywhere.

In front of most of these glaciers there is very little morainic material, because the small amount of material brought down by the glaciers has gradually been washed away by the glacier brooks and laid up into large alluvial cones and gravel plains.

Isachsen and Hoel (1913) believe that Lovénbreane have advanced several hundred metres from 1861 to 1907. I do not believe, however, that it is possible to specify any figure as to this presumed advance, as the old statements, including the map of Hamberg, are too

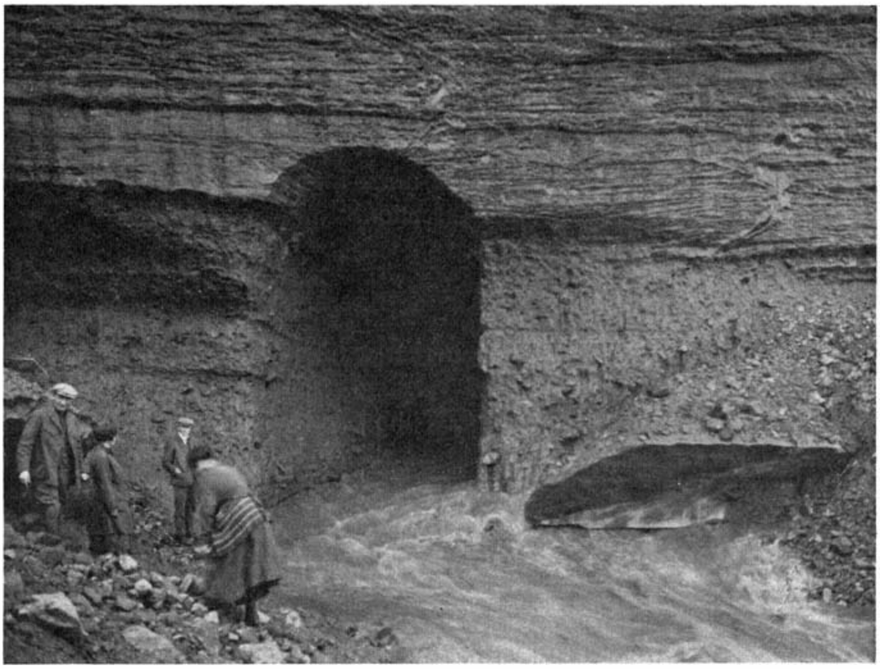

Fig. 3. Ice cave in the terminal front of Austre Brøggerbre.
A. K. Orvin phot. 27/8 1922.

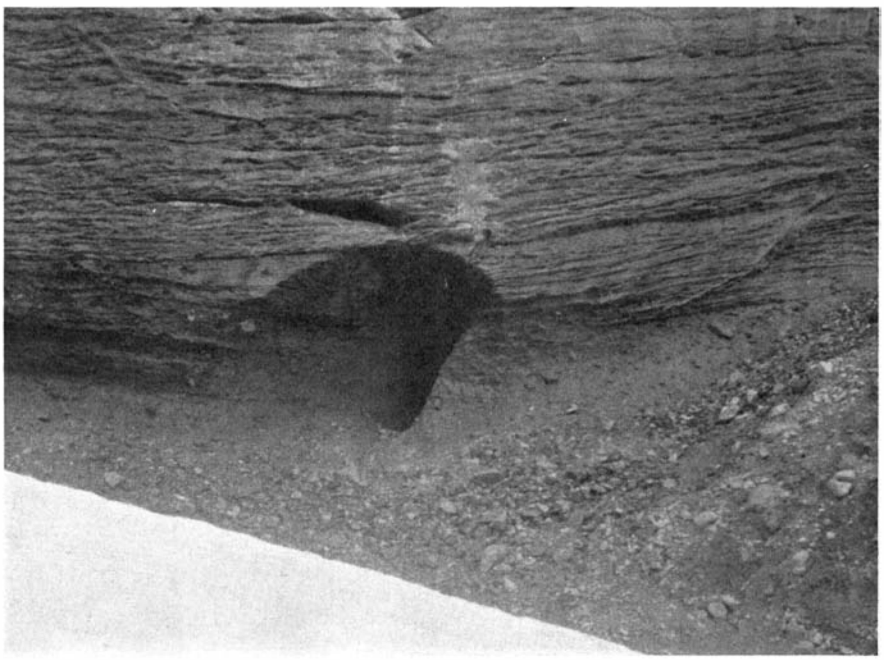

Fig. 4. The same ice cave a year later.
A. K. Orvin phot. 27/7 1923.

sketchy to be used as a basis for such a calculation. The only glacier for which the statements are likely to be of any accuracy is Lovénbre No. 1, in front of which Blomstrand in 1861 has laid in the outcrop of a coal seam on the sketch map. This coal seam, however, is evidently lying at about the same distance from the terminal front now as at that time, and my opinion is that it is quite impossible to determine any movement in either this or that direction.

Valleys and Rivers.

From the map it will be seen that within the property area there is a great number of valleys of varying size and shape, but almost all of them are filled with glaciers. Without exception they are all glacial-carved, U-shaped valleys and some of them are typical trough valleys. The valleys lead in all directions; we find longitudinal as well as transverse valleys. The trend of the valleys has chiefly been influenced by the original inclination of the land-surface formed during the period when the whole land was covered with ice; the glaciers having chosen the shortest course towards the sea along the dip of this surface.

On the western part of Brøggerfjellet and Kiærfjellet three of these glacier-carved valleys are now found to be without glaciers or only with small remnants of the glaciers at the head of the valleys. These valleys are typically trough shaped with steep sides. Moraines will usually still be found at their outlets. The valley lying northwest of Brøggertinden, named by me Traugdalen, is a very fine type of a trough valley. The outlet of the valley-bottom, now occupied by a lake is limited by a rock bar.

The rivers are generally small, and only during the spring flood is the flow of water of any importance. Strictly speaking, only one or two of them deserve this name. The rivers, as well as the numerous large and small rivulets and brooks, are almost without exception glacier streams issuing from the glacier-fronts. In their course across the coastal plain they have partly worked out some metres-deep canyons in the solid rock. V-shaped valleys formed only by flowing water do not occur within the property area.

Scheteligelva and Kvadehukelva are two of the largest streams, both issuing at the front of Trangskarbreen. This glacier comes from a narrow and deep gap between Kiærfjellet and Scheteligfjellet. I observed it in 1922 and have named it Trangskaret. The two rivers wind their way across the coastal plain, in which they have at some points cut out small canyons.

On the coal field there are several rivulets and creeks flowing down from the mountains and glacier fronts towards the sea. In front

Fig. 5. Watershed in Brøggerfjellet showing the ablation of Vestre Brøggerbre.
A. K. Orvin phot. 26/8 1922.

Fig. 6. Folds in the terminal front of Lovénbre No. 1, showing flowing structure.
L. J. Orvin phot. 25/8 1922.

of Lovénbre No. 1 we find Wexelva, Voitelva, and Nannestadelva. All of these have deposited large and almost flat cones of sand and gravel. Farther west debouches a small brook, Smithelva in Strandvatnet, a little pond or coastal lake, and west of the loading place Westbyelva has its outlet into Thiisbukta. This brook gets its water partly from Storvatnet and partly from the area around the mines.

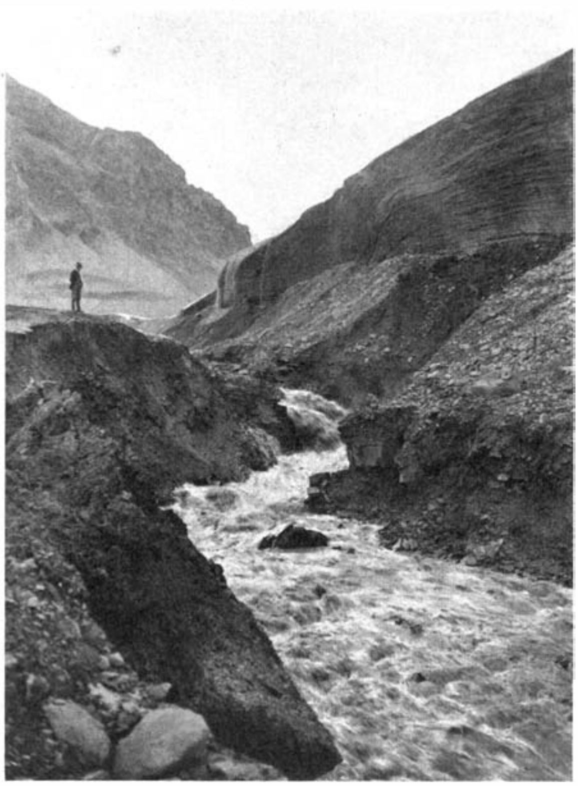

Fig. 7. The stream from Brøggerdalen at the terminal front of Austre Brøggerbre.
A. K. Orvin phot. 27/8 1922.

A number of glacial streams coming from the front of Brøggerbreen join in Bayelva, the only stream on the coal field deserving the term of river. The streams often change their beds in running across the extensive, pebbly river bottom in front of the glacier. One of the affluents to Bayelva comes from Tvillingvatnet, from which the company has taken water for household and mining purposes.

The depression in front of Brøggerbreane has been filled in with pebbles and gravel from the glacier streams, and now forms a great pebbly plain with very little vegetation. Here we find great pieces of coal, brought down by one of the streams running alongside the eastern part of the glacier front, where it has intersected a coal seam.

In springtime all the streams are considerably swollen, and then a great deal of loose material is carried downstream.

In the autumn, however, the water disappears from all streams as the frost sets in, with the exception of those flowing out from under the glaciers. These will be water-bearing for several weeks longer.

I have already mentioned that the streams often change their courses. This is especially the case on the great alluvial cones, and at the glacier fronts. During my work on the coal field I have observed this on several occasions. On August 7, 1922 I measured a section of the coal seam at Anneksjonshytta in the easternmost part of the field in a cutting made by the brook through the gravel cone. At the end of the month the stream had changed its bed and deposited a thick layer of gravel and boulders all over the section, so that nothing whatever could be seen of the bedrock. In 1928 the section was also covered during my visit, whereas during the visit of Blomstrand in 1861 far more of the section lay uncovered than in 1922.

In the front of Brøggerbreen I have observed a similar case, In 1921 the eastern afflux of Bayelva had its source innermost in Brøggerdalen, and flowed out into the brook coming from Tvillingvatnet. In 1922 the river made its way under the glacier and ran out of an ice cave in the eastern part of the glacier front (fig. 3). In a few weeks the stream had cut its way through from three to six metres of frozen earth and solid rock along the glacier front (fig. 7). It carried away a good deal of coal from the Ragnhild Seam, which it intersected, and scattered the pieces all over the river floor, where bags of them may still be picked up.

In the following year the stream ran in its old bed and the cave had sunk down to an irregular hole. In 1928 both these river-beds were nearly dry, and the river had worked out an entirely new bed under the glacier farther to the west. That summer I could walk several hundred metres under the glacier on the rocky bottom of the ice cavern.

Lakes.

On Brøggerhalvøya there are only a few small lakes. The largest one is situated in Traugdalen south of Kiærfjellet. I have named it Traugvatnet. The lake is about 600 metres long and a little less broad. Some distance higher up the valley there is a smaller glacier lake.

On the coal field there are some small lakes, of which Tvillingvatnet has supplied water to the mine workings at Ny-Ålesund. One of the other lakes, Storvatnet, is quite shallow and freezes to the bottom in the winter.

Along the coast of Brøggerhalvøya some small coastal lakes and ponds occur, mostly containing brackish water.

In the area of Ossian Sarsfjellet four lakes occur, three of which are quite small glacier lakes. The fourth is about 500 metres long and situated in a trough-shaped, transversal valley, carved out by the ice. A brook from the glacier flows through the lake and down the steep mountain to the sea. I have named it Sarsvatnet.

Coast.

The run of the embayed coast line will be seen from the maps. The best harbours are situated at Ny-Ålesund. On Kolhamna large steamers may anchor sheltered by the cuspate foreland, Brandalpynten.

The inner part of this bay, which is termed Thiisbukta, is a fine little cove for rowing and motor boats. Further: Zeppelinhamna inside Prins Heinrichs Øy offers a good anchorage for small vessels. At the pier of Ny-Ålesund steamers of up to 4000 net tons can be loaded.

Shelter against the swell will also be found in Dyrvika and Nordvågen in Blomstrandhamna, but, as a rule, calf-ice from the glaciers is floating about in both these places.

The length of the whole coast line limiting the property area is about 66 kilometres, eight of which are situated west of Blomstrandhalvøya. Twelve kilometres of the coast line is made up of high and steep glacier fronts belonging to Kongsbreen, Kongsvegen and Blomstrandbreen. Because of the frequent calving it is dangerous to approach these ragged ice-walls. About 25 kilometres are made up of a steep cliff, and on the remaining 21 kilometres one will find low coast with sandy beach, and low crags which may be climbed from the sea. The height of the cliff varies considerably. Usually it is from 6 to 10 metres, but in some places it is much higher. At Ny-Ålesund, where the cliff is made up of Upper Carboniferous limestone, which is highly soluble, the cliff has partly been undercut by the waves and contains small coves, sink-holes and stacks, entirely separated from the coast. Such a stack will be seen on figure 8. It is situated a short distance west of the power station, and seen from the southeast it much resembles the face of a man.

Even at low-water it is in several places impossible to walk on the sandy beach under the cliff. This is evidently due to the solubility of the limestone. Farther west, where the cliff is made up of Devonian sandstone, I have at low-water walked under the cliff the whole distance from Brandalpynten to Scheteligelva. Here the limestone is again found in the cliff, and it is impossible to walk any farther. On the coast, facing Forlandssundet, I had the same experience. Below the limestone cliff walking was impossible, but below cliff made up of insoluble rock there was everywhere a sandy beach at low-water. The same conditions are typically developed also in Bear Island. This fact one must have in mind when drawing conclusions from the cliff, about the land being submerged or raised. Conclusions will have to be drawn only from the parts of the cliff which consist of rocks that are practically insoluble.

As previously mentioned, a plain with marine deposits is found around the coast. This plain, belonging to the strandflat, rises smoothly up to 50—60 metres above sea-level and is almost everywhere covered by marine terraces. They are mostly dry, but also small boggy areas and clayey tracts may occur. In the lower parts of the terrace cover,

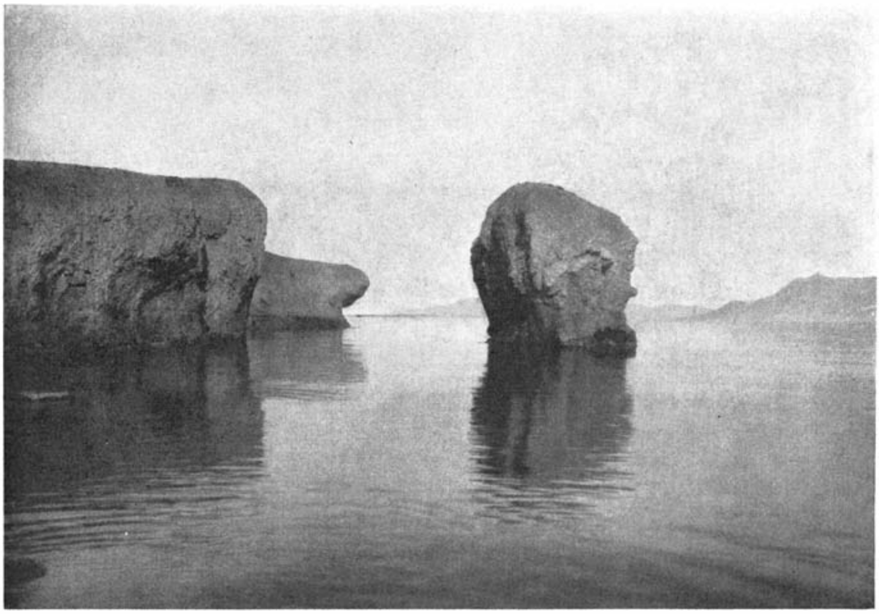

Fig. 8. The cliff west of the power station.
A. K. Orvin phot. 3/8 1928.

clay is found almost everywhere, and it partly contains shells of marine mussels. On the undulating lowlands polygonal soil is seen everywhere.

Soil.

The earth at Kings Bay is rather poor and the vegetation is thus poorer than in the great valleys around Ice Fjord and Bell Sound. In 1925 I took a sample of the uppermost layer of the soil between Nye-Advokaten and the sea. The sample was taken on the terrace, the upper part of which consisted of stone fragments and gravel, with only very little earth. Below the cover of gravel lay marine clay with mussels. The terrace cover rests on a bedrock of Permo-Carboniferous chert, but the loose material does not originate only from this rock.

The sample was examined by Dr. K. O. Bjørlykke, professor at *Norges Landbrukshøiskole.* Bjørlykke (1927) describes the earth as homogeneous, brownish coloured, and terms it a gravel earth containing sand and stones. From 0 to 25 centimetres deep it contained 54 per cent. gravel and stones, from 25 to 40 centimetres 82 per cent., and from 40 to 50 centimetres 87 per cent.

The earth does not contain humous substances worth mentioning with the exception of the uppermost stratum, which contained some thin root fibres.

The upper stratum from 0 to 25 centimetres gave the following result in the chemical analysis: N 0.09 per cent., P_2O_5 0.04 per cent., K_2O 0.05 per cent., CaO 0.53 per cent., Fe_2O_3 5.98 per cent., ignition loss 6.16 per cent., and reaction pH 6.54. As will be seen, the earth is very poor in fertilising agents.

Frozen Ground.

My original intention was to undertake measurements of the temperatures of the frozen ground in the boreholes, but I regret to say that this proved quite impossible. The fact was that the boreholes froze up instantaneously if the drilling tools were raised without warm brine being simultaneously pumped down into the hole. Accordingly it was impossible to keep the thermometer in the hole till it got the temperature of the soil. Even when brine was used the hole would freeze up when remaining unworked for some hours. The freezing up might perhaps have been prevented by making the brine very concentrated, but in that case one would only have got an artificial freezing mixture, as the frozen rock always contains ice. Under these conditions I considered it impossible to undertake any measurement in the boreholes.

I would also have made such measurements in the mines, but during my visit the accessible parts of the mines had already for a long time been in contact with the warm air pumped down from the surface. Mr. Slåtto promised to undertake such measurements when a new mine was to be worked, but unfortunately mining operations were discontinued before this could be done.

As the average temperature is about —8° C, the lowest temperature of the soil is likely to be about —7° at a depth of 10—20 metres below the surface, this being the coldest zone.

In the summer the frozen surface is usually thawed to the depth of 50—60 centimetres, occasionally more. Where the ground is raised or consists of dry sand, the thaw will go a little deeper than it does in grooves and clayey ground.

To what depth the frozen ground extends has not yet been exactly determined. The frozen zone is thickest in the mountains and thinnest at their base. The bottom of the Josefine Mine was driven below the depth of frost. The vertical distance from the surface was here 130 —140 metres. If the temperature near the surface is about —7° as supposed, the geothermic depth will be about 17 metres. In the mountains and below the plains this figure will be considerably greater. Thus in Sofie Mine, lying on the plain, the ground was still frozen at the bottom of the mine, 150 metres below the surface. According to our experience during the drilling and observations made in the mines the coldest horizon is situated about 20 metres below the surface. The figures given above are, obviously, only approximate, as no measurements have been made, but they will probably not be very far out.

One would think that the circulation of water in the frozen ground would be rendered difficult, but this has proved not to be a fast rule. In several places in Spitsbergen I have had the opportunity to observe springs coming out of the ground. Some of these seem to flow throughout the winter, because there are great sheets of ice at their outcrop. At Kings Bay such springs exist in front of Lovénbreane, but the most interesting observations in this connection have been made on the coal field. As we have heard, the mining company has for several years taken water for household and mining purposes from the Austre Tvillingvatn, which do not freeze to the bottom in winter. Despite the fact that this water was constantly pumped out, a little stream issued from the lake for a long time during the autumn, after all afflux from the surface had frozen away. In drilling borehole 3, the site of which was placed between the two small lakes, we confirmed that an underground stream springs up in the bottom of the lake, which forms a 6—7 metres deep pool. At a depth of 14—18 metres we drilled through an open space in the rock filled with water under pressure and coarse sand, which was brown with iron-oxides and of which the finer material had been washed out. When the drilling tools pierced the space, water and gravel were hurled up through the drilling-pipe more than three metres above the level of Tvillingvatnet. Later on, after the drilling was finished, the water flowed out of the casing top until it froze up late in the autumn. We had thus struck the water, which otherwise issues only at the bottom of Tvillingvatnet, where it is filtered through sand and clay.

In 1927 a great vein of water broke into Ester Mine abt. 140 metres under the surface. The inflow of water amounted to 1300 litres per minute and the temperature was $^{1}/_{10}{}^{\circ}$ C. The mine had to be deserted until the autumn of 1928, when pumping machinery of sufficient capacity was installed. The water has been analysed and proves to be surface water, which has passed only a short time through the underground. The content of salts was very low. The reaction was alcalic. The question of the source of this water has not been quite satisfactorily settled, although it is highly probable that the water comes from behind Zeppelinfjellet and through a system of tectonic disturbances is led to the surface of the coal field. In a cirque behind Zeppelinfjellet a little lake without any outlet appears to rest on the glacier ice. It is probable that the water source is to be found here.

The lake is about 180 metres long and 100 metres in width. The elevation above sea-level is about 315 metres measured by barometer. The bottom of the lake was covered by a brown mud which probably rested on ice. All over the lake small bubbles rose to the surface, and even in sunshine it seemed to be raining on the lake. At first I thought that it might be gas from the coal seems which ascended this way, but on examining it closer I came to the conclusion that it must be air-bubbles or gas coming from the mud. Gas coming from the depth would have come out in one place. From the lake there was no outlet down the glacier, as the water was held by the ice lying about five metres above the water-level.

During the drilling of the other holes we also found that the frozen ground was not impenetrable to water. Several times during the drilling we lost the drilling-water without this coming up to the surface in any place near the drilling site. This fact I can only explain by the upper part of the frozen ground, due to temperature variations of the air, being subjected to contractions forming fissure-systems on which the water may escape. If the surface water, the temperature of which in the summer will be up to 6—7° C, begins to circulate on these fissures they will be kept open.

Stratigraphy.

Hecla Hoek.

W. Scoresby (1820) is the first to mention the Hecla Hoek rocks in the environs of Kings Bay. He (Vol. I, p. 149) speaks about marble of "real beauty", "found in some parts of King's Bay", and farther down he says: "Captain Jacob Broerties, an intelligent whale-fisher of Amsterdam, informed me that he had in his possession a slab table of great beauty, manufactured out of a block of Spitsbergen marble, which he himself procured". He further (in App. No. VI) notes some rock specimens collected by himself at Kings Bay and determined by Professor Jameson, who describes them as "Bluish-grey foliated-granular limestone, Gneis, Quartz-rock, Rhomboidal calcareous-spar".

Blomstrand (1864) has given us the first geological description of the Hecla Hoek rocks at Kings Bay, but he did not try to fix the age of these rocks. Garwood (1899) mentions that the rocks in the inner part of Kings Bay belong to the Hecla Hoek, which had previously been described from other places by A. E. Nordenskiöld. Later on this tract has been dealt with in part by Hoel (1914) and Holtedahl (1913 and 1926).

In the summer of 1928 I devoted a few days to mapping within the Hecla Hoek area, and tried to divide the different series. It is, however, at present difficult to place the divisions at Kings Bay in the general Hecla Hoek sequence, because this is still insufficiently known. The sequences of the various authors are more or less deficient, and the sections in the different localities do not always correspond. Reliable results cannot be expected until the Hecla Hoek rocks have been examined and mapped in great areas. Rocks now designated Hecla Hoek, i. e. all rocks older than Downtonian, with the exception of the igneous rocks, certainly embrace a very great space of time, and may really contain rocks far down into the Pre-Cambrian.

In Bear Island, the only place where determinable fossils have so far been found in the Hecla Hoek, the age has been fixed as Younger Cambrian and Middle Ordovician. Owing to several points of resemblance it is fairly certain that this sequence is contemporaneous with a part of the Hecla Hoek in Spitsbergen. In Bear Island the sequence is of a comparatively limited thickness, and is mainly made up of limestone and dolomites, secondary sandstones and shales. In Spitsbergen the sequence is also made up of large series of quartzites, phyllites, and mica schists. The rocks on Bear Island have been changed very little by metamorphism, whereas the rocks in Spitsbergen have undergone strong metamorphism.

Hoel and Holtedahl (1914) found that the granites in the northwestern part of Spitsbergen are younger than the Hecla Hoek, and that there thus seems to be no Archean rocks. The appearance of the rocks here is therefore not due to age but to stronger metamorphism.

Holtedahl (1926) points out that the metamorphism of the rocks is strongest in the northern part of Spitsbergen, and he suggests that this may be due to a greater elevation of the land in this direction, so that the rock laid bare here originally, when the metamorphism took place, belonged to a deeper part of the earth crust. This may also be the case, but it might perhaps suffice to explain this fact merely as a result of the great eruptions during the forming of the Silurian mountain chain. At all events, these eruptions have increased the metamorphism.

In 1917 I had the opportunity to investigate a small area of gabbro not far from the coast north of Horn Sound. Near the gabbro the Hecla Hoek rocks had been strongly metamorphosed and the mica schist contained big garnets.

The metamorphism decreased gradually from the gabbro. This shows us that the metamorphism may be very strong also in the southern parts where the sequence has been penetrated by igneous rocks.

The Hecla Hoek at Kings Bay is situated within two different tectonic areas. The one is made up of the southeastern part of Brøggerhalvøya, where the strike is about E 15° S—W 15° N and the dip 45°—70° to the south. The other area is situated north and east of the fjord. The strike is here north—south and the dip varies from east to west.

The rocks on Brøggerhalvøya are phyllites, mica schists, quartzites, and subordinate limestones and dolomites. The sequence has been intersected by the glaciers, and thus the different layers may not be traced continuously for any great distance along the strike. Only on the narrow, often nearly inaccessible, crests between the glaciers the sections are uncovered. The mountain slopes are everywhere covered by talus. During mapping work I examined some of these sections. It is, however, difficult to determine the thickness because of the varying dip, tectonic disturbances, and the difficulty of fixing their limits in some places.

In fig. I—J pl. V. I have drawn up a continuous section of the Hecla Hoek sequence from the Devonian in the crest south of Zeppelinfjellet to Forlandssundet. In the northern part of the section there is a frequent alternation of quartzites, phyllites, and mica schists, so that it is almost futile to try to divide the different strata. The thicknesses given in the section are only approximate.

The different series from north to south are:

		Thickness in metres
1.	Phyllite, grey, and greyish-yellow quartzite with masses of small mica flakes on the bedding planes	150
2.	Quartzite, yellowish-white	140
3.	Mica schist, with small buckles and yellowish-white quartzite	140
4.	Mica schist, partly stalky structure, and quartzite	250
5.	Mica schist, phyllites and quartzites in alternating layers	380
6.	Phyllite, dark grey and greyish-green and brown mica schists and quartzite, partly buckled and with mica	600
7.	Phyllite, grey with mica schists containing stalky greyish yellow quartzite with mica on the bedding planes	600
8.	Qartzite, reddish-yellow with mica and some layers of mica schist	140
9.	Phyllite, grey with lenses of quartzite and yellow phyllite	120
10.	Dolomitic marble with sacharine structure and some mica, yellowish-brown marble with some mica flakes and iron spath, fine-grained light-blue dolomite with clorite, greyish-blue dolomite and compact, hard, light-brown dolomite, enumerated from north to south	270
11.	Mica schist, partly containing lime and with quartzite and phyllite. Farthest south mica schist with garnets, limestones and quartzites	1500
	Then follow dolomites and limestones at Forlandsundet.	

Nos. 1—9 must be combined into one series: The Quartzite and Mica Schist series, No. 10 I have named the Steenfjell Dolomite, No. 11 consists almost exclusively of mica schist, in part strongly metamorphosed. I have termed it the Bogegg Mica Schist.

The division from north to south is as follows:

	Thickness in metres
Quartzite and Mica Schist series	ca. 2520
Steenfjell Dolomite	„ 270
Bogegg Mica Schist	„ 1500
Dolomites and limestones at Forlandsundet	?

On the last three sections on pl. V some of these layers will also be seen. The thickness varies a great deal in the different sections.

The Hecla Hoek area on the north side of the fjord differs to a fair extent from the other. The sequence is here made up of two different main series. The lowermost consists of quartzite, phyllite, and mica schist cropping out on the western part of Ossian Sarsfjellet, in Feiringfjellet, and the western part of Olssønfjellet. It forms a great syncline below Blomstrand breen, where it is overlain by limestone, and an anticline in the western part of Ossian Sarsfjellet and Feiringfjellet. This series closely resembles the Quartzite and Mica Schist series on Brøggerhalvøya, and I think they are identical.

The great limestone series, which in the eastern part of Ossian Sarsfjellet and east of Feiringfjellet has a dip of 40° to the east, is eroded away in the aeriel arch of Feiringfjellet, but is seen in the western part of this mountain with a steep westerly dip. Below Blomstrandbreen it forms a syncline and reappears on the west side of this glacier with easterly dip. It is this limestone which is found on Blomstrandhalvøya and on Lovénøyane, and on which the Northern Exploration Co. Ltd., London has tried to work a marble quarry. The border layers between these to great divisions are made up of alternating beds of limestone and quartzite.

As the limestone on the north side of the fjord is overlying the quartzite mica schist layers in great areas, it is extremely probable that it is the younger of these two series. If this were not the case, very great inversions must have taken place here, but such great disturbances would scarcely have left the sequence so regular. If therefore the quartzite mica schist series on both sides of the fjord are identical, the sequence in Brøggerhalvøya must have been inverted, as here a great sequence of mica schist with garnets is found south of, and apparently above, the Quartzite and Mica Schist series. The limestone in Blomstrandhalvøya is thus very likely the youngest part of the Hecla Hoek here. This explanation is not altogether unreasonable. We know that the layers belonging to the younger formations have been folded and partly inverted during the Tertiary folding period, and, as the Hecla Hoek rocks have taken part in this folding, it is but probable that they, too, have been inverted within part of the folding zone.

Before the folding took place the Hecla Hoek strata on the south side of the fjord must also have had a north and south strike in direct continuation of the present-day strike on the north side of the fjord. If the limestone on Blomstrandhalvøya is the youngest it may seem strange that it is not found as the base of the Devonian layers south of Zeppelinfjellet. The explanation must be that the layers now forming the base of the Devonian strata before the folding took place were situated farther to the west and then formed a direct continuation of the quartzite and mica schist west of Olssønfjellet. As early as the Devonian period these layers had an easterly dip. This may directly be observed from the fact that the Devonian strata have been deposited with an angular unconformity in relation to the Hecla Hoek rocks, and the thickness of the Hecla Hoek will be found to increase in an easterly direction.

The limestone, which already in Devonian time pinched out towards the west, really exists as the base of the Devonian farther east up the fjord. Fig. S—T pl. V may perhaps contribute to the explanation of this problem.

All the rocks belonging to the Hecla Hoek are of sedimentary origin, made up as real sediments as sandstone and shales, or precipitated as marine lime and magnesia carbonates.

Granite occurs in Stemmeknausane and outside the border line of the company a short distance east of Feiringfjellet. The Hecla Hoek rock is here entirely traversed by granite dikes.

The metamorphism of the Hecla Hoek rocks into phyllites, mica schists, quartzites and marble must be explained as the result of a combined contact and press metamorphism during the Silurian mountain folding period. The eruption of the igneous rocks took place contemporaneously with the folding. In the neighbourhood of the igneous rocks one will find an increased effect of metamorphism by contact metamorphism.

The Hecla Hoek rocks now found at the base of the younger formations at Kings Bay must originally during the metamorphism have been situated at a considerable depth. A great part of the sequence must thus have been eroded away from the beginning of the Silurian mountain folding until the deposition of the Downtonian layers.

It is possible that the Hecla Hoek layers have been folded upon themselves several times so that the same layers may reappear in different places of the sequence between Kings Bay and Forlandsundet, but I have failed to find any proof of this. I should therefore think that the section I—J pl. V really shows the existing conditions.

I shall not try in this work to correlate the Hecla Hoek rocks at King Bay with the Hecla Hoek layers in other parts of Spitsbergen. Holtedahl is of opinion that the limestone in Blomstrandhalvøya is identical with the Tetradium Limestone in Bear Island. I should, however, be inclined to think that the two series are not contemporaneous, because the limestone on Blomstrandhalvøya is resting on quartzite and mica schist, whereas the Tetradium Limestone rests upon a thick series of dolomites. The Tetradium Limestone is also much darker. I should think that the limestone in Blomstrandhalvøya belongs to an older period.

Devonian.

During mapping work in 1922 I observed a great series of conglomerates, sandstones, sandy shales, etc., in the cliff north of Scheteligfjellet, almost all of which are of a red colour and contain very much mica. I believed that these rocks belonged to the Devonian system and searched very closely for fossils, yet I only found one or two badly conserved fish fossils. In the following year I measured an exact and very detailed cross section of the sequence; but again failed to find any determinable fossils. Professor J. Kiær and Conservator A. Heintz have been good enough to examine these fish fossils. I regret to say that they were so defective that it was impossible to determine their exact nature. The only conclusion arrived at was that they were Devonian or Downtonian fishes.

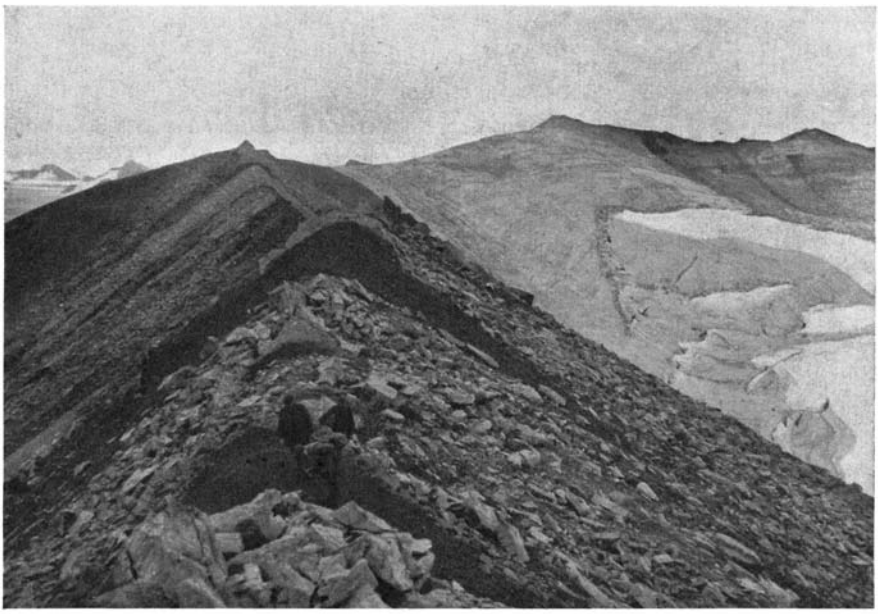

Fig. 9. Devonian strata in Brøggerfjellet.
L. J. Orvin phot. 26/8 1922.

This sequence is further exposed in the crest south of Brøggertinden in Brøggerfjellet, where I measured a detailed cross section in 1928. Here, too, I did not succeed in finding a single fossil until the Middle Carboniferous beds were reached. Also in the crest south of

Zeppelinfjellet these layers crop out. In Brøggerfjellet as well as in Zeppelinfjellet there seems to be a greater percentage of conglomerates in this sequence than in the beach section north of Scheteligfjellet. The latter contains, especially in the upper part, far more shaly and fine-grained rocks with more mica on the bedding planes. It is not quite clear to me what the reason may be. It is obvious that such coarse-clastic layers at these will vary much in development, but as it is a question of great thicknesses and relatively small distances one would think that the modifications would not be of any importance. I should also imagine that the upper part of the beach section is younger than the corresponding parts of the other two sections, and that only the lower part of this section is quite identical with the other two. The lower part of the beach section is also made up of conglomerates and coarse sandstones, but is so covered with loose material that a detailed section cannot be measured.

It was not possible to find any layers here belonging to the Culm, and I very much doubt that such layers are to be found at all at this point. In the upper part of the beach section, however, some benches of pure sandstones occur, corresponding to the common Culm type and overlain by the limy Middle Carboniferous layers, but I could not locate any fossils in these benches, nor could I observe any unconformity downwards.

I shall now go through the cross sections in the cliff north of Scheteligfjellet and in the crest of Brøggerfjellet (fig. 10). In the section north of Scheteligfjellet the lower part of the Devonian sequence is below sea-level and to the east the visible part of the section is cut by the great fault along Scheteligfjellet. The eastern part is also extensively covered, and it is thus impossible to make any detailed measurement here. The section along the beach from east to west is as follows:

Thickness in metres	
23.0	Sandstones, sandy shales and laminated sandstones of red colour with mica.
50.0	Covered.
4.0	Conglomerate, dip 30° SW.
50.0	Covered.
10.0	Conglomerate with red sandy matrix and large pebbles of light quartz. Contains also mica.
2.3	Sandstone, red, argillaceous, with mica. Upper 5 cm greenish-yellow.
15.0	Conglomerate, with sandy matrix of green colour, containing mica and pebbles of quartz and some layers of sandstone.
5.0	Covered.
0.4	Sandstone, hard and red.
1.3	Sandy shale, red, with mica.
0.4	Sandstone, hard, brown with mica.
0.6	Sandy shale, red, with mica.
0.6	Sandstone, hard, brown, with mica.
1.5	Sandy shale, red, with mica.

Thickness in metres	
1.0	Sandstone, hard, brown with mica.
0.8	Sandy shale, red, with mica.
0.7	Sandstone, red.
2 8	Sandstones and sandy shale, all red, alternating.
0.4	Sandstone, red.
0.2	Shale, red.
0.6	Sandstone, laminated, red, with mica.
0.5	Shale, red, with mica.
	Unconformity or small disturbance.
0.4	Conglomerate and red sandstone.
0.6	Sandstone, laminated, argillaceous, with mica.
2.4	Sandstone, red, partly laminated, with sandy shale containing mica.
2.6	Conglomerate with cross bedding, brown, very finely grained, with mica.
1.2	Sandstone, red, with mica and partings of shale.
1.2	Conglomerate, same kind as above.
0.6	Sandstone, thin laminated, red, containing very much mica on the bedding planes, looking like silver.
1.0	Sandstone, red, argillaceous, weathering in small, irregular pieces.
1.2	Sandstone, partly laminated with much mica.
0.4	Sandstone, red argillaceous, weathering in small irregular pieces.
0.6	Sandstone, hard, red.
1.2	Sandstone and shale, red, alternating.
3.0	Conglomerate, finely grained, brown and sandstone, with much mica.
2.0	Sandstone, red argillaceous, with mica and partings of shale.
0.7	Conglomerate, brownish-green, with sandy matrix and quartz pebbles.
0.4	Sandstone, red argillaceous, with mica.
0.5	Conglomerate, same kind as above.
0.9	Sandstone, grey, partly laminated with mica.
0.7	Sandstone, red, laminated, argillaceous, with mica.
0.3	Sandstone, yellowish-green.
1.0	Sandstone, reddish-brown, with mica.
2.0	Sandstone, very coarse, with mica and a thin layer of greyish-green laminated sandstone.
0.3	Sandstone, grey.
0.7	Sandstone, green alternating with red, sandy shale.
0.4	Sandstone, laminated, green, with mica.
2.1	Sandy shale, red, alternating with layers of sandstone.
1.2	Sandstone, reddish-brown, laminated, with mica.
1.4	Shale, red, sandy, irregular pieces by weathering.
1.0	Sandstone, red, with mica.
1.0	Shale, same kind as above.
0.6	Sandstone, brown.
1.2	Shale, same kind as above.
1.0	Sandstone, red, laminated, with mica.
2.9	Conglomerates, finely grained and sandstones alternating.

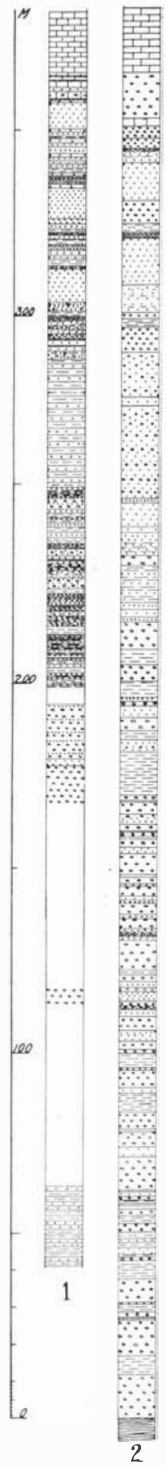

Fig. 10. Sections through the Devonian sequence. — 1. From the cliff north of Scheteligfjellet. 2. From the crest of Brøggerfjellet.

Thickness in metres	
3.0	Sandstones, red, laminated, alternating with sandy shales.
35.0	Sandstone, conglomerates and shales, which cannot be measured because the section is covered with ice.
2.1	Sandstone, red, argillaceous, columnar structure at right angles to the bedding planes.
3.2	Sandstone, red, agillaceous with two small layers of harder, red sandstone.
1.3	Sandstone, red, crossbedded, with mica.
4.0	Sandstone, red, laminated, partly with much mica and partly crossbedded.
0.7	Sandstone, reddish-brown, with mica.
1.3	Shale, red, sandy, easy weathering.
2.6	Sandstone, reddish-brown, hard and coarse.
9.0	Sandstones, partly argillaceous and laminated, partly covered.
0.8	Sandstone, hard, brown and coarse.
1.4	Shale, red, sandy, weathering in irregular pieces.
2.4	Sandstone, argillaceous, laminated and loose, with mica.
0.9	Sandstone, hard, red, with mica.
0.2	Sandstone, finely grained, argillaceous, with mica.
1.4	Shale, red, sandy, with mica.
1.0	Sandstone, red, laminated, with mica.
1.7	Sandstone and sandy shale, red, with mica.
1.4	Sandstone, reddish-brown, partly hard, with mica.
1.2	Sandstone, reddish-brown and laminated, argillaceous sandstone with mica.
8.5	Sandstones, partly laminated, reddish-brown.
1.0	Sandstone, hard, dark brown.
0.5	Sandstone, dark brown, laminated, with some mica.
0.8	Sandstone, laminated, argillaceous, with mica.
0.6	Sandstone, hard, dark brown, with mica.
0.5	Sandstone, laminated, dark brown.
0.7	Sandstone, dry, light red, with some mica.
1.3	Shale, dark brown, sandy, with mica.
1.0	Sandstone, dark brown.
1.0	Sandstone, dry, brick-red.
0.9	Sandstone, dark brown, knotted, and shale.
1.0	Sandstone, dark brown with mica.
1.8	Sandstone, dry, brick-red.
0.9	Sandstone, laminated, dark brown, with mica.
1.3	Sandstone, dark red, hard.
0.7	Sandy shale, dark red.
1.0	Sandstone, hard, dark red.
1.0	Sandstone and sandy shale, dark red, alternating.
7.0	Sandstone, greyish-white. hard.
0.5	Shale, chocolate brown.
0.5	Sandstone, greyish-white, hard.
0.1	Shale, brown.
0.5	Breccia with large pieces of grey sandstone in matrix of limestone. This breccia is shown in fig. 11. It is most probably the base of the Middle-Carboniferous strata.
1.3	Limestone, grey, hard, partly sandy, and with agate and cavities with crystals of calcite.
1.1	Sandstone, argillaceous, partly red, partly green.
1.5	Limestone, light, tight.
0.3	Sandstone, red and green, argillaceous.

Thickness
in metres
1.0 Limestone, grey, tight.
0.2 Sandstone, loose, green.
1.0 Limestone, grey.

The section is here cut by a fault. On the other side of the fault there is about 15 metres of limestone with chert and corals, and above this grey cyathophyllum limestone.

The visible part of the thickness of the Devonian sequence up to the Middle Carboniferous strata is thus about 317 metres. How much more is situated below sea-level is impossible to determine, but I am inclined to think that it is only a small part of the sequence.

The section in the crest of Brøggerfjellet was measured by me in 1928. It was measured from the Hecla Hoek in the south to the Carboniferous strata to the north. The layers were measured horizontally along the crest, and the figures obtained were reduced in proportion to the dip.

The base is made up of greyish-black and brown phyllite with som layers of quartzite. The dip of the Hecla Hoek seems to be about parallel to the dip of the Devonian layers.

Thickness
in metres
11.5 Conglomerate with sandy matrix and quartz pebbles of the size of a hazel-nut and yellowish-red colour. Contains also layers of dark red, sandy shale. Shows also great deal of slip-planes.
5.0 Shale, dark reddish-brown, sandy with laminated sandstone.
9.5 Conglomerate, same kind as above.
1.0 Shale, reddish-brown.
1.5 Conglomerate, alternating green and red, fine-grained, sandy.
2.0 Shale, reddish-brown, sandy and laminated sandstone.
0.6 Conglomerate, reddish, sandy matrix and quartz pebbles with up to hazel-nut size.
0.5 Shale, reddish-brown.
6.2 Conglomerate, grey, with slip-planes and some layers of red shale in upper part.
5.0 Shale, sandy and laminated sandstone, all red.
0.9 Conglomerate, light grey, sandy matrix and pebbles of white quartz of hazel-nut size.
0.6 Sandy shale, red.
2.0 Sandstone, light-grey, and coarse and fine-grained conglomerate.
1.5 Sandy shale, dark brown.
1.1 Conglomerate, light yellowish-grey, with sandy matrix and pebbles of up to wal-nut size.
1.8 Shale, sandy, dark brown.
2.0 Conglomerate and sandstone, grey, with sandy matrix and pebbles of up to wal-nut size.
2.4 Sandy shale, dark brown.
1.8 Conglomerate, reddish-brown, with sandy matrix and pebbles of quartz of hazel-nut size. Dip 38° N.
1.2 Sandy shales, dark reddish-brown.
0.6 Sandstone, partly laminated, dark brown with yellow spots.
0.5 Sandstone, laminated, argillaceous, dark brown with mica.

Thickness in metres	
1.3	Conglomerate, hard, dark brown, with sandy matrix and small pebbles of quartz.
1.3	Sandstone, partly laminated, dark brown with spots in yellow.
0.6	Shale, sandy, dark reddish-brown.
9.0	Conglomerate, reddish-brown, with sandy matrix and pebbles of quartz of up to walnut size.
2.5	Shale and laminated sandstone alternating, all dark reddish-brown with mica.
4.0	Conglomerate, same kind as above.
0.6	Sandy shale, dark red.
4.8	Conglomerate, same kind as above.
5.2	Sandy shale, dark red.
1.7	Sandstone, laminated, dark red, with mica.
4.8	Conglomerate, reddish brown, with sandy matrix and pebbles of quartz of up to walnut size.
0.6	Sandstone, dark red, with mica and laminated.
4.0	Sandy shale and laminated, argillaceous dark reddish-brown sandstone.
1.1	Conglomerate, dark red, fine-grained and sandstone of dark red colour with yellow spots.
2.3	Conglomerate, light yellowish-red, with sandy matrix and pebbles of white quartz of up to walnut size.
3.0	Sandstones, laminated, dark red, with mica and sandy shales.
3.7	Conglomerate, white, with masses of pebbles of white quartz up to walnut size. Dip 33° N.
1.8	Sandstone, dark reddish-brown, laminated, with mica, partly argillaceous.
2.2	Sandstone and conglomerate, dark brown cross-bedded.
2.6	Sandstone, dark reddish-brown, laminated, with mica and partly argillaceous.
1.1	Conglomerate, brownish-red, with pebbles of white quartz.
1.6	Sandstone, laminated, dark reddish-brown, with mica.
2.3	Conglomerate, brown, sandy matrix, with mica and pebbles of quartz of up to walnut size.
1.1	Sandy shale, dark reddish-brown, with mica.
8.0	Conglomerate, same kind as above and with some layers of brown, laminated sandstone.
1.0	Sandstone, laminated, dark brownish-red and argillaceous.
0.3	Sandstone, dark brown, coarse.
0.4	Sandstone, laminated, dark brown.
0.3	Conglomerate and laminated sandstone.
0.9	Sandstone, laminated, dark reddish-brown, argillaceous and with mica.
2.7	Sandstone and conglomerate, brown, alternating.
1.0	Sandstone, argillaceous, laminated, chocolate brown.
3.0	Conglomerate, chocolate brown with two layers of about 0.5 m laminated, brown sandstone with mica.
0.9	Sandstone, laminated, chocolate brown, argillaceous, with mica.
2.7	Conglomerate, chocolate brown and brown laminated sandstone with mica, alternating.
0.7	Sandstone, laminated, brown, argillaceous with mica.
2.0	Conglomerate, reddish-brown with pebbles of quartz of up to walnut size. Dip 42° N.
0.6	Sandstone, laminated, argillaceous, brown.
5.7	Conglomerate, red and coarser than is usual here. In upper part some red shale.
1.7	Sandstone, laminated, reddish-brown with mica, partly argillaceous.
2.2	Conglomerate, same kind as above.
0.4	Sandstone, laminated, brown, with mica.

Thickness in metres

1.2 Conglomerate, chocolate brown, with pebbles of quartzites from the Hecla Hoek formation.
0.3 Shale, red.
1.9 Conglomerate, sandy matrix with pebbles of light quartz.
2.7 Sandstone, argillaceous, and laminated, chocolate brown with a conglomerate bed in the upper part.
3.2 Conglomerate, with sandy matrix and pebbles of quartz and dolomite from the Hecla Hoek formation of up to potato size.
0.4 Sandstone, argillaceous, red.
1.4 Conglomerate, greyish-white, sandy matrix and quartz pebbles. Dip 35° N.
11.5 Sandy shale, chocolate brown with thin layers of sandstone.
3.2 Sandstone and fine-grained conglomerate, all greyish-white. Dip locally only 20°.
2.5 Covered, probably red, argillaceous sandstone.
3.2 Conglomerate and sandstone, greyish-white.
3.0 Sandy shale and sandstone, dark brown, containing much iron-oxides.
1.3 Conglomerate, greyish-white, with sandy matrix and pebbles of white quartz of hazel-nut size.
1.0 Sandstone, laminated, grey. Dip 28° N.
4.3 Sandy shale and sandstone, all reddish-brown.
4.3 Quartz-conglomerate, greyish-white.
4.2 Sandy shale and sandstone, all dark brown.
7.5 Quartz-conglomerate, very fine-grained of light red colour. Dip 43° N.
1.2 Sandstone, laminated, argillaceous, dark brown.
2.0 Sandstone, partly laminated, brown, with mica.
1.8 Sandstone, grey and brown, hard.
10.0 Sandy shale, brown with mica and layers of hard brown sandstone with mica.
2.6 Conglomerate, brown and brown laminated sandstone.
6.3 Sandy shale, brown alternating with hard laminated sandstone of the same colour. All with mica.
1.5 Sandstone, brown, hard.
6.3 Sandstones, brown, hard, with mica, partly coarse, alternating with brown, sandy shale
1.0 Sandstone, brown, laminated, with mica.
25.0 Sandstones with mica, laminated, argillaceous sandstones, fine-grained conglomerates, all brown alternating. Partly calcite on cracks.
2.0 Sandstone, brown, coarse, partly laminated and with mica.
12.2 Sandstones with mica, partly laminated and argillaceous, and fine-grained conglomerates alternating.
7.0 Conglomerate, reddish-brown with sandy matrix and pebbles of white quartz of hazel-nut size and mica.
2.4 Sandy shale, brown.
1.7 Sandstone and fine-grained conglomerate, brown.
7.5 Sandstone and sandy shale, all brown and with mica, alternating.
13.0 Sandstone, brown, dry, with some layers argillaceous sandstone with mica.
1.0 Iron ore.
0.4 Sandstone, brown, laminated and dry.
2.4 Sandstone, argillaceous, shale, red and grey. Upper part grey, lower red.
6.0 Conglomerate, mottled, partly with iron ore as matrix. Also containing small layers of sandstone.
10.0 Sandstone, red and grey, dry with small layers of conglomerate.
1.0 Sandstone, heavy with iron oxides.
1.5 Sandstone, white.

