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THE JURASSIC COAL OF SPITZBERGEN.

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The Spitzbergen archipelago, consisting of five large and many small islands, extends from N. Lat. 76° 30′ to 80° 30′ and lies about midway between Nova Zembla and Greenland, while the southern point of the principal island, West Spitzbergen, is about three hundred miles north from the North Cape. The greater part of the archipelago is inaccessible for shipping except in rare seasons, as a cold current brings down the ice along the northern and eastern portions; but the western coast of the main island is accessible ordinarily during about three months each year. Until less than a century ago, little was known respecting Spitzbergen beyond the information brought by whalers, of whom William Scoresby was easily chief. The first systematic exploration was by the Norwegian geologist, Keilhau, who, in 1827, studied West Spitzbergen as well as the lonely Bear island, one hundred and fifty miles southward, and made collections, described in part by von Buch in 1846. A French expedition of 1839 gave notes upon the islands, some of which are of interest. The most important contributions, however, are those of the Swedish geologists, whose studies began before 1860 and have continued at frequent intervals until within ten years, their results being published for the most part by the Stockholm Academy of Sciences. Prof. Franz Toula of Vienna visited West Spitzbergen in 1873 and made important observations upon the Carboniferous.

West Spitzbergen extends from N. Lat. 76° 30′ to 79° 55′ and is indented deeply by bays, of which the most conspicuous are Kings and Cross, with common outlet at 79°, the long Ice-

fiord, 78° 10′, extending inland to 78° 50′, with numerous bays, Dickson, Klass Billen, Sassen and Advent, and Bell's sound, 77° 30′, with Lewis sound and Recherche bay as its principal divisions. All of these are more or less accessible from the middle of June until some time in September.

This ready accessibility of the west coast has encouraged attempts to utilize the mineral resources. Many years ago a deposit of phosphates was discovered on Icefiord but the effort to work it proved to be unprofitable. Coal was discovered almost one hundred years ago in the northern portion on Kings bay, where it was mined by Dutch whalers. Keilhau found coal on Cross bay in 1827 and in 1861 Bloomstrand rediscovered the deposit on Kings bay, the glacier concealing it having retreated. He traced the bed for 7,000 feet but was unable to ascertain its thickness though he determined that the coal is brilliant, with conchoidal fracture, burning completely to ash and showing here and there some woody structure. The associated plant remains were long leaves and stems of deciduous plants.[1]

Von Buch cites Robert as an authority for the statement that whale fishermen had taken sixty tons of coal from Icefiord to Hammerfest, evidently prior to 1839; and he says that *Calamites*, *Sigillaria* and even *Lepidodendron* are not of rare occurrence in these coals.[2] The Swedish expedition under Nathorst and DeGeer in 1882 studied very carefully the deposits on Icefiord and Bell's Sound. They succeeded in rediscovering a coal horizon on Advent Bay, but were unable to determine whether or not it is of workable thickness. An important collection of plants made in that year by Nathorst and described by him in 1897, enabled him to determine the age of the deposit as upper Jurassic.[3] It is certain that the Carboniferous plants

[1] Bloomstrand's publication in the *Trans. of the Stockholm Academy* is not accessible to the writer and the reference is taken from F. Mohr, Geshichte der Erde, 1866, pp. 128–9.

[2] Robert, *Bull. Soc. Geol. du France*, xiii, as cited by von Buch, *Berlin Akad. des Wissenschaften*, May, 1846, p. 73.

[3] A. G. Nathorst, "Zur Mesozoischen Flora Spitzbergens," *Trans. K. Svenska Vetenskaps Akad.*, Band 30, No. 1, pp. 5, et seq.

mentioned by Robert, as cited by von Buch, must have been collected at some other locality and not in association with coal, as no coal occurs in the Carboniferous of Icefiord.

