



SKRIFTER NR. 164

W. B. HARLAND, C. A. G. PICKTON, N. J. R. WRIGHT
C. A. CROXTON, D. G. SMITH, J. L. CUTBILL, and
W. G. HENDERSON

Some coal-bearing strata in Svalbard



NORSK POLARINSTITUTT
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Type section of the Helvetiafjellet Formation, on the eastern side of Helvetiafjellet. The crags of this formation are typical, standing in marked contrast between softer slopes formed by the underlying Janusfjellet Formation and overlying Carolinefjellet Formation.



Hultberget, viewed from the south side of Ebbadalen. The displacement of the Hecla Hoek basement by the Ebbabreen Fault can be clearly seen. The overlying Billefjorden Group (Svenbreen Formation) is thicker on the downthrow side and the fault is overstepped by unfaulted cliff-forming Gipsdalen Group.

This publication (Norsk Polarinstitutts Skrifter Nr. 164) contains four separate papers that are related to the single theme of coal-bearing strata in Svalbard. All are based on work by Cambridge Svalbard Expeditions as explained in the first paper.

- I. W. B. HARLAND, C. A. G. PICKTON and N. J. R. WRIGHT: *Some coal-bearing strata in Svalbard.*
- II. C. A. CROXTON and C. A. G. PICKTON: *The Van Mijenfjorden Group (Tertiary) of South-West Nordenskiöld Land, Spitsbergen.*
- III. D. G. SMITH and C. A. G. PICKTON: *The Helvetiafjellet Formation (Cretaceous) of North-East Nordenskiöld Land, Spitsbergen.*
- IV. J. L. CUTBILL, W. G. HENDERSON and N. J. R. WRIGHT: *The Billefjorden Group (Early Carboniferous) of Central Spitsbergen.*

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Some coal-bearing strata in Svalbard

By W. B. HARLAND, C. A. G. PICKTON and N. J. R. WRIGHT

Abstract

The stratigraphic column in Svalbard is peculiarly rich in coal, continental coal-bearing sequences occurring in at least six separate stratigraphic units, ranging in age from Givetian to Oligocene. This paper reviews these strata briefly, for the first time since HOEL 1925 (1929). The stratigraphic distribution of the strata is outlined in relation to the tectonic framework of the region. Finally, the circumstances of coal formation in relation to palaeolatitudes, rate of subsidence and depth of burial are considered, and data from various sources are used to compare these parameters for the several periods of coal formation.

The paper also serves as an introduction to the papers that follow on specific areas of Carboniferous, Cretaceous and Palaeogene coal.

I. Introduction

The occasion for this publication is the completion of investigations in three concession areas in Spitsbergen for the Store Norske Spitsbergen Kulkompani A/S (S.N.S.K.). Results of this work are given in the following three main papers in this *Skrifter*: CROXTON and PICKTON 1976; SMITH and PICKTON 1976; CUTBILL, HENDERSON and WRIGHT 1976. A short account of the light drilling technique used in two of the investigations is given elsewhere by WRIGHT and HENDERSON (*Norsk Polarinstitutt Årbok 1974* (1976)). Each of the papers may be regarded as an independent publication but this first paper is intended to serve as an introduction to the whole and will save repetition within the individual studies insofar as it is useful to mention the circumstances of the work, the historical background to coal mining in Svalbard, the geological background to the occurrence of coal and a brief bibliography of coal in Svalbard.

This work began with the invitation to the Cambridge Svalbard Exploration Group in Cambridge by Mr. G. F. CHRISTIANSEN of the S.N.S.K., Bergen, to survey the coal potential of the three concession areas Grønfjordbotn, Saksedal and Indre Billefjord (see Fig. 1).

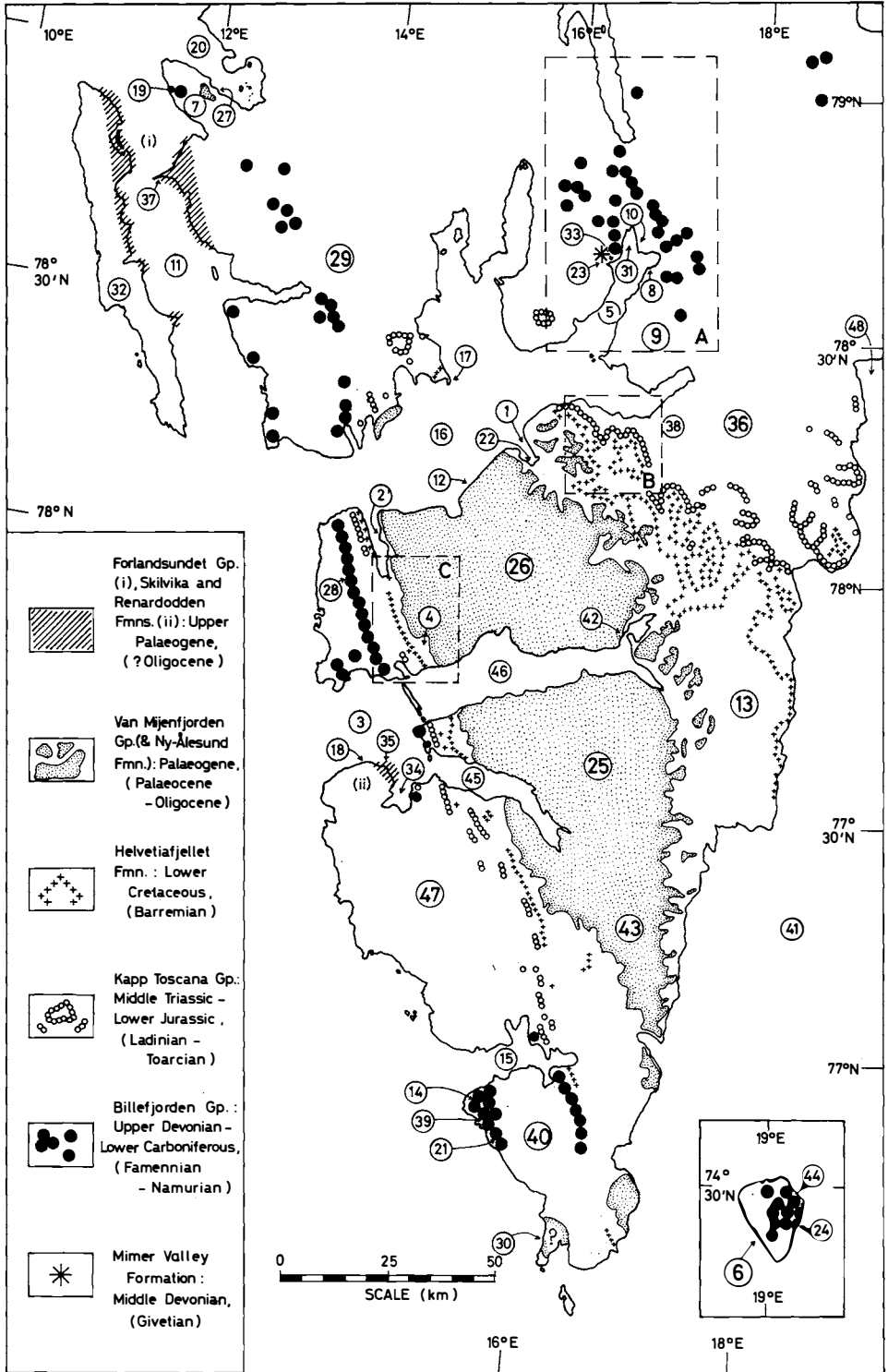


Fig. 1. Map of southern Spitsbergen and Bjørnøya to show selected coal-bearing rock units and place-names.

- A. Billefjorden area : discussed by CUTBILL, HENDERSON and WRIGHT (this volume).
- B. Saksedal area : discussed by SMITH and PICKTON (this volume).
- C. S. W. Nordenskiöld Land : discussed by CROXTON and PICKTON (this volume).

Place names referred to in this text are indicated by number and are listed below in alphabetical order.

- | | |
|---------------------------------|--------------------------|
| 1. Adventfjorden | 25. Nathorst Land |
| 2. Barentsburg | 26. Nordenskiöld Land |
| 3. Bellsund | 27. Ny-Ålesund |
| 4. Berzeliusdalen | 28. Orustdalen |
| 5. Billefjorden | 29. Oscar II Land |
| 6. Bjørnøya | 30. Øyrlandet |
| 7. Brøggerhalvøya | 31. Petuniabukta |
| 8. Brucebyen | 32. Prins Karls Forland |
| 9. Bünsow Land | 33. Pyramiden |
| 10. Ebbadalen | 34. Recherchefjorden |
| 11. Forlandsundet | 35. Renardodden |
| 12. Grumantbyen | 36. Sabine Land |
| 13. Heer Land | 37. Sarstangen |
| 14. Hohenlohefjellet | 38. Sassendalen |
| 15. Hornsund | 39. Sergiejev fjellet |
| 16. Isfjorden | 40. Sørkapp Land |
| 17. Kapp Boheman (Bohemanneset) | 41. Storfjorden |
| 18. Kapp Lyell | 42. Svea |
| 19. Kiaerfjellet | 43. Torell Land |
| 20. Kongsfjorden | 44. Tunheim |
| 21. Lidfjellet | 45. Van Keulenfjorden |
| 22. Longyearbyen | 46. Van Mijenfjorden |
| 23. Mimerdalen | 47. Wedel Jarlsberg Land |
| 24. Miseryfjellet | 48. Wichebukta |

Outcrops of coal-bearing Triassic rocks are known also on Barentsøya and Edgeøya, which are not shown ← in this figure.

We agreed a plan to accomplish this within the three field seasons 1971 to 1973. Accordingly in 1971 Saksedal was surveyed and a reconnaissance was made of northern Grønfjordbotn (Cambridge Norwich Spitsbergen Expedition 1971, Parties A and C, HARLAND and REYNOLDS 1972). In 1972 the Indre Billefjord work was done and the work in northern Grønfjordbotn was completed (Cambridge Spitsbergen Expedition 1972, Party C, HARLAND, HENDERSON and SMITH 1973). In that year portable drilling equipment was used to sample coal seams where covered by talus and to survey stratigraphical sections more completely than is possible with only the exposed rocks in these areas. In the final year southern Grønfjordbotn was surveyed (Cambridge Svalbard Expedition 1973, HARLAND and REYNOLDS 1974).

For each of the surveys a distinct party of the annual Cambridge Spitsbergen Expeditions (C.S.E.) was allotted the task. There was some advantage in sharing expedition facilities that were currently being developed at the C.S.E. base in Ny-Ålesund, but in each case the main logistic support was provided by the S.N.S.K. in Spitsbergen from their mining city — Longyearbyen. We are indebted to all S.N.S.K. personnel for every courtesy and help, and for hospi-

tality in Longyearbyen. In particular, we mention Mr. A. ORHEIM, S.N.S.K. Geologist, who provided a constant link between the needs of the party and the company.

Although geological work has continued on the coal-bearing strata from the mid-19th century until the present day, not a great deal has been published since the definitive work by HOEL in 1929. It would be an impertinence to attempt to revise that work on the basis of our short investigations. On the other hand our group has been working on Spitsbergen geology now for some years and it may be useful to others, as it has been to us, to review some of the salient geological features associated with the occurrence of coal. Indeed the planning of the sequence of Cambridge Spitsbergen Expeditions in 1948 was closely related to the investigation of the coal potential of what was then the Scottish Spitsbergen Syndicate concession around Billefjorden.

It so happens that the three investigated areas exposed three of the rock groups in Svalbard richest in coal, respectively of Early Carboniferous, Early Cretaceous and Early Palaeogene age, so we begin by putting these strata in relation to the whole.

II. Tectonic framework

For a more complete account of the whole geology of Svalbard, the reader is referred to such works as NORDENSKIÖLD 1866, NATHORST 1910, FREBOLD 1935 and 1951, ORVIN 1940 and HARLAND 1967 and 1969a. Each of these presents a similar outline in an evolving context of geological science.

It is perhaps convenient to view the structure and history of Svalbard as controlled by three major events when Svalbard was on the line of mobile plate margins.

The first event was the complex Caledonian Orogeny. It was both intensive and extensive, affecting at least the whole of Eastern Svalbard if not the west as well. In the east the Hecla Hoek geosyncline, with more than 18 km of strata from mid-Riphean to mid-Ordovician, was deformed. In the west the deformed geosyncline represents in addition to older strata a thicker early Palaeozoic sequence that was terminated by a later Caledonian event, possibly continuing through Silurian. This was followed by the characteristic Old Red Sandstone facies of Early and Middle Devonian age in the west.

The second major tectonic event occurred in Late Devonian time and was first known as the Svalbardian Folding. It has lately been interpreted as a time of major sinistral transcurrence in which Eastern Svalbard moved northward at least 200 km, and possibly more than 1000 km, from a position adjacent to the (present) east of Greenland to a point north of Greenland and near the Queen Elizabeth Islands. There it joined Western Svalbard which had moved from a lesser distance if, indeed, it was not already there (HARLAND, CUTBILL, et al. 1974).

The third movement reversed the second by (dextral) transcurrence through Cenozoic time but with transpression deforming the Greenland and Eurasian plates during the ?Mid-Eocene West Spitsbergen Orogeny (HARLAND and HORSFIELD 1974).

Between Late Devonian and Eocene time a relatively complete sedimentary record is preserved in the deposits that have been termed the Platform Sequence: Tournaisian through Albian and then Palaeogene (HARLAND 1969b). There were interruptions in this sequence with:

- (1) posthumous Svalbardian subsidence and graben formation in Carboniferous time especially along the Billefjorden Fault Zone (HARLAND et al. 1974);
- (2) magmatism in latest Jurassic and Early Cretaceous time;
- (3) uplift and warping in Late Cretaceous time.

This Platform Sequence contains all the known economic coal, and a significant part of the petroleum potential of Svalbard and surrounding areas.

The West Spitsbergen Orogeny thrust and folded the platform sequence along the west coast of Spitsbergen, so defining the western margin of the Central Basin within which the minor folds and faults of this age are of interest to the oil industry.

The post-tectonic history is one of massive denudation, peneplanation, uplift, and dissection in which the main areas of Neogene deposition are now offshore.

However, there is a series of Cenozoic outcrops along the west of Spitsbergen; notably the Forlandsundet Graben in the north and the Renardodden outcrop south of Bellsund (possibly also the small Øyrlandet outcrop in the extreme south). These appear to be basins faulted into the structures of the West Spitsbergen Orogen which itself deformed the Central Basin and Ny-Ålesund Tertiary strata. On this basis we have considered the age of the Forlandsundet Graben rocks to be post-Mid-Eocene, say Oligocene, and the Renardodden outcrop (and possibly the Øyrlandet one) by analogy of the same age. The "Forlandsundet-Bellsund" basin then is separated from the main outcrops to the east by much of the West Spitsbergen Orogen in space and probably in time by the movement that caused it. On palaeomagnetic evidence from ocean-spreading the Orogeny may be dated, for example, at 47 Ma by PITMAN and TALWANI (1972). Therefore, the whole of the Van Mijenfjorden Group and the Ny-Ålesund Formation would be of Palaeocene and Early Eocene age. It must be said at once that this is only one hypothesis and LIVSHITS has made a different age assessment postulating that the Van Mijenfjorden Group spans Palaeocene through Eocene and Oligocene (even to Miocene) time and that the Ny-Ålesund and Forlandsundet Graben rocks may be as young as Oligocene. FLOOD et al. (1971) have followed LIVSHITS whereas ATKINSON (independently) and BIRKENMAJER (following HARLAND) have used the models adopted in this paper, and KELLOGG (1975) has compromised.

III. Sequences of coal-bearing strata

The sequence just outlined above is schematised in Figure 2 against which is marked the occurrence of continental facies and occurrence of coal. The following outline gives some details of the sequence in order of age.

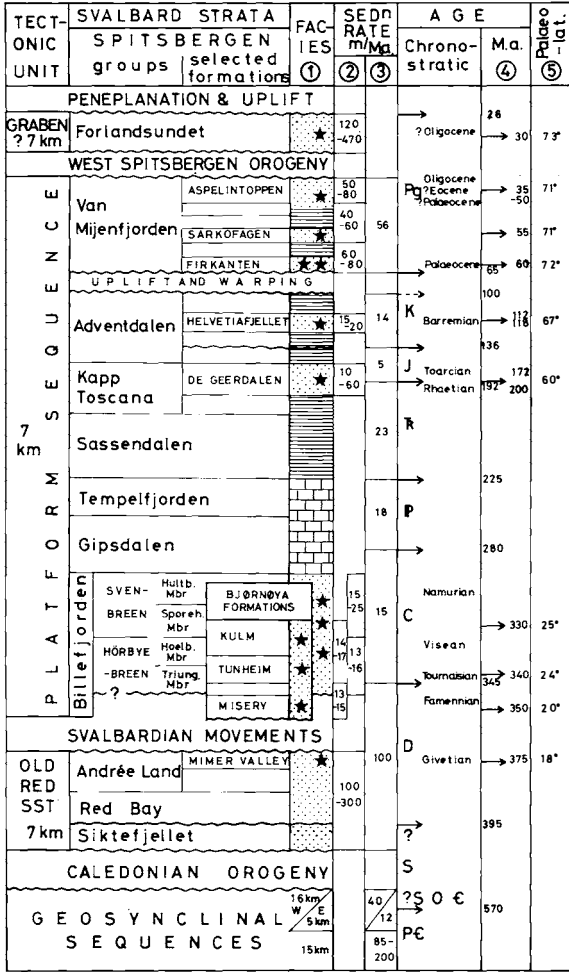


Fig. 2. Stratigraphic and Tectonic framework of coal-bearing strata in Svalbard.

Notes:

1. Facies (much generalised)
Stipple; continental sandstone sequences: star indicates the presence of coal.
Horizontal lines; marine shale sequences.
Blocking; marine carbonates and evaporites.
2. Sedimentation rates estimated in metres per million years (m/Ma).
3. Phanerozoic rates averaged over major geological periods, from HARLAND 1969(b): Early Palaeozoic and Late Precambrian rates in Eastern Svalbard, from HARLAND and GAYER 1972.
4. Geochronometrical ages in million years (Ma): on left for period boundaries and on right for selected strata.
Values from HARLAND et al. (Eds.) 1964.
5. Palaeolatitude of Spitsbergen for ages of coal-bearing strata, taken from A. G. SMITH (see Fig. 3).

III. 1. DEVONIAN COAL

There are two main areas in Spitsbergen where known Devonian rocks occur — the main graben to the north and a strip of outcrop north and south of Hornsund. No coal is reported from Hornsund and it is only in the youngest of the northern strata that coal occurs, in Mimerdalen very near to Pyramididen (where Carboniferous coal is mined but entirely distinct geologically and separated by an unconformity). Late Devonian rocks transitional to thicker Early Carboniferous rocks occur in Bjørnøya.

III.1.A. Mimerdalen

This is the classic occurrence of Devonian coal. The Old Red Sandstone sequence spans earliest Devonian to late Mid-Devonian time. These coals come near the top of the Old Red Sandstone sequence but in a distinctive south-eastern facies of it: the Mimer Valley Formation. The Mimer Valley Formation in its eastern development (in Mimerdalen) comprises four members.

4. Plantekløfta conglomerates
3. Planteryggen sandstone
2. Fiskekløfta Member
1. Estheriahaugen Member

They appear to span approximately Givetian time. The black shales of the lower two members with clay ironstone nodules, containing plants and occasional vertebrates, are somewhat similar in facies to the clay-ironstones of the English Coal Measures. Sheets of sandstone occur between the shale members and it is in one of these that a lens of cannel coal occurs (HORN 1941, VOGT 1941). This appears amongst the Old Red Sandstone facies as a unique and distinctive indication of stagnant fresh water lakes periodically invaded by small deltas of coarse detritus (FRIEND 1961) at a time of rapid spread of vegetation. The coal present is massive and dipping 55° WNW. It is homogeneous with a fairly even fracture, black with a brown streak, tough and compact, but very slickensided. Much iron oxide staining is present in all the joints and the average specific gravity of 1.316 is roughly equal to that of standard bituminous coal. In rank it is true (rather than brown) coal and in thin section it can be seen to be composed mainly of flattened plant spores, 0.02–0.1 mm long, making it cannel coal, though it does not show the typical conchoidal fracture or dull lustre. The ash content is probably high, as is the volatile content and tar yield.

III.1.B. *Bjørnøya* (*Bear Island*)

All the coal mined in *Bjørnøya* was once considered Devonian in age. It is now thought that only the earliest rocks are Devonian. In any case they are closely related in facies to the early Carboniferous deposits that follow in *Bjørnøya* and occur in Spitsbergen, so they will be considered in the next division (III.2.A).

III. 2. EARLY CARBONIFEROUS COAL

Coal bearing strata occur in shaly sequences of Tournaisian, Viséan and possibly Namurian age and are not recorded in later Carboniferous and Permian strata in Svalbard. This distinctive coal measure facies was named "Kulm" or "Culm" in the old descriptions (e.g. NATHORST 1910, ORVIN 1940).

A lithostratigraphic unit for this was set up (FORBES, HARLAND, and HUGHES 1958) and named Billefjorden Sandstones which later acquired *Group* status in the developing nomenclature.

In Spitsbergen strata of this age are very irregularly distributed in small basins and outcrops and commonly with thin coal seams. In *Bjørnøya* coal-bearing strata are well-known but there is some uncertainty as to their age.

III.2.A. *Bjørnøya* (*Bear Island*)

The "*Misery*" and "*Tunheim Series*" of *Bjørnøya* have long been known to be coal-bearing and have been regarded as Late Devonian in age (e.g. HORN and ORVIN 1928). The basis of this age correlation has been the occurrence of the *Cyclostigma*–*Archaeopteris* flora, which is now thought not to be unique to the Upper Devonian.

KAISER (1970) distinguished a sequence of palynomorphs with four distinct assemblages; the "Misery Series" he found to contain a purely Late Devonian assemblage, while the "Tunheim Series" contains assemblages characteristic of the earliest Tournaisian and (at one locality) Late Tournaisian. A fourth assemblage of Viséan age is restricted to the "Culm Series", a sequence of continental sandstones and thin coals which had always been recognised to have a Lower Carboniferous age.

There is, however, no stratigraphic break between the Devonian and Carboniferous strata in Bjørnøya, and the close similarity of facies allows the "Misery Series" to be discussed here.

In Bjørnøya the coal is best exposed in the cliffs of the east coast and several seams have been proved of which only one or two are workable. The seams extend most probably under the whole island, excepting only the area of Hecla Hoek outcrop in the south, but in the north-west they will be at least 500 m below the surface. The seams are rarely over 1 m thick and occur in two horizons, with up to 12 very irregular seams in the lower unit "Misery Series", then a gap of 105 m of barren rock before reaching three seams in the upper unit "Tunheim Series", the lowest of which (0.65–0.70 m) has been mined. All are coking coals with 22% volatile from pure coal substance and up to 16% ash.

HORN and ORVIN (1928) calculated for the "Misery Series" a reserve of 2 million tons (proved) and a large potential reserve. For the "Tunheim Series" the reserves were 290,000 tons in 3 small separated areas. At this time none of the deposits were considered viable, especially as all seams are thin, split by stony partings, and high in ash. The irregular, faulted strata would also complicate attempts at extraction.

One thin seam appears higher up in the "Culm" and above the Tunheim unit of Bjørnøya, proved by borings in three places (HOEL 1929). The seam is, like the Devonian ones, a coking coal, and is classed by HORN as unworkable.

III.2.B. *Billefjorden area*

Carboniferous coal is well known in the type area of the Lower Carboniferous Billefjorden Group, where there have in the past been several conflicting national claims for the potential coal fields.

The area around Petuniabukta was claimed by Sweden following expeditions from 1912–1917. The area to the west around Pyramidene later passed into the hands of the U.S.S.R., who established a mining town which is at present the only mine extracting Carboniferous coal from Spitsbergen. The Scottish Spitsbergen Syndicate (S.S.S.) had extensive claims on the east side of Billefjorden, including Bünsow Land and also the Ebbadalen area which was previously Swedish. Early Cambridge expeditions were based at Scottish huts in the area and continued to advise the S.S.S. after the war, until they sold the concessions to the Norwegian Government. More recently we have advised the Store Norske Spitsbergen Kulkompani on their concessions in this region.

There is not only a complex history but a complex structure and stratigraphy, as the whole area lies within the Billefjorden Fault Zone. The main reason for considering it carefully is that similar deposits extend underground to the south-

east especially in Bünsow Land, where these may be the deposits of economic importance.

The succession in the area is as follows (CUTBILL and CHALLINOR 1965).

Gipsdalen Group		unconformity					
	Svenbreen Formation		Hultberget Member	140 m			
Billefjorden Group	Hörbyebreen Formation	unconformity	Sporehøgda Member	80 m			
			Hoelbreen Member	170 m			
			Triungen Member	100 m			
	major unconformity						

Old Red Sandstone in west and Lower Hecla Hoek in east.

Coal occurs in each of the three upper members and, because this area is treated by CUTBILL, HENDERSON and WRIGHT (this volume), further stratigraphical details will not be given here.

The thicknesses are variable and maximum values are given in the table above. These are related to the unconformities and in turn to the complex fault sequence of the area. Major Svalbardian faulting and folding of Late Devonian age along this line (Billefjorden Fault Zone) not only divided older contrasting rocks to east and west but probably determined the later subsidence with faulting that localised the deposition of the rocks. Still later movements (probably Tertiary) faulted and folded these strata so that they now outcrop in a basin structure that reflects to some extent the earlier subsidence and in part defines the fjord (Billefjorden).

III.2.C. *Kiærfjellet*

On the south-west shore of Brøggerhalvøya, in the coast section below Kiærfjellet, a small outcrop of Lower Carboniferous sandstones and conglomerates occurs, overlying Hecla Hoek rocks. The sequence contains a coal seam which is approximately 3 m thick, but of poor quality, being very impure (ORVIN 1940, CHALLINOR 1967). Lithologically the sequence resembles the Orustdalen Formation (CUTBILL and CHALLINOR 1965), but this is the only known occurrence of coal in this formation.

III.2.D. *Western Nordenskiöld Land*

Although the Orustdalen Formation in this region is devoid of coals, the overlying Vegard Formation contains abundant black carbonaceous shales and some thin coals, for example in the section exposed in Orustdalen. The seams are, however, extremely thin, and of a rather poor quality coal.