Thickness in metres	
2.5	Sandstones and conglomerates with iron oxides and sandy shales, all brown.
5.8	Conglomerates, mottled with red sandy shale.
2.0	Breccia of grey limestone. Probably the base of *Middle Carboniferous.*
12.0	Conglomerates, red and yellow limestones alternating.
.	Limestones of great thickness.

The sequences from Hecla Hoek to the Middle Carboniferous measures 350 metres in Brøggerfjellet, this figurere presenting the total thickness of the Devonian layers in Brøggerfjellet. In the crest south of Zeppelinfjellet the development and thickness of the Devonian sequence is about the same as in Brøggerfjellet.

The iron ore layers found in the upper part of the sequence of Brøggerfjellet, and which I have observed also in Zeppelinfjellet, consist of hematite and limonite in sedimentary layers. One of the richest samples was analysed by Sherdahl, who found 50 per cent. Fe. The ore is of no economic interest.

The red colour of the Devonian strata is due to iron oxides which are found in the cement of the rocks. The sediments must have been deposited in a dry climate, during which also iron hydroxides were formed. The greater part of the rocks must have been deposited in water, as they are very finely stratified, and show a frequent alternation of well classified sediments. The great amount of conglomerates shows us that the layers must to a great extent be beach deposits. As the fishes found in these sediments have been determined as mainly fresh and brackish water forms, it is very likely that the Devonian sediments have been deposited in an isolated basin during a desert climate. The vegetable life must have been very poor, because no plant fossils are found. The iron ore must have been deposited in lakes where the water containing iron in solution has evaporated. In several conglomerates the cement consists of hematite.

With respect to the age of the Devonian strata on Brøggerhalvøya it is still doubtful whether they belong to the Wood Bay series[1] or the Red Bay series, the latter being of Downtonian age. The lack of fossils, and the great percentage of conglomerates might agree with the Red Bay series. On the other hand, it is very probable that it is the lower part of the Wood Bay series which is cropping out here. As pointed out by Holtedahl, the Devonian must have been deposited in a basin to the east, and it may therefore be the oldest coarse beach deposits which are found on Brøggerhalvøya now.

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[1] The lowermost of the Devonian in Spitsbergen, lying unconformably on the Downtonian Red Bay series.

Culm.

Strata of Culm age have been found only at the sea west of Kiærfjellet. Nathorst (1910) is the first to mention the occurrence of Culm rocks here. He supports his hypothesis on pieces of rock brought home by Blomstrand and on his description. Later on the sequence has been examined and described by Holtedahl (1913). I visited this place in 1922 and 1928, but did not undertake any detailed measurement of the outcropping part of the sequence, nor did I find any fossils.

The Culm strata are seen to rest with a pronounced angular unconformity on the Hecla Hoek mica schist. Whereas the mica schist is dipping about 80° to the west, the Culm strata have an easterly inclination of about 10°. The sequence is made up of light and pure sandstones with beds of shale and a coal seam. Thus the rocks here are considerably different from the Devonian conglomerates and sandstones resting on the Hecla Hoek farther east, the latter containing no organic coaly matter. Red conglomerates are also to be found in the section west of Kiærfjellet; they, however, belong to the Middle Carboniferous. From the sections E—F and G—H, pl. V the position of the beds here may be seen. In the same way as in the Ice Fjord. Bell Sound district the lowermost bed of the Culm is made up of a light conglomerate with sandy matrix and pebbles of quartz. Upwards follow light, crossbedded sandstones with beds of conglomerates and red and grey shales; and in the lower part is a coal seam interbedded in dark shale and coaly shale.

During my short visits I found no fossils, which seem to be rare in the Culm sequence here, but according to the appearance and occurrence of coal it can scarcely be doubted that the sequence is of Culm age. The thickness hardly exceeds 125 metres.

The coal seam had earlier been exposed in a pit near the hut built by the mining company. The pit is situated only a few metres above the base of the Culm, but during my visits it was filled with ice, and thus I have not personally seen the coal seam exposed. According to information given by Mr. Peter S. Brandal, one of the directors of the company, the total thickness of the coal and shale horizon was about three metres. In the upper part some good coal had been found. I took a sample amongst the best coal pieces on the dump. The analysis made by Dr. J. Gram in the autumn of 1922 gave the following result:

			In pure coal
Moisture	0.40	per cent.	—
Ash	33.90	—„—	—
Coal substance	65.70	—„—	—

			In pure coal
Sulphur	8.14	per cent.	—
Coke	82.70	—„—	74.25
Volatile matter	16.90	—„—	25.75
Gross calorific value	5394	cals.	
Net calorific value	5222	—	

Contents of crude oil by low-temperature distillation was 5.2 per cent. Pieces of coal which I tried to burn in the stove of the hut were so rich in ash that they retained their form also after they had been burned. These coals are thus of quite another type than the coal on the Tertiary field, and must almost be regarded as valueless because of the high content of ash. From the content of volatile matter in pure coal they must be classified as coking coal (*Fettkohlen*). The greater part of the coal seam must be made up of coaly shale and bony coal.

Middle Carboniferous.

The Carboniferous strata in Spitsbergen are developed in the same way as the Russian deposits of that age, and accordingly the Russian designations have been used in Spitsbergen. The littoral facies deposited during the first submersion of the land in post-Culm time have been separated as a special stratigraphic division belonging to the Middle Carboniferous. In Central Europe the synchroneous deposits are included under the Upper Carboniferous system. The term Middle Carboniferous has not been adopted here, because the development is quite another. The first to call attention to the Middle Carboniferous fossils at Kings Bay was J. G. Andersson (1909). He found a *Spirifer Mosquensis* Fischer from Kings Bay in the Stockholm Riksmuseum. This is a guide fossil of the Russian Moscovian. It was, however, Holtedahl (1911 and 1913) who during his work on Brøggerhalvøya found this fossil *in situ* and pointed out that this substage with certainty occurs on the peninsula. He gathered about 40 species of fossils, and has given a detailed description both of the fossils as well as of the sequence. Amongst the fossils the corrals, productus, and spirifer species are predominant.

As mentioned above, the Middle Carboniferous strata have been deposited during the submersion of the land after the end of the Culm period. Before the submersion took place the land had been eroded down during a long period, and for this reason the Middle Carboniferous strata now rest with a non-evident unconformity on the Devonian to the east and the Culm to the west. Notwithstanding this long period of denudation the strata of the latter systems had an almost horizontal position when submersion began. Accordingly the Middle Carboniferous strata and the underlying older rocks have an almost parallel bedding, and thus the unconformity can hardly be noticed in in the field.

The fact that the Middle Carboniferous strata are resting on Culm to the west and Devonian to the east is due to an old line of dislocation through the peninsula along which the western part has been thrown down in later Culm. For this reason the Culm layers have been preserved west of the old fault line.

The lowermost beds of the Middle Carboniferous are littoral deposits made up of alternating conglomerates and limestones. These conglomer-

Fig. 11. Block from the lowermost Middle Carboniferous bed in the cliff north of Scheteligfjellet.
A. K. Orvin phot. 23/8 1922.

ates are more or less calcareous and differ only in this respect from the Devonian conglomerates. They are made up of Hecla Hoek and Devonian rocks cemented by limy matrix, and have preponderatingly a reddish colour. In the western part of the sequence north of Scheteligfjellet there occurs a breccia of great angular pieces of sandstone and limy cement. This breccia certainly represents the lowermost bed of the Middle Carboniferous and a hiatus must exist between it and the underlying beds. It must have been formed through the upbroken rocky surface having been cemented by the precipitated lime. In the other places where the lowermost beds of the Middle Carboniferous are exposed I have placed the lower limit of this sequence at the lowermost limy beds of conglomerates, which have about the same stratigraphic position as the above mentioned breccia, and they must thus belong to about the same horizon.

The upper part of the Middle Carboniferous is made up of marine limestones containing abundance of corals and brachiopods, etc. They are neritic facies settled in shallow water. The upper limit is difficult to determine, as the limestones upwards have been deposited unbroken in connection with the thick and monotonous Upper Carboniferous cyathophyllum limestone. For this reason they have been put into the map together.

Holtedahl gives a detailed description of the fossils as well as of the stratigraphical conditions, and I refer to his works concerning these matters. The fossils have partly been silicified, and consequently one may find pretty specimens, especially of corals, protruding out of the limestone, which has been dissolved around them.

The Middle Carboniferous strata have not been proved to exist in the southern part of Spitsbergen, and Holtedahl is therefore inclined to think that the submersion of the land in Middle Carboniferous time took place from the north, and that the submersion did not reach the southern part until the Upper Carboniferous time. As Middle Carboniferous strata also exist in Bear Island, the southern part of Spitsbergen must in this case have formed an island or peninsula with a Middle Carboniferous sea both on the northern and southern side. Considering that the Middle Carboniferous in Middle Europe and Moscow-Ural is of marine origin, the sea must, as also pointed out by J. G. Andersson (1900), broadly speaking have transgressed from the south. The Middle Carboniferous strata in Bear Island have a far greater thickness than those in Spitsbergen, which also must be due to a more extended period of deposition. It is thus believable that the Sea had reached Bear Island while the denudation was still in progress at Kings Bay. Personally I am not quite sure that the Middle Carboniferous is missing in the area between the Ice Fjord and Bell Sound. During the mapping in 1925 south of the mouth of the Ice Fjord, I noticed some red layers at the base of the Cyathophyllum Limestone containing beds of conglomerates exactly like those in Bear Island and Kings Bay. It was, however, difficult to find any exposed sections and I thus found no fossils. Of course these beds may also be younger, only marking the transgression of the sea in Upper Carboniferous time.

Upper Carboniferous.

The first to mention the great series of limestone on Brøggerhalvøya was Blomstrand (1864) p. 27), yet without any determination of their age. Amongst the fossils gathered by Blomstrand at Kvadehuken, Nordenskiöld found *Eomphalus* and *Cyathophyllum* and accordingly he drew the conclusion that the limestone belongs to the "Bergkalk" formation. In 1907 Hoel (1914) visited Brøggerhalvøya, and he noticed both the cyathophyllum limestone and the underlying sandstones and conglomerates. Holtedahl (1911 and 1913), however, was the first to make a close examination of these beds in 1909, 1910 and 1911. He has given an exact description of them in his papers, to which I refer.

The sequence is made up of limestones with dolomites in the lower part, and beds of chert, limestone, siliceous shale, and partly shales in the upper part. The lower non-siliceous part has in Spitsbergen been named Cyathophyllum Limestone, and the upper part, representing the uppermost layers of the Carboniferous system, Permo-Carboniferous.

Cyathophyllum Limestone.

The Cyathophyllum Limestone is made up in continuation with the Middle Carboniferous beds, on which they rest conformably, and consists of a fairly uniform series of limy rocks. The total thickness including the Middle Carboniferous strata is about 450 metres. The whole sequence is of marine origin, and according to Tschernyschew it corresponds to the Timan-Ural Cora horizon and partly to the Omphalostrochus layers in Russia. It was Nordenskiöld who named it Cyathophyllum Limestone. This name does not include any petrographical unity, the sequence being composed of layers of different development and appearance. Nathorst observed limestone with vugs and stylolithes in the lower part of the sequence. I also noticed limestone with vugs in the cliff near Kvadehuken, but the bed in question must be of Middle Carboniferous age. In some layers a great deal of flinty concretions and lumps will be found, and in the lower part also a horizon containing *fusulina* occurs. The bed containing this fossil is according to Holtedahl four metres thick. The fusulina limestone also contains asphalt and is supposed to have been formed as sapropel in saline or brackish water at a depth of maximum 60—80 metres, at which depth fusulina lived together with microscopical algæ which constituted their food. The content of asphalt originates from these algæ. In the upper part of the Cyathophyllum Limestone there are very few fossils. The highly fossiliferous Spirifer Limestone which caps the Cyathophyllum Limestone in the Ice Fjord district, has not been found at Kings Bay. The Cyathophyllum Limestone is successively followed upwards by the Permo-Carboniferous flinty layers.

Gypsum, which occurs in the Ice Fjord—Bell Sound area, does not appear at Kings Bay. This may perhaps be indicative of an existing shore development in the centre of Spitsbergen when there was already deeper sea to the north. This fact may thus confirm the supposition that in the central and southern part of Spitsbergen there was land in Middle Carboniferous time.

Some layers of the Cyathophyllum Limestone are of a rather irregular composition and give rise to the most odd-looking erosional forms, partly resembling porous lava. Rock pieces eroded in this way are found in great masses in the inner edge of Kvadehuksletta. These erosional forms are due to the irregular distribution of the silica content of the limestone. The flinty lumps are often made up of concentrical, thin, alternating layers of limestone and chert, and when exposed to the dissolving activity of the water the limestone laminæ will be partly removed, and the lumps will assume the appearance of several egg-shells having been put concentrically into each other.

The extension of the Cyathophyllum Limestone will be seen from the map. Along the southern shore of Kings Bay it crops out with a south-westerly dip. In Scheteligfjellet, which is mostly made up of this rock, the strata dip 10—20° to the west. In Kiærfjellet, Brøggerfjellet, and Zeppelinfjellet the dip is varying and mostly steep.

Where the cliff is made up of cyathophyllum limestone one will notice, as already mentioned under the description of the coast, coves and sink-holes. Blomstrand points to the fact that no dropstone is found in these coves, and he suggests that this may be due to the small quantities of circulating water in the rocks of Spitsbergen. This may also be the case with the cavities which are protected against the dissolving activity of the sea, but in the coves of the cliff one may as a matter of fact not expect to find any calcareous sinter, as these coves are permanently laid open to the erosional activity of the sea.

Permo-Carboniferous.

The Permo-Carboniferous strata is the uppermost part of the Upper Carboniferous series. From a petrographical point of view they differ from the cyathophyllum limestone in that the rocks are composed of chert, siliceous shales and strongly siliceous and hard limestones. On the top this series is capped by a glauconitic sandstone with beds and lumps of chert. This series is rich in fossils, especially brachiopodes bryozoes and crinoid stems. The fossils are usually strongly silicified and are so firmly attached to the rock that it is difficult to separate them from it.

According to Tschernyschew the Permo-Carboniferous in Spitsbergen is contemporaneous with the Artinskian stage in Ural, and is by several geologists transferred to the Permian.

Some fossils may be found eroded out of the rock in a very fine way. This is especially the case with corals, halichondria, productus, and spirifer species.

The total thickness of the Permo-Carboniferous strata is about 250 metres, consequently it is considerably smaller than in the section at Kap Starostin on the south side of the entrance to the Ice Fjord, where

I have made a very detailed measurement of the sequence and found the thickness to be 388.5 metres. The sequence is rather uniform with a frequent alternation of tight beds of chert or flinty limestone with beds of black, siliceous shales and some beds of shales and pure limestones. The colour is grey, yellowish, and partly black. The upper chert-bearing sandstone is green. This sandstone I did not notice in the section at Kap Starostin, but I observed it on the south side of the Sassen Fjord in 1925, also here as the uppermost part of the Permo-Carboniferous sequence. The thickness was about 40 metres. It was also observed by Willander and Nathorst at Skans Bay as early as 1870. This glauconitic sandstone is thus doubtless the uppermost Upper Carboniferous bed ever deposited in Spitsbergen. The thickness at Kings Bay is also about 40 metres. This fact seems to prove that the Upper Carboniferous series had still their full thickness at Kings Bay when the first deposition of the Tertiary took place. The reason why this sandstone is missing at the outer part of the Ice Fjord is unknown.

The whole sequence is of marine origin, neritic and pelagic facies deposited in a sea with a depth of maximum 300 metres. It is partly built up of animals and animal remains, or settled in a chemical way; they are partly transported, mechanical sediments. According to statements by G. H. Hinde the compact beds of chert are partly made up of skeleton fragments of halichondria, whereas the shales include grains of quartz.

Tertiary.

Tertiary rocks occur only on the coastal plain between Scheteligfjellet and Lovénbre No. 1 on the northeastern side of Brøggerhalvøya. From the maps it will be seen that the Tertiary field does not reach the sea at any point, the area along the shore being occupied by cyathophyllum limestone and Permo-Carboniferous chert.

The Tertiary beds are resting unconformably on Permo-Carboniferous chert and glauconitic sandstone. This unconformity, however, is not distinctive in the field, because the beds belonging to the two different formations are nearly parallel, and because the outcrop of the unconformity is everywhere covered by loose material.

The lowest part of the sequence is made up of a shale horizon, in which Blomstrand found fish fossils which he thought were too badly preserved to be determined. This shale might be Cretaceous, and accordingly it is perhaps not quite correct to say that the Tertiary is resting directly on the Permo-Carboniferous. Blomstrand considered the thickness of the shale horizon to be about 250 feet in the eastern part of the area. As the thickness of this shale series to the west is only trifling and the age very doubtful, I will deal with it in connection with the Tertiary layers; the more so, because I have not been able to find any trace of Cretaceous fossils and doubt that this series, especially the upper part of it, belongs to the Cretaceous system.

The lowermost part of the shale is partly exposed as a breccia with angular bits of chert and thin layers of limestone. This stratum is quite thin and is not found everywhere. At several points the limit between the shale and the underlying chert and sandstone is very sharp. The Permo-Carboniferous rock has thus partly been uncovered before the deposition of the shale, and partly been covered by rock fragments. If the shale had been of marine origin one would, without doubt, have found a conglomeratic bed at the bottom of it, indicating the transgression of the sea. Such a conglomerate I have found only in the westernmost part of the field, but here the shale has wedged out and the conglomerate is the bottom bed of the sandy Tertiary beds. This conglomerate bed is locally developed and probably younger than the shale.

The shale above the green, glauconitic sandstone in Pit 44 proves under the microscope to be a calcareous shale containing some angular grains of quartz with a diameter up to 0.2—0.3 milimetres. Small flakes of mica and black figures of coaly substance are seen in a light grey substance. A small fissure filled with secondary calcite is also seen in thin section.

Also the shale nine metres below the Ester Seam, Pit 45, is highly calcareous with some grains of quartz.

In the upper part of the shale horizon another conglomeratic rock appears. This rock is quite singular. The matrix consists of shale, and in this shale great masses of partly angular and partly rounded bits of green claystone and shale occur, of the kind found farther down in this series. Only in some sections have I found pebbles of chert in this conglomerate. Both the conglomerate and the shale and claystone soon disintegrate when exposed to weathering. For this reason these layers are hardly anywhere visible on the surface. Only in some brook cuttings they may be observed; everywhere else the subterraneous outcrop is hidden by a thick cover of residual soil.

The series of shales, claystone, partly also marly claystone and conglomerates, which together might be termed the *Bottom Shale*, has its greatest thickness to the east and pinches out to the west. At Anneksjonshytta the thickness is above 50 metres, in borehole 5 it was about 25 metres, in boreholes 2 and 3 near Tvillingvatna 13—14 metres, and in borehole 4 on Leirhaugen 10 metres. At Skjerva the thickness is only trifling. The shale-forming clay has here originally been deposited in an upbroken surface of chert, and accordingly the bottom bed has a brecciated appearance. In the eastern part of Lagunefeltet the shale is missing, and the Tertiary basal bed is a rather coarse conglomerate. It is possible that this conglomerate represents a part of the shoreline belonging to a basin in which the lowest Tertiary sediments have been deposited.

That the Bottom Shale has been deposited in a lake or perhaps a lagoon may be concluded from the fact that the development differs greatly in horizontal extension. Thus the alternation of the conglomerates and shales varies very much in the different cross sections obtained. Whereas in some of them green and brown shale make up the sequence, red shale is in others found to be the prevailing rock, as is the case in borehole 3. These red shales are certainly made up of material derived from the red Devonian layers. The explanation seems to be that the shales and conglomerates must have been deposited in rather quiescent water, where the material, which has been transported hither by the rivers and brooks from different rock areas, has been deposited near the outlet of the respective streams.

As the land surface surrounding the present Tertiary field at the entrance of the Tertiary period consisted of Upper Carboniferous rocks, the Devonian material must have been transported far from the north, where this formation at that time must have been exposed. This fact confirms the supposition of De Geer that the denudation in Cretaceous time reached down to the Hecla Hoek rocks in the northernmost part of Spitsbergen.

The claystone pebbles in the conglomerate must have been derived from the underlying shale and claystone in the immediate neighbourhood. There is no older rock with such an appearance. It may therefore be suggested that the shales and claystones under the conglomerate horizon now found in the eastern part of the field are considerably older than the conglomerate horizon and belong to the Cretaceous system, whereas the claystone conglomerate constitutes the basal bed of the Tertiary. The great resemblance between the lower and the upper part of the Bottom Shale in this case must be due to the upper part being made up of material derived from the lower part. In this case there is also a stratigraphical break under the conglomerates. This explanation I consider to be a very likely one, and it may also give us the clue to Blomstrand's finding fish shells in the lower lying shales in the eastern part of the field, where these layers were then far better exposed than during my visits. Between the claystone conglomerate and the overlying Tertiary beds it is quite impossible to detect any unconformity. On the other hand, the Ester Seam is resting absolutely conformably on the underlying shale.

We shall now deal with the established Tertiary sequence lying above the Ester Seam. It was very difficult to draw up a close stratigrafical section of this sequence, until, through the deep-drilling in 1928, we got exact cross sections through the lower part of the series at several points. From borehole 4 on Leirhaugen (see p. 90 and pl. VII)

we have got a continuous and detailed section from 45 metres above the Agnes-Otelie Seam down to the Upper Carboniferous chert. It may be regarded as a normal section of the lower part of the sequence on Vestfeltet. The other drill-logs will show the development on the Vestre Centerfelt and Agnesfeltet. From the upper part of the sequence we have no such detailed section.

Concerning details, I refer to pl. VII and the description of the drill records.

The lowermost part of the Tertiary resting on the Bottom Shale is a 20 to 40 metres thick series of sandstones, shales, and their transitional rocks, and include several coal seams. As will be seen from the drill records the development varies somewhat in the different sections. In this series, which may be called the Lower Coal horizon, the most important coal seams are found, viz. from below: The Ester Seam, the Sofie Seam, and the Advokat Seam. From east to west the number of seams decreases. This is also, broadly speaking, the case with the thickness of the single seam.

As will be seen from the drill records the Ester Seam rests everywhere on the Bottom Shale. For this reason one is led to believe that it is the Ester Seam which is found as the lowermost coal seam in pit 35 in the Olsen Mine, and that it is the Sofie Seam on which this mine was worked. I have also in the description of the coal seams followed this scheme. On examination of the rocks belonging to this horizon, under the microscope, I have, however, found resemblances between the rocks of the hanging and foot wall of the Ester Seam and the main seam in Olsen Mine, which really makes me doubt whether this seam is not the Ester Seam. I have only seen the rocks from the Olsen Mine on the refuse dump, as the mine was then inaccessible, and accordingly it is very difficult to place the rocks examined from the refuse in the mine sections measured by Sherdahl. If the main seam in Olsen Mine really is the Ester Seam, I consider it most probable that the seam in pit 35 belongs to the same horizon, and that the layers have in some way been repeated by thrusting. This is a possibility which I will not omit to point out.

In some of the rocks belonging to the Ester horizon I found great masses of small tubular silicified fossils with a diameter of abt. 0.03—0.06 millimetres and 0.2—0.4 millimetres in length. I thought they might be siliceous algæ, and sent two thin sections containing these fossils to Dr. Hans Frebold, Greifswald. In a letter he confirms the supposition, and says that Dr. Richter at the Institute in Greifswald has pointed out that several forms of these fossils are to be seen in the sections. A closer determination has not been made, and it will perhaps be difficult to state whether these fossils are marine or freshwater forms. They have been observed in the foot wall of the Ester Seam in pit

34 on Kolhaugen, but only in the hanging wall of the Ester Seam in the same pit are they found in abundance in a dark brown siltstone. Also in some rocks on the refuse dump at Olsen Mine I have found just the same rock with masses of these fossils, but I do not know whether this rock originates from above or below the main seam here.

In the rock forming the foot wall of the seam in Olsen Mine I could find no such fossils. A sample taken at the bottom of the rise 36 contains much lime and grains of quartz in a dark matrix containing coaly substance, and it closely resembles the rock forming the foot wall of the Ester Seam in pit 45.

The rock containing the fossils in Olsen Mine is a sandy shale with angular quartz grains with a diameter up to 0.1 millimetre and a matrix of a brown, partly pellucid substance, which under crossed niccols is black. The brown colour is certainly due to iron oxides and also coaly substance. The fossils occur in abundance.

Other samples from the refuse do not contain such fossils, but are more or less coarse and also contain mica and pyrites.

In a sandstone lowermost in the sequence west of Skjerva I have also noticed these fossils.

Upwards in the section I have found no beds containing siliceous algæ as a part of the rock, but in some beds of sandstone and conglomerate there are included grains and pieces of the rock containing fossils.

In the four metres of sandstone in rise 36 in Olsen Mine some grains of rock consisting mostly of these fossils are found. The sandstone is otherwise made up of grains of quartz, mostly rounded and with a diameter of 0.2—0.3 millimetres. The matrix is black to blackish brown and is certainly of organic origin. Small flakes of mica and small pieces of chalcedony, which may be of fossiliferous origin, are also seen.

The uppermost rock in which I have seen these fossils is the small conglomerate abt. 0.5 metres above the Advokat Seam. It is very characteristic and made up of pebbles of quartz of up to one centimetre, angular bits of quartz, and brown pieces of shales. These pieces contain great masses of siliceous algæ, and are certainly derived from the lower bed. The matrix is partly made up of pyrites.

The fact that the sandstone and conglomerate contain pieces of the lower lying fossiliferous shale show us that there must have been a rather long break in sedimentation in the Sofie horizon or thereabouts, sufficient to form rock, which by erosion has afforded material for new sedimentation. That this land, which has partly been exposed to erosion and partly overgrown with wood or overflown by water, shows a sequence with alternating short periods of sedimentation and erosion of irregular extensions, is not more than could be expected. To trace these irregularities in a sequence containing similar rocks and fossils is, however, very difficult.

Siliceous algæ live in both fresh and saline water, and it would of course have been of great interest to know if the forms occurring in the Ester horizon belong to the one or the other kind. This might perhaps be decided by a specialist, but judging from the rock itself I should think it fairly certain that they have lived in fresh or brackish water. The rock contains too much coaly substance and is too irregularly deposited to be of marine origin, but it might be a lagoon deposition. As, however, no marine fossils are found in this sequence, it does not seem very probable that there should have been sea at Kings Bay at a time when there is no certainty of its having existed farther south. The lowest marine mussels in the Ice Fjord district are found above the coal horizon, and the Ester Seam is situated at the bottom of it.

We return to the section above the Advokat Seam.

Upwards follows a fairly uniform, about 70 metres thick, sandstone series with some layers of conglomerate. All these conglomerates contain pebbles of Permo-Carboniferous chert in sandy matrix. It appears to be mainly made up of material belonging to this system. On the top of this sandstone series, which I term the Light Sandstone, comes the Agnes-Otelie Seam, overlain by a conglomerate several metres thick. Also below the coal seam, beds of conglomerates are seen in several places. The pebbles of these conglomerates consist of chert and quartz, are very finely rounded, and of about hazel-nut size.

The uppermost part of the sequence is made up of green and greenish-grey sandstones and laminated sandstones, including a few horizons with shale and coal seams. The greatest thickness of this series, which I term the Green Sandstone, is found on Vestfeltet, but it is very difficult to fix; I should estimate it to amount to about 100 metres.

In the Green Sandstone on Østre Centerfelt we find the Josefine Seam about 20 metres above the Agnes Otilie Seam and the Ragnhild Seam about 35 metres above the Josefine Seam.

The sandstone above the Ragnhild Seam is very similar to the sandstone above the seam KBI. The quartz grains with a diameter of up to 0.5 millimetre, constitute about one-third of the rock. Many grains of finegrained quartzites, shales, weathered feldspar, and fragments of marble are also seen. Round the latter is found secondary calcite. The rock is weathered and brown from the oxidising of pyrites.

Whereas it is difficult to find any fossils in the Light Sandstone, the shales and sandy shales of the Green Sandstone are very rich in fossils. Thus the light grey shale in the hanging wall of Josefine Mine is highly fossiliferous. This is partly also the case with the shales near the Ragnhild Seam. The most prominent amongst the fossils are well preserved leaves of foliage trees.

No marine fossils have been found in the Tertiary beds at Kings Bay, and accordingly no marine transgression appears to have taken place in the space of time represented by the sequence now existing. The development and thickness of the coal seams indicates also that the vegetation at Kings Bay must have been far more diversified in the horizontal as well as in the vertical direction than is the case in the Ice Fjord—Bell Sound area. It all seems to be consequent upon the great rise of the land in the northern part of Spitsbergen in Cretaceous time.

The Ice Fjord—Bell Sound area must, during the earlier Paleocene age, have been a great lowland near the sea-level covered at intervals with extensive forests, which at different brief periods have been submerged and covered with sediments partly marine. The Kings Bay area, however, must at that time have been situated farther inland more elevated, and the vegetation now forming the coal seams must have been confined to rather limited basins of moors and swampy forests.

The Tertiary beds at Kings Bay, the thickness of which amounts to about 200 metres, are probably all continental deposits. It can scarcely be doubted that the Tertiary at Kings Bay is contemperaneous with the lower Tertiary series in the great syncline between the Ice Fjord and Bell Sound.

Heer (1870) informs us that on the Swedish expeditions in 1858, 1861 and 1864, fossils were collected also at Kings Bay. In 1868 Nordenskiöld, Malmgren, and Nauckhoff brought home about 500 pieces containing Tertiary fossils from the same area. All these fossils were determined by Heer (1868 and 1870) to be of Miocene age. He found altogether 16 species, all of which had been found in the more sandy rocks. Practically all the pieces contained remains of *Equisetum arcticum*, which is supposed to have lived in great peat moors and over great areas. As they have been fossilized with roots, suckers and tubers they must have lived on the spot and must be autochthoneous. The following species were also noticed: sedgegrass, *Carex ultima;* flagflower, *Iris latifolia*; *Nymph. thulensia*, *Populus Richardsoni*, and *P. arctica*, *Pinus Abies* L., and *Nordenskiöldia borealis*; a juniper sp., a thuya, *Thuites Ehrenswärdi*, and a large-leaved lime-tree, *Tilia Malmgreni.* At that time *Taxodium* had not been observed at Kings Bay.

Later on, during mining operations, a large number of fossils were collected, but, as far as I know, they have not yet been examined and described. Fritz Schäfer, who for several years acted as surgeon at the mining works, made a great collection of fossils from the shale in the top wall of Josefine Mine. In this shale great masses of leaves of hardwood as well as needles of softwood were interbedded. In 1922 and 1923 I also collected some fossils both in this shale and farther up in the sequence, but neither have been more closely examined. In this collection many different leaves of the just mentioned hardwood occur; and in the shale of the hanging wall of Josefine Seam I found great masses of *Taxodium*, which is certainly *Taxodium distichum miocenum*, Heer, which is well known from the lowermost of the Tertiary at the Ice Fjord.

Whereas Heer adduced from the plant fossils that the Tertiary in Spitsbergen was of Miocene age, I. P. Ravn (1922) has pointed out that it is of Paleocene and Eocene age. This conclusion he has drawn from the determination of mussels found in the lower marine beds of the formation at the Ice Fjord. As to the sequence at Kings Bay it is probable that only the Paleocene strata have not been subject to erosion. Fossils which might settle this question have not been found at Kings Bay.

In Tertiary time there has thus been a far warmer climate in Spitsbergen than in our day. The vegetation corresponds to that next to the Middle European of the present day. Nordenskiöld calculates the yearly average to have been about 5° C, it is 12—13° more than at present.

As I have already pointed out, pebbles of Permo-Carboniferous chert occur throughout the Tertiary series of strata at Kings Bay. These pebbles are never particularly large, being only occasionally of more than hazelnut size. During the whole time of sedimentation there must accordingly have been a conveyance of rock material from this formation, which must have been exposed to denudation in the neighbourhood during the older Tertiary time. These pebbles have certainly not been carried any great distance.

It is conspicuous that the Tertiary at Kings Bay is made up of coarser sediments than is the case in the Ice Fjord--Bell Sound area. This fact can only be due to a shorter distance of transportation at Kings Bay. Also this fact points to the existence of a higher land to the north, from which the rivers have carried pebbles, gravel and clay in a southerly direction. The coarsest material has been deposited after being transported only a short distance, whereas the finest has been carried farthest away.

Fig. 12. Geological section along the coast of Brøggerhalvøya. — 1. Permo-Carboniferous. 2. Upper and Middle Carboniferous. 3. Culm. 4. Devonian. 5. Hecla Hoek.

It is likely that the land at Kings Bay and northwards has not been submerged at all during the oldest Tertiary, as have been the southern lowlands. At a later date when the thick shales known from the Ice Fjord—Bell Sound district were deposited, it is possible that the whole land was involved in the submersion. It may, however, also be that the marine shales have not been deposited at Kings Bay, and that the sequence here corresponds to a far greater thickness at the Ice Fjord—Bell Sound district.

Structure.

In dealing with the structure in the property area of the company I shall mostly confine myself to the tectonics of Brøggerhalvøya. Here the older and younger series of strata have not only been preserved, but the peninsula is situated in the most prominent line of weakness of Spitsbergen, and tectonical disturbances of the different periods can best be traced here.

The areas east and north of the fjord, to the contrary, are made up entirely of Hecla Hoek rocks, and accordingly possible younger disturbances cannot be dated here. As already alluded to under the treatment of the Hecla Hoek, it is not probable that any great disturbances have taken place here since the forming of the Caledonian Mountain Chain. The almost undisturbed Devonian and Upper Carboniferous farther to the east also points in this direction.

The trend of the Hecla Hoek rocks in these areas is the same as elsewhere within the Caledonian Mountain Chain on Spitsbergen, where it has not been influenced by younger tectonical disturbances, as is the case on Brøggerhalvøya. I do not mean to say that these areas have been quite undisturbed since the Silurian folding. Great changes in level have taken place as upheavals and lowerings of land blocks; but these movements have not resulted in further folding of the strata or changes in trend and dip worth mentioning.

The tectonical conditions on Brøggerhalvøya are certainly the most complicated ever observed within the younger formations on Spitsbergen. The elucidation of these problems is not only of the greatest importance to the valuation of the coal field, but affords weighty contributions to the knowledge of the structure of the whole of Spitsbergen.

In the stratigraphical part of this paper I have already dealt with the development and distribution of the different rocks and formations within the property area. I shall try below to give a description of the tectonical observations made on the peninsula, the understanding of which will perhaps be best obtained by studying the geological maps and sections. The conditions along the coast will be seen from fig. 12.

Observations on the Structure.

Folding.

Within the southeastern part of the peninsula, where only rocks belonging to the Hecla Hoek occur, there is not very much to be seen of tectonical interest. The great sequence of phyllites, mica schists, quartzites and limestones has everywhere a southwesterly dip of 45—70°. These rocks have been strongly pressed and metamorphosed, and it would be difficult to point out any possible older unconformity here. The trend and dip, however, are fairly uniform all over this area, and this part of the peninsula must therefore have taken part as a whole in the younger tectonical disturbances.

The conditions within the northwestern part are otherwise. Here the older and younger rocks have been folded and faulted in a way

Fig. 13. The folded strata in Brøggerfjellet seen from the east.
a Hecla Hoek. b Devonian. c Middle Carboniferous. d Cyathophyllum Limestone. e Permo-Carboniferous.
A. K. Orvin phot. 21/8 1922.

giving some of the mountains an almost chaotic appearance. This is especially the case with the mountains situated nearest to the boundary of the Hecla Hoek area, such as Zeppelinfjellet, Brøggerfjellet, and the eastern part of Kiærfjellet, where the strata are strongly folded, thrust and faulted. Only along the coast and in Scheteligfjellet have the rocks a tolerably regular dip of 10—20° SW, in some spots more.

If we study the section I—J, pl. V across the coal field and Zeppelinfjellet, we shall find that the Carboniferous strata near the sea have a normal succession with a southwesterly dip. Crossing the Tertiary field from north to south, we have younger and younger layers until at the base of the mountain we suddenly again fall in with the Carboniferous, but here with an inverted position. Farthest down in the mountain slope Permo-Carboniferous chert is observed, upwards it is followed by cyathophyllum limestone, of which rock the bulk of the mountain is made up. On the south side of the summit the Middle Carboniferous and then the Devonian strata crop out, all lying in inverted order. Farthest south and uppermost the Devonian is overlain by Hecla Hoek rocks.

In Brøggerfjellet the structural conditions are still more entangled (sect. O—P, pl. V and fig. 13). From Scheteligfjellet the Upper Carboniferous series dip into the lower part of Brøggerfjellet, where they are seen to form a fold overturned towards the north.

In the middle part of Brøggerfjellet the cyathophyllum limestone is tilted up into a fan-form with some contorted layers in the gap between the summits 630 and 714. Southwards from the latter summit the Middle Carboniferous and Devonian strata crop out with a northerly dip of about 40°. Near the little summit 608 the lower limit of the Devonian is reached. Here an inlier of Hekla Hoek mica schist and quartzite crops out in a little cone on the ridge, around which the Devonian dips to the northwest and south; and the strike direction forms a semi-circle about the small peak.

In the crest eastward from point 603 the Devonian has also a southeasterly dip. In the small peak 511 on this ridge the cyathophyllum limestone is met with again, but immediately on the eastern side of this point the younger strata are cut and overlain by Hecla Hoek mica schist and quartzite.

A still more interesting section is seen in the southern ridge of Kiærfjellet (sect. G—H, pl. V). In 1922 I noticed a deep gap, previously unknown, between Scheteligfjellet and Kiærfjellet, which I have named Trangskaret. On the eastern side of this gap the Upper Carboniferous rocks of Scheteligfjellet have a westerly dip, whereas on the western side the sequence is tilted and partly overtilted towards the east. Westward along the ridge of Kiærfjellet the whole sequence consisting of Permo-Carboniferous rocks, Cyathophyllum Limestone, Devonian and Hecla Hoek rocks are found in the upper part of the mountain with steep inclination, whereas the lower part is made up of cyathophyllum limestone with a dip of about 30° to the northeast. The same conditions prevail also on the southern side of Traugdalen. The upper, tilted parts are tectonically connected with the layers in Scheteligfjellet, and there is a distinct structural discordance between the upper tilted part and the underlying cyathophyllum limestone. The plane of structural discordance, the outcrop of which can be seen from the geological maps, has an easterly inclination under the eastern part of Kiærfjellet and Scheteligfjellet.

In the northern part of Kiærfjellet the tilted layers cannot be observed. According to the observations of Holtedahl (1913, p. 73) a part of the sequence is here repeated, for he found the fusulina horizon at both 250 and 450 metres above sea-level.

In and below summit 611 the limestone dips 25° towards the south, whereas in the northern summit the layers have the usual dip towards the east. In this summit the Permo-Carboniferous chert is also found as the uppermost layers. The explanation must be that the plane of tectonic disturbance is cropping out between the two summits, and thus summit 611 belongs to the upper tilted and thrust part, whereas the northern summit is connected with the underlying block.

Towards Forlandsundet and Kvadehuken the position seems to be undulating. In this covered lowland it is, however, difficult to trace the tectonical lines.

After this short review of some of the sections we shall try to separate the different tectonical disturbances. It is evident that the layers have been folded for some reason, but the tectonical breaks observed at a great many points within the peninsula make the question of tectonics a very difficult one. We shall therefore endeavour to separate the different thrusts and faults, and finally try to draw up the order of tectonical development.

Thrusts.

We are able to follow two distinct tectonical lines in the peninsula, which are indisputedly due to thrusting. The one mostly follows the boundary between the Hecla Hoek massif and the younger rocks, and the other is situated within the younger rocks in Brøggerfjellet and Kiærfjellet. As I have just described the sections in this mountains, I shall deal with the latter thrust first. As mentioned above, the cyathophyllum limestone in Kiærfjellet is partly repeated and partly overlain by tilted older rocks in a way making it doubtless that the conditions here are due to thrusting.

Holtedahl (1913) gave his attention to the outliers of Hecla Hoek lying on younger rocks both here and in Brøggerfjellet. He may not have had an opportunity to trace the tilted rocks in the crests and ridges eastward, and therefore he arrived at the conclusion that the thrusting had taken place only from the south. This, however, cannot be the case, because, as I have already pointed out, the whole sequence is found in the normal order tilted up eastward from the small Hecla Hoek cap in Kiærfjellet, and these rocks are eastward connected with the mountain block of Scheteligfjellet. On both sides of Traugdalen and Kiærdalen[1] the thrust plane is seen dipping to the northeast. In the northern part of Brøggerfjellet this plane can only be observed between the Hecla Hoek mica schist and the cyathophyllum limestone, but south of Traugvatnet, as well as in the ice-covered crest north of summit 609 in Brøggerfjellet, the Devonian can be observed with a steep dip. The outcrop of the thrust plane can be followed almost continuously from Kiærfjellet to this summit, and its existence cannot therefore be doubted. It has, however, not been observed on Kvadehuksletta, but it is most likely that the continuation northwards is to be found somewhere near Kvadehukelva.

Eastward, the outcrop of the thrust plane is mostly covered by ice, but it can hardly be questioned that it is the same thrust plane which

[1] The valley south of peak 602 in Kiærfjellet.

is seen to crop out in the cleft between summits 714 and 630 in Brøggerfjellet, but here with a considerably steeper inclination.

The continuation from here eastward must be found somewhere under Brøggerbreane, but on the eastern side of these glaciers I have not observed it at all.

I shall now proceed with the description of the other thrust and begin with its western part, where it forms the boundary between the Hecla Hoek and the younger formations.

On the coastal plain and in the beach at Forlandsundet the outcrop of the thrust plane is covered, but in the southwestern slope of Brøggerfjellet the Hecla Hoek rocks are seen to rest upon the cyathophyllum limestone with steep southwesterly dip. In the valley south of the mountain the limestone has been cut away and the Hecla Hoek rests here on Devonian. The boundary line is however covered in this valley, but in the crest at the head of this valley the Hecla Hoek is distinctly resting on the younger rocks along the thrust plane here dipping locally in a southeasterly direction. The limestone in the small peak 551 has been bent up, evidently a result of the thrusting towards the north of the overlying mica schist.

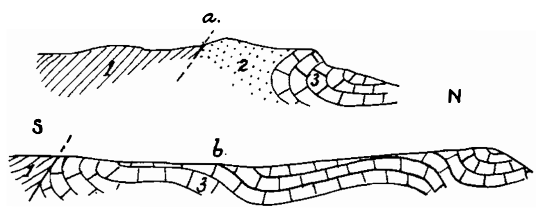

Fig. 14. Sections from the overthrust northwest of Steenfjellet.
1. Hecla Hoek mica schists and quartzite. 2. Middle Carboniferous, perhaps Devonian in lower part. 3. Cyathophyllum Limestone.

As Holtedahl (1913) points out, the thrust on this stretch has undoubtedly taken place from a southerly direction. Also in two counterforts towards the north from the easternmost part of Brøggerfjellet the boundary line is exposed (fig. 14).

Farther east in the crest south of the summit of Zeppelinfjellet the junction between the inverted strata of Devonian and Hecla Hoek does not represent any tectonical break, but the ordinary angular unconformity between the two series (fig. 15).

At the inner edge of the Tertiary field, however, we have already heard that there is a structural disturbance, which in reality is the continuation of the southern thrust plane towards the east. As the thrust here is of the most vital importance to the appraisement of the coal field, I shall try to give a close description of its connection with the coal field and its influence on the coal seams.

From the section I—J, pl. V and pl. VI it will be seen that the Tertiary field, broadly speaking, is lying in an assymetric syncline, formed during overfolding towards the northwest. As a matter of fact, one would have expected to find also the Tertiary with inverted position in the southern part of the field. This, however, is only the case in Østfeltet. Along the whole northern slope of Zeppelinfjellet the conditions are quite different. As already pointed out, there are found younger and younger Tertiary beds until the Carboniferous rocks are again struck at the southern boundary line.

During my first visit to Kings Bay it was still uncertain whether the coal field was limited against faults or if it was lying in a syncline. On close examination of the northern boundary line I came to the certain result that the Tertiary layers here rested directly on Permo-Carboniferous chert and sandstone, and that only the Bottom Shale increased from west to east. As this statement has now been confirmed

Fig. 15. Zeppelinfjellet seen from the west.
PC Permo-Carboniferous. UC Upper Carboniferous. D Devonian. HH Hecla Hoek.
A. K. Orvin phot. 28/7 1922.

by subsequent deep-drilling and sinking of test-pits, I shall not repeat my observations here.

The southern boundary line, on the other hand, proved to be rather complicated.

The easternmost point of the field where Tertiary layers and coal seams have been observed is in the brook at Anneksjonshytta (section A—B pl. VI). As will be seen from the section, the lowermost layers of the Tertiary here form an assymetric syncline. In the southern part of the section the Bottom Shale is seen with a thickness of about 65 metres, and farther to the north the Ester Seam and the overlying sandstones were observed in 1922 with vertical dip. The northern part of this section between the coal seam and Anneksjonshytta has always been covered during my visits, but it cannot be doubted that the coal seam and the Bottom Shale reappear here below the gravel cover. It was certainly here that Blomstrand years ago observed the other seam, which he has drawn into his section. The bottom of the Tertiary syncline is here close to the surface and is uninfluenced by the younger hrust and faults.

In the southern bend of the syncline, part of the underlying chert crops out, and farther south follows cyathophyllum limestone in a smaller part of the mountain slope and then Hecla Hoek rocks. None of the boundary lines is exposed, but the thickness of the two Upper Carboniferous series here is very small, and can only be explained by tectonical breaks both between the chert and the limestone and between the latter and the Hecla Hoek. This must be explained by the thrust plane here being cut by a younger fault which I shall deal with below.

From Anneksjonshytta the southern boundary line runs westward under the front of Lovénbre No. 1, and as the folding-axis dips in this direction, younger and younger beds will appear in the middle of the syncline westward.

A section similar to the one described is also seen at the western side of the glacier (sect. C—D pl. VI). Also here the Permo-Carboniferous chert reappears in the southern part of the section, but the thickness of the outcropping chert is only a few metres, and on the south side of it we again find cyathophyllum limestone. The thrust plane also in this instance passes between the chert and the cyathophyllum limestone. On Østfeltet the erosion has at present exposed the lowermost part of the Tertiary syncline, which is now lying below the thrust plane in this area.

On the western side of Nannestadelva the conditions are quite different. This brook follows a fault, the East Fault, with north-southerly trend. Here the beds of the Agnes-Otelie horizon have a slanting trend towards the cyathophyllum limestone, and the lowermost beds of the Tertiary do not reappear here.

From this point the boundary line is covered westward to KB. Following this line it can be observed from the surface forms that younger and younger beds are continually cut against the boundary line, and at KB we find the uppermost beds of the Tertiary sequence at Kings Bay. At KB it could with certainty be confirmed that the Tertiary beds were dipping in under the Carboniferous rocks at an angle of 40—45° SW. The thrust plane, which on Østfeltet was situated entirely within the Carboniferous rocks, here forms the boundary between this formation and the Tertiary, and all the Tertiary beds have been cut against this plane. At KB a cutting has been made, the section of which is seen in fig. 44.

From KB to KB2 the boundary line follows nearly the same horizon of the Tertiary. Also at KB2 the chert is found close above the coal seam (fig. 41).

The westernmost point where the outcrop of the thrust plane can be observed is at the head of the narrow ravine of Brøggerdalen. The dip is here about 50° SW. Against the thrust plane the 2—10 centimetres thick remains of a coal seam are seen, and on the junction between the coal and chert there is a white, pasty clay, resembling putty. Below the coal seam we find a shale horizon, about 2 metres thick and with plant fossils (fig. 16).

From this point westward the outcrop of the thrust plane is covered by the glaciers.

Having made these observations I felt as early as in 1922 certain that the Tertiary field to the south was limited by a thrust plane, along which the Carboniferous rocks of Zeppelinfjellet had been pushed towards the northeast upon the Tertiary beds. From the observations made on the surface I wrote that year in my report that Josefine Mine would probably reach the thrust plane after an indrift of 125—150 metres along the dip from the vertical below the outcrop of the plane. In fact this distance proved later to be 135 metres when further downdrift had to be suspended owing to the great tectonic disturbances rendering coal mining operations quite impossible. There certainly then remained only a few metres to the Carboniferous rock.

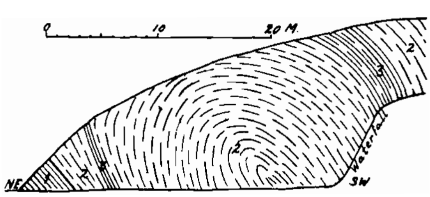

Fig. 16. Section from the east side of the ravine in Brøggerdalen.

1. Grey Tertiary shale with plant fossils.
2. Green and yellow chert, Permo-Carboniferous.
3. Shale and cherty shale.

At some points on the surface, where the outcrop of the thrust plane has been observed, the disturbances are astonishingly small, as is the case at KB and KB2. This seems especially to be the case where the movement has taken place along shale and coal horizons, which have evidently acted as a sort of grease. In these places the beds have evidently also had a tendency to arrange themselves parallel to the thrust plane.

In other places, however, the thrusting has caused great disarrangements of the beds. In the area between the Agnes and the Josefine mines there is outcropping rock belonging to the lower part of the Tertiary sequence. This fact can only be explained by the thrusting having taken place stepwise along two parallel planes. The isolated part between the two planes has been carried along only a short distance. This partly overthrust Tertiary block has also to a great extent been crushed, and small blocks of the light sandstone have been scoured and polished to a very high degree, and bear a close resemblance to a two-edged wedge. A large number of these wedge-shaped blocks with slickensides and scratchings are now found on the surface in this area. It is very likely due to this double break that the working of Josefine Mine had to be abandoned in a southeasterly direction earlier than expected, because the coal seam has been thinned out, certainly by the movement of the hanging wall against the foot wall. That such disturbances really have taken place within the Tertiary beds has been noticed at several points during mining work, to which these disturbances have been a great impediment.

In the lower part of Josefine Mine the coal seam had been so strongly folded and crushed that the timbering of the mine was very difficult. In the southwestern part of the mine the coal seam and its hanging wall had been folded together on the foot wall and formed coal-pockets of a thickness up to seven metres. This folding I have outlined in fig. 17. Below this coal-pocket the coal seam and in part also the shale had been scoured away.

Farther up in this mine I observed another result of the thrusting. Here the sandstone in the hanging wall had been pushed northwards

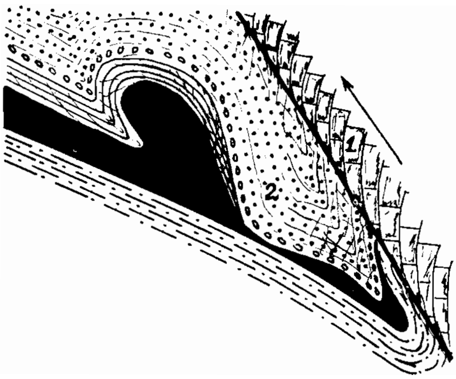

Fig. 17. Schematic section of the folded coal seam in the Josefine Mine.
1. Carboniferous. 2. Tertiary.

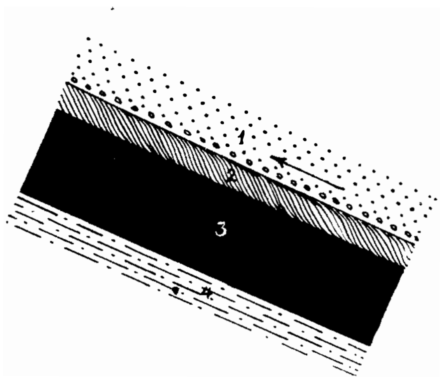

Fig. 18. Schematic section of false current bedding in the Josefine Mine, formed by slipping of the layers.
1. Sandstone with conglomerate. 2. Shale with false current bedding. 3. Coal. 4. Shaly sandstone.

on the coal seam, and the soft shale above the seam had acted as a grease. The shale had thereby got what may be called a *false current bedding* (fig. 18). Owing to the movement and pressure the shale has been crushed and transported in the direction of movement, and the different shale flakes have been stowed upon each other in a way giving the least resistance to the movement.