Carboniferous rocks do exist in West Spitzbergen, and the map given by Nathorst shows extensive areas of these rocks on several branches of Icefiord as well as on Bell's sound and further south. In 1827 Keilhau obtained *Spirifer keilhavii* from the South cape and in 1839 the French expedition collected the same spirifer with *Productus giganteus* from Bell's Sound. Toula in 1873 found a Carboniferous fauna in the northern portion of Icefiord, which shows a commingling of Permian and Coal Measures forms much like that existing in Nebraska and West Virginia. Nathorst has described recently the Carboniferous plants collected at several localities on Icefiord and Bell's sound, referring them to the Lower Carboniferous.

Thus far no workable coal bed has been found in this formation on Spitzbergen. Coaly streaks are present at some of the northern points along Icefiord but they are not beds. Last year, Mr. G. A. Fangen found on Recherche bay of Bell's sound, about five miles below the anchorage, a bed of excellent coal, four to five inches thick and associated with a dark shale showing abundant impression of plants. The outcrop is covered with débris and the stay at this locality was too brief to admit of uncovering the coal and its plant bed. It seems to be near the spot at which Professor DeGeer observed Lower Carboniferous plants. The absence of workable coal in southern Spitzbergen at the bottom of the Carboniferous is the more noteworthy because coal is present on Bear island, N. Lat. 74° 30′, which was discovered in 1684 by Bennet, who took some of this coal to England. In 1827, Keilhau found four coal beds in a vertical section of about 200 feet, the intervening rocks being fine grained sandstone. Higher beds, unquestionably of Coal Measures age, are here as shown by the mollusks, and von Buch was inclined to place the coals in the Lower Carboniferous, which would make them equivalent to the plant beds of Spitzbergen.[1] Professor Nathorst, however, made

[1] Von Buch, op. cit., pp. 67, 73.

collections on Bear island in 1898 and still later additional collections were made by Doctor J. G. Anderson, all of which were described by Nathorst in 1902.[1] The study of these plants led him to refer the beds to the upper Devonian. The shallow water between Spitzbergen and Bear island suggests a land connection between the two areas until comparatively recent times. The Bear island coal field must have extended much further south and west, for even since the glacial period the island has lost much on those sides, the glacial trough now on the westerly side of the island having lost the greater part of its west wall and the cirque on the southerly side has been removed.

The coal beds on the east side of Advent bay are placed by Nathorst in the upper Jurassic. During the last decade spasmodic attempts at mining have been made, chiefly to supply the whalers who ply their trade by means of steam launches. The whole region was explored in 1903 by an English-Norwegian company and in 1904 that company began systematic development on the east side of Advent bay. At the time of the writer's visit, the work in charge of Mr. G. A. Fangen, M.E., of Bergen, was advanced sufficiently to exhibit the coal and the conditions of its occurrence.

The opening is at perhaps a mile and a half from the mouth of the bay and at 330 feet above the water. Mining was begun early in June with the expectation that it could be continued until late in September, when a shipment of about 1,000 tons might be made to Tromsoe in order to make a thorough comparative test with the English coal used there. The main heading had been driven sixty yards from the crop and a room had been opened, extending perhaps twenty yards northward to another heading, which has been abandoned. The section of the bed is

	Feet.	Inches.
1. Coal	0	4
2. Parting		
3. Coal	0	5

[1] A. G. Nathorst, "Zur Ober-Devonian Devonischen flora der Bären Insel,' *Trans. K. Sven. Vetens. Akad.*, Band 36, No. 3.

	Feet	Inches.
4. Parting		
5. Coal	0	11
6. Clay	0	2 to 4
7. Coal	1	7
8. Rock, sandy	0	3 to 5
9. Coal	1	0

The measurements are exact only for the place at which they were made and the portion, Nos. 1 to 5 inclusive, averages not more than 1 foot 3 inches. The whole of the coal is mined, but the character is not the same throughout. The "top," that above No. 8, is hard, grayish black, with fracture more or less conchoidal and much like a splint coal; the "bottom" is black, lustrous, with layers of brilliant coal and a somewhat prismatic structure. It is tender and shows some mineral charcoal, but this is not abundant. The composition is shown by the following analysis, for which I am indebted to the courtesy of Mr. Andrew S. McCreath, so long the chemist of the Second Geological Survey of Pennsylvania, who has added this to the series of similar favors for which I am under obligations to him.