III.2.E. *North-west Sørkapp Land*

The Lower Carboniferous sequence in this area has been reported by SIEDLECKI (1960), who distinguished two series, later raised to the rank of formation (CUTBILL and CHALLINOR 1965). The lower Hornsundneset Formation is largely arenaceous, in many ways resembling the Orustdalen Formation. It contains some carbonaceous fragments but no real coal seams. The overly-

ing shaly Sergiejev fjellet Formation occurs on Lidfjellet, Sergiejev fjellet, and Hohenlohefjellet, where Siedlecki reported a coal seam 0.95–1 m thick.

This formation is probably of Late Namurian age (SIEDLECKI and TURNAU 1964).

III.3. TRIASSIC COAL

Details on Triassic coals are scarce, the most recent being by KLUBOV, ALEKSEJEVA and DROZDOVA (1967). In 1962–1964 KLUBOV (1964, 1965) described and mapped the coal of Wilhelmøya, Barentsøya and Edgeøya and in 1966 PCHELINA and PANOV established the presence of Triassic coal in two more areas, around Wichebukta and in the upper reaches of Sassendalen.

The coal is present in Upper Triassic deposits, as a single band fluctuating from 0.10 to 0.40 m but persistent over a reasonably large area. It is semi-lustrous with a glimmering, satiny lustre, dense, homogeneous or indistinctly banded with fracture varying from sub-conchoidal to scalariform. The bed lies at the top of the Karnian stage in a sandstone with leaves below it (sometimes accompanied by 0.1–0.2 m clayey silt in between) and a well-defined band of thinly platy argillites 2–8 m thick usually above it.

Formation of the coal appears to be from gelified products of the transformation of plant leaves and cuticle, with some spore and pollen casings subordinate. The degree of carbonification is high.

III.4. CRETACEOUS COAL

Cretaceous seams were worked for a short while at Advent City and Moskushamn, near Longyearbyen (HOEL 1929). An English company operated here from 1904 to 1908, but sold the mines in 1916 to a Norwegian company. A Dutch syndicate mined Cretaceous coal at Kapp Boheman, directly across Isfjorden from Adventfjorden, from 1920 to 1921 with poor results. There appears to have been no attempt to mine Cretaceous coal in Spitsbergen since that date.

At the mine entrance at Advent City there are two seams, the lower one of 40 cm thickness and the upper 50 cm, separated by 9 cm of shale. However, the coal-bearing strata are very variable, and the seams split into as many as five benches, although the total thickness of coal remains approximately constant. The seams are slightly faulted in places, but it is probably the variability of the seams and the quantity of interbedded rock that made mining operations uneconomic. HOEL (1929) quoted an analysis of coal from Advent City as having an ash content of 12.6%, a sulphur content of 0.47% and a calorific value of 6748 cal. Recent analyses from the same source suggest even higher ash contents from 14% to over 19%.

Cretaceous coal is also present at Grumantbyen where it is below sea level.

HOEL (1929) made an estimate of possible reserves of Cretaceous coal in Spitsbergen, basing his estimate on the area under which the coal-bearing horizon occurs at not more than 600 m from the surface, and on an average thickness of 1 m of coal. The estimate gave 1,500 million tons. However, it seems from the work by SMITH and PICKTON (this volume) that the thickness of

the seams at Advent City may be exceptional, and that a more realistic estimate of the reserves would be considerably less, if indeed there are any further occurrences of Cretaceous coal in Spitsbergen in seams of economic thickness.

III. 5. PALAEOGENE COAL

The Tertiary strata of Spitsbergen may be divided into 5 distinct areas as follows:

III.5.A. *Kongsfjorden Area*

A Tertiary coalfield, with a stratigraphic thickness of perhaps 240 m and a shallow dip to the south is exposed here on the coastal plain over a strip measuring approximately 1×7 km. It is bounded by fault and thrust contacts with Permo-Carboniferous rocks to the west and south, and rests on thin (?) Triassic strata to the north and east. The stratigraphy was recorded in detail by ORVIN (1934), although his divisions have since been renamed by CHALLINOR (1967) and LIVSHITS (1974). The deposits are thought to be contemporaneous with those of the Central Area, but are correlated with the lowest strata of that area by some authors (e.g. ATKINSON 1963) and with the uppermost by others (e.g. LIVSHITS 1974). The age range may therefore be anywhere between Palaeocene and (?) Oligocene.

The area has been well explored, and all major seams have probably therefore been discovered, all of which vary greatly in thickness and appearance.

Coal seams occur within the lowermost and uppermost strata, which are separated by a barren sequence of sandstones. Six seams, named from the lower to the upper Ester, Sofie, Advokat, Agnes-Otelie, Josefine and Ragnhild, have been worked or are workable. Thicknesses of up to 3 m are common, especially close to the thrust plane to the south which has folded and thickened the seams locally. (The areal extent of each seam, however, decreases rapidly going up the succession).

At various times over the last half-century, the seams have been worked from the mining town of Ny-Ålesund, but following a tragic explosion in 1962 the mining camp was finally closed down and the shafts covered over.

The coal, though chemically similar to cannel coal, is a typical durite on the classification of POTONIE (1924) and, as shown by HORN (1928), will yield up to 20% or more crude-oil on low-temperature distillation.

III.5.B. *The Central Area*

This area represents the most extensive development of Tertiary deposits within the archipelago. The rocks extend from the north side of Isfjorden to Sørkapp Land in an oval outcrop pattern with axes of approximately 200 and 90 km. Over 2,300 m of strata are preserved in the general form of a large syncline. These strata were initially described and divided into six units by NATHORST (1910). Renaming and further division of some of these units has followed by KOTLUKOV (1936), LYUTKEVITCH (1937b), HARLAND (1969a), MAJOR and NAGY (1972) and LIVSHITS (1965, 1974). The divisions of MAJOR and NAGY are employed in the first (Adventdalen) geological map of the 1:100,000 series produced by Norsk Polarinstitut.

Thin seams have been recorded within the Sarkofagen Formation of this Van Mijenfjorden Group (HARLAND 1969a), for example a seam of a few centimetres in the Berzeliusdalen area (CROXTON and PICKTON, this volume), and a seam up to 1 m thick in the Barentsburg region (LIVSHITS 1965), but major seams of extensive development are restricted to the lowest (Firkanten) and uppermost (Aspelintoppen) Formations.

The coal seams in the Firkanten Formation are those presently exploited by the Norwegian company S.N.S.K. at Longyearbyen and by the Soviet company Arktikugol at Barentsburg. MAJOR and NAGY have named 5 seams, from the bottom the Svea, Todalen, Longyear, Svarteper and Askeladden seams. Details of the quality of these coals are scarce compared, for example, to the exhaustive lists of analyses given by ORVIN for the Ny-Ålesund coals. MAJOR and NAGY did, however, point out that the Todalen seam is typically less than 60 cm thick and that the Askeladden seam, though well developed, has a poor quality due to a high sulphur content.

The lower part of the Aspelintoppen Formation is characterised by a coal-bearing sequence, but, though numerous, the beds are very thin or lensoidal. Investigations by C.S.E. have recorded no seams greater than 30 cm thick.

The age of the deposits within the Central Area is taken as Palaeocene-Eocene by some authors (e.g. ORVIN 1940; HARLAND 1961 and 1969a) and by others as Palaeocene to Oligocene (LIVSHITS 1965, 1974; FLOOD et al 1971).

III.5.C. *The Forlandsundet Area*

Tertiary strata are exposed along 2–3 km wide strips of coast on either side of Forlandsundet, over a distance of about 30–40 km. On the eastern side, the western coast of Oscar II Land, the exposure is poor and on the western side, on Prins Karls Forland, folding and faulting considerably hamper attempts to unravel the stratigraphy. LIVSHITS (1967) divided the strata into 5 units (upgraded to formations in 1974) of which only the lower two are exposed on Oscar II Land. Over 2,800 m of strata are exposed on Prins Karls Forland and over 1,300 m on Oscar II Land. Strata on both shores dip towards the axis of the graben and the effects of faulting suggest that the depth of strata within the graben may be considerably over the 2,800 m so far recorded.

The rocks are in unconformable contact with those of the Hecla Hoek complex to the west and east, faulted in places, and the north-south extent of the graben in which they are developed is open to question. A gravity survey by C.S.E. has suggested possible closure at either end of Forlandsundet. Lithological and tectonic studies imply a close analogy with the Renardodden deposits which may represent a southern extension of the same graben, or a separate one. A close connection is also implied by aeromagnetic survey (ÅM 1975).

The age of the rocks is equivalent to or younger than the youngest of the Central Area, and as the only fossils determined were in the lower strata the age possibly ranges from Eocene to Oligocene (LIVSHITS 1974).

Coal is known from both sides of the sound. LIVSHITS (1967) quoted thicknesses of 3–10 cm for several thin seams in his Sesshøgda Formation on Oscar II Land, but fragments of 15 cm minimum diameter found by C.S.E. imply the

existence of still thicker ones. On Prins Karls Forland coal is found in thin seams or as clasts. ATKINSON (1962) recorded seams of 1–2 cm thickness somewhere in his McVitiepynten Formation (not illustrated), which may be taken as the equivalent in the north-eastern part of the island to LIVSHITS' upper four formations.

Though the individual occurrences of coal in this graben are rather insignificant, the total volume present is considerable, given the extent of the graben and the thickness of the deposits. Natural gas, presumably from such coals, has already been struck by the Norsk Polar Navigasjon A/S well at Sarstangen (*Petroleum Economist* 1975).

III.5.D. *The Renardodden Area*

This region (near Kapp Lyell) contains a Tertiary coalfield at Calypsobyen perhaps 700 m wide and nearly 4 km long on the headland west of the mouth of Recherchefjorden. A detailed stratigraphy was given by LIVSHITS (1967), who recorded many coal seams in the 400 m of strata which he divided into two formations. The lower (110 m thick) contains 17 seams, mostly 0.02 to 0.2 m thick, but with three of 0.28, 0.46 and 0.65 m. An unspecified number of coal seams and lenses are present in the upper (c 300 m thick) formation of 0.02 to 0.3–0.5 thickness. The Tertiary strata of this area dip at 10°–25° to the north-east and are in unconformable contact with rocks of the Hecla Hoek complex to the south-west.

III.5.E. *The Øyrlandet Area*

This area is a flat coastal plain, covered in the main by glacial debris and outwash material. It was shown by ORVIN (1940) to be an area of perhaps 25 sq. km with faulted contacts to the west with Carboniferous strata, but apparently overlying Cretaceous rocks to the north and north-west. Little is known of the stratigraphy except for a mention by LIVSHITS (1974) of >50 m of quartz sandstones. No coal is known from these strata, which BIRKENMAJER (1972) suggested represent an outlying arm of the main basin in which the strata of the Central Area were deposited. They are correlated by LIVSHITS (1974) with the lowermost (Palaeocene) strata of the Central Area.

IV. Circumstances of formation of coal in Svalbard

From Mid-Devonian through to Palaeogene (Eocene or possibly Oligocene) time, coal formed and has been preserved in a remarkably rich record. This record provides an opportunity for the re-examination of some of the factors generally associated with the formation of coal.

The obvious needs are an adequate production of vegetable tissue, its preservation *in situ* or concentration in basins near growth areas, and conversion by diagenesis or anchimetamorphism to coal. Three aspects may be considered in this connection and in each case, insofar as the conditions for coal formation be assumed, constraints are set on the geological history of Svalbard or conversely a knowledge of that history may set some constraints on hypotheses of coal formation. These aspects are:

1. palaeoclimates and palaeolatitudes;
2. sea level, sedimentation and subsidence;
3. depth of burial and tectonic control.

IV.1. PALAEOCLIMATES AND PALAEOLATITUDES

IV.1.A. *Climatic evidence*

Palaeoclimatic world maps with reconstructed positions of Svalbard all agree on a general progression of Svalbard climates through Phanerozoic time from tropical to polar climates, placing Spitsbergen near the equator at the beginning of Phanerozoic time. These reconstructions generally depend much on the critical Spitsbergen data which have long been available, so that we need to look more carefully at the direct evidence of the climatic indicators used. If we ignore the coals and associated plant beds as evidence the other indicators are not very discriminating: Late Precambrian dolomites (and tillites); Cambrian and Ordovician dolomites with a very rich Ordovician fauna; Old Red Sandstone facies with abundant fish; Carboniferous and Permian facies following the Billefjorden Group with dominantly carbonate and evaporite facies. The whole Palaeozoic record therefore suggests a warm or hot climate. The Mesozoic sequence is more difficult to assess. Certainly marine Triassic faunas are rich, and Early Cretaceous conditions must have yielded luxuriant vegetation to support the bulky *Iguanodon* in Helvetiafjellet (?Barremian) times (HEINTZ 1963). Palaeogene biostratigraphy is altogether enigmatic. Nevertheless, up to the latest preserved Palaeogene deposits vegetation must have been prolific and therefore suggests humid temperature conditions.

IV.1.B. *Magnetic evidence*

Geomagnetic inclinations interpreted as latitudes bring quite independent evidence to bear on the problem. Whereas palaeoclimatic evidence for Svalbard plays a key part in synoptic world maps, the palaeomagnetic evidence used for world maps depends little or not at all on Svalbard rocks, which hitherto have proved disappointing in this respect. On the other hand, with Svalbard belonging to the Barents Shelf and the European plate since Devonian time and for much of that time also being adjacent to the Sverdrup Basin, geometrical reconstruction of Svalbard can place it in a global context. This has been done several times and the most recent attempt has been made available to us by Dr. A. G. SMITH directly from his computer programs that employ geometric fit and Dr. J. C. BRIDEN's palaeomagnetic data. A series of computed palaeolatitudes for Svalbard for every 10 Ma of Phanerozoic time is plotted in Fig. 3 and abstracted in Fig. 2. The errors by this method are likely to be considerable and further comparisons taking more fully into account data for the Sverdrup Basin are in progress; but the results do have the advantage of being completely independent of all the foregoing palaeoclimatic considerations.

The curve suggests a relatively rapid northerly Triassic motion of Svalbard and somewhat surprisingly high Cretaceous through Palaeogene latitudes. Indeed, the clear evidence of rich floras through to Eocene or Oligocene at latitudes near or even within the Arctic Circle confirms that global climates as a

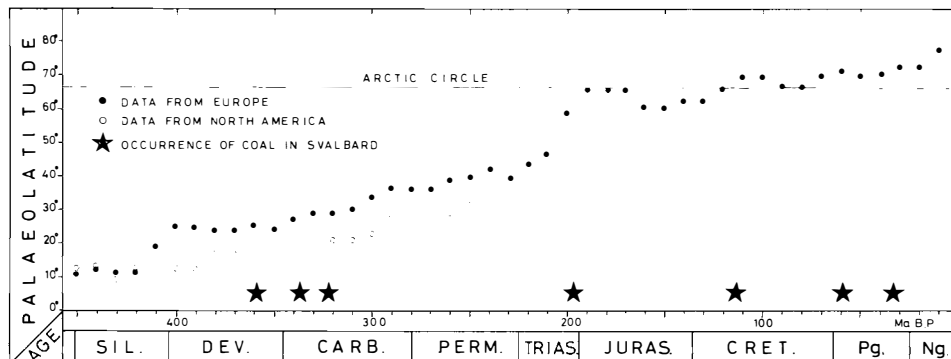


Fig. 3. Palaeolatitudes of Spitsbergen from 450 Ma B.P. to present day.

Values taken from computer programs of Dr. A. G. SMITH, utilising best-fit criteria and Dr. J. C. BRIDEN's palaeomagnetic data.

whole were more equable and altogether warmer than today. Moreover, this suggests that in such conditions latitude was not so critical for biological activity as it is today and this has some bearing on palaeolatitudinal predictions for the habitat of petroleum.

IV. 2. SEA LEVEL, SEDIMENTATION AND SUBSIDENCE

The formation of coal *in situ* may require growth near sea level and periodic submergence and burial. Rapid and/or differential subsidence may lead to the splitting of seams. Of this we have little evidence.

Calculations of net sedimentation, which over a long time probably reflects subsidence rate, were attempted (HARLAND 1969b) and these figures are used in Fig. 2 for average rates. Other estimates have been made of possible average rates of subsidence for the coal-bearing formations considered here (Fig. 2). Neither set of values suggests other than relatively stable conditions in which uniform conditions and correlation might be expected over wide areas without significant splitting of coal seams. The only exceptionally thick seams known appear to be the result of tectonic thickening (Kongsfjorden at Ny-Ålesund and Billefjorden at Pyramiden). Thick seams are reported locally, e.g. Svea, from the centre of the main basin. Within the fault graben situations, namely in the Billefjorden and the Forlandsundet Groups, the overall pattern of seams is not known.

Short term eustatic changes of sea level are likely to be reversed in the course of time and so may give rise to sedimentation or erosion without affecting the long term average. No conspicuous cyclothemic coal sequences are observed in most of the coal bearing sequences, although BARBAROUX (1967 thesis) distinguished 3 types of sequences within the Tertiary deposit around Ny-Ålesund, and others (e.g. VONDERBANK 1970) have expressed the whole Central sequence in terms of cycles of sedimentation.

IV. 3. BURIAL AND ANCHIMETAMORPHISM

After burial of the coal deposit, diagenic and low grade metamorphic processes have the effect of altering the coal to successively higher ranks. This

depends on the principal factors of pressure, temperature and time, and the results are commonly observed physically by reflectance etc., and chemically by carbon content etc.

All known Svalbard coals have gone beyond any stage of lignite or brown coal and are hard and shiny. This may not be surprising for the earlier coals but it is worth considering the latest in more detail.

Within the Van Mijenfjorden Group the highest coals we have sampled come from the Aspelintoppen Formation and Mr. S. LARTER allows us to quote from a reconnaissance investigation of these as follows:

The reflectivities of vitrinite in the various samples examined represent from 77% to 82% C in the vitrinite, leading to their classification as hard brown coals to bituminous hard coals. There is some evidence of increasing rank with depth over the thickness of the Aspelintoppen Formation and this variation combined with other petrological data from these coals should allow estimates of depth of burial to be made. Work is continuing on this problem, but it now seems probable at this stage that the overburden amounted to not less than 5 km. This is not inconsistent with the minimum 2.5 km overburden suggested by LIVSHITS (1974). The implications of this for understanding the West Spitsbergen Orogeny are indicated elsewhere (e.g. HARLAND 1975) and include the delineation of a probable syntectonic clastic wedge immediately to the east of the Orogen. Indeed, the interpretation of the ubiquitous coals in Svalbard coupled with investigations of palynomorphs and other vegetable residues may well provide a sensitive anchimetamorphic indicator of considerable tectonic value.

Not least of the consequences of the changes due to burial of coal is the generation of gas. Gas may equally arise (or even be caused to arise) from many thin seams and finely disseminated organic matter as from seams of workable thickness, so that formations not yet seriously considered for mining may well have some importance (cf. report on gas strike at Sarstangen, Forlandsundet: *Petroleum Economist* 1975).

Therefore coal in Svalbard has a threefold economic significance that is not likely to diminish.

1. There are considerable reserves of coal that could be mined.
2. There is a far greater bulk of coal that may be unmineable but may yield gas.
3. Understanding of the exact state of coal will play an important part in understanding the tectonic history of Spitsbergen, particularly in relation to potentially oil-bearing formations.

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The Van Mijenfjorden Group (Tertiary) of South-West Nordenskiöld Land, Spitsbergen

By CATHERINE A. CROXTON and C. A. G. PICKTON

Abstract

Field parties of the Cambridge Spitsbergen Expedition, during the summers 1971–1973, were engaged in a survey of the Grønfyordbotn concession area on behalf of the Store Norske Spitsbergen Kulkompani A/S. A geological map of the area showing the six Tertiary formations, detailed stratigraphic sections of the five lower formations, a plot of coal occurrences, a structural contour map of the Basal Tertiary unconformity and structural cross-sections of the area are presented.

I. Introduction

In response to a request by the Store Norske Spitsbergen Kulkompani A/S (S.N.S.K.) a geological survey of the Grønfyordbotn concession area was undertaken by parties of Cambridge Spitsbergen Expeditions (C.S.E.). This area, lying between Grønfyorden and Berzeliusdalen, was surveyed over a period of three years. A preliminary reconnaissance by W. B. HARLAND, assisted by D. CLARK-LOWES and C. JOURDAN in 1971, preceded a survey by W. HENDERSON and C. A. CROXTON, assisted by P. COOPER, B. H. HARLAND, B. KISSIN, S. R. LARTER, A. G. PACK and N. J. R. WRIGHT, in 1972. The latter work, based in Grønfyorddalen, was chiefly concerned with the coal-bearing strata of the lowest (Firkanten) Tertiary Formation. Due to the poor exposure of the Formation in this area a portable 4M packsack drill was used to supplement the standard taped stratigraphic sections. Specifications of this drill are given in a paper by WRIGHT and HENDERSON (Norsk Polarinstitutt Årbok 1974 (1976)).

In 1973 the project was completed by C. A. CROXTON and C. A. G. PICKTON, assisted by A. A. BOLTON-MAGGS and D. YOUNG, who were based in Berzeliusdalen. Fig. 2 shows the areas studied by the various field parties. The 1973 party concerned itself with a more general study of the whole Van Mijenfjorden Group, in order to assess the possibility of economic coal seams within younger

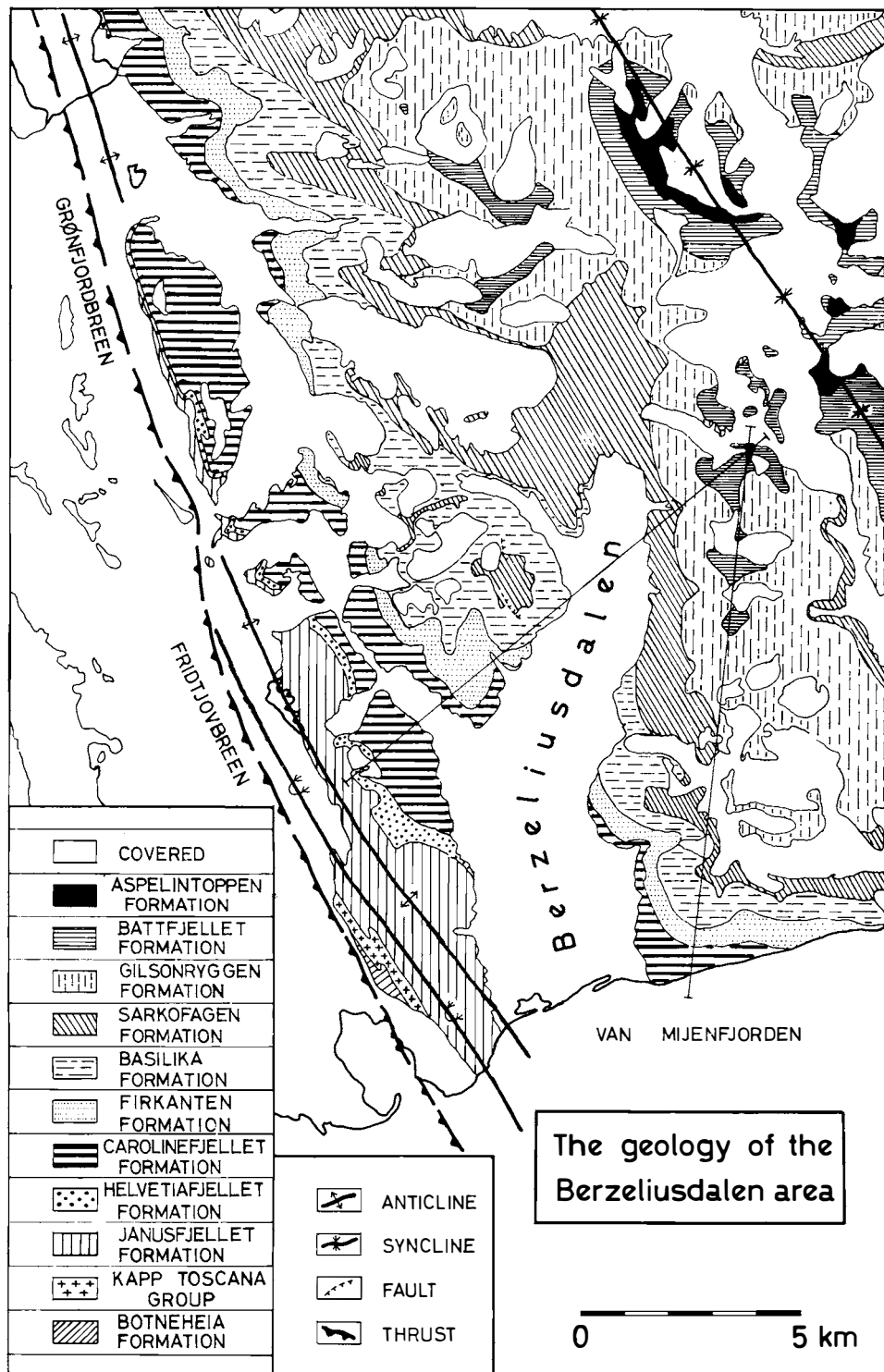


Fig. 1. Outline geological map of the Berzeliusdalen-Grønfjorddalen area.

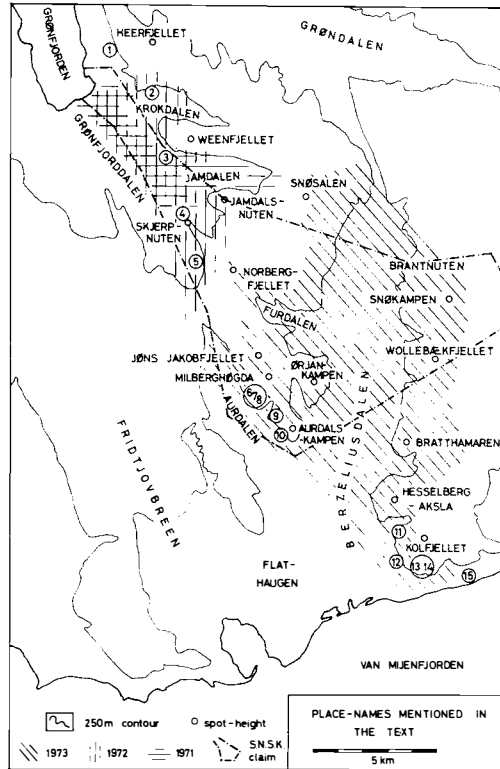


Fig. 2. The Berzeliusdalen-Grønfjorddalen area; place names mentioned in text. 1-15 refer to Fig. 10.

strata, to collect data for the compilation of isopach maps for the individual formations, and to assess the overburden to the seams of the Firkanten Formation over the whole concession area.