In the Ester and Sofie mines it was also apparent that shearing had taken place to a great extent in the lower coal and shale series, whereas the sandstones series had offered greater resistance to the pressure.

Mining work has shown that such shearing has taken place over distances of up to 300 metres and more along breaks partly following the coal seams and partly the shale. The result is that the coal seams have partly been cut away and partly folded or crushed so as to be quite unworkable. The Ester Seam thus proved to be cut away over

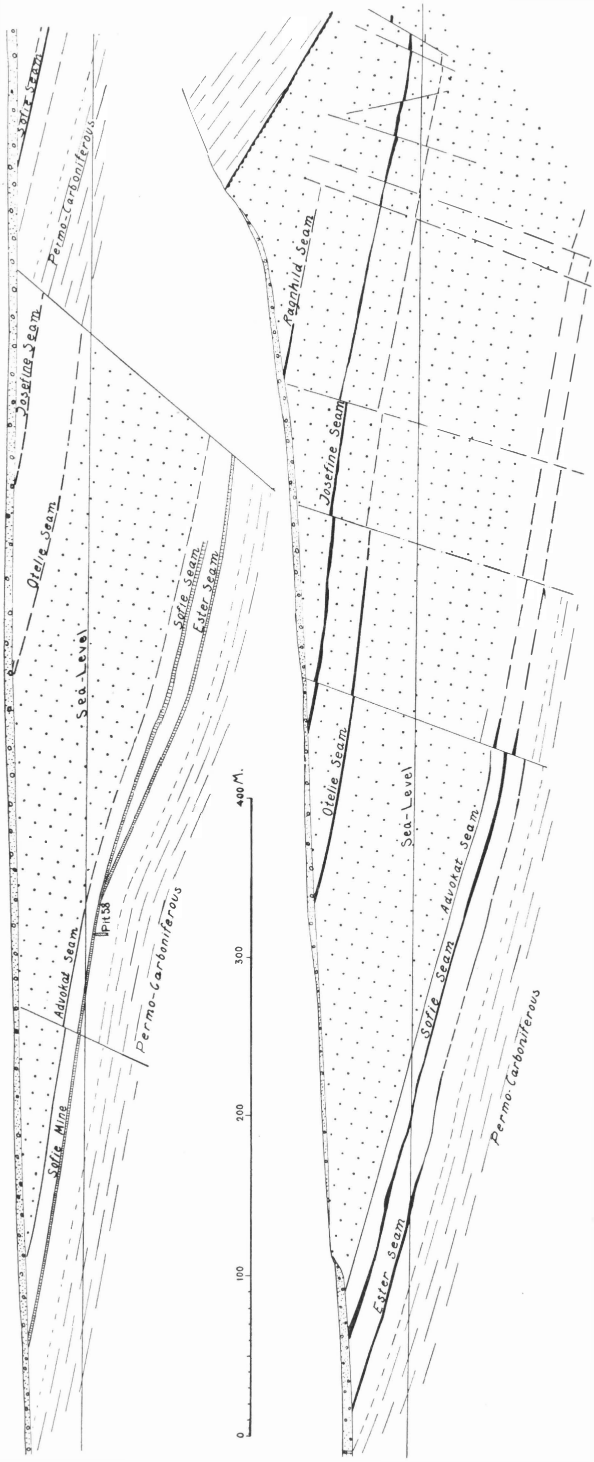

Fig. 19. Sections through the mines.

The upper section is along the eastern main slope in Sofie Mine, the lower section along the main slope in the Josefine Mine. See map pl. III.

a distance of 300 metres along the trend of movement. This must therefore be the minimum length of the shearing. In one place within this area the Sofie Seam even rests on the Ester foot wall. The section fig. 19 has been drawn up from the plans of the mines and elevations which I have obtained from the Mining Office at Kings Bay.

Also the Sofie Seam indicates great irregularities and disturbances of the coal seam, so that great areas of the mine have had to be left as unworkable. In fig. 20 I have drawn up some detailed sections from Sofie Mine showing the influence of the shearing on this seam.

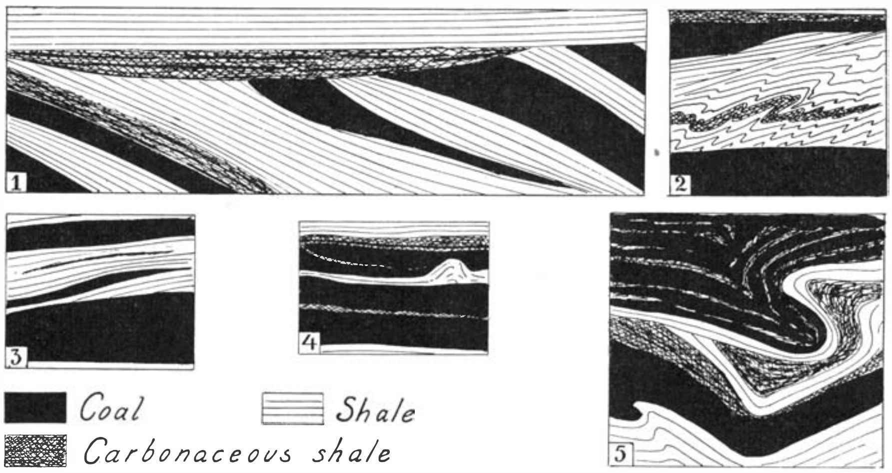

Fig. 20. Sections from the Sofie Seam in the Sofie Mine.
1. Section in the upper part of the western main slope. 2. From the crossing of adit 33 and the main slope. 3. Section at the winch in 10 S in Ester-Sofie Mine. 4. Section near the bottom of the main slope. 5. Adit 32.

From the experience gained during mining operations we have reason to believe that such disturbances also in future mines will impede mining; but it is impossible to say to what extent this will be. From the drill record I could observe that local disturbances had taken place also in other areas of the field. Borehole 5 pierced a gas vein at a depth of 57.95 metres. At that point the drill pierced an open space of about 10 centimetres lying far below the coal seams. The only satisfactory explanation of the gas remaining under pressure here must be that it has followed such a plane of shearing, which crosses the coal seams farther down along the dip. Thus tectonical disturbances will certainly be found in future mines on this area.

These shearing movements within the Tertiary layers must be due to a smaller resistance to movement in the thrust direction of the upper part than in the lower part of the sequence.

Contorted beds due to a similar shearing are also visible in the eastern slope of Scheteligfjellet, where the movement has acted along a special horizon of the cyathophyllum limestone.

A further result of the folding and thrusting is that the coal has been repeatedly traversed by a great number of tiny fissures, which are now filled with calcite. When exposed to weathering the frozen coal has a tendency to fall to pieces. This may partly also be due to the tectonical influence.

East of the coal field the outcrop of the thrust plane can be observed north of Haavimbfjellet but here with steeper dip (fig. 21).

A very fine thrust is seen east of Kings Bay in the Upper Carboniferous layers of Garwoodfjellet. It can hardly be doubted that it is the same thrust which reappears here.

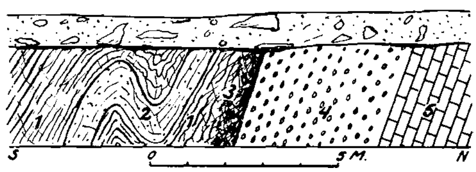

Fig. 21. The thrust on the border between Hecla Hoek and the cyathophyllum limestone north of Haavimbfjellet (detail from fig. 22).
1. Mica schists. 2. Quartzite. 3. Friction breccia. 4. Middle Carboniferous conglomerate. 5. Cyathophyllum limestone.

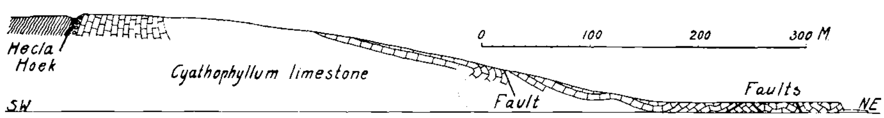

Fig. 22. Section of the fault zone north of Haavimbfjellet.

Faults.

Along the southern side of Kings Bay we find several faults, all of which must be younger than the thrusts. These faults can be divided into two distinct groups, namely main faults with trend NW—SE and smaller faults with strike N—S.

The *main faults* belong in reality to a single fault zone, but the two different main branches are partly divided so much that they must be treated separately.

Along the southern side of the inner part of Kings Bay the whole fault zone is rather contracted. Farthest east, north of Nielsenfjellet, the fault lines cannot be seen because they are covered by glaciers and talus from the mountain slope. A section of the fault zone is, however, exposed in the northern slope of Haavimbfjellet. The limit of the Carboniferous strata against the Hecla Hoek mica schist is formed by the thrust plane. The tectonic contact is represented by a breccia about one metre in thickness. The breccia contains rocks from both formations. The conglomerate consists of dark and light quartz pebbles imbedded in a light, spangled, sandy matrix, containing some lime. It is wholly unpressed and is unquestionably of Middle Carboniferous age.

The cyathophyllum limestone crops out close to the north of the conglomerate and has here a northerly dip and some local folding (fig. 22). At the shore the dip is more irregular and the limestone is traversed by a series of faults.

Westward from this section the two fault lines diverge.

The southern runs along the Hecla Hoek boundary line and through Zeppelinfjellet, and the northern westward along the shore. Between these two fault lines the Tertiary field is situated.

We shall first follow the westward run of the southern fault. Below the mountain between Lovénbre No. 2 and Lovénbre No. 3, which I have termed Slåttofjellet, the outcrop of the fault line is covered. The downthrow is not very great at Slåttofjellet, but it is increasing westward.

Farther to the west the fault line reappears in the lower part of the northern slope of Sherdahlfjellet. Thence it runs under Lovénbre No. 1 and is again visible in Zeppelinfjellet, here forming the so-called "Skorsten" (chimney).

The fault here is of the greatest interest, because it is seen to cut right through the great series of strata overfolded towards the north, and must thus be younger than the folding itself.

From fig. 15 the visible part of the folding and faulting in Zeppelinfjellet will be seen, and in section I—J pl. V, I have drawn up the tectonical conditions as I believe them to be from the observations made on the surface. The northern part has been lowered about 400 metres along the fault plane, having a dip of about 60° towards the north.

From Zeppelinfjellet the fault runs westward under the front of Brøggerbreane and reappears along the eastern side of Scheteligfjellet. The fault line is not uncovered at any point here, but from the rocks of both sides it can be determined fairly exactly. Along the mountain the fault zone is developed as a step-fault (sect. G—H, pl. V) with two branches, a main fault to the west and a minor fault to the east. The total downthrow of the northeastern side is here about 500 metres. The layers now capping Scheteligfjellet also form the base of the Tertiary below the mountain. The block between the two branches of the fault has not been lowered so much as the other part of the Tertiary beds. For this reason the lower part of the Tertiary series now reappears at the base of the mountain.

This fault zone runs across the shore somewhere in the little bay west of Brandalpynten, after having intersected the other main faults along the shore.

The fault zone along the coast is not to be seen anywhere westward from Haavimbfjellet before reaching the cliff on the south side of

Kolhamna. Here it is observed in the cyathophyllum limestone (fig. 23). It runs across the outlet of Bayelva and immediately north of the small lake of Trihyrningen.

As will be seen from the map, this fault only touches the coal field in the area west of Bayelva, here limiting Lagunefeltet towards the southwest. In the spit just east of the outlet of Bayelva the Permo-Carboniferous chert has a dip of 20° SW on the north side of the fault line, whereas cyathophyllum limestone is found on the southern side. West of the river the boundary line between the chert and the Tertiary basal conglomerate is exposed. Westward the thickness of the Tertiary

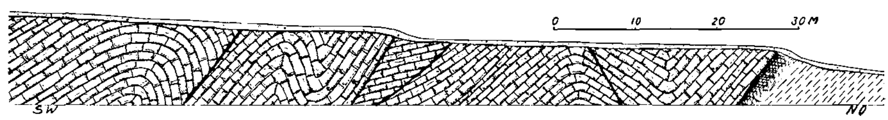

Fig. 23. Section of the fault in the cliff at Kolhamna.
To the left Cyathophyllum Limestone, to the right Permo-Carboniferous chert. To the right a thrustfault.

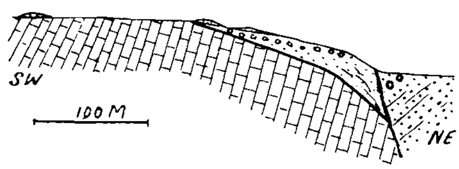

Fig. 24. Section through the fault northeast of Trihyrningen.
To the right Tertiary, to the left Cyathophyllum Limestone.

strata, which are cut against the fault plane, increases continually so that on the western part of Lagunefeltet the uppermost Green Sandstones are found against the fault plane and the cyathophyllum limestone. The existence of Lagunefeltet is thus due to this fault. By drawing up the strata on both sides of the fault one will find that the northern side has been lowered about 600 metres.

At Trihyrningen I observed a small area covered with Tertiary sandstones and conglomerates from the Agnes-Otelie horizon resting directly on cyathophyllum limestone. The only explanation I can find is that it must be remnants of the hanging wall of a branch fault, which has had a rather low dip towards the northeast (fig. 24).

The faults seen crossing Scheteligelva and the coast line in the eastern part of Kvadehuksletta also certainly belong to this fault zone (fig. 25 and 26).

The fault plane certainly has a northerly dip, and, as a matter of fact, the different coal areas of Lagunefeltet must be smaller than the surface areas between the fault line and the outcrops of the respective coal seams.

The other group of faults are local faults going north-south. Crossing the Tertiary field, at least four large and several smaller faults of this type have been observed. These faults divide the coal field into several separated areas, as far as coal mining is concerned. The majority of them were indicated during the mapping of the field in 1922. They all run into the sea towards the north, but I was not able to refind them in the crest of Zeppelinfjellet. They thus seem to die out in the limestone block towards the south.

With the exception of the fault in Brøggerdalen the eastern side has everywhere been lowered or pushed northwards in relation to the western side. Owing to the dip a horizontal faulting also will appear as a lowering. Broadly speaking, they together form a step-fault hading with the dip from Scheteligfjellet and eastwards.

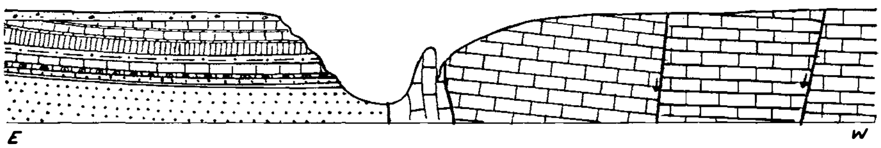

Fig. 25. Fault in the cliff east of Kvadehuken.
To the left Middle Carboniferous, to the right Cyathophyllum Limestone. The two faults to the right only one metre each.

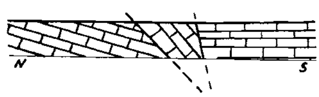

Fig. 26. Fault in the Cyathophyllum Limestone in the ravine of Scheteligelva.

I fig. 27 I have projected the sections on both sides of the respective faults into the fault planes. From these sections both the direction and displacement of the faulting can be derived.

Below I shall deal with the various faults, the position of which is seen from the geological maps.

The East Fault. I have used this name for the fault running from the western side of Lovénbre No. 1 to the western point of Prins Heinrichs Øy. This fault, which divides Østfeltet from Agnes-feltet, I observed in 1922. The fault line can be directly observed in the upper part of Nannestadelva. On the western side of this brook Tertiary sandstone is cropping out, whereas on the eastern side in the strike direction of the sandstone from south to north we find cyathophyllum limestone, Permo-Carboniferous chert and the shales below the Ester Seam. The Tertiary sandstone does not reappear until we get farther north.

Farther northwards the fault can be traced immediately west of test-pit 37, where the sandstone above the Advokat Seam is found in a projecting rock, whereas in its trend direction westward the chert crops out. From this point to the beach the fault can be traced on the surface forms, the extended chert ridge along the shore being displaced northwards on the east side of the fault line.

The fault runs into the sea across Strandvatnet, and its further trend is probably close to the western point of Prins Heinrichs Øy.

From section A, fig. 27 it will be seen that the faulting is really a horizontal one with a displacement of the eastern side about 300 metres towards the north. Owing to the dip the eastern side appears to have been lowered up to 100 metres.

As the depth of the syncline on both sides of the fault is still unknown, it is difficult to state whether any vertical or rotary faulting has taken place contemporaneously with the horizontal displacement. It appears as if the blocks during the faulting have got an oblique position to each other through the eastern part being lowered to the north and upthrown in the southern part. As mentioned above, the syncline on the east side of the fold is not now touched by the thrust plane, whereas the corresponding part on the west side is still situated far below it. This fact may also be due to a further folding together of the layers on the eastern side during the horizontal faulting. In this case the sections on both sides of the fault are no longer congruent.

The Agnes Fault divides Agnesfeltet from Østre Centerfelt. It was first met with during the working of the Agnes Mine, which is limited towards the west by the fault plane. The fault can be followed northwards along the small depression north of Agnes Mine. The displacement of the light sandstone and the Advokat Seam is here very distinct. This fault also forms the eastern limit of the working-places in Sofie and Ester mines. It runs into the sea a short distance east of Månevatnet.

The fault has been drawn up in section B fig. 27. As will be seen, it is a normal fault with a vertical downthrow of 50—60 metres of the eastern side.

The *Josefine Fault* is the next fault to the west, dividing Østre Centerfelt from Vestre Centerfelt. I first became aware of this fault in the vicinity of Thiisbukta, where the cyathophyllum limestone on the western side strikes against the chert on the eastern side. On examining the ground in a southerly direction I could trace the fault at several points. At the eastern edge of Kolhaugen chert crops out on the western side in strike direction of the sandstone above the Advokat Seam on the eastern side.

It stands out still more distinctly in the slope of Zeppelinfjellet. Whereas on the eastern side of the small brook at KB the Permo-Carboniferous chert is cropping out above 100 metres above sea-level, the Green sandstone can be traced up to 150 metres and more on the western side. In the mountain slope the fault consists of two branches.

During the working of the Josefine Mine the fault was met with in several places, and the mine is limited towards the west by this fault. Later the fault was struck also in Sofie Mine, where also a minor branch has been observed.

From section C, fig. 27, it will be seen that the faulting is a diagonal fault with an oblique downthrow of the eastern side towards the north.

The diagonal distance of movement is about 200 metres. The vertical component is about 160 metres and the horizontal one about

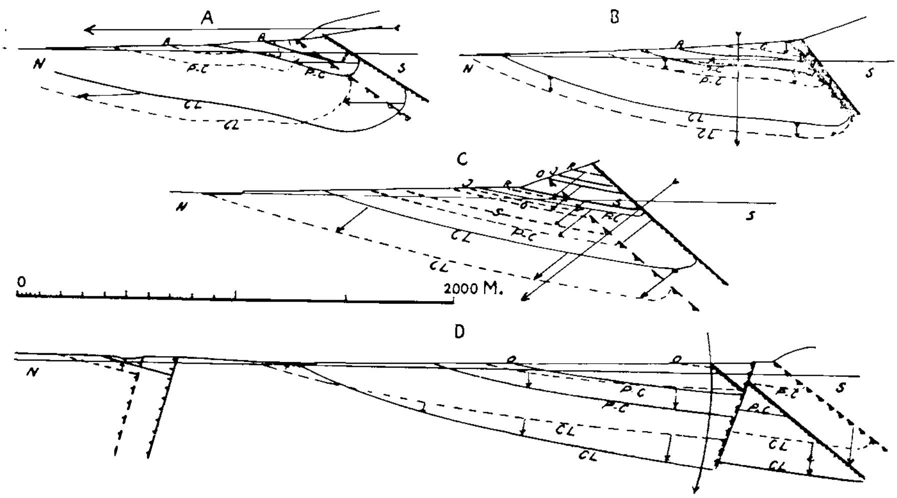

Fig. 27. Faults across the coal field seen in the fault planes.
The punctuated lines indicate the strata on the east side of the fault plane, the full lines on the west side. The large arrows show the fault direction, the small ones also the distance. A The East Fault. B The Agnes Fault. C The Josefine Fault. D The Brøggerdalen Fault. R The Ragnhild Seam. J The Josefine Seam. O The Otilie Seam. A The Advokat Seam. S The Sofie Seam. PC Upper limit of Permo-Carboniferous strata. CL Upper limit of Cyathophyllum Limestone.

120 metres. The dip of the fault plane is about 60° in an easterly direction.

From the maps it will be seen that the coal seams have been considerably displaced through this fault. On its western side the Sofie Seam is found in the Olsen Mine; and the Agnes-Otelie Seam, the Josefine Seam, and the Ragnhild Seam will have to be sought for far up in the mountain slope. The result is that all these coal seams on Vestre Centerfelt are only extended over small areas, and the extension along the dip is also very small on the higher coal seams.

The *Brøggerdalen Fault (Brøgger Valley Fault)*, which divides Vestre Centerfelt from Vestfeltet, I observed in 1922. It is distinctly seen on the surface from the ravine of Brøggerdalen to the brook flowing from Tvillingvatna. At the head of the ravine below the waterfall Tertiary beds with coal and shales are seen on the eastern side of the stream, whereas the western side about 200 metres northwards is made up of Permo-Carboniferous rocks, the latter being folded and showing a couple of east-west going faults (fig. 28). On the plain northwards from the outlet of the ravine the fault line is distinctly marked. On the eastern side the light sandstones below the Agnes-Otelie Seam crop out, and on the western side the green sandstones from near the Ragnhild Seam are seen. From Tvillingvassbekken further north the fault line is covered, but, owing to some observations of outcropping chert and surface marks, the trend of the fault line can be determined fairly exactly. Although no direct connection can be proved to exist, I should think it more than probable that it is the same fault line which reappears on the western side of Bayelva, at the outlet of which a north-southerly fault is seen to cross the main fault along the shore.

In the area south of Brøggerdalen the western side has been lowered, whereas at the mouth of Bayelva the eastern side has been thrown down, resulting in the repetition of the lowermost conglomerates. The fault thus seems to be a rotary fault with pivotal axis somewhere within the Carboniferous on the east side of Bayelva (section D, fig. 27). Southernmost the downthrow of the westside is up to 100 metres, and at the outlet of Bayelva the east side is lowered 30—40 metres. From the map it will be seen that the main fault along the coast has been displaced by this fault. This fact should point to the eastern part having been pushed northwards about 150 metres; it may, however, also be due to a simultaneous forming of the faults, so that the main fault along the coast had originally been formed with this displacement across the other fault line.

The *Skjerva Fault* must be regarded as a branch of the great main fault along Scheteligfjellet. I first became aware of it in 1923. On crossing from the green sandstone west of Skjerva towards the southwest I found Permo-Carboniferous chert cropping out in some small hillocks. Some distance farther south we pass in the same way from green sandstone to light sandstone from the lower series by walking in a southwesterly direction. This can only be explained by a fault-line with the downthrow on the eastern side. Immediately facing Brøggerbreen, where the eastern and western glacier branches join, a great disturbance can be observed. On the eastern side of a fault line the green sandstones are cropping out with 25—70° dip SE, whereas on the western side the layers of the Agnes-Otelie horizon are seen with a 45° dip SW. The fault line cannot be observed directly on the surface here, but as the distance between the two different points is small, such a fault must exist also here. It can hardly be doubted that this is the continuation of the Skjerva Fault. In this covered area other faults may also occur.

Other faults. Besides the faults already described we know several small ones, which have been observed during the working of the mines. All these faults have a north-southerly trend. The downthrow amounts only to a few metres. Small faults do certainly occur also in other parts of the field, but the displacements are too trifling to be noticed on the surface.

I really doubt that any further great faults will be found in the future, though there may be a possibility of such faults existing in the covered area in front of Brøggerbreen.

History of Structure.

Caledonian Mountain Folding Period.

In Spitsbergen no rocks younger than the Hecla Hoek have been metamorphosed. Between the Hecla Hoek and the younger systems

Fig. 28. Section showing faults in the Permo-Carboniferous layers in the Brøggerdalen brook.
1. Chert. 2. Hard, grey limestone. 3. Yellow-green chert. 4. Yellow layers of chert with silicious shales and shale. 5. Grey shale.

there is therefore a far more distinct dissimilarity than between any of the younger systems mutually.

As we know, the series of strata belonging to the Hecla Hoek at the end of the Silurian period were exposed to a very strong folding under which eruption of granites and gabbros took place. All the existing rocks within the mountain folding zone were during this time strongly metamorphosed. The general opinion is that this folding period in Spitsbergen is connected with the Caledonian mountain folding in Scotland and Norway, and that the old chain in Spitsbergen is a direct continuation of the Norwegian[1]. The pressure acted from the west, and for this reason the Hecla Hoek rocks have a north-southerly trend. Where no younger disturbances have acted the strike direction is unchanged, as is the case on the north side of Kings Bay. The irregular trend direction of the Hecla Hoek on Brøggerhalvøya is, as we have heard, due to younger folding.

It is most probable that the folding extended over a fairly long period, and that the mountain chain was gradually eroded down. The Hecla Hoek rocks now forming the base of the younger rocks on Brøggerhalvøya have during the time of metamorphosis been situated at a considerable depth. Thus garnets are found in the mica schists.

[1] The Downtonian in Spitsbergen has not taken part in this folding, and thus the folding in Spitsbergen must be older than the folding in Scotland.

Earth Movements in younger Paleozoic and Mesozoic Time.

The tectonical disturbances, chiefly giving Brøggerhalvøya and the whole western coast of Spitsbergen their present structural character, are of Tertiary age. Even if the Tertiary folding cannot, in extent, be compared to the Silurian, it has nevertheless within Brøggerhalvøya mixed up the rocks in a way which makes it difficult to point out earlier disturbances that may have taken place. Especially, it is very difficult to make out disturbances which may have occurred in Mesozoic time, because the series of strata belonging to that era are missing at Kings Bay.

Between the Silurian and Tertiary periods we can point out orogenic movements in different parts of Spitsbergen, but they are all due to vertical block movements. No folding from this long period has been observed.

Between the Hecla Hoek rocks and the overlying younger rocks there is a pronounced angular unconformity representing a long period of the younger Silurian. The oldest of the unmetamorphosed rocks is of Downtonian age.

As pointed out, the Hecla Hoek rock is everywhere overlain by Devonian strata, except at Forlandsundet, where it is overlain by Culm. The 300-metres-thick Devonian series thus disappear at a rather short distance, which fact can hardly be explained otherwise than by an old fault. At first I thought that a part of the sequence in Brøggerfjellet and Zeppelinfjellet might perhaps be of Culm age, and that the difference between the layers here and at Forlandsundet might be due to a period of erosion and a unconformable deposition of the Culm layers on the Devonian, wedging out towards the west. However, I searched in vain for Culm fossils in the upper part of the Devonian sections. It seems most probable that the Culm occurs only at Forlandssundet.

If these conditions were due to an unconformity, one might expect to find a visible angular discordance somewhere in the upper part of the Devonian strata. Such an unconformity cannot even be seen at the base of the Middle Carboniferous, where there must be a great gap of sedimentation. In fact, not the slightest divergation can be observed.

As we know, the Devonian is also missing along the southern part of the west coast of Spitsbergen, a fact which is explained by a pre-Culm fault, along which the eastern Devonian area has sunk. Before the deposition of the Culm, the Devonian has been eroded away on the west side of this fault. This explanation is considered the most reasonable one also concerning Brøggerhalvøya. This fault must have traversed the western part of Brøggerhalvøya, and is probably directly connected with the southern fault. The fault line must run somewhere below the Carboniferous series east of Safe Harbour and east of the Culm at St. Johns Bay. The further run northward cannot be fixed at present. It is likely that its trace is somewhere along Comfortlessbreen.

The Culm now forms a small area along Forlandsundet, and is limited towards the south by the overthrust, but originally it has certainly been connected with the southern Culm areas.

As the old fault line seems to run into the sea north of Kings Bay, it is most likely that the whole northern part of Spitsbergen was also covered by Devonian layers when the Culm was deposited, and that the Hecla Hoek rocks were then only exposed along the west coast south of Kings Bay.

When the Culm had been deposited on Devonian to the east and on Hecla Hoek to the west, the fault was once more torn open, but this time the western side was lowered. During the following erosion the greater part of the Devonian was once more laid bare to the east. When the great submersion in Middle Carboniferous time took place the limy strata of this period was deposited on Culm to the west and on Devonian to the east. The different stages of development will be seen from fig. 29. According to Stensiö and Tyrrell there is at Klaas Billen Bay a reflexion of the conditions just described. The area between these two fault lines has thus sunk in younger Devonian time and has been relatively raised in later Culm. For this reason the marine Carboniferous layers rest on Culm also east of Klaas Billen Bay and Wijde Bay.

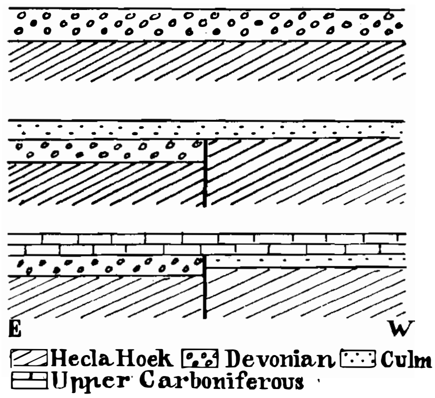

Fig. 29. Sections showing the deposition of Devonian, Culm, and upper Carboniferous strata at Kings Bay.

On Brøggerhalvøya Mesozoic rocks are entirely missing, but it can hardly be doubted that rocks belonging to this era have also been deposited here, but have been eroded away in Cretaceous time.

We know that the Tertiary at Calypso Bay and Forlandsundet rest directly on Hecla Hoek. This is explained by a pre-Tertiary upheaval of the coast along a fault line. The Kings Bay coal field, however, is situated on the eastern side of this old fault line. The absence of Mesozoicum here is therefore not due to this fault, but to a rise of the northwestern part of Spitsbergen, and a subsequent denudation in Cretaceous time, so that the Mesozoic series at the deposition of the Tertiary has gradually wedged out towards the north to disappear at Kings Bay. De Geer (1919) has pointed out a pre-Tertiary plane of denudation on the Hecla Hoek rocks in the northwestern part of the country. The gradually wedging out of the younger series towards the north confirms this.

Tertiary Folding and Faulting.

The development of the Tertiary tectonics is of particular interest to coal mining at Kings Bay, and also gives the key to the understanding of the structural form of the whole of the west coast of Spitsbergen.

Personally, I have had the opportunity to map the folded zone between Ice Fjord and Bell Sound, and have also during casual visits seen the folds in Midterhuken in Bell Sound, the section on the south side of Van Keulen Bay and the one at Safe Harbour. When the structural observations from these points are compared with the structure of Brøggerhalvøya, it will be seen that they are fairly easy of explanation on the same fundamentals. Tectonical conditions which have seemed inexplicable are in reality quite simple.

Nathorst, as well as several later authors, has explained the Tertiary folding as a secondary result of a great fault along the west coast, and the presumed fault line has been drawn along the present boundary line between the Hecla Hoek and the Culm. The faulting was taken to have been formed by a block-formed upheaval of the west coast. De Geer has suggested that the folding may be due to an ordinary mountain folding, but has later abandoned this point of view and pointed out that, along the boundary of the younger series of strata, horsts have been pressed up, resulting in the horizontal pressure and folding of the strata. Holtedahl ((1913) p. 80) is of opinion that the folding is due to a fault during horizontal pressure from the west.

During my work in the field I have come to the result that the folding is not a result of faulting, *but is an ordinary mountain folding due to pressure from the west. The faults are younger than the folding.*

I dealt with this question during a lecture in *Geologisk Forening* on May 6, 1926. As this was not printed I shall also touch upon the conditions south of Kings Bay here.

I shall first try to draw my conclusions from the tectonical observations made on Brøggerhalvøya. In the maps and sections I have drawn in all certain observations with unbroken lines, whereas uncertain lines are broken.

As we have seen from the description, there are on Brøggerhalvøya an overfolding towards the northeast and two overthrusts, one from the southwest and the other from the opposite direction, and many faults, of which some can be seen to penetrate the folds, and must therefore be younger.

The folding on Brøggerhalvøya has a somewhat irregular trend, about northwest-southeast, whereas the fold along the western coast of

Spitsbergen has, broadly speaking, a more north-southerly direction, and must be due to horizontal pressure from west-southwest. The divergence on Brøggerhalvøya is probably due to the thrusting, which is seen to have caused irregularities in the trend of folding.

The pressure at Kings Bay must, however, have been considerably stronger than farther south, because it has not only caused the over-folding but also the great thrusts. During the thrusting the layers have certainly been more extremely folded, but not more than the original fold can be pointed out on both sides of the thrusts. There can thus be no doubt about the *thrusting being formed as the last feature of the folding.* The thrusts are thus preponderantly shear thrusts and not break thrusts of which the folding is the secondary result. If the thrusting was not the latter, there would not be formed sections of the appearance as now seen in Zeppelinfjellet, Brøggerfjellet and Kiærfjellet. It is here clearly seen that the thrust planes have intersected already folded strata.

The really astonishing result is the forming of the thrust from the northeast.

Along the southern thrust we find only in Zeppelinfjellet younger rocks in the overthrust part. This fact is of course due to the erosion, as the overthrust part originally contained younger rocks along the whole boundary.

As can be seen from the sections, the southern thrust plane has not everywhere the same position in relation to the fold. Only along the coal field is it a clean shear thrust according to the common definition. Westward towards Forlandsundet the greater part of the fold is lying below the thrust plane. The southern thrust plane has thus cut through the fold obliquely to the folding axis. The reason may be, as we shall see below, that the lower part of the fold towards Forlandsundet has encountered a very strong back-pressure, so that the break has, for this reason, been formed farther to the south in the upper bend of the fold.

Whereas the distance of overthrusting along the southern thrust at Forlandsundet must be at least about 1000 metres, it is under Zeppelinfjellet perhaps not more than 500 metres. Here the pressure has, however, also effected the great shearing along the bedding planes of the Tertiary strata. At Slåttofjellet and Sherdalfjellet it is again at least 1000 metres. In Garwoodfjellet the dip of the thrust plane is less steep, and here the visible part of the overthrust part is made up of Upper Carboniferous rocks.

How far and in what direction this thrust can be traced to the southeast I cannot say. It is not found along the coast south of Ice Fjord.

De Geer (1919) has in the section along the north side of the Ice Fjord drawn up thrusts in Lapplandsryggen and Jemtlandsryggen. The continuation of the southern thrust at Kings Bay may perhaps be refound here. If this is the case it is situated far under the western main fold, which in this section is situated at Safe Harbour. It may also be a parallel thrusting. Future investigation of the district north of the Ice Fjord will certainly clear up the structural conditions here.

The thrusting from the northeast is rather difficult to explain. As already pointed out, the overthrust younger rocks in Kiærfjellet and Brøggerfjellet are directly connected with the mountain block of Scheteligfjellet, and consequently it is quite impossible that it has anything to do with the thrusting from the southwest. There remains no other explanation than that the overthrusting has taken place directly against the direction of pressure. From the sections pl. V it will be seen how this thrust plane has cut the original fold. It is evident that this plane has a far steeper dip in the eastern part of Brøggerfjellet than in the western part.

The question is now how this thrust has been formed. That it is due to a horizontal pressure from the northeast must be deemed impossible, as such a pressure would certainly have left traces also in other places. It might also be believed to be a secondary result of the great faults north of Scheteligfjellet, but this is quite unthinkable, because the distance of overthrusting is greater than the downthrows. In this case there would have been far greater disturbances along the fault lines.

The most acceptable explanation is that the thrust is formed contemperaneously with the southern thrust during strong pressure from the southwest, and is due to the following circumstances: As already mentioned, Brøggerhalvøya is traversed by an old fault zone, which has been broken up at different periods. When the great series of strata during the Tertiary folding period were folded together upon this line of weakness, the overweight has at last been so great that the underlying ground has sunk in, and the different sheets from the northeast and southwest have both been pushed upon the middle block under the strong pressure. The great resistance from northeast, not allowing of any further overthrusting in that direction, must be due to the old and compact northern mountain mass, partly made up of eruptives.

As both the northern and the southern overthrust are greatest near Forlandsundet, the pressing down of the central part must have been greatest here. The northern overthrust seems to decrease rapidly towards the east, and it really appears as if it would fade away somewhere under Brøggerbreane. This thrust must thus have been formed by a rotary movement of the upper limb against the lower limb about a pivotal axis somewhere in the central part of the peninsula. The rotary movement is in turn due to an oblique downthrow of the central part towards Forlandsundet during strong horizontal pressure, which may also have induced a considerable upheaval of the upper limbs. The length of the northern overthrusting is about three kilometres or perhaps somewhat more.

Through the pressing down of the central block we also get a satisfactory explanation of the peculiar conic position of the strata in the southwestern part of Brøggerfjellet. The dip towards the west is due to the oblique sinking towards Forlandsundet, whereas the dip towards the north, south, and southeast is due to the folding and pressing down during the thrusting. The greatest compression of the originally horizontal layers has taken place near Forlandsundet and amounts to about five kilometres in all.

The faults are probably all of about the same age and all of them younger than the folding and thrusting. They are all connected with a great downthrow along Kings Bay, and this must have taken place in a period when the horizontal pressure had ceased to act and had been replaced by a tensional stress, a mere reaction after the folding period. This fault system is certainly of the same age as the great faults along the west coast of Spitsbergen.

Also on the northern side of Bell Sound I have been able to establish that the great faults along the coast are younger than the folding. The faults at Forlandsundet, between which also Tertiary beds are found, are most probably the same fault lines as are seen farther south. These faults along the coast have been formed by the western anticlinal of the Tertiary folding breaking down, and at Kings Bay also the eastern pressed up layers have broken down. The greatest faults are found in the anticlinal of the west coast, where the layers were most elevated after the folding, but are now eroded away.

The fault zone of Kings Bay thus belongs to an easterly fault zone, which can be traced from Kings Bay along the border of the Hecla Hoek to Grensefjellet (Holtedahl (1913)). Farther southward the fault zone probably forms the boundary line to the interior of St. Johns Bay. It may possibly be the last traces of this fault zone which are seen in the cliff from Advent Bay to Coles Bay.

Holtedahl has pointed out a fault in Pretender in the inner part of Kings Bay. This fault, which can be observed from a great distance, has a displacement of about 600 metres. Here, however, it is the southwestern part which is lowered. This fault probably runs out to sea down Kings Bay, the depression of which is then a graven. The known fault on the south side of the fjord in connection with the southerly dip would otherwise be enough to explain the outcropping of the Hecla Hoek on the north side of the fjord.

I shall briefly describe below some sections at Ice Fjord and Bell Sound, and try to show that the structural conditions here, broadly speaking, are very similar to those at Kings Bay, only far more simple.

Along the Hecla Hoek boundary line between Ice Fjord and Bell Sound there is no fault line as drawn up by former authors. I have traced this boundary line the whole distance from Bell Sound to Ice Fjord, and everywhere the basal conglomerate is resting with

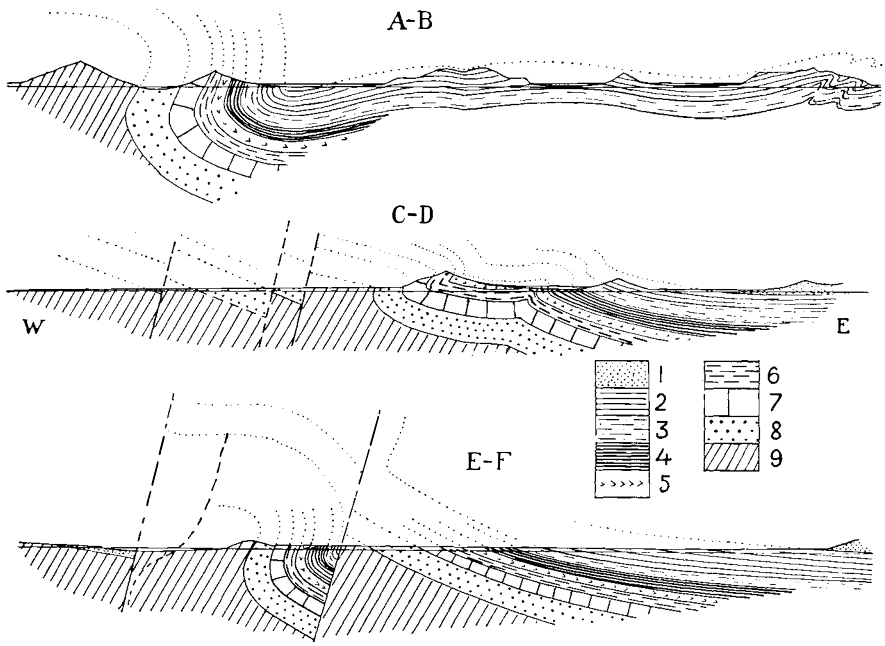

Fig. 30. Tertiary folding and faulting along the western coast of Spitsbergen.
A—B North of Ice Fjord. C—D North of Bell Sound. E—F South of Bell Sound.
1. Tertiary. 2. Cretaceous. 3. Jurassic. 4. Triassic. 5. Permian. 6. Permo-Carboniferous. 7. Upper Carboniferous. 8. Culm. 9. Hecla Hoek.

angular unconformity on the Hecla Hoek rocks, and there is no trace of a younger break.

Section C—D fig. 30 from the north side of Bell Sound shows that the sequence here has been overfolded towards the east. Close to the now existing folding of the younger series I have not observed any fault, but in 1925 I found two faults on the coastal plane. They are seen to the left in the section. On the western side of both these fault lines the lowermost Culm beds crop out with an easterly dip, as the layers must have had in the western anticline before the faulting took place. The downthrow of the western side amounts to about 1300 metres on the eastern fault and a little less on the western. The downthrow along the coast is thus considerable.

On the southern side of Van Keulen Bay between Reinsdyrpynten and Kap Ahlstrand the younger series are seen with inverted position farthest to the west. Eastward from this point one finds at first Hecla Hoek rock and then once more the younger layers, but here with a normal position. Nathorst says that the inverted layers were a mystery to him. With the old theory it was quite inexplicable, but through a folding cut by a younger fault the conditions are easily explained (section E—F fig. 30).

In the same way, the conditions in Midterhuken in Bell Sound can certainly be explained.

Finally I shall briefly mention the section at Safe Harbour on the north side of Ice Fjord. Nathorst mentions that there is a big fault here forming the boundary line between the Culm and the Hecla Hoek. He states that the Culm layers are dipping about 50° under the Hecla Hoek rocks. Holtedahl (1913) shows that the lowermost layer of the Culm is a conglomerate with a dip parallel to the unconformity. This I should think is most probably the basal conglomerate of the Culm, which is here seen resting unconformably on the Hecla Hoek in inverted order.

In the mountain on the east side of the fjord the Upper Carboniferous strata are seen with inverted position and steep dip towards the west. If the known thickness of the Culm is put into the section across the fjord it will exactly fill out the open space. All observations here thus point to an overfolding towards the east without any faulting.

De Geer (1919) has described a sort of folding here, but on the map he has drawn in the supposed fault line, and it is therefore difficult to understand what his real opinion is.

East of St. Johns Bay Holtedahl ((1913) p. 29) has stated that a fault occurs at the boundary between the Hecla Hoek and the younger rocks. It is therefore not unlikely that the fault zone from Kings Bay runs along the boundary south to this point.

As this paper deals with the Kings Bay tract I shall not deal in detail with the structural conditions farther south. What has been said should be sufficient to affirm that there has been a *Tertiary folding period followed by a faulting period.*

The influence of the structure on the Kings Bay coal field is obvious enough. Originally the coal field probably belonged to the same extensive Tertiary area as the southern Tertiary syncline, and has not been deposited in an isolated basin. Its present existence is only due to Tertiary folding, thrusting, and faulting.

The Kings Bay coal field is the northernmost known Tertiary field in Spitsbergen. We therefore lack the necessary field evidence to form an opinion about possible Tertiary disturbances farther north. It is, however, likely that the Tertiary folding and faulting zone north of Kings Bay lies in the sea west of Spitsbergen.

Before the folding took place the Tertiary land surface was most probably situated near the sea-level. The first upheaval must be due to the folding, during which the western coast has been elevated. The folding process has certainly been very slow, and the erosion, which at the beginning of the rise has got hold of the land, has later acted hand in hand with the folding, until the land some time in later Tertiary period was lying about 500 metres higher than now. The younger changes in level until the land got its present position belong to the Quaternary history.

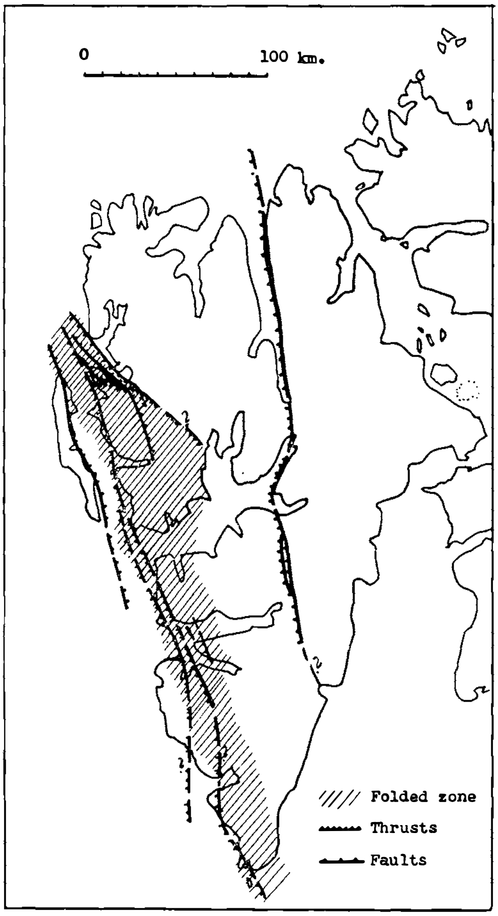

Fig. 31. Sketch-map showing the Tertiary main structure lines of Spitsbergen.

Concerning the age of the Tertiary folding we only know that it is of post-Eocene age. It is highly probable that this folding is contemporaneous with the great Miocene mountain folding running from Spain to Australia and along the entire west coast of America, but the folding in Spitsbergen is obviously of a far smaller magnitude. As mountain folding it is quite inconsiderable. There has been no metamorphosis at all. All changes are only of a mechanical nature.

No continuation southwards from Spitsbergen of this folding zone has been ascertained. It is possible that the folding ebbs out before reaching the European continent, but if it has acted also in northern Norway, it will be very difficult to trace, because the younger formations do not occur here.

Holtedahl (1925) points out that the Tertiary disturbances in Spitsbergen might be of post-Miocene age and formed simultaneously with American earth-movements.

In the sketch map fig. 31 I have drawn up the tectonical main lines of the Tertiary folding and faulting. As will be seen, the folding zone running along the west coast narrows and runs out to sea north of Kings Bay. Also the faults on both sides of Brøggerhalvøya run together here. The further trend of the thrusts into the sea will never be ascertained.

It may be that this zone of Tertiary disturbances continues across the Arctic Sea and is thus connected with the American contemporaneous disturbances, but as the distance is great such a hypothesis can hardly be confirmed.

The geological development of the Kings Bay tract can briefly be summarized as follows:

1. Deposition of rocks belonging to the Hecla Hoek formation of partly marine origin. Possible structural disturbances from this period are now difficult to point out.

2. The Silurian folding period with eruptions of igneous rocks. The Hecla Hoek rocks have been strongly folded and metamorphosed.

3. Denudation of the Hecla Hoek rocks until Downtonian time.

4. Possible deposition of Downtonian and following erosion, deposition of the Devonian, partly littoral, and partly continental.

5. Lowering of the central part along fault lines in the western part of the present Brøggerhalvøya and along Wijde Bay. Erosion of the Devonian on both sides of the sunken area.

6. Deposition of the continental Culm on Devonian in the central area and on Hecla Hoek at Forlandsundet.

7. The old fault line has been broken up and the central area relatively raised. The Culm eroded away in this area.

8. Submersion of the whole land and deposition of the Middle and Upper Carboniferous littoral and marine facies.

9. A long interval between the Permian and Cretaceous periods from which nothing can be seen at Kings Bay. It is possible that in this great interval a thick sequence has been deposited, which has been denuded away in younger Cretaceous time, during the rise of the northern part of Spitsbergen. If the lowermost shale horizon on the Kings Bay coal field is of Cretaceous age, these layers must have been deposited after the older series have been eroded away, and a new shorter period of erosion must have taken place before the Tertiary was deposited.

10. Deposition of the Tertiary partly on the shale and partly on Permo-Carboniferous chert and sandstone. Perhaps also series of the younger Tertiary have been deposited.

11. The Tertiary folding and thrusting with subsequent faulting took place in younger Tertiary time with the result that the land was raised and the present erosion commenced.

Quaternary.

I have not made any special examination of the Quaternary within the property area, and shall only make brief reference to this period. Hoel (1914) has carried out a series of measurements of terraces and elevated shorelines.

We know that Spitsbergen, too, has been covered with ice, and almost everywhere one can see erratic blocks on the mountains. At Kings Bay Hoel has seen such blocks on Blomstrandhalvøya 374 metres above sea-level, and in 1928 I observed several such erratics of Hecla Hoek rocks on the eastern crest of Zeppelinfjellet 280 metres above sea-level. This fact shows us that the present elevation of these crests must be about the same as when the last ice cover existed.

Whereas Blomstrandhalvøya and Ossian Sarsfjellet distinctly show us by their forms that they must have been scoured by the ice to the very summits, the other mountains form sharp ridges and crests between the glaciers. This is due to the work of the now existing glaciers. Where the mountains still have rounded forms such glacier erosion has not taken place in later time.

The observations which can now be made about the raised beaches and from the loose material nearly all refer to the younger part of the Quaternary period.

Hoel estimates the last ice cover to have been about 700—800 metres. Owing to the weight of the ice the land has been submerged, and we do now find terraces and shorelines indicating the old positions of the sea.

According to measurements made by Hoel, the elevations of the terraces at Kings Bay above sea-level are 14, 28, 36 and 55 metres. To the north and south there are also raised beaches of 105, 120 and 130 metres. The lowermost terraces contain shells of marine mussels. The most prominent amongst these steps are found on the coastal plain running along the coast and rising from sea-level up to abt. 55 metres. This coastal plain is a part of the great strandflat formed before the last glacial period.

In the northwestern part of Scheteligfjellet there is a fairly extensive plateau 200—250 metres above sea-level. It is bounded towards the coastal plain by a steep and high cliff. This plain is most probably due to an elevated position of the sea.

At South Cape Hoel and Werenskiold have observed still higher shorelines with boulders. These high elevated shorelines are very old.

The coastal plain around Brøggerhalvøya is fairly smooth and widest where it lies in easily soluble rock, as at Kvadehuken, where it attains a width of five kilometres.

During the latest great advance of the glaciers the coastal plain has been partly covered by ice. This can be seen on the coal field, where Brøggerbreen at that time has carved out the depression of Tvillingvatna and in front of the glacier down to the low ridge along the shore. Brøggerbreen has at that time been advanced about 1500 metres compared with the present front line. Moraine remnants are still found along the old front line. This progression must have taken place earlier than the last submersion of the land, during which the youngest terraces have been deposited, as these would otherwise have been removed.

The old moraine has certainly been almost continous around the old front, but during the last submersion it has been washed out and scattered broadcast and partly deposited as terraces. Accordingly it is now difficult to determine what is moraine and what is terrace. Only at the higher points which the sea has not reached, are the moraines still recognisable.

Vogt (1927) has pointed to a present sinking of the land and, amongst other proofs, he mentions that the beach is not laid bare at low water. As I have already mentioned under the description of the coast, this fact is due to the easy solubility of the limestone. Almost everywhere at projecting points of the cliff, where transported material is not deposited, we find these conditions along the limestone cliff. A cliff of soluble rock will thus not give reliable data as to level changes of the land. It is possible that the land has sunk in the last few centuries, but, if so, it is only inconsiderable.