"The two samples of Spitzbergen coal yield on analysis respectively:

	Top.	Bottom.
Moisture	3.310	4.696
Volatile matter	19.790	28.560
Fixed carbon	62.763	57.171
Sulphur	.467	.413
Ash	13.670 (gray)	9.160 (light brown)
	100.000	100.000

"The ratio of fixed carbon to volatile matter differs considerably in the two coals; but three determinations were made in each case. Such a difference has already been noted between the coal of the upper and lower benches, but it is unusual; and generally the coals in a vertical section show approximately, at least, the same ratio of volatile matter to fixed carbon. (See Survey Report, MM, pages 94 to 97.)

"The coals yield gases burning with a luminous but feebly smoky flame, and neither of them shows the slightest tendency to form a coherent coke.

"Both coals seemed to be quite dry, that is, free from hygroscopic moisture and yet the percentage of moisture at 212° F. is quite high in both coals. This is suggestive that either the samples represent outcrop coal — where, owing to some peculiar physical change in structure, the 'dry' coal may yet hold an excessive amount of moisture and have its coking qualities (if it ever had any) entirely destroyed or to a different kind of vegetation forming the coal. In the present case the action of caustic potash solution has a marked effect on both coals, but more noted in the bottom coal, where the action is so marked as to suggest a lignite or a coal of such character or origin."

Mr. McCreath's reference to the difference in volatile, shown by the two portions of the bed, is too important to be passed over. The relations are, ash and moisture being neglected,

	Top.	Bottom.
Volatile matter	23.9	33.3
Fixed carbon	76.1	66.7
Fuel ratio	1 : 3.17	1 : 2

giving a difference of somewhat more than 9 per cent. This is considerably more than the usual difference; commonly one finds not more than 2 or 3 per cent. though in a few of Mr. McCreath's analyses it reaches 5. The especial case to which he makes reference is that of a coal bed at a mile and a half east from Bernice in Sullivan county of Pennsylvania, whose two branches, according to his analyses, show

	Upper.	Lower.
Volatile matter	28.36	12.61
Fixed carbon	71.64	87.39
Fuel ratio	1 : 2.52	1 : 6.93

At Bernice, a bed at very nearly the same horizon, possibly the same, shows practically no variation in the benches and the average ratio of several analyses is almost 1 : 9, closely approaching anthracite. In this connection note should be made of another fact shown by Mr. McCreath's analyses. At sixty feet below the Bernice semi-anthracite bed, is coal which has the ratio of 1 : 4.63, while at six miles southwest, a still lower

bed yields coal with the ratio of 1 : 2.52, the same with that from the upper bench of the bed east from Bernice.[1]

More remarkable are the differences existing in the benches of the Mammoth coal bed within the anthracite region at the Locust Spring and Indian Ridge colleries of the Philadelphia and Reading company, as shown by the analysis of Doctor C. M. Cresson, made for that company. At Indian Ridge the extremes are

Volatile matter	3.2	10.42
Fixed carbon	96.8	89.58
Fuel ratio	1 : 30.2	1 : 8.6

and at Locust Spring

Volatile matter	1.89	15.3
Fixed carbon	98.11	74.7
Fuel ratio	1 : 52	1 : 4.88

Other benches show ratios between those quoted. In four other colleries belonging to the same company, the differences between the several benches are insignificant.[2]

The varying proportion of ash has no bearing upon the difference in volatile. At Advent bay, the upper bench has the higher ash and lower volatile; but near Bernice the high volatile of the upper bench is associated with nearly five times as much ash as is found in the lower bench; at Locust Spring, the bench richest in volatile is high in ash while another at seven feet lower has almost the same ash but less than one fourth of the volatile. Similar conditions exist at Indian Ridge. Nor has the relative position of the benches any influence. At Advent bay, the lower bench is the richer; near Bernice, the upper; at Locust Spring, the highest bench of the mammoth is the richest, while at Indian Ridge the highest volatile is found midway in the bed. The difference in physical features brings no explanation for coal in Virginia, analyzed by Mr. McCreath and very closely resembling the top coal of Advent

[1] A. S. McCreath, Reports of Second Geol. Surv. Penn., MM. pp. 94-97. Ann. Rep. for 1885, p. 318, GG, p. 214.