At present the seams within this formation are mined at Longyearbyen (Norwegian) and Barentsburg (Soviet). Until 1925 they were worked at Sveagruba (Swedish), and S.N.S.K. is now re-opening this mine. In the early part of this century mining (on a small scale) was briefly conducted at Kolfjellet.

The map area has been studied previously, notably by LIVSHITS, who compiled a map showing the distribution of the Tertiary formations over the whole of Nordenskiöld Land (1965), and VONDERBANK (1970) who proposed a genetic scheme for the division of the Van Mijenfjorden Group into four units, each representing major sedimentary cycles. The area to the north around Barentsburg and along the coast to Longyearbyen was also described in great detail by LYUTKEVICH (1937).

II. Stratigraphy

The 1:100,000 geological map (Fig. 1) includes strata ranging from Triassic (Botneheia Formation) through to Tertiary (Aspelintoppen Formation). Only the Tertiary formations, however, were studied in detail. The litho-stratigraphy of these formations, comprising the Van Mijenfjorden Group, is described below.

The stratigraphic scheme employed is that of MAJOR and NAGY (1972), which follows the purely descriptive divisions of NATHORST (1910). A full description and a drawn stratigraphic section (with corrected thicknesses) is given for each formation to allow comparison to the area on the other side of the Central Basin described by MAJOR and NAGY in 1972.

The recognition of the upper and lower formational boundaries is often very difficult, due to the lateral variations in lithology of some formations. In particular, the level of the Battfjellet/Aspelintoppen junction remains open to question, as the coal-bearing beds typical of the lower part of the Aspelintoppen Formation are not seen in this area.

II.1. THE SUCCESSION

Van Mijenfjorden Group

This group of rocks was mentioned by NORDENSKIØLD (1866) but was first described as a distinct unit with six divisions defined by NATHORST. Its general character is of continental sandstones, siltstones and shales with plant beds and coal seams; marine beds with molluscs, conglomerates and slumped beds are less frequent.

The six formations as used here are described from the top as follows:

	Aspelintoppen Formation	80 m + (top not seen)
	Battfjellet Formation	330 m
Van Mijenfjorden Group	Gilsonryggen Formation	290 m
(typical thicknesses within map area)	Sarkofagen Formation	380 m
	Basilika Formation	305 m
	Firkanten Formation	215 m

These formations are relatively conformable and lie with slight angular discordance on members of the Carolinefjellet Formation of the Adventdalen Group.

The ages of the rocks in question, except those of the upper formations, are generally regarded as Palaeocene-Eocene and generally referred to as the Tertiary rocks overlying strata of Albian age. The upper formations have been variously taken in recent years as from Palaeocene to early Neogene in age, and it is not certain that the oldest rocks are not of late Cretaceous age. The problem of age determinations in these sequences has been discussed by HARLAND (1975).

II.1.A. *Aspelintoppen Formation*

In the area surveyed, only one measured section (Snøkampen, Fig. 3) included the lowest part of this formation and, due to the poor exposure, the boundary at the top of the Battfjellet Formation below is difficult to determine. No massive cliff-forming sandstone is apparent, but a small outcrop of resistant sandstones occurs at the very peak of the mountain and may be its equivalent. These sandstones are medium grained, yellow weathering, in 2cm–4cm beds, carbonaceous, with plant fragments, marked slump structures, ripple markings and rusted mud flakes 2cm–3cm across. Leaf impressions, in silty layers, are

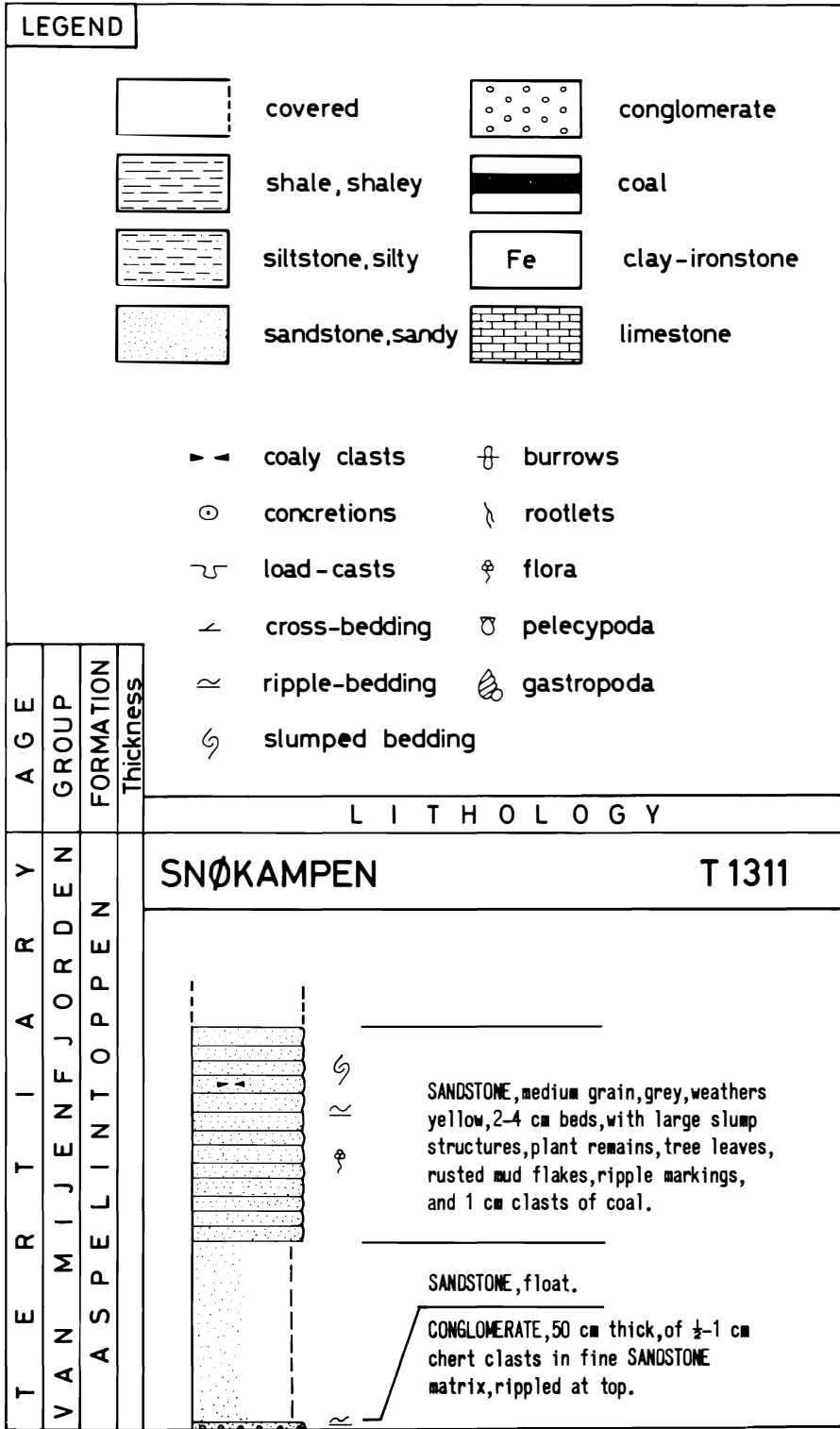


Fig. 3. Section on Snøkampen and key to figured sections.

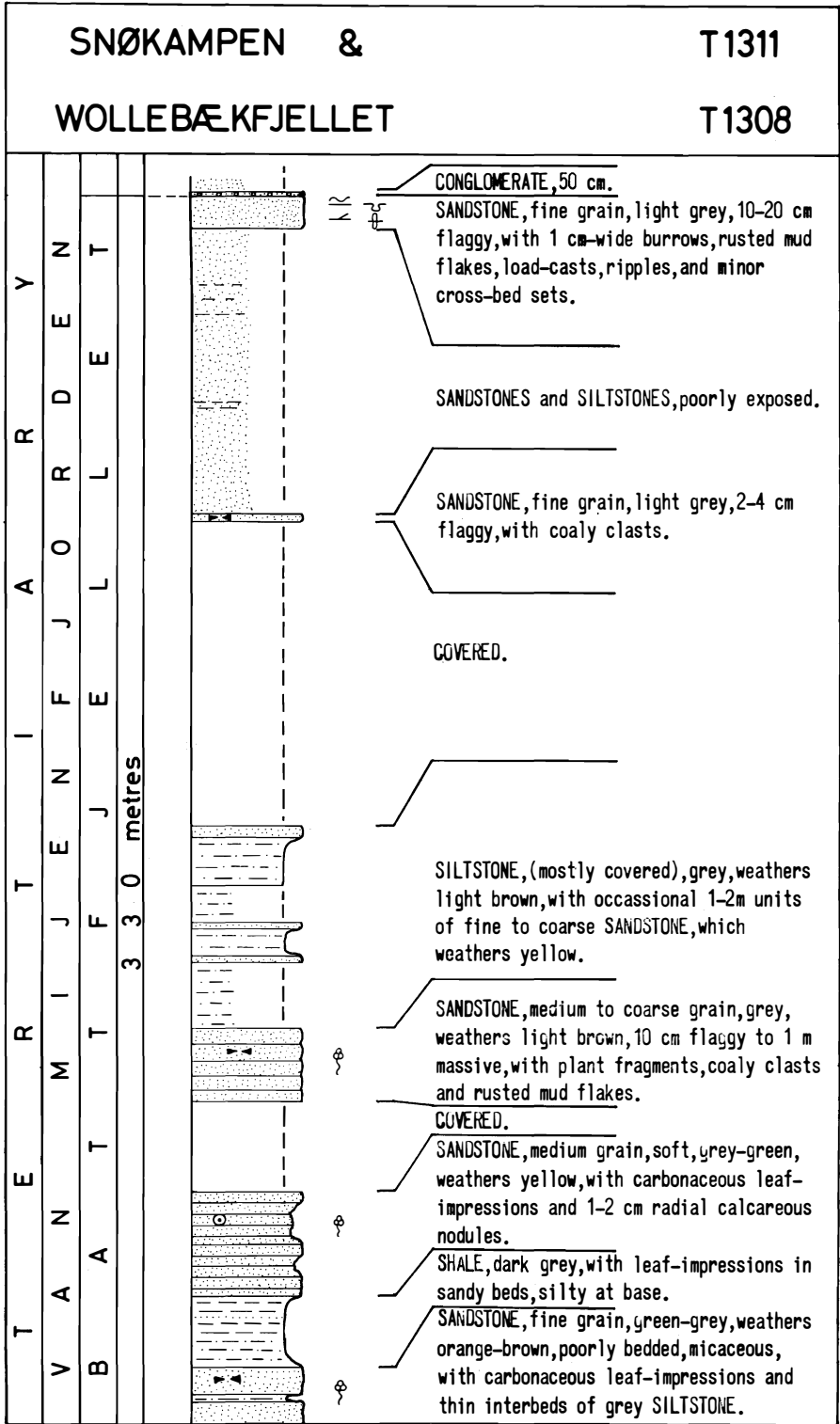


Fig. 4. Section on Snøkampen and Wollebækfjellet.

abundant. The total thickness is about 80 metres, forming a small tor on the otherwise scree-covered slopes. Approximately 50m below the base of these sandstones another set occurs, about 8.5m thick, overlain by about 50cm of chert conglomerate, in its turn overlain by a ripple-bedded sandstone. As this conglomerate occurs at the base of the more resistant beds it is taken here as the base of the Aspelintoppen Formation. The top of the formation is not seen and no thicknesses are therefore given.

II.1.B. *Battfjellet Formation*

This formation is present around the upper reaches of Berzeliusdalen, but seen fully only on Snøkampen (Fig. 4). Predominantly it consists of fine grain sandstones, grey-green, weathering light brown, with coaly clasts, leaf and plant preservations, rusted mud flakes and occasional calcareous concretions. Softer, less well exposed, shale and siltstone interbeds are present, but seen clearly only in the lower half of the formation. One coarse grained set of beds is present, about 100 m above the base of the formation, represented 1 km to the north on Brantnuten by a short series with grits, local conglomerates and slump structures. On Brantnuten the rest of the Battfjellet Formation is covered, and the base of the formation, at the base of the lowest hard sandstone, is marked only by the sharp levelling of slope forming a distinct plateau which is easily traceable on the aerial photographs.

The formation is 330m thick on Snøkampen.

II.1.C. *Gilsonryggen Formation*

This is a uniform series of soft shales and siltstones, grey, weathering to a variety of reds/browns/blues and yellows, with thin 1cm–3cm bands (and occasional 5cm nodules) of clay-ironstone and commonly with well-rounded chert pebbles up to 5cm across (see BIRKENMAJER et al. 1972). Burrows are visible in only the coarser beds or the clay-ironstone bands.

Two sandstone bands (Wollebækfjellet, Fig. 5) are present, both coarse grained, poorly sorted and with plant fragments. Two equivalent sandstones were also noted on Snøsalen about 7km to the north-west, but these are here each 1m thick, fine grain, micaceous, with rusty nodules.

On Snøsalen and Brantnuten (4km to the north) the exposure of the lower parts of the formation is good, showing a higher abundance of clay-ironstone concretions and bands (some up to 10cm thick) and occasional large chert and quartzite boulders up to 12cm across.

The formation is 290m thick on Wollebækfjellet, 310m on Brantnuten. The base of the formation is taken at the base of the soft slopes, immediately above the last hard sandstone/siltstone of the Sarkofagen Formation.

II.1.D. *Sarkofagen Formation*

This formation, measured on Bratthamaren (Fig. 6), is dominated by a 100m series of sandstones. These are fine grain (medium in lower beds) light green-grey, weathering green-brown, in 20cm–50cm massive units, with silicified “*Chondrites*” tubes, 1cm–2cm chert pebbles, rusted burrows, clay-ironstone

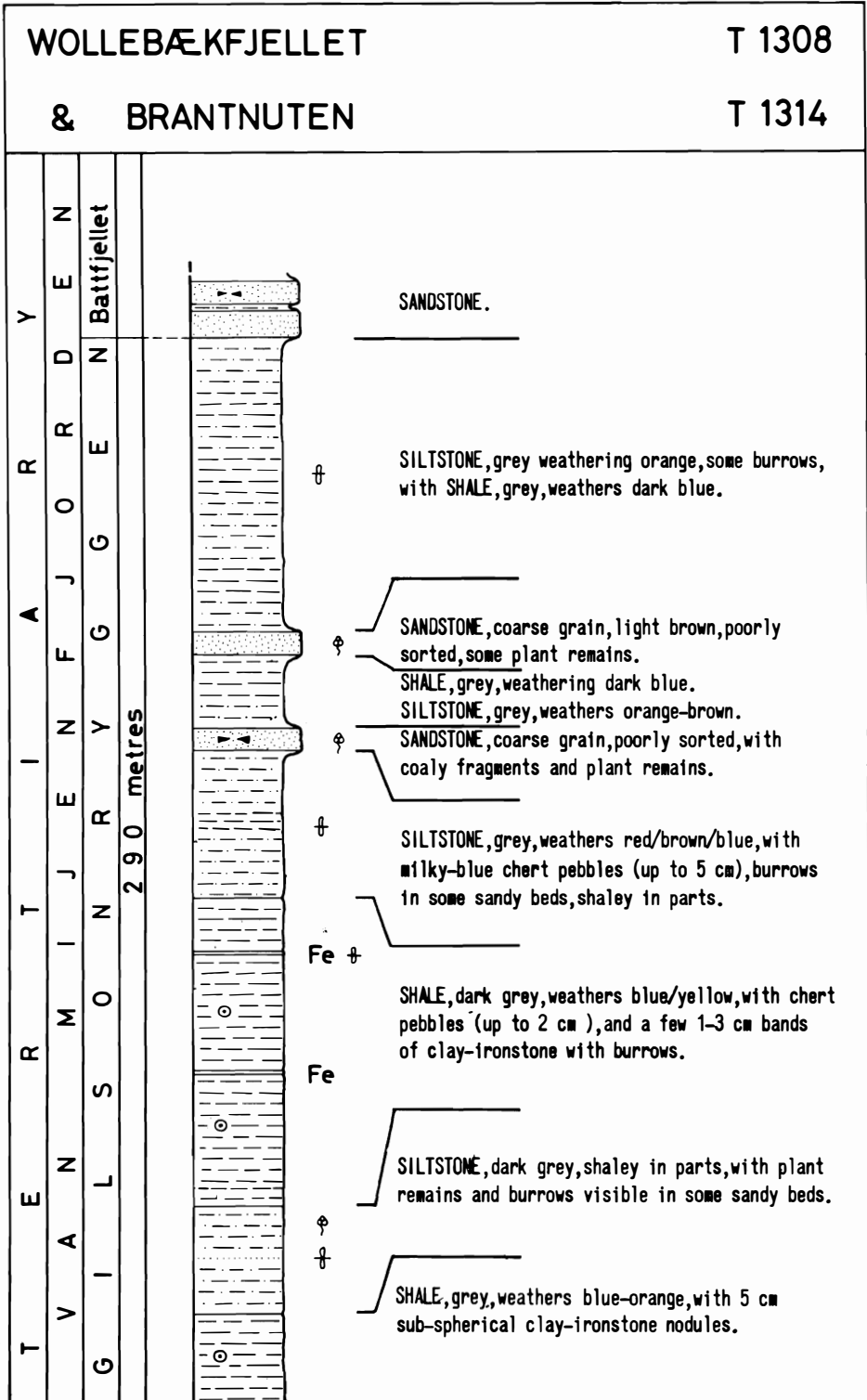


Fig. 5. Section on Wollebækfjellet and Brantnuten.

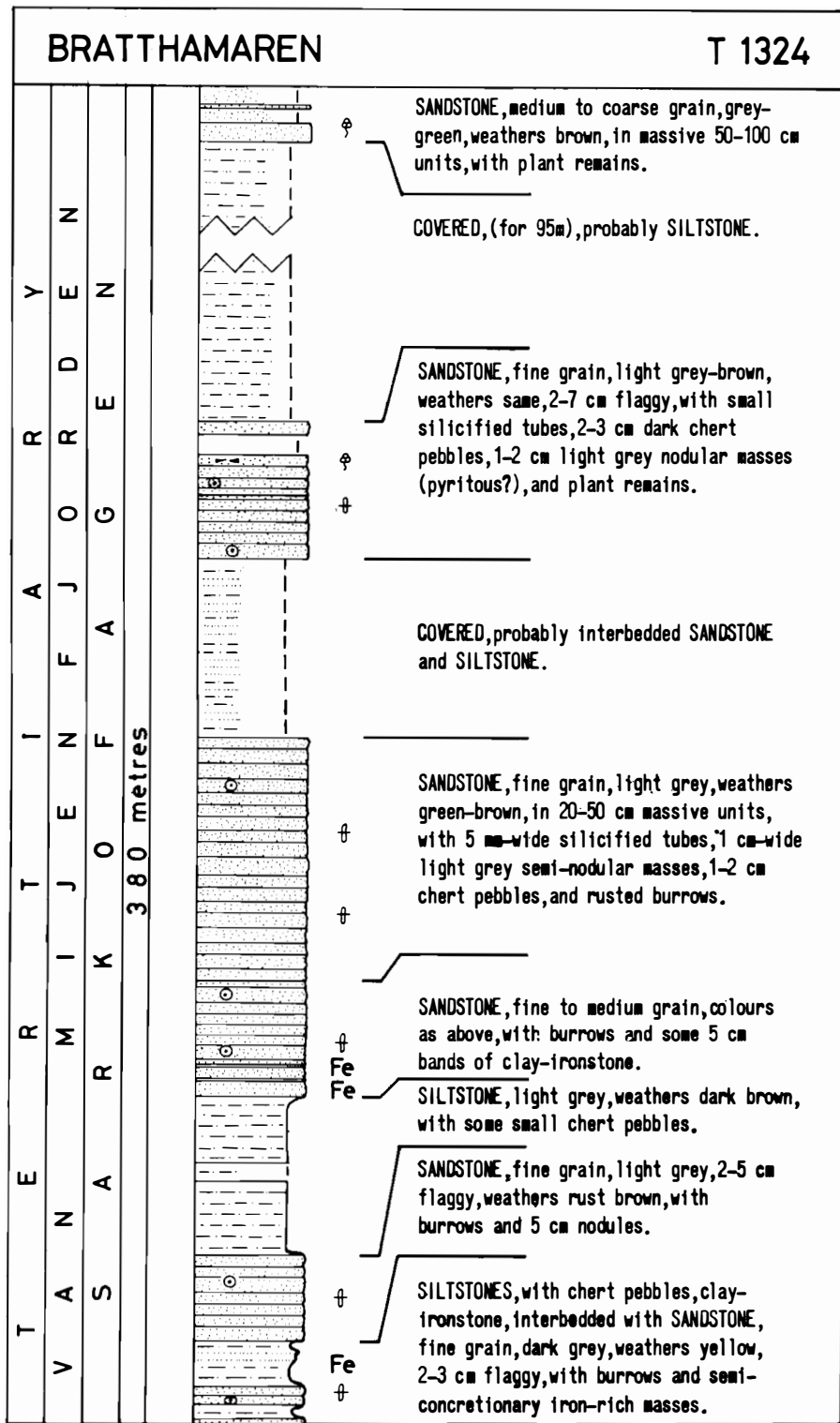


Fig. 6. Section on Bratthamaren.

bands and semi-nodular light grey aggregations which have a high iron content and may be early stage representatives of either pyrite or clay-ironstone concretions.

Above these sandstones, which are crag-forming, alternating thick units of sandstone and siltstone appear, which often show topographically as two or three “steps” between the crags below and the soft but steep slopes of the Gilsonryggen shales. Below the crags is a 50+ m set of siltstones with cherts, underlain by 20m of sandstone, which then grades down through a series of alternating sandstones (with burrows and concretions) and siltstones to the top of the Basilika Formation. The base of the Sarkofagen Formation is taken at the base of the first extensive hard sandstone bed in this alternating series.

A thickness of 380m was found on Bratthamaren.

7km to the north on Brantnuten, the uppermost sandstones just below the Gilsonryggen shales are fine grain, with coaly clasts, plant remains and pelecypods. 3km to the north, on Wollebækfjellet, this sandstone is coarse grained, with plant remains. To the north-west on Snøsalen, a 2cm–3cm coal seam is present within the sandstones.

II.1.E. *Basilika Formation*

This formation is a series of soft grey shales and siltstones weathering blue/red/yellow/brown, often giving rise to visible banding on slopes of otherwise poor exposure. Pebbles of quartzite and chert up to a diameter of about 10cm are common, as are a variety of calcite, clay-ironstone and more complex sub-spherical concretions, some of which have a thick, black, very fine grain skin (see LIVSHITS 1965). A common feature is a set of shales or siltstones, possibly silicified and in all 10m–30m thick, which tends to outcrop about two-thirds of the way up the formation as two or three hard bands.

The lower boundary is taken at the top of the last sandstone bed of the Firkanten Formation.

On Jøns Jakobjellet the formation is 345m thick. A thin (50cm) chert pebble conglomerate is found 50m up into the formation here. 3 km to the east, on Ørjankampen (west side) it is 305m thick (Fig.7), the coarsest bed now being a thin (50cm) soft, dark grey sandstone 20m from the base of the Sarkofagen Formation. 3km north-west of this exposure (on Norbergfjellet) there is only one 50cm sandstone, fine grain, in the middle of the formation.

On the east side of Berzeliusdalen, on Hesselbergaksla, the formation is 300m thick, but poorly exposed. On Kolfjellet the exposure is reasonable, but an accurate thickness is difficult to obtain as the formation covers a large plateau on top of the Firkanten cliffs. VONDERBANK (1970) recorded thin horizons of tuff here.

II.1.F. *Firkanten Formation*

During the course of our survey it was found that this formation could usefully be subdivided into two members, the lower of which is coal-bearing, the boundary between the two being marked topographically by a line of resistant crag-forming sandstones.

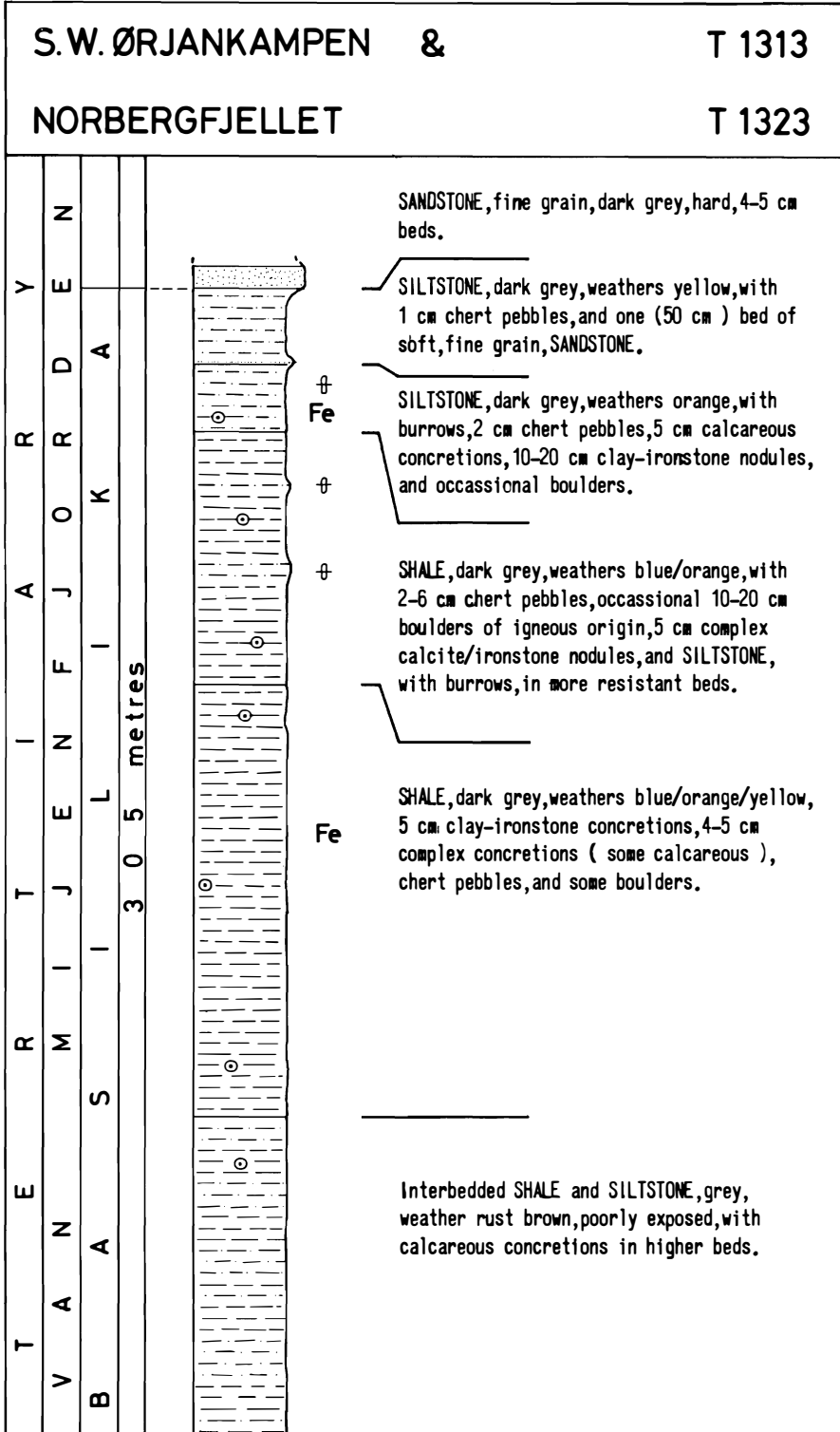


Fig. 7. Section on S.W. Ørjankampen and Norbergfjellet.