Coal Seams.

Several years elapsed before all the seams on the Kings Bay coal field were known. During drilling work in 1928, however, we gained such detailed knowledge of the sequence that we may now say with a fair degree of certainty that no further seam of any importance will ever be found. Small seams without any economic value and only extending over limited areas may be found in the westernmost part of the field and in the upper part of the sequence.

The examination of the coal field has confirmed the supposition that the seams vary widely in thickness and appearance, even over short distances.

As already pointed out under the treatment of the Tertiary, the seams are concentrated in the lower and upper parts of the sequence, whereas the Light Sandstone does not contain any seam.

In the Lower Coal horizon, which is 20—40 metres thick, the most important seams are from below: the Ester, Sofie and Advokat seams, but also some small seams occur. The Agnes-Otelie, Josefine, and Ragnhild seams are in the upper part. These six seams have either been worked or are workable, at all events in some areas in the field. All the other known seams are too trifling to be of any commercial importance. Yet a seam lying between the Sofia and Advokat seams may perhaps be workable in a smaller area on Agnesfeltet.

Because both the series of strata as well as the thrust plane dip in a southerly direction, the lowermost seams have far more extensive areas than the uppermost. These seams therefore play the most prominent rôle in the appraisement of the field.

On Agnesfeltet, Østre Centerfelt, and Vestre Centerfelt the seams have been exposed at enough points to give us the necessary facts for the valuation of these parts of the field; on Vestfeltet we have only partly detailed knowledge of the seams, and on Lagunefeltet no uncovering work has been undertaken, so that we know nothing about the details of the seams here.

The position of the different seams within the sequence will be apparent from the following description of the drill records and the columnar sections on pl. VII. Their outcrop is seen on the geological maps of the coal field.

Sections of Boreholes.

The following boreholes have all been drilled by *Norges Svalbard- og Ishavs-undersøkelser* with outfit from *Norsk Diamantborings A/S*, Oslo, in the summer of 1928. Only chilled-shot drilling was done, and the holes are all drilled in a vertical direction. As the strata are not horizontal, but have a south-westerly dip from a few up to 30 degrees, the following depths in metres do not represent the thickness, but the depths in which the boreholes have pierced the different layers. To get the real thickness the drilled lengths must be reduced in accordance with the dip. Reduction of thickness: Dip 5° 0.4 per cent., 10° 1.5 per cent., 15° 3.5 per cent., 20° 6 per cent., 25° 9.5 per cent., 30° 13.5 per cent.

All the geological sections have been measured by the writer.

The figures indicate the lower limit of the various beds. The distance pierced will thus be found for the respective beds as the difference between the figure at the head of the description of the bed in question and the foregoing figure.

Borehole No. 1.

Co-ordinates: y = + 9146.93, x = + 8011.94. Elevation of top of 6″ casing 44.27 metres. Drilled, July 16 to Aug. 15. Depth of hole from top of 6″ casing 106.65 metres. Cores 76 per cent. of the drilled length. The hole was drilled from about 15 metres under the Agnes-

Otelie Seam to the Carboniferous layers. Cores: From 0.75 metres to 2.25 metres 4″, from 2.25 metres to the bottom 3″. Casing: From 0 to 0.75 metres 6″, to 2.25 metres 5″.

Geological Section:

Depths in metres	
2.75	Sandstone, greyish-white with dark spots of coal substance. Some mica and pyrites. Yellowish-grey weathering.
2.85	Conglomerate with black pebbles of chert from the Permo-Carboniferous strata in sandy matrix.
8.85	Sandstone, same kind as above. Partly fine-grained.
10.75	Sandstone, dark grey, heavy, with some pebbles of dark chert, some mica and coaly substance.
10.95	Conglomerate with sandy matrix and pebbles of light quartz and dark chert.
15.25	Sandstone, light grey, partly fine-grained, partly coarse, with irregular dark spots, stripes and thin layers of coaly substance and some pebbles of chert.
26.05	Sandstone, same kind as above, but darker and heavier. Some mica.
28.45	Sandstone, same kind as above, but coarse and with more pebbles of chert.
29.05	Conglomerate, light brown, sandy matrix with pebbles of white quartz and dark grey and black chert of hazel-nut size.
34.45	Sandstone, grey and white spotted, coarse, with small 2—4 mm pieces of black chert. At 32 metres the dip was measured to be 20°. This must be local, as it is less higher up and farther down.
34.60	Conglomerate, fine-grained with white quartz and dark chert in sandy greyish-white matrix.
35.55	Sandstone, the same kind as above.
54.65	Sandstone of the same kind as above with small conglomerate layers in the upper part.
55.05	Sandstone and conglomerate alternating.
61.45	Sandstone, same kind as above.
62.95	Shale, dark brown with small mica flakes, slickensides and plant remains.
63.15	Coal and perhaps carbonaceous shale. No core.
63.27	Shale, soft, brownish-black.
64.78	Sandstone, fine-grained, grey, with mica and dark streaks.
66.75	Shales, dark greyish-brown, sandy, with mica alternating with laminated sandstone.
69.65	Sandstone, laminated with alternating grey layers and black bituminous layers with mica. Dip 10° SW.
69.75	Coal.
70.25	Shale, dark brown, sandy, with slickensides and plant remains.
70.35	Sandstone, grey, laminated.
70.75	Shale, dark brown, soft, with plant remains. Dip 10° SW.
71.08	Sandstone, grey, fine-grained and partly laminated.
73.75	Shale, dark greyish-brown and soft.
76.60	Sandstone, grey, a little slaty sandstone with thin layers with mica and coaly substance.
76.65	Coal. Dip 20° SW.
77.10	Sandstone of same kind as above.
78.03	Coal. 40 cm core. The upper 12 cm of the core was coal and carbonaceous shale, the lower 28 cm pure coal. (Sample 4, 1928).
78.38	Shale, blackish-brown, a little sandy, with black, irregular slickensides.

Depths in metres	
79.09	Coal. 30 cm core. Upper 11 cm of the core was coal, middle 8 cm bony coal with black shale and streaks of coal, and lower 11 cm coal, (Sample 3, 1928).
81.38	Shale. greyish-brown, a little sandy, with slickensides, plant remains and some pyrites. Dip 17° SW.
81.42	? Coal.
83.85	Shale, same kind as above.
83.58	? Coal.
83 75	Shale, same kind as above.
84.85	Sandstone, brown, very fine-grained, with small traces of coal and pyrites.
85.25	Coal and brownish-black, soft shale with shiny, black slickensides.
86.82	Sandstone, grey, laminated with mica, partly argillaceous. Dip 17° SW.
89.00	Sandstone, grey, laminated, partly argillaceous with thin slip-planes.
91.85	Shale, black, with shiny slip-planes. Dip 17° SW.
92.20	Coal. 20 cm core. Ester Seam. (Sample 6, 1928).
92.45	Shale, black.
93.35	Sandstone, laminated with alternating grey and black thin layers with mica and black, shiny slip-planes. Dip 20° SW.
93.50	Shale, black, with slickensides.
95.08	Shale, dark grey alternating with very thin black layers with plant remains.
95.75	Shale, greyish-black. Dip 13° SW.
100.40	Claystone, partly shaly, greyish-brown, partly conglomeratic with pebbles and angular bits of green clay stone in greyish-brown matrix of clay stone. Soft. Also some pebbles of Permo-Carboniferous chert.
105.65	Claystone, grey, laminated, soft. Dip 15° SW.
	Here upper border of Permo-Carboniferous strata.
106.65	Glauconitic sandstone and chert. Permo-Carboniferous.

Borehole No. 2.

Co-ordinates: y = + 8772.30, x = + 8307.42. Elevation of the top of 6″ casing 29.89 metres. Drilled, July 19 to Aug. 16. Depth of hole from top of 6″ casing 59.36 m. Cores 60 per cent. of the drilled length. The drilling site selected was a place about 30 metres above the Advokat Seam, and the drilling was finished in the shale about 2 metres below the Ester Seam. Cores: From 1.45 to 3.83 metres 4″, from 3.83 to 28.36 metres 3″ and from 28.36 to the bottom 2¼″. From 0 to 1.45 metres we dug a pit and placed 6″ casing. To 3.83 metres 5″ casing was used, and down to 28.36 metres 4″ casing.

Geological Section:

Depths in metres	
1.45	Gravel.
6.45	Sandstone, light-grey, with a thin layer of conglomerate at five metres depth.
6.75	Conglomerate, fine grained, with sandy matrix and 3—5 mm large, light and dark pebbles of chert, partly angular.
12.45	Sandstone, light grey.
25.30	Sandstone, grey with brown weathering, partly coarse.
25.50	Conglomerate, sandy matrix with pebbles of chert of up to walnut size.
29.75	Sandstone, grey.
29.95	Chert conglomerate (the Advokat conglomerate) with pebbles of chert in green grey and black colours, of up to walnut size. Sandy matrix.

Depths in metres	
30.71	Sandstone, grey, compact with 5 cm conglomerate lowermost.
30.75	Coal.
32.10	Shale, grey, partly sandy with small pieces of coal. Dip 15° SW.
32.20	Sandstones, dark grey with pyrites.
34.50	Shale, grey, sandy with plant remains and a thin layer of coal.
36.15	Sandstone, grey, laminated with mica flakes.
36.71	Shale, brownish-black, sandy, with a thin layer of coal at 36.30 metres depth, and probably a small coal seam of about 10 cm from 36.35 to 36.45 metres. Dip 15° SW.
40.00	Sandstone, grey, highly argillaceous, and with small pieces and streaks of coal.
40.05	Coal streak.
40.73	Sandstone, grey.
41.15	Coal seam. Upper 8–10 cm with shale. Core 15 cm. Dip 13° SW.
43.20	Shale, dark greyish-brown and sandy, with plant fossils on the bedding planes.
44.25	Sandstone, dark brown, slaty, with mica and plant remains.
44.32	Coal.
44.90	Shale, greyish-brown, sandy.
44.93	Coal streak.
45.85	Sandstone, greyish-brown, argillaceous and with mica. Fine-grained.
46.52	Coal. Core 25 cm. Uppermost carbonaceous shale. (Sample 9, 1928).
47.67	Shale, grey, highly sandy with mica. In the upper part also blackish-brown, soft shale.
48.00	Shale, blackish-brown with partings of coal. A streak of coal lowermost.
48.48	Shale, greyish-black, sandy and hard.
48.63	Coal or carbonaceous shale. No core.
49.48	Sandstone, grey, slaty.
49.55	Carbonaceous shale.
49.77	Sandstone, grey slaty.
50.06	Shale, blackish-brown, soft, with carbonaceous shale lowermost.
50.15	Coal. Dip 14° SW.
50.75	Sandstone, slaty, grey, with mica and plant remains on the bedding planes.
50.88	Coal and carbonaceous shale.
52.85	Sandstone, grey.
55.72	Sandstone, laminated, brown, with mica, plant remains and partings of sandy shale. Dip 10° SW.
56.75	Coal. Ester Seam. Core 25 cm. (Sample 8, 1928).
57.24	Shale, very soft, grey with small plant remains.
59.36	Conglomerate, greenish-grey, with matrix of greyish-brown claystone with pebbles and angular bits of green shale. Dip 3—5° SW in the lower part.

Borehole No. 3.

Co-ordinates: y = + 9149.14, x = +8404.73. Elevation of top of 6″ casing 29.65 metres. Drilled, Aug. 8 to Aug. 30. Depth of hole from top of 6″ casing 46.90 metres. Cores 40 per cent. of the drilled length. Drilling was commenced about 15 metres above the Advokat level, and the hole was drilled down to the Permo-Carboniferous strata. Cores: From 2.16 to 8.72 metres 4″, from 8.72 to 21.34 metres 3″, and from 21.34 metres to the bottom 2¼″. From 0 to 2.16 metres a pit was dug and 6″ casing used. Down to 8.72 metres 5″ casing was used and to 21.34 metres 4″ casing.

Depths in metres

Geological Section:

Depths in metres	
2.16	Gravel.
12.08	Sandstone, light grey and coarse with streaks of conglomerate.
13.60	Shale, grey.
14.00	Clay.
18.16	Water spring with brown sand from iron oxside.
21.55	Sandstone, grey, laminated, argillaceous, with 10 cm core of coal uppermost.
22.67	Coal seam Sofie. Core: 35 cm. (Sample 5, 1928).
28.19	Sandstone, laminated, highly argillaceous, fine-grained and with mica on the bedding places.
28.70	Shale, greyish-brown.
29.10	Sandstone, grey, very fine-grained, argillaceous.
29.20	Carbonaceous shale.
30.30	Sandstone, grey, fine-grained and argillaceous. Partly laminated and with coal from plant remains on the bedding planes.
30.40	Shale, dark brown and soft.
30.90	Sandstone, grey, fine-grained, partly laminated.
31.01	Shale, brownish-black and carbonaceous shale.
31.60	Coal. Core 7 cm.
31.80?	Sandstone, grey, hard, with mica.
32.09	Shale, dark brown.
33.09	Coal seam. Ester Seam. Core only 6 cm. The drilling mud contained much carbonaceous shale.
33.50	Shale, brown, soft.
35.55	Claystone conglomerate, grey matrix of claystone with green pebbles and angular bits of claystone and black pebbles of Permo-Carboniferous chert.
37.66	Claystone, grey, soft. At the bottom red from iron oxide.
38.30	Claystone, red, a little shaly, with flakes of mica. Material from Devonian strata.
38.70	Claystone conglomerate, same kind as above.
40.30	Shale red, containing plant remains.
42.00	Claystone conglomerate, partly grey, partly reddish with pebbles and pieces of green claystone and chert in claystone matrix.
44.00	Shale, red.
46.70	Claystone conglomerate with some red layers. Same as above, but also some pebbles of chert and some small irregular layers of limestone. Here upper border of Permo-Carboniferous strata.
46.90	Conglomerate of green, glauconitic sandstone and chert belonging to the Permo-Carboniferous.

Borehole No. 4.

Co-ordinates: y = + 8236.07, x = + 8293.41. Elevation of top of 6″ casing 18.52 metres. Drilled, Aug. 20 to Oct. 3. Depth of hole from top of 6″ casing 149.09 metres. Core: 40 per cent. of drilled length. Drilling site on Leirhaugen about 45 metres above the Agnes-Otelie Seam. Drilled down to the Permo-Carboniferous strata. Cores: From 2.40 to 7.62 metres 4″, from 7.62 metres to the bottom 3″. From 0 to 2.40 metres 6″ casing in dug pit, down to 12.50 metres 5″ casing.

Geological Section:

Depths in metres	
2.40	Gravel, clay and stones.
7.62	Drilled in a mixture of frozen earth, clay and loose stones, containing streaks and small pieces of coal.

Depths in metres

9.00? Sandstone, grey, argillaceous and very sandy shale alternating.
11.00? Sandstone, grey, highly argillaceous with bits of coal from plant remains.
11.95 Shale, grey, sandy.
15.50? Sandstone, grey, fine-grained and argillaceous, partly laminated with coal on the bedding planes. Also layers of sandy shale.
16.50 Shale, dark grey with masses of plant fossils on the bedding planes.
16.82 Sandstone, fine-grained and highly argillaceous.
16.97 Coal with black streak and resin in small pieces.
17.80 Shale, black, with streaks of coal and plant fossils. Traces of resin.
18.70 Sandstone, grey, argillaceous, fine-grained.
18.78 Sandstone, greyish-green, laminated, with pyrites.
21.40 Sandstone of the same variety with coal (vitrite) on the bedding planes. Contains pyrites. Dip 15° SW.
25.50 Sandstone, coarser and with pieces of coal.
26.35 Conglomerate, greyish-green with sandy matrix and grey and black chert pebbles of hazel-nut size. Contains also small pieces of coal and is stained by pyrites.
26.55 Sandstone, greyish green and fine-grained.
26.92 Shale, blackish-brown.
27.09 Coal, carbonaceous shale and dark shale containing coal substance.
27.25 Shale, grey and sandy.
27.60 Sandstone, greyish-green.
27.99 Conglomerate, greyish-green, with sandy matrix and pebbles of chert. Some small pieces of coal.
28.40 Sandstone, green, coarse.
33.40 Conglomerate, sandy matrix and masses of chert pebbles of white and greyish-black colour of up to walnut size and partly angular.
36.00 Sandstone, grey, fine-grained and highly argillaceous with plant remains.
36.30 Sandstone, light grey and hard.
37.20 Conglomerate with light grey, sandy matrix and pebbles of chert and quartz of up to walnut size in white and dark grey colours.
37.55 Sandstone, greyish-white.
38.80 Conglomerate with sandy matrix and pebbles of white quartz and dark chert. Only partly over hazel-nut size.
39.40 Sandstone, light grey and coarse with some large pebbles. Dip 20° SW.
44.50 Conglomerate with light grey, partly greyish-green matrix and pebbles of quartz and black chert of up to walnut and potato size.
44.75 Shale, dark grey.
45.50 Coal seam. Agnes-Otelie Seam. Only 7 cm core. From the drilling mud it is seen that the coal seam contains a high degree of carbonaceous shale and shale.
45.75 Shale, black with coal substance.
50.50 Sandstone, grey and coarse.
52.20 Sandstone, grey with mica flakes, a little slaty. Partly current bedding. Dip 20° SW.
52.80 Sandstone of the same kind as above, but with some conglomerate streaks in which black angular bits of chert of pea size.
57.20 Sandstone, grey and coarse.
59.20 Sandstone, grey, laminated, partly argillaceous and with mica.
61.50 Sandstone, grey and coarse.
62.20 Sandstone, laminated with coal on the bedding planes.
64.50 Sandstone, grey. Dip 20° SW.
65.35 Sandstone, grey with darker irregular figures.

Depths in metres	
65.50	Chert conglomerate, black spotted.
71.80	Sandstone, grey with some lamination. Dip 20° SW.
82.00	Sandstone, grey compact.
82.25	Conglomerate with beautiful green-mottled, sandy matrix and white and black pebbles of quartz and chert, and partly also glauconitic sandstone from the Permo-Carboniferous layers. Contains also pyrites.
86.50	Sandstone, grey with pyrites and a few pebbles of chert.
86.85	Conglomerate with sandy matrix and pebbles of light and dark quartz and chert from pea to hazel-nut size.
91.90	Sandstone, grey with mica, lower part coarse.
92.15	Conglomerate with greenish, sandy matrix and pebbles of chert.
93.00	Shale.
108.70	Sandstone, grey.
109 00	Conglomerate with about 10 cm sandstone in the middle.
110.00	Sandstone, grey, partly coarse.
110.20	Chert conglomerate.
114.00	Sandstone, grey, partly coarse.
114.20	Conglomerate, sandy matrix and chert pebbles.
116.00	Sandstone, grey. Dip 17° SW.
118.20	Shale, highly sandy with mica and stems of plants. Partings of sandstone in the lower part.
118.40	Sandstone, grey, laminated.
121.25	Shale, grey, sandy with mica and masses of plant remains.
121.30	Coal. Durite with streaks of shale.
122.55	Sandstone, grey, laminated, highly argillaceous with mica. Coal and plant fossils on the bedding planes. Contains also layers of brown shale.
123.15	Shale, dark brown, soft, with plant remains.
124.20	Shale, grey, sandy, with mica and plant stems on the bedding planes. In the bottom traces of coal.
126.10	Shale, highly sandy, with coal and plant remains on the bedding planes. Traces of coal on 126.10 m.
126.77	Shale, dark greyish-brown, in the upper part very sandy, in the lower part less sandy and with black, shiny slip planes. Contains plant remains.
127.15	Shale with a little coal and carbonaceous shale. No core.
127.57	Coal and shale.
129.40	Shale, grey, sandy with mica and small pieces of plant stems. Brown shale with bits of coal in lower part.
129.55	Coal (Durite) and carbonaceous shale.
129.75	Shale, brown, sandy, with mica and plant remains.
129.94	Coal. Core 12 cm.
130.22	Sandstone, dark brown, very fine-grained, argillaceous with plant remains.
130.32	Coal (Durite) with streaks of shale. Core 5 cm.
130.53	Carbonaceous shale, coal and brown shale.
130.95	Sandstone, brown, fine-grained with plant remains.
131.05	Coal. Dip 16° SW.
131.40	Sandstone, brown, fine-grained with plant remains.
131.80	Coal and carbonaceous shale. Core 23 cm.
134.29	Shale, brown, highly sandy with mica and plant remains on the bedding planes.
134.90	Shale, grey, sandy with a coal streak at the bottom.
136.28	Shale, grey, partly very sandy with coal on the bedding planes.

Depths n metres		
137.38	Coal. Core 20 cm. On 137.38 probably a thin layer of shale.	Ester seam. (Samples 10 and 11, 1928).
138.25	Coal. Core 80 cm. The lowermost 30 cm of the core was bony coal.	
138.40	Shale, brown, with plant remains.	
138.70	Claystone, greyish-green, with some pebbles and angular bits of green claystone.	
147.40	Claystone conglomerate with greyish-brown matrix of claystone and pebbles and angular bits of green claystone and more rarely chert.	
148.80	Shale, brown and green alternating. Dip 16° SW. Upper border of Permo-Carboniferous strata.	
149.09	Glauconitic sandstone, green and with pyrites. Permo-Carboniferous.	

Borehole No. 5.

Co-ordinates: y = + 11019, x = + 8912. Elevation of top of 6″ casing 50.04 metres. Drilled, Sept. 3 to Sept. 15. Depth of hole from top of 6″ casing 68.74 metres. Core: 42 per cent. of drilled length. Drilling site just above the Advokat Seam. Drilled down to the Permo-Carboniferous strata. Cores: From 1.45 to 7.11 metres 4″, from 7.11 metres to the bottom 3″. From 0 to 1.45 metres a pit was dug, in which was placed a 6″ casing, to 7.11 metres the hole was lined with 5″ casing.

Geological Section:

Depths in metres	
1.45	Sandstone, loose blocks.
2.17	Conglomerate, fine-grained with grey, sandy matrix and black chert pebbles of up to pea size. Much pyrites (the Advokat conglomerate).
3.97	Sandstone, grey, possibly also shale.
4.47	Coal. No core.
6.00	Shale.
7.11	Coal. No core.
7.65	Shale.
8.35	Coal. No core.
9.48	Shale, brown.
10.00	Coal. Core 35 cm. (Sample 2, 1928).
10.46	Shale, grey, with carbonaceous shale.
11.14	Coal seam. Core 55 cm. Upper 13 cm of the core was carbonaceous shale, the middle 34 cm coal and the lower 8 cm carbonaceous shale. (Sample 1, 1928).
12.20?	Shale, brown, soft and carbonaceous shale.
13.00?	Sandstone, dark brown, argillaceous, heavy, with small grains of pyrites.
13.60?	Shale, dark brown and soft.
14.00	Sandstone, fine-grained, grey and argillaceous.
14.40	Shale, brown and soft.
14.72	Sandstone, argillaceous, laminated and sandy shale with mica alternating.
15.24	Coal seam. No core.
15.35	Shale, brown and soft.
19.38	Shale, brown, sandy with mica and partly with plant remains. The upper part highly sandy and may be termed argillaceous, laminated sandstone.
20.23	Coal seam. No core. Dip between 7 and 19 metres depth 30° on the average.

Depths in metres	
20.33	Shale, brown, highly sandy.
20.43	Coal. No core.
21.00?	Shale, highly sandy, brown and containing mica. Dip locally up to 45°, which shows us that disturbances must have taken place.
23.33	Sandstone, grey with coal from plant remains on the bedding planes. Dip also here locally up to 45°.
23.63	Coal. Core 7 cm.
24.00	Sandstone, grey.
24 60	Shale, brown, sandy, with mica.
26.29	Shale, greyish-black, in the upper part very sandy.
26.49	Coal. Core 10 cm.
27.10	Cabonaceous shale with coal. The core indicates that disturbances have taken place.
27.30	Shale, brown and with traces of coal.
29.72	Sandstone, light grey, argillaceous and with mica. A little shale in the middle.
30.75?	Shale, greyish-brown, sandy.
31.42	Sandstone, grey, argillaceous with shiny slip planes. Dip up to 35°.
32.74	Coal. Core 65 cm. (Sample 7, 1928). Dip 25° SW.
33.00?	Shale, black and argillaceous.
33.70	Sandstone, greyish-green, laminated, containing mica.
34.68	Shale, greyish-black, sandy, with mica.
35.82	Coal. No core. Also shale in the drilling mud. Thus the seam does not contain only coal.
36.35	Sandstone, very fine-grained, grey and highly argillaceous. Contains pyrites.
37.40	Coal. Core 7 cm. The drilling mud contained practically nothing but coal. Dip 25° SW.
40.40	Shale, grey, highly sandy. May partly be termed argillaceous, laminated sandstone. Dip 17° SW.
41.35	Shale, greyish-black, upwards gradually turning to grey, sandy shale.
43.72	Coal. Ester Seam. Core 1.80 metres. (Sample 13, 1928).
45.50?	Claystone, brown, soft with some bits of green claystone interbedded in the lower part.
48.20	Claystone, light brown with some pebbles and angular bits of green claystone.
50.25	Claystone conglomerate, greyish-brown matrix of claystone with pebbles and angular bits of green claystone.
53.75	Claystone, green, soft.
68.00	Shale, greyish-brown, soft, wits some green layers uppermost. At 57.95 metres depth the drill pierced a gas spring with methan. Dip at 52 metres 20°, at 54 metres irregular on behalf of disturbances, between 54 and 58 metres 5°, at 61 metres 8°, and lowermost 10° SW.
	At 68.00 metres upper limit of Permo-Carboniferous strata.
68.74	Glauconitic sandstone with chert. Permo-Carboniferous.

Ester Seam.

The Ester Seam is the lowermost seam and the most important in the whole coal field. It has not only a good average thickness, but also, owing to the low stratigraphical position, the largest coal area. Excepting some areas, where the seam has been exposed to extensive tectonical disturbances, it has, from the majority of the pits and boreholes, been localised with workable thickness.

The Ester Seam was not proved to be a self-existent seam until the autumn of 1923, when Sherdahl, through test-pit workings, examined the sequence below the Advokat Seam. The reason why the test-pits were driven down at that time was that the seam in the Olsen Mine had been found through the geological mapping to be situated in about the same stratigraphical horizon as the Advokat Seam, but did not seem to be identical with this seam. Sherdahl then undertook an examination of the sequence below the Advokat Seam in Østre and Vestre Centerfelt and found both the Ester and the Sofie seams. The Ester Seam had certainly been observed earlier on Kolhaugen and at Anneksjonshytta, but the sequence upwards in both these spots was so covered with loose material that it was impossible to state with certainty that the seam did not belong to the Advokat horizon.

The Ester Seam rests everywhere on the Bottom Shale, which is very easily recognised, and is a certain indication of the presence of this coal seam.

Under the microscope the rock forming the foot wall of the seam in Pit 45 is seen to be a shale containing much calcite and some grains of quartz in a dark, partly organic, matrix.

In the foot wall in Pit 34 is a dark brown fine-grained rock, which should rather be termed a shale rich in coaly substance. About one-half of the rock is made up of angular quartz grains with diameter of 0.02—0.03 millimetres and small flakes of mica. The rock contains calcite.

The hanging wall, which is usually good and strong, consists in Agnesfeltet and on the eastern part of Østre Centerfelt of shale, farther to the west also of very sandy shale and sandstone.

The microscopical examination of the sandstone from the hanging wall in Pit 34 on Kolhaugen shows that the quartz grains are of a diameter of 0.1—0.2 millimetres. The matrix is made up of silica with a great many silicified, tubular grains (Silicious algæ) with a circular transverse section of 0.03 millimetres diameter. The grains are partly rimmed by secondary iron oxide formed from pyrites. Chlorite is also seen.

Between the Ester Seam and the above-lying Sofie Seam there is a distance of 8—12 metres filled up with shales, sandy shales and sandstone.

The Ester Seam represents the lowermost growth period of the Tertiary. The coal seam is of autochthonous origin, made up of plant material growing into a great, swampy moor.

The thickness varies somewhat. It is greatest in Agnesfeltet and Østre Centerfelt, viz. up to 2—3 metres. In Vestre Centerfelt it is 1.0—1.5 metres, and in borehole 4 in Vestfeltet it is again greater, but the lowermost part is here very rich in ash, and must be termed bony coal.

The detailed sections of the seam from the different points will be seen from fig. 32. The sections are arranged from east to west. Sections measured in the mines or in the test-pits are all exact, whereas those from the drill records may contain partings of shale or other rock, which have not been noticed owing to missing cores. Commonly, partings of shale are interbedded in this seam. These partings have usually only a thickness of from a few millimetres to some centimetres, and are very difficult to separate from the coal by hand.

As the coal seam varies considerably in development, the sections will be more or less casual, and do not show any average of the seam in the different areas.

The *section at Anneksjonshytta*, co-ordinates: Abt. x + 8750, y + 12650, is the only one from Østfeltet. The total coal thickness is 1.20 metres with a parting of 0.2 metres shale. The section was measured in the brook cutting south of the hut in 1922. The spot has later been covered by gravel and boulders.

Thickness in metres	
	Sandstone with plant fossils and coal fragments.
2.00	Shale with coal substance.
0.30	Sandstone, light.
0.15	Shale, sandy.
0 25	Carbonaceous shale.
0.25	Shale, dark brown, with much coal substance.
0.35	Shale, grey.
0.60	Coal (Analysis 3).
0.20	Shale, brown.
0.70	Coal (Analysis 4).
6 00	Shale, green and easy weathered.

The next section westward is from borehole 5, Agnesfeltet. As the thickness here is 2.25 metres, there is every reason to believe that the thickness is workable throughout Østfeltet. The observations of Blomstrand also point in this direction. At his locality 3 in the brook on the eastern side of Lovénbre No. 1, he found the coal seam cropping out with a horizontal width of about 8 feet and a dip of 60°. This corresponds to a thickness of about 2.2 metres. Østfeltet is, however, very narrow, and the attitude of the layers is in some instances very steep. This area will thus be very difficult to work.

In Agnesfeltet the average thickness from borehole 5 and test-pit 51 is a little above 2 metres. In the autumn of 1929 Sherdahl worked down some test-pits along the outcrop here. Along a distance of about 200 metres he found a thickness of only 0.5 metres, and accordingly the coal seam must be irregular also in this area.

The section from borehole 5 is seen from the drill record.

Test-pit 62. Co-ordinates: x + 9100, y + 10900, worked $^{24}/_{8}$—$^{21}/_{9}$ 1927 by Smith Meyer, mining engineer. The depth of the pit was 10.2 metres, and from the bottom of the pit 2.5 metres was drilled by machine. Dip 45° SW.

The geological section was:

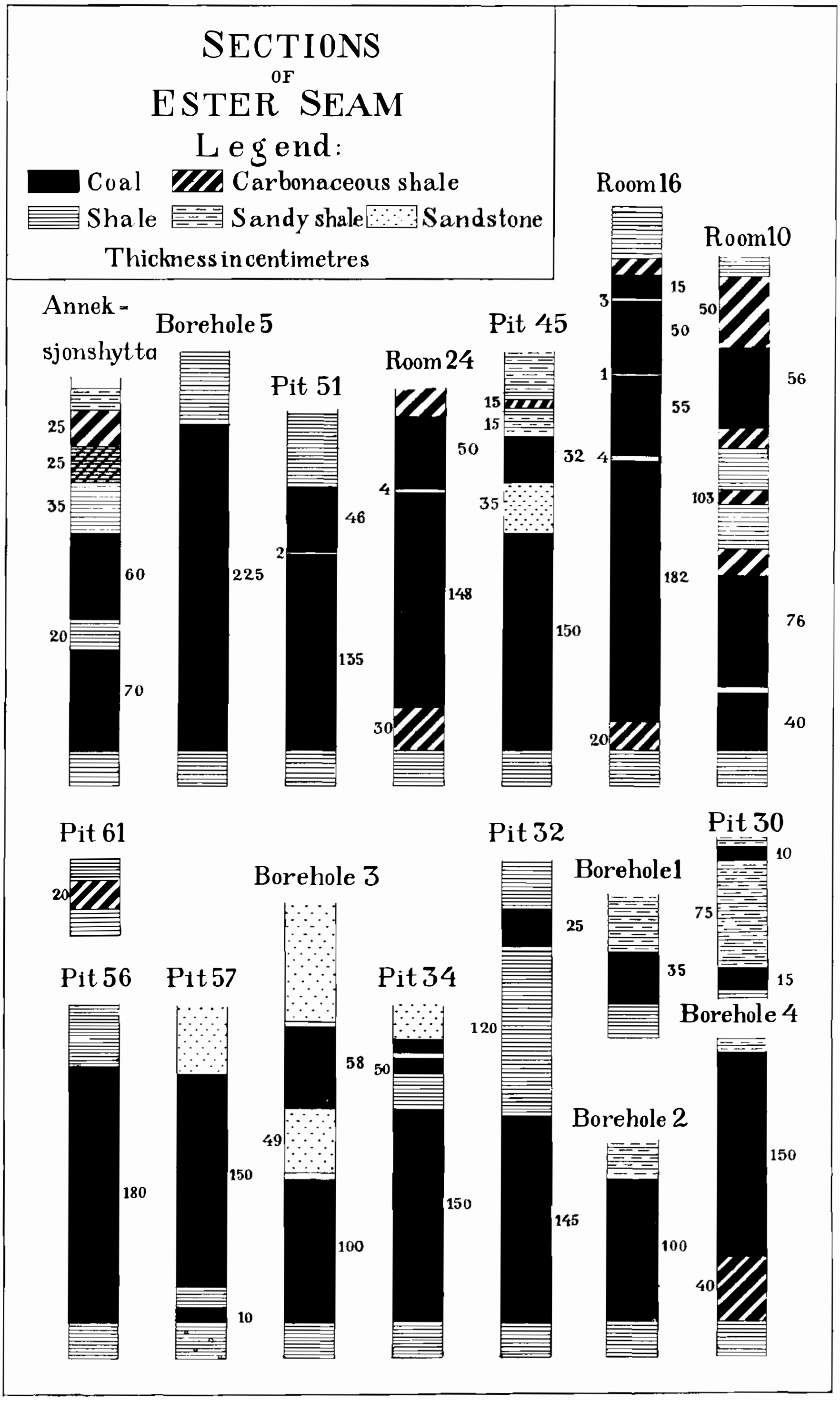
SECTIONS
OF
ESTER SEAM
Legend:
Coal
Carbonaceous shale
Shale
Sandy shale
Sandstone
Thickness in centimetres
Annek-sjonshytta
Borehole 5
Pit 51
Room 24
Pit 45
Room 16
Room 10
Pit 61
Borehole 3
Pit 32
Borehole 1
Pit 30
Pit 56
Pit 57
Pit 34
Borehole 4
Borehole 2

Fig. 32.

Thickness in metres	
2.10	Clay and gravel
2.90	Shale, light and soft
2.30	Sandstone, light, hard and fine-grained
5.40	Shale, light and sandy

The section in the pit was very irregular owing to folding, and seems to be situated in the foot wall of the Ester Seam.

From the test-pit 62 to seven metres north of test-pit 67, a trench was dug and blasted down to 1.5 metres, and in seven spots with regular spacing small pits were blasted down to two metres without any coal being found.

Test-pit 65. Co-ordinates: x = + 9087, y = + 10892, elevation 40.2, depth 3.1 metres, worked August 1929. Section by Sherdahl.

The geological section was:

Thickness in metres	
1.30	Gravel and clay
1.10	Clay
0.70	Shale from the Ester foot wall

Test-pit 66. Co-ordinates: x = + 9074, y = + 10886.5, elevation 41.2 metres, depth 2.7 metres. Section by Sherdahl. Worked Aug. 1929.

The geological section was:

Thickness in metres	
1.30	Gravel and clay
1.10	Clay
0.30	Claystone conglomerate from the Ester foot wall

This pit was thus situated below the coal seam.

Test-pit 68. Co-ordinates: x = + 9121, y = + 10806, elevation 40.5, depth 8.5 metres. Geological section by Sherdahl was:

Thickness in metres	
7.4	Gravel with some clay
1.1	Clay and argillaceous sandstone. Ester foot wall

From the pit a 9.7-metres-long crosscut was driven towards the south. After an advance of 7.8 metres the seam was found with a thickness of 0.50 metres. The coal was weathered, and an analysis showed 15.46 per cent. ash.

Test-pit 70. Co-ordinates: x = + 9144.5, y = + 19692, elevation 36.0, depth 10.15 metres. The work was finished on September 12, 1929.

Geological section measured by Sherdahl was (fig. 35 p. 111):

Thickness in metres	
8.00	Gravel and clay
1.00	Sandstone and clay
0.30	Coal, tight and partly earthy through weathering. Sample 7 gave by analysis 17.97 per cent. ash
	Shale in the foot wall

From this pit a crosscut was driven into the Sofie Seam. The section from this seam is included under the description of the Sofie Seam.

Test-pit 71. Co-ordinates: x = + 9199.5, y = + 10602, elevation 31.5. depth 7.00 metres. The work was finished on Sept. 26, 1929. Geological section by Sherdahl:

5.40	metres	Gravel and some clay
2.60	„	Shale

From the bottom of the pit a crosscut was driven 10.60 metres towards the south without striking any coal. The dip was about 18° southerly.

Test-pit 51. Co-ordinates: Abt. x = + 9270, y = + 10515. Section by Sherdahl 1925. (Pit 51; fig. 32).

The seam was struck with a 6.40-metres-deep pit in gravel and clay. From here the seam was followed along the dip by a slope. After an advance of 8 metres the seam was 1.60 metres thick, and after 9.80 metres the thickness was 1.83 metres.

In Østre Centerfelt the Ester Seam has been worked from the Ester Mine and also from the Sofie Mine. When the mining work was closed down in the autumn of 1929 only this seam was being worked. Owing to shearing of the strata the seam has been scoured away in the whole northwestern part of this area. In a more limited part of the destroyed area the whole sequence between the Ester and Sofie seams has been cut away, so that the Sofie Seam is resting on the Ester foot wall.

Mining operations in the autumn of 1929 showed that the Ester Seam was unworkable in the western part of the Ester Mine as well as in the area under the Sofie Mine. There was only a workable coal-thickness along a 400-metres-long working front downwards in the eastern part of the Ester Mine. This irregularity of the seam, in connection with the occurrence of gas and water in the mines, led to the closing down of the mine in the autumn of 1929, although the thickness along the eastern front averaged nearly two metres.

Some test-pits in Østre Centerfelt gave the following results:

Test-pit 44. Co-ordinates: x = + 9182, y = + 10273, elevation 38.5 metres, depth 6.70 metres. Work finished December 1923. Section by Sherdahl:

Thickness in metres	
5.80	Gravel
0.40	Shale, light grey, a little limy
	Green glauconitic sandstone, Carboniferous

The test-pit was situated below the coal seam.

Test-pit 45. Co-ordinates: x = + 9143, y = + 10157, elevation 38.7. depth 22.60 metres. Work finished July 1924. Geological section measured by Sherdahl was (Pit 45, fig. 32):

Thickness in metres	
5.00	Clay and gravel
4.40	Sandstone, light and hard
0.50	Sandstone, dark and highly argillaceous, with coal substance and carbonised plant-fossils
0.15	Carbonaceous shale
0.15	Shale
0.32	Coal. Analysis No. 16
0.35	Sandstone, dark, greyish-brown and fine-grained
1.50	Coal. Analysis No. 17
10.15	Shale, soft and light
	Green glauconitic sandstone. Carboniferous

Test-pit 39. Co-ordinates: x = + 9135, y = + 9888, elevation 34.2, depth 3.7 metres. Worked October 1923. Geological section by Sherdahl:

1.20	metres	Gravel
2.50	„	Sandstone, hard, compact with spots of pyrites

Test-pit 56. Co-ordinates: x = + 8780, y = + 10086, elevation of top of pit — 56.5 metres. The pit was driven from Sofie Mine to the Ester Seam along a fault. Length 4.80 metres. Geological section by Sherdahl (Pit 56, fig. 32):

Thiekness in metres	
	Sofie Seam
3.00	Rock
1.80	Coal, Ester Seam

The Ester foot wall west of the fault was situated — 61.3 metres above sea-level.

Test-pit 58. Co-ordinates: x = + 8933, y = + 9901, elevation of top of the pit — 6.4 metres. The pit was driven down from the Sofie Mine. Ester Seam and the sequence between the two coal seams were missing. Depth of pit 7 metres. The pit, which was finished in January 1927, had thus been driven exclusively in the claystone conglomerate of the Ester foot wall.

Test-pit 60. Co-ordinates: x = + 8888, y = + 9876, elevation of the top of the pit — 17.5 metres. Worked January 12, 1927 from Sofie Mine down to the Ester Seam, which was here made up of only

0.10 metres carbonaceous shale. Between the Sofie and the Ester seams there was a rock parting of 1.5 metres. Depth of pit was 2.00 metres. Section measured by the coal company.

Test-pit 57. Co-ordinates: x = + 8887, y = + 8814, elevation of the top of the pit — 21.2 metres, depth of pit 6.70 metres. The pit was driven down from Sofie Mine to Ester Seam in January 1927. Geological section measured by Sherdahl was (Pit 57, fig. 32):

Thickness in metres	
	Sofie Seam
3.20	Sandstone, hard and compact
1.50	Coal with small shale partings
	Parting, thickness not specified, probably about 20 centimetres
0.10	Coal
2.10	Claystone conglomerate. Ester foot wall

In a crosscut three metres towards the south the total thickness of the coal seam was 1.80 metres.

Test-pit 61. Co-ordinates: x = + 8922, y = + 9681, elevation of the top of the pit — 17.9 metres, depth of pit two metres. Geological section by Sherdahl. The pit was driven on January 12, 1927, from the Sofie Seam towards Ester Seam. The seams were parted by 1.30 metres of rock, and the Ester Seam consisted of 20 centimetres of carbonaceous shale.

Test-pit 64. Co-ordinates: x = + 8865, y = + 9633. The pit was driven down from the Sofie to the Ester Seam in January 1928. Geological section by Sherdahl. The distance between the two seams was only 2.25 metres, and the Ester Seam consisted of 46 centimetres coal, greatly mixed with shale.

Test-pit 54. Co-ordinates: x = + 9155, y = + 9592, elevation 23.3 metres, depth 14.90 metres + 2.75 metres drilled down from the bottom of the pit. Geological section measured by Sherdahl:

Thickness in metres	
3.00	Gravel
11.35	Clay with boulders lowermost
3.35	Shale. Ester foot wall

The pit is situated below the coal seam.

In Vestre Centerfelt the seam has been pierced by boreholes 1, 2, and 3, as well as by two test-pits on Kolhaugen. The drill records show that the thickness is rather variable, so that the average thickness does not amount to more than abt. 1.10 metres. It is highly probable that the small thickness in borehole 1 is due to tectonical disturbances.

The sections of some test-pits from Vestre Centerfelt are as follows:

Test-pit 35. Co-ordinates: x = + 8483, y = + 9660, elevation of the top of the pit 39.80 metres, of the bottom 20.60 metres, depth 19.20 metres. The pit was driven down from the eastern gallery in the Olsen Mine (see also page 114). Geological section measured by Sherdahl was:

Thickness in metres	
	Sofie Seam
7.50	Sandstone, greyish-white and argillaceous
1.30	Sandstone with a shale bed uppermost
0.50	Carbonaceous shale
13.70	Sandstone, soft and highly argillaceous, dark

The lower 2.5 metres was drilled.

Whether the 50-centimetres-thick carbonaceous shale represents the Ester Seam is not quite certain, although this is most probable. Yet I could not find the typical rocks of the Ester foot wall on the dumps.

Test-pit 33. Co-ordinates: x = + 8487, y = + 9032, elevation 30.9. The pit was worked in the autumn of 1923 by Sherdahl, but it did not reach the coal seam. The depth was 7.20 metres, of which 6.70 metres in morainic material and 0.50 metres through dark shale. The dip was 21° S 30° E.

Test-pit 32. Co-ordinates: x = + 8658, y = + 8976, elevation 42.5 metres, depth 5.10 metres. Work finished October 1923. Geological section measured by Sherdahl was:

Thickness in metres	
1.20	Gravel
1.00	Shale
0.25	Coal, impure
1.20	Shale
1.25	Coal. Coal pieces contains 3.7 per cent. ash
	Shale from Ester foot wall

Test-pit 34. Co-ordinates: x = + 8630, y = + 8961, elevation 40.8 metres, depth 13.2 metres. Work finished December 1923. Dip 25° S 30° E. Geological section measured by Sherdahl was:

Thickness in metres	
6.50	Gravel
3.00	Shale, dark
0.20	Coal and shale
1.50	Sandstone, brown, very fine-grained and argillaceous
0.50	Coal and shale
1.50	Coal. Analysis 19. Coal pieces contained 8.46 per cent. ash according to Sherdahl
	Shale, dark. Ester foot wall

On Vestfeltet the coal seam has been pierced by borehole 4 on Leirhaugen. It was here 1.90 metres thick. The lowermost part of about 40 centimetres contains very much ash, and can therefore not be taken into account. The net thickness is thus about 150 metres.

Further, the seam has been exposed in:

Test-pit 30. Co-ordinates: x = + 9018, y = + 7000, elevation 40 metres, depth 3.00 metres. Geological section measured by Sherdahl in October 1923 (Pit 30, fig. 32):

Thickness in metres	
0.90	Gravel
0.10	Coal
0.75	Shale
0.15	Coal

As will be seen the coal seam is here of no value.

Quality of Ester Coal. The analysis table includes all available analyses of coal from the Ester Seam. Several of the samples are more or less occasional and do not represent the average of the seam at the point in question. The analyses of exported coal are mainly of cargoes containing coal from both the Ester and Sofie mines and have not been included in the table. Some average analyses of exports are included in the chapter Quality of Coal.

Below I shall give in connection with the analyses a description of some of the coal samples taken by myself on the Ester Seam.

From borehole 3 no analysis has been included because we did not get sufficient core to give a workable sample.

Sample 13, 1928 (Analysis 7) was taken from the Ester Seam in borehole 5 from the depth of 41.35 to 43.72 metres. The analysis is made of coal from a coal core 1.80 metres long, representing 76 per cent. of the whole seam. The analysis is thus an approximate average analysis. The thickness is 2.25 metres, when the drilling length is reduced in accordance with the dip.

The uppermost 20 centimetres of the core contained a few streaks of shale and carbonaceous shale some millimetres thick. The greater part of the coal was compact and semi-dull (durite), but there were also some slaty or laminated parts. The following 10 centimetres were pure coal, then 20 centimetres of coal with pyrites found on fissures and as small lenses in semi-dull coals with brownish-black streak. The following 100 centimetres contained almost pure coal with small, scattered spots of pyrites. The lowermost 30 centimetres were a little more impure, containing pyrites in small lenses and sparks. The streak was in all parts brownish-black, and the coal was chiefly durite with a black, semi-dull colour.

The sample was taken as an average of the whole core.

Sample 8, 1928 (Analysis 9) was from the Ester Seam, from 55.72 to 56.75 metres deep in borehole 2, west of Tvillingvatnet. The core

Analyses of coal

Number of analysis		1	2	3	4	5	6	7	8
Locality of Sample		Kolhaugen 1922. Loose coal pieces	The 0.60 metres seam in the brook at Anneksjonshytta	The 0.70 metres seam in the brook at Anneksjonshytta	Ester Mine	Ester Mine 1927	Ester Mine 1927	Sample 13, 1928 from borehole 5	Sample 6, 1928 from borehole 1
Moisture		2.50	1.55	1.35	1.45	2.33	2.19	1.50	1.20
Ash		6.48	7.30	11.42	9.62	-	-	6.15	21.65
Coal substance		91.02	91.15	87.23	88.93	-	-	92.35	77.15
Carbon		-	-	-	-	-	-	70.38	-
Hydrogen		-	-	-	-	-	-	5.81	-
Sulphur		2.40	1.37	0.98	5.76	-	-	1.79	2.35
Nitrogen and oxygen		-	-	-	-	-	-	14.37	-
Coke		58.80	57.30	60.50	56.50	56.46	53.96	55.70	61.60
Volatile matter		38.70	41.15	38.15	42.05	41.21	43.85	42.80	37.20
Gross calorific value		7414	7667	7204	7543	6900	7062	7556	6363
Net calorific value		7104	7362	6914	7252	6516	6889	7252	6106
Low-temperature distillation	Water	8.0	6.4	8.0	5.6	9.8	7.6	6.8	5.2
	Gas	8.0	6.8	6.0	10.4	11.9	7.2	8.4	7.0
	Crude oil	14.4	19.6	16.8	20.8	11.9	18.2	17.2	16.2
	Semi-coke	69.6	67.2	69.2	63.2	66.4	67.0	67.6	71.6
In pure coal	Carbon	-	-	-	-	-	-	76.22	-
	Hydrogen	-	-	-	-	-	-	6.29	-
	Sulphur	2.64	1.50	1.01	6.48	-	-	1.94	3.05
	Nitrogen and oxygen	-	-	-	-	-	-	15.55	-
	Coke	57.48	54.85	56.27	52 27	-	-	53.59	517 8
	Volatile matter	42 52	45.15	43.73	47.28	-	-	46.41	48.22
	Gross calorific value	8145	8411	8258	8482	-	-	8182	8248
	Net calorific value	7821	8087	7934	8158	-	-	7807	7924
In pure coal, Low-temperature distillation	Water	6.0	5.3	7.6	4.7	-	-	5.8	5.1
	Gas	8.9	7.5	6.9	11.7	-	-	9.1	9.1
	Crude oil	15.8	21.5	19.2	23.4	-	-	18.6	21.1
	Semi-coke	69.3	65.7	66 3	60.2	-	-	66.5	64.7
Remarks		Unweathered coal. Sample by Orvin 1922	Unweathered coal. Sample by Orvin 1922. Not exact average	Unweathered coal. Sample by Orvin 1922. Not exact average	Sample by Hoel and Orvin, Coke: molten, porous, vesicular	Sample by K. B. K.	Sample by K. B. K.	Coke: sintered and brittle	Coke: sintere dand brittle
Analyst		Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1925			Dr. Gram 1928	Dr. Gram 1928

from the Ester Seam.

9	10	11	12	13	14	15	16	17	18	19	20	21
Sample 8, 1928 from borehole 2	Sample 10, 1928 from borehole 4	Sample 11, 1928 from borehole 4. Lower part of the seam	Face, Gateway 2. Ester Mine	Face, Gateway 4. Ester Mine	Face, Gateway 6. Ester Mine	Face, Gateway 6. Ester Mine	Pit 45. Upper coal seam, 0.32 metres	Pit 45. Lower coal seam, 1.50 metres	Pit 45. Average of 1.5 metres	Pit 34. Kolhaugen	Average of 1—4 and 7—10	Average of 30 cargoes 1925
1.90	1.15	-	-	-	-	-	-	-	-	-	1.58	-
9.30	12.03	47.20	13.94	9.82	17.44	18.39	10.63	12.19	6.72	11.11	10.49	11.07
88.80	86.82	-	-	-	-	-	-	-	-	-	87.93	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
4.34	2.95	-	-	-	-	-	5.14	5.13	-	-	2.73	-
-	-	-	-	-	-	-	-	-	-	-	-	-
58.45	55.55	-	-	-	-	-	-	-	-	-	58.05	-
39.65	43.30	-	-	-	-	-	-	-	-	-	40.37	-
7298	7279	-	-	-	-	-	-	-	-	-	7291	-
6999	6991	-	-	-	-	-	-	-	-	-	6998	-
6.4	5.6	5.2	3.4	3.4	3.6	3.9	3.7	4.6	3.9	5.3	6.50	-
9.2	9.6	5.6	8.5	8 6	7.5	7.6	7.6	7.0	9.4	6.5	8 17	-
15.6	19.6	12.4	20.9	21.7	18.0	18.8	21.2	19.0	19.2	17.7	17 53	-
68.8	65.2	76.8	67.2	66.3	70.9	69.7	67.5	69.4	67.5	70.5	67.80	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
4.89	3.39	-	-	-	-	-	-	-	-	-	3.10	-
-	-	-	-	-	-	-	-	-	-	-	-	-
55.35	50.24	-	-	-	-	-	-	-	-	-	54.04	-
44.65	49 76	-	-	-	-	-	-	-	-	-	45.96	-
82 18	8382	-	-	-	-	-	-	-	-	-	8291	-
7894	8058	-	-	-	-	-	-	-	-	-	7960	-
5.0	5.2	-	-	-	-	-	-	-	-	-	5.6	-
10.4	11.0	-	-	-	-	-	-	-	-	-	9.3	-
17.6	22.6	23.0	-	-	-	-	-	-	-	-	20.0	-
67.0	61.2	-	-	-	-	-	-	-	-	-	65.1	-
Coke: sintered and brittle	Coke: sintered, loose	Bony coal	2.14 metres coal	1.40 metres coal	0.77 metres coal	Sample is average of 1.47 metres			Large	Thickness 1.5 metres		Ester-coal in the cargoes
Dr. Gram 1928	Dr. Gram 1928	Dr. Gram 1928	Sherdahl 29/10 1924	Sherdahl 29/10 1924	Sherdahl 29/10 1924	Sherdahl 20/2 1925	Sherdahl 1924	Sherdahl 1924	Sherdahl 1924	Sherdahl 1923		Sherdahl

was only 25 centimetres or 24 per cent. of the seam. The coal was semi-dull durite with visible white cacite on fissures and bedding planes. The streak was dark brown to blackish-brown. Irregular bedding and slickensides pointed to tectonical disturbances.