[2] Ann. Rep. Sec. Geol. Surv. Penn. for 1885, p. 321.

bay, is very rich in volatile. The cause of the difference must be sought in conditions existing during the accumulation of the coaly matter, chief among which must be the length of exposure to the influences bringing about continued combination of carbon and hydrogen to pass off as marsh gas.

The coal obtained for analysis is not "crop coal." On Advent bay it has not been exposed to variations in temperature and moisture which are so efficient in causing deterioration of coals in our latitude. It was frozen long ago, before the present configuration of the valley was completed and it has remained frozen ever since. The temperature in early August, at no time rose above 39° F. The land surface is boggy in great part and is covered in many places by lowly flowering plants, but the summer thaw reaches to only a few inches below the surface. There is not the alternation of freezing and thawing so destructive to crop coal in our climate. The condition is well shown in the Fangen mine where at 180 feet from the crop and somewhat more below the top of the rock bench, ice was found covering the rock in the heading. Yet the temperature outside had seldom fallen below freezing after the mine was opened. In the original heading, now abandoned, ice was reached along a fault line, fifty feet from the crop and it continued to the end of the heading. The explanation of the moisture must be sought elsewhere. At the same time, it must not be forgotten that the moisture in the Advent bay coals, though three to four times as great as that usually found in the bituminous coals of Pennsylvania, is not higher than that of many coals from Ohio, while it is much less than that in most of the Iowa coals. The great majority of analyses from the last-named State show upwards of six per cent. and not a few show ten per cent. and upward — all of these being carboniferous.

The reaction of the coal with caustic potash suggested other comparisons. Mr. Norman A. Dubois, Instructor in Quantitative analysis at New York University, very kindly analyzed the coal from the lower bench with the following result:

Moisture	4.14
Carbon	67.88

Hydrogen	4.05
Oxygen and Nitrogen	11.90
Ash	12.03

The ash is higher than Mr. McCreath's analysis because the latter was made from the lump coal while the coal for this was fine coal. The nitrogen is present in small proportion, considerably less than 1 per cent. and it was not determined separately.

The Fangen coal from Spitzbergen, wholly non-caking, is attacked by caustic potash very energetically even in the cold. For comparison, several non-caking coals were tested. The lignitic coal of Carbon, Wyoming, Laramie in age, resembles in color the upper bench but in structure the lower bench of the Fangen bed; that from Rock Springs, Wyoming, also of Laramie age, has a fracture like cannel, and, unlike the Carbon coal, shows no mineral charcoal. These coals are attacked slowly in the cold but very rapidly at the boiling temperature. A non-caking coal from Des Moines, Iowa, of Coal Measures age, is attacked notably in the cold and almost as rapidly as the Fangen coal at boiling temperature. This coal is very like that from Carbon, but has more mineral charcoal and contains upwards of 6 per cent. of water.

A coal from Savanna, Indian territory, of Coal Measure age, and yielding an inferior coke, is attacked slowly in the cold and the solution becomes distinctly tinted after prolonged boiling.

Several caking coals were tested; they are from Canon City, Colorado, and Madrid, New Mexico, of Fox Hills age; Starkville, Colorado, of Laramie; Vancouver's island, of Upper Cretaceous; Leavenworth, Kansas, Wolf county, Kentucky, Fayette and Westmoreland counties, Pennsylvania, of Coal Measures. Not one of these caking coals caused the slightest discoloration of the solution after ten minutes of boiling.

In both classes are coals of Carboniferous and Cretaceous age, coals made under similar conditions of cover and similar relations to disturbing agencies, so that one is led to suspect that the character of the coal was determined very soon after burial.