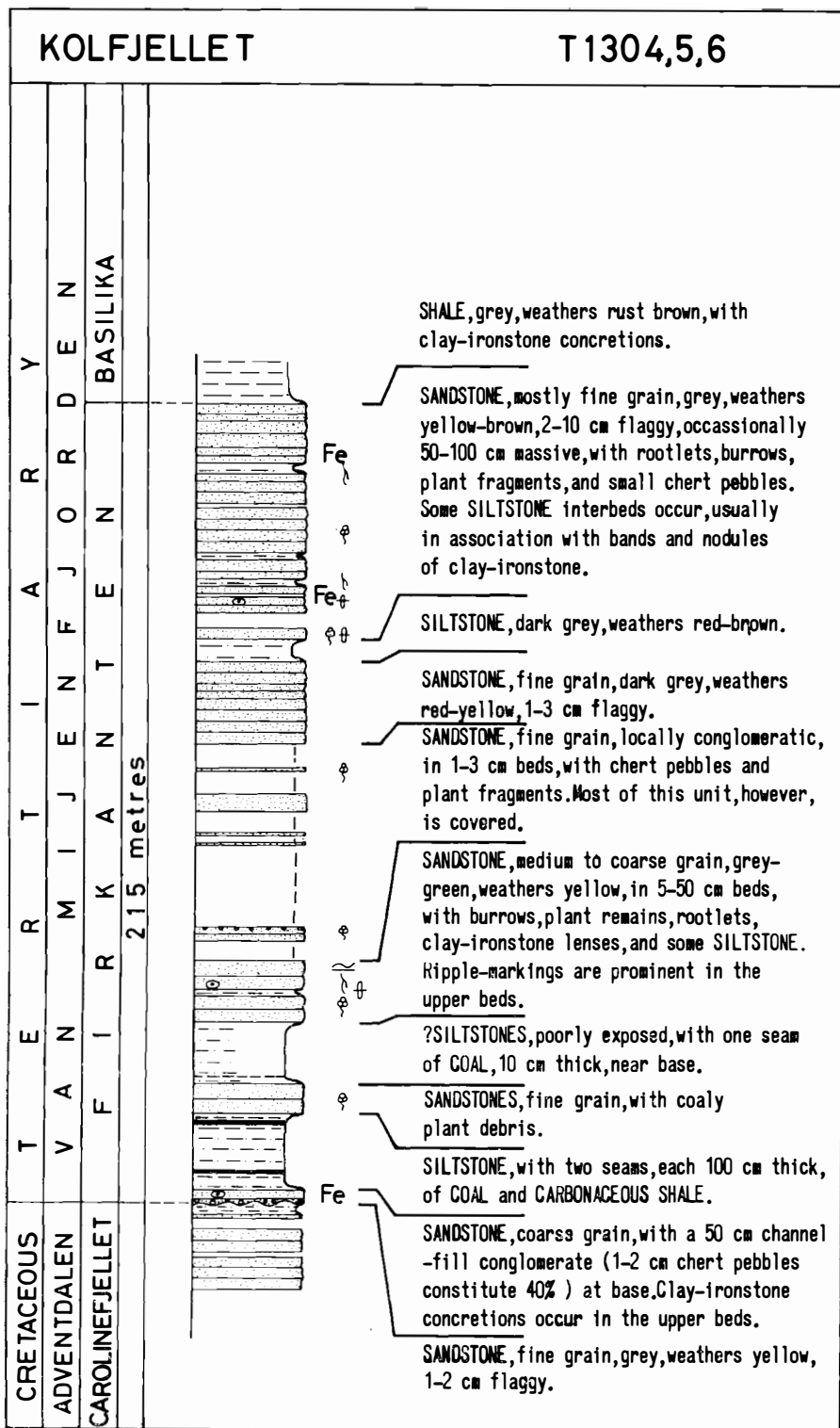


Fig. 8. Section on Kolfjellet.

It being probable, however, that such a boundary is not extensively developed, the two members are not formally named.

Upper Member

This member is dominated by 100m or so of sandstones which form the upper crags of the formation. The sandstones are mostly fine grain, grey weathering to yellow, 2cm–10cm flaggy, occasionally massive, with a variety of roots, burrows, plant fragments, chert pebbles, and nodules of pyrite (2cm–4cm diameter) and clay-ironstone. Few siltstones occur. Below these lies a series of interbedded sandstones, usually barren, locally conglomeratic, and siltstones which are nearly always covered by scree.

The base of this member is taken at the top of the ripple-bedded sandstone described below, and is marked as the top of a set of crags.

Lower Member

On Kolfjellet (Fig. 8) this member is marked at the top by a set of cliff-forming coarse to medium grained sandstones, 10m–20m thick, grey weathering yellow, with roots, burrows, plant fragments and clay-ironstone. Sometimes thin conglomerates are present, but the most consistent feature is a marked ripple-bedding.

The base of the member, the base of the Tertiary strata, is an unconformity, marked by coarse grained quartz sandstone, often with coaly clasts and clay-ironstone, overlying a channel-fill conglomerate, 50–100cm thick, with pebbles (mostly of chert) up to 10cm in diameter.

Between the two sandstone sets appear 30m–40m of siltstones with seams of coal and carbonaceous shale, with up to 10m of fine grain sandstone in the middle. On Kolfjellet two coal seams, each 1m thick, are present.

The lithological variation of the Firkanten Formation between Grønfjorden and Van Mijenfjorden is shown in Fig. 9. The upper/lower member boundary is laterally persistent, as is the general lithology of the upper member. The coal-bearing lower member is much more variable, the channel-fill conglomerate at its base, for example, disappearing completely in Aurdalen.

The thickness of the formation as a whole is 215m on Kolfjellet, 225m on Aurdalskampen and Milberghøgda, 230m on Jøns Jakobfjellet, 205m on Skjerpnuten, 220m in Jamdalen and 225m in Heertjeldalen.

II.2. THE LOWER BOUNDARY

The unconformity at the base of the Tertiary Van Mijenfjorden Group is marked locally by a conglomerate. Regionally, however, the base of the Group is seen to rest directly on the fine grained flaggy sandstones of the Langstakken Member of the Carolinefjellet Formation (Adventdalen Group) on Kolfjellet and also in Aurdalen, where at least 70m of the Langstakken Member is visible. In Heertjeldalen, to the north-west, only about 10m of the Langstakken sandstones underlie the unconformity, being themselves underlain by the soft siltstones of the Innkjegla Member. In the classic Festningen section the unconformity rests directly on the Innkjegla Member.

The unconformity therefore oversteps the Cretaceous strata, apparently to the north-west. This is confirmed by NAGY (1970) with his sections in Norden-skiöld Land to the east, and Nathorst Land to the south.

III. Structure

The strata shown on the geological map (Fig. 1) are part of a structural basin with a NW-SE axis, of which they form part of the western limb. The extreme western limb of this basin is bounded by the fold and thrust belts of the West Spitsbergen Orogen (Tertiary) with a more NNW-SSE axis.

Dips are steeply to the east and north-east, close to this boundary, but slacken rapidly eastwards, so that over most of the central and north-eastern part of Fig. 1 the Van Mijenfjorden Group strata have a NNW strike. In the south-east

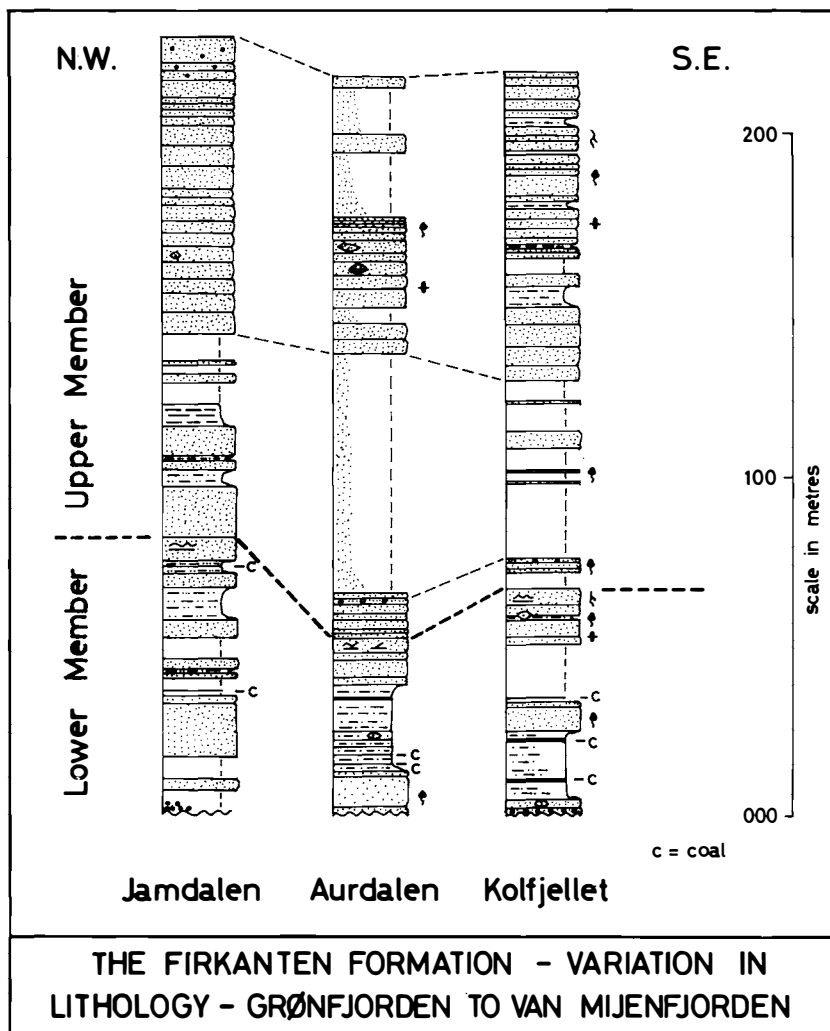


Fig. 9. Lateral lithological variation in the Firkanten Formation from Grøn fjorden to Van Mijenfjorden.

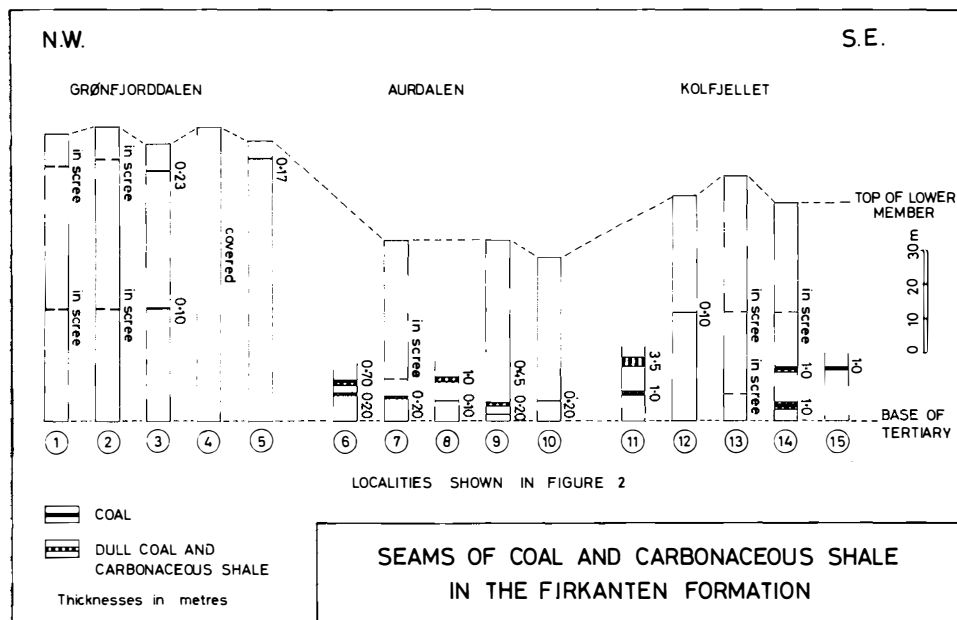


Fig. 10. Coal seams in the Firkanten Formation.

around Kolfjellet the strike swings to the NW and the dips are steep (up to 20°) lessening rapidly to 10° NE on Hesselbergaksla and to 2° (with NNW strike) on Brantnuten.

Fig. 11, a structural contour map of the base of the Firkanten Formation with respect to sea level, is compiled from isopach data on the various formations above it, showing the variations in strike and otherwise uniform trend towards the main axis of the Central Basin.

The strata of the Carolinefjellet Formation, truncated by the unconformity overstepping to the north-west, appear to have dipped in an easterly or south-easterly direction prior to erosion, but are now folded with the Tertiary strata.

No major structural axes pass through the area mapped. The Fridtjovhamna thrust, mapped by CHALLINOR, will be discussed in detail in a later paper. The syncline to the north-east is postulated from a study of aerial photographs.

A few minor faults are scattered throughout the area. In the Cretaceous strata, small low angle reverse faults and normal faults with throws generally less than 4m down to the east are found in Heerfjelldalen and Krokdalen. Evidence of gentle folding of the Cretaceous is also present in this area. No evidence exists in the lower Tertiary formations of that area of similar faulting and folding. Around the head of Berzeliusdalen, however, minor high angle normal faults with throws of 4m-10m eastwards are recorded on Snøsalen, in Furdalen, on Jøns Jakobfjellet and Wollebækfjellet. The strike of these faults varies between NW and NNE, the general trend being roughly parallel to that of the main Tertiary deformation. On Ørjankampen is a much larger feature, located within the Sarkofagen sandstones, which appears to be a series of fractures trending NNW with a curved plane in the nature of a slip to the east, rather

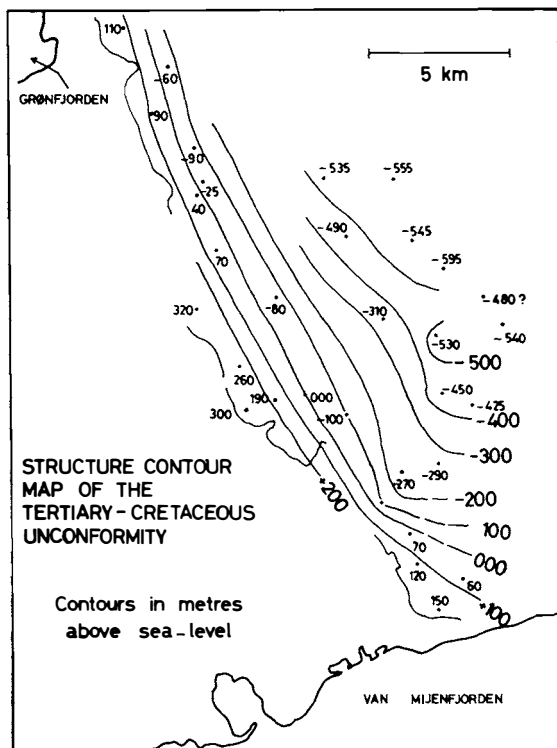


Fig. 11. *Structural contour map of the Tertiary-Cretaceous unconformity.*

than a major structure, as the Basilika shales to the north and south show no signs of displacement. Fig. 12 shows two cross-sections of the Tertiary formations in the Berzeliusdalen area.

IV. Coal

A major aim of our survey was to assess the coal potential of the Grønfjordbotn claim area. No laboratory work on the quality of the coals found has yet been carried out by ourselves, but enough information has now been collected to assess the continuity and thickness of the seams present (Fig. 10).

Due to the variability of the quality and thicknesses of the seams, and their tendency to split into two or more benches it is difficult to predict what may happen to them at depth within the area mapped. Some correlation between the seams in Aurdalen and on Kolfjellet is clear, but their relationship with the seams in the Grønfjorddalen area is not so readily apparent. The two thick seams on Kolfjellet correspond well with those of Aurdalen, the lower seam splitting into two benches in parts. The thin uppermost seam on Kolfjellet may be equivalent to the lowermost seam in the north-west. The equivalent to the uppermost seam of the north-west appears to be a dark siltstone on Kolfjellet, lying a few metres below the ripplebedded sandstones at the top of the lower member of the Firkanten Formation.

The extreme variability of the coal seams, the tendency for coal to appear between or within layers of carbonaceous shales, and the lack of good ganister sandstones seems to indicate an allochthonous process of formation, though the source of vegetation may well have been not very far away.

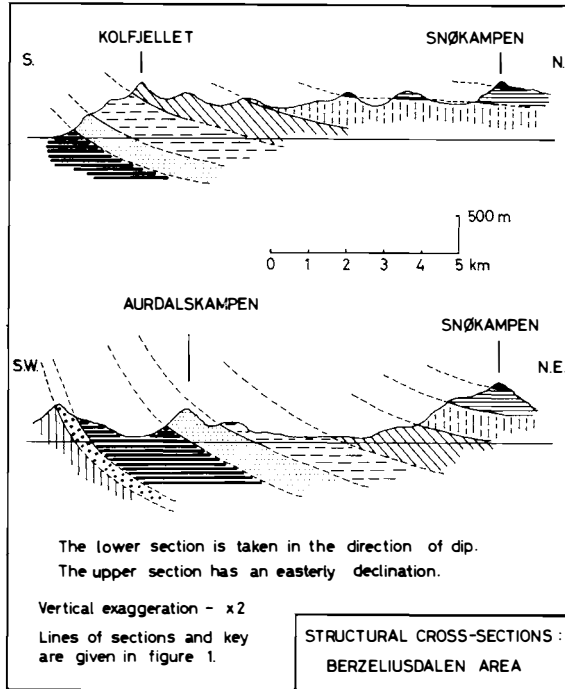


Fig. 12. *Structural cross-sections in the Berzeliusdalen area.*

V. Summary and acknowledgements

The Tertiary strata within the south-western part of Nordenskiöld Land are situated on the western limb of a structural basin and overlie the Cretaceous strata with slight angular unconformity. No major faults or folds have affected the Tertiary strata within the area studied apart from the regional dip to the east resulting from the Tertiary orogeny (West Spitsbergen Orogen of HARLAND and HORSFIELD 1974).

Major coal seams within the Tertiary strata are confined to the lowest (Firkanten) Formation, which may be conveniently divided into a lower coal-bearing member and an upper sandstone member within the area studied. Two seams are normally present, but there may be three or more. The maximum exposed thickness of any one seam is 1m, which is maintained over only a very limited area. There appear, therefore, to be no seams of viable thickness developed over a large enough area to be economically mined, at least along the line of outcrop. Due to the variability of these deposits, however, only by drilling could one ascertain the actual coal potential within the concession-area. Should good deposits be found then the situation, 200-300m below sea-level, may well demand a new approach to the problem of mining in Spitsbergen, as all those deposits presently mined are situated well above sea-level.

We should like to thank the employees of S.N.S.K. for the help and hospitality during the execution of the fieldwork, in particular ALV ORHEIM and G. CHRISTIANSEN, Mr. W. B. HARLAND who was the leader of the expedition, and Miss A. B. REYNOLDS for the organisation both before and after the summer's work.

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The Helvetiafjellet Formation (Cretaceous) of North-East Nordenskiöld Land, Spitsbergen

By D. G. SMITH and C. A. G. PICKTON

Abstract

A field party of the 1971 Cambridge Spitsbergen Expedition was engaged on a survey of the Saksedal concession area on behalf of the Store Norske Spitsbergen Kulkompani A/S. A composite map showing the outcrop pattern of the coal-bearing Helvetiafjellet Formation (Cretaceous) and the geological structure of the area is presented, along with a plot of coal occurrences. The lithological variations and coal potential of the formation are also discussed.

I. Introduction

The Store Norske Spitsbergen Kulkompani (S.N.S.K.) concession area known as Saksedal, from an earlier name for Sassendalen, lies in Nordenskiöld Land to the east of Longyearbyen. It is an area of some 290 km², bounded by Isfjorden to the north and Adventdalen to the south. The western boundary runs southward from Diabasodden roughly parallel with De Geerdalen and Helvetiadalen. To the east it follows Brentskardet, Eskerdalen and Sassendalen. The area thus enclosed consists principally of the mountainous and partially ice-covered area centred on Lusitaniafjellet and rising to 937 m at Arctowski-fjellet, but includes the eastern flank of the Helvetiafjellet massif also (Figure 1). (Lower Tertiary strata as found in Helvetiafjellet outside the boundary of this claim area, however, are also accounted in the text below.)

Geologically the area includes sediments of Permian to early Tertiary age which have been mapped and reported on in detail by FLOOD et al. (1971) and MAJOR and NAGY (1972). The structure is largely flat-lying but disturbed along a zone of faulting which runs roughly north-south and bisects the concession area (HARLAND et al. 1974). Dolerite is intruded into rocks of Triassic age in the north of the area, but does not affect the Cretaceous rocks (PARKER 1966). The area exposes a sequence of sediments of non-marine and marine origin. The occurrences of non-marine beds are of late Triassic, early Cretaceous and early

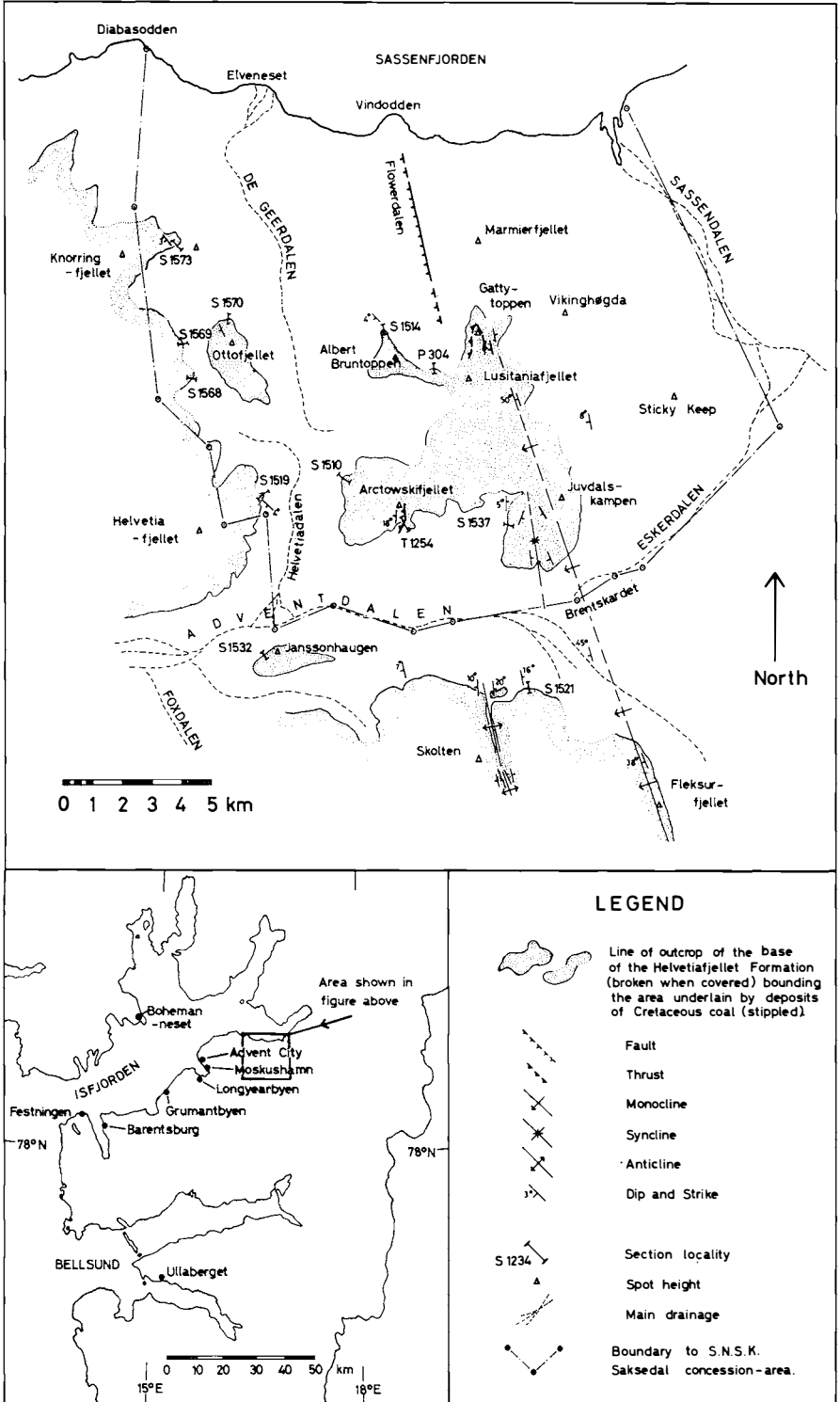


Fig. 1. a) Outline structural map of the Saksedal claim area, showing area underlain by Cretaceous coal. b) Central Spitsbergen, showing place names mentioned in text.