Sample 6, 1928 (Analysis 8) was of the Ester Seam in borehole 1, Brøggerdalen from 91.85 to 92.20 metres depth. The thickness was 34 centimetres and the length of the core 25 centimetres or 76 per cent. The whole core consisted of semi-dull and partly of dull coal (durite) with blackish-brown streak and was partly slaty. Sample was taken of the whole core.

Sample 10, 1928 (Analysis 10) was of the Ester Seam in borehole 4 on Leirhaugen. The analysis was made on 60 centimetres core, of which 20 centimetres were from 136.28 to 137.38 metres depth and 40 centimetres from the upper part of the 70 centimetre-long core obtained by drilling from 137.38 to 138.25 metres depth. The coal was semi-dull and partly brighter with dark brown to blackish-brown streak without distinctive lamination. Calcite occurs on tiny fissures and bedding planes.

Sample 11, 1928 (Analysis 11) from the lowermost 30 centimetres of the core from 137.38 to 138.25 metres depth in borehole 4 on Leirhaugen. The analysis contains so much ash that the coal must be termed bony coal. The lowermost part of the bed here can thus hardly be worked.

The samples from the boreholes do not give an exact average of the coal seams. The coal type will certainly be nearly correct in the analyses calculated on pure coal, but in the other analyses the ash content, in particular, may be erroneous. One would think that the purest coal of the core would be crushed and lost during the drilling, because this part is the most brittle. This is, however, hardly any rule, because the soft shale often gives an equally small core percentage as does the coal. Moreover, it often happens that part of the core becomes jammed in the core-tube, and in this case the soft rock below will be ground into mud.

From the analysis table it will be seen that the ash content varies a great deal. In borehole 5 it is particularly low, namely 6.15 per cent.

The coke is sintered and brittle. The coals would have to be mixed with other coals to obtain a hard and strong coke.

The high ash content is not only due to the common impurities, shale and carbonaceous shale, but is also in great measure due to the secondary calcite which has been deposited on tiny fissures and cracks. Only part of the calcite is white and can be perceived macroscopically. The greater part is black and is only seen under the microscope on polished planes or in thin sections. Dr. Gunnar Horn (1928) found such calcite in all the Kings Bay coals. This content of calcite is unquestionably due to the specific conditions of the coal field. Owing to tectonical disturbances the coal has been crushed. so that now innummerable miniature thrusts and faults can be seen in it under the microscope. On these calcareous water has circulated. The lime certainly originates from the overlying Carboniferous limestone. The black colour must be due to intermixed coal dust and perhaps soluble ingredients of the coals. The inferior content of ash in some areas may thus directly point to less crushing and a smaller content of calcite.

This calcite is obviously a disadvantage, because it not only increases the ash content but also directly consumes warmth for decomposition of the carbonic acid.

What has been written here about the ash content of the Ester coal concerns also the other seams.

Neither the coal from Ester Seam nor from other seams at Kings Bay is cannel coal, according to the examination of Horn. The chemical composition is certainly about the same as the composition of the cannel coals, but the structure is quite different.

The coal from Ester Seam gives off methane (CH_4) and partly sulphuretted hydrogen (H_2S), the smell of which could be perceived in some workings in the Ester Mine.

The greater part of the ash content was found in the small coals. The table below includes some analyses made by the Company of the run-of-mine coal on the spot.

Mine and remarks	Coal	Ash pct.	By low-temperature distillation		
			Moisture pct.	Crude oil pct.	Coke pct.
Ester and Sofie mines, average of 12 analyses 1927–28	Large	8.69	-	-	-
	Smalls	22.91	-	-	-
Ester Mine, average of analyses 1928–29	Large	8.00	-	-	-
	Smalls	20.90	-	-	-
Ester Mine, average of 14 analyses 1924—27	Large	9.26	4.76	20.45	66.33
	Smalls	19.83	4.96	18.09	69.32
The eastern slope of Ester Mine, average of 6 analyses 1925	Large	9.13	-	-	-
	Smalls	21.28	-	-	-

Three samples of carbonaceous shale from Ester Mine gave an average of 34.07 per cent. ash and by low-temperature distillation 4.95 moisture, 14.51 crude oil and 74.55 coke.

Coal quantity. The table below includes the total quantity of coal in the Ester Seam. As the western areas are still little known, the figures concerning these areas are only an estimate. This is also partly the case in Østfeltet, where the coal area cannot be fixed as long as the depth of the Tertiary syncline is not known. In the table are thus

Area	Coal area sq. kilometres	Thickness in metres	Coal quantity in mill. tons
Østfeltet	0.30[1]	1.3[1]	0.50[1]
Agnesfeltet	0.33	2.0[1]	0.86[1]
Østre Centerfelt	0.40	1.8[1]	0.97[1]
Vestre Centerfelt	0.76	1.0	0.99
Vestfeltet	1.90	1.1[1]	2.70[1]
Lagunefeltet	0.40	1.0[2]	0.50[2]
Total....	4.09	-	6.52

also included probable coal and both the workable and unworkable parts of the coal seams.

In Østfeltet the coal area is not known with certainty because the strata are partly tilted, and the depth of the syncline is not known. Nor is the thickness known from a sufficient number of localities.

The average thickness in Agnesfeltet is about two metres measured in borehole 5 and the test-pit 51, where the seam is undisturbed. The thickness along the Agnes Fault was also good in the Ester Mine, but, as we have heard, the examination made by Sherdahl in the autumn og 1929 has shown us that also in this area there occur tectonical disturbances and irregularities. It is, however, impossible to predict to what extent the coal seam may be damaged owing to such disturbances It is probable that the above figures concerning the quantity will be reduced owing to disturbed areas in a future mine here. The above calculation is made on the supposition that the seam here is undisturbed.

After the closing down of the mines in Østre Centerfelt it is obvious that the remaining quantity of coal in this area is of somewhat doubtful value. The eastern part of the remaining area can be worked out through a new mine on Agnesfeltet by penetrating the fault, but the coal remaining in the western part must be regarded as lost for ever, the more so as the area worked at the closing down of the mine was most irregular and not workable. The figures above concerning the Ester Seam in Østre Centerfelt are thus far higher than the quantity which can actually be mined.

The thickness in Vestre Centerfelt is fixed at one metre in the table. This is a little less than the average from the boreholes and the test-pit on Kolhaugen. This I have done because the result from borehole 1 and the Olsen Mine points to some parts of the coal area here being too poor to be taken into account. I have tried partly to make up for this diminution of quantity by a reduction of the average thickness.

[1] The figures are only approximate.

[2] The figures are only an estimate and thus quite uncertain.

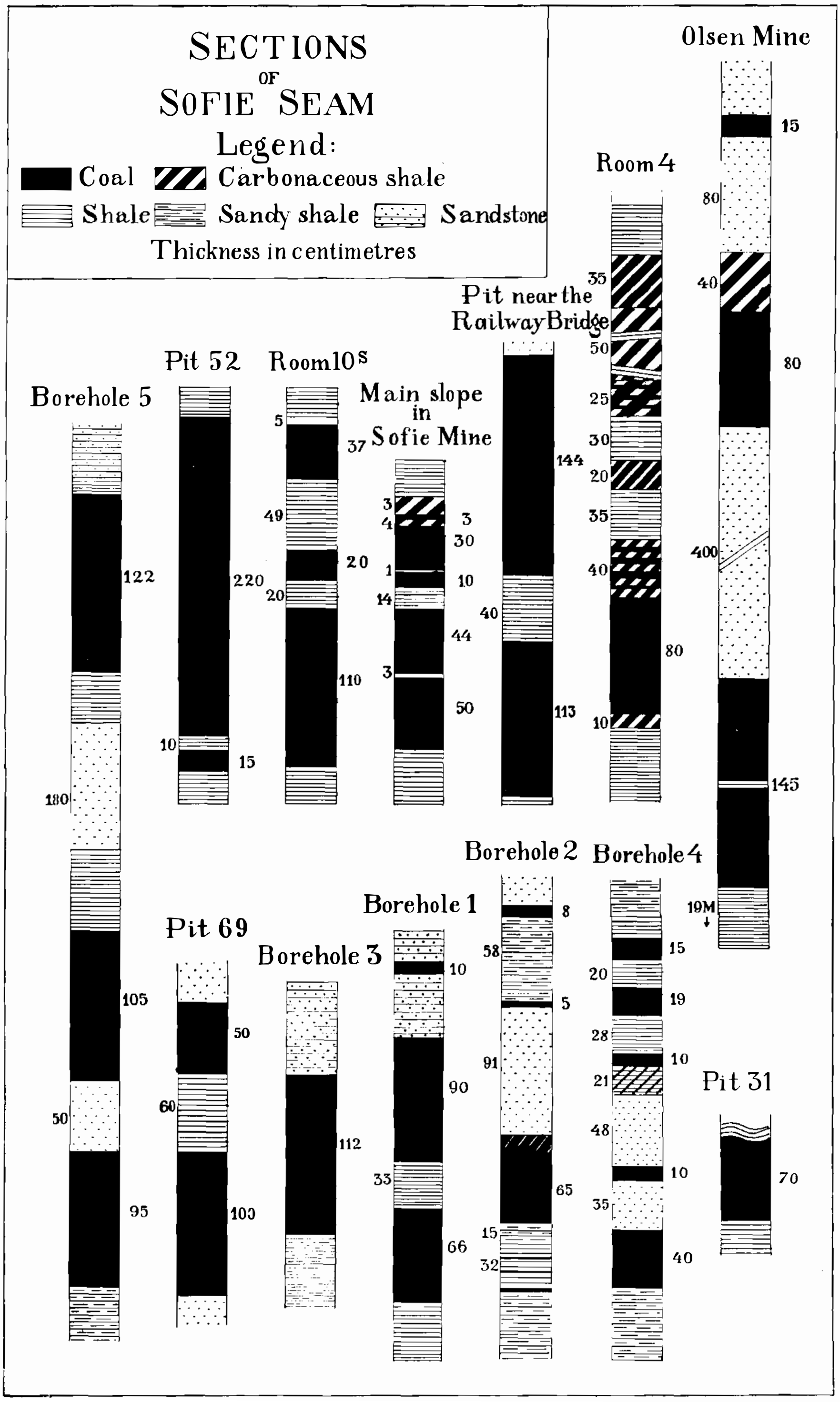
SECTIONS
OF
SOFIE SEAM
Legend:
Coal
Carbonaceous shale
Shale
Sandy shale
Sandstone
Thickness in centimetres
Olsen Mine
Room 4
Pit near the Railway Bridge
Pit 52
Room 10s
Main slope in Sofie Mine
Borehole 5
Borehole 2
Borehole 4
Borehole 1
Pit 69
Borehole 3
Pit 31

Fig. 33.

In Vestfeltet the workable part of the seam in borehole 4 is about 1.5 metres, but if the sections in borehole 2 and test-pit 30 are considered, the average thickness can hardly be more than 1.10 metres, which will give a quantity of about 2.7 mill. tons. The western part of the area, however, is scarcely workable. The area below the ice sheet of Brøggerbreane cannot be examined, and the coal area here is therefore judged on the basis of the probable geological conditions. The calculation of this part of the coal field will accordingly always be of more doubtful value. I should think that the actual workable quantity of coal will amount to somewhat more than two mill. tons. Only on the northeastern part of Vestfeltet can the quantity of coal be relied on. The average thickness on the 400 000 sq. metres here is about 1.3 metres, and the coal quantity about 0.67 mill. tons.

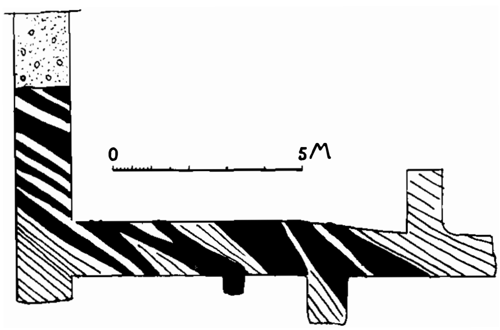

Fig. 34. Section of pit 67, Sofie Seam.

The thickness of the Ester Seam on Lagunefeltet is quite unknown, and the figures from this area are thus only conjectures.

In the whole field there is probably about 6.52 mill. tons coal on the Ester Seam. How much of this quantity may be workable is of course very difficult to say, but I should think that a considerable loss must be calculated owing to areas with a small coal thickness or damaged by tectonic disturbances. According to the experience gained during mining operations I should think that about 4 mill. tons can actually be worked out from the Ester Seam in the entire coal field.

Sofie Seam.

This seam is situated stratigraphically 8—12 metres above the Ester Seam. It varies greatly both in thickness and development. In some spots the seam is made up of tolerably pure coal, while neighbouring parts may be divided by partings of sandstone, shale and carbonaceous shale. The foot wall is made up of a shale, which is in part very sandy. The top wall, which consists of shale, carbonaceous shale, sandy shale and sandstone, was rather bad. Also along this seam tectonical disturbances have taken place by northward shearing of the top wall on the footwall along the seam. In reality it is the same disturbance which has partly affected the Ester Seam and partly the Sofie Seam. Where the shearing has acted along the coal seam, it has crushed, folded, and scoured it away in parts, so that great areas of the mine had to be left as valueless, although they might have been worked originally in undisturbed condition. From fig. 20 the appearence of the disturbed seam can be seen in some spots. These sections are only casual. There are all variations.

From the sections in fig. 33 the development of the seam will be seen in different localities. The sections have been arranged from east to west, but because the coal seam varies so greatly, the sections are perhaps still more casual than those from the Ester Seam.

As will be seen from these sections, the coal thickness distinctly decreases from east to west.

East of the Agnes Fault the seam has not been uncovered, but it exists at all events on the western part of Østfeltet.

In Agnesfeltet the Sofie Seam is known from borehole 5 and several test-pits.

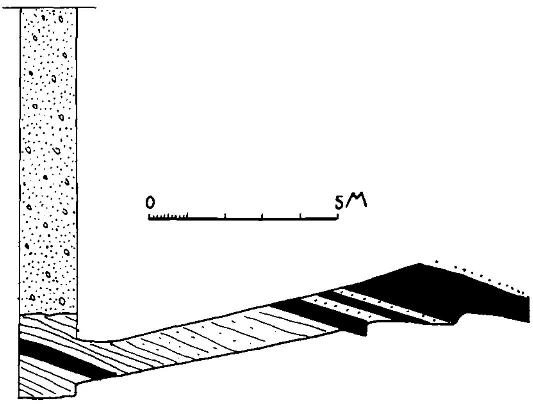

Fig. 35. Section of pit 70, Ester and Sofie seams.

Test-pit 67. Co-ordinates: x = + 9063, y = + 10883, elevation 42 metres, depth 7.6 metres. Work finished 5/9 1929. Geological section measured by Sherdahl was (fig. 34):

Thickness in metres	
2.20	Gravel and clay
4.00	Coal and carbonaceous shale
1.60	Shale, dark

From the bottom of the test-pit a crosscut was worked 11 metres to the south. The section of the coal seam here is most irregular and approximately the following:

Thickness in metres		
0.40	Shale and sandstone	
0.20	Shale, soft	
0.35	Coal	Both samples are an average of the two coal beds. Sample 1 contained 32.7 per cent. ash; sample 2, 35.85 per cent.
0.15	Stone band	
1.00	Coal and small layers of shale	
0.20	Shale, dark	
1.20	Coal	Sample 3, taken as average of both beds, gave by analysis 27.0 per cent. ash
0.50	Shale	
0.50	Coal	
	Shale, dark	

The cross section was water-bearing, and the coal highly oxidised with a white coating, certainly calcite.

According to the description of the pit and the analyses it can hardly be doubted that the seam is here situated in a zone of disturbances, and that there has been deposited more calcite than usual.

Test-pit 69. Co-ordinates: x = +9106, y = + 10804, elevation 41.7 metres, depth 8 metres. Work finished $^5/_9$ 1929. Section measured by Sherdahl was (Pit 69, fig. 33):

Thickness in metres	
5.30	Gravel and clay
2.30	Shale with some thin partings of sandstone and a thin coal seam in the lower part
3.40	Shale

From the bottom of the pit drilling was done three metres in rock. A three-metres-long slope was worked down along the dip of the seam, and from the bottom of this slope a three-metres-long rise was driven. The section here was as follows:

Thickness in metres	
0.90	Sandstone, argillaceous
0.50	Coal. Sample 4 gave 16.25 per cent. ash
0.60	Stone band
1.00	Coal. Sample 5 gave 20.80 per cent ash
	Sandstone, brownish black, argillaceous

Test-pit 70. Co-ordinates: x = + 9144.5, y = + 10692, elevation 36.00 metres. From the bottom of the pit, where this pierced the Ester Seam (see page 98) a crosscut was driven 13 metres towards the south. The Sofie Seam was cut with the following section (fig. 35):

Thickness in metres	
	Sandstone
1.20	Coal. Sample **9** is from the eastern side and gave 21.49 per cent, ash. Sample 10 is from the western side and gave 24.72 per cent. ash.
0.15	Sandstone
0.15	Coal
0.30	Sandstone
0.40	Coal. Sample 8 gave 27.07 per cent. ash
	Sandstone, dark, argillaceous

The section is measured and the analyses made by Sherdahl.

The ash content from these pits is in every instance astonishingly high.

Test-pit 52. Co-ordinates: Abt. x = + 9200, y = + 10492, elevation abt. 72 metres, depth 9.45 metres. Worked 1925. Geological section by Sherdahl (Pit 52 fig. 33):

Thickness in metres	
5.30	Gravel and clay
1.35	Stone
2.20	Coal
0.10	Shale
0.15	Coal
	Stone

From this point I have got no analysis.

In Østre Centerfelt the coal seam has been worked from the autumn of 1923 until the winter of 1928—29. The thickness was very great in parts, but in other parts the seam was so destroyed by shearing that great areas had to be left as unworkable. For this reason the work was suspended on the Sofie Seam in this area. It is, however, still possible that the seam might be partly workable farther down along the dip.

Some sections from test-pits in Østre Centerfelt will be seen below:

Test-pit 42. Co-ordinates: x = + 9112, y = + 10162, elevation 41.5 metres, depth 9.5 metres. Work finished December 1923. Geological section by Sherdahl was:

Thickness in metres	
1.70	Gravel
2.20	Coal, increasing to 3.25 metres after 11.5 metres downdrift along the dip
4.60	Shale, dark
4.70	Sandstone, hard and light

The lowermost 3.7 metres were drilled from the bottom of the pit.

Test-pit 40. Co-ordinates: x = + 9117, y = + 10068, elevation 39.3 metres, depth 5.70 metres. Work finished October 1923. Geological section by Sherdahl: Uppermost 2.00 gravel, lowermost 3.7 metres coal.

Test-pit 41. Co-ordinates: x = + 9114, y = + 9989, elevation 38.2 metres, depth 5.50. The work was finished in December 1923. Geological section by Sherdahl:

Thickness in metres	
4.00	Gravel
0.50	Coal pieces and gravel
0.30	Coal
0.20	Shale
0.50	Coal. Analysis 15

A three-metres-long slope along the dip gave the same result.

Test-pit east of the railway bridge. Section by Sherdahl:

Thickness in metres	
	Gravel cover
3.00	Sandstone, light
1.44	Coal
0.44	Shale
1.13	Coal
	Shale, dark

Analysis 21 is from this pit.

Test-pit 63. Co-ordinates: x = + 8861, y = = 10366.5. Worked January 1928 as a rise along a fault from the mine. The displacement is about 6 metres and the thickness of the seam about 2 metres. Section by Sherdahl.

Rise from room 15 in Sofie Mine. Co-ordinates: x = + 9002, y = + 10002. The Sofie foot wall 40 metres above sea-level. Worked September 1924. Geological section by Sherdahl:

Thickness in metres	
2.00	Sandstone, dark and hard
0.14	Coal
3.40	Sandstone, soft, dark with streaks of carbonaceous shales
1.50	Coal. The Sofie Seam

Test-pit 55. Co-ordinates: x = + 9077, y = + 9593, elevation 23.40 metres, depth 15.60 metres. Geological section measured by Sherdahl:

Thickness in metres	
12.5	Gravel
	Coal-streak
3.1	Shale and slaty sandstone

The coal-streak was followed down along the dip with a 7-metres-long slope, in which the seam was found to be 1.00 metre thick.

In Vestre Centerfelt the Sofie Seam is known from the Olsen Mine and boreholes 1, 2 and 3. The thickness seems to be greatest in the southern and eastern parts of this area, namely, up to 1.5 metres, whereas in the northwestern part it was found to be only 0.65 metres.

Olsen Mine. This mine was opened in the autumn of 1923. A main slope was worked down along the dip of the seam. The average thickness of 17 measurements made by Sherdahl was 1.097 metres of coal and 0.165 metres of stone band. The dip was 10°. The pit 35 was worked down from the eastern gallery (see p. 102 and fig. 36).

From the western gallery the rise 36 was worked. The bottom of the slope was situated 37.1 metres above sea-level and the top of the rise 36 is 45.5 metres above the sea. The rise is 8.4 metres long. The surface above the rise is situated on the 51.7 level. Geological section by Sherdahl (fig. 33):

Thickness in metres	
0.40	Gravel
0.40	Sandstone, light
0.15	Coal. Analysis 16
0.80	Sandstone, light
0.40	Carbonaceous shale, 51 per cent. ash, 10.5 per cent. crude oil.
0.80	Coal. Analysis 17
4.00	Sandstone, light and hard
1.45	Coal seam with a thin shale band in the middle. Analysis 18.

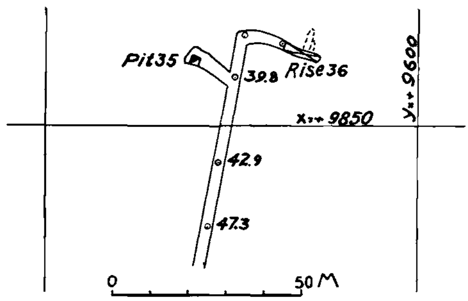

Fig. 36. The Olsen Mine.

Work finished January 1924.

In Vestfeltet the coal seam was found in borehole 4 on Leirhaugen divided by several stone bands. The thickest coal bed was only 0.40 metres (see pl. VII and bore section p. 90).

Farthest west in this area the seam has been uncovered in *test-pit 31*, the co-ordinates of which are x = + 7000, y = + 9010, elevation about 40 metres. The pit was worked in October 1929. Geological section by Sherdahl: A tilted coal seam was found in dark shale. Near the surface the thickness was about 70 centimetres, but decreased downwards. The depth of the pit was 5.2 metres, of which the upper 1.2 metres in gravel. Analysis 20 is made on coal from this spot. The coal seam here is believed to be identical with the Sofie Seam. The results from borehole 4 and the pit 31 point to the seam being unworkable in Vestfeltet. Yet it is certainly far better in the southeastern part, according to the result from borehole 1. The seam may, of course, be workable also in the areas of Vestfeltet not yet examined.

Broadly speaking, the Sofie Seam decreases towards the west and is not so uniform in development as the Ester Seam.

Quality of coal. In the analysis table are included the available analyses of the Sofie Seam. Below I shall give a description of the coal cores from the boreholes in 1928.

Analyses of coal

Number of analysis	1	2	3	4	5	6	7	8	9
Locality of sample	Olsen Mine, lower seam	Olsen Mine, lower seam	Sofie Mine From the pile	Sofie Mine,	Sample 7, 1928 from borehole 5	Sample 5, 1928 from borehole 3	Sample 3, 1928 from borehole 1	Sample 4, 1928 from borehole 1	Sample 9, 1928 from borehole 2
Moisture	-	1.65	1.70	1.78	1.80	1.55	1.05	1.20	1.80
Ash	7.48	9.10	9.67	-	5.93	9.65	26.10	24.55	11.95
Coal substance	-	89.25	88.63	-	92.27	88.80	72.85	74.25	86.25
Carbon	-	-	-	-	70.42	69.96	-	-	-
Hydrogen	-	-	-	-	5.71	5.82	-	-	-
Sulphur	-	1.59	4.40	-	2.33	2.12	4.04	2.59	2.09
Nitrogen and oxygen	-	-	-	-	13.81	10.90	-	-	-
Coke	-	56.22	55.70	56.93	57.60	56.80	59.25	58.20	58.30
Volatile matter	-	42.13	42.60	41.29	40.60	41 65	39.70	40 60	39.90
Gross calorific value	-	7439	7446	6999	7493	7315	6164	6156	6995
Net calorific value	-	7141	7148	6813	7183	7028	5922	5908	6705
Low-temperature distillation: Water	6.6	7.2	4.0	6.8	8.0	6.8	4.8	6.0	6.8
Low-temperature distillation: Gas	7.2	9.2	10.0	8.7	9.2	8.4	6 8	7.6	8 0
Low-temperature distillation: Crude oil	18.7	19.2	19.6	20.9	16.4	17.6	18.4	18.8	16.8
Low-temperature distillation: Semi-coke	67.5	64.4	66.4	63.6	66.4	67.2	70.0	67.6	68.4
In pure coal: Carbon	-	-	-	-	76.32	78.78	-	-	-
In pure coal: Hydrogen	-	-	-	-	6.17	6.55	-	-	-
In pure coal: Sulphur	-	1.78	4.95	-	2.53	2.38	5.55	3.49	2.42
In pure coal: Nitrogen and oxygen	-	-	-	-	14.98	12.29	-	-	-
In pure coal: Coke	-	52.80	51.82	-	56.00	53.10	45.50	45.32	53.74
In pure coal: Volatile matter	-	47.20	48.18	-	44.00	46.90	54.50	54.68	46.26
In pure coal: Gross calorific vulue	-	8335	8401	7126	8121	8238	8461	8292	8111
In pure coal: Net calorific value	-	8011	8077	6937	7797	7928	8137	7968	7787
In pure coal: Low-temperature distillation: Water	-	6.2	2.6	-	6.6	5.9	5.2	6.5	5.8
In pure coal: Low-temperature distillation: Gas	-	10.3	11.3	-	10.0	9.5	9.3	10.2	9.3
In pure coal: Low-temperature distillation: Crude oil	-	21.5	22.1	-	17.8	19.8	25.3	25.3	19.4
In pure coal: Low-temperature distillation: Semi-coke	-	62.0	64.0	-	65.6	64.8	60.2	58.0	65.5
Remarks	Average of 1.3 metres thickness. Sample by Sherdahl	Average of 1.3 metres thickness. Sample by Sherdahl	Sample by Hoel og Orvin 1925. Coke: sintered	Sample by K. B. K. 1927	Sample by Orvin 1928. Coke: sintered, brittle	Sample by Orvin 1928. Coke: sintered, brittle	Sample by Orvin 1928. Coke: sintered	Sample by Orvin 1928. Coke: sintered	Sample by Orvin 1928. Coke: sintered and a little brittle
Analyst	Sherdahl 1923	Dr. Gram 1923	Dr. Gram 1925		Dr. Gram 1928	Dr. Gram 1928	Dr. Gram 1928	Dr. Gram 1928	Dr. Gram 1928

from the Sofie Seam.

10	11	12	13	14	15	16	17	18	19	20	21	22
Sample 12, 1928 from borehole 4	Average of preceding analyses nr. 2, 3 and 5—10	Gateway 4, Sofie Mine	Gateway 16, Sofie Mine	Gateway 1, Sofie Mine	Pit 41	15 cm seam uppermost, pit 36, Olsen Mine	Middle seam 0.80 metres, pit 36, Olsen Mine	Lower seam 1.45 metres thick, pit 36, Olsen Mine	Slope, Olsen Mine at St. 4 Eastern side	Pit 31 Skjerva	Pit east of the railway bridge	Average of 30 cargoes 1925
1.15	1.49	-	-	-	-	-	-	-	-	-	-	-
22.25	14.89	8.51	16.04	22.52	9.33	13.10	13.36	6.78	8.48	23.47	8.58	14.36
76.60	83.62	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
1.50	2.58	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
61.20	57.91	-	-	-	-	-	-	-	-	-	-	-
37.65	40.60	-	-	-	-	-	-	-	-	-	-	-
6431	6930	-	-	-	-	-	-	-	-	-	-	-
6166	6650	-	-	-	-	-	-	-	-	-	-	-
6.0	6.2	5.0	4.1	4.1	3.6	6.2	4.6	5.0	6.6	4.1	5.7	-
7.2	8.3	7.6	7.7	7.0	8.5	8.2	7.6	7.4	7.1	7.8	7.4	-
18.0	18.1	21.2	20.2	17.5	24.0	19.9	19.2	16.7	18.7	19.4	19.7	-
68.8	67 4	66.2	68.0	71.4	63.9	65.7	68.6	70.9	67.6	68.7	67.2	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
1.96	3.08	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
50.85	51.14	-	-	-	-	-	-	-	-	-	-	-
49.15	48.86	-	-	-	-	-	-	-	-	-	-	-
8395	8294	-	-	-	-	-	-	-	-	-	-	-
8071	7972	-	-	-	-	-	-	-	-	-	-	-
6.4	5.64	-	-	-	-	-	-	-	-	-	-	-
9.4	9.91	-	-	-	-	-	-	-	-	-	-	-
23.5	21.85	-	-	-	-	-	-	-	-	-	-	-
60.7	62.60	-	-	-	-	-	-	-	-	-	-	-
Sample by Orvin 1928. Coke: sintered		Thickness 1.45 metres	Thickness 0.85 metres							Coke: brittle. Oil: reddish-brown	Coal thickness 2.53 metres	Ester and Sofie coal
Dr. Gram 1928		Sherdahl	Sherdahl	Sherdahl	Sherdahl	Sherdahl	Sherdahl	Sherdahl	Sherdahl 1924	Sherdahl	Sherdahl	Sherdahl

Sample 7, 1928 (Analysis 5) is from borehole 5 on Agnesfeltet from the seam at 31.42—32.74 metres depth. The analysis was made on a sample from a 0.65-metres-long core obtained by drilling from 31.54 to 32.33 metres. The thickness of the seam is 122 centimetres: The percentage of core is 49. The whole core obtained consists of rather bright coal with slickensides. In the middle part of the core five 0.5—3-millimetres-thick partings of shale were found. The streak is dark brown, in part nearly black. On some of the bedding planes imprints of stems are seen. The coal contains visible pyrites. The sample was taken as an average of the whole core. It is probably the upper part of the Sofie Seam.

Sample 5, 1928 (Analysis 6) is from borehole 3 at Tvillingvatna from the seam at a depth of 21.55—22.67 metres. The thickness is about 1.10 metres. The length of the core was about 0.35 metres or 31 per cent. of the thickness. The whole core was almost homogeneous and consisted of semi-dull coal (durite) with some lamination. The streak was dark brown to nearly black. Analysis sample was taken of the whole core.

Sample 4, 1928 (Analysis 8) is from borehole 1 Brøggerdalen of the uppermost part of the Sofie Seam at 77.10—78.03 metres depth. The thickness is 0.90 metres, the length of core obtained 0.40 metres or 43 per cent. of the seam.

The section of the core was: From 77.10 to 77.53 only about 12 centimetres core was obtained, which, owing to pressure and shearing has been given a certain resemblance to carbonaceous shale with slickensides and polishes. From 77.53 to 78.03 we obtained 28 centimetres of core. The coal was semi-dull durite with some lamination. The streak was dark brown. The analysis sample was taken as an average of the whole core, in all 40 centimetres.

Sample 3, 1928 (Analysis 7) is from borehole 1, Brøggerdalen of the lowermost part of the Sofie Seam from 78.38 to 79.09 metres depth. The thickness was about 68 centimetres and the core obtained 30 centimetres or 42 per cent. of the seam. The section of the core was: The uppermost 11 centimetres was made up of semi-dull, massive coal with polishes. The streak was dark brown. The next 8 centimetres was made up of coal-streaks in carbonaceous shale and brownish black shale. The lowermost 11 centimetres was like the upper part. The analysis sample was taken as an average of the whole core.

Sample 9, 1928 (Analysis 9) is of the Sofie Seam in borehole 2 from 45.85 to 46.52 metres. The thickness was about 67 centimetres, and core 25 centimetres or 37 per cent. of the seam. The coal was semi-dull with dark brown to blackish brown streak, and small fissures were filled with calcite. The analysis sample was taken as an average of the whole core.

Sample 12, 1928 (Analysis 10) was from the Sofie Seam from 131.40 to 131.80 metres depth in borehole 4 on Leirhaugen. The thickness was about 40 centimetres, and the length of the core was 23 centimetres or 57 per cent. The upper 7 centimetres were laminated, semidull to dull coal with dark brown streak. The following 7 centimetres were dull, heavy coals with partly conchoidal fracture and dark brown streak. Sample taken as an average of the whole core.

The samples from borehole 5 in Agnesfeltet gave a very low content of ash on both the Ester and Sofie seams. This fact is thus not in accordance with the result obtained from the test-pits worked in 1929 on this area.

In some of the samples, which contained carbonaceous shale or shale partings, the ash content proved to be very high. The percentage of crude oil is moderate, namely 16—19 per cent. The coke is sintered and brittle.

Some analyses of large and smalls from the Sofie Seam made at the mine gave the following results:

Samples	Coal	Ash	By low-temperature distillation		
			Moisture	Crude oil	Coke
Average of 15 analyses from Sofie Mine 1925	Large	10.88	-	-	-
	Smalls	28.95	-	-	-
Average of 14 analyses from Sofie Mine 1924–27	Large	10.27	5.10	20 57	66.03
	Smalls	26.51	4.70	16.84	71.48
Average of 4 analyses from Ester-Sofie Mine 1926—27	Large	7.51	5.49	20.78	64.48
	Smalls	19.42	5.66	17.71	68.06
Average of 8 analyses of the production 1928—29	Large	7.05	-	-	-
	Smalls	28.62	-	-	-
Average of 5 shale samples 1927		49.57	4.44	11.64	79.07

The last analysis shows the percentage of crude oil in carbonaceous shale from the Sofie Seam.

Quantity of coal. In the table below I have tried to include the whole quantity of coal on the different areas, both the workable and the unworkable.

Area	Coal area sq. kilometres	Thickness in metres	Coal quantity in mill. tons
Østfeltet	0 25	1.20 [1]	0 40 [1]
Agnesfeltet	0.29	2.00	0.75
Østre Centerfelt	0.30	0.65 [1]	0 25 [1]
Vestre Centerfelt	0.71	1.20	1.10
Vestfeltet	1.80	0.65 [2]	1.50 [2]
Lagunefeltet	?	?	?
	3.35		4.00

[1] The figures are only approximate.

[2] The figures are only estimated and quite uncertain.

The Sofie Seam has not been uncovered in Østfeltet, but it is without doubt distributed over the western part of this area. Owing to the tectonical disturbances it is doubtful whether it can be worked here.

In Agnesfeltet a coal thickness of 2.00 metres has been calculated. This is a little less than the average of the thicknesses found in the pits and borehole 5. There is, however, reason to believe that the thickness will decrease downwards along the dip, because it did so in the mine on the western side of the Agnes Fault.

In the three pits worked by Sherdahl 1929 he found very high ash contents. In the pits 67, 69, and 70 the average ash percentage was thus 31.85, 18.53 and 24.44 respectively. This is far more than usual.

In Østre Centerfelt the remaining coal cannot be worked, since the mines here have been closed down. The lower part may perhaps be examined by piercing the fault from a possible future mine on Agnesfeltet.

In Vestre Centerfelt an average thickness of 1.20 metres has been calculated, which is about the average of the thickness found in the pits and drill records.

In Vestfeltet it is doubtful whether the Sofie Seam can be mined at all, because the thickness was found too trifling both in borehole 4 and pit 31. This was also the case in borehole 2 near the boundary of this field. In Lagunefeltet the seam is quite unknown, but it is hardly more workable here than in Vestfeltet.

It is thus only in Agnesfeltet and Vestre Centerfelt that the Sofie Seam can at present be regarded as workable, with a total coal quantity of about 1.85 mill. tons, which reduced by 20 per cent. for loss by mining will give 1.48 mill. tons net.

Advokat Seam.

This coal seam is the uppermost of the lower coal and shale horizon. The seam is everywhere divided by stone bands in greater measure than any of the other seams.

Drilling in 1928 showed this seam to be very irregular, the only part revealing any great thickness being the eastern areas of the field including the eastern part of Østre Centerfelt. On the western areas it is either only trifling or missing altogether. The sections from east to west are shown in fig. 37.

In Østfeltet the seam is known from two pits:

In the cutting about 200 metres from the front of Lovénbre No. 1 with co-ordinates abt. $x = +9000$, $y = +11390$, worked by Sherdahl in 1921. The cutting was filled up by gravel at the time of my visits, and thus I do not know the section. Analysis 2 is of loose coal pieces from this spot.

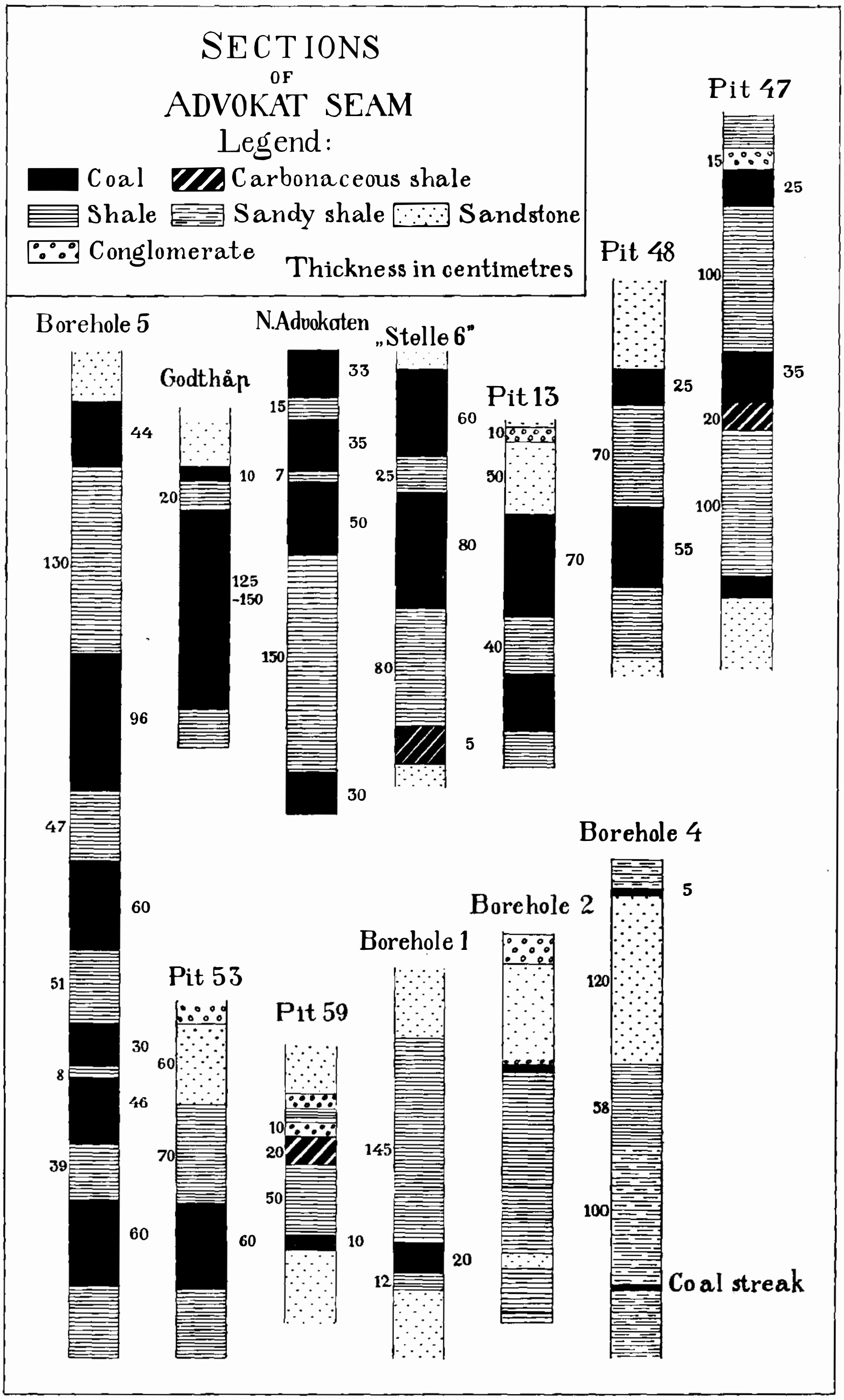
SECTIONS OF ADVOKAT SEAM
Legend:
Coal
Carbonaceous shale
Shale
Sandy shale
Sandstone
Conglomerate
Thickness in centimetres
Borehole 5
Godthåp
N.Advokaten
„Stelle 6"
Pit 13
Pit 48
Pit 47
Borehole 4
Borehole 2
Borehole 1
Pit 53
Pit 59
Coal streak

Fig. 37.

The other point is the *pit 37* with co-ordinates abt. x = + 9275, y = ca. + 11010. The depth was 2.50 metres, of which the upper 1.5 metres was worked in gravel. Downwards was found 0.70 metres sandstone and 0.30 metres coal. Analysis 8 is of coal from this seam. A 2.4-metres-long slope was driven down along the seam, which had here the same thickness. This seam is situated so close to the sandstone that it must belong to the Advokat Seam. I am of the opinion that further coal seams belonging to this horizon would have been found here if the work had been continued downwards, because it is near borehole 5, where the Advokat Seam consists of several coal benches. The section is measured by Sherdahl.

The Advokat Seam was one of the first seams found in the coalfield, and during the first period of working several cuttings and slopes were worked in Agnesfeltet and Østre Centerfelt. I have had no opportunity to see the exposed sections at these points, because they were all filled up with débris on my first visit to Kings Bay. Below I have included the available sections measured by others.

As will be seen from borehole 5 and the pit-sections the seam varies a great deal also in this area. The drill record reveals, in all, six different coal benches with a total thickness of 3.36 metres with five intermediary shale bands with a total thickness of 2.75 metres (fig. 37). We got core only from the two beds of 60 and 46 centimetres thickness. It is thus possible that the upper benches are impure and contain shale-partings.

The pit sections were the following:

Godthåp. Here the coal thickness was about 1.5 metres according to Karl Bay.

Nye Advokaten, x = + 8980, y = + 10965. The section was measured by Hoel about 10 metres from the mouth of the adit. (fig. 37).

Thickness in metres	
0.33	Coal
0.15	Shale
0.35	Coal
0.07	Shale
0.50	Coal
1.50	Shale
0.30	Coal

Pit 13. Co-ordinates: x = + 9070, y = + 10800. Section measured by Hoel (fig. 37).

Thickness in metres	
8.00	Sandstone
0.10	Conglomerate
0.50	Sandstone
0.70	Coal
0.40	Shale
0.40	Coal
	Shale with plant fossils

"*Stelle 6*" is situated somewhere along the outcrop of the Advokat Seam, but I do not know the exact spot, as there are several old cuttings of which no details have been available. The geological section was measured by Wex 1911 (fig. 37).

Thickness in metres	
	Sandstone, slaty
0.60	Coal (Oberbank)
0.25	Stone band
0.80	Coal (Unterbank)
0.80	Sandstone, slaty
0.20—0.25	Coal, impure
	Sandstone, compact

Gamle Advokaten (Pit 14?). Co-ordinates: x = +9160, y = +10455. Geological section, (old measurement).

Thickness in metres	
	Sandstone
	Coal-streak
0.25	Shale, brown
	Coal seam, thickness not specified
	Shale

At Nye Advokaten there were four coal benches with a total thickness of 1.48 metres, and three intermediary stone bands with a total thickness of 1.72 metres. At pit 13 there were two coal benches with a total thickness of 1.10 metres and a stone band of 0.40 metres. Hoel says in his report that the seam here commonly consisted of two coal benches with an intermediary shale of from 0.40 to 1.00 metre thickness.

In Østre Centerfelt the seam has been uncovered at the following points.

Test-pit 48. Co-ordinates: x = + 9021, y = + 10398, elevation 46.7 metres, depth 5.9 metres. The dip was 36° SW. Work finished September 1924. The geological section is measured by Sherdahl:

Thickness in metres	
	Sandstone
0.40	Conglomerate
3.00	Sandstone and shale in alternation
0.25	Coal
0.70	Carbonaceous shale and shale
0.55	Coal
0.50	Shale
0.50	Sandstone

Analysis 9 is taken as an average of the upper and lower coal benches. Analysis from the shale and carbonaceous shale layer gave the following result: ash 80.76, sulphur 3.98, and by low-temperature distillation: water 5.6, gas 4.6, crude oil 3.0, semi-coke 86.8 per cent.

Test-pit 43. Co-ordinates: x = + 10032, y = + 10366, elevation 46 metres, depth 8.3 metres. Section by Sherdahl:

Thickness in metres	
2.50	Gravel
1.25	Sandstone, dark and soft
0.07	Coal-streak
4.55	Sandstone, dark and soft

This pit is situated in the layers below the Advokat Seam.

Test-pits 46 and 47. Co-ordinates for pit 46: x = +9075, y = + 10166, elevation 42.8 metres. Co-ordinates for pit 47: x = + 9066, y = + 10169. The two pits form a coherent section, the pit 46 being worked down from the mouth of an 11-metres-long slope along the dip of the Advokat Seam and pit 47 as a rise from the bottom of this slope (fig. 37).

Thickness in metres		Thickness in metres	
	Sandstone, rust-coloured	1.00	Shale, dark grey
0.50	Shale, soft		Coal-streak
0.15	Conglomerate	6.30	Sandstone, the upper and middle part light, the lower part dark
0.25	Coal. Analysis 10	0.25	Coal. Analysis 12
1.10	Shale, dark	3.50	Shales and argillaceous sandstones
0.35	Coal. Analysis 11		The Sofie Seam
0.20	Carbonaceous shale		

An analysis of the 0.20-metres-thick carbonaceous shale gave 50.64 ash and 4.34 sulphur, and by low-temperature distillation: water 4.7, gas 4.9, crude oil 11.0. semi-coke 79.4 per cent.

Test-pit 53. Co-ordinates: x = +9030, y = +9760, elevation 31.20 metres, depth 5.80 metres. From the bottom of the pit 1.30 metres was drilled down. Geological section measured by Sherdahl (fig. 37):

Thickness in metres	
1.00	Gravel
2.00	Sandstone
0.90	Conglomerate
0.60	Sandstone, hard
0.70	Shale
0.60	Coal
1.30	Drilled in stone

Test-pit 59. Co-ordinates: x = + 8811, y = + 10054. The pit was driven upwards from the Sofie Mine. Elevation of the lower mine here - 31 metres and at the conglomerate — 23.4 metres. Work finished January 1927. Geological section measured by Sherdahl. The rise was worked along a fault with a displacement of about 10 metres. The distance between the foot wall and hanging wall of the Sofie Seam was here about 4 metres.

Thickness in metres	
0.60	Sandstone, coarse and hard
0.10	Conglomerate
0.10	Shale
0.10	Conglomerate as above
0.20	Carbonaceous shale. Ash 54.99 per cent., crude oil 11.54 per cent.
0.50	Shale, black with lenses of sandstone
0.10	Coal. Ash 33.24 per cent., crude oil 17.63 per cent.
1.90	Sandstone, hard and flinty
0.60	Shale, dark
0.60	Carbonaceous shale. Ash 53.30 per cent., crude oil 11.78 per cent.
4.00	Sandstone with two thin layers of shale
	The hanging wall of the Sofie Seam

On the western areas the development of the Advokat Seam will be seen from the drill records.

In fig. 37 I have included the available sections of the Advokat Seam from east to west. As will be seen from these sections the seam decreases in a westerly direction, and is unworkable already in the western part of Østre Centerfelt.

Quality of coal. From the earlier working of this seam the ash-content has been found to be very high, and even by cleaning it is difficult to get a sufficiently low ash content. The Advokat coals are for this reason poor bunker coals, nor are they suitable for the production of semi-coke, because this latter will be very rich in ash. They might, however, be used as raw material for crude oil distillation at Kings Bay, if distillation or hydration works were to be built there in the future.

From the analysis table it will be seen that these coals also contain much sulphur and volatile matter. Accordingly they also give a high percentage of crude oil by distillation.

The analysis table includes two analyses of cores obtained by the drilling of borehole 5. I shall give below a detailed description of these cores.

Sample 1, 1928 (Analysis 7) is from a depth of 10.46 to 11.14 metres in borehole 5. The thickness is 60 centimetres, when the drilled length is reduced in proportion to the dip, which is here 30°. The length of the core was 55 centimetres or 80 per cent. of the seam. The coal core shows a greatly varying dip, which points to tectonical disturbances along the seam. The uppermost 13 centimetres consisted of carbonaceous shale with dip 10—60° and slickensides. Downwards followed 34 centimetres coal, semi-dull and partly laminated with 0.5—1 millimetre thick partings of shale. The streak is brown. The lowermost 8 centimetres is carbonaceous shale with irregular bedding. The analysis sample was only taken from the 34 centimetres coal core. The actual coal seam is thus hardly above 40 centimetre thick.

Analyses of coal from

Number of analysis		1	2	3	4	5	6
Locality of sample		100 kilogrammes coal	Cutting in front of Lovénbre No. 1	Advokaten	Advokaten	Advokaten	Sample 2, 1928, borehole 5
	Moisture	1.00	1.20	0.80	1.00	1.50	0.63
	Ash	18.00	20.85	17.00	15.40	11.75	7.38
	Coal substance	81.00	77.95	82.20	83.60	86.75	91.99
	Carbon	63.49	-	66.00	65.29	68.62	-
	Hydrogen	6.18	-	5.41	5.75	5.52	-
	Sulphur	4.50	5.82	4.23	4.34	5.49	7.62
	Nitrogen and oxygen	6.83	-	6.56	8.22	7.12	-
	Coke	56.70	55.85	59.50	56.83	58.00	46.80
	Volatile matter	42.30	42.95	39.70	42.17	40.50	52.57
	Gross calorific value	-	6536	6984	7035	7375	7885
	Net calorific value	-	6280	6660	6719	7068	7583
Low-temperature distillation	Water	4.1	4.6	-	-	-	4.0
	Gas	8.7	8.8	-	-	-	10.2
	Crude oil	20.7	22.4	-	-	-	24.0
	Semi-coke	66.5	64.2	-	-	-	61.8
In pure coal	Carbon	78.38	-	80.31	78.10	79.11	-
	Hydrogen	7.63	-	6.58	6.87	6.36	-
	Sulphur	5.56	7.5	5.14	5.19	6.33	8.29
	Nitrogen + Oxygen	8.43	-	7.97	9.84	8.20	-
	Coke	47.77	44.90	54.13	49.52	53.31	42.85
	Volatile matter	52.23	55.10	45.87	50.48	46.69	57.15
	Gross calorific value	-	8385	8496	8415	8501	8572
	Net calorific value	-	8061	8104	8043	8158	8248
In pure coal, Low-temperature distillatien	Water	3.8	4.4	-	-	-	3.6
	Gas	10.7	11.2	-	-	-	11.1
	Crude oil	25.6	28.7	-	-	-	26.1
	Semi-coke	59.9	55.7	-	-	-	59.2
Remarks			Loose coal pieces. Sample by Orvin 1922				Coke: molten and firm
Analyst		Dr. J. Gram	Dr. J. Gram 1922	Dr. J. Gram	Dr. J. Gram	Dr. J. Gram	Dr. J. Gram 1928

the Advokat Seam.