Ultimate analyses of the coals referred to are not available in most cases, but a few can be given. They may be tabulated as follows:[1]

	H_2O	C	H	O	N	Ash.
1. Fangen	4.14	67.88	4.05	11.90		12.03
2. Carbon	7.35	63.65	4.60	19.44	1.40	2.80
3. Canon City	6.59	70.64	5.13	10.79	0.97	5.30
4. Starkville	0.44	73.58	4.81	9.41	0.31	10.80
5. Connellsville	0.89	82.48	4.50	5.61	1.45	4.13

The roof at the Fangen mine is a black slate, but throughout it is frozen so that none of it has been taken down. No plant impressions were observed in any of the little fragments that had fallen nor had any been seen by the superintendent or the foremen.

To secure a complete section of the rocks, to the top of the bluff, fully 1,600 feet, would be extremely difficult owing to the abruptness of the face. If one may determine from a somewhat close examination of the loose fragments up to about 400 feet, the result of the effort would hardly repay the labor. The softer beds are concealed by débris except in some precipitous portions, while the exposed rocks are flaggy sandstones. Evidently, one has here a succession of brown, gray, reddish and yellow flaggy sandstones and sandy shales with apparently some streaks of black shale. But from the palæontologist's standpoint the detailed section might prove of great interest. Professor Nathorst collected from a ravine near the head of the bay the interesting series of plants, *Tæniopteris*, *Lycopodites*, *Baiera*, *Feildenia* and *Elatides*, which enabled him to determine the age of the beds as Upper Jurassic. These remains were found in a black shale, but they are not confined to that stratum, for Mr. D. H. Morris, accompanying the writer, obtained among other specimens a block of sandstone with *Tæniopteris* from a

[1] No. 2 is by C. E. Munsell, *Jour. Amer. Chem. Soc.*, xiii, 4. Nos. 3 and 4 by R. C. Hills, Min. Res. U. S., 1892, p. 362. No. 5 by J. L. Lilienthal, unpublished, communicated by Prof. J. F. Kemp. The writer will present the results of studies upon this matter and others bearing on the variations in coal at a later time.

ravine toward Sassen bay. A sandstone fragment, obtained by the writer on the bluff along the east side of Advent bay, shows an imperfect mould of an *Astarte* which Dr. R. P. Whitfield thinks related to a Cretaceous form found in the Rocky mountain region. Curious ferruginous concretions are abundant and the sandstones often bear markings similar to those long regarded as fucoids.

The beds are evidently conformable throughout, but they are not undisturbed. The general dip is N. 30° W. Mag. (error 15° W.) at the rate of three feet per hundred. Faulting is not infrequent. The original heading at the Fangen mine reached at somewhat more than fifty feet a downthrow fault, which was followed for nearly thirty yards before the work was abandoned. The crushing along the fault is slight and the throw, as is seen in a hard sandstone above the crop, does not exceed six feet. Other faults were observed in the face of the cliff, but they are all insignificant.

The coal bed opened by Mr. Fangen is not the only one. The outcrop of another is distinct at perhaps three hundred feet below the crest, which Mr. A. E. Stevenson found on the opposite side of Advent bay to be 1,600 feet (by barometer) above the water. This bed is of workable thickness, but at present it is practically inaccessible, being about 1,300 feet above the shore. Traces of an intermediate bed were seen, but nothing has been ascertained respecting it.

The coal has been traced around the face of the cliff along Icefiord to and along Sassen bay, a distance of more than ten miles; and Mr. D. H. Morris, following a ravine between Advent and Sassen to its head in the plateau, found fragments of coal along the whole distance. The outcrop of the lower bed is thoroughly distinct to the head of Advent bay on this easterly side. A coal cropping appears on the westerly side at a little way above the anchorage, whence croppings were followed to Icefiord and for some distance along the southerly shore. Coal is mined in a ravine coming down almost to the anchorage and an abandoned opening was seen at almost a mile further northwest, where a Holland company had marked out a claim. Pro-

fessor Nathorst is inclined to refer the coals on the westerly side to the Tertiary; but there seem to be no differences between the rocks on the two sides of the bay; the sandstones bear the same markings and the curious ferruginous concretions are as characteristic on the westerly as on the easterly side. Collections made by D. H. Morris and A. E. Stevenson on the plateau between Advent and Coal bays, a distance of about ten miles, as well as along the southerly side of Icefiord between those bays, show the same features throughout; so that one appears to be justified in regarding all as of the same age and in referring all the coals of Advent bay as well as that on Coal bay to the Jurassic, in accordance with Professor Nathorst's determination for the beds on the easterly side.