Table of stratigraphic succession in Saksedal area, with approximate ages and thicknesses of rock units

VAN MIJENFJORDEN GROUP (early Tertiary)
Continental sandstones and shales with coal
ADVENTDALEN GROUP (middle Jurassic to middle Cretaceous)
<i>Carolinefjellet Formation</i> (<270 m).
Marine sandstone and shale
<i>Helvetiafjellet Formation</i>
<i>Glitrefjellet Member</i> (<90 m)
Continental sandstone, etc. with coal
<i>Festningen Sandstone Member</i> (<12 m)
Massive coarse sandstone
<i>Janusfjellet Formation</i> (<450 m)
Marine shales
KAPP TOSCANA GROUP (middle Triassic to early Jurassic)
<i>De Geerdalen Formation</i> (<200 m)
Continental sandstone with thin coals
<i>Tschermakfjellet Formation</i> (<100 m)
Marine shale and siltstone
SASSEDALEN GROUP (early to middle Triassic)
Marine shales, etc.

Tertiary age and all include coal seams; they are separated by dominantly shaley, ammonite-bearing marine sequences of Jurassic and early Cretaceous age (see table below). Coal of early Tertiary age is mined at Longyearbyen and elsewhere; the late Triassic coals, being very thin and irregularly developed, have never been considered as an economic proposition. Cretaceous coal has a brief history of mining in the Adventfjorden area, hence the interest in the possibility of economic coal deposits in Saksedal.

The coal of Cretaceous age occurs in the Helvetiafjellet Formation, the type section of which lies within Saksedal. The base of the formation is marked by a massive bed of coarse or pebbly sandstone, the Festningen Sandstone Member, which outcrops as a prominent marker horizon throughout the area, overlying the softer shales of the Janusfjellet Formation. Indeed, the difference in resistance to weathering frequently causes undermining of the Festningen Sandstone, and large masses of it occur as landslips on the lower slopes of the hills (see 1:100 000 geological map C9G; MAJOR and NAGY 1972). The Festningen Sandstone is remarkably widespread, being found from near Sørkapp to Isfjorden, and appears to represent an abrupt shallowing of the sea, for it marks the change from the marine, ammonite-bearing Janusfjellet Formation to the non-marine plant-bearing Glitrefjellet Member.

In response to a request from the S.N.S.K. for a field study on the Cretaceous coal prospects in the Saksedal concession area, Mr. W. B. HARLAND (Department of Geology, University of Cambridge) arranged for a field party to undertake a season of field work in the area and to report on the coal prospects. The party formed Party C of the Cambridge Spitsbergen Expedition 1971 (HARLAND and REYNOLDS 1972) and consisted of D. G. SMITH (leader), with C. A. G.

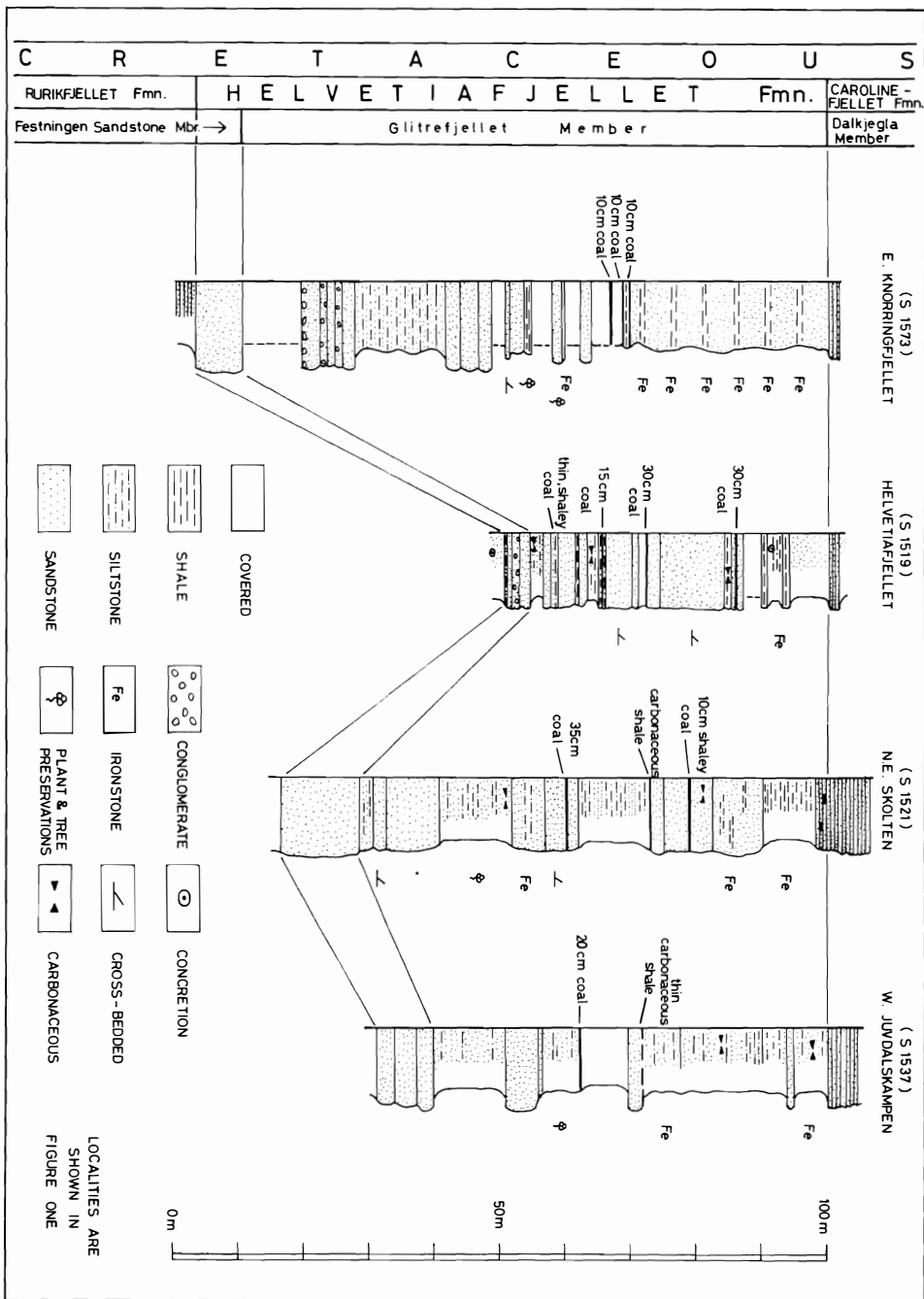


Fig. 2. Comparison of stratigraphy of the Helvetiafjellet Formation across the Saksedal claim area.

PICKTON, D. P. THEWLIS and A. R. WYATT. The party spent a total of 47 days in the field, transport between Longyearbyen and the base camp at Elveneset being provided by S.N.S.K. The authors thank the officials of S.N.S.K., in particular A. ORHEIM, for assistance before, during and after the field season. Miss A. B. REYNOLDS organised the expedition in Cambridge and the various parties of the expedition were directed by Mr. W. B. HARLAND in the field.

II. The Helvetiafjellet Formation

This formation is divided into two members, defined by PARKER (1967) who also produced an illustrated type section. The lower Festningen Sandstone Member consists of beds of cliff-forming sandstones and local conglomerates. The upper Glitrefjellet Member is a variable unit of coal-measure type, containing beds of massive sandstone very like the Festningen Sandstone, as well as shales, ironstones and thin coal seams. Plant remains, usually compressed, are common, but petrified wood is found in places. The formation was probably deposited in fresh water, perhaps deltaic, conditions; its age is mainly and perhaps completely Barremian (PARKER 1967; PHELINA 1965a).

The formation is well exposed over most of the concession area as shown in Fig. 1. The extensively developed landslips of this formation, mostly on Arctowskifjellet and the western slopes of Albert Bruntoppen, are not shown in this figure.

The exact determination of the upper and lower boundaries of the Glitrefjellet Member, and therefore an estimate of thickness for both members, is often difficult. As mentioned above, the upper Member often contains hard sandstones similar to those of the lower Member, and the upper Member grades upwards into the sandstones and shales of the overlying lowest (Dalkjegla) member of the Carolinefjellet Formation.

The original "Festningen Sandstone" of NATHORST (1913) was the resistant set of sandstone, about 3.5 m thick, which forms the promontory at Festningen at the mouth of Isfjord (Fig. 1). HAGERMAN (1925) reported its equivalent as being two sandstone sets, 15 m and 4 m thick with softer material between, in the Kjellströmdalen area. PARKER's definition (1967) of the Festningen Sandstone Member quoted a type section from Festningen which is 29.5 m thick and included NATHORST's sandstone in the lowest part. He also defined the Glitrefjellet Member (HAGERMAN's Shore Sandstone), which is 69 m thick in its type section.

The type section for the formation as a whole, however, is situated on Helvetiafjellet, and the measurements in this area by various authors are unfortunately rather diverse. MAJOR and NAGY (1972) recorded the lower member as 6.3 m thick, the upper as 90 m. PARKER (1967) recorded 4 m and 49 m respectively. Our own readings, as shown in Figure 2, are 4 m and 45 m. This discrepancy may well, however, reflect the rapid lateral variations of the formation even over a few hundred metres rather than any errors in the measuring techniques. It may also arise from the previously mentioned lack of clarity in the definition of the upper boundary of each of the two members. Our own

measurements within Saksedal recorded no coal, for example, within the lower Member, whereas there are several thin seams within the 29.5 m of the Festningen type section. Further to the south-west on Ullaberget, on the north shore of Van Keulenfjorden, the lower part of the Helvetiafjellet Formation consists of 30–40 m of resistant sandstones, but contains a 2 m band of shales and coal only 8 m from its base (C.S.E. unpublished material; PCHIELINA 1965b).

Assuming, therefore, that the coal deposits are restricted to the continental Helvetiafjellet Formation and do not occur in the under and over-lying marine deposits, one can calculate the thickness of the Formation with reasonable accuracy. The distinction of the two members, however, appears to be of value only for general descriptive purposes and the boundary between them rather subjective due to the rapid lateral lithological variations.

III. Structure

The structure of the area was not studied in detail but certain observations were made on the major faults and folds within the area, and these are summarised also in Fig. 1. A detailed map of the area has already been published by MAJOR and NAGY (1972).

The structure is relatively complex compared with the areas immediately to the west and east, as the Saksedal area lies across an important fault belt which runs north-south across Spitsbergen (Billefjorden Fault Zone of HARLAND et al. 1974). This belt is known to have been active during Palaeozoic time and probably moved twice during Mesozoic as well as later in Tertiary time. The Mesozoic movements were prior to the deposition of the Helvetiafjellet Formation, the most obvious result of the later one being the Flowerdalen Fault which disappears southwards under the cover of the Rurikfjellet Formation. The later Tertiary movements, however, have folded the coal-bearing series and control its present form.

The regional dip of the area is from the north-east, where older Permian rocks are exposed, to the south-west where Tertiary strata are approached. A monocline running NNW-SSE from Lusitaniafjellet to Fleksurfjellet is modified by an almost parallel synclinal structure running from Juvdalskampen to Lusitaniafjellet virtually along the line of the Flowerdalen Fault. Around Gattytoppen the junction of the syncline, monocline and fault is further complicated by thrust faulting which has caused repetition of the Helvetiafjellet Formation over about one square kilometre.

To the south, again close to the line of the Flowerdalen Fault, is a tight anticlinal structure on Skolten. This is shown by MAJOR and NAGY (1972) as a fault/thrust plane which downthrows (to the east) small areas of Helvetiafjellet strata on Dröntoppen, 5 km to the south. The actual structure is probably a rather complex one resulting from both folding and faulting.

IV. Coal

No coal has been mined in Saksedal, but Cretaceous seams were worked over a brief period at Advent City and Moskushamn in the early part of this century

(HOEL 1929). Within the Saksedal concession area we found no coal that could currently be considered of economic importance, and the results of our survey are summarised in Fig. 3. Thin seams, 5 to 30 cm thick, often contained bright coal, but any thicker seams consisted mainly of carbonaceous shale with streaks of bright coal. In comparison, HOEL (1929) records the following short sections from Advent City:

I	from above	0.48 m	coal	
		0.35 m		shale
		0.30 m	coal	
		0.45 m		shale
		0.07 m	coal	
		0.15 m		shale
II	from above	0.20 m	coal	
		0.50 m	coal	
		0.37 m		shale
		0.25 m	coal	
		0.20 m		shale
III	from above	0.30 m	coal	
		0.37 m	coal	
		0.40 m		shale
		0.80 m	coal	

Seams appear at all levels within the Glitrefjellet Member and no obvious correlation was found between the seams in different parts of the Saksedal concession. Although no work of our own has been carried out on the quality of these coals, S.N.S.K. has kindly provided us with 5 representative samples for publication. The details are given in the table below:

Coal analyses : Saksedal 1971

Sample	Ash %	S %	P ₂ O ₅ %	Vol. mat. %	Cal. val. Kcal/kg
S2426	36.8	0.4		31.3	3490
S2429	11.1	0.5	0.03545	25.8	6335
S2432	5.1	0.4		32.1	7385
S2435	6.5	0.5	0.02810	29.4	7177
S2455	9.7	0.6		36.0	6074

Localities

S2426: Carbonaceous shale just below uppermost 30 cm coal seam on Helvetiafjellet (Figs. 2, 3).

S2429: 35 cm coal seam on north-east Skolten (Figs. 2, 3).

S2432: Float sample from a ?30 cm seam on south Juvdalskampen (not sectioned).

S2435: 20 cm coal seam on west Juvdalskampen (Figs. 2, 3).

S2455: 20 cm coal seam on north spur of Ottofjellet (Fig. 3).

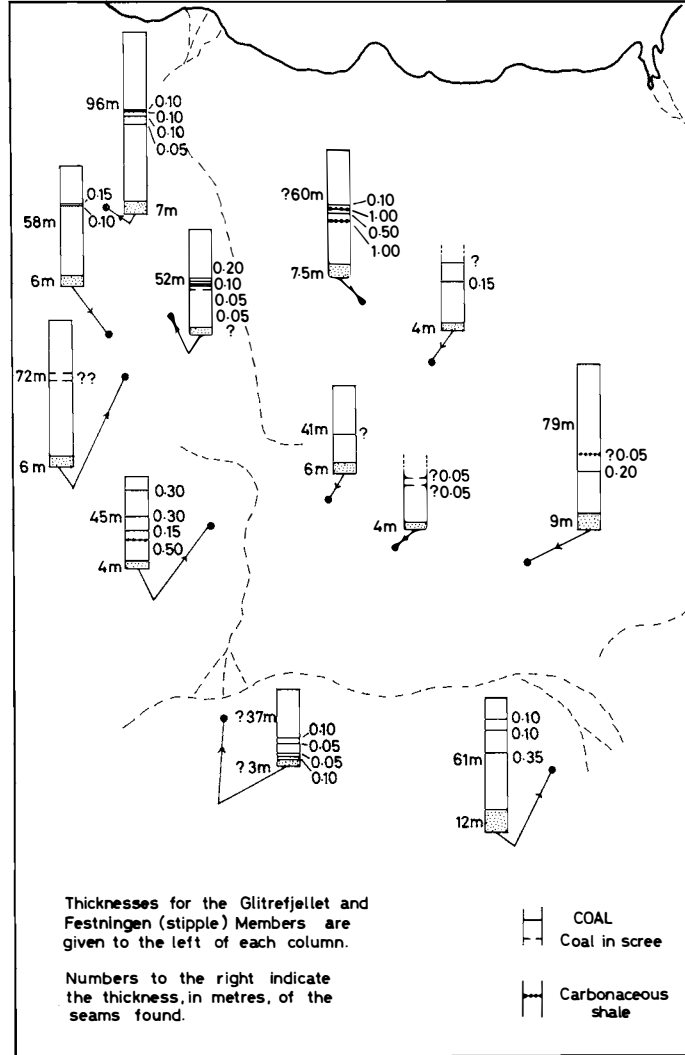


Fig. 3. Coal horizons in the Helvetiafjellet Formation in the Saksedal claim area.

Although this coal of Cretaceous age appears to occur in seams too thin to be economically extracted, and as disseminated clasts in some of the coarser sandstones, the possibility of reserves of natural gas, given suitable traps, must not be overlooked. S.N.S.K. has already recorded gas release from one borehole in the Adventdalen area, and the source appears to lie within the Helvetiafjellet Formation.

V. Summary

The Saksedal claim area contains exposures of rocks ranging from Permian to Early Cretaceous age (closely underlying Tertiary rocks). It is situated on part of the Billefjorden Fault Zone, and is structurally more complex than adja-

cent areas. A regional dip from the north-east to the south-west is complicated by the presence of a monocline, syncline, anticline and faulting (in the eastern part of the area) whose inter-relationships were not studied in detail.

Up to 5 coal seams are present within the strata of the Glitrefjellet Member of the Helvetiafjellet Formation (Cretaceous) in the concession area. Good quality coal has been found only in seams <30 cm thick, while thicker seams tend to contain much carbonaceous shale and are not extensively developed. It must be stressed, however, that our survey was brief, and that better deposits of coal or reserves of natural gas may exist (probably over limited areas) at depth within the concession area.

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The Billefjorden Group (Early Carboniferous) of Central Spitsbergen

By J. L. CUTBILL, W. G. HENDERSON and N. J. R. WRIGHT

Abstract

The Billefjorden Group in Billefjorden is a coal-bearing continental sequence occurring at the bottom of the Spitsbergen Platform sequence. The sediments are preserved locally within a rather restricted basin which formed along the line of the Billefjorden Lineament.

The complex history of investigation in the area is briefly reviewed. The two formations are described in detail from a large number of measured sections and field observations made by members of Cambridge expeditions over the years, and are combined with recent work for Store Norske Spitsbergen Kulkompani A/S which involved shallow drilling. Other data have been obtained from the unpublished manuscripts of the Scottish Spitsbergen Syndicate, which are deposited at the Scott Polar Research Institute, Cambridge.

Special attention has been paid to the geometrical configuration and the coal content of the basin, and these are illustrated with lithological sections, isopach diagrams and fence diagrams suggesting the proposed correlation of seams. Fifteen coal analyses, from the Scottish Spitsbergen Syndicate manuscripts, are given.

The Billefjorden Group, since it has been deposited within the Billefjorden Trough, also serves as a sensitive index to the major tectonic movements of the Nordfjorden and Ny Friesland Blocks, which flank the Trough. An interpretation of these tectonic movements, as implied by the stratigraphy of the Group, is suggested.

I. Introduction

I.1. OUTLINE GEOLOGY

The Billefjorden Group occurs at the bottom of a 7 km thick sedimentary sequence of flat-lying platform deposits ranging in age from Tournasian to Palaeocene. In the region around Billefjorden these Lower Carboniferous sediments overlie Devonian sandstones in the west and metamorphic Hecla Hoek rocks in the east — the tops of the mountains being Permian.

The divide between the two types of basement is the Billefjorden lineament, a north-south fault zone stretching for at least 250 km through central Spitsbergen. It has a long tectonic history involving an inferred sinistral displacement of at least 200 km in late Devonian times and normal faulting at various times from Carboniferous to Tertiary.

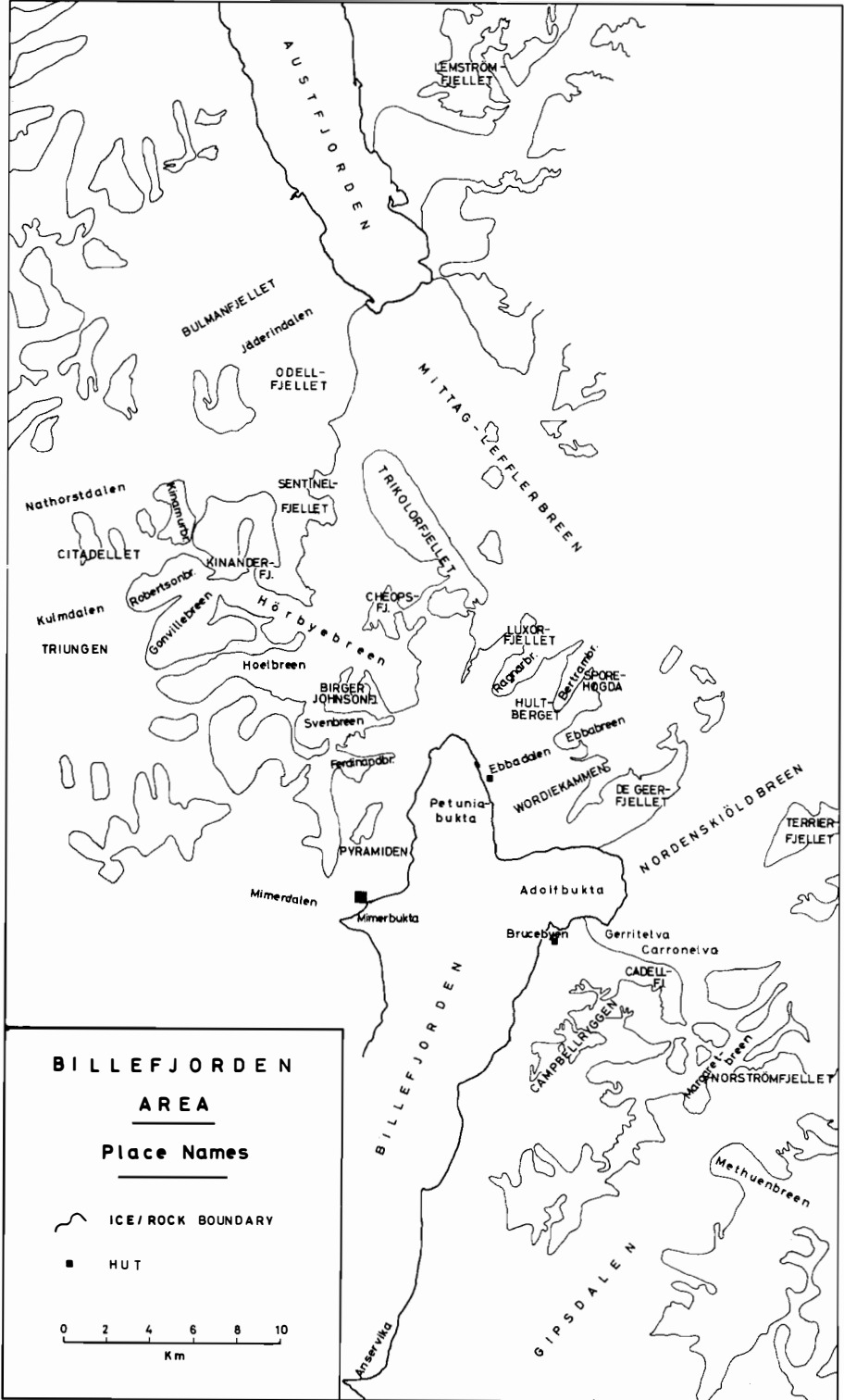


Fig. 1. The Billefjorden area, showing ice-rock boundary and place names used in the text.



Fig. 2. The Billefjorden area; outline geological map, after HARLAND et al. 1974.

Faults: Ål, Ålandvatnet; Ba, Balliolbreen; Ch, Cheopsfjellet; Co, Cowantoppen; Eb, Ebba-breen; Fe, Ferdinandbreen; Gd, Gipsdalen; Gi, Gipshuken; Ka, Karnakfjellet; Kn, Kinanderfjellet; Lm, Lemströmfjellet; Pt, Petuniabukta; Py, Pyramiden; Ra, Ragnardalen; Sv, Svenbreen; Tr, Triungen; Yg, Ygdrasilkampen.

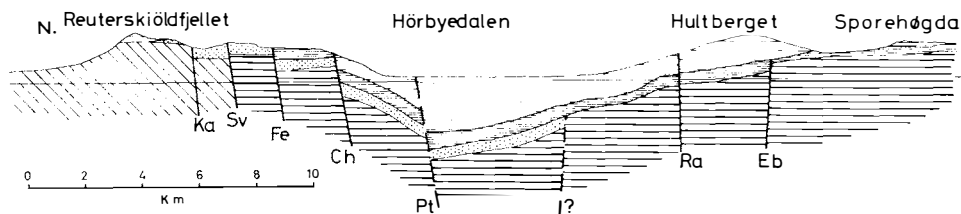


Fig. 3. Structural cross-section across Petuniabukta. Legend as for Figure 2.

Movement within the Billefjorden Fault Zone has profoundly affected the distribution of the Svenbreen and underlying Hörbyebreen Formations. Thus although the Svenbreen Formation occurs on both sides of the lineament, the Hörbyebreen Formation is restricted to the west [see HARLAND et al. 1974, Fig. 8]. Thicknesses of these two formations are variable and reflect the trend of the underlying Billefjorden lineament. Fig. 3 shows these relationships diagrammatically.

Billefjorden Group strata dip towards the centre line of the Billefjorden lineament at low angles (less than 20°) except near some faults. Faulting is associated only with the Billefjorden Lineament and is confined to definite narrow planes.

Table 1
Stratigraphic divisions in Central Spitsbergen used in this paper
(after HARLAND et al. 1974)

Sassendalen Group (outcrops to SE & SW)	Triassic
Tempelfjorden Group (outcrops on mountain tops to SE & SW)	late Permian
Gipsdalen Group (outcrops on neighbouring mountain slopes)	
Gipshuken Formation	Artinskian
Nordenskiöldbreen Formation	Asselian to Moscovian
Ebbadalen Formation (with limestone, shale and gypsum)	Bashkirian
Billefjorden Group	
Svenbreen Formation	Namurian
Hultberget Member (red sandstone and shale)	
Sporehøgda Member (sandstone and shale with coal)	
Hörbyebreen Formation	Viséan to Tournaisian or Famennian
Hoelbreen Member (shale and coal)	
Triungen Member (sandstone and conglomerate)	
Andrée Land Group (only to west of Billefjorden Fault)	
Mimer Valley Formation (red and grey sandstones, siltstones and conglomerates)	Eifelian, Givetian and late Emsian
Wood Bay Formation (red siltstones and red or grey sandstones)	Early Emsian to Siegenian
Stubendorffbreen Supergroup (only to east of Balliolbreen Fault) (= Lower Hecla Hoek)	
Finnlandveggen Group (pelites, psammites, marbles, feldspathites, amphibolites)	Precambrian

I.2. HISTORY OF INVESTIGATION

The coal-bearing "Kulm" rocks of the Billefjorden area were mentioned by NATHORST (1910) and the following fifteen years saw a great deal of activity by conflicting interests in the area. These activities have been exhaustively documented by HOEL (1929, 1966/67) from which the following resumé has been taken.

One of the first areas to be claimed was the Pyramiden and Mimerdalen district — an expedition on behalf of the Swedish A.B. Isfjorden-Bellsund claimed the area on 12 July 1910. The Swedes lost no time in investigating further the coal potential of their claimed prospect; the following year a party of miners from Sweden arrived, and opened up a 50 m working into one of the seams. Samples were taken, which later proved to be encouragingly good, with low ash content (6.7 and 8.0%).