7	8	9	10	11	12	13	14	15
Sample 1, 1928, borehole 5	Pit 37	Pit 48, average of both seams	Pit 47, upper bed, 0.25 metres	Rise 47, middle bed, 0.35 metres	Pit 46. The seam below Advokaten, 0.25 metres	Coal from Advokaten	Average of Analyses Nos. 3, 4, 5	Average of Analyses 1, 2, 6, 7, 8
0.70	-	-	-	-	-	1.2	1.10	-
13.00	9.90	22.69	16 01	11.97	16.72	16.2	14.72	-
86.30	-	-	-	-	-	-	84.18	-
-	-	-	-	-	-	-	66.63	-
-	-	-	-	-	-	-	5.56	-
9.28	-	7 03	7.55	7.16	5.87	-	4.69	-
-	-	-	-	-	-	-	7.30	-
48.50	-	-	-	-	-	53.5	58.11	-
50 80	-	-	-	-	-	-	40.79	-
7411	-	-	-	-	-	-	7131	-
7127	-	-	-	-	-	-	6816	-
3.6	5.2	4.4	4.7	1.9	6.8	4.5	-	4.30
11.6	8.4	6.9	8.4	11 1	7.7	-	-	9.54
23.6	22.8	19.9	20.6	23.2	19 0	24.5	-	22.69
61.2	63.6	68 8	66.3	63.8	66.5	-	-	63.47
-	-	-	-	-	-	-	79.16	-
-	-	-	-	-	-	-	6.60	-
10.76	-	-	-	-	-	-	5.57	-
-	-	-	-	-	-	-	8.67	-
41.15	-	-	-	-	-	-	52.32	-
58.85	-	-	-	-	-	-	47.68	-
8588	-	-	-	-	-	-	8471	-
8264	-	-	-	-	-	-	8102	-
3.3	-	-	-	-	-	-	-	-
13.4	-	-	-	-	-	-	-	-
27.3	-	-	-	-	-	-	-	-
56.0	-	-	-	-	-	-	-	-
Coke: molten and firm								
Dr. J. Gram 1928	Sherdahl	Sherdahl 1924	Sherdahl 1924	Sherdahl 1924	Sherdahl 1924	Duisburg 1926		

Sample 2, 1928 (Analysis 6) is also from borehole 5, from the coal bed at the depth of 9.48—10.00 metres. The thickness is 46 centimetres, and the length of the core 35 centimetres or 67 per cent. of the whole bed. The coal is rather dull and massive with a brown streak. Calcite is found on tiny fissures. The analysis sample is the average of the whole core.

Both the samples contain a high percentage of crude oil, namely 23.6 and 24 per cent. in crude coal and 29.25 and 26.11 in pure coal. The coke is molten and strong, and the coals would be very suitable for crude oil distillation. The ash content is, however, high in sample 1, and the thickness and extension of the seam is small. For this reason it is, after all, not of any great value.

Also the shales of the Advokat horizon yield crude oil by distillation. Thus the shale band between the two coal benches gave 8 per cent. Sherdahl made some crude oil determinations in the autumn of 1922. He found that the carbonaceous shale from the cutting in front of Lovénbre No. 1 gave 9.42 per cent. and from Nye Advokaten 8.5 per cent. crude oil. In grey shale from the two points he found 2.10 and 5.0 per cent. respectively.

Shale samples taken by Hoel in 1918 and analysed by Andreas Rødland in 1922 gave:

	A	B
Crude oil	8.67	8.75
Moisture	2.55	2.00
Coke	86.45	85.00
Gas	2.64	3.25
	100.31	99.00

It is thus only the brown shale and the carbonaceous shale which can be used as crude oil material, the light shales being too poor.

Quantity of coal. It is difficult to make a calculation of the quantity of coal in this seam. Only Østfeltet, Agnesfeltet, and the eastern part of Østre Centerfelt can be taken into consideration. On the western areas the seam is entirely unworkable.

Area	Coal area sq. kilometres	Thickness in metres	Coal quantity in mill. tons
Østfeltet	0.06	1.3 [1]	0.1 [1]
Agnesfeltet	0.25	1.5	0.49
Østre Centerfelt	0.40 [1]	0.7 [1]	0.36 [1]
	0.71	-	0.95

[1] The figures are only approximate.

In the above calculation I have included the coal thickness down to 0.60 metres. It may be doubted whether the seam will ever be workable in Østre Centerfelt. If we calculate with 18 per cent. crude oil net by distillation, the coal would give in all 170 000 tons. The shales in this area will scarcely give more than one-sixth of this quantity, or about 30 000 tons, and they are thus of no great importance in the valuation of the seam. In mining this seam a great part of the coal and shale would be lost, and the above-mentioned figures will have to be reduced by at least 20 per cent.

In 1920, 277 tons were raised from Nye Advokaten, but of this quantity nothing was exported. This seam has therefore only been worked experimentally.

Agnes-Otelie Seam.

This seam is situated stratigraphically 70—80 metres above the Advokat Seam. Between the two seams there is no other coal seam, but only sandstones and conglomerates.

The seam has been worked in Agnes Mine in Agnesfeltet, where it has been exhausted, and in Otelie Mines I and II in Østre Centerfelt; these mines were both closed down after a short period of work, because they proved to be profitless.

The Agnes Mine is apparently situated on a lower stratigraphical level than the two mines in Østre Centerfelt, but this is only due to the Agnes Fault, which limits the Agnes Mine towards the west. This mine was already filled with water on my first visit to Kings Bay in 1922, and grooves on the surface showed that the hanging wall had broken down over great areas. The whole Agnes Syncline had then been worked out, and the mine stretched beneath the carboniferous rock on the surface, where the seam had been cut by a fault in an east-westerly direction. I should think it most probable that this had not been a fault but the thrust plane, and that on working further in that direction the Carboniferous rock would have been met with.

According to the mining company's report, 65 548 tons of coal have been taken out of the Agnes Mine.

The seam in the Agnes Mine consisted of two different coal benches with an intermediate band of sandstone. The thicknesses were according to Sherdahl as follows:

	Average in metres	Maximum in metres	Minimum in metres
Upper bench	0.70	1.40	0.20
Sandstone band	0.42	1.00	0.10
Lower bench	1.20	1.80	0.30

The average thickness was thus 1.90 metres. Mining was commenced in 1917 and the works were closed down in 1921.

Sherdahl analysed the sandstone band and found respectively 0.74 and 3.14 per cent of crude oil by distillation. The sandstone is thus valueless as raw material for crude oil distillation.

No exact average samples have been analysed from the Agnes Mine, but the coal had certainly about the same ash content as the coals from the Otelie Mines. When the exported coal from Agnes Mine contained 17—18 per cent. ash, 3—4 per cent. of shale must have been included in the coal.

As the seam is missing in Østfeltet and has been worked out in Agnesfeltet, it is of interest for future mining only west of the Agnes Fault. On my visit in 1922 I measured two sections in the Otelie Mine I. The sections are seen from fig. 38. In the summer of 1923 the mine was inaccessible.

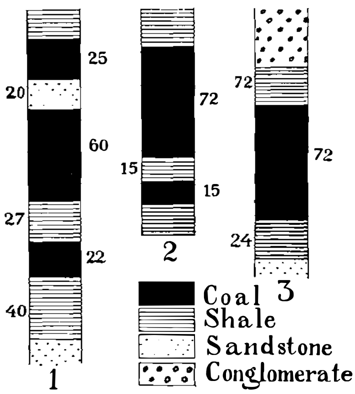

Fig. 38. Sections of the Agnes-Otelie Seam.
1 and 2. From Otelie Mine I.
3. From borehole 4. Thickness in centimetres

The mine had chiefly been opened for development work by a main slope along the dip, and from these short gateways led towards the east and west. The bottom of the slope and the western gateways were partly filled with ice already at the time of my visit.

The section PI is measured about 60 metres down the main slope and 10 metres into the uppermost eastern gateway, and PII not far from the bottom of the slope at the surveying bolt 21. The samples were taken as an exact average of the different benches. The analyses made by Dr. Gram are included in the analysis table. I also took some shale samples for crude oil distillation.

Geological section at PI:

Thickness in centimetres	
25	Coal (PIa)
20	Sandstone (PIb)
60	Coal (PIc)
27	Shale, brown (PId)
22	Coal (PIe)
40	Shale (PIf)
	Sandstone

Section at PII:

Thickness in centimetres	
	Shale, grey (PIIa)
72	Coal with a 3-centimetres-thick sandstone parting near the hanging wall (PIIb)
15	Shale (PIIc)
15	Coal (PIId)
	Shale (PIIe)

Above the shale of the hanging wall is a light conglomerate overlain by green conglomerate and green sandstone.

The shales from the Agnes-Otelie Seam are of no economic value as raw material for crude oil distillation. The grey shale in the hanging wall gives no crude oil by distillation; the shale between the upper and

Analyses of shale from Otelie Mine I:

Number of sample	PId	PIf	PIIa	PIIc	PIIe
Moisture	-	-	-	1.05	1.05
Ash	-	-	-	74.45	65.10
Coal substance	-	-	-	24.50	33.85
Coke	-	-	-	85.50	77.30
Volatile matter	-	-	-	13.45	21.65
By low-temperature distillation:					
Moisture	2.00	4.0	-	4.0	3.6
Crude oil	3.2	1.2	0.0	3.2	8.8
Semi-coke	93.6	93.6	-	90.0	83.2
Gas	1.2	1.2	-	2.8	4.4
In pure coal:					
Coke	-	-	-	45.10	36.04
Volatile matter	-	-	-	54.90	63.96
By distillation:					
Distilled water	-	-	-	12.2	7.5
Crude oil	-	-	-	13.1	26.0
Semi-coke	-	-	-	63.3	53.5
Gas	-	-	-	11.4	13.0

the middle bench gives 3.2 per cent., and the shale in the foot wall gives 1.2 and 8.8. The last figure is certainly unusually high.

As will be seen from the sections, the coal seam varies a good deal. The upper bench, which at PI is 25 centimetres, is almost missing at PII, and the sandstone below this bench is missing in the western part of the mine. It was probably the two upper benches which were found in the Agnes Mine, whereas the two lower ones are those found in Otelie Mine II. In the westernmost part of this mine the upper bench was entirely missing. This points to a distinct interchange of the benches, so that the upper bench is wedging out towards the west and the lower bench towards the east.

The total thickness in Otelie Mine I was considerably less than in the Agnes Mine, at PI 107 centimetres and at PII 87 centimetres. According to information from Sherdahl the total thickness farthest west in this mine was 102 centimetres.

The microscopic examination of the stone band in Otelie Mine I showed a compact sandstone consisting almost solely of rounded quartz grains up to 0.1 millimetre, larger grains being an exception. Some mica. In the matrix there are pyrites and secondary iron oxides as well as coaly substance.

The sandstone below the Otelie Seam in Otelie Mine I contains large grains of quartz of up to 0.5 millimetres in a black to blackish-brown matrix, made up of pyrites edged with secondary iron oxides. Some grains are quartzitic. Some muscovite is also observed.

The rock above the Otelie Mine is a sandstone with grains of quartz with a diameter of up to 0.5 millimetre. This sand forms about

Analyses of coal from

Number of analysis		1	2	3	4	5	6	7	8	9
Locality of sample		Agnes Mine	Agnes Mine	Agnes Mine	Agnes Mine	Agnes Mine	Agnes coal in stock at Kasfjord	Agnes coal in stock at Bodø	Agnes coal in stock at Kabelvåg	Agnes coal in stock at Lødingen
Moisture		1.60	1.00	1.60	1.58	2.00	5.98	7.30	4.76	7.66
Ash		19.80	11.00	7.40	11.12	8.80	21.31	16.43	16.04	17.22
Coal substance		78.60	88.00	91.00	87.30	89.20	72.71	76.27	79.20	75.12
Carbon		61.83	70.20	73.19	-	-	57.27	59 26	62.26	59.01
Hydrogen		6.00	6.01	6.50	-	-	4.82	4.79	5.04	4.69
Sulphur		3.37	2.68	3.18	1.12	0.75	2.66	1.18	2.87	1.59
Nitrogen and oxygen		7.40	9.11	8.13	-	-	7.96	11.04	9.03	9.83
Coke		60.68	60.70	-	55.85	55 00	60.80	56.36	59.12	59.53
Volatile matter		37.72	37.30	-	42.57	43.00	33.22	36.34	36,12	32.81
Gross calorific value		6448	7271	7520	7217	7332	5853	5993	6423	5985
Net calorific value		6114	6940	7159	6923	6083	5569	5691	6122	5686
Low-temperature distillation	Water	-	-	-	-	-	-	-	-	-
	Gas	-	-	-	-	-	-	-	-	-
	Crude oil	-	-	-	-	-	-	-	-	-
	Semi-coke	-	-	-	-	-	-	-	-	-
In pure coal	Carbon	78.66	79.81	80.42	-	-	78.77	77.69	78.62	78.55
	Hydrogen	7.64	6.83	7.14	-	-	6.62	6.28	6.36	6.25
	Sulphur	4.29	3.02	3.49	1.28	0.84	3.65	1.54	3.62	2.12
	Nitrogen and oxygen	9.41	10.34	8.95	-	-	10.96	14.49	11.40	13.08
	Coke	52.01	57.62	-	51.18	51.80	54.34	52.35	54.39	56.32
	Volatile matter	47.99	42.38	-	48 82	48.20	45.66	47.65	45.61	43.68
	Gross calorific value	8204	8262	8264	8276	8220	8049	7857	8109	7967
	Net calorific value	7793	7893	7878	7952	7996	7692	7518	7766	7630
In pure coal, Low-temperature distillation	Water	-	-	-	-	-	-	-	-	-
	Gas	-	-	-	-	-	-	-	-	-
	Crude oil	-	-	-	-	-	-	-	-	-
	Semi-coke	-	-	-	-	-	-	-	-	-
Remarks		Sample by Sherdahl 1919	Sample by Sherdahl 1919							
Analyst							Dr. Gram 1920	Dr. Gram 1920	Dr. Gram 1920	Dr. Gram 1920

the Agnes-Otelie Seam.

10	11	12	13	14	15	16	17	18	19	20	21	22	23
Average of analyses No. 6, 7, 8, 9	Average of 14 cargoes in 1920	Otelie Mine I. Upper bench. PIa	Otelie Mine I. Middle bench. PIc	Otelie Mine I. Lower bench. PIe	Otelie Mine I. Upper bench. PIIb	Otelie Mine I. Lower bench. PIId	Skjerva. Loose coal pieces	Pit in front of Brøggerbreen	Average of monthly analyses from Oct. 1924 to June 1925. Otelie Mine II			Average of the analyses No. 12—16	Average of 30 cargoes 1925
									Large	Smalls	7/10 large, 3/10 smalls		
6.43	1.99	1.87	1.95	1.24	1.95	1.82	4.30	6.30	-	-	-	1 77	-
17.75	17.98	14.37	12.96	14.09	13.20	18.03	6.00	3.33	11.17	14.40	12.24	14.53	11.92
75.82	80.03	83.76	85.09	84.67	84.85	80.15	89.70	90.37	-	-	-	83.70	-
59.41	-	-	-	-	-	-	-	-	-	-	-	-	-
4.84	-	-	-	-	-	-	-	-	-	-	-	-	-
2.08	2.89	3.72	4.80	2.39	4.23	4.98	1.72	0.83	-	-	-	4.02	-
9.49	-	-	-	-	-	-	-	-	-	-	-	-	-
58.95	60.05	56.15	55.60	61.48	57.90	61.00	63.70	56.75	-	-	-	58.22	-
34.62	37.96	41.98	42.45	37.28	40.15	37.18	32.00	36.95	-	-	-	40.01	-
6014	6606	6920	7178	6991	7058	6623	6103	6887	-	-	-	6954	-
5767	6335	6637	6891	6709	6771	6352	5793	6556	-	-	-	6672	-
-	-	7.2	8.0	7.2	8.0	8.0	11.2	-	5.05	5.90	5.62	7.68	-
-	-	9.2	10.8	8.4	8.8	8.0	5.2	-	8.45	7.55	7.87	9.04	-
-	-	18.4	17.2	16 0	16.4	14.8	8.4	-	20.00	18.53	19.56	16.56	-
-	-	65.2	64.00	68.4	66.8	69.2	75.2	-	66.50	68.02	66.95	66.72	-
78.41	-	-	-	-	-	-	-	-	-	-	-	-	-
6.38	-	-	-	-	-	-	-	-	-	-	-	-	-
2.73	3.60	4.44	5.64	2.82	4.99	6.21	1.92	0.92	-	-	-	4.80	-
12.48	-	-	-	-	-	-	-	-	-	-	-	-	-
54.35	53.60	49.88	50.11	55.97	52.68	53.61	64.33	59.11	-	-	-	52.45	-
45.65	46.40	50.12	49.89	44.03	47.32	46.39	35.67	40.89	-	-	-	47.55	-
7995	8230	8261	8435	8256	8319	8264	6804	7621	-	-	-	8307	-
7652	7917	7937	8111	7932	7995	7940	6480	7297	-	-	-	7983	-
-	-	6.4	7.1	7.0	6.8	7.6	7.7	-	-	-	-	6.98	-
-	-	11.0	12.7	9.9	10.4	10.0	5.8	-	-	-	-	10.80	-
-	-	22.0	20.2	18.9	19.4	18.5	9.4	-	-	-	-	19.80	-
-	-	60.6	60.0	64.2	63.4	63.9	77.1	-	-	-	-	62.42	-
		Sample by Orvin 1922. Exact average	Sample by Orvin 1922. Exact average	Sample by Orvin 1922. Exact average	Sample by Orvin 1922. Exact average	Sample by Orvin 1922. Exact average	Sample by Orvin 1923. Strongly oxidised	Sample by Orvin. Not average					
Dr. Gram		Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1924	Dr. Gram 1924	Sherdahl	Sherdahl	Sherdahl		Sherdahl

90 per cent. of the rock. Between the grains is a black matrix, partly of organic origin and containing some muscovite.

From Otelie Mine I a total of 9435 tons of coal was raised.

In the autumn of 1923 the Otelie Mine II was opened farther to the west. The thickness was here 1.5 metre at the outcrop, but downwards along the dip it decreased, and according to Sherdahl the total thickness of 110 metres down the main slope was only 88 centimetres with a stone band of 16 centimetres. It is the middle and lowermost benches from the Otelie Mine I which are found here. By a gateway towards the east the two mines were linked up with each other. The mine was closed down because it could not be run on a profit-earning basis.

Farther to the west immediately at the Josefine Fault the seam was exposed by Sherdahl in 1923. The thickness was here 2.3 metres. It is thus likely that a small area in the northwestern part of Østre Centerfelt has a greater thickness than in the mines.

In Vestre Centerfelt the coal seam is refound in the mountain slope about 90—100 metres above sea-level, and the outcrop from here sinks westward toward Brøggerdalen. The seam has not been exposed in this area, as the coal area is of very small extent. The distance along the dip from the outcrop to the thrust-plane scarcely exceeds 250 metres.

In Vestfeltet the seam was pierced by borehole 4 on Leirhaugen, where the thickness was 72 centimetres including shale partings. Further, it has been uncovered at Skjerva, where, according to Sherdahl, a test pit had been worked 8 metres down without reaching solid coal. Sherdahl found 12.55 per cent. of crude oil by distillation of coal mixed with shale from this spot. The thickness is thus still unknown here. This is also the case in Lagunefeltet.

In 1923 I tried to uncover the seam in front of Brøggerbreen, but did not reach the solid rock.

The analyses of the Agnes-Otelie Seam will be seen from the analysis table. As will be seen, several of the samples are from the oxidised outcrop and are thus strongly weathered. The sulphur content of these samples is also lower, because the pyrites have been oxidised. The red-coloured ash from these coals is due to this content of pyrites.

The production analyses from the Otelie Mine II, according to Sherdahl, showed 12.2 per cent. of ash and 2.34 per cent. of water. By dry distillation at 500° C they gave 6.1 per cent. moisture and 19.6 per cent. crude oil.

Quantity of coal. The Agnes-Otelie Seam does not exist in Østfeltet and has been worked out in Agnesfeltet. In Østre Centerfelt the seam is well known from the two mines which have been worked in this area. In Vestfeltet the seam is known only from borehole 4. The figures concerning the thickness in the western areas cannot therefore be relied upon.

In the table below I have included both coal in sight and probable coal. In Østre and Vestre Centerfelt I have calculated with a thickness of 1.00 metres, and in Vestfeltet with only 0.80 metres. It is thus very difficult to say how much of the existing quantity of coal may be workable. At present the workability of the seam is doubtful on the whole.

The table below shows the whole existing coal quantity of the Agnes-Otelie Seam.

Area	Coal area in sq. kilometres	Thickness in metres	Coal quantity in mill. tons
Østre Centerfelt	0.4	1.00	0.52
Vestre Centerfelt	0.16	1.00	0 21
Vestfeltet	1.5	0.80[1]	1.50[1]
Lagunefeltet	0.22	0.80[2]	0.23[2]
	2.38	-	2.46

As will be seen, the thickness in not great anywhere in this seam, and it is thus very doubtful whether the seam can be worked at a profit unless coal prices are exceptionally high. Owing to the stone band the coal must be separated very carefully.

Josefine Seam.

This coal seam was found in 1920 about 20 metres above the Agnes-Otelie Seam, and the work was concentrated on this seam in the Josefine Mine. The Josefine Seam does not occur east of the Josefine Mine in Østre Centerfelt, because the upper part of the sequence is missing eastwards. In Josefine Mine the seam contained no partings of shale and sandstone. In the hanging wall, however, a thin layer of carbonaceous shale occurred, which frequently fell down during the blasting and got mixed with the coals.

The hanging wall above the carbonaceous shale was made up of a light grey, soft shale with an abundance of plant fossils. The foot wall consisted of an argillaceous, laminated sandstone.

The thickness of the seam varied from 0.5 to 3 metres in the mine. Also greater thicknesses were met with, but these were of a secondary nature, due to folding of the seam.

The mine extended 135 metres beyond the outcrop of the thrust plane above, and was limited towards the west by the Josefine Fault. In the northwestern part of the mine the thickness was too small to be worked. Also towards the south east the work had soon to be stopped, because the seam pinched out in this direction behind a coal-pocket. The reason

[1] The figures are only approximate.
[2] The figures are only estimated and quite uncertain.

is that the seam along this boundary line has been folded together during the thrusting, and behind this fold the seam had been scoured away by shearing.

The work was particularly difficult in the lower part of the mine owing to great tectonical disturbances. The top wall was bad everywhere, and the timbering was a very expensive item.

I have mentioned on page 63 some of the typical disturbances in this mine. The great coal-pockets were up to 7—8 metres in height. Also several north-southerly faults were met with in the mine. These can be seen from the map and the section fig. 19. In this section the coal seam is seen along the western main slope in Josefine Mine.

In Vestre Centerfelt, Vestfeltet, and Lagunefeltet the Josefine Seam is altogether unknown because the seam has not been uncovered in these areas. West of the Josefine Fault it is refound cropping out in the mountain slope about 120 metres above sea-level. From here the outcrop runs down towards Brøggerdalen. It can hardly be doubted that the thickness of the Seam is fairly good also here. However, the seam is situated so close up to the thrust plane that the extension of the seam along the dip cannot amount to more than about 200 metres, and near the thrust plane great disturbances may also occur. The coal seams cropping out in the mountain slope here might perhaps best be worked from a common adit crossing all the seams. Obviously, the outcrops will first have to be exposed by cuttings to be certain that the coal thicknesses are great enough. From the pieces of coal found down along the slope the seams here must be presumed to have partly workable thicknesses.

In Vestfeltet the position of the Josefine Seam is somewhat doubtful. If the distance between the Josefine Seam and the Agnes-Otelie Seam in Østre Centerfelt and in Vestfeltet is the same, it must be the Josefine Seam which was pierced from a depth of 16.82 to 16.95 metres in borehole 4 on Leirhaugen. If this is the case the Josefine Seam is of no value here. Yet the shales on top of Leirhaugen are very similar to those above the Josefine Seam, and it is thus possible that the distance between the two seams is greater westward. In this case, however, the seam is here situated so close to the surface that it can hardly be worked in the northeastern part of this area.

The Josefine horizon also occurs in Lagunefeltet, but the seam has not been uncovered.

The Josefine Seam had been exhausted on Østre Centerfelt in the spring of 1924 and the mine was then closed down. In all about 300 000 tons were raised from this mine. The average thickness was about 1.40 metres.

Quality of coal. Fig. 39 shows some sections from the mine. In these localities average samples have been taken from the foot wall to the top wall. In 1922 I took six such samples and in 1923 one, namely the one from room 26 b. The analyses of coal from these spots, e. g. PI—PVI and 26 b, represent the most exact analyses from this seam. As will be seen from the analysis table, the content of ash is considerably higher in the exported coals than in these mine samples.

Sample PI (Analysis 1 and 2) is from a pillar in room 12 in the northeastern part of the mine on a coal thickness of 2.60 metres, sampled on the Aug. 18, 1922. PI a is from the upper half of the seam, PI b from the lower part.

Sample PII (Analysis 3) was collected on Aug. 18, 1922 in the upper and western part of the mine in room 13, about 30 metres from the face. The thickness was 1.45 metres.

Sample PIII (Analysis 4) was collected on Aug. 18, 1922 about three metres from face in room 3 c, westernmost in the mine on a coal thickness of 1.30 m. The section is seen from fig. 39, 1. At the face the section was as in fig. 39, 2.

Sample IV (Analysis 5) was collected on Aug. 18, 1922 on a coal thickness of two metres in the room 9 b, westernmost in the mine.

Sample V (Analysis 6) was collected on Aug. 19, 1922 at the bottom of the slope 1 b on a coal thickness of 1.20 metres. (Fig. 39).

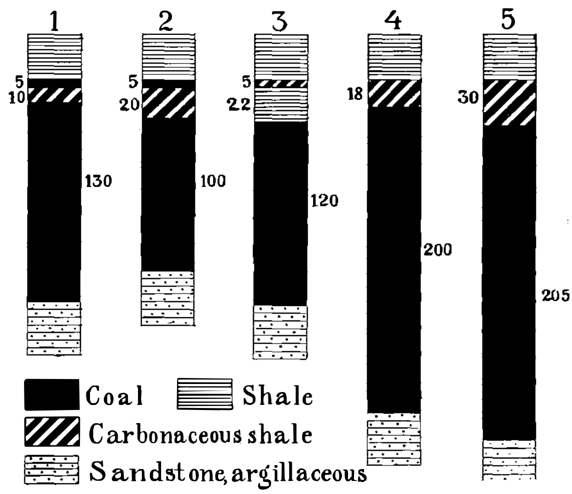

Fig. 39. Sections of the Josefine Seam in Josefine Mine.

1. From room 3 c, analysis PIII. 2. From room 3 c. 3. From main slope 1 b, analysis PV. 4. From room 31, analysis PVI. 5. From room 26 b, analysis K 6 Thickness in centimetres.

Sample VI (Analyses 7 and 8) was collected on Aug. 19, 1922 near gateway 31 at the main slope on a coal thickness of 200 metres. The sample PVI a is from the lower half of the seam and PVI b from the upper half. (Fig. 39).

Sample 26 b (Analysis 10) was collected on August 7, 1923 in room 26 b in the lowermost part of the mine on a coal thickness of 2.05 metres. (Fig. 39).

The average analysis No. 9 is certainly very close to the actual composition of the Josefine coal in Josefine Mine.

From the analyses and the working of the mine it was found that the ash content was higher in the lower part of the mine than in the upper part. This may to a certain extent be due to greater downfall of rock from the top wall, but it is also highly probable that the coal

Analyses of coal

		Number of analysis	1	2	3	4	5	6
		Locality of sample	Josefine Mine. Sample P I a. Room 12	Jøsefine Mine Sample P I b. Room 12	Josefine Mine. Sample II. Room 13	Josefine Mine. Sample III. Room 3 c	Josefine Mine. Sample IV. Room 9 b.	Josefine Mine. Sample V. Slope 1 b
		Moisture	1.85	2.28	1.80	1.79	1.81	1.55
		Ash	8.11	10.50	10.80	10.06	9.98	13.66
		Coal substance	90.04	87.22	87.40	88.15	88.21	84.79
		Carbon	-	-	-	-	-	-
		Hydrogen	-	-	-	-	-	-
		Sulphur	1.23	1.12	1.30	1.18	1.18	1.97
		Nitrogen and oxygen	-	-	-	-	-	-
		Coke	56.42	57.92	55.25	56.56	58.33	58.06
		Volatile matter	41.73	39 80	42 95	41.65	39.86	40.39
		Gross calorific value	7538	7303	7254	7334	7284	7064
		Net calorific value	7235	7007	6960	7038	6987	6780
Low-temp-erature distillation		Water	7.6	5 6	6.4	6.0	8.0	6.4
		Gas	8.4	7.6	6.0	7.6	5.6	9.2
		Crude oil	17.2	19.6	18.8	19.6	17.6	21.2
		Semi-coke	66.8	67.2	68.8	66.8	68.8	63.2
In pure coal		Sulphur	1.36	1.28	1.49	1.34	1.34	2.32
		Coke	53.65	54.36	50.84	52.75	53.76	52.42
		Volatile matter	46.35	45.64	49.16	47.25	46.24	47 58
		Gross calorific value	8370	8376	8299	8322	8258	8332
		Net calorific value	8046	8052	7975	7998	7934	8008
	Low-temp-erature distillation	Water	6.4	3.8	5 1	4.8	6.9	5.8
		Gas	9.3	8.7	6.9	8.6	6.4	10.9
		Crude oil	19.1	22.5	21.6	22.2	20.0	25.0
		Semi-coke	65 2	65.0	66.4	64.4	66.7	58.3
		Remarks	Exact average sample by Orvin 1922	Exact average sample by Orvin 1922	Exact average sample by Orvin 1922	Exact average sample by Orvin 1922	Exact average sample by Orvin 1922	Exact average sample by Orvin 1922
		Analyst	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922

[1] In pure coal: C. 83.16, H 6.56, N + O 8.72.

from the Josefine Seam.

7	8	9	10	11	12	13	14
Josefine Mine. Sample VI b. Main slope	Josefine Mine. Sample VI a. Main slope	Average of analyses Nos. 1—8	Josefine Mine. Room 26 b I	Average of analyses of 95 kilogrammes coal included rock-parting	Average of 21 cargoes 1922	Average of 31 cargoes 1921	Average of 36 cargoes 1923
1.07	1.73	1.74	1.85	1.88	1.87	2.41	2.02
13.27	10.28	10.93	11.60	19.06	17.25	15.45	16.29
85.66	87.99	87.33	86.55	79.06	80.88	82.14	81.69
-	-	-	71.98	-	-	-	-
-	-	-	5.68	-	-	-	-
1.49	1.46	1.38	1.35	-	-	-	-
-	-	-	7.54	-	-	-	-
54.34	57.76	56.90	56.55	61.35	60.99	-	60.94
44.59	40.51	41.36	41.60	36.77	37.14	-	37.04
7268	7295	7273	7124	6540	6652	6779	-
6984	6999	6980	6833	6273	6380	6498	6465
7.2	8.8	6.73	-	-	-	-	-
9.2	8.0	7.50	-	-	-	-	-
22.8	17.2	19.44	-	-	-	-	-
60.8	66.0	66.33	-	-	-	-	-
1.74	1.66	1.58	1.56	-	-	-	-
47.95	53.96	52.45	51.94	-	53.82	-	54.70
52.05	46.04	47.55	48.06	-	46.18	-	45.34
8485	8290	8328	8232	-	8267	8252	-
8161	7966	8005	7908	-	8043	7928	7071
7.0	8.0	5.86	-	-	-	-	-
10.8	9.1	8.62	-	-	-	-	-
26.6	19.6	22.13	-	-	-	-	-
55.6	63.3	63.39	-	-	-	-	-
Exact average sample by Orvin 1922	Exact average sample by Orvin 1922		Exact average sample by Orvin 1923				
Dr. Gram 1922	Dr. Gram 1922		Dr. Gram 1924	Dr. Gram	Dr. Gram		Dr. Gram

in the lower part contained more calcite, because it was situated nearer the limestone and the thrust plane. I also observed some pebbles of shale interbedded in the coal seam.

Shale from the Josefine horizon is of no value as raw material for the production of crude oil. A sample from the shale above the seam in room 3 c contained 2.4 per cent. moisture, 0.8 per cent. crude oil, 96.0 per cent. semi-coke, and 0.8 per cent gas. An analysis made by Sherdahl on light shale from the tip in 1922 contained only 0.60 per cent. crude oil. The carbonaceous shale in the hanging wall had too small a thickness to have any value as crude oil material.

The *quantity of coal* is impossible to determine in the remaining three western areas. Both coal areas and thicknesses are only estimated.

Area	Coal area in sq. kilometres	Thickness in metres	Coal quantity in mill. tons
Vestre Centerfelt	0.12[1]	1.40[1]	0.22[1]
Vestfeltet	0.80[2]	1.00[2]	1.00[2]
Lagunefeltet	0.20[2]	1.00[2]	0.26[2]
	1.12	-	1.48

As will be seen from the table, no certain coal area has been opened on this seam. It is highly probable, that there is about 220000 tons in Vestre Centerfelt. In Vestfeltet there may possibly be about one million tons in all, but the coal will here be difficult to win. How much can be counted upon as workable coal it is impossible to say. In Vestre Centerfelt there may be great tectonical disturbances, and in Vestfeltet the seam may in part be situated so near to the surface that water from the glaciers will break into a future mine.

A rise from the Josefine Mine penetrated a small seam six metres above the Josefine Seam. The thickness was 0.60 metres at this point, but on further examination the extension proved to be very limited, so that the seam must be regarded as valueless.

Ragnhild Seam.

This seam is stratigraphically situated about 36 metres above the Josefine Seam. The sequence between the two seams is mostly covered, and thus it is impossible to get a detailed cross section of these layers. The greater part is, however, made up of green sandstone with some layers of shale.

[1] Approximately correct figures.

[2] The figures are only an estimate and thus quite uncertain.

The Ragnhild Seam is found in Østre Centerfelt and the areas to the west. The seam has, however, been examined very little. It has been exposed in Ragnhild Mine in Østre Centerfelt. The section is seen in fig. 40. The dip is 10° SW. Above this section is found light green, partly coarse sandstone with carbonised plant-remains. On my visit in 1922 the mouth of the addit was already covered by fallen débris, and I could only measure the section seen in the cutting. According to Smith Meyer a 30-metres-long slope had been worked, and from the bottom of this a 20-metres-long gallery led to the south-east, resulting in the wedging out of the seam in that direction down to five

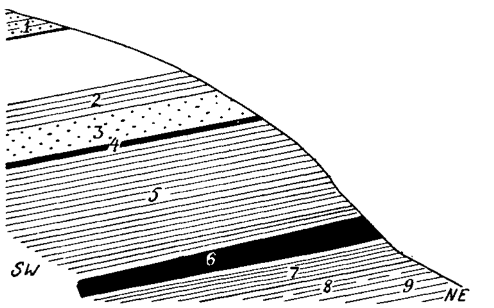

Fig. 40. Section of the Ragnhild Seam at Ragnhild Mine.

1. Green sandstone with a small coal seam at the bottom. 2. Brown shale. 3. 0.9 metres sandstone with small pieces of coal. 4. 0.10–0.12 metres coal. 5. 3.0 metres shale with leaves of foliage trees. 6. 0.4–0.7 metres coal, the Ragnhild Seam. 7. 0.9 metres greyish-brown shale 8. 0.2 metres sandy, brown shale. 9. Grey shale with plant-remains.

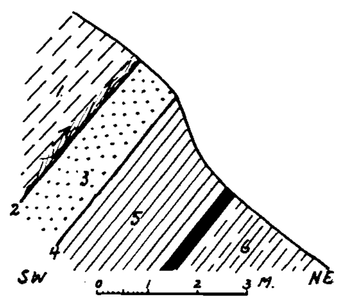

Fig. 41. Section of the cutting at KB 2.

1. Permo-Carboniferous chert. 2. Thrust-plane. 3. Green sandstone 4. Coal. 5. Brown shale with plant fossils. 6. Sandy shale with yelolwish-brown weathering.

centimetres. This contraction is certainly only local, because the seam has been observed at several points westward with a thickness of not far from one metre.

About 400 metres east of the Ragnhild Mine the seam is cut against the thrust plane, and east of this point the Ragnhild horizon does not occur. Between these two points the outcrop can be traced from the float coal.

In a small cutting between the two branches of the Josefine Fault west of the Ragnhild Mine the coal seam has been uncovered by Sherdahl. Above the seam follows green sandstone, and farther up six to eight metres of greyish-brown argillaceous and laminated sandstone is seen. In the upper part of this sandstone was a horizon containing plant remains and plant stems. Farther up was a green laminated sandstone like the one at the bottom of KB, then a thin layer of carbonaceous shale, and uppermost in the exposed part of the sequence was an easy-weathering shale. The dip was minimum 20° towards the SW.

On the western side of the Josefine Fault pieces of coal are found in the slope up to 150 metres above sea-level, but the slope is covered

Analyses of the Ragnhild Seam

Number of analysis			1	2	3	4	5
Locality of sample			Ragnhild Mines 40—70 centimetres seam	Ragnhild Mine 10—12 centimetres seam	Ragnhild Seam from the 22—100 cm seam, Brøggerdalen	Ragnhild Seam from the brook, Brøggerdalen	Ragnhild Seam west of KB1. 0.5 m
Moisture			3.27	2.82	2.06	2.06	2.10
Ash			7.34	11.53	5.05	4.04	3.54
Coal substance			89.39	85.65	92.89	93.90	94.36
Carbon			-	-	-	-	-
Hydrogen			-	-	-	-	-
Sulphur			0.55	0.89	0.98	1.33	0.82
Coke			58.05	61.38	55.14	55.33	57.00
Volatile matter			38.68	35 80	42.80	42.61	40.90
Gross calorific value			6953	6742	7658	7768	7735
Net calorific value			6644	6448	7345	7451	7415
Low-temperature distillation		Water	8.4	7.2	8.0	8.6	8.0
		Gas	8.0	8.8	8 8	8.8	8.8
		Crude oil	16.4	13.0	17 2	17.6	17.2
		Semi-coke	67.2	71.0	66.0	65.0	66.0
In pure coal	Sulphur		0 62	1.04	1.05	1.42	0.87
	Coke		56.73	58.20	53.92	54.62	56.66
	Volatile matter		43.27	41.80	46.08	45.38	43.34
	Gross calorific value, cals		7778	7872	8244	8273	8197
	Net calorific value, cals		7454	7548	7920	7949	7873
	Low-temperature distillation	Water	5.7	5.0	6.3	6.9	6.3
		Gas	9.0	10.3	9.5	9.4	9.3
		Crude oil	18.3	15.2	18.5	18.7	18.2
		Semi-coke	67.0	69.5	65.7	65.0	66.2
Remarks			Weathered coal. Average sample by Orvin 1922	Sample by Orvin 1922. Not average of seam	Sample by Orvin 1922. Unweathered	Sample by Orvin 1922. 25 cm seam. Unweatherad coal	Almost unweathered coal
Analyst			Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1922

and the above-lying coal seams.

6	7	8	9	10	11	12[1]	13
Ragnhild Seam, 110 m above sea-level south of Tvillingvatna	Ragnhild Seam Average of analyses 1, 3, 4 and 5	Coal seam in the brook west of Tvillingvatna	KB2 Seam, No. 1	KB2 Seam, No. 2	KB2 Seam. Average of 9 and 10	KB1 Seam from KB1	KB1 Seam from KB1
3.85	2.37	3.32	3.90	3.20	3.55	3.36	5.72
3.75	4.99	3.91	11.80	4.13	7.97	4.64	4.88
92.40	92.64	92.77	84.30	92.67	88.48	92.00	89.40
-	-	-	-	-	-	76.45	-
-	-	-	-	-	-	5.43	-
1.45	0.92	0.79	3.14	2.44	2.79	1.09	0.75
54.83	56.38	56.86	62.58	56.45	59.52	55.72	57.30
41.32	41.25	39.82	33.52	40.35	36.93	40.92	36.98
7152	7529	7463	6694	7421	7058	-	6790
6829	7214	7142	6398	7101	6750	7205	6477
-	8.2	9.6	10.0	-	-	-	12.0
-	8.6	8.0	8.0	-	-	-	7.6
-	17.1	14.4	11.2	-	-	-	9.6
-	66.1	68.0	70.8	-	-	-	70.8
1.57	0.99	0.85	3.74	2.64	3.16	1.18	0.84
55.28	55.48	57.08	60.23	56.46	58.35	55.60	58.63
44.72	44.52	42.92	39.77	43.54	41.66	44.40	41.37
7776	8123	8045	7941	8008	7975	-	7595
7452	7799	7725	7617	7684	7651	7476	7271
-	6.30	6.8	7.2	-	-	-	7.1
-	9.30	8.6	9.5	-	-	-	8.5
-	18.43	15.5	13.3	-	-	-	10.7
-	65.97	69.1	70.0	-	-	-	73.7
Sample by Orvin 1923. Weathered coal. Not average		Sample by Orvin 1922. Nearly unweathered coal	Sample by Orvin 1922. Weathered coal	Sample by Orvin 1923. Weathered coal. Ash red from iron oxides		Sample from Anker's expeditions	Strongly weathered coal
Dr. Gram 1924		Dr. Gram 1922	Dr. Gram 1922	Dr. Gram 1924		Heidenreich 1912	Dr. Gram

[1] No. 12 0.558 per cent. phosphorus in ash. In pure coal C 7810, H 5.90.

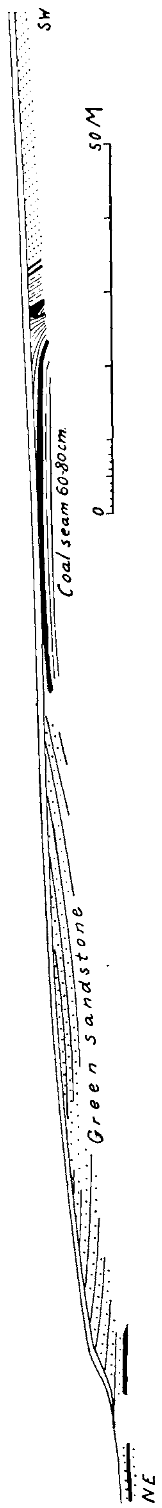

Fig. 42. Section along the eastern side of the creek in Brøggerdalen showing the Ragnhild Seam.

all over by scree. 300 metres farther to the west and 110 metres above sea-level a coal seam crops out, and a great quantity of coal pieces are found in the rock waste. I tried to uncover the seam here, but had to give it up owing to lack of assistance.

It is perhaps the Ragnhild Seam which has been exposed in the cutting at KB_2 but it may as well be one of the above-lying small seams. The seam is here found close under the thrust plane and the Carboniferous chert. The thickness, 20—25 centimetres, is hardly the original one, because the seam has certainly been thinned out. The section is seen in fig. 41. The dip is rather great, viz. about 50° SW. The seam at KB_2 is quite valueless.

In Vestfeltet the seam could be observed in the brook along the east side of Brøggerbreen immediately west of the fault. The brook had cut through the undulating seam, which lay uncovered for some distance. The section here was as follows; measured from south to north (fig. 42):

Thickness in metres	
	Sandstone, green, partly laminated with carbonised plant remains. Dip 50° S 20° W.
1.30	Sandstone, bluish-green, compact
0.05	Coal
0.50	Shale, brown, with plant fossils
0.10	Coal
1.00	Shale, green, sandy, with large leaves of hard wood
0.05	Shale, dark brown
0.60	Shale, dark grey with plant fossils
1.60	Sandstone, greyish-green, fine-grained with carbonaceous plant remains on the bedding-planes
1.00	Coal, thickness irregular and small near the fault seen in the section
4.00	Shale, brown and strongly folded with lenses of sandstone in the upper part
0.25	Coal, the same seam as above. The thickness increases to 0.7—0.8 metres northwards, where the seam is lying just below the surface cover.

About 80 metres northwards the seam is covered, and here is probably a little fault, because to the north we find green sandstone, partly coarse and partly laminated with carbonised plant fossils in the bedding planes. 185 metres north of the little fault a coal seam is cropping out below a small waterfall. It was not uncovered, but to judge from the outcrop the thickness must be above 0.5 metres. It is certainly the Ragnhild Seam which again crops out here.

Farther to the west pieces of coal are found in the brooks coming from below the glacier front, and it is very probable that these pieces originate in part from the Ragnhild Seam. The seam is thus probably situated so close under the glacier that working is impossible. Farther to the west the seam is unknown.

Coal quality. The analysis table on page 142 includes some analyses of coal from the Ragnhild Seam. As will be seen, the ash content is comparatively small. This is also the case with the percentage of crude oil obtained by low-temperature distillation.

In the autumn of 1922 Sherdahl made some crude oil determinations in respect of coal from the Ragnhild Seam. He found that coal from the Ragnhild Mine gave 16.20 per cent., shale from the same point 1.9 per cent., coal from the cutting 200 metres to the west of the mine 16.95 per cent. on the middle layer, and 19.08 per cent on the lower layer. In coal from Brøggerdalen he found 16.70 per cent.

The *quantity of coal* in the Ragnhild Seam is of no great importance because of the high stratigraphical position of the seam. For this reason the coal areas are quite trifling. Further, the thickness is so small that the seam can hardly be worked everywhere. With the present coal prices it is scarcely workable at any point so far known. The total coal quantity in this seam is seen from the following table.

Area	Coal area in sq. kilometres	Thickness in metres	Coal quantity in mill. tons
Østre Centerfelt	0.075	0.60	0.06
Vestre Centerfelt	0.065	0.70	0.06
Vestfeltet	0.500[1]	0.70[1]	0.45[1]
Lagunefeltet	0.14	0.70[2]	0.12[2]
	0.780		0.69

On account of the high position and the small areas the workability of this seam will be particularly doubtful.

Other Coal Seams.

Besides the six main seams several small seams have been observed on the field. Some of them extend over only small areas and are of no economic interest. Their position will best be seen from the drill records.

The greatest of these seams is situated between the Sofie and the Advokat seams. This seam has been met with almost at every point

[1] The figures are only approximate.
[2] The figures are estimated and quite uncertain.

where this horizon has been penetrated. In several localities it is up to 40—50 centimetres, but impure. In the Olsen Mine it is, according to Sherdahl, 80 centimetres, but also here it is of poor quality (fig. 33). The only locality in which this seam may be of any interest for mining is in the eastern part of Agnesfeltet, where borehole 5 pierced a seam with 0.80 metres of coal uppermost, and downwards 0.10 metres shale and 0.10 metres coal. This is probably the same seam, though I am not quite sure, because there are so many seams in this section that a repetition owing to thrusting might have taken place. I regret to say that we got no core of the seam here.

At the head of Brøggerdalen just below the waterfall and against the Carboniferous rock a small coal seam crops out. The thickness is

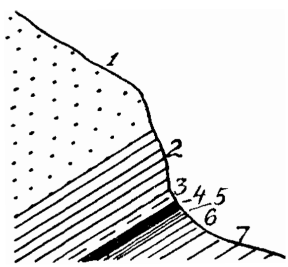

Fig. 43. Section of the cutting at KBI.
1. Green sandstone. 2. 0.8 metres light grey shale with plant fossils. 3. 0.12 metres shale with pieces of coal. 4. 0.07 metres of coal. 5. 0.13 metres black shale. 6. 0.10 metres yellow shale. 7. Grey shale.

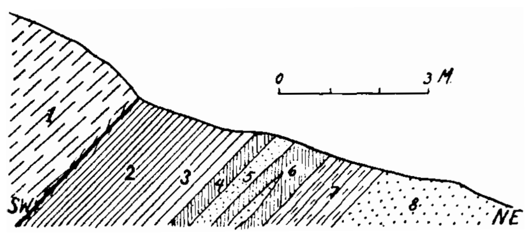

Fig. 44. Section of the cutting at KB.
1. Argillaceous chert. 2. 1.4 metres greyish-brown shale. 3. 0.7 metres light grey shale. 4. 0.3 metres carbonaceous shale with some lenses of sandstone. 5. 0.35 metres flinty sandstone. 6. 0.70 metres carbonaceous shale with lenses of sandstone. 7. 1.0 metres brown shale with carbonaceous shale. 8. Grey sandstone.

only 7 centimetres. The seam is only a remnant of a seam which has been destroyed during the thrusting, which has acted along the seam here. It is one of the small upper seams and of no value. Below the seam is 2.5 metres of shale containing an abundance of plant fossils, This shale gave no crude oil by distillation.

The *KBI-Seam* lying about 30 metres above the Ragnhild Seam is known only from Østre Centerfelt. Below the seam is a light green, laminated and rather fine-grained sandstone containing some leaves of hardwood and an abundance of carbonised plant remains on the bedding-planes.

The sandstone above the seam is coarse, greenish-brown. The section from the cutting measured by myself is seen from fig. 43.

An analysis made of coal from this seam is seen as number 13 in the table on page 143.

Owing to strong oxidation the content of moisture is high and the calorific value small. In fresh condition this coal would be of about the same type as the coal from the Ragnhild Seam. The seam is of no economic value owing to the small thickness and high stratigraphical position.

The *KB-Seam* is situated about 8 metres above the KBI-Seam, and close beneath the overthrusted Carboniferous chert (fig. 44). This seam is only known from the cutting in Østre Centerfelt, where it merely consists of carbonaceous shale. The thickest of the shale-layers gave by distillation: Moisture 6.4 per cent., crude oil 4.0 per cent., semi-coke 85.6 per cent. and gas 4.0 per cent. Another shale sample (P7) from the one-metre-thick layer gave: Moisture 1.6 per cent., crude oil 0.8 per cent., semi-coke 96.8 per cent., and gas 0.8 per cent. A third sample gave no crude oil by distillation. The seam is of no value whatever.

It is possible that KB and KBI belong to the same horizon, because the seam at KB seems to be bent up, so that it might reappear at KB. This could not be stated with certainty and is for that matter of no importance. In both spots the seams are so close to the thrust plane that if they had really been workable in other respects, they could not have been worked here.

Quality of coal.

Coal is a solid mixture of complicated carbon compounds, and belongs to the group of sediments which Henry Potonié has named *Kaustobiolithe*. Coal in a general sense includes only such compounds as are fossiliferous. The classification of the different qualities of coal is very difficult, because every possible transition is found between the more distinct types.

A general distinction is made between two main varieties of coal, namely ordinary coal and brown coal. Ordinary coal is divided into anthracite, semi-anthracite, caking coal, steam coal (sand and sinter coal) and cannel coal[1]. Brown coal is divided into black lignites (*Pechkohle*), ordinary brown coal, earthy brown coal, woody brown coal, and cannel brown coal.

Brown coal is usually younger than ordinary coal, but several instances are known of ordinary coal being younger than brown coal of the same district. This is the case in Spitsbergen, where the Tertiary coals are real bituminous, whereas the coal from the Cretaceous formation is partly brown coal. Thus, time alone is not the decisive factor in the formation of any coal variety.

The general rule is that the greater the age of the coal the more gas it has lost. Undisturbed seams are usually richer in gas than corresponding coal which has been exposed to folding or other tectonical disturbances. It is also of importance if the rocks are porous enough to let out the gas. It is often noticed that the seams are poorer in

[1] Bituminous coal include caking coal and steam coal.

gas near the outcrop than deeper down, and poorer in the anticlines than in the synclines.