While, along the line followed by Messrs. Stevenson and Morris, only Jurassic beds were seen, it is necessary to go eastward but a short distance to reach Tertiary beds, of which some knobs remain well-marked at not more than seven miles from Advent bay. These flaggy, grayish standstones are loaded with leaves of dicotyledons, with which occur stems of horsetails and apparently leaves of cycads. The succeesion throughout appears to be conformable and the passage from Jurassic to Tertiary seems to be very gradual.

The effort to mine the Fangen coal in commercial quantities, if successful, will be of more than passing interest. The market is ample in northern Norway, where the coal can be placed at less cost than that from England. The long wintry night and the closing of the harbor by ice during nine months each year seem almost prohibitory. But the company, in case the test be satisfactory, purposes to make new openings at a more favorable point further up the bay, to erect comfortable dwellings and to instal a complete electric plant, so that the work may continue uninterruptedly throughout the year. The proposition is by no means chimerical, as some might suppose. The average January temperature is said to be not lower than 15° F. and evidently Advent bay is less cold than other places not more than a few miles away. On the northerly side of Icefiord, about eight miles from the Advent bay anchorage, a continuous

glacier extends for more than ten miles, from Cape Bohemian to Alk point; ice was present during August, 1904, in bays further up Icefiord, yet around Advent bay and in the long Advent dale, extending southward from that bay, there was no ice except in some sheltered ravines where petty glacierets remain.[1] The ill-success of attempts to winter on the island were not due to the severity of the climate for Russian tribes wintered there during many successive seasons. Scurvy, not the climate, made wintering impossible for Europeans. That terror no longer exists.

One must not fail to note that the general conditions during accumulation of the Spitzbergen coal did not differ from those during the accumulation of coals in our land. Even the intermittent deposit is proved by the lamellar partings as well as by the thicker rock parting. The climatic conditions from Carboniferous to Tertiary were like those of lower latitudes. Nathorst says of the Carboniferous, "The plants already known in Europe are in Spitzbergen as great as here, Ferns, Lepidodendron and Sigillaria." Toula discovered a familiar fauna in portions of the Icefiord area, as did also Keilhau and the French explorers in the southern part of the island; the Jurassic flora is of a type familiar in Europe, while the later flora abounds in deciduous plants.

Reference to the occurrence of seaweeds along the Spitzbergen coast is not out of place here. It may be remembered that Mohr, forty years ago, asserted that coal beds are due to accumulation of seaweed material and found a strong support for his theory in the existence of coal on Spitzbergen. He quotes from some writer in the bulletin of the French Geological Society and also from Naumann the statement that "Even now there flourishes on the Spitzbergen coast a so luxuriant Fucus vegetation that often the boat can scarcely work its way through."[2] He regards the Gulf Stream as the great carrier of material and as responsible for the existence of the weed. There is no room

[1] It may be stated in passing that the glaciers of southern Spitzbergen are clearly decreasing.

[2] Mohr, *op. cit.*, p. 130.

for doubt that the great northward drift has some influence on the climate of West Spitzbergen, for the conditions along the westerly shore are much more tolerable than those on Bear island, 150 miles south, but exposed to a southward drift. At the same time the conditions are not such as Mohr supposed, for he seems to have imagined the surface densely covered as in the Saragasso sea. For 150 miles along the west coast, the water during August of 1904 showed few and small patches of seaweed and the amount stranded on the shore is utterly insignificant; so that even had there been a Gulf Stream during the Jurassic, its seaweed would not have been an important factor in coal-making.