Further investigations followed in 1912, 1914 and 1916, during which further excavations were opened and a total of 15 m of coal was reported, of which two thirds was of good quality. The thickest seam found was 2 m, and assuming a total of 7 m of mineable coal, the total reserves over the area (39 km²) was calculated to be 380 M tons.

The quality of the coals was investigated and was reported by mine engineer BIRGER JOHNSON to be grey "splint coals" and rather shaley "bright coals", low in sulphur and phosphorous and having an ash content of 6.7–15% (average 10%) and a calorific value of 6550–7130.

However, in 1926, following the clarification of claims made by the Svalbard Commission, the Pyramiden concession was taken over by the Russian Seve-roles interest in exchange for the Rindersbukta claim area at the head of Van Mijenfjorden, and a settlement of £1,000.

The Russians began serious investigation of their claim area in 1932, when J. M. AUSLÄNDER made a geological map of the area. Further investigations were published by LYUTKEVICH (1937). These workers recognised two coal-bearing horizons, about 25 m apart, occurring near the base of the sequence. The upper unit was reported to be 1–8 m of pure coal, having about 14% ash content, while the lower unit was about 6 m of coals and shales. LYUTKEVICH (1937) reported tectonic thickening of seams in the axes of folds (amplitude 600–700 m) giving local development of coals up to 10 m thick.

These results encouraged the Russians to begin exploitation of the coalfield, and in 1939 a party of 20 men began work repairing houses and building a wharf. The following year 42 people arrived, including 4 women; extensive building work was undertaken and the workings in the upper seam were extended.

The winter of 1940/41 saw the first large wintering population in Pyramiden, 80 men, and although interrupted by the evacuation of 1941, this was really the beginning of the modern history of Pyramiden.

The Bünsow Land area was first claimed in 1909 by W. S. BRUCE on behalf of the Scottish Spitsbergen Syndicate, a company which he had formed earlier that year. The basis of that claim was the extensive gypsum and anhydrites in the area, although he did note the existence of culm sandstones.

The Swedish expedition of 1910 also claimed Bünsow Land on behalf of A.B. Isfjorden Bellsund, and the 1911 expedition, based at Pyramiden, extracted 88 tons of gypsum and shipped it back to Sweden. The company extracted the mineral again the following year, from Anservika. Another claim was also made in 1911, by the Northern Exploration Company. This confused situation was resolved by the Svalbard Commission of 1920–1925, which recognised the priority of the Scottish claim. This was in two areas — Gipsdalen to Brucebyen and a coastal strip around Tempelfjorden.

The S.S.S. made extensive investigations of their concessions during the summers of 1912, 1914 and especially 1919–1922, when an extensive mapping and drilling programme was carried out (see below).

The slump in coal prices during the 1920s led to a loss of interest in the estates, until 1948 when a small expedition led by E. R. GEE re-assessed the coal prospects of the Syndicate's estate (GEE 1948). A consulting firm, Powell Duffryn, compiled a report on the potential of the area, and in 1952 the company agreed to go into voluntary liquidation, while the concession areas were sold to the Norwegian State for 550,000 Kr.

The area to the east of Petuniabukta was investigated by Swedish expeditions from the University of Uppsala under Professor STENSIÖ during the years 1912–1917 (see, for example, STENSIÖ 1918) and in 1917 a wide area from Petuniabukta to Austfjorden in the north and as far east as Mittag-Lefflerbreen was claimed. The Scottish Spitsbergen Syndicate had previously claimed the Ebbadalen–De Geerfjellet part of this area and this claim was upheld by the Svalbard Commission. The area inland from this claim, known as the Indre Billefjord concession, was granted to the Swedish group. This was sold to the Svenska Stenkolsaktiebolaget Spetsbergen in April 1925.

No further work was done on the Indre Billefjord concession by the Swedes, and in November 1933 the Swedish properties in Spitsbergen were sold to the Store Norske Spitsbergen Kulkompani (S.N.S.K.)

Cambridge expeditions to Spitsbergen began in 1932. The early Cambridge expeditions were based at the head of Billefjorden, at Brucebyen and Skottehytta at the mouth of Ebbadalen, and these were also the centres of a topographic survey of the area which extended the maps of Sindballe 1927 (HARLAND 1952, p. 93; and HARLAND and MASSON-SMITH 1962). The expeditions of 1938 and 1949 were particularly concerned with Carboniferous studies (McCABE 1939, HARLAND 1950). Geological work up to and including 1949 is summarised in McWHAIE (1953) and GEE, HARLAND and McWHAIE (1953) which also gave the results of studies by LYUTKEVICH (1937) at Pyramiden.

From 1959 to 1965 parties from six Cambridge expeditions investigated further the Carboniferous rocks in the area (see HARLAND 1962, 1963a, 1963b, 1964, 1965a, 1965b). Partly on this basis CUTBILL and CHALLINOR (1965) revised the Carboniferous and Permian stratigraphy of Svalbard. CUTBILL (1968) described the Carboniferous and Permian rocks of Ny Friesland. In their paper on the Ebbadalen Formation, HOLLIDAY and CUTBILL (1972) reported on the top of the Svenbreen Formation.

HARLAND et al. (1974) brought together data on the evolution of the Bille-

fjorden Fault Zone, which has determined the location and behaviour of the basin within which the Billefjorden Group was deposited.

In 1972, Party C of the Cambridge Spitsbergen Expedition, directed by W. B. HARLAND, re-investigated the coal-bearing strata within the Indre Billefjord concession on behalf of the Store Norske Spitsbergen Kulkompani (HARLAND, HENDERSON and SMITH 1973). This field party, led by W. HENDERSON and CATHY CROXTON, attempted shallow drilling with a hand-held coring drill to improve knowledge of the coals (WRIGHT and HENDERSON 1976). The results of this work were reported to the Store Norske Spitsbergen Kulkompani.

This paper combines data from these reports prepared for S.N.S.K. with previously unpublished results from Cambridge expeditions in the area, largely collated by J. L. CUTBILL, and with unpublished data from the records of the Scottish Spitsbergen Syndicate, which are deposited in the archives of the Scott Polar Institute, Cambridge. An attempt has been made to give a general account of what is known of the Billefjorden Group in its type area, with special reference to the coal. N. J. R. WRIGHT, a member of the 1972 expedition, has assembled these results in this paper.

I.3. DEFINITION AND AGE OF THE BILLEFJORDEN GROUP

The "Kulm" of NATHORST (1910) was generally recognised as the earliest distinctively continental, coal-bearing strata of the Carboniferous and Permian sequence (e.g. Culm of ORVIN 1940).

Based on more detailed lithostratigraphy in the region (e.g. GEE, HARLAND and McWHAE 1953), FORBES, HARLAND and HUGHES (1958) proposed the name Billefjorden Sandstones for this group of rocks resting unconformably on Old Red Sandstone or Hecla Hoek metamorphic rocks and overlain by the Lower Gypsiferous Series of marine sediments. The group was then believed to span a large part of Lower Carboniferous time, on the basis of plant macrofossils. PLAYFORD (1962/63) investigated the palynomorphs of the group and recognised two distinct assemblage zones, *Rarituberculatus* and *Aurita*. The upper *Aurita* zone he thought to be divisible into two sub-zones. The Billefjorden Sandstones were given the formal status of a group by CUTBILL and CHALLINOR (1965).

CUTBILL and CHALLINOR divided the Billefjorden Group into the Hörbyebreen and Svenbreen Formations. The assemblage zones determined by PLAYFORD are shown on section C865. All the specimens he thought might belong to an upper sub-zone of the *Aurita* Assemblage, or which contain *Retialetes radforthii* Staplin, have proved to be from the Svenbreen Formation. The major unconformity within the Billefjorden Group was not known to PLAYFORD, who did not visit the area.

The sharp break between the two assemblages occurs within the Hoelbreen Member and is not marked by any lithological change yet recognised. The coal-bearing Misery and Tunheim Series of Bjørnøya, once thought to be Late Devonian in age, have now been shown to range from Upper Famennian age through to Viséan (KAISER 1970, 1971). The similarity of facies allow these

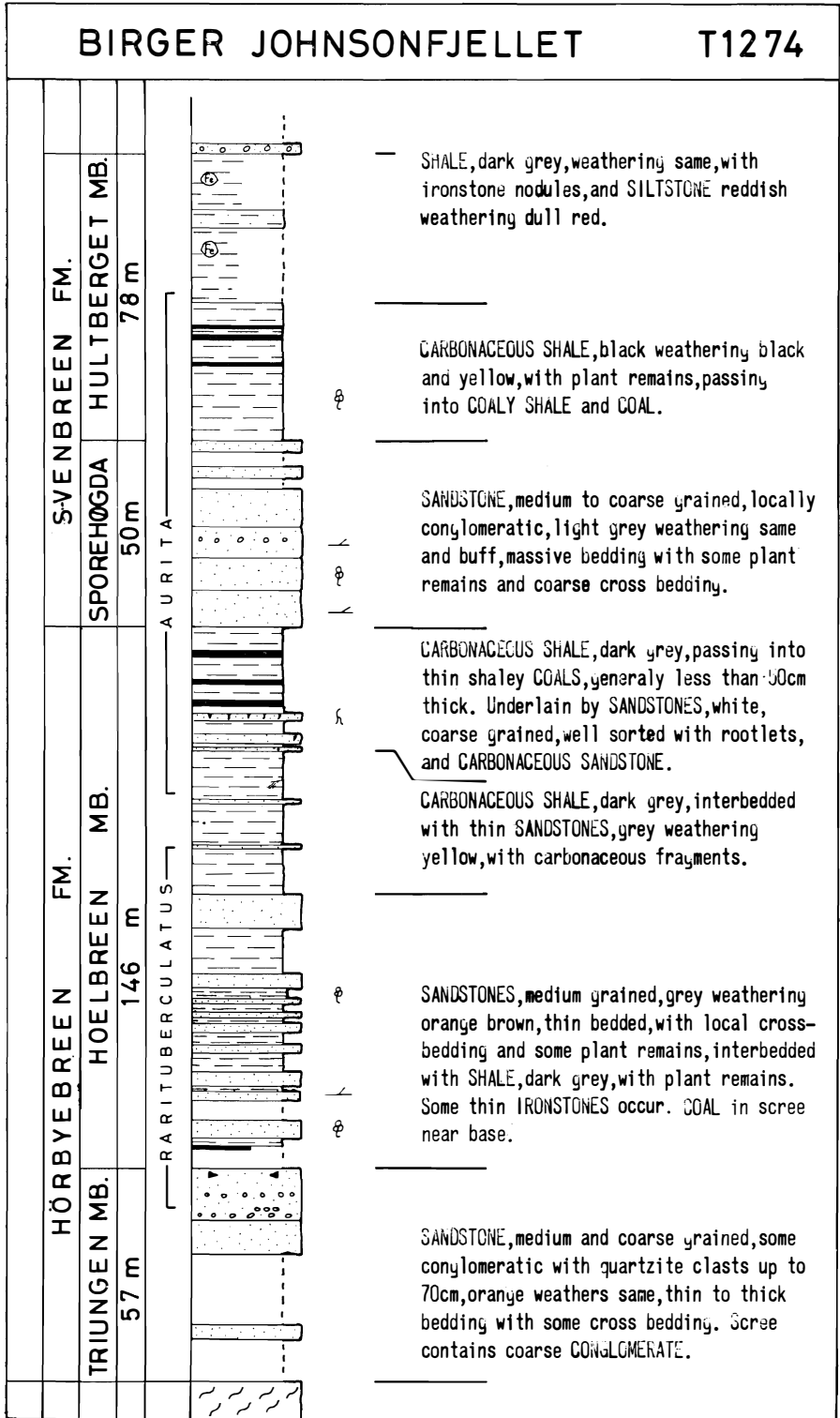


Fig. 4. Birger Johnsonfjellet section.

strata all to be included within the Billefjorden Group, which therefore extends into the Late Devonian. The majority of the Triungen Member in Billefjorden has not yielded a flora of any sort, but it is suggested that the lowest part of the Member may also have a Famennian age.

It therefore seems reasonable to regard the Hörbyebreen Formation as of possibly late Famennian, Tournaisian and early Viséan age and the Svenbreen Formation as late Viséan to Namurian.

II. The Hörbyebreen Formation

This unit was defined as "a lower shale and coal series" of the Billefjorden Group by CUTBILL and CHALLINOR (1965), but in fact it contains a considerable thickness of sandstone and conglomerates. It is discordant with the underlying pre-Carboniferous rocks and its upper boundary is a disconformity, with sandstones of the Svenbreen Formation or the basal Nordenskiöldbreen Formation concordantly overlying the shales at the top of the unit.

The Formation is known only from central Dickson Land with outliers in south Ny Friesland. It is divided into the Triungen and Hoelbreen Members.

II.1. THE TRIUNGEN MEMBER

The type section for this Member is at Gonvillebreen (C863). The dominant lithologies are thick bedded sandstones and almost uncemented heterogeneous conglomerates, with coarse cross bedding and a variety of pebbles including white, pink and purple quartzites, black and grey cherts and rare mica schists. The upper twenty metres are less conglomeratic, passing by concordant transition into the overlying carbonaceous sandstones and shales. The upper boundary is at the top of the highest thick bedded sandstone. The conglomerates are not resistant to weathering and are rarely well exposed. However, the pebbles always form a distinctive element in the scree. The conglomerates at Birger Johnsonfjellet are noticeably coarser than at Kinander or Triungen. A similar reduction of particle size to the west was noted by MOORE (Ms. 1955) between Sentinelfjellet and Citadellet. Together with the lithology, this suggests rapid sedimentation from an adjacent source in the east, possibly the north-south zone of the middle and upper Hecla Hoek rocks in central Ny Friesland.

II.2. THE HOELBREEN MEMBER

The type section is on Birger Johnsonfjellet (C865 and T1274). Carbonaceous shales and siltstones predominate, with subordinate carbonaceous sandstones, ganisters and poor coals. Badly preserved plant fragments are common. The top of the Member is at the unconformity at the base of the Svenbreen Formation. In practice this is marked by the re-appearance of massive sandstones. The lithologies indicate quiet conditions without any close source of sediments.

II.3. AREAL DISTRIBUTION

The Hörbyebreen Formation is mainly restricted to central Dickson Land. Comparison of sections from Birger Johnsonfjellet and Ebbadalen shows that

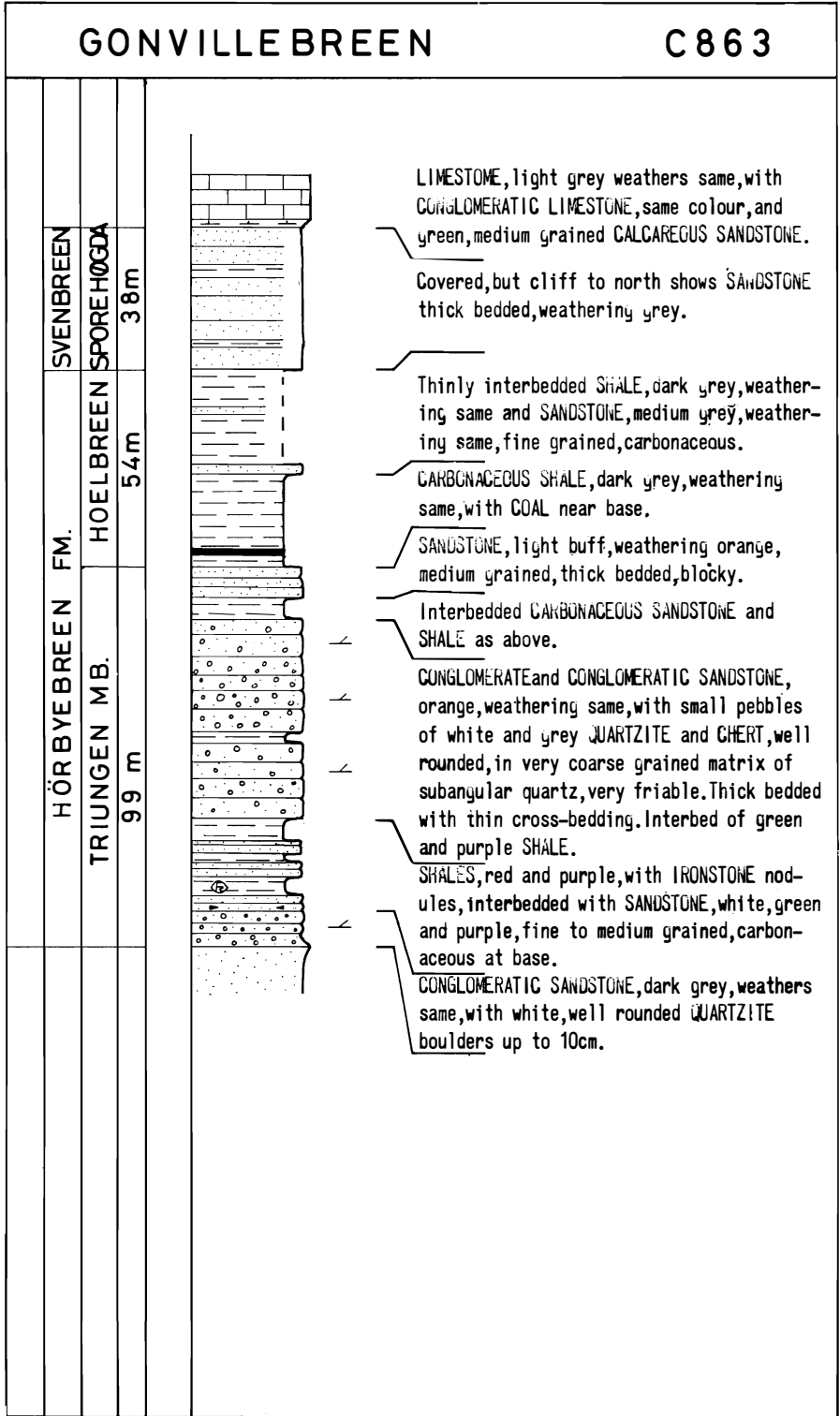


Fig. 5. *Gonvillebreen* section.

no rocks similar to the Hörbyebreen Formation occur to the east of Petunia-
bukta. In west Dickson Land the massive thick bedded sandstone at the top of
the section cuts down to rest directly on the conglomerates at the west end of
Triungen; Fig. 6 shows the thickness of the Hörbyebreen Formation preserved
below this unconformity. The eastern boundary of this trough was probably a
fault or fault zone lying between the Cheopsfjellet fault and the most westerly
outcrop of Hecla Hoek in Ebbadalen. The net downthrow was about 250 m to
the west. Further north the Formation is now bounded to the east by the
Lemströmfjellet fault with a 500 m throw. There is no direct evidence of the
age of the fault, but if the boundary of the trough had been substantially
further east, outcrops might be expected in Ragnardalen or Ebbadalen; it is

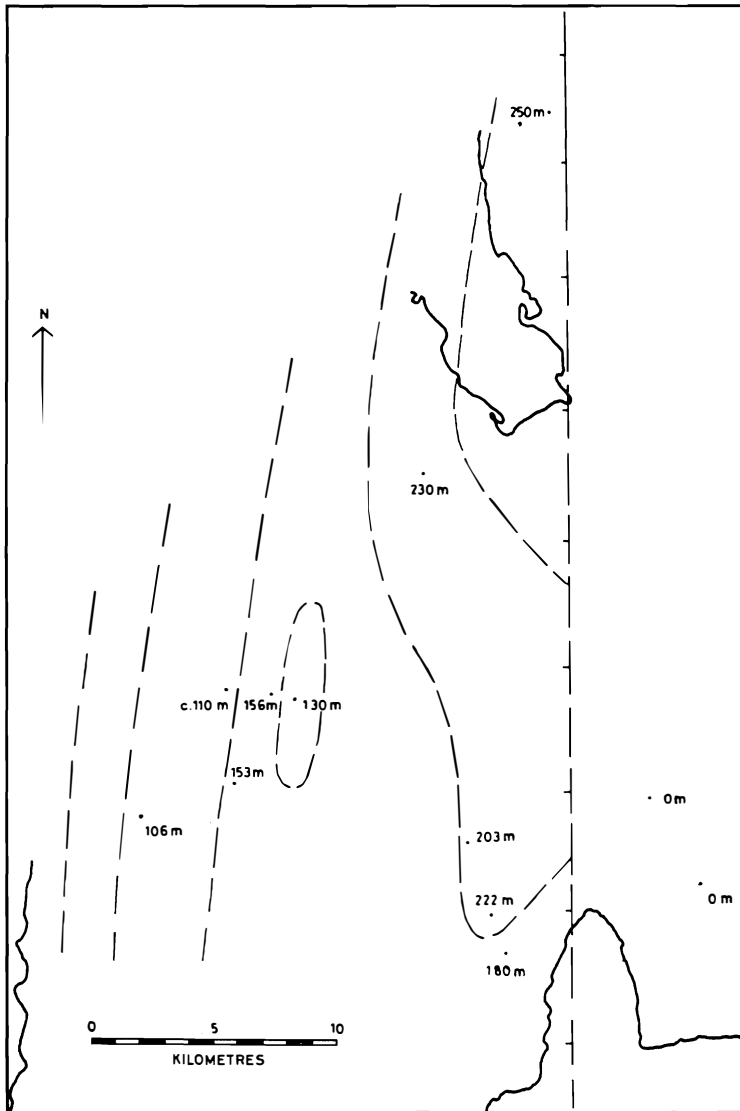


Fig. 6. Isopach map for the Hörbyebreen Formation. Isopach interval 50 m.

likely therefore that part of the throw occurred in Lower Carboniferous times. The western boundary may have been a simple unconformity, but west of Triungen the whole Lower Carboniferous is cut out by later faulting. The original western extension cannot therefore be determined, but HARLAND et al. (1974) estimated an extension 35 km west of the fault zone. Nowhere is the Svenbreen Formation seen resting directly on Devonian rocks. Along the line of the East Dickson Land Axis, prominent in later movements, the evidence has also been eroded.

On the east face of Bulmanfjellet a faulted outlier of the Triungen Member rests directly on Devonian (FRIEND, Ms. 1955). Just to the east carbonaceous sandstones and shales are exposed in an anticline on the shore of Austfjorden (MOORE, Ms. 1955; SIMPSON, Ms. 1958). On lithology these beds seem to belong to the Hoelbreen Member, but the lower part of the Svenbreen Formation could also be present. This area north of Jäderindalen is poorly exposed and has not been mapped in detail.

In south Ny Friesland, HARLAND (1941) recorded about 100 m of Culm on Lemströmfjellet, downfaulted against Hecla Hoek. M. H. P. BOTT (Ms. 1951) recorded the following section:

- | | |
|---|----------|
| 3. Massive thick bedded white sandstones, with subordinate shales | 80 m |
| 2. Shales and siltstones with subordinate thin sandstones and poor coals. | 160 m |
| 1. Sandstones and conglomerates, very poorly exposed and exact thickness unknown. | 65-140 m |

The two lower units correlate with the Hörbyebreen Formation and the upper sandstones with the Svenbreen Formation. Small outcrops of the basal conglomerates occur on Einsteinfjellet and Flatøyrdalen further north (BOTT, Ms. 1951).

II.4. THICKNESS VARIATION

The variation of thickness in the Hörbyebreen Formation is shown both in the isopach map, Fig. 6 and the fence diagram, Fig. 7.

The Formation was deposited in a small continental basin, fault-bounded in the east. The sediment source, during Triungen times at least, was the uplifted Hecla Hoek rocks east of the fault, and there is a general reduction in particle size to the west. Although the Formation as a whole shows a general thinning towards the west (Fig. 6) the Triungen Member is much thicker on Triungen (96 m) than in the east (c. 60 m). It will be seen from the fence diagram that this variation is not particularly uniform, and may therefore be due simply to topographic irregularities.

It seems, however, that during the quieter conditions of the Hoelbreen Member, subsidence was greatest adjacent to the eastern, faulted margin of the basin.

II.5. COAL

Coal seams occur at several horizons in the Hoelbreen Member, but are absent from the Triungen Member. They have been marked on the fence diagram with some tentative extrapolation.

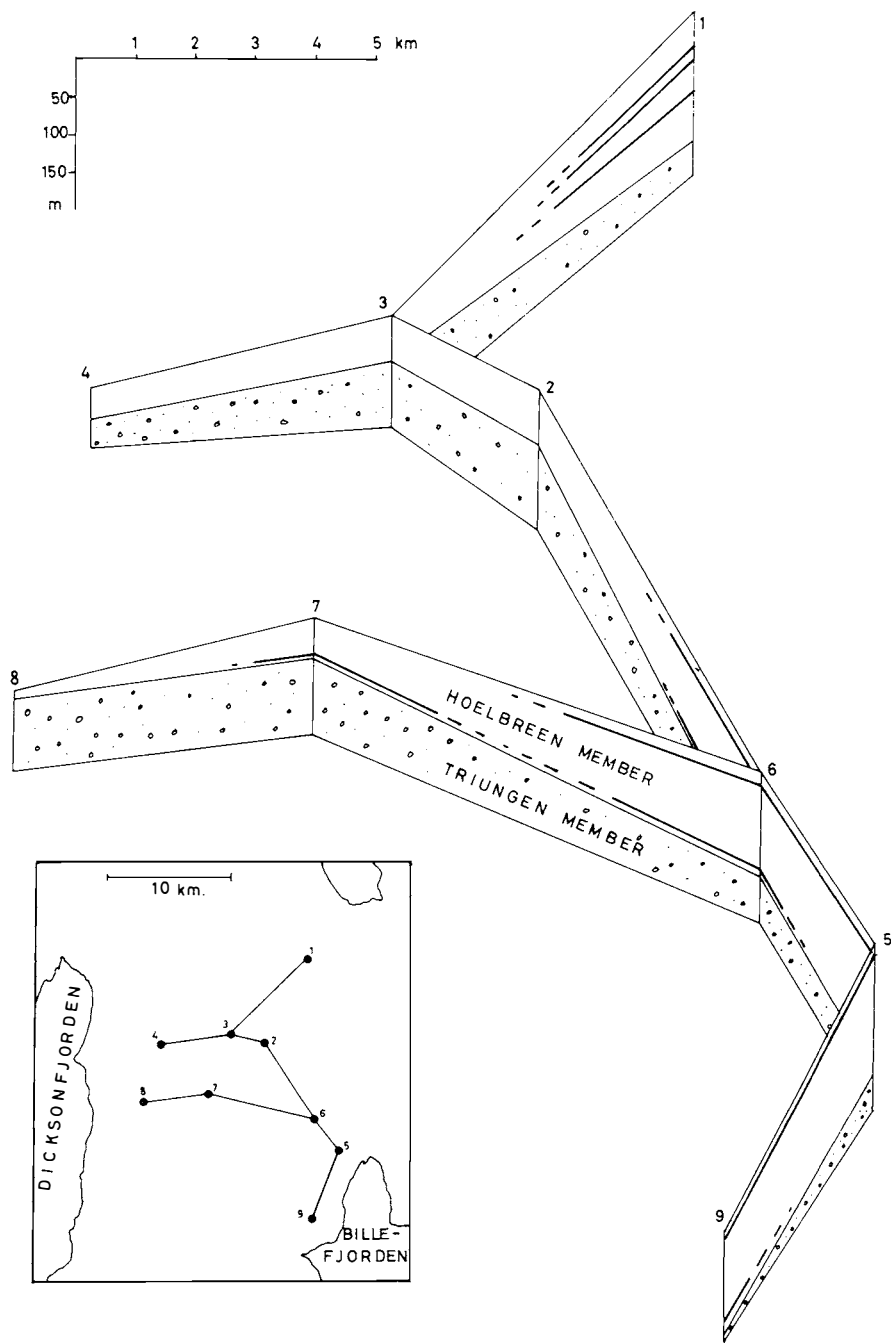


Fig. 7. Fence diagram for the Svenbreen Formation, showing proposed correlation of coal horizons. Coals shown in black.