We shall not go further into this matter here, but only mention the common classification according to the content of volatile matter as applied in Westphalia (R. Potonié 1924):

Name of Coal	Percentage of volatile matter
Anthracite and semi-anthracite (*Magerkohle*)	4—19
Coking coal (*Fettkohle*)	19—28
Gas coal (*Gaskohle*)	28—32
Steam coal (*Gasflammkohle*)	32—45

From its appearance the coal has been divided into bright coal, dull coal and mineral charcoal.

Owing to the high percentage of volatile matter the Kings Bay coals have earlier been designated cannel coal. Cannel coal is, however, coal of a dull appearance with a uniform, dense composition and conchoidal fracture. Boghead coal is a coal composed of rounded bodies of a bituminous substance in a more or less prominent groundmass.

As Dr. Gunnar Horn (1928) has pointed out, the coals from Kings Bay are not cannel coal, even though they are chemically very similar to that coal.

For scientific purposes several classifications of the coals have been attempted, but the definition of the different coal ingredients has been rather vague. Dr. Marie Stopes is to be credited with having introduced terms which can be exactly defined (fusain, vitrain, clarain and durain). Instead of these four ingredients, now usually three are recognised and, slightly modifying the terms of Stopes, called fusite, vitrite and durite (R. Potonié 1924), which correspond to faser coal, bright coal and dull coal respectively.

Fusite is mineral charcoal. It is dull with woody structure and, as a rule, plays an inferior rôle in the different coal varieties. Vitrite is always very shiny and consists of carbonised wood with or without structure, partly also of colloidal humic substances. Euvitrite is the wholly structureless vitrite. In provitrite the plant structure is still seen. Durite is the dull substance of the coal. It is composed of a mixture of vitrite, fusite, spores, pollen-grains, cuticles and resin in a matrix of finely divided plant substance, partly also colloidal substance.

Between vitrite and durite there is, as will be understood, every transition. By continued carbonization (*Inkohlung*) the duller durite may change into vitrite, and there may be formed a so-called meta-durite, in which the duritical origin is perceptible only by the presence of fusite.

The only close microscopical examination which has been performed on coal from Spitsbergen, amongst which also was coal from

Kings Bay, was made by Dr. Horn (1928) in the winter of 1927—28. The samples had been taken on the coal field on different occasions.

Microscopical coal examinations are done on polished surface as well as in thin section. Further, the Mazeration method is used, by which the humic substance is dissolved, so that resin, spores, cuticles and mineral ingredients remain. These methods used along with the old methods of examination, of which chemical analysis is the most important, will give a result as satisfactory as can be obtained with our present facilities.

I shall now give the results obtained by Horn with coal from Kings Bay.

From analyses made by Dr. Gram in 1923 Horn has calculated the following average of coal from Kings Bay:

		In pure coal
Moisture	1.8	
Ash	12.2	
Coke	57.8	53
Volatile matter	40.4	47 (42—52)
Sulphur	2.5	
Gross calorific value	7130 cal.	8285 cal.
Net calorific value	6800 „	7943 „

The composition of pure coal			On 1000 C the following quantity of H.		
C	H	O + N	Disposable	Bound	Total
82.5	7	10.5	68.93	16.07	85.00

Macroscopically the various Kings Bay coals are very similar. They are throughout typically duritic coals. The colour is black, partly dull and partly a little bright, and for the most part without distinct lamination. The fracture is irregular. Almost all coals show a tectonical influence, are strongly marked by cracks and fissures. In several places the coal shows folding and is slaty.

The coking tests which have been made gave somewhat varying results. Coal from the Ester Seam gave melted, porous and rather hard coke, coal from the Sofie Seam gave a caked, somewhat porous coke, coal from the Agnes-Otelie Seam gave more or less sintered coke, whereas coal from the Josefine and the Ragnhild seams gave black, sandy coke.

To judge from the coke the various coal qualities thus belong to back, sinter, and sand coals from below and upwards.

The coals have black to blackish brown streak, and do not colour a solution of potassium hydroxide or diluted nitric acid. For this reason the coals from Kings Bay must be termed ordinary coals. Owing to their brittleness all samples for making thin sections had to be boiled in paraffin.

The Ester coal is mostly durite with some streaks of vitrite, which is quite structureless. Small spots of fusite are also present. In the durite small sparks of pyrites and epidermic fragments and resinous bodies are found. On the small cracks in the coal there has been deposited calcite, which, owing to its dark colour, is difficult to distinguish from the coal macroscopically.

The Sofie coal also shows a duritic composition. Thin streaks and lenses of vitrite are interbedded in the durite, which also contains some fusite and finely distributed pyrites. The latter also occurs in greater quantities. In thin section a distinct lamination is seen. The ash content is arranged in streaks. The durite has a humitic appearance and contains small streaks of vitrite and fragments of other components, especially epidermic fragments. Some spore exines also occur and also resinous bodies, partly with flow structure. Horn has pointed out that these resinous bodies are birefringent. This is also the case with some duritic streaks.

Also in the coals from the Sofie Seam there has been found an abundance of small cracks filled with calcite, especially in the vitrite. In polished surfaces it is seen as a smooth, homogeneous mass of about the same hardness as the coals, and for this reason it is difficult to observe directly without using hydrochloric acid.

The Agnes-Otelie coals macroscopically show an indistinct lamination. Microscopically they prove to be distinctly duritic with some streaks and thin lenses of vitrite, and also some lenses of fusite of varying size. In the durite some megaspores are seen and also several small bodies, which may be considered to be partly spore exines and pollen, and partly crushed epidermic fragments. Also resin is present and is particularly easy of recognition in thin sections. On the polished surface some curious, spherical bodies with several tiny circular depressions are seen. They are supposed to be sclerotia (Jeffrey and Crysler 1906). Such sclerotia or "*Dauerzustände*" are products of transformation of the plasmodium of certain fungi (Myxomycetes) to survive dry periods. This should point to a periodical drying up of the swamps in question. In the durite also finely distributed granules of pyrites occur. The coals can easily be mazerised. A considerable residue will remain, which mostly consists of epidermic fragments and partly of pollen. The yellow epidermic fragments occur partly with and partly without structure. In the residue also some waterclear and angular pieces of quartz occur.

The argillaceous sandstone from the footwall of the Agnes-Otelie Seam is traversed by thin, tubular coal streaks, often angular to the bedding. They originate without doubt from roots, and confirm that the coals of this seam are autochthonous.

Also the Josefine coals are distinctly duritic. The durite is rather homogeneous and vitritic. Very small bodies of bitumen occur in the duritic mass. Some of them are doubtless of resin, whereas the majority part are so small that it is impossible to state of what substance they are made up. In these coals the vitrite is less in evidence. It is seen in thin sections as thin, homogeneous streaks of brown colour. Fusite is present as a characteristic constituent. It occurs as lenses and streaks with very fine cellular structure. Pyrites are present in small quantities. The coals are crushed, and on the cracks calcite has been deposited.

One of the samples from the Josefine mine differed widely from the others. It was coal with a massive and homogeneous structure and a greyish-black colour. It showed a strong tectonical influence and bore a certain resemblance to pseudo-cannel coal, but was too coarse-grained to be termed as such. An analysis of this coal made by Dr. Horn gave the following result:

		In pure coal
Moisture	2.6	
Ash (light grey)	15.00	
Coke	81.4	80.06
Volatile matter	16.0	19.4

The coke was black and pulvureous. This coal must be termed semi-anthracite. This sample thus shows a more extensive carbonization than the other coals. If the sample really is from Kings Bay, it may be connected with the tectonical conditions.

The Ragnhild coals also consist of a durite of the common variety with humitic matrix in which epidermic fragments and some larger bodies of resin are found uniformly distributed. Streaks and lenses of vitrite are only scantily present; this is also the case with the pyrites.

Horn summarizes the result of his examinations in the following description:

The coals from Kings Bay are duritic throughout. The durite consists of a matrix (*Attritus*), which is apparently of humitic nature and is mixed with many cutineous epidermic fragments. Spore exines only occur scattered. Subordinately also streaks of vitrite are found, these nearly always being structureless. Also fusite is present in small quantities. The latter often has a well preserved structure and seems to play a greater rôle in some of the coal seams (Josefine). Yet a considerably greater material has to be examined before it can be decided whether the seams differ essentially in this respect. In nearly all the coals pyrites is fairly abundant. It is found characteristically as sparks or spherical incrustations in durite.

The coals from Kings Bay are both macroscopically and microscopically very similar to the German gasflame coal; but the spore exines, which are a feature of these coals, are missing in the Kings Bay coals.

The coal from Kings Bay is characterised by a very high content of hydrogen, which cannot be explained merely by the visible bitumen bodies, because these are not present in sufficient quantities to form the hydrogen. By low-temperature distillation the coals from Kings Bay yield 15—20 per cent. of crude oil. It must be supposed that also the oil-forming substances are distributed in the duritic matrix, but so finely that they cannot be identified. The whole is seen in the microscope as a dark brown mass. The vitrite is probably formed in the main of colloidal, humic depositions, but also wood and cellular tissue have certainly been the initial material in its formation. As to the fusite it is the general opinion that it has been formed by a quick oxidation of wood, which may have been caused by a conflagration.

Of the mineral constituents the calcite is particularly characteristic. Owing to its dark colour it is very difficult to recognise macroscopically, but microscopically it is very much in evidence. Rødland (1924) found that 15 per cent. of the ash consisted of CaO. The greater part of this lime percentage must be present as carbonate. The remaining part of the ash must have about the same constitution as waterless kaolin. 15 per cent. CaO is equivalent to 11.7 per cent. CO_2. The mineral content in the coals is thus greater than the ash percentage indicates. About one-fourth of the mineral content is calcite, and the coals themselves contain about four per cent. of this. By combustion the calcite is decomposed by the absorption of heat, which will in turn reduce the calorific value of the coals.

The calcite has been deposited from calcareous water, which has circulated on the thin cracks and fissures in the coals. The lime content originates from the Upper Carboniferous limestones of Zeppelinfjellet.

In 1918 Dr. J. Gram observed that coal from Kings Bay yielded a considerable quantity of crude oil by low-temperature distillation. To obtain the crude oil, experiments were carried out on a semi-technical scale. This work was done partly in Germany and partly at *Greaker Cellulosefabrik* on an industrial scale with a Pintsch generator plant, which was originally purchased to be put up at Sydvaranger. In the meantime the work at the latter concern was stopped, and part of the plant was erected at Greaker Cellulosefabrik in connection with the steam engine plant.

In the period 1925—27 a total of 400 tons of crude oil was produced. The experiment did not give the result anticipated. This was partly due to the fact that the coals delivered from the mines varied considerably in quality.

In March 1925 an exact experiment lasting four days was undertaken. This confirmed that crude oil distillation in a Pintsch generator ought to give satisfactory economic results if the coke could be used to heat the boilers.

It has also been investigated whether, by hydration, i. e. technical production of hydrocarbon compounds of coal and hydrogen, the coal

Average of cargoes, chiefly containing Ester and Sofie coal, showing the quality of exported coal from the main seams.

Cargoes	Average of 27 cargoes 1924[1]	Average of 15 cargoes 1926		Average of 15 cargoes 1929		Average of 27 cargoes 1929
		Coal as delivered	Air dried coal	Coal as delivered	Air dried coal	
Moisture	3.24	5.00	1.25	5.69	1.18	4.87
Ash	16.61	17.86	18.59	20.31	21.30	18.26
Coal substance	80.15	77.14	80.16	74.00	77.52	76.87
Coke	58.31	59.55	61.92	61.16	64.08	-
Volatile matter	38.45	35.45	36.83	33.15	34.74	-
Gross calorific value	6532	6377	6625	6252	6550	6285
Net calorific value	6328	6096	6367	5993	6303	6000
In pure coal:						
Coke	52.03	54.01	54.03	55.20	55.23	-
Volatile matter	47.97	45.99	45 97	44.80	44.77	-
Gross calorific value	8150	8260	8268	8470	8448	8169
Net calorific value	7895	-	-	-	-	7845
Analyst		O.W. Rambech and Alf Riise		O.W. Rambech and Alf Riise		Dr. Gram

would be economically advantageous, but the result was that this method of utilising Svalbard coal could not be recommended at present. The older method of low-temperature distillation was found to be the most suitable.

In 1927 a committee consisting of the following members was appointed: B. Stuevold-Hansen, Dr. Johan Gram, A. Scott-Hansen, Hj. Batt, Jens Gram, and Karl Schønning as technical consulting member. Scott-Hansen acted as chairman. This committee was to determine in what way the Kings Bay coals could best be utilised. The report of the committee was published on April 24, 1928. The crude oil, of which about 180 kilogrammes could be produced per ton of coal, was found to be most suitable for the impregnation of wood. According to the investigations of Dr. J. Gram, its physical and chemical quality made it especially suitable for this purpose. Before using it the benzine would have to be distilled from the crude oil. All the impregnation crude oil produced at Greaker was used by the State Railways for the preservation of railway sleepers.

The coke produced by distillation amounted to about 65 per cent. of the coal used. As the coal from Kings Bay alone gave a porous,

[1] 24 cargoes 1924 contained, according to analyses by Sherdahl, an average of 12.45 per cent. of ash.

Average analyses of the various coal seams.

	Analyses number[1]	9, 10	1, 3—5	1—8	12—16	3—5	2, 3, 5—10	1—4 and 7—10
	Seam	KB2	Ragnhild	Josefine	Otelie	Advokaten	Sofie	Ester
	Moisture	3.55	2.37	1.74	1.77	1.10	1.49	1.58
	Ash	7.97	4.99	10.93	14.53	14.73	14.89	10.49
	Coal substance	88.48	92.64	87.33	83.70	84.17	83.62	87.93
	Sulphur	2.79	0.92	1.38	4.02	4.69	2.58	2.73
	Coke	59.52	56.38	56.90	58.22	58.11	57.91	58.05
	Volatile matter	36.93	41.25	41.36	40.01	40.79	40.60	40.37
	Gross calorific value	7058	7529	7273	6954	7131	6930	7291
	Net calorific value	6750	7214	6980	6672	6816	6650	6998
Low-temperature distillation	Water	-	8.2	6.7	7.7	4.3	6.2	6.5
	Gas	-	8.6	7.5	9.0	9.5 [2]	8.3	8.2
	Crude oil	-	17.1	19.4	16.6	22.7	18.1	17.5
	Semi-coke	-	66.1	66.4	66.7	63.5	67.4	67.8
In pure coal:								
	Sulphur	3.15	0.99	1.58	4.80	5.57	3.08	3.10
	Coke	58.35	55.48	52.45	52.45	51.54	51.14	54.04
	Volatile matter	41.65	44.52	47.55	47.55	48.46	48.86	45.96
	Gross calorific value	7975	8123	8328	8307	8471	8294	8291
	Net calorific value	7651	7799	8005	7983	8102	7972	7960
Low-temperature distillation	Water	-	6.3	5.9	7.0	-	5.6	5.6
	Gas	-	9.3	8.6	10.8	-	9.9	9.3
	Crude oil	-	18.4	22.1	19.8	-	21.9	20.0
	Semi-coke	-	66.0	63.4	62.4	-	62.6	65.1

sintered coke, the committee concluded that it would have to be mixed with other coals to give a firm coke. It was supposed that an addition of 27.5 per cent. of coal from *Store Norske Spitsbergen Kulkompani's* mine at Advent Bay would be suitable for the purpose. This has, however, not yet been more closely tried out.

Apart from the plant in Sydvaranger, there was no steam-engine plant big enough to use all the coke, and after accurate calculations the committee came to the result that a distillation plant should be erected in southern Norway and built with a capacity of 180000 tons a year. Of this quantity, 50000 tons should be taken from Advent Bay and 130000 tons cleaned coal from Kings Bay, the latter corresponding to 160000 tons of raw coal. This plant would need a capital of six million Kroner in Norway and one million Kroner for

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[1] The numbers are found in the analysis tables in the chapters dealing with the different seams.

[2] Average of analyses Nos. 1, 2, 6, 7, 8.

the improvement of the works in Spitsbergen. It was supposed that by erecting such a plant the company would be able to pay interest on 7500000 Kroner of the old debt.

In the meantime the committee found that before erecting these works, it would have to be proved by drilling on the coal field that there was coal enough to repay the capital invested. Further the intention was to make experiments on an industrial scale with mixed coals.

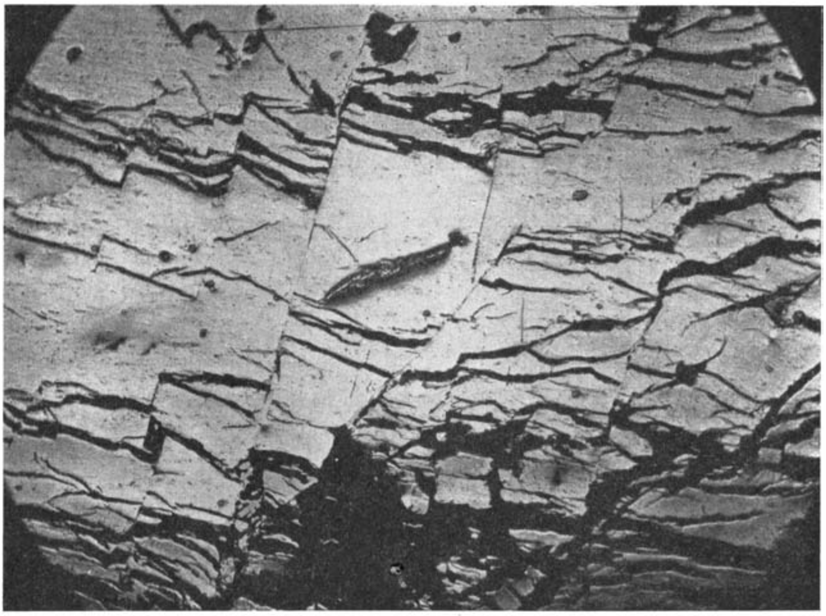

Fig. 45. Coal from Josefine Mine.
Small veins of calcite (black) in duritic coal. In the middle fusite. ×55. Phot. Horn 1928.
(From Horn (1928), Tafel V, Abt. 5).

The investigation of the coal field in the summer of 1928 showed that the proved quantity of workable coal was less than was necessary for such a big plant. When mining was stopped in the autumn of 1929 owing to various difficulties in the existing Ester Mine, which made it impossible to continue on a profit-earning basis with the low prices than existing, further work in connection with the distillation plant was suspended.

As to the quality of the Kings Bay coal as heating coal for steamship boilers, various tests have been carried out on board several steamers. In 1926 such experiments revealed that Kings Bay coal equalled English coal for steam-raising purposes. The price had to be fixed according to the quality. The best results were obtained by small and frequent, feeds of fuel and the use of a secondary, adjustable air supply, as otherwise part of the combustible gases was lost. The content of ash and slag proved to be very high, mostly between 20 and 30 per cent., and for smalls up to 38 per cent.

Based on heating results secured in 1929 on an average of cargoes in that year, the value of Kings Bay coal (Ester and Sofie) was fixed for sale to various steamship companies in the following way: *Møre Fylke Ruteselskap* 80 per cent. of English coal (DCB and West Hartley), *Det Bergenske Dampskibsselskab* 83 per cent. of English coal (Hastings), and *Det Nordenfjeldske Dampskibsselskab* 84 per cent. of English coal (Hastings). Further reduction owing to great content of ash was fixed by the Norwegian Steamboiler Association at four per cent., whereas steamship companies insisted on 10 per cent.

As to the analyses made of coal from the various seams I refer to the tables included in the chapters dealing with the various seams. As will be seen, there are not included any analyses of coal exported from the Ester and Sofie Seams. The reason is that the coal exported in the later years consisted of a mixture of coal from these two seams and partly also from the Otelie Seam, and the analyses do not thus give any result from any one seam. In the table on page 153 I have included some averages of exports, and these averages are of the greatest interest in so far as they show the quality of the coal exported from the main seams of the coal field. And as in future mining operations these seams would supply the bulk of the coal, future exports will scarcely differ very much from the coal delivered in the last few years of mining at Kings Bay. As will be seen, the ash content in these analyses, which have been made by the purchaser, is considerably higher then in the analyses made by the company. Of course this is to some extent a matter of sampling. Samples including a high percentage of *smalls* will give much ash, and *large* alone will give a low ash content, as do the mine samples.

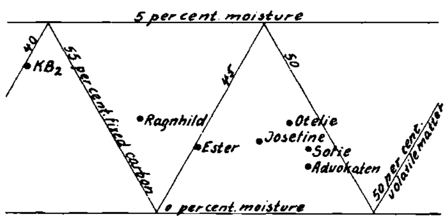

Fig. 46. Diagram showing the carbonization of different coal seams.

From the figures below it will be seen that the ash was to be found chiefly in the *smalls*. In 1923 a detailed examination was made by Dr. Gram of 95 kilogrammes of coal from the Josefine Mine. The coal was separated into different sizes giving the following ash content:

Size in centimetres	0—0.24	0.24—2.5	2.5—8.0	above 8.0
Percentage of total coal weight	28.6	31.9	21.6	17.9
Percentage of ash	26.17	16.0	13.68	9.95

In 1925 coal from the Sofie Mine was screened into *smalls* below 1/2″ and *large* above that size. About 25 per cent. of the Sofie coal went through the screen and a somewhat higher percentage of the Ester coal. *Large* from Sofie Seam contained 11—12 per cent. of ash, and *smalls* 28—29 per cent. In January, February, and March 1925 the average ash content of coal from the Ester Seam was: In *large* 9.84 per cent. and in *smalls* 21.98 per cent. In January and February 1929 the average of ash in Sofie coal was 7.00 per cent. in *large*, and 30.4 per cent in *smalls*; and in Ester coal *large* gave 8.4 per cent. ash and *smalls* 24.1 per cent. As will be seen, the *smalls* contained from three to four times as much as the *large*.

If the export analyses are compared with the average analyses of the various seams in the table page 154, it will be seen that there is quite a great difference between the ash content in these analyses. In the latter table I have tried to find the real averages of the various seams by calculating the average from the most reliable samples. These analyses represent the average of the different seams excluding thicker partings of stone, which have not been included in the samples, and which in any case ought to be separated from the coal.

The high ash content of the Kings Bay coal gave them a rather bad reputation as steam coal. This high ash content could certainly have been reduced by a good separation of the *smalls*. During the working of the mines only the large pieces of stone were removed by hand. The cleaning of the *smalls* would require a large cleaning plant, which would of coarse increase the cost of production. As it is a fact that the ash content in the Kings Bay coals is really high, it cannot of course be reduced below a certain limit, but I should think that the maximum of ash in the exported coal ought not to exceed 15 per cent.

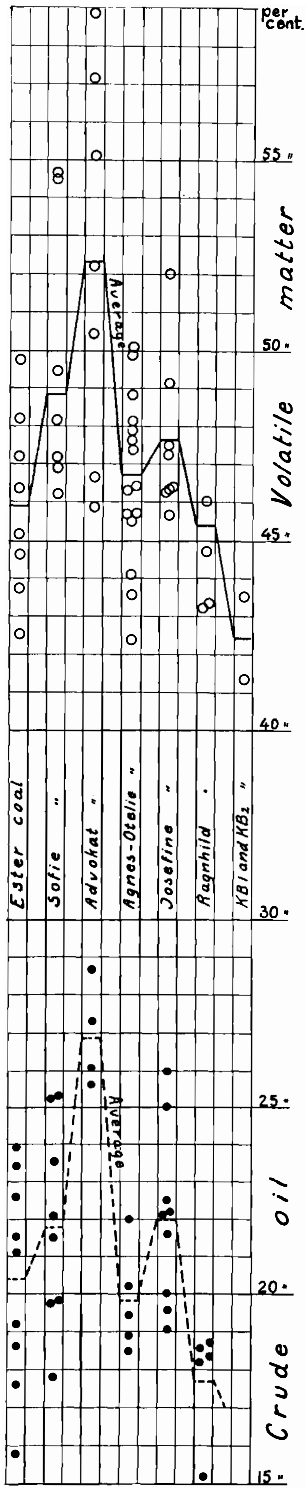

Fig. 47. Diagram showing the content of volatile matter and crude oil of different coal seams calculated on pure coal.

As will be seen, there is less ash in the upper seams than in the lower, but these seams are of but minor importance owing to the small quantity of coal they contain.

In fig. 46 I have drawn up a diagram from these average analyses, calculated on ashfree but not waterfree coal to see whether any conclusion can be arrived at as to the degree of carbonization. The analyses are made mostly on mine samples giving an almost correct percentage of moisture, with the exception of the analyses from the Ragnhild and KB2 seams, the samples of which were taken at the surface on weathered coal. The moisture in these analyses is thus too high.

With the exception of the Ester Seam it will be seen that carbonization is more advanced from below and upwards. This fact may perhaps be explained by the upper seams being situated closer to the thrust plane. They may thus have lost more of the gases owing to the tectonical pressure. As pointed out, also the Ester Seam has been subject to such disturbances and possibly the more advanced carbonization of this seam may be due to this fact. The differences in volatile matter are, however, so small that they may also be explained by an original difference of the coal-forming material.

In fig. 47 I have drawn up the percentage of volatile matter and crude oil for a series of analyses, and with lines I have combined the average of these analyses. All analyses have been calculated on pure coal. In this scheme I have used more analyses than in the calculation of the averages in the table on p. 154. For this reason the results differ somewhat. As will be seen the content of volatile matter and crude oil is especially high in coal from the Advokat Seam and low in the uppermost seams.

Quantity of Coal.

In the chapters dealing with the various coal seams tables are included showing the coal area, thickness, and quantity in the different areas. I regret to say that the figures given in these tables, in spite of the exploring work done and the greatest care taken in the calculation, may differ considerably from the really existing quantities of coal. The reason is to be found in the exceptionally great irregularities in the coal seams, irregularities which are partly due to the original deposition, but perhaps still more so to the tectonical disturbances. In fact these irregularities are so great and distributed all over the field, that an accurate knowledge of the seams could be obtained only by an investigation which would require an inordinate amount of work and expense. This work had to be reduced to what was absolutely necessary for a satisfactory calculation to be made. I should think that the errors made are within reasonable limits. The greatest difficulty is, however, to fix the workable part of the total quantity of coal. This is, of course, also a matter of market prices and wages. In the tables I have calculated with thicknesses down to 0.6 metres for the whole quantity, but of course all this coal is not workable at present.

In the table below I have included the totals of the tables for the different seams.

Seam	Area in sq. kilometres	Total of coal in mill. tons	Workable coal in mill. tons
Ragnhild Seam	0.78	0.69	?
Josefine Seam	1.12	1.48	?
Otelie Seam	2.38	2.56	0.73
Advokat Seam	0.71	0.95	?
Sofie Seam	3.35	4.00	1.85
Ester Seam	4.09	6.52	4.00
Total	11.73	16.20	6.58

The total of the coal areas of the various seams is thus about 11.7 sq. kilometres, the total quantity of coal about 16 mill. tons, of which about 6.5 mill. tons is probably workable. This figure does not include the remaining coal in the Ester Seam in Østre Centerfelt, because this coal must perhaps be regarded as lost after the mine has been closed down and filled with water. It is at present impossible to determine the amount of coal workable on the upper seams and also on the lower seams in the western part of the field, and it is likely that the really workable coal will exceed the above figure.

Genesis of Coal Seams.

As we have seen from the description of the various coal seams all the coals in the Kings Bay deposits are of about the same type, namely bituminous coal very rich in gas, which can more accurately be termed gasflame coal.

All the seams must have been formed under approximately the same conditions, and all of them must be regarded as autochthonous. The vegetation shows us that there must have existed extensive moors and swamps, which according to Nordenskiöld have grown in a temperate climate with an average temperature of about five degrees. The presence of *Equisetum arcticum* with roots and suckers as well as the existence of roots in the foot wall of the coal seams show that the trees and plants have grown on the spot.

The irregular layers of shale and sandstone which occur in the seams indicate that the land at different periods, and rather frequently, has been flooded or submerged, so that clay, sand and gravel have been washed over the vegetation. The great number of stone bands wedging out at short distances show distinctly that most of these overflows have been of a local nature and have only extended over limited areas. This has, however, not been the case in the Ice Fjord, Bell Sound district, where such stone bands are found over great areas.

In the Josefine Mine I observed some pebbles of sandy shale interbedded in the coal seam. This fact tells us that during the time of vegetation there must have existed rivers or shores with pebbles in the neighbourhood and thus confirm the local nature of the moors.

In older Tertiary time there must have existed a great lake at Kings Bay, which within the now remaining coal area must have had its greatest depth towards the east. This lake has been filled in with clay and pebbles of claystone and chert from different streams debouching into the lake. Afterwards the whole area has been covered by a moor now forming the Ester Seam. Then it has been overflown by freshwater, or perhaps brackish water, in which an abundance of siliceous algæ has lived in the first period of sedimentation. Clay and sand, representing the sequence between the Ester and Sofie Seams, has been gradually deposited with some break in deposition.

The next period of vegetation must have been concentrated in the middle part of the depression, or more easterly. This has been still more the case with the third great period of vegetation, representing the Advokat Seam. The western part of the swamp had then already been laid dry, so that no coal seam has been formed here. To the east, however, the vegetation in this period has been very rich, but it has often been broken by overflows from south or east. At last the whole area has been covered with gravel and sand, and the barren section between the Advokat horizon up to the Agnes-Otelie Seam has been formed.

The latter seam as well as the overlying coal seams have been formed in a similar way.

From the conglomerates below and above the Agnes-Otelie horizon it is seen that there must at this time have been rather broken ground with strong currents.

As already pointed out, no marine mussels have been found in the sequence at Kings Bay, but, on the other hand, a very rich vegetation has been found in some of the layers forming the hanging wall of the coal seams, such as is the case with the hanging wall of the Josefine Seam. This plainly shows us that these layers have been deposited in freshwater basins. There thus exists quite a great difference between the forming of the coal seams at Kings Bay and in the Ice Fjord district. In the latter district the coal seams extend over great areas with tolerably uniform thickness, and the marine trangression distinctly reveals that the vegetation here must have grown near the shore. The irregular thickness and extent of the coal seams at Kings Bay, as well as the great number of local stone bands, are explained by the local nature of their formation. The tectonical disturbances have later on accentuated these differences.

The coal at Kings Bay and the coals in the Ice Fjord district have been formed in approximately the same way and of the same initial material, and it is therefore quite astonishing that the Kings Bay coals contain far more gases owing to a less advanced carbonization. What can the reason be? This question is really difficult to answer.

Owing to the tectonical disturbances, one would indeed expect to find conditions just the opposite of these, namely, that the process of carbonization would have been more advanced at Kings Bay. Of course, the high content of hydrogen and volatile matter might be due to a difference in the initial material, but the reason may perhaps also be that, in the middle and southern parts of Spitsbergen, there has been deposited a greater sequence above the coal horizon, and that the more advanced carbonization here is due to a greater pressure in a long period. There is thus some reason to believe that the land surface, also after the old Tertiary period, has been less emerged in the northern than in the southern part of Spitsbergen.

History of Coal Mining.

The coal occurrence at Kings Bay was discovered on July 19, 1610 by some English whalers on a boating excursion to the interior of the fjord. The ship, which was under the command of the well-known whaler Jonas Poole, then rode at anchor in Cross Bay. He writes about this incident [Purchas, 1625, Vol. 14, p. 19]: "and in Deere-sound they found Sea-coales, which burnt verry well". This is the very first account of the finding of coal in Spitsbergen. The coal was certainly found as loose pieces scattered on the river plains. From later accounts we know that such coal pieces were found in several spots on the coal field.

From the account of Scoresby (1820) it is seen that the coal was not forgotten. The whalers picked up coal here and used it on their way home. He writes about this (Vol. I, p. 149): "Though Spitzbergen is probably rich in minerals, yet the examination of it has been so partial, and indeed trifling, that nothing of any value, excepting marble and coal, has yet been met with. The former is found in some parts of Kings bay of real beauty; and the latter, of a tolerable quality, near the same place. The coal is so easily procured, that many of the Dutch fishers, a few years ago, were in the habit of laying in a stock of this useful article, for fuel, on the passage homeward."

Fries and Nyström (1869) relate that the Swedish expedition in 1868 worked out coal from a small seam and brought 70 cubic feet of coal on board the *Sofia* for steam raising. This is certainly the first time these coals have been used for heating a ship's boiler. Coal has probably been mined on the seam found by Blomstrand in 1861 in the eastern part of the field, probably the Ester Seam, for this seam has been observed here in later years.

Lamont (1876) also relates that in 1869 he picked up 120 bag-fuls of coal on the gravel cone north of Anneksjonshytta in the easternmost part of the field. He also found the coal seam *in situ* by following the brook upwards.

In 1901 the land south of Kings Bay was occupied by a joint concern from Bergen on the initiative of Skipper B. Pedersen. He undertook an expedition to Spitsbergen in 1901 with the M/K *Colibri* of Tromsø and built a small house on the coal field. Claim-boards were erected with the following inscription: "Aktieselskapet Bergen 22/7 1901. B. Pedersen". The company did not undertake any work later on. On July 22, 1922 these rights were transferred to *Kings Bay Kul Comp. A/S.*

The Northern Exploration Co., Ltd., London claimed to have occupied the coal field in 1905 or 1906.

In 1906 the land on the south side of the fjord was claimed by the Earl of Morton and Lord Balfour of Burleigh.

Chr. Anker, Fredrikshald, who had taken interest in the coal deposits of Spitsbergen, formed a joint concern for coal exploration in Spitsbergen and sent out expeditions to Kings Bay every summer from 1909 to 1915. These expeditions did exploratory work and maintained the rights of the concern.

In 1909 an expedition was sent out with S/S *Evviva* under the leadership of F. Nannestad, who on June 23 claimed the coal field for the joint concern. Besides the coal field, he claimed an area around Kings Bay five kilometres inland from the shore. The claim was made on June 23—25 by the setting up of claim-boards, and was notified to the Ministry of Foreign Affairs on July 26 and 28, 1909. Four men worked on the field for a week.

In 1910 an expedition was despatched under the leadership of S. Smith. At Agnes Mine an adit was worked by six men from July 19 to 25. A house was built.

In 1911 Karl Bay was the leader of an expedition to Kings Bay with M/K *Sletvold.* The German mining director, Otto Wex, took part in the expedition as coal specialist. From August 5 to 26 four men and a foreman worked at Agnes Mine, Godthåp, and a place called Cutting B on the Advokat Seam, which was found that year. On August 5 the claim was extended so as to include the whole Brøggerhalvøya. The extension of the claim was notified to the Ministry of Foreign Affairs on November 3, 1911.

Karl Bay was also the leader of the expedition in 1912 with M/K *Onsø*. In that year three men worked from August 4 to 25. A house was built, and the coal seams at KBI and KBII were uncovered.

In 1913 Bay used the same boat and continued work for six weeks with one foreman and four men. He made a map of the coal field on the scale 1 : 10000. The work on Agnes Mine, KBI and KBII was continued.

The coal seams at Kolhaugen, KB4, and at Skjerva, KB3, were found that year. The German geologist and mining engineer, Dr. F. W. Voit, undertook an examination of the coal field in that year.

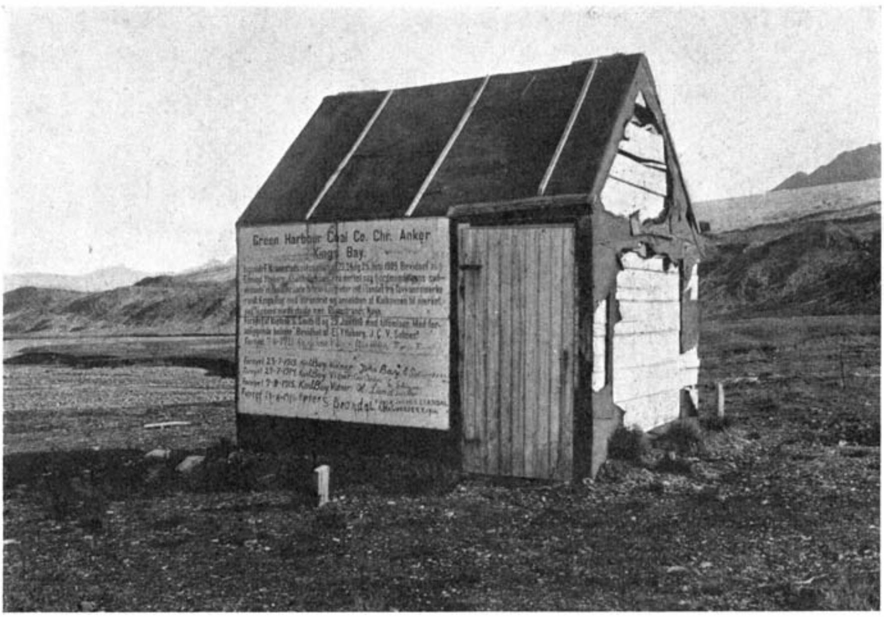

Fig. 48. Claim hut at Lovénbre No. I.
A. K. Orvin phot. 25/8 1922.

In 1914 Bay and four men visited the coal field from July 29 to 31. Adolf Hoel undertook a preliminary examination and geological mapping of the field. As his topographical base he used the map surveyed by Bay in 1913.

In 1915 Kings Bay was visited by Bay, the Russian mining engineer Maliavkin, and Henrik Lund, a Norwegian engineer. The work was carried on three or four days in the beginning of August. The M/K *Onsø* was used also in 1914 and 1915.

On May 25, 1916 the claim was offered for sale by Anker to Peter S. Brandal, shipowner, of Brandal, Ålesund. In that year Brandal went to Kings Bay with an expedition consisting of two vessels and 60 men in all. They worked for six weeks from July 21, and about 300 tons of coal were worked out of Agnes Mine. About 250 tons were exported. Also

Godthåp was re-opened, and the coal seam here showed a thickness of 1.3 metres. The coal from Agnes was transported down to the shore by a provisional aerial rope-way. When Brandal arrived he found three houses on the coal field.

The property was transferred to Brandal by contracts of Sept. 23 and 30, 1916. These contracts given to Brandal were at first transferred to a joint concern, the members of which were: Peter S. Brandal, Trygve Klausen, M. Knudsen and Trygve Jervell. In December of the same year these gentlemen tranferred the rights to the *Kings Bay Kul Comp. A/S*, Ålesund, for an amount of 250 000 Kroner.

The four above-mentioned members were the only shareholders of the company. In general meeting of December 14, B. A. Sherdahl, mining engineer, was appointed technical manager of the company from April 1, 1917, and Jens K. Bay business manager from January 1, 1917. The share capital was 500 000 Kroner divided into 100 shares.

On July 12, 1917 Sherdahl left Norway for Kings Bay with an expedition consisting of 30 workmen and officials, besides the crew of the ship. Construction work was commenced.

On August 26 the steamer *Deneb* arrived with the winter provisions and workmen, the number of which was now 143. Later in the autumn several sealers went to Kings Bay with material and stores.

Kings Bay was visited 14 times that summer. The tonnage of the ships used was 3 105 tons d. w.

About September 20 the railway was ready for use. About 800 tons of coal from the Agnes Mine were sent to Norway in sealers, of which the last left Kings Bay on October 9.

During the summer of 1917 and the winter 1917—18 the following houses were built: Three barracks for workmen, workmen's mess, offices, two storehouses, stable, cattle-shed, forge and workshop, locomotive shed and pumping station. Further 2.2 kilometres of railway were built and two locomotives, waggons, a steam-shovel and a steam-power plant procured.

Coal mining was continued during the winter with 62 men.

In 1918 the first steamer left Norway on April 19 and arrived on May 5. Four 2000-ton steamers, a barque of 800 tons, a tugboat of 300 tons, and several sealers were chartered, in all 11 vessels, of the total of 10 168 tons d. w. The Advokat Mine was opened in the autumn. Coal mining and examination of the coal area was undertaken in the summer. The maximum number of workmen in the summer was 300. Exports were about 15 000 tons. The steamers called 20 times and various sealers 12 times. Also a ship belonging to the Northern Exploration Co. Ltd. bunkered in Kings Bay, and on the same occasion this company entered a protest against the coal field being worked by the *Kings Bay Kul Comp. A/S.*

The last ship left Kings Bay on October 10.

The following building work was done in the summer: Power station in camp with steam engine for electric light, later replaced by a motor, staff mess, five workmen's houses, one storehouse, two barracks at the mine, baths, coal tip, provisional loading arrangement at the shore with five lighters, and a wireless station which was ready for use in October. A new locomotive and 30 waggons were also procured.

In 1918 Mr. Jervell sold his stocks to Brandal, Klausen and Knudsen. That year Dr. J. Gram found the high content of crude oil in the coal.

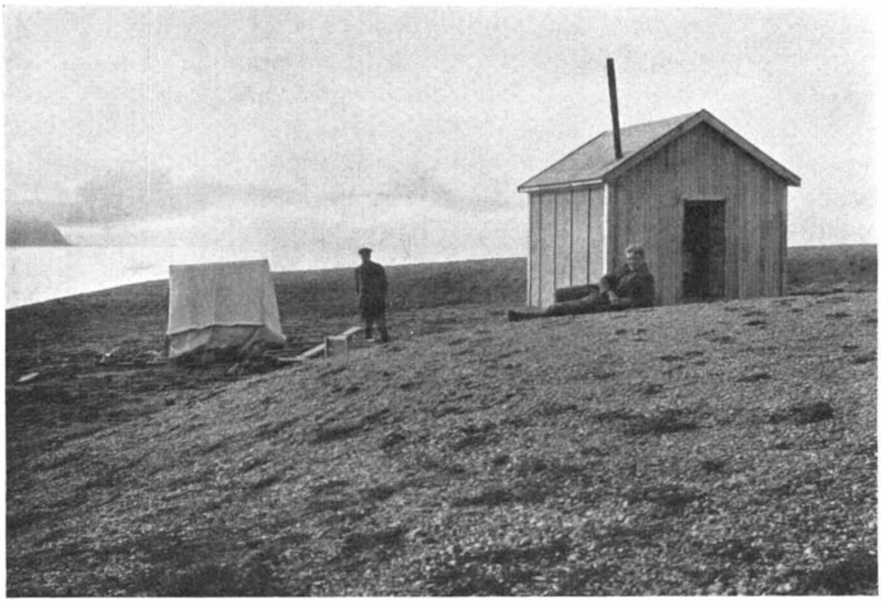

Fig. 49. Hut belonging to the mining company at Forlandsundet.
L. J. Orvin phot. 9/8 1929.

The number of hands in the winter of 1918—19 was 143. In addition, seven men wintered from S/S *Lods* which arrived at Kings Bay in the latter part of October and froze in there.

Johan Hangeraas was manager that winter. During the winter a new power station was built at the Agnes Mine with a 60 h. p. steam engine, and about 18 000 tons of coal were mined until the beginning of the shipping season. The work was partly restricted by a strike.

In the summer of 1919 the first steamer arrived on May 12. Exports totalled 14 509 tons of coal, in addition to which 980 tons were used for bunkering.

The working strength in the summer of 1919 was about 250 men. No work was done in the mine during the summer because of a wages dispute, but the following houses were built: Store house, two double staff houses, manager's house, foremen's mess, hospital, office building, barracks for 76 men, four houses each for eight men, power house for the wireless station and an extension of the wireless station. The last boat left Kings Bay on October 4.

The wintering force in 1919—20 consisted of 156 men, eight women and five children.

The work in the mine was resumed in the month of October; there was, however, again a stoppage of work from November 10 to January 27, 1920.

In the spring of 1920 the first ship arrived on May 5. At the beginning of the shipping season at the end of June, there was 11 000 tons coal in stock. During the summer, however, so much coal was produced that 35 162 tons were shipped, of which 2 354 tons were used for bunkers.

The working strength in the summer of 1920 consisted of 274 men and four women. In addition, three women and three children belonging to the staff families lived at Kings Bay.

In the course of the summer a new loading quay was built. The barque *Vega* of 900 tons was sunk, filled with stones, and connected with the shore by a bridge 120 metres long and 10 metres high, on which the coal trains were run from the mine direct to the ship's side. The quay was used from early in July.

Further, there was built a piggery for 60 pigs, a house for baking and sausage-making, and extensions were made to the baths, the engine house at Agnes Mine, the locomotive shed and the workshop. In that year the Otelie Mine I was opened, and the Josefine Seam was found. The last ship left Kings Bay on October 15.

In the winter of 1920—21 mining was continued in Agnes Mine, and Otelie Mine I and Josefine Mine were opened. The working strength was 224 men and 12 women under the leadership of Sherdahl, who had acted as manager since 1919. Ten women and 23 children not employed by the company also wintered. In all there were 269 inhabitants at the works.

In the spring of 1921 the first ship visited Kings Bay on April 13. During the summer there were 49 steamer calls. The last boat left Ny-Ålesund on October 29. Exports amounted to 69 082 tons, not including bunkers. Of this coal 100 tons were delivered to Braganza Bay and 7 936 tons to various sealers. For bunkers 5 397 tons were used. The average number of persons employed was 299 men and 23 women. In addition, there were five women and seven children belonging to the staff families. There were thus 334 inhabitants at the works that summer.

In the autumn of 1921 the central part of the coal field was mapped on a scale of 1 : 1000 by A. Koller and W. Solheim, topographers with the Norwegian Svalbard expeditions. The mapped area was 11 sq. kilometres.

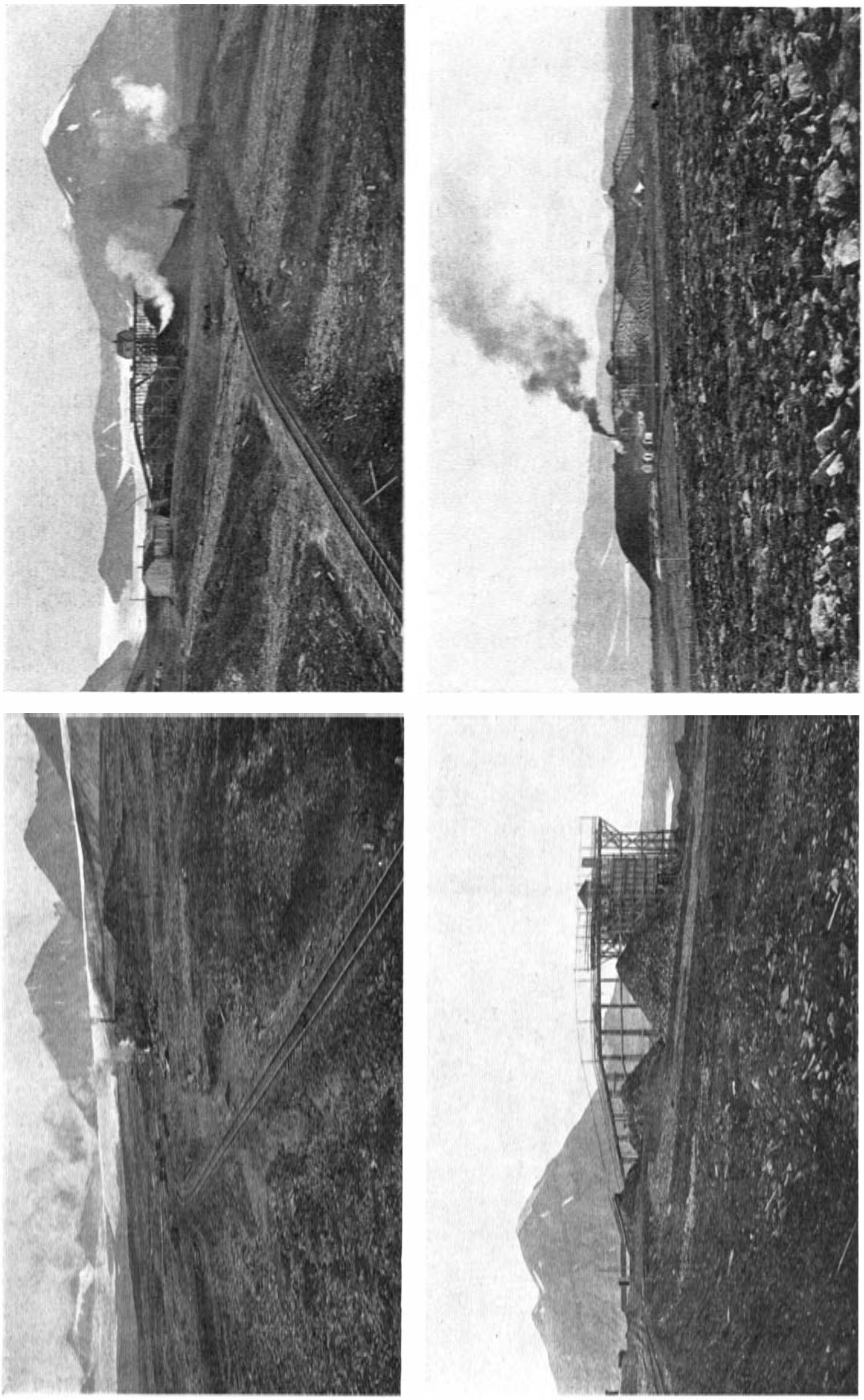

Fig. 50. Some of the mines at Kings Bay.

1. The power station and Agnes Mine, 29/8 1922.
2. The Josefine Mine from the east, 29/8 1922.
3. The Otelie Mine II from the east, 23/8 1925.
4. The Sofie and Ester Mines from the southwest, 29/8 1925.

A. K. Orvin phot.

In 1921 the Spitsbergen Coal Committee visited Kings Bay. This committee had been appointed on June 26, 1920. The members were: B. Stuevold-Hansen, general director, chairman, A. Hillestad, under-secretary of state and Hj. Batt, director of industries. Carl C. Riiber, mining inspector, also took part in the trip.

In the winter of 1921—22 Hans Merckoll acted as manager. Work-people and staffs totalled 154 men and 18 women. Seven other women and nine children wintered. There were thus 188 inhabitants in Ny-Ålesund. Only the Josefine Mine was worked that winter.

In the summer of 1922 Ny-Ålesund received 33 steamer calls, and exports were 68 610 tons, excluding bunkers, which amounted to 4 416 tons. The last collier left Kings Bay on October 28.

In that year the rights of the Bergen company were purchased.

In the summer of 1922, 190 men and 16 women were employed. Further, ten children and eight women not employed, lived in Ny-Ålesund. Geological work was undertaken by the author that summer.

In the winter of 1922—23 the Josefine Mine was worked, 169 men and 19 women being employed. As also nine other women and nine children lived at the works, the number of inhabitants was 206. Sherdahl was manager that winter.

In the summer of 1923 Ny-Ålesund had 34 calls by colliers. The last boat left Kings Bay on October 14. Coal exports were 85 437 tons, and for bunkers 6 159 tons were used. There were 338 inhabitants at the works, of which 301 men and 19 women were employed, and ten women and eight children not employed. The Olsen Mine was opened in the summer, and the Sofie and the Ester mines were opened on the respective seams, the existence of which was proved that summer. A geological map of the field was surveyed on a scale of 1 : 5000 by the author.

Jens K. Bay had left in 1920, and Thorleif Berger was appointed in his place. He died, however, in the spring of 1922. The office in Ålesund was then managed by Arth. Jürgens until the spring of 1923, when Arne Brøgger was appointed business manager, an appointment which he held until the mines closed down.

In the winter of 1923—24 Sherdahl was manager. The Olsen Mine was abandoned, and the work was concentrated in the Ester and Sofie mines. In the spring the Josefine Mine was exhausted and was abandoned. 231 persons lived at Ny-Ålesund that winter.

In the summer of 1924 Ny-Ålesund had 29 steamer calls. Coal exports exclusive of bunkers were 82 677 tons and bunkers 6 267 tons. The last boat left Kings Bay on October 12. There were on the average 259 workmen, 21 persons belonging to the staff, 28 servants, and 28 other persons, in all 336 inhabitants.

The following winter, 1924—25, S. Smith Meyer was manager. Number of inhabitants 271. Of these 206 were workmen, 20 were on the staff, 23 were servants, and 22 were unemployed. Ester and Sofie mines were worked.

In the summer of 1925 31 cargoes, containing 87 722 tons, were exported. Two cargoes of 7 115 tons were shipped to *A/S Greaker Cellulosefabrik* for crude-oil distillation experiments. Seven colliers of 21 720 tons d. w. were used. The average freight paid per ton of coal was Kr. 8.88. The loading capacity was 3 000 tons a day. The last boat left Kings Bay on October 22.

The Northern Exploration Co., Ltd., which still claimed to be in possession of the coal field, was bought out that summer. The matter was arranged by Dr. Arnold Ræstad, who in 1925 visited Kings Bay together with Ole Røed and Fr. Marstrander. They were appointed by the Norwegian Government to deal with the settlement of the claims in Svalbard.

The mines were closed down in the winter of 1925—26 owing to lack of working capital. Only a watch of 20 persons remained to take care of the works and to keep the mines free of water.

After the death of Klausen in 1924 the board of directors consisted of the remaining two members, Brandal and Knudsen. Out of respect to *Aalesunds Kreditbank* and the Norwegian State, new members were appointed, viz. T. Berset, Ålesund, and Lauritz Devold, Ålesund. Brandal was re-appointed. Berset was appointed chairman.

Mining work was resumed on June 7, 1926 in Ester and Sofie mines. In July water broke into Ester Mine from a fissure in the foot wall of the mine about 40 metres below the sea-level. The quantity of water was about 450 litres per minute. For this reason the development work in the mine could not be prosecuted until the month of October.

The average of persons engaged in the summer was 280. Of these 144 worked underground, 17 were on the staff, and 17 were women. Total exports were 90 499 tons, of which 72 973 tons were delivered to the State-supported steamship companies, 7 652 tons were bunkers, 2 670 tons used for oil-distillation experiments, and 314 tons were retail sales at Kings Bay. There were 30 steamer calls. Shipping commenced on June 12, and the last collier left Kings Bay on November 20.

In the year (January 1—December 31) 1926 131 039 tons of coal and rock were mined; 101 817 tons were raised from the mines, and of this quantity 14 058 tons were waste rock. By further cleaning of the remaining 87 759 tons of raw coal 84 722 tons of coal were won. For its own use the mine needed 1 973 tons coal. In 1926 3 652 metres of gateways, crosscuts and slopes were driven, 84 718 sq. metres of coal seams were removed, and 42 992 metres of timber and 30 442 kilogrammes of explosives were used. Wages paid amounted to Kr. 872 906.

In the winter of 1926—27 the number of hands employed totalled 276, of which 154 worked underground, 15 were on the staff, and 16 were women. The number of inhabitants was 282.

58 men, who should have returned to Norway by the last steamers, had to stay because these steamers did not reach Kings Bay in November. The icebreaker *Isbjørn*, sent out to assist these colliers, was compelled to return to Norway owing to bad weather.

The work went on in Ester and Sofie mines. In Sofie Mine a new main slope was commenced in December.

During the winter two gas explosions took place in the Ester Mine on Sofie Seam, the one on April 20, by which four persons were killed, the other on May 2, by which the same number was injured.

In January 1927 the locomotive shed and the work-shop were destroyed by fire.

On June 1, 1927 the Svalbard Commissioner (1927)[1] had given his sanction to the companies claim to the area: *Matr. no. 38, l. no. 1, Kongsfjord.* Deed of conveyance was executed by the Department of Trade on September 24, 1924.

In the summer of 1927 an average of 258 persons were employed. Of these 105 worked underground, 16 were on the staff, and 17 were women.

In August 1927 a fresh inflow of water of about 2 500 litres a minute took place in the Ester Mine. As sufficient power for pumping machinery was not available, a new power station was built in the following winter at the shore a short distance west of the loading bridge. In the meantime work had to be stopped in the Ester Mine. The Sofie Mine was worked throughout the year.

Coal exports in the summer of 1927 were 98 672 tons including 7 664 tons bunkers and 602 tons retail sale in Spitsbergen. Ny-Ålesund had 38 steamer calls, and the shipping season was from May 20 to November 10.

In the year 1927 179 115 tons coal and rock were mined, and 132 678 tons raised from the mine including 18 300 tons waste rock. Of the remaining 114 378 tons raw coal 108 931 tons coal were won by cleaning. The mines' own consumption of coal was 4 074 tons. 3 725 metres of gateways, crosscuts and slopes were driven, 114 435 sq. metres of coal seams were removed, and 75 714 metres of timber and 33 735 kilogrammes of explosives were used. Wages amounted to Kr. 1 247 176.

From the commencement of the mining operations in 1917 until the autumn of 1927, 673 979 tons of coal were exported to Norway. The total value was Kr. 28 793 648.

The Sofie Mine was worked through the winter of 1927—28. Sherdahl was manager. The number of hands was 162, of which 65 worked underground, 13 were on the staff, and 14 were women.

[1] On Aug. 14, 1925 Norway got sovereignty over Svalbard and the ownership of the various claims was to be decided by a commissioner nominated by the Danish Government.

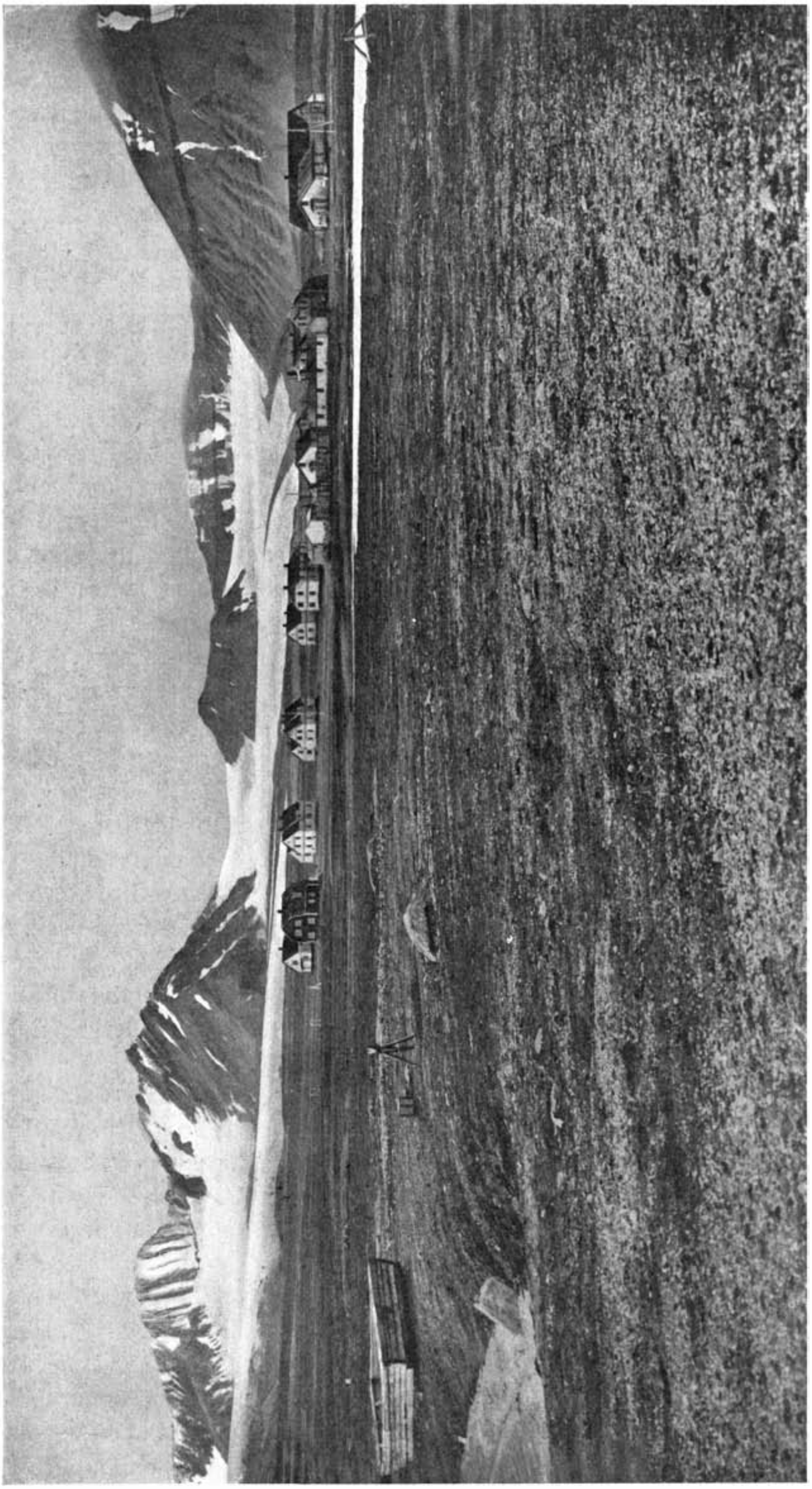

Fig. 51. Ny-Ålesund.
Alfred Koller phot. 1921.

The new power station was completed in the summer of 1928. A steam turbo-motor and a generator of 500 kw. were installed. From now on electric energy was used for pumping as well as for other work.

In the summer of 1928 the Svalbard Delegation, five members of the Financial Committee of the *Storting*, visited the Spitsbergen coal mines, including also Kings Bay, under the leadership of Mr. Hornsrud. The average working force that summer was 222. Of these 92 worked underground, 16 were on the staff, and 16 were women. Five steamers each of 3 050 tons d. w. and one of 2 050 tons were used. These boats made 33 calls, and the freight paid per ton was Kr. 6.28. The shipping season was from June 10 to October 20. In June and July an epidemic of influenza broke out among the mining population.

Coal exports in 1928 were 96 943 tons, of which 82 796 tons were sold in Norway. Retail sales in Svalbard amounted to 3 137 tons, 2 689 tons were stored at Ålesund, and 6 516 tons were used for bunkers.

On June 14, 1928 the *Storting* granted Kr. 70 000 for deep drilling on the coal field. This work was executed from July 9 to October 6, 1928. As deep drilling has never before been done so far north, it is of especial interest, and has therefore been dealt with in a special chapter of this paper.

In the year 1928 159 737 tons of coal and rock were mined, and of this quantity 60 502 tons were waste rock. 118 745 tons were raised from the mine, of which 14 770 tons were waste rock. By cleaning the remaining 103 975 tons of raw coal 99 235 tons coal were won. The mine consumption of coal amounted to 4 850 tons. 3 357 metres of gateways, crosscuts and slopes were driven in the year 1928; 100 544 sq. metres of coal seams were removed, and 63 420 metres of timber and 24 159 kilogrammes of explosives were used.

In the autumn of 1928 the Ester Mine was worked, and in the winter of 1928—29 work was prosecuted under the leadership of Slåtto. The number of hands was 158, of which 75 worked underground, 13 were on the staff, and 13 were women.

In Sofie Mine the remaining pillars were removed, and from this mine the Ester Seam was worked downwards along the dip in *Kjelleren*. The Sofie Seam proved, however, to be unworkable downwards along the dip, and as also the Ester Seam in *Kjelleren* wedged out, the Sofie Mine was almost abandoned during the winter, and the work was concentrated on the Ester Seam in the Ester Mine. As, however, the main slope in this mine also stretched into an unworkable area, all winning work had to be done from the eastern slope in Ester Mine. This slope had been weakened by removing a part of the pillars, and in the working places operations were hampered by gas in such great masses that work had repeatedly to be stopped until the gas had been ventilated out of the mine. Owing to this trouble and working on impure coal areas, the coal produced contained an unusually high percentage of ash. The company was thus in a particularly unfortunate position because it had been impossible to open the lower part of the Ester Seam in the Ester Mine owing to the great inflow of water. When the Sofie Mine and the main slope in Ester Mine failed, mining had to be prosecuted in a limited area, where work was much impeded by water and gas.

In the spring of 1929 the first steamer bound for Kings Bay left Norway on June 10, but it had to return owing to difficult ice conditions. The first shipment of coal could not therefore be made until July 4.

In the summer an average of 188 persons was employed. Of these 76 worked underground, 15 were women, and 13 were on the staff. The greatest number, 262 persons, was employed in July.

On August 16, 1929 a gas explosion took place in Sofie Mine, and two workmen were killed. Owing to the above-mentioned difficulties the company was not able to present any estimate for a profitable working of the mines the following winter, and for this reason mining at Kings Bay was finally discontinued in the autumn of 1929. The last cargo was shipped on September 27. The Ester Mine was abandoned, and again filled with water. The mine can never be re-opened.

In the year 1929 78 060 tons of coal and rock were mined; 69 785 tons were raised from the mines, of which 16 970 tons were waste rock. By cleaning the remaining 52 807 tons, 49 197 tons of coal were won. The mine used 4 152 tons coal. In all 58 856 tons were exported, including 996 tons retail sales in Spitsbergen and 5 446 tons bunkers.

In the winter of 1929—30 only three persons wintered at Ny-Ålesund to guard the houses and stores.

Since the closing down of the mines no work has been done in Kings Bay. Only a small guard is still maintained to look after the house buildings and stores.

The wireless station was again opened in the summer of 1930 and has since corresponded with Svalbard Radio in Longyearbyen.

As the share capital of the company was relatively small and was chiefly used for purchasing the coal field and for preparatory work, it was necessary to borrow money for the construction of works. This money the company got as a loan from *Aalesunds Kreditbank*, to whom it owed 5.2 mill. Kroner in the autumn of 1921.

From 1920 the company also received financial support from the Government, in the form of advances against coal deliveries to the State-supported steamship companies. This State aid was given to the coal companies owing to the fluctuating conditions on the world's coal markets and the difficulty in obtaining coal from foreign countries. The

English coal market was for some time closed altogether owing to the English embargo on the exportation of coal.

In 1919 English coal exports were controlled by the Government. During the railway strike in the autumn of that year exports diminished, so that the Norwegian State had to buy coal from the U.S.A. and other countries. Coal prices were continually rising, and in September 1920 they soared to Kr. 245.00 per ton. It was thus of the greatest importance to make this country as independent as possible of foreign coal supplies. At the same time there was some possibility of the coal field passing into foreign hands, and thus there was all the more reason for this coal being secured for Norway by State support.

At first the State bought the coal and resold it to the steamship companies, but in this way losses were incurred during the period of failing trade. Afterwards the steamship companies purchased the coal direct.

During the English coal strike in 1926 the coastwise traffic in northern Norway would hardly have been maintained to its full extent without the coal from Svalbard. Also the fishing fleet was able to keep going with coal from the Norwegian mines.

State support of coal mining was also found desirable during the negotiations relating to the nationalisation of Svalbard and during the consideration by the Svalbard Commissioner of the rights of ownership to the claims.

Broadly speaking, mining in Kings Bay resulted in a considerable deficit. This was chiefly due to the low prices ruling on the coal market in the later years of working. Falling market prices were especially unfortunate for the *Kings Bay Kul Comp. A/S*, which each autumn had to base the work for the following winter on the market price and on the wages ruling when the labour contracts for the following season were signed. Receding prices during the winter, when no changes could be made in wages, and no coal could be sold, would altogether upset all calculations.

Already in 1920 the loan from *Aalesunds Kreditbank* was spent, and the company had nothing left for continued work and coal production. The company then applied to the Government for support in the shape of advances against coal deliveries. In view of the position on the coal market the Government found it expedient to provide such advances.

In 1920 the company got Kr. 207 per metric ton of coal, and produced coal for about double the value of the advance received. In the following year the price had declined to about Kr. 59 per ton, and the work gave a great deficit. This was also the result in 1922, when the price had declined to about Kr. 38 per ton.

In 1923 and 1924 the prices were respectively about Kr. 38.60 and Kr. 34, and for these two years the work gave a profit. In 1925, however, the price declined to Kr. 25.40, and resulted in a rather large deficit. That year also the Northern Exploration Co., Ltd. was bought out for Kr. 780 000.[1]

In 1926 the prices of coal rose owing to the English coal strike, and the mining gave a surplus of about one million Kroner. The following two years there was a small deficit, because the price then had again declined.

The debt to *Aalesunds Kreditbank* with interest had increased, and on January 1, 1929 was Kr. 8 866 000. After the works had been closed down in 1929 the chances of the company being able to pay its debt were very small. As *Aalesunds Kreditbank* had to be reconstructed owing to the great loss on *Kings Bay Kul Comp. A/S*, the Government paid Kr. 125 000 to cover this loss. The whole of the property thus passed to the Norwegian State in 1931, in which year the company owed Kr. 6 272 000 to the State.

More detailed information about the company's relations to the State are to be found in *Stortingets Forhandlinger* 1920—31.

The total of coal exported including bunkers from 1917 to 1929 was 833 864 tons, and the total value was about 32 mill. Kroner.[2]

Mining statistics of *Kings Bay Kul Comp. A/S* will be seen from the following tables.

The specifications concerning the mining from 1926 to 1929 I have for the greater part got from the mining inspector of Svalbard, Mr. Hans Merckoll.

Coal Exports.

Year	Exports excluding bunkers in metric tons	Bunkers in metric tons	Total exports in metric tons
1916	250	-	250
1917	800	-	800
1918	15 000	-	15 000
1919	14 509	980	15 489
1920	32 808	2 354	35 162
1921	69 082	5 397	74 479
1922	68 610	4 416	73 026
1923	85 437	6 159	91 596
1924	82 677	6 267	88 944
1925	87 722	6 426	94 148
1926	82 847	7 652	90 499
1927	91 008	7 664	98 672
1928	90 427	6 516	96 943
1929	53 410	5 446	58 856
1916—1929	774 587	59 277	833 864

[1] In this amount is also included payment for other properties which belonged to the Northern Exploration Co., Ltd.

[2] Amount given in paper *Kroner*, the gold value of which was fluctuating in this period.

Persons Employed and Inhabitants.

Year and season	Number of hands employed		Total of number of hands employed	Women and children not employed by the company	Inhabitants at Ny-Ålesund
	Men	Women			
Summer .. 1909	5	-	5	-	-
— .. 1910	7	-	7	-	-
— .. 1911	7	-	7	-	-
— .. 1912	4	-	4	-	-
— .. 1913	9	-	9	-	-
— .. 1914	6	-	6	-	-
— .. 1915	5	-	5	-	-
— .. 1916	30	-	30	-	30
— .. 1917	143	-	143	-	143
Winter 1917—18	62	-	62	-	62
Summer .. 1918	300 max.	-	300 max.	-	300 max.
Winter 1918—19	150	-	150	-	150
Summer .. 1919	250	-	250	-	250
Winter 1919—20	156	4	160	9	169
Summer .. 1920	274	4	278	6	284
Winter 1920—21	224	12	236	33	269
Summer .. 1921	299	23	322	12	334
Winter 1921—22	154	18	172	16	188
Summer .. 1922	190	16	206	18	224
Winter 1922—23	169	19	188	18	206
Summer .. 1923	301	19	320	18	338
Winter 1923—24	193	20	213	18	231
Summer .. 1924	284	24	308	28	336
Winter 1924—25	229	20	249	22	271
Summer .. 1925	254	24	278	17	295
Winter 1925—26	15	5	20	18	38 [1]
Summer .. 1926	263	17	280	18	298
Winter 1926—27	260	16	276	13	289
Summer .. 1927	241	17	258	14	272
Winter 1927—28	148	14	162	15 [2]	277
Summer .. 1928	206	16	222	15	237
Winter 1928—29	145	13	158	9	167
Summer .. 1929	173	15	188	9	193
Winter 1929—30	2	1	3	-	3

Mining.

From the chapter dealing with the history of coal mining operations it will be seen when the various mines at Kings Bay were worked. Mining on a large scale combined with exportation has been done on the Josefine Seam in the Josefine Mine, on the Agnes-Otelie Seam in the Agnes Mine, Otelie Mine I, and Otelie Mine II, on the Ester and Sofie seams in the Ester and Sofie mines. All other workings have been more or less exploratory work. No coal has thus been exported from the Advokat mines, the Ragnhild Mine, and the Olsen Mine. Coal production and exports, as well as the number of hands in the different seasons, will be seen from the above tables.

[1] In addition 32 men who had put up a hangar for the expedition of Amundsen and Ellsworth lived at Ny-Ålesund.

[2] Also including the district judge and his assistant with family.

All the mines have been worked by the room and pillar method and opened by a main slope along the dip from the outcrop of the seam. To ensure more effective ventilation and shorter transport two or three such main slopes were worked down in fan form from the mine opening. At every 18 to 20 metres along the dip gateways or rooms were driven to the right and left from the main slope. These gateways were further combined with crosscuts to get good ventilation. The dip of the main slopes would, according to the dip of the different coal seams, vary between 8 and 16 degrees in a southerly direction. The gateways were given a slight inclination towards the main slope to ensure easy transport. Owing to the unevenness of the stratification the gateways had a curved trend. The length of the main slopes in Agnes Mine was up to 400 metres, in Josefine Mine 450 metres, in Sofie Mine 575 metres, and in Ester Mine about 550 metres. In Otelie Mines I and II the length was only about 150 metres and 170 metres respectively. The length of the gateways was up to 200 metres, but usually they were far shorter.

From the description of the different coal seams it will be understood that mining has been done on seams of widely different development and thickness, from less than one metre up to several metres, and on coal seams without partings as well as on seams with stone bands, which had to be separated from the coal in the mine. Greatly disturbed areas of small thickness had to be left unworked. Such areas were met with quite frequently and caused considerable difficulty in the working of the mines and the calculation of the output.

Owing to the uneven strike and dip, undercutting machines were not used. All coal was won by drilling and blasting. In the first mining period only hand-drilling machines were used, but later on electrically driven drilling machines were also employed.

The method of working the seams was varied to some extent owing to the development of the seam. In Agnes Mine, where the seam was parted by a fairly thick stone band, the lower seam was first removed by drilling and blasting, and afterwards the stone band and the upper seam were wedged loose and broken down. Where the seams consisted only of coal, the whole seam was blasted out. The explosive used was coal-carbonite. For rock blasting also dynamite was used.

During the working of the gateways only part of the coal was taken out. When the gateways had reached the outer limit of the area to be worked to the main slope, the seam was worked back towards the main slope, and the pillars were removed. The emptied parts of the mine were abandoned, and the roof gradually broke down. Only along the main slope were the pillars left undisturbed until the whole mine had to be abandoned; then they were gradually mined out from below and upwards along the slope.

At the workings the coal was loaded into waggons of one cubic metre. This work was done either by hand, or the coal was tipped directly from the higher foot wall. From each gateway the coal was taken out only on its upper side, and where the thickness was not great the gateway was partly ripped down into the rock of the foot wall. Thus in many of the gateways the upper edge of the waggon would be on a level with the foot wall on the upper side of the gateway. The waggons were hauled by hand to the main slope on a tramway. When several such waggons had been trammed out to the mouth of the gateway and coupled together, they were in turn hauled up the main slope by a winding engine erected above the dump, on to which the waggons were tipped.

In the first years no separation plant was used. The large stones were picked out by hand on the slopes of the dump. In the winter it was of course difficult to get this work done thoroughly. In the last years in which the Ester and Sofie Mines were worked the coals were tipped into a pocket and screened into *smalls* below 0.5 inches and *large*; the latter went on a picking belt, where the stones were picked out, whereupon *large* and *smalls* were mixed and shipped together.

In the shipping season the coal was loaded into railway waggons by means of two steam shovels, one of which had a capacity of three cubic metres. The waggons, which loaded five tons net, were pulled down to the shore by a locomotive on a railway with a gauge of 90 centimetres. During the early working period at the Agnes Mine, the coal was emptied into a pocket at the shore with a capacity of 300 tons. From this pocket the coal was run off into boxes, each taking 700 kilogrammes, on flat-bottomed lighters with a capacity of 50 tons. The lighters were hauled out to the steamer by its winches, and the boxes were emptied into the hold. In this way 700 to 800 tons were loaded in twenty-four hours. After the loading bridge was built the coal-train ran alongside the steamer and tipped the waggons directly on board. This made loading far more effective, and up to 3000 tons were loaded in twenty-four hours. The steamers employed were of from 1500 to 4000 tons d. w., mostly about 3000 tons. The coal was sold to northern Norway and to the State-supported steamship companies.

The output per man per day, all included, was in 1920 0.96 tons, in 1921 1.15 tons, in 1922 1.62 tons and in 1923 1.27 tons. Per miner and shift the production was 4.4 tons in the winter 1924—25 and 6.26 tons in the summer of 1925.

As to the percentage of *smalls*, Sherdahl found that in 1925, 15 to 35 per cent (average 25 per cent.) was under 0.5 inches.

There have been no coal-dust explosions in the mines at Kings Bay, but already during the working of the lower part of the Josefine Seam gas was perceptible, and in Sofie and Ester mines gas was observed as early as 1925 in several crosscuts, by which year five gas-explosions had taken place. Of these two were in the Ester Mine and three in the Sofie Mine. Some of the workmen were so severely burnt that they had to be taken to hospital.

Until 1925 only ordinary open carbide lamps had been in use. From that time these lamps were prohibited in the dangerous crosscuts; they were soon discarded and new electric safety lamps adopted.

However, there have in more recent years been difficulties with the gas, which increased towards the depth. Thus on April 20, 1927 four persons were killed by an explosion in the Ester Mine on Sofie Seam, and on May 2 of the same year four men were injured by an explosion. In another explosion in August 1929 in Sofie Mine two men were killed, and this accident, with other trouble, led to the closing down of the mines.

Also during the drilling of borehole 5 great masses of gas were met with. The outbreak of gas was so strong that the drilling water was flung six or seven metres above the tube.

The gas from the Kings Bay field has never been analysed, but it is mostly inodorous and certainly consists chiefly of methane. In the Ester Mine, however, also H_2S was detected by its smell.

Nearly all the work in the mine was done on contract, the workmen finding their own explosives and tools. The prices given per metre of slope, gateway, and crosscut differed according to coal thicknesses. The laying down of rails was included in the prices stipulated. This was also the case with tramming work up to 50 metres from the main slope. For tramming over greater distances they got extra payment.

From the mining reports given to the mining inspector of Svalbard the amount of work done per annum will be seen. For the years 1927—28—29 the following figures are given:

	1926	1927	1928	1929
Numbers of metres of slopes, gateways and crosscuts worked	3652	3725	3357	-
Coal area worked in sq. metres	84718	114435	100544	-
Timber used in metres	42992	75714	63420	41000
Explosives in kilogrammes	30442	33735	24159	16472
Total of coal production	84722	108931	99235	49197

Some figures concerning the mining will be found in the chapter dealing with the history of coal mining.

Drilling.

On June 14, 1928 the *Storting* voted means for drilling on the Kings Bay coal field in the summer of 1928. The Department of Trade placed this work in the hands of *Norges Svalbard- og Ishavs-undersøkelser*, and as geologist at this institution I had to superintend drilling operations.

Deep drilling had never been done in such high latitudes, and the experience we gained may be of some interest for future drilling in the Arctic.

Norges Svalbard- og Ishavs-undersøkelser had previously carried on such work in Bear Island in 1924 and 1925. Also here the ground is frozen to the depth of about 75 metres, but drilling in this island did not encounter anything like the difficulties it did at Kings Bay. This was chiefly due to the lower temperature of the ground. Whereas the temperature of the coldest zone of the frozen ground in Bear Island scarcely exceeds — 3° C, it is at Kings Bay more than twice as great. Unfortunately, we are not in possession of temperature measurements from the ground at Kings Bay, but if we take as our basis the average temperature of air, which at Green Harbour is —7.6° C and at Kings Bay probably somewhat lower, perhaps about —8°, we may take it that the lowermost temperature, which is found at about 20 metres depth, is about —7°.

The frozen ground at Kings Bay extends to a depth of 150 metres, and thus we drilled exclusively in the frozen zone. This low temperature in the ground made our task a very difficult one, and only by exercising the greatest care were we able to carry through the drilling with the outfit we had brought with us or could procure at the mine workings at Ny-Ålesund.

The drilling was done with two drilling machines, hired from *Norsk Diamantborings A/S*, Oslo. The drillers were also attached to this company, and several of them had experience in drilling in Bear Island.

We used chilled shot or steel grit, this method having proved to be suitable for drilling in sedimentary rocks, where the dip of the layers is not too great. The fact is that this method can only be used for almost vertical drilling.

Drilling took place from July 14 to October 3. We used a 5 h. p. oil-engine for driving the drilling-machines.

The diameters of the crowns used were: 5¼″, 4¼″, and 3¼″ giving cores of 4″, 3″ and 2¼″ respectively. Cores of 3″ diameter must be deemed most suitable for coal-drilling.

In all 5 holes were drilled totalling 422.39 metres drilling length. The bore holes were lined with 35.21 metres 5″, and 44.28 metres 4″ casing.

During the drilling 650 kilogrammes of steel grit was used, i. e. 1.3 kilogrammes per metre.

All this grit was not actually expended in the drilling itself, because part of it was lost in fissures and open spaces in the upper part of the ground. In comparison, the expenditure of steel grit in Bear Island was 3 kilogrammes per metre, and in drilling in granites about 5 kilogrammes are used. The crown wear was also comparatively small. The small amount of wear to drilling material was due to the rocks at the Kings Bay coal field, particularly the lower part of the Tertiary strata, in which the greater part of the drilling took place, being very soft. It is chiefly made up of shales, argillaceous sandstones and coal. Through these rocks we partly drilled without the addition of steel grit.

Only at one drilling site, borehole 1, we could begin to drill on fairly compact rock near the surface; everywhere else on the coal field the bedrock is covered by frozen, loose material, at most points to the depth of several metres. At such places we had to dig small pits down to the bedrock, and on this a 6″ casing for the direction of the bore-crown was cemented. The length of these pits, the drilled depth and the total depth from the surface, as well as the percentage of core obtained have been collocated in the following table.

Borehole No.	Depth of pit and 6″ tube in metres	Drilled length in metres	Total depth from upper edge of 6″ tube in metres	Core percentage
1	0.75	105.90	106.65	76
2	1.45	57.91	59.36	60
3	2.30	44.60	46.90	40
4	2.40	146.69	149.09	40
5	1.45	67.29	68.74	42
	8.35	422.39	430.74	

The rock near the surface on Bear Island was fairly unbroken, and when casing had been got down through the uppermost 2—3 metres there was no further trouble with rock falling down the hole.

At Kings Bay, on the contrary, the upper part of the bedrock was quite broken up, in some spots down to a depth of 20 metres and more. This is mainly due to the activity of the frost, but it may partly be the result of the tectonical disturbances. The drilling through this zone is very difficult. It could be avoided by working a pit down to solid rock. This work has, however, to be done in the autumn, when the surface is frozen. In the spring it is difficult to work pits down from the surface, because, during the melting of the snow, water is flowing everywhere. For this reason we only dug the pits down to a block on which the casing could be cemented and the drilling commenced. It is obviously not possible simply to drive the casing down through frozen ground containing great masses of large and small blocks, as is usually done in unfrozen earth.

Drilling through frozen ground is not difficult, as ice and stones are combined to a rigid mass; but as soon as the circulating water has melted the walls of the hole, the stones will loosen and trouble begins. It is just as well to put down the casing at once, as otherwise the drilling tools will soon stick fast, or one will have to drill only in fallen rock. When a new casing has been put down a smaller crown has to be used for the further drilling, and when such casing work has been repeated two or three times one gets down to so small a diameter of the crown that the percentage of core will diminish, and the whole result of the drilling is less reliable.

To be prepared for this eventuality the drilling outfit must include a sufficient number of transitions of crowns and casings for drilling through the upper broken rock.

We were not in possession of the necessary tools and were forced to lengthen the uppermost casing and drive it down into the smaller hole drilled within it. This was done by enlarging the hole below the casing by blasting with dynamite and driving the casing down by framing with the heavy lead. We did this in borehole 4 from a depth of 7.62—12.50 metres to get through a downfall zone without changing the crown diameter; but during the driving down of the casing its lower end was turned inwards, so that it had to be straightened out with the chisel before the drilling tools could pass through it.

In the meantime the coupling boxes hitched on to the lower rim of the casing during the levelling of the drilling tools, so that we had to make the upper part of the muffs conical upwards by cutting them in the lathe. This method should be avoided.

I am of opinion that one would at all events be safe in using crowns and casings of three different sizes greater than the size usually required for penetrating the coal seams. The differences between the diameters of these casings should be as small as possible, as otherwise the largest sizes will be very heavy.

It would certainly be best to use casings without coupling boxes, but with screw-threads on the casings themselves. These should be cut in different lengths, of which some should be quite short and be made ready for use in the workshop. Thus the total length needed could be screwed together without too much delay caused by cutting and threading work. In this way some metres could be drilled before the stones are loosened by thawing, and the hole should be lined out before the downfall begins. The next size is used some metres further down, and so on until real solid rock is reached. When first down in the compact rock drilling does not offer any further difficulty in respect of falling rock.

We were not prepared for these difficulties and had only brought with us one size of casing (5″), as we considered that only one casing was sufficient, as in Bear Island. For this reason our work was greatly impeded by rock falling into the boreholes.

The greatest difficulty we encountered was in borehole 2, where we were delayed for sixteen days through having to drill in fallen stone, whereas we only used twelve days for effective drilling. We saved the hole by welding together, during the lowering process, 28.3 metres of 4″ iron casing, which was produced from the mining works.

In borehole 3 we had later to undertake the same process to a depth of 21.34 metres. The welding together of the casing cannot be recommended, because the welded joints easily break when the casing is framed down through the downfall in the hole.

Our experience was that it was very difficult to drill more than 6—7 metres in the upper cracked part of the rocks before further drilling was made impossible by the downfall of loosened rock. In boreholes 3 and 4 we were compelled to put down the casing after 6.5 metres drilling. As the great fissures and spaces from which the loose stone falls are to be found down to a depth of 20 metres, and sometimes still deeper, the hole in this case has to be lined three times before really solid rock is reached.

We tried also to cement the loose parts and afterwards drill through the cement and go farther down with the same crown diameter. We tried first with pure cement, afterwards with quick-binding cement in the ratio of one bag of cement to one bucketful of soda and four buckets of water, but it did not bind and some of it could be washed out of the hole. The greater part seemed to be frozen and was brought in solution by the circulating water. This method cannot be used under such conditions.

Strange to say, we also lost the water several times at the depth of several metres. This must be due to fissures in the upper part of the frozen ground, which must have been formed during contractions of the ground owing to variations of temperature.

The greatest difficulty in drilling in Spitsbergen is, however, that the drilling tools are frozen fast in the hole. The possibility of freezing partly depends on the temperature of the ingoing flushwater.

The surface water in brooks not passing over snow or ice will attain a temperature of about 5—6½° C in the warmest part of the summer. This water could be used directly for the drilling without any risk of freezing, as long as the drilling tools were in rotation. If, however, drilling stopped for some minutes, the temperature of the water would soon fall below zero and the drilling tools would freeze fast to the hole if not raised at once.

When we used water from snow-filled valleys or from the brooks in the autumn when the temperature of the surface water was between 0° and 2°, ice would often begin to form even when we were drilling. We came to the conclusion that if the depth of the hole was more than 50 metres, the ingoing flushwater must not be colder than 2.5° C.

On Bear Island the boreholes could remain a day unworked without freezing, if only brine was poured into the hole. This was, however, not possible at Kings Bay. We were here troubled with the hole freezing even when warm brine of calcium chloride was pumped down.

On one occasion the crown and drilling tools froze fast in the hole because of a short motor stoppage. Another time the drilling was delayed through the hole freezing during a suspension of drilling from Sunday morning till the evening of the same day to repair our motor pump. The hole was then 74 metres deep. Just before we stopped we pumped down warm brine, but nevertheless the hole had frozen up in the evening 42 metres from the bottom. It took three days to drill out the ice again. Another drillhole froze during the winding up of the tools, when the crown was 30 metres above the bottom of the hole. The crown was thawed loose in some hours, but in the meantime the 30 metres down to the bottom had frozen, and we had to drill ice more than a day.

Drilling had, for this reason, to go on continuously, also on Sundays. In the summer we used the tempered surface water direct from the brooks, but to prevent the hole from freezing during the raising of the drilling tools we filled the hole with warm brine. The water was warmed in iron drums under which a continuous coal fire was kept burning. The hot brine was pumped down with a handpump just before the raising of the rods, until the water coming out of the hole had also been tempered. In this way we kept the hole from freezing. The pumping down of the brine by means of a machine pump should be avoided, because the valves will thereby be damaged.

When we drilled with cold surface water it happened that the hole began to freeze during the drilling. We then at once threw the suction tube into the hot water container and pumped down warm water.

In the autumn, when the surface water was too cold, we used exclusively artificially heated, circulating water. We used three iron drums connected with tubes. Into number one we fed the flush water coming from the hole, and here the greater part of the mud settled. From this container the water flowed over to numbers two and three, from which it was again pumped down into the borehole. By keeping up a continnous fire under all the drums we kept the temperature of the incoming water at about 6° and the outgoing water at 3°—4°, varying with the depth of the hole. If it is in any way possible to avoid the use of circulating water in coal-drilling, it should not be used.

The water will get so muddy that it is very difficult to determine from the drilling-mud in what kind of rock one is drilling, or when the drill is piercing coal seams. This must be closely watched, because one will scarcely get cohesive core from such loose rocks. To keep the water sufficiently clean we had to put up two such sets of cases for the hot-water circulation, and used the one while the other was being cleaned out and filled with fresh water.

During the last stage of the drilling work at the end of September and the beginning of October we had to work in —14° and a snow-

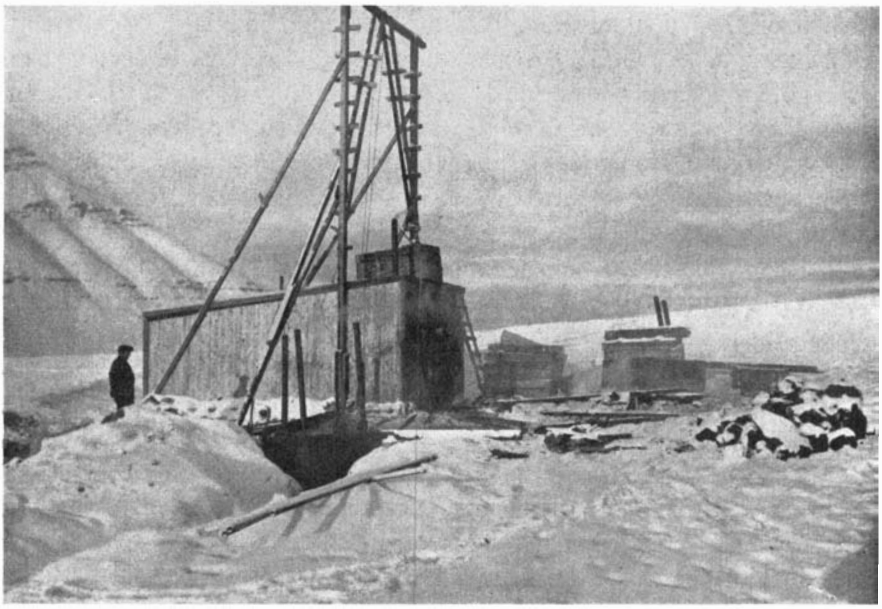

Fig. 52. Drilling site at Borehole 4 on Leirhaugen.
A. K. Orvin phot. 30/9 1928.

storm. When the drilling tubes were raised the rods were so cooled down that as soon as they were again put down in the hole the water would freeze. At first we only poured hot water over the rods when lowering them into the hole, but at last we had to lay them on a continuous coal fire to keep the drilling going. Muffs and threads had to be put into a bucket of hot water before they were screwed on, or they would shed ice.

Towards the end of our work we had to carry the water up from the brook to a hole dug at the drilling site, because it froze in the water pipes laid out for pumping. We had also some trouble through the freezing of the rubber tubes which led water and steel grit into the top of the machine. This we prevented by placing a stove in the drilling-shed and a big box on the roof above the opening for the water-swivel.

In this way we contrived to finish drilling the last hole. Drilling work in Spitsbergen should cease about September 10, if not, a covered and heated drilling derrick will have to be used. This will, however, be more expensive. The sites for holes to be drilled in the autumn should be chosen at points where water from lakes or streams coming from beneath the glaciers is found in the neighbourhood, because all other small streams will disappear as soon as the frost sets in.

Even though the greatest care be exercised there is risk of the hole freezing. Perhaps the drilling tools stick fast in falling stone, or the pump may be put out of action for a while, so that drilling comes to a standstill. To eliminate the risk of a water stoppage there should always be a hand pump all ready for coupling in at each drilling site. One should always be prepared for the freezing of the hole and for a momentary thawing of the ice. Large hot-water containers should always be ready to hand. Drilling outfits must include a rubber tube of the same length as the deepest borehole, and thin enough to be put down through the drill rods and coupling-boxes. At the same time it must also be able to withstand considerable pressure. The couplings must not be narrower than the rods, because in this case it is difficult to pass the rubber tube through them.

We found that the best way to loosen the drilling tools was to pump down boiling water (or still better, steam if available) through such a thin rubber tube while lowering this through the rods. The ice within the rods will then gradually melt away, and the water will ascend on the outer side of the rubber tube, and be brought back to the hot water container. At last the rubber tube will reach the core, where it remains until the ice is melted to the bottom, and the water ascends on the outer side of the core-barrel and the rods. When the ice is melted, the tools can be loosened by striking the heavy lead lightly upwards. It is impossible to loosen drilling tools stuck by frost in this way without previous thawing, as any tool will be rendered useless without there being any chance of loosening it.

At our first attempt to release the tools before we were quite sure that the crown had been frozen fast, we damaged a five-ton jack-screw. We also tried to release them by dynamite, which was lowered down to the core through the rods and lighted electrically, but the explosion was barely perceptible at the surface and resulted in nothing at all.

If the borehole is frozen when the drilling tools are out of the hole, which may very easily occur, the ice must be drilled out. By using the ordinary crowns for chilled shot drilling or the ordinary tooth crown this drilling is very slow. For this reason specially constructed ice drills of different sizes should be included in the drilling outfit, so that this work can be done quickly.

If the above-described precautions are taken the work can certainly be carried through without any great delay. With the ordinary outfit alone the result may be a complete failure.

When the time used for thawing and drilling in fallen rock is excepted, we drilled 4.75 metres per twenty-four hours. We worked in two twelve-hour shifts with two men on each shift.

Summary.

The area belonging to *Kings Bay Kul Comp. A/S* is situated at Kings Bay, Spitsbergen, in about 79° N Lat. and 12° Long. E of Gr. The distance to Tromsø is about 1100 kilometres or two days and a half by coal steamer. The annual mean temperature is about — 8° C, and the fjord is frozen from the end of October to the middle of June. Shipping operations can be carried on from middle June to middle October.

The total area of the property is 295 sq. kilometres, of which 42 per cent. is covered with ice. The southern part of the area includes Brøggerhalvøya. This peninsula is a rugged alpine land with valley glaciers in cirques between jagged crests and summits. The northwestern part of the peninsula is made up of sediments belonging to the Devonian, Carboniferous and Tertiary systems, whereas all the remaining part of the property area is made up of metamorphosed Hecla Hoek rocks.

Along the coast of Brøggerhalvøya runs a coastal plain with a width of up to five kilometres. It is to a great extent covered by marine terrace material. On this plain a small Tertiary area including coal seams occurs in the middle part of the northeastern coast towards Kings Bay. The length of this field is between six and seven kilometres, and the width in the western part is up to 1100 metres. The area is about 4.5 sq. kilometres and is to a great extent covered by marine clay and gravel, moraines, river deposits, and débris. For this reason the examination of the field has required much exploration work.

The glaciers are all valley glaciers not reaching the sea, with the exception of Kongsvegen, Kongsbreen and Blomstrandbreen, which issue from extensive ice areas and debouch into the sea with ragged terminal fronts, from which calving is going on throughout the summer.

The valleys are all U-shaped, glacier carved valleys, and only a few of them are free from ice. The rivers have a considerable flow of water only in the spring and the early summer. Only some small lakes occur. The mining company got water for the household and workings from a small lake, Tvillingvatnet, situated in the middle of the coal field. This lake never freezes to the bottom.

The 66 km long coast line is embayed. Twelve kilometres are made up of glacier walls, and 25 kilometres form a steep cliff from six to ten metres high.

The soil at Kings Bay is very poor, and the vegetation only trifling. The ground is frozen down to about 150 metres, and only the uppermost fifty to seventy centimetres thaw in the summer.

The oldest rocks are metamorphosed Hecla Hoek limestones, mica schists, and quartzites with a total thickness of about 6000 metres. These rocks, of which the exact age is still unknown, occupy the whole southeastern part of Brøggerhalvøya and the part of the property area situated east and north of the fjord.

In the western part of Brøggerhalvøya is found a series of Devonian conglomerates, sandstones, and shales resting with angular unconformity on the Hecla Hoek. The Devonian rocks are mostly of a red colour and contain much mica, giving the bedding planes a silver hue. The total thickness is minimum 300 metres. The Devonian now seen in the western part of the peninsula is certainly also at present connected with the Devonian east of Kings Bay through Devonian strata on the bottom of the fjord. The sequence probably belongs to Lower Devonian.

At Forlandsundet the Devonian is missing, and a sequence of Culm sandstones and conglomerates rests with angular unconformity on the Hecla Hoek mica schist. The lower part of this sequence includes a black shale horizon containing an impure coal seam.

The Culm in the west and the Devonian in the east are overlain by littoral and marine, limy beds of Middle Carboniferous age. The mentioned stratigraphical conditions must be explained by an old fault along which the eastern side has been relatively lowered in later Devonian so that the Devonian strata have been eroded on the western side of the fault before the deposition of the Culm took place. In post Culm time the western part has sunk and the Culm strata have been eroded away east of the fault. During the following submersion of the land the Middle Carboniferous was deposited on Devonian east of the fault line and on Culm west of it.

The Middle Carboniferous strata and the Cyathophyllum Limestone which follows concordantly upwards, are together 450 metres thick, and uppermost a series of chert, cherty limestones, cherty shales form the upper part of the Upper Carboniferous sequence. The uppermost part of this cherty series, which is about 250 metres thick, is made up of a 40 metres thick glauconitic, green sandstone with layers of chert. This sandstone is the youngest rock in the western part of the peninsula. Only in the small coal field are still younger rocks found. Here marly shale and claystone rest discordantly upon the glauconitic sandstone with a thickness of up to about 50 metres. This shale and claystone horizon, which I have named the Bottom Shale, may perhaps be of Cretaceous age. Concordantly above the Bottom Shale follow about 200 metres of conglomerates, sandstones, shales, and coal seams of Paleocene and possibly Eocene age, probably corresponding only to the lowermost Tertiary beds at the Ice Fjord.

The structural conditions within the property area are rather entangled. During the Silurian mountain folding period the Hecla Hoek rocks were strongly folded and metamorphosed. From then to Tertiary time no great tectonical disturbances have taken place, except as block movements now visible as unconformities and missing series of strata.

The last great tectonical disturbance, which has given the younger rocks their present structural appearance, took place in younger Tertiary time. Owing to pressure from west-southwest all the younger strata and also part of the Hecla Hoek were overfolded and thrust in an easterly direction. During this thrusting the younger rocks on the northeastern side of the thrust plane were covered with older rocks. This was the case with the now existing Tertiary field. During the strong pressure, part of the earth crust, now forming the western part of Brøggerhalvøya, sank down towards the present Forlandsund, and, owing to the great resistance of the partly eruptive block in the north east, the northeastern part of the folded strata was overthrust towards the southwest in proportion to the sunken block between the two thrust planes. The lower and upper limbs of the northeastern thrust seem to have moved about a pivotal axis somewhere under Austre Brøggerbre (Eastern Brøgger Glacier).

When folding and thrusting had been accomplished a period of faulting took place owing to the cessation of the pressure. Part of the coast along Forlandsundet and down the western coast of Spitsbergen broke down, and another *Graben* was formed along Kings Bay and south to the Ice Fjord. Between two branches of the main fault along the southern side of Kings Bay, one of which is seen to cut through the fold in Zeppelinfjellet, several north—south-going faults were formed. These faults form, broadly speaking, a step fault hading with the dip from Scheteligfjellet eastwards, and divide the coal field into separated areas from east to west named Østfeltet, Agnesfeltet, Østre Centerfelt, Vestre Centerfelt, Vestfeltet and Lagunefeltet. The latter is separated from Vestfeltet by a branch of the main fault along the fjord.

That the Tertiary field has been preserved down to the present time is only due to the folding, thrusting and faulting described above. It has originally been of a far greater extent and probably coherent with the Tertiary in the central part of Spitsbergen.

In the Tertiary sequence several coal seams occur, and six of them are of a thickness that might render them workable under favourable market conditions. Three of these seams are situated in the lowermost 20—40 metres of the sequence, namely from below: Ester, Sofie and Advokat seams. About 70 metres above the latter lies the Agnes-Otelie

Seam, and in the upper part of the sequence Josefine and Ragnhild seams are found.

Ester Seam is the most important. It is found over an area of about 4.09 sq. kilometres, with a total quantity of coal of about 6.52 mill. tons, of which about 4 mill. tons are supposed to be workable.

Sofie Seam is scarcely workable in the western part of Vestfeltet and in Lagunefeltet. Where known it is more irregular than the Ester Seam. Its coal area is about 3.35 sq. kilometres, with a total quantity of coal of about 4 mill. tons, of which about 1.85 mill. tons are supposed to be workable.

Advokat Seam varies still more, and is only found with a tolerable thickness in Østfeltet, Agnesfeltet, and the eastern part of Østre Centerfelt. The seam contains several partings and is rather impure. It is extended over about 0.71 sq. kilometres with about 0.95 mill. tons of coal. It may be doubted whether the seam is workable at all.

The Agnes-Otelie Seam is exhausted in Agnesfeltet and is now only found in the areas farther west. The seam is fairly regular, but the thickness is rather small. The seam is divided by one or two stone partings. It extends over about 2.38 sq. kilometres, and the quantity of coal is calculated at about 2.46 mill. tons. The workability is doubtful at the present low market prices.

The Josefine Seam is exhausted in Østre Centerfelt and is now present only in the areas farther west. The seam has, however, not been examined here. It is probably extended over an area of about 1.12 sq. kilometres with a total quantity of coal of about 1.48 mill. tons. It is, however, doubtful whether the seam can be worked with profit owing to its being too close to the surface.

The Ragnhild Seam is found in Østre Centerfelt and the areas farther to the west. The coal area is about 0.78 sq. kilometres, and the quantity of coal about 0.68 mill. tons. The workability is at present doubtful.

The total quantity of coal in the whole field is calculated to be about 16.2 mill. tons, of which about 6.58 mill. tons may be regarded as workable.

The quality of coal from the different seams does not vary much. All seams contain coal very rich in hydrogen and volatile matter, and must be classified as gasflame coal. The content of volatile matter is from 37 to above 41 per cent.; and up to 49 per cent. in ash-free coal. By low-temperature distillation they yield from 16.6 to 22.7 per cent. crude oil or tar. The ash content is high, mostly from 10 to 15 per cent.

All the coal seams are of autochthonous origin formed from moors of a somewhat limited extent.

The mining method used was the room and pillar method with drilling and blasting. Coal has been exported from six different mines, one on the Josefine Seam, three on the Agnes-Otelie Seam, and two on the Ester and Sofie seams. From the mine the coal was tipped on a dump, whence in the summer it was run on to a loading bridge by railway and tipped directly on board the colliers, which were usually of a d. w. of about 3000 tons. In all 833864 tons have been exported from Kings Bay from 1916 to 1929.

The coal occurrence was first discovered in 1610 by English whalers, and in 1868 the coal was used for the first time for raising steam in the Swedish steamer *Sofia.* The coal field was claimed in 1901 by a joint concern from Bergen, and in 1909 an expedition sent out by Chr. Anker, Fredrikshald claimed an area around Kings Bay including the coal field. Mining operations were commenced in 1916 by Peter S. Brandal, and the same year the mining rights were transferred to *Kings Bay Kul Comp. A/S.* This company worked the field almost without any break until the autumn of 1929, when work was suspended owing to misfortune and low market prices.

The mines are now filled with ice, but a small watch has been retained to look after the mining camp.

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