Measured sections : 1 Odellfjellet (D651); 2 Kinanderfjellet (C865); 3 Kinamurbreen (C864); 4 Citadellet (G924); 5 Ferdinandbreen (C857); 6 Birger Johnsonfjellet (C865 and T1274); 7 Gonvillebreen (C863); 8 Triungen (G935); 9 Pyramiden (after LIVSHITS 1966).

On Pyramiden, the early workers recognised only two coal seams, which were stated to be near the base (LYUTKEVICH 1937, work of AUSLÄNDER in HOEL 1966). More recently, LIVSHITS (1966) recognised four coal seams, the middle two being of economic significance. Two of these he placed in the Hörbybreen Formation, the higher occurring at the top of the Formation. Livshits quotes FOKINA and SHMAYONOK's opinion that this is Pyramiden's most persistent coal seam and varies from 2.5 m to 2.9 m thick. Local tectonic thickening on the north slope of the mountain has developed pockets of coal up to 10 m thick (LYUTKEVICH 1937), which may correspond to this seam.

The lower horizon occurs near the base of the Formation, above a 5 m conglomerate sequence which may represent a thin Triungen Member. The seam is thin and is not of any economic importance.

The section on South Ferdinandbreen contains two thin coals at the base of the Hoelbreen Member, occurring in carbonaceous shales. On the north side of the glacier these seams are not exposed, but a poorly exposed seam occurs at the very top of the Member. This probably correlates with the upper Hoelbreen seam in Pyramiden.

Further north, on Birger Johnsonfjellet, the Hoelbreen Member contains several thin coal seams. Thin coals occur at the base and about 60 m up the succession while within the top 10 m three seams occur, two of 40 cm and one of 75 cm.

On Odellfjellet, CUTBILL reported a sequence of thin interbeds of sandstone, carbonaceous shales and coals. About 75 m above the base, this sequence becomes very coaly, with shaly coals, carbonaceous sandstones, siltstones and shales interbedded with white rootlet-bearing ganisters.

On Kinanderfjellet and at Kinamurbreen, the Member is not sufficiently exposed to estimate the coal content. The section at Gonvillebreen contains a coal at the base, and the overlying shales and thin sandstones are carbonaceous. On Triungen and Citadellet, the thin Hoelbreen Member contains no coal seams and the sandstones and shales are markedly less carbonaceous.

II.6. ENVIRONMENT OF DEPOSITION OF HÖRBYEBREEN FORMATION

It has been shown that the geometric form was a small, elongate, partly fault bounded basin. There is a complete absence of marine fossils, but plant remains are common, although the coals are often very thin, and of limited lateral extent. The basin was therefore continental.

Except on Odellfjellet, there is a general lack of seat earths and ganisters, the coals frequently occur within carbonaceous shale beds. Also, vertical "in place" plant fossils do not occur.

In the eastern part of the basin, where coals occur, the whole sequence is 'coaly', the sandstones contain many discrete coal fragments and plant remains, while the shales and siltstones are carbonaceous, often with coaly partings.

There is a general reduction in coal and carbonaceous content of the Hoelbreen Member towards the west.

Sandstone horizons in the Hoelbreen Member are fairly thin, laterally impersistent, and die out to the west. It is suggested that this evidence indicates

that the coals are generally allochthonous in character, and accumulated along with 'normal' shales and siltstones during the quiescent conditions that followed the deposition of the Triungen Member conglomeratic sandstones. Rivers draining a vegetated landmass to the east brought in plant debris, which would have accumulated into thin and laterally impersistent coaly layers. This plant debris would be concentrated fairly near the source and would not occur near the centre of the lake (Triungen is 18 km from the assumed fault margin). Sandstone horizons, representing shifting deltas, would also be impersistent and die out to the west.

The occurrence of coal with ganisters and rootlet beds on Odellfjellet may represent a different mode of formation, autochthonous coals resulting perhaps from the local development of coal swamp conditions on the margin of the lake.

It is unfortunate that only the eastern margin of this basin is exposed. As mentioned above (II.3) it is suggested that the western margin of the basin was a simple unconformity, and the general thinning to the west suggests a margin at least 15 km west of Triungen.

III. The Svenbreen Formation

The Svenbreen Formation type section is on Birger Johnsonfjellet (C865 and T1274). The unit outcrops over a much wider area than the Hörbyebreen Formation and occurs in Dickson Land, east of Petuniabukta and in Bünsow Land, with outliers in south and east Ny Friesland.

The Formation is defined by CUTBILL and CHALLINOR (1965) as the "upper coarse sandstone series" of the Billefjorden Group. Its base is an unconformity — in the west it concordantly overlies the upper shales of the Hörbyebreen Formation and in the east, where the lower formation is absent, it rests directly on the metamorphic Hecla Hoek basement. The upper boundary of the unit is the unconformity at the base of the calcareous and gypsiferous marine sediments of the Gipsdalen Group.

The Formation is divided into the Sporehøgda and Hultberget Members.

III.1. THE SPOREHØGDA MEMBER

The beds are mainly massive, white, thick-bedded coarse sandstones. Except in the type section, several thin coals and carbonaceous layers occur. However, these have little lateral continuity. The whole unit shows signs of rapid deposition, with coarse cross-bedding, washouts and rapid lateral change in thickness of individual beds.

Certain white sandstones low in the Sporehøgda Member, especially on Sporehøgda and on the south side of Ebbadalen, contain sizeable carbonaceous fragments and moulds of *Lepidodendron* stems.

Within the area coals are most abundant in the Sporehøgda Member in Ebbadalen and are nearly always associated with black shales. Thus coal is found in sequences of black shale; it underlies and overlies black shale and often coal grades through highly carbonaceous black shale to black shale with some plant remains. In the sections investigated in Ebbadalen, coal lies above

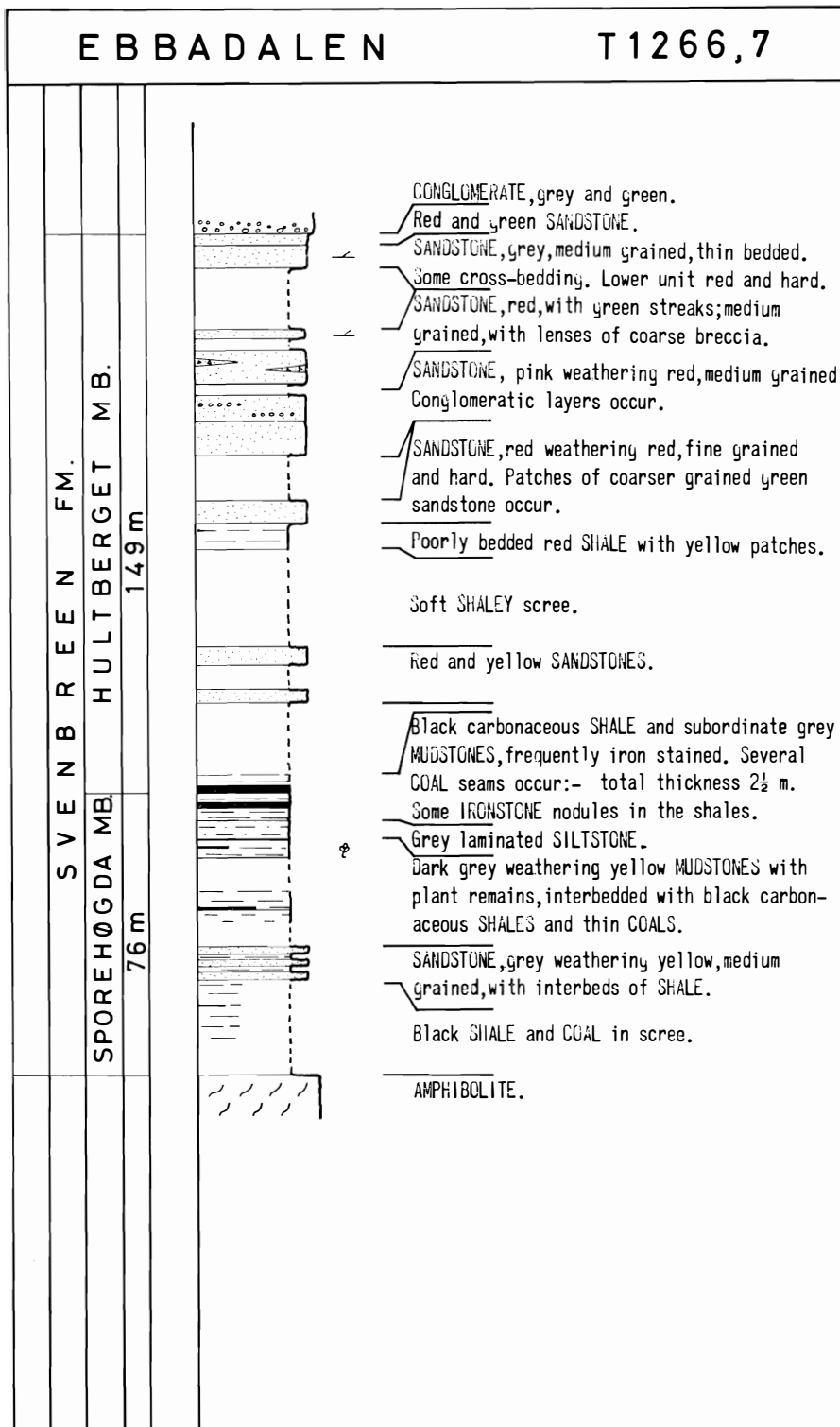


Fig. 8. Ebbadalen section.

mudstone or below siltstone but only on the north side of Hultberget was it seen lying in contact with sandstone.

The black shales are often highly carbonaceous and contain ironstone concretions. There is no evidence for rapid change in depositional environment before or after deposition of the coals. Only rarely do coals lie on a rootlet horizon; apparently most of the vegetable matter forming the coals was brought in from elsewhere.

A thin basal conglomerate of locally derived pebbles is present where the sandstones rest directly on the Hecla Hoek, but are absent elsewhere. Within the Member, medium and coarse conglomerates are almost absent and the sediment source may have been at some distance. The Member is conformably overlain by coals and shales of the Hultberget Member.

III.2. THE HULTBERGET MEMBER

The coal seam at the base is followed by grey shales, passing gradually upwards into red shales, mudstones, siltstones and sandstones, contrasting strongly with the preceding rocks. There are some thin (less than 20 cm) ironstone bands which appear to be recrystallized limonitic muds. Sometimes, however, nodular ironstone concretions within a mudstone are sufficiently abundant to let the name ironstone be used. Ironstone nodules occur in beds of black shale and form a frequent feature in the soft scree.

Exposures are usually poor, the best being on the shore at Anservika. The top of the formation is defined at the unconformity below the marine beds of the Gipsdalen Group. [In the field, discordancy can only be demonstrated close to the Ebbabreen Fault (see below). Elsewhere the two units are concordant]. The disconformity is marked by an abrupt change from red sandstones and siltstones to the grey gypsiferous sandstones of the Ebbadalen Formation. In most of Dickson Land, both the Hultberget Member and the lower units of the Gipsdalen Group are absent and the Spørehøgda Member is overlain by limestones of the Nordenskiöldbreen Formation. In exposures northwest of Elsabreen, conglomerate layers appear in the upper part of the Hultberget Member, suggesting that uplift along the East Dickson Land Axis started about this time.

III.3. AREAL DISTRIBUTION

The Svenbreen Formation outcrops in Dickson Land east of Petuniabukta, and in Bünsow Land. In Central Dickson Land it has been largely removed by pre-Bashkirian erosion, but is partly preserved on Triungen, and occurs to the east of the East Dickson Land Axis, on Pyramiden, Birger Johnsonfjellet, Trikolorfjellet and Odellfjellet. The Formation outcrops extensively in the area east of Petuniabukta and it is in this area that the Formation has been studied in the greatest detail.

In Bünsow Land, the Formation outcrops on the shore north of Anservika. It also occurs east of Brucebyen and a typical Hultberget Formation section is exposed in the stream at Carronelva. At the head of Gipsdalen, below the west end of Norströmfjellet, about 100 m of Svenbreen Formation are present but

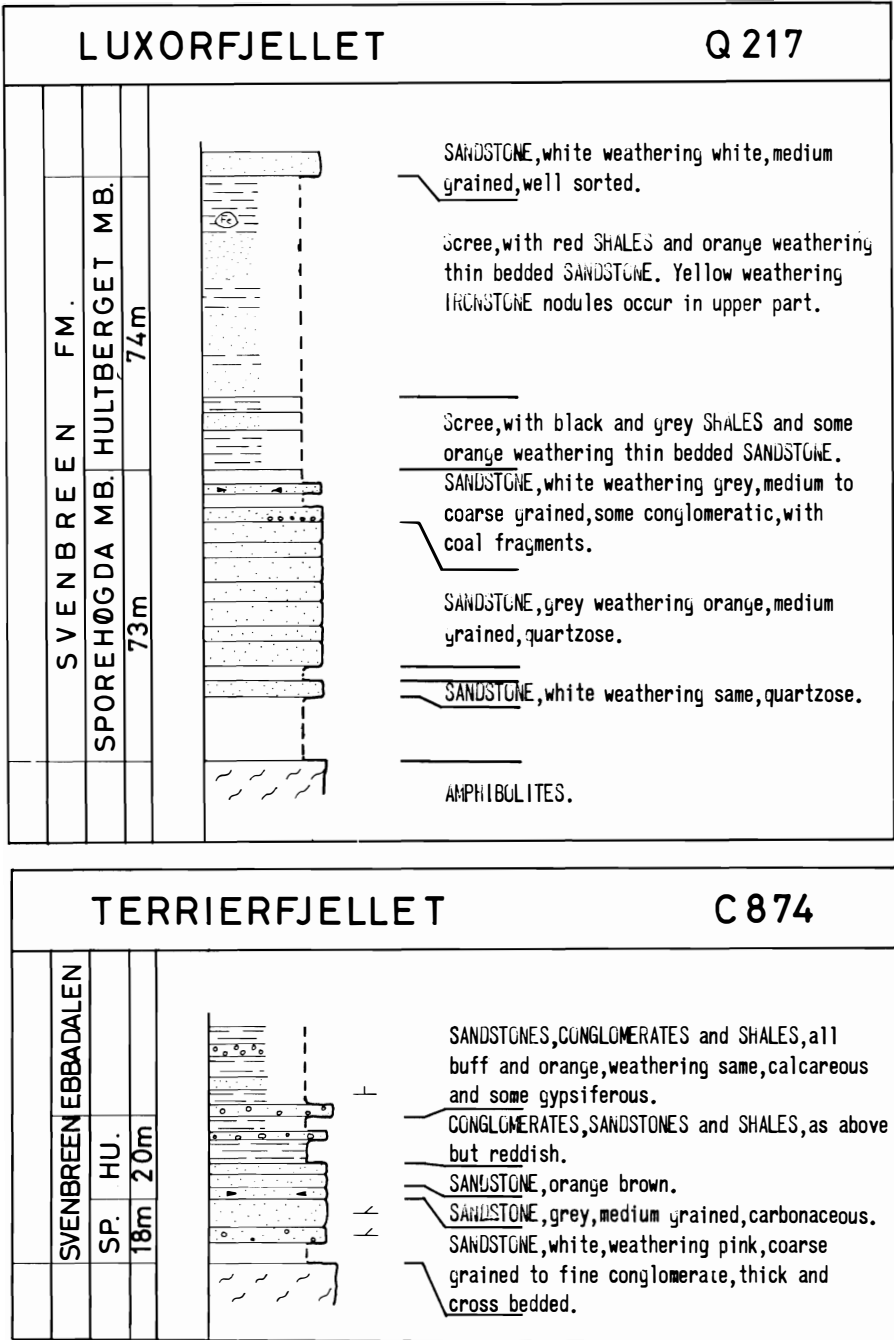


Fig. 9. Luxorfjellet and Terrierfjellet sections.

occur directly on top of Sporehøgda rocks; the figures are therefore minima.

It can be seen that subsidence was greatest around Wordiekammen, and the whole basin follows the general Billefjorden lineament. The picture has been complicated by uplift along the East Dickson Land Axis. It was suggested from lithological evidence that this uplift began in Hultberget times (III.2) and the isopach evidence implies that it was no earlier than this. Had the positive feature of the axis been active during Sporehøgda times, one would expect sediments thinning to the east within the Central Dickson Land Basin. The Sporehøgda Member in fact thickens eastwards and fits in with the general outline of the basin.

Uplift along the East Dickson Land Axis has removed the Member along an 8 km wide strip west of the Karnakfjellet and Svenbreen Faults. The Member comes in again, fully preserved, on Birger Johnsonfjellet and Pyramiden, and this implies that the uplift was fault-bounded in the east. On the western side of the axis, however, a more widespread doming must have occurred, as the junction between fully preserved and eroded Sporehøgda rocks is not across a fault.

Fig. 11, the isopach map for the Hultberget Member, is considerably more complicated, as the preserved thicknesses are strongly affected by the pre-Gipsdalen Group erosion.

The centre of subsidence corresponds with that for the Sporehøgda Member and this indeed would be expected. Although uplift along the East Dickson Land Axis has removed nearly all of the Hultberget Member from the Central Dickson Land Basin, one outlier on Triungen shows that the original limits of the basin were essentially the same as before. If uplift did occur along the East Dickson Land Axis in Hultberget times, this outlier would be the remnant of another separated basin.

The general red colour of the Hultberget rocks may indicate an Old Red Sandstone source. This would result from a general uplift of the Nordfjorden Block starting in early Hultberget times.

III.5. THE PRE-UPPER CARBONIFEROUS UNCONFORMITY

HOLLIDAY and CUTBILL (1972) stated that the top of the Hultberget Member is an unconformity. The overlying Gipsdalen Group rocks are fully concordant and the existence of an erosion interval can only be demonstrated in Ebbadalen, across the Ebbabreen Fault. This fault had previously been interpreted as an expression of pre-Carboniferous relief by GEE et al. (1953), McWHAE (1953) and GOBBETT (1964).

Fig. 13 is a compilation of sections from Sporehøgda and Ebbadalen, projected onto a line running perpendicular to the fault. It shows the general thickening towards the west of the Sporehøgda Member in this area, displaced about 100 m by the western downthrow on the fault.

The Hultberget Member is much thicker due to protection on the downthrow side and continues to thicken rapidly down the valley. To the east, the Hultberget Member has been considerably eroded, and now appears to thin towards the fault.

Since the fault is covered by unfaulted Ebbadalen Formation, movement along it must represent a late Namurian, earliest Bashkirian interval. Elsewhere, the base of the Gipsdalen Group has to be recognised on lithological grounds.

Thus, the Ebbabreen Fault movements represent local uplift to the east, accompanied by the general cessation of subsidence in the Billefjorden Trough. The extent of the uplift is illustrated in Fig. 11, and can be seen to be fairly restricted. This represents a brief pause in sedimentation prior to the next major subsidence, and the Upper Carboniferous marine transgression.

Data from the boreholes drilled by the Scottish Spitsbergen Syndicate in the Brucebyen area suggest that the Hultberget Member is locally absent, or very thin, in an area where more than 100 m might be expected. This may represent local uplift along a fault of the same generation as the Ebbabreen Fault, which has since been buried beneath Gipsdalen Group rocks. As there is no surface evidence for such a fault, no alteration has been made to Fig. 11, and a major discrepancy remains.

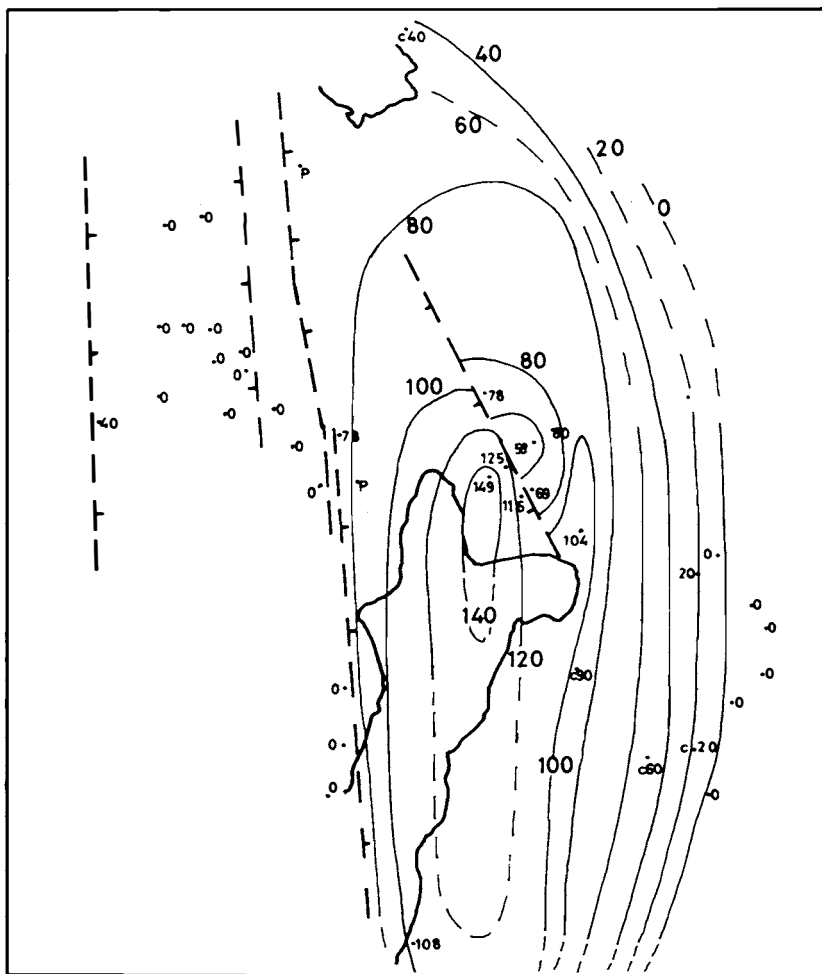


Fig. 11. Isopach map for the Suenbreen Formation, Hultberget Member. Isopach interval 20 m.

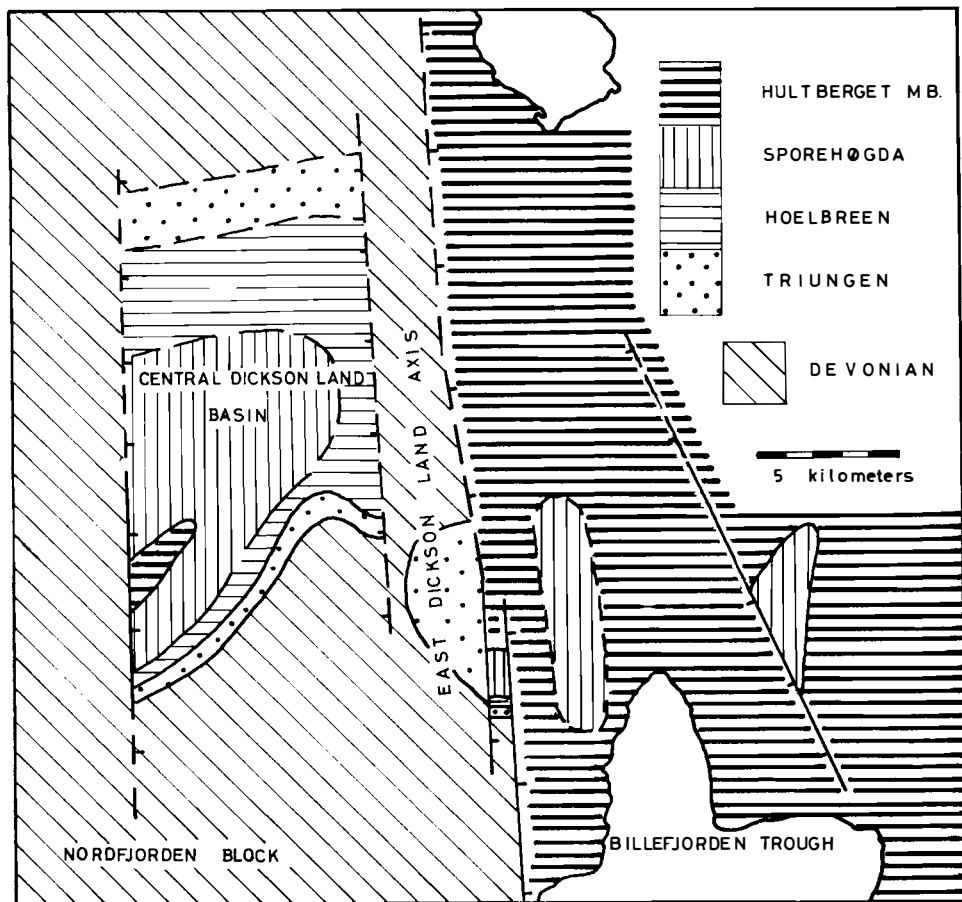


Fig. 12. Pre-Bashkirian palaeogeological map.

It is unlikely that any appreciable thickness of Lower Carboniferous sediments was removed over a wide area during this interval. It is possible that thin fluvial deposits covering the supposed flat landscape connecting the Billefjorden basin with those to the east were eroded during this period, but probably the outline of the basin shown in Fig. 10 is substantially correct.

III.6. COAL

Coal seams occur in both Members of the Svenbreen Formation, but are largely confined to the Sporehøgda Member. The seams are generally thin, and grade horizontally and vertically into carbonaceous shales; only rarely do sandstone rootlet beds with autochthonous plant remains occur.

Although they are laterally inpersistent, the coal seams tend to be grouped into recognisable stratigraphic horizons, in which the sequence contains a high proportion of black shale. Three such units were recognised in Ebbadalen in 1972 — one near the base, one within and one at the top of the Sporehøgda Member (Units 1, 2 and 3, respectively).

Ten of the analyses of coals made in the 1920s by the Scottish Spitsbergen Syndicate are given in Table 2, and a further five by Powell Duffryn Ltd., dating from the 1940s, are given in Table 3 for comparison.

III.6.1. *Dickson Land*

On Birger Johnsonfjellet, the Sporehøgda Member contains no coals and few coaly fragments, The bottom 35 m of the Hultberget Member, however, consist largely of black shales in which occur at least four coal seams, the biggest being 30 cm thick.

In the Pyramiden area, LIVSHITS (1966) has recognised two coal horizons which he correlated with the Svenbreen Formation. The lower of these horizons contains two workable seams, said to be 1.5–2.0 m and 1.5 m thick. These seem to occur near the base of the Formation and may correspond to the Unit 1 in Ebbadalen (see below). The coal-bearing nature of the Sporehøgda Member on Pyramiden contrasts strongly with the section on Birger Johnsonfjellet, only 9 km to the north.

The higher seam is marked by LIVSHITS (1966, Fig. 3) as occurring near the top of the preserved Lower Carboniferous. This seam, which is thin and not exploited commercially, may correspond either to the other Sporehøgda coal units in Ebbadalen or to the coaly sequence at the base of the Hultberget Member on Birger Johnsonfjellet.

No coal seams are found in the Svenbreen Formation of the Central Dickson Land Basin. Coaly shales occur at the base of the Hultberget Member on Triungen and coaly sandstones and carbonaceous shales occur in the Sporehøgda Member at Kinamurbreen and Robertsonbreen.

III.6.2. *Ragnardalen–Ebbadalen–De Geerfjellet*

On Luxorfjellet, there are no coals exposed in the Sporehøgda Member. Coaly fragments occur in the sandstones towards the top of the Member, and these pass into black carbonaceous shales, taken to mark the base of the Hultberget Member, in which no coals occur.

On the north side of Hultberget, a 28 m section of basal Sporehøgda Member contains two 10 cm poor quality coal seams, 4 m and 15 m above the base. These are associated with sandstones, and the upper one has a well-developed rootlet bed. These coals may be correlated with the Unit 1 from Ebbadalen, although developed in a more arenaceous facies.

This basal coal-bearing unit was investigated in Ebbadalen by the 1920 Scottish Spitsbergen Syndicate expedition, who excavated a small exploratory mine shaft. This was located 3 miles (4.8 km) from the sea on the south side of the valley at an altitude of 880ft (268 m). The remains of this working can still be seen. Three sections were recorded in the mine shaft (CADELL 1920). These have been replotted in Fig. 14, and show clearly the lateral variation of the coal/carbonaceous shale sequences.

This coal unit is underlain by about 1.8 m of brown sandstone, which rests unconformably on the Hecla Hoek basement. The excavation exposed about 2.5 m of coals and shale and thus it probably represents the lower part of Unit 1. Three analyses are available for coals taken from the innermost part of the mine. These are presented in Table 2, analyses 1, 2 and 3.

The sections on Sporehøgda contain several coals within the Sporehøgda Member. At the eastern end of the mountain (C813), coals occur in the scree at

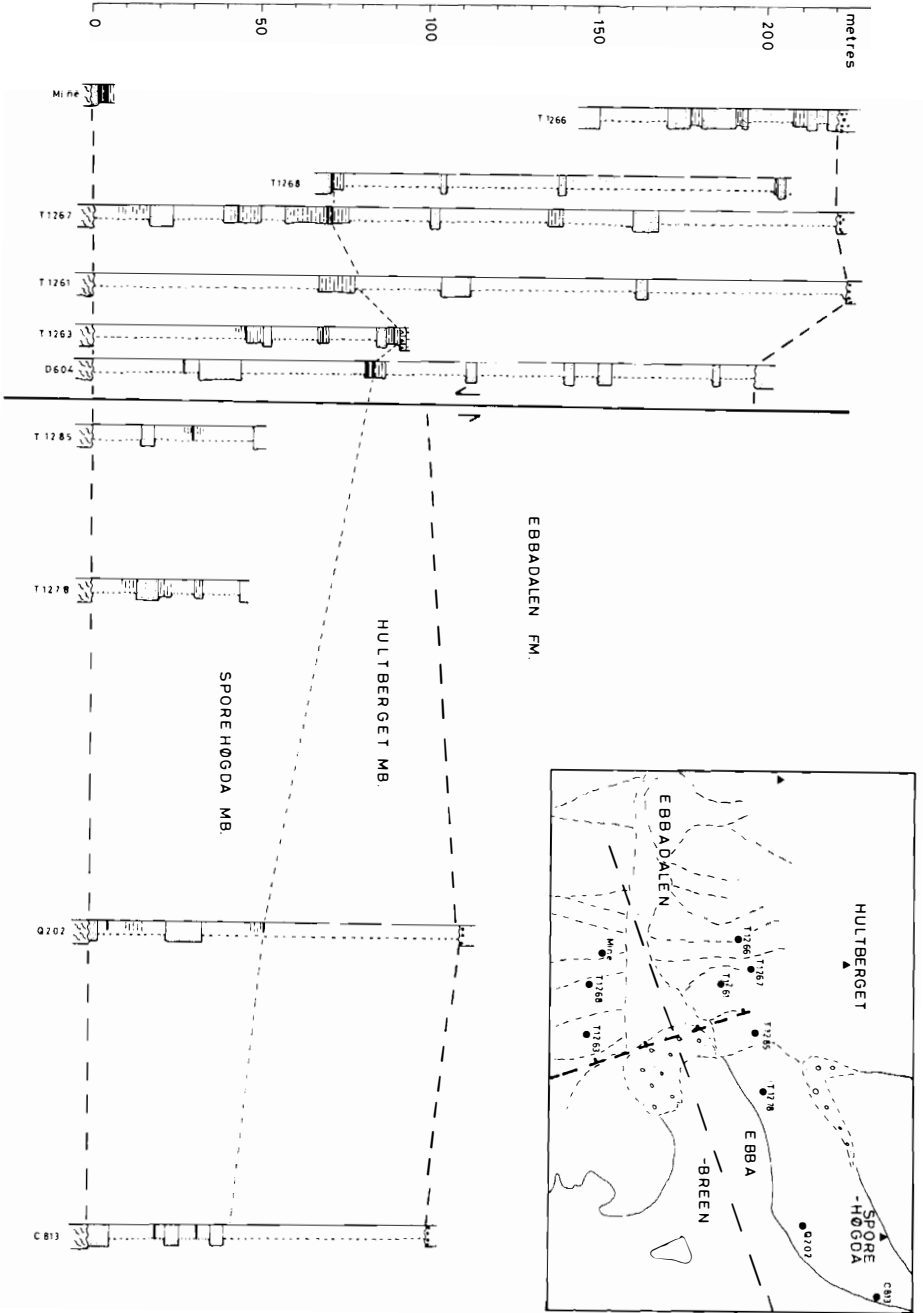


Fig. 13. Profile of sections in Ebbadalen, showing stratigraphical relations across the Ebbabreen Fault.

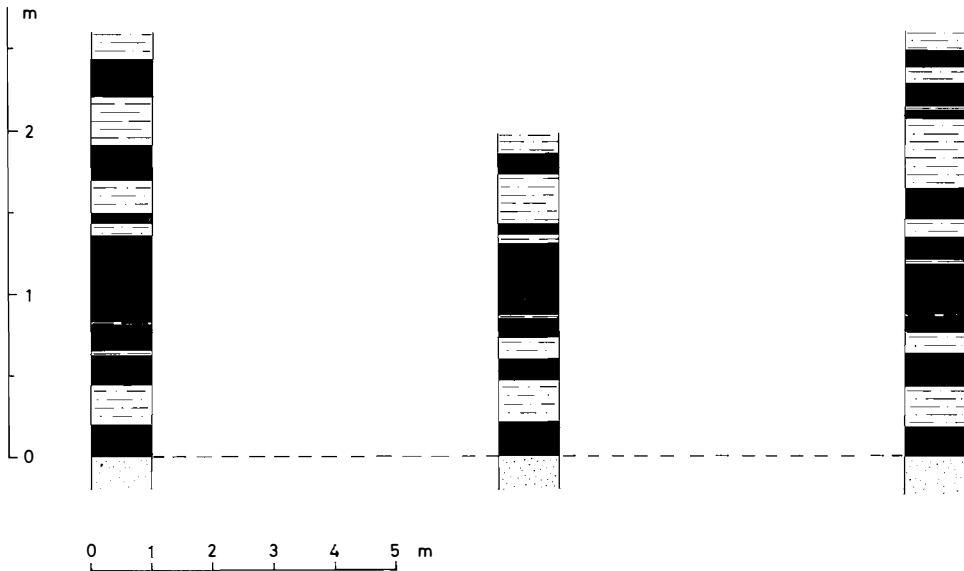


Fig. 14. Profile of coal seam from mine workings in Ebbadalen (from Scottish Spitsbergen Syndicate records). Table 2 analyses 1, 2 and 3 are from the top, middle and bottom seams, respectively, of the innermost section.

calculated heights of 18 m and 32 m above the base. These may represent Unit 2. Further west, a shaley coal is found 5 m above the base, representing Unit 1, and another coal is found at 51 m (Q202). This has been taken to represent Unit 3. In section T 1285, close to the Ebbabreen Fault, a coal-bearing unit is recorded 30 m above the Hecla Hoek, suggesting a correlation with Unit 2. A section through the exposure shows:

- (Top not exposed)
- | | |
|---|---------|
| Black shale | 75 cm |
| Poor quality coal with a mudstone parting | 30 cm |
| Mudstone with rootlets at the top | } |
| Black shale | |
- (Base also not exposed)

West of the fault, a poorly exposed coal occurs 42m above the base (T 1267). This may represent the upper part of Unit 2.

Coals from Unit 2 also outcrop on the south side of Ebbadalen, just west of the Ebbabreen Fault (D604) and further west below a landslipped mass of Ebbadalen Formation rocks (T 1263). A section through this exposure gives:

- | | |
|---|---------|
| (White medium-grained sandstones | 2.10 m) |
| Black shales with some silty bands | 2.10 m |
| Dark thinly-laminated medium sandstone, overlain by black siltstone with ironstone nodules and underlain by black siltstone . | 0.80 m |
| Three coals of varying quality with two shale partings, one 5 cm, the other 20 cm thick | 0.75 m |
| Black shales and dark mudstones | 1.10 m |
- (Base not exposed)

Unit 3 is up to 20 m thick and is the highest Sporehøgda Member coal-bearing horizon. It is the most prominent of the coal-bearing units in Ebbadalen and can be recognised on either side of the valley. It is correlated with the highest Svenbreen Formation beds exposed on De Geerfjellet and the uppermost coal on Sporehøgda. Because of its obvious wide extent and position above the base of the Svenbreen Formation, it is taken as the base of the Hultberget Member since CUTBILL and CHALINOR (1965) described the Hultberget Member as having a coal seam at the base. In particular, the thickest of the coals, which occurs near the top of Unit 3, is taken as the base. Above it in Ebbadalen are developed the red Hultberget shales and sandstones.

Unit 3 was examined in detail in 1972 by means of two shallow drill holes (see WRIGHT and HENDERSON 1976) and considerable excavation. An abridged version of the sequence (from T 1267) is as follows:

(Top not exposed)	
Black shales with ironstone nodules, mudstone and 1 m of coaly shale	1.80 m
Grey sandstone	0.20 m
Black shales and dark mudstones with 5 beds of coal from 5 cm to 75 cm thick	5.60 m
Grey laminated siltstone	1.50 m
Well-laminated shale with pebbles	0.80 m
Grey mudstones and black shales with two coals, one 7 cm, the other 37 cm thick	7.50 m
Black siltstone with sandy laminae	1.50 m
(Base not exposed)	

Unit 3 coals outcrop in section T 1263, just below a landslipped mass on the south side of Ebbadalen. Here the section is:

(Landslipped mass of Ebbadalen Formation bedded gypsum and sandstone)	
Black shale	1.00 m
Coal	0.50 m
Black shale	2.00 m
(Sandstone with plant remains)	

Another poorly exposed coal 20 m below this exposure may represent the lowest part of Unit 3.

Poorly exposed coals in section D 604 on Wordiekammen and Q202 on Sporehøgda are referred to Unit 3.

A coal in Unit 3 is probably the one mentioned in HUGHES and PLAYFORD (1961) as occurring 620 feet (189 m) above the base, the microflora of which "shows less diversity of species than that of the clastic sediments...".

South of Ebbadalen, on the south slopes of De Geerfjellet, only the Sporehøgda Member is exposed. In surface outcrop it is lacking in coals and seems to be developed in a more arenaceous facies. However, a borehole (No. 6) drilled by the Scottish Spitsbergen Syndicate in 1920 on the north side of Adolfbukta penetrated about 40 m of "Culm" before reaching the Hecla Hoek basement.

The well records show a sequence of thinly interbedded sandstones, shales and mudstones and a total of ten coal seams, having a combined thickness of nearly 2 m. These all occur within the bottom 13 m. The thickest, 69 cm, is the top-most seam, occurring 13 m above the base, while the only other seam of any consequence, 43 cm, occurs at 8.5 m.

The lowest coal (5 cm thick) occurs 1.9 m above the base, overlying a brown sandstone. This 11 m sequence therefore correlates with Unit 1 in Ebbadalen.

Six analyses of coals from this borehole were made in 1921. The analyses of the two thickest seams are given in Table 2.

The thin 38 m Svenbreen Formation section on Terrierfjellet contains no coals, but the base of the Hultberget Member is marked by the appearance of coaly sandstones.

III.6.3. *North Bünsow Land*

The Lower Carboniferous outcrops on the south side of Adolfbukta in the Brucebyen area were extensively investigated by the Scottish Spitsbergen Syndicate expeditions during the years 1919 to 1921. Outcrops of coal were found on both banks of Carronelva and a mine working, the "Bridgeness Mine", was opened up, penetrating 21 m into the coal. The seam was found to vary from 68 cm to 1 m in thickness. Three analyses, from the top, middle and bottom parts of the seam at the deepest part of the mine, are given in Table 2.

In 1919 and 1920, a borehole (No. 3) was drilled about 1.7 km to the north-east of Brucebyen. This penetrated about 50 m of red and green sandstones, conglomerates and marls, undoubtedly representing Gerritelva Member beds of the Ebbadalen Formation (HOLLIDAY and CUTBILL 1972). The sequence then becomes more shaley and cuts a coal seam at 74 m. Below this, the sequence is of alternating shales, fine grained sandstones and thin coals as far as the bottom of the hole at 92 m, where very hard beds were encountered and the site was abandoned.

It is difficult to re-interpret these borehole logs in terms of the present subdivision of the Billefjorden Group. There are no samples to be studied and the lithological descriptions are in the archaic Scottish nomenclature (including terms such as "fakes", "blae" and "ribs"). However, the monotonous development of coal-bearing sandstones and shales suggests that the Hultberget Member may be absent, or at least very thin, in this area.

Another borehole (No. 5) was drilled in 1920, 500 m to the north-east, on the south bank of Gerritelva. This reached the Hecla Hoek basement at a depth of 116 m, having penetrated the following coal seams:

1.	At 35 m	Coal	45 cm thick
2.	At 43 m	Coal	88 cm thick
3.	At 86 m	Coal and shale	61 cm thick
4.	At 93 m	Coal	38 cm thick
5.	At 97 m	Coal	46 cm thick
		Dirtband	7 cm thick
		Coal	39 cm thick

Above the first coal seam encountered, the lithologies are marls and “dolomite bearing” sandstones. It seems therefore that the Hultberget Member is again absent and the Ebbadalen Formation is resting on the uppermost part of the Sporehøgda Member.

An analysis of the coal from the bottom seam is given in Table 2.

The data from this borehole led the Scottish geologists to the recognition of two major coal bearing horizons in the Brucebyen area; the second seam penetrated they correlated with the “Carron Seam” from the Bridgeness Mine, while the fifth seam was named the Lower or Main Seam.

It can be seen that these coal horizons do correlate to some extent with those apparent to the north of Adolfbukta. The lower seam in the Brucebyen area occurs at 19 m above the base of the Svenbreen Formation, somewhat higher than the Unit 1 recognised in Ebbadalen. The “Carron Seam” and the thinner coal above it may however be near the top of the Sporehøgda Member, and therefore be the equivalent of Unit 3.

The recognition of the two Svenbreen Formation members has proved to be very difficult in Bünsow Land. It is thought, however, that the Hultberget Member, if present, is very shaley and contains frequent thin coals. In this respect it resembles the Hultberget section of Birger Johnsonfjellet rather than the more arenaceous facies developed in Ebbadalen.

III.6.4. *Gipsdalen*

Lower Carboniferous outcrops at the head of Gipsdalen were investigated by the Scottish Spitsbergen Syndicate in 1921 (J. M. FINLAY, S.S.S. Ms 120).

Table 2
Analyses of Coal made in 1920–1922

Location	Coal horizon	Moisture	Ash	Sulphur	Fixed carbon	Volatiles	Calorific value in B.T.U. per lb.	C.V. in KCALS/kg.
1 Ebbadalen Mine – Top seam	Unit 1	2.74	10.39	0.25	60.51	26.11	12,978	7,194
2 Ebbadalen Mine – Middle seam	Unit 1	5.38	9.92	0.27	59.68	24.75	12,636	6,999
3 Ebbadalen Mine – Bottom seam	Unit 1	1.82	14.85	0.29	57.50	25.54	12,402	6,870
4 Bore hole No. 6 – coal 13 m above base	Unit 1	0.82	20.60	1.28	53.55	23.75	11,259	6,237
5 Bore hole No. 6 – coal 8.5 m above base	Unit 1	0.61	19.93	0.59	52.32	26.05	11,466	6,351
6 Bore hole No. 5 – coal at 97 m	Unit 1	0.76	10.01	1.84	60.19	27.20	13,054	7,231
7 Bridgeness Mine – Top of seam	Unit 3	0.69	37.95	0.58	40.20	20.58	8,910	4,935
8 Bridgeness Mine – Mid. of seam	Unit 3	0.79	20.15	2.71	49.80	26.55	11,376	6,301
9 Bridgeness Mine – Bot. of seam	Unit 3	0.53	25.05	2.25	50.32	21.85	10,962	6,072
10 Gipsdalen	Unit 1	1.54	6.25	0.64	62.80	28.77	13,716	7,598

Table 3
Analyses of coals made by Powell Duffryn Ltd.

	Ebbadalen (11)		Ebbadalen (12)		Ebbadalen (13)		Brucebyen No. 5 bore (14)		Gipsdalen (15)	
	DAF		DAF		DAF		DAF		DAF	
Moisture	2.8		1.8		2.0		0.7		1.7	
Volatile Matter	26.8	30.2	26.0	30.9	27.5	31.9	24.9	31.0	28.7	32.9
Fixed Carbon	61.9	69.8	58.5	69.1	58.8	68.1	55.3	69.0	58.5	67.1
Ash	8.5		13.7		11.7		19.1		11.1	
Carbon	73.9	83.3	70.7	83.7	71.6	83.1	70.1	87.4	73.6	83.6
Hydrogen	4.2	4.7	4.0	4.7	4.1	4.8	4.1	5.1	4.0	4.6
Nitrogen	1.0	1.1	1.0	1.1	0.8	0.9	0.8	1.0	1.2	1.3
Sulphur	0.3	0.4	0.3	0.3	0.4	0.4	0.3	0.4	0.4	0.5
Oxygen	8.3	11.5	8.5	10.2	9.4	10.8	4.9	6.1	8.0	10.0
Calorific Value in B.T.U./lb	12,450	14,050	12,550	14,600	12,200	14,150	11,900	14,800	12,380	14,700
C.V. in Kilo- calories/kg	6,896	7,783	6,952	8,087	6,758	7,838	6,592	8,198	6,858	8,143

The "Lower Coal" was found to outcrop at several localities on both sides of the valley above Margaretbreen and Methuenbreen and four excavations were made. These revealed a seam of coal about 1 m thick in a sequence of carbonaceous shale. A band of shale about 10 cm thick occurred in the most easterly excavation, but thinned to the west and was absent in an excavation 500 m to the west. The quality of the coal was observed to improve in this direction.

An analysis of the coal from the westernmost excavation is given in Table 2.

The "Upper Coal Horizon" was examined in a waterfall exposure near Margaretbreen, and was found to contain no coal seams, the section consisting of alternating black shales and yellow sandstones.

The following year an extensive drilling programme was undertaken in an attempt to prove the extent of this "Lower Coal". Seven boreholes were attempted, but were unsuccessful due to the unexpected thickness of surface deposits. Thus, the stratigraphical position of the "Lower Coal" in Gipsdalen is not known, but it is presumed to correlate with the Lower Coal in the Brucebyen area.

III.7. ENVIRONMENT OF DEPOSITION

The sediments of the Svenbreen Formation are essentially similar to those of the Hoelbreen Member, suggesting a similar environment of deposition. Deposition was in a rather restricted elongate basin (Fig. 12 and 13) along the line of the Billefjorden Trough; although pre-Bashkirian erosion has further restricted the Formation, the original basin was probably no more than 45 km across and perhaps 100 km in length. The basin contains sediments of fresh or brackish water origin and no marine incursions are apparent. The sandstone beds show signs of rapid deposition, such as cross bedding, wash-outs and slump

structures and show rapid lateral changes in thickness. They frequently contain coaly clasts and plant remains. The coals are thin, laterally impersistent and pass into shales both horizontally and vertically. Only rarely do true seat earths occur. This is taken as evidence for an autochthonous source of plant detritus.

Sandstone units are interpreted as the bed load deposits of rivers draining into quiescent fresh or brackish water. As the rivers meandered over the deltas sandstone/siltstone/shale sequences would be formed and carbonaceous matter in the suspended load of rivers draining land with abundant plant life would settle out in quiet water with clay and silt grade material. Coals would form where deposition of carbonaceous matter exceeded that of silt and clay particles.

There is considerable lateral facies variation within the two members. Where it is thickest, in Ebbadalen, the Sporehøgda Member contains a high proportion of shale and correspondingly more coal than in, for example, the type section on Birger Johnsonfjellet. Conversely, the Hultberget Member on Birger Johnsonfjellet (and perhaps in Bünsow Land) is largely comprised of shale, in contrast to the arenaceous facies developed in Ebbadalen.

This is taken to be an expression of the development of contemporaneous high and low energy environments within the basin.

No palaeocurrent directions are known from the Formation, so the source area can only be guessed at. However, the relative abundance of iron in the Hultberget rocks, expressed as a general red colouration and the common occurrence of ironstone nodules, may indicate an Old Red Sandstone source.

As mentioned above (III.2), conglomerates also appear locally in this member, suggesting uplift along the East Dickson Land Axis. It is therefore suggested that the source was in the west and resulted from a general beginning of uplift of the Nordfjorden Block. Red beds occur in the Svenbreen Formation in the east Ny Friesland outcrops (CUTBILL 1968) but a similar source need not be ruled out as the low-lying land between the basins would not have formed a barrier to sediments.

Petrological work on Billefjorden Group rocks by P. F. HUTCHINS (unpublished thesis, 1953) revealed no metamorphic minerals, such as garnet or amphibole, in the sediments. It is thought that all his specimens came from the Svenbreen Formation and so this work generally supports a western (Old Red Sandstone) sediment source.

However, these suggestions await palaeocurrent data and are only intended to be tentative.

IV. Conclusions

We record in Spitsbergen the Early Carboniferous development of a low-lying landscape, upon which may have been deposited a thin sequence of fluvial deposits. Local subsidence led to the development of several small lacustrine basins; one such basin developed in the Billefjorden Trough, a negative structural feature active throughout much of Upper Palaeozoic time. The Billefjorden Trough formed along the line of the Billefjorden Fault Zone,

and faulting within the Zone in many cases restricted sedimentation and/or preservation of sediments within the trough.

The Lower Carboniferous (Billefjorden Group) stratigraphy is an index not only to fault movements within the zone, but also to the larger scale movements of the major structural blocks on either side of the Trough, the Nordfjorden Block to the west and the Ny Friesland Block to the east.

Thus, the lower stratal unit within the group, the Hörbyebreen Formation, is restricted to the west of Petuniabukta by contemporaneous faulting within the zone. In the north the Lemströmfjellet Fault can be seen to cut out the Formation to the east, and a southern extension of this fault is assumed. The sediment source during this interval was probably to the east, reflecting a general uplift of the Ny Friesland Block with respect to the Nordfjorden Block.

The Svenbreen Formation presents a rather different picture — the area of deposition shifted within the trough further to the east, the eastern margin being a simple unconformity. The western margin of the Formation is complicated by faulting and uplift along the East Dickson Land Axis and by faulting on the eastern margin of the Nordfjorden Block. The occurrence of some conglomerates and the general red colour of the Hultberget Member is taken to be an indication of uplift of the Nordfjorden Block and the associated East Dickson Land Axis during the deposition of the Hultberget Member at least. It is therefore suggested that the western margin of the Svenbreen Formation basin developed by contemporaneous faulting with a sediment source from the west. This is a mirror image of the situation in the underlying Hörbyebreen Formation.

The deltaic and lacustrine sediments within these basins contain a considerable quantity of coal, a fact which has excited speculative interest in the area since the beginning of the century. The only Carboniferous coal at present mined in Svalbard is from this basin, at the Russian mining settlement of Pyramiden, but it is probable that fairly extensive reserves exist beneath Bünsow Land and in the Ebbadalen area. The coals themselves are of variable quality, but in general are fairly good. They are of bituminous rank, and “should be suitable for gas making or the production of metallurgical coke” (POWELL DUFFRYN Technical Report, c. 1952).